A Profile of the
San Francisco Bay National Estuarine Research Reserve

China Camp State Park

Rush Ranch Open Space Preserve

December 14, 2011

The San Francisco Bay National Estuarine Research Reserve is part of the National Estuarine Research Reserve System (NERRS), established by Section 315 of the Coastal Zone Management Act, as amended. Additional information about the system can be obtained from the Estuarine Reserves Division, Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration, US Department of Commerce, 1305 East West Highway - N/ORM5, Silver Spring, MD 20910

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A PROFILE OF THE
SAN FRANCISCO BAY NATIONAL ESTUARINE RESEARCH RESERVE

EXECUTIVE SUMMARY

San Francisco Bay National Estuarine Research Reserve (SF Bay NERR or Reserve) is a partnership among the National Oceanic and Atmospheric Administration (NOAA), San Francisco State University (lead state agency), California State Parks, Solano Land Trust, and the Bay Conservation and Development Commission, that was established for long-term research, education, and stewardship of the San Francisco Estuary. Two of the few remaining historic tidal wetlands in the estuary are protected as part of SF Bay NERR: China Camp State Park in Marin County and Rush Ranch Open Space Preserve in Solano County. SF Bay NERR (http://sfbaynerr.org/) is part of a network of 28 research reserves nationwide (http://www.nerrs.noaa.gov/) that all share common goals of conducting standardized long-term monitoring, supporting applied environmental research, providing stewardship of estuarine natural resources, and linking science with decision making in pursuit of effective solutions to coastal management problems.

The Estuarine Reserves Division of NOAA's Office of Ocean and Coastal Resource and Management requires that each reserve publish a site profile that summarizes current knowledge on the physical and biological aspects of the Reserve sites, management issues of concern, and the most pressing gaps in knowledge and needs for future research. This site profile of SF Bay NERR was initiated as a book project and later developed in parallel with a special issue of the open-access journal *San Francisco Estuary and Watershed Science* (http://escholarship.org/uc/jmie_sfews). The special issue of the journal widens distribution of the important summaries and articles that were contributed and provides a regionally-recognized, peer-reviewed publication for the many authors who participated in the project. Much of the same material from these authors is also included in the originally conceived book: *Ecology, conservation and restoration of tidal marshes: the San Francisco Estuary*. That book is planned for publication by University of California Press in 2012 and will further amplify the impact of this important project. The final component of this site profile is a comprehensive report on the existing ecological conditions of Rush Ranch. That existing conditions report was written in 2010 under contract for the Solano Land Trust, the non-profit organization that owns and manages Rush Ranch, and is included here as an Appendix.

Two general goals of this site profile are (1) to inform the Reserve's research and monitoring activities and (2) to identify research topics and questions that should be addressed in the future. Overall, this document allows scientists, graduate and undergraduate students, natural resource managers and other decision makers to delve into complex and important topics pertaining to the health and management of the San Francisco Estuary. The chapters are arranged so that they provide a broad introduction to the estuary as well as a review of site-specific detailed information. The introduction (Chapter 1) describes the national and regional context of SF Bay NERR, reviews the monitoring and research taking place within the Reserve, and describes some of the broader context in which these activities are relevant. Other key topics covered in the document are briefly described below with reference to specific chapters about each topic. The Reserve continues to support additional research and monitoring to fill gaps in knowledge identified herein.

Information on the historical ecology and formation of the San Francisco Estuary and its tidal marshes is summarized in Chapter 2. Additional site-specific background on the formation and development of the Reserve's tidal marshes is incorporated into Chapter 6 (for China Camp) and is a major topic covered in the Appendix (for Rush Ranch). Both site-focused sections also describe the contemporary relationship between landforms, geomorphology, and hydrology in an ecologically meaningful way that relates directly to the patterns of emergent vegetation found at each site.

Nearly all chapters describe the primary plight of the estuary, which is the degradation and loss of tidal wetlands through diking, draining and filling for agriculture and coastal development. This backdrop of widespread habitat destruction provides much of the incentive to study and conserve those portions of the ecosystem that still remain. Over the past few decades, wetland creation and habitat restoration have become major priorities for science and management in the estuary; Chapter 3 reviews the history and future challenges of these efforts. Both China Camp and Rush Ranch are used as reference sites for design and evaluation of regional restoration projects, and as described in Chapters 3, 5, 6, 14 and the Appendix, both sites also have multiple regions of marsh that are currently in need of restoration.

The biological foundation of tidal wetlands is the emergent vegetation that stabilizes channels and sloughs, slows water flow and traps sediment to allow for marsh expansion, and provides food and shelter for a variety of species. Chapter 4 describes an ambitious monitoring study that documents tidal marsh plant diversity at multiple scales in marshes along the estuarine salinity gradient from China Camp to Rush Ranch and into the freshwater portion of the estuary. The general pattern of an inverse relationship between ambient salinity and plant diversity found in that study is supported by more detailed descriptions of vegetation at Rush Ranch (Chapter 5) and China Camp (Chapter 6). The latter two chapters provide extensive detail on the various species, ecotones, and habitat associations found within and around the marsh, including evaluations of rare and invasive species and their interactions. Chapter 7 builds on these previous chapters to forecast the likely trajectories of tidal marsh vegetation patterns in response to future environmental change and, in particular, to the combination of rising sea levels and decreasing freshwater inputs due to lower snowpack in the mountains, earlier and more rapid spring runoff, and continued diversion of freshwater from the estuary for agriculture and export.

Water quality and waterborne constituents such as nutrients and plankton are critically important drivers of productivity and species distributions in the estuary; these are reviewed to varying degrees in Chapters 1, 8 and the Appendix. Chapter 8 also summarizes a series of regular sampling efforts in which nutrients and chlorophyll were measured in tidal sloughs and compared to long-term monitoring data in nearby open water. In addition to being a monitoring focus for SF Bay NERR, water quality has long been a major area of study for scientists and regulatory agencies throughout the region and a number of comprehensive regional syntheses are available on the topic.

Contaminants are also a major issue in the estuary; entire agency and interagency programs are dedicated to monitoring contaminants, regulating their release, and mitigating their impacts. Chapter 9 reviews what is known about legacy pollutants and emerging contaminants in tidal marshes of the estuary, in many cases drawing on what is known from open water and bay sediments to infer likely patterns of contaminant distribution in marshes. That same chapter also describes the biological and ecological implications of contaminants, particularly uptake by plants and subsequent accumulation in wildlife.

Invertebrates are abundant and widely distributed throughout the estuary, providing important links between primary producers and higher order consumers. Chapter 10 reviews the diversity and distribution of invertebrates across the range of estuarine habitats present at China Camp, including tidal marsh plain, channel levees and banks, subtidal sediments, and rocky shores. Invertebrates at Rush Ranch are summarized in the Appendix with several additional aquatic species noted in Chapter 1. There is an abundance of non-native invertebrate species in the San Francisco Estuary but native species also thrive, as exemplified by the Olympia oyster that was more abundant at China Camp than anywhere else in the region in 2010.

All of the sections on vertebrates in the estuary provide a solid introduction to the literature, and many promote the need for monitoring and research in the Reserve to support the conservation and recovery of key vertebrate species. A variety of rare, threatened, and endangered fish species are native to the estuary, although many of those species spend part of their life at sea. The Appendix provides a detailed description of special-status species known to be important at Rush Ranch. Additional species of concern commonly found in the tidal marshes at China Camp are listed in Chapter 1. From the perspective of many scientists working in the Reserve, one of the main functions of fish in the estuary is as food for birds. Chapter 11 reviews the birds that utilize marsh habitats around the estuary and categorizes these species according to feeding ecology and habitat associations. Chapters 12 and 13 provide more detailed census data from long-term monitoring of secretive marsh birds at China Camp and Rush Ranch, respectively. Chapter 14 reviews what is known of mammals in the Reserve, with a focus on the rare and endangered species of small mammals that live in the tidal marsh at both sites.

Several general conclusions and recommendations emerge from the diverse topics reviewed in this site profile. First, climate change and sea level rise pose immediate and severe threats to tidal marshes around the San Francisco Estuary. Future research, monitoring, restoration, and management must consider this unavoidable context of change. Second, the physical structure and resultant ecological function of tidal marshes is more important than total acreage, and restoration efforts should therefore be designed and evaluated with this functionality as a central goal. Third, listed species (those that are officially listed as rare, threatened or endangered at the state or federal level) live in and around tidal marshes and serve as an important incentive for conservation, restoration and adaptive management of these habitats, yet more research is needed on the basic biology and ecology of listed species to ensure effective conservation and recovery. Chapter 15 reviews the main ecological issues and challenges facing the Reserve, and places these issues in the context of the Reserve's management plan and focus areas for the years 2011-2016. That concluding chapter also outlines major topics of research that are most needed to improve understanding and management of natural resources and processes within the Reserve sites. Priority research topics include: climate change, sensitive species, invasive species, grazing, human impacts, water quality, and the ecology of rocky intertidal and subtidal habitats. The Appendix complements this prospectus by presenting conceptual models of key drivers of change in conditions at Rush Ranch and other regions of the estuary, as well as inferences as to the ecological responses to those drivers.

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1. Conservation through Research and Monitoring at the San Francisco Bay National Estuarine Research Reserve

Matthew C. Ferner

San Francisco Bay National Estuarine Research Reserve
San Francisco State University, Romberg Tiburon Center for Environmental Studies
3152 Paradise Drive, Tiburon CA 94920

1.1 Introduction to the Reserve

The San Francisco Estuary (SFE) encompasses San Francisco Bay, its surrounding embayments and tidal wetlands, and the Sacramento-San Joaquin Delta. Conservation of estuarine habitats and resources is critically important in the SFE where recent human activities have had devastating effects on the natural environment and the species that live there. By the end of the 20th century, the majority of tidal wetlands in the estuary had been diked, filled or otherwise modified for development and agricultural use. Historic tidal marshes were reduced from about 190,000 acres to 16,000 acres over only 150 years, with corresponding decreases in associated habitats such as channels, pans and ponds, and tidal flats (Goals Project 1999). Habitat loss and degradation continue to threaten numerous endemic and special status species living in the SFE, including rare and endangered plants, fish, mammals and birds (Goals Project 2000). In the context of persistent anthropogenic stressors, changing climate and rising sea levels, it is increasingly important to have areas of estuarine habitat protected from human alteration and development, both as a refuge for sensitive species and a point of reference for better understanding and management of other, more impacted habitats around the estuary.

To address this need for conservation, in 2003 two of the best preserved historic tidal wetlands in the estuary were included in the designation of the San Francisco Bay National Estuarine Research Reserve (SF Bay NERR, or Reserve), which is part of the National Estuarine Research Reserve System (NERRS). The NERRS is a nationwide network of estuarine areas (Figure 1) protected for the purpose of informing coastal management through a combination of research, education and stewardship. This designation brought national attention to the intrinsic value of SFE tidal wetlands and strengthened regional initiatives to connect science and management in the estuary. Both of these NERRS sites, China Camp State Park in Marin County and Rush Ranch Open Space Preserve in Solano County, have been largely protected from development and alteration and are widely recognized for their expansive tidal marshes and undeveloped adjacent uplands. These sites have long been a focus of environmental and ecological research, providing important baseline data and serving as reference areas for the evaluation of restored, enhanced, or created wetlands around the estuary (e.g., Goals Project 1999, Simenstad et al. 2000, Williams and Orr 2002, Collins and Pearce 2004, PEEIR 2006, Enright 2008). Scientists from government agencies, academic institutions, consulting firms and non-profit groups have cooperated in the long-term study and use of these sites to promote regional conservation and management. As time goes on and partnerships among these groups continue to develop and thrive, the mission and activities of the Reserve will facilitate applied science, inform resource management and policy, and improve ecosystem health in support of coastal communities.

The Reserve sites of China Camp and Rush Ranch occur in two distinct regions of the SFE: San Pablo Bay and Suisun Marsh, respectively (Figure 2). Together these sites bracket a substantial portion of the salinity gradient within the estuary from predominantly brackish marsh at Rush Ranch to salt marsh at China Camp. Both sites include complex channel systems and an intact marsh-upland ecotone that are no longer present in most other tidal wetlands in the region. The interconnected aspects of physical marsh structure, hydrology and habitat connectivity present in these sites can take many decades to develop and are closely tied to the ecological function that the marshes provide (Enright 2008). One outcome of these healthy ecosystems is the rare,

Figure 1. Map of the National Estuarine Research Reserve System. This network of protected estuaries was established in 1972 by section 315 of the Coastal Zone Management Act. This landmark legislation was designed to encourage the participation and cooperation of local, regional, state and federal agencies and governments having programs affecting the coastal zone of the United States. The National Oceanic and Atmospheric Administration (NOAA) is the lead federal agency in the NERRS federal-state partnerships to develop and maintain a network of biogeographically representative special-use areas dedicated to long-term research, monitoring, education, and stewardship activities that contribute to improvements in coastal zone management. Since its inception in 1972, the NERRS has grown to a network of 28 Reserves in 23 states and territories. NOAA provides each reserve with funding, national guidance and technical assistance, while the states provide matching funds, personnel, and administrative oversight. The NERRS helps to protect more than one million acres of estuarine land and water providing essential habitat for wildlife; offers educational opportunities for students, teachers and the public; and serves as a network of living research laboratories for scientists.

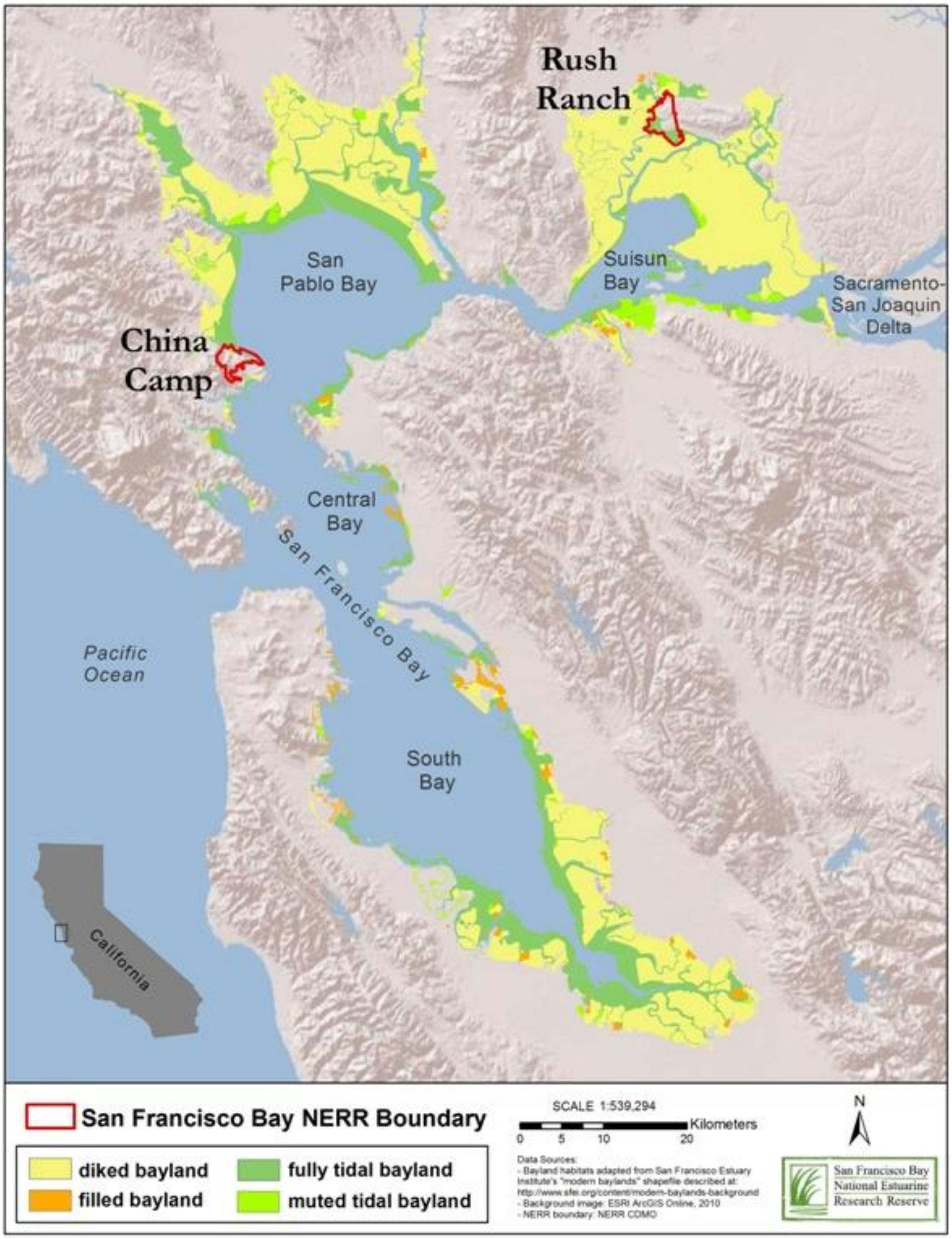


Figure 2. Map of the San Francisco Estuary. The estuary includes subembayments (South Bay, Central Bay, San Pablo Bay, and Suisun Bay), their associated marshes, and the western edge of the Sacramento-San Joaquin Delta. Colored shading indicates modern distribution of tidal baylands (i.e., marshes, tidal flats) within the San Francisco Estuary.

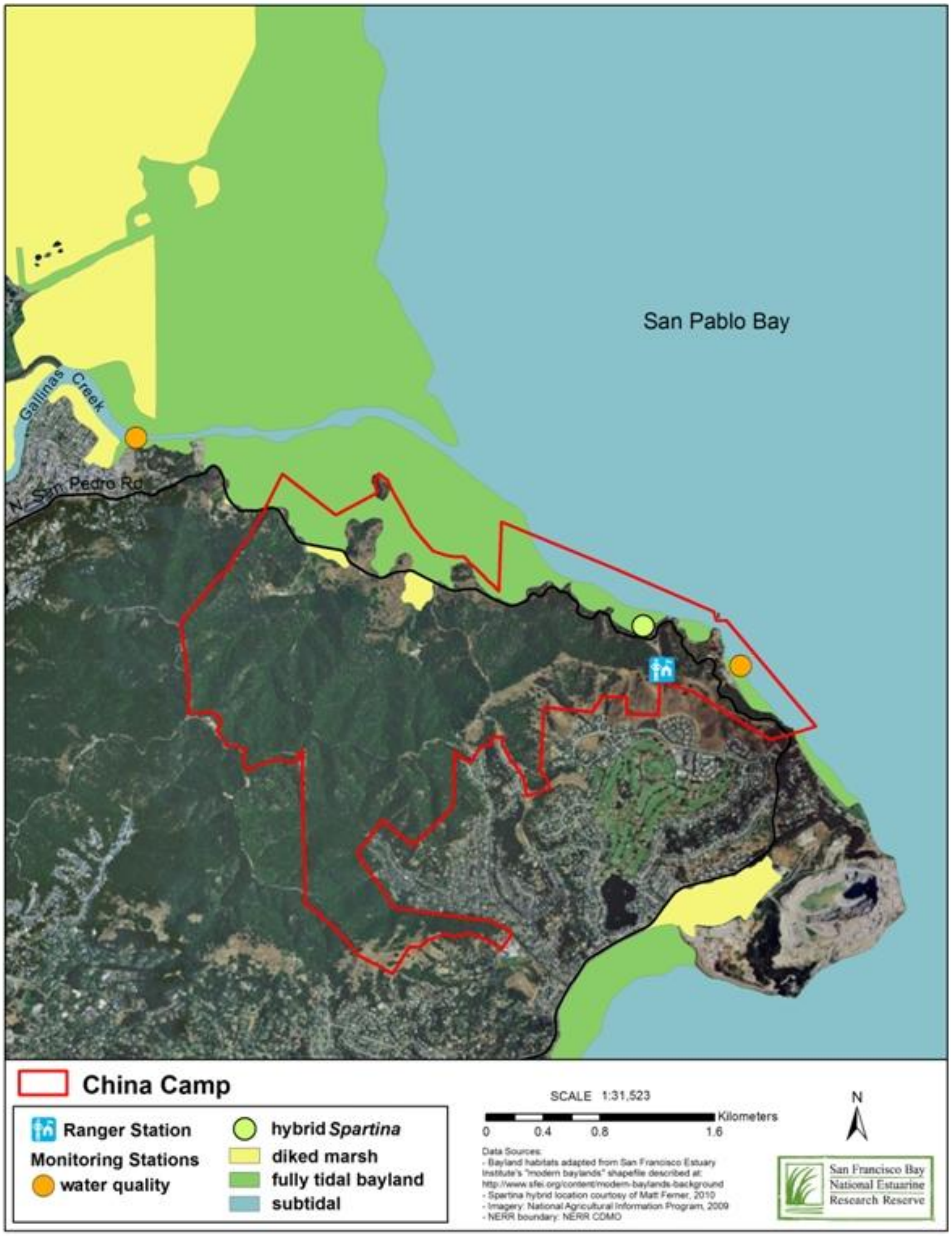
threatened, and endangered species of plants and animals that occur within the Reserve. At China Camp (Figure 3) these species include the California black rail, California clapper rail and salt marsh harvest mouse. Notable species at Rush Ranch (Figure 4) include soft bird's beak, Suisun marsh aster, Suisun thistle, Delta tule pea, California black rail, California clapper rail, Chinook salmon, steelhead trout, Sacramento splittail, Delta smelt, and salt marsh harvest mouse. All of these species rely to some degree on the protected nature of the Reserve sites, but at the same time they are threatened by regional influences (e.g., pollution, water diversion, reductions in sediment supply) and site-specific problems (e.g., invasive plants; Figures 3 and 4). Site-focused research and monitoring offers many opportunities to learn from ecological processes and responses to stressors in these relatively protected habitats, potentially leading to more effective management of natural resources elsewhere in the estuary. Studies in both sites have been led by academic scientists as well as local, state and federal governmental agencies and environmental organizations, including the U.S. Geological Survey (http://www.usgs.gov), California Department of Fish and Game (http://www.dfg.ca.gov), California Department of Water Resources (http://www.water.ca.gov) and the Interagency Ecological Program (http://www.water.ca.gov/iep/), San Francisco Estuary Institute (http://www.sfei.org), PRBO Conservation Science (http://www.prbo.org), and others.

Niche of the Reserve

Following a complicated 14-year designation process (summarized in the Reserve's original Management Plan, NOAA 2002), an initial challenge for the Reserve has been to identify and articulate a relevant niche among the broad assortment of existing research and monitoring programs and organizations focused on the SFE. The Reserve's niche continues to evolve and currently some of its defining aspects include:

- promotion of site-based research and monitoring to inform restoration and management;
- integration with a national system of similar reserves that employ similar approaches to conservation science and management in other estuaries; and
- coordination of research, education, stewardship and training with the goal of connecting scientists and managers with each other and the human communities they serve in order to improve resource management and conservation.

These attributes set the Reserve apart from other regional organizations and are unique to the SF Bay NERR when taken as a whole. The overall vision and mission of the Reserve (SF Bay NERR 2010) reflect the roles listed above and direct the Reserve to support regional and national research with a spirit of cooperation and collaboration. As the Reserve's capacity grows, its role among scientists, restoration practitioners and decision makers will be further refined using careful consideration of past successes, ongoing efforts, and evolving needs of a variety of stakeholders. For example, the SF Bay NERR is currently developing agreements with



Data Sources:
- Bayland habitats adapted from San Francisco Estuary Institute's "modern baylands" shapefile described at: http://www.sfei.org/content/modern-baylands-background
- Spartina hybrid location courtosy of Matt Ferner, 2010
- Imagery: National Agricultural Information Program, 2009
- NERR boundary: NERR CDMO

*Figure 3. Map of China Camp State Park. Colored shading indicates modern distribution of tidal baylands (i.e., marshes, tidal flats), locations of NERR water-quality monitoring stations, and the known distribution of invasive hybrid cordgrass (*Spartina alterniflora *x* S. foliosa*) that was first detected and treated in 2010 by the State Coastal Conservancy's Invasive* Spartina *Project. Regular measurement of water quality at China Camp began in 2005 off the fishing pier (38° 0' 4.49 N, 122° 27' 37.28 W) and then expanded to include a monitoring station in Gallinas Creek (38° 00' 57.3 N, 122° 30' 30.6 W), just north of China Camp.*

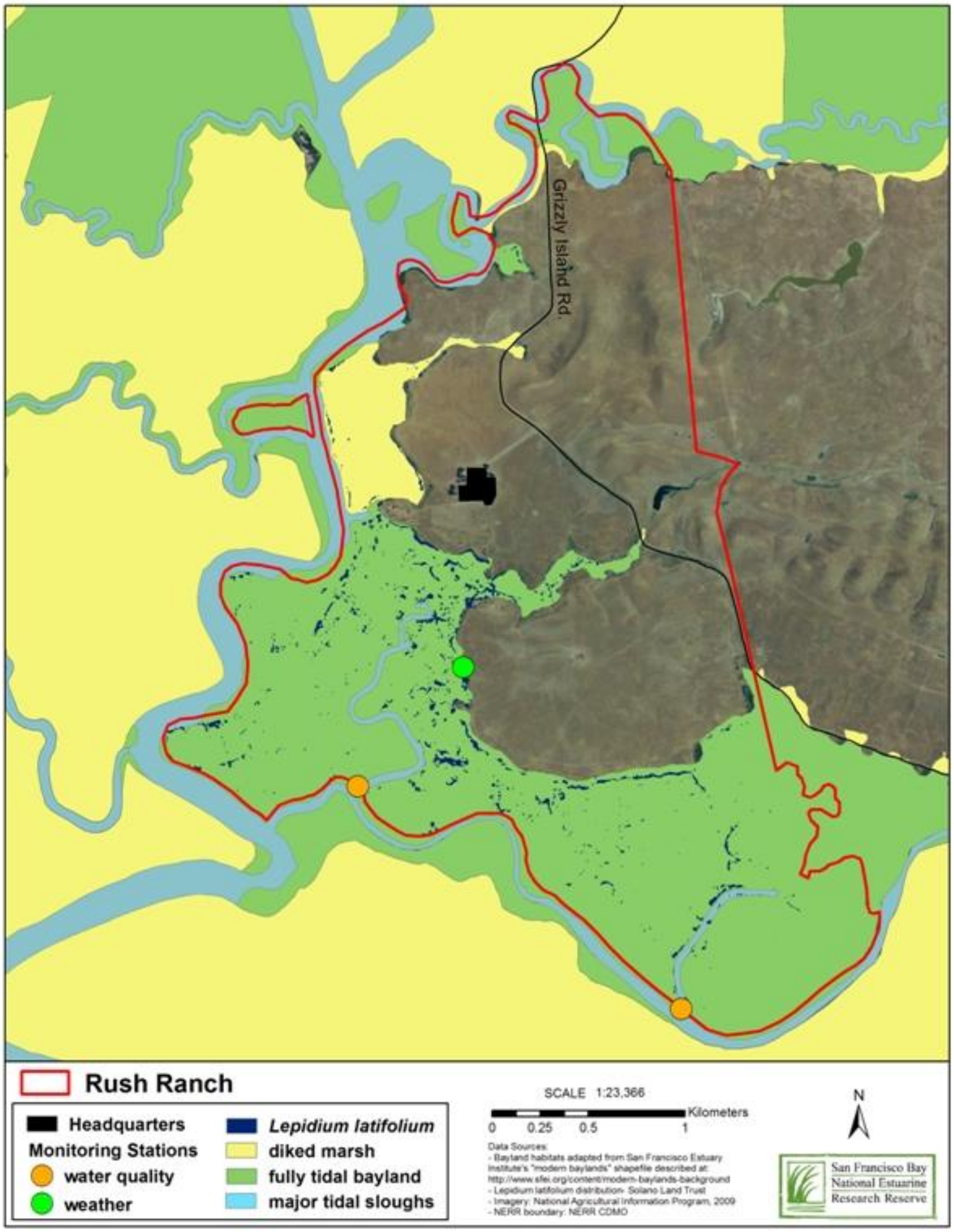


*Figure 4. Map of Rush Ranch Open Space Preserve. Colored shading indicates modern distribution of tidal baylands (i.e., marshes, tidal flats), locations of NERR water-quality and weather monitoring stations, and the known distribution of invasive broadleaf pepperweed (*Lepidium latifolium*) that is being adaptively managed by the Solano Land Trust. A weather station was erected in 2006 to measure meteorological conditions on the edge of the marsh (38° 12′ 01.6 N, 122° 1' 35.3 W). The Reserve began monitoring water quality at Rush Ranch in 2008 at the mouths of First Mallard Slough (38° 11' 41.70 N, 122° 1' 58.02 W) and Second Mallard Slough (38° 10' 59.40 N, 122° 0' 46.68 W).*

a variety of land managers as one attempt to define the Reserve's strengths and capabilities, as well as the areas where partner assistance is needed.

Management issues

The first revision of the Reserve's management plan (SF Bay NERR 2010) formally identifies four management issue areas around which Reserve programs are focused: climate change, species interactions, water quality, and habitat restoration. Regional interest in these broad issue areas is not new and these topics have widely been acknowledged as critical aspects of effective resource management in the estuary. For example, the issue of climate change is of paramount importance to the future of estuarine habitats and coastal communities in the region, and as such has been the focus of comprehensive reports (Largier et al. 2010), planning initiatives (http://www.bcdc.ca.gov/planning/climate_change/climate_change), and economic analyses (Heberger et al. 2009). The role of the NERR is not to "reinvent the wheel" on these issues, but rather to enhance understanding and management of estuarine natural resources through a dedicated and sustained focus on research at the Reserve sites, coupled tightly with education, stewardship and training programs that share research results with appropriate audiences.

Programmatic goals of the Reserve

Specific challenges and opportunities related to the issue areas listed above vary between the two Reserve sites (and are discussed in the concluding chapter of this document) but most are well suited to be addressed through integration of the Reserve's research, education, stewardship and coastal training programs (e.g., Figure 5). The Reserve collaborates with its partner organizations to pursue the following broad goals:

- To ensure that habitats and species within the reserves sites are protected.
- To coordinate research in the reserve sites and to communicate results of that research to scientists, managers, visitors, teachers and students.
- To direct and encourage research that meets the needs of land managers at our sites and in the estuary more broadly.

In conjunction with national-level programs and initiatives (http://www.nerrs.noaa.gov) and through increased collaboration locally, the impact of SF Bay NERR on the understanding and management of valuable habitats and species in the estuary continues to improve and expand.

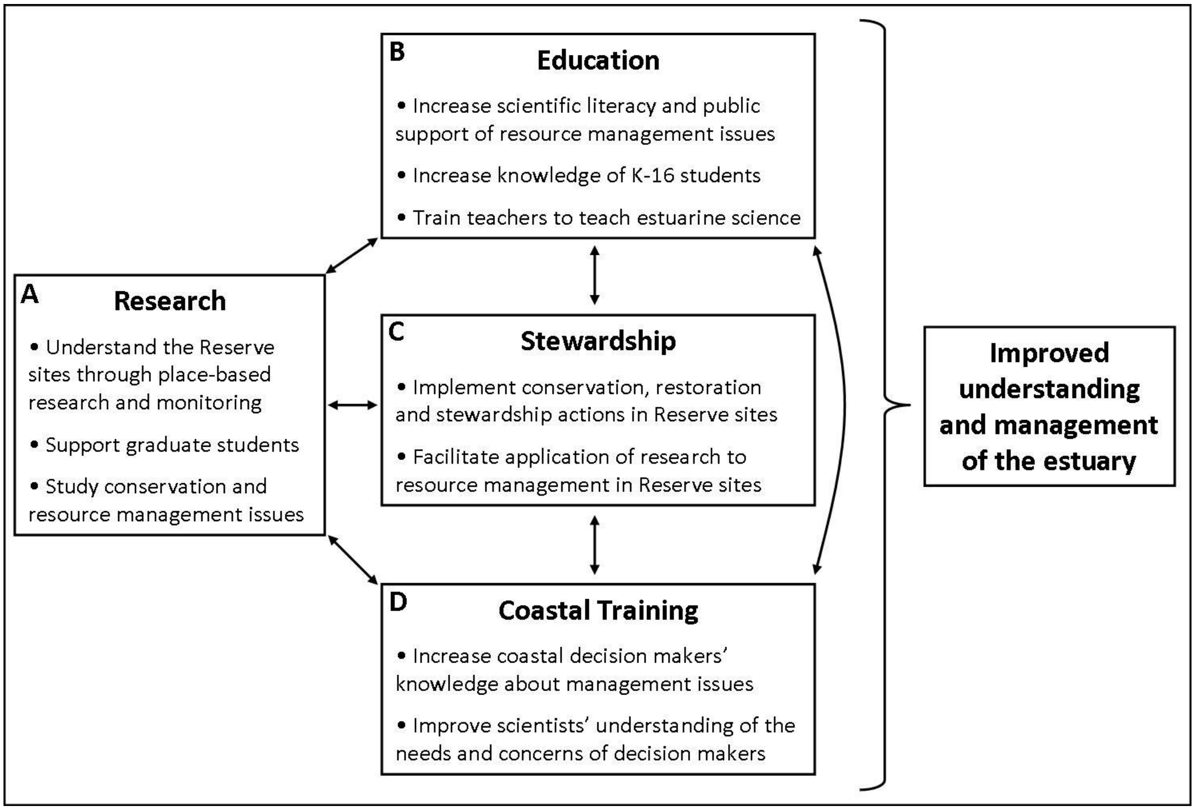


Figure 5. Illustration of how Reserve programs support each other for the benefit of coastal communities. Integration of research, education, stewardship, and coastal training within the Reserve has the potential to lead to improved understanding and management of the estuary, primarily at the Reserve sites themselves but also within similar habitats throughout the region. For example, one important and unresolved management issue relates to the future impacts of sea level rise in the estuary. In Suisun Marsh, most tidal wetlands have been diked and managed for waterfowl, leading to marsh subsidence and risk of flooding in the event of dike or levee failure. Currently projected rates of sea level rise suggest that catastrophic flooding of the marsh is likely unless management changes are enacted. SF Bay NERR could inform and improve this impending situation through integrated efforts of its programs: (A) Research and monitoring of sediment elevation, water levels and vegetation changes in both diked and natural marshes can provide baseline data for understanding and predicting marsh responses to changing water levels; (B) Education of local communities about challenges facing Suisun Marsh and the realities of sea level rise can increase support for environmentally sensible policy changes; (C) Stewardship and resource management in existing marshes can provide examples to private land owners and generate data and case studies for future planning and adaptation; and (D) Training workshops and facilitated discussions can provide opportunities for information exchange among scientists, resource managers, private land owners and politicians, ultimately leading to more informed policy and action. Through integration of these programs, the NERR, its partners, and local land owners and managers can reach mutually beneficial agreements and enact necessary changes in the management of Suisun Marsh. For more information about programs within SF Bay NERR and the NERRS in general, visit http://www.nerrs.noaa.gov.

1.2 Long-Term Monitoring and Research in the Reserve

A variety of research and monitoring activities are currently underway to better understand the ecology of tidal wetlands at China Camp and Rush Ranch. Some of these investigations are led by scientists from regional institutions, whereas other ongoing studies were initiated by SF Bay NERR. Reserve-based efforts include the Graduate Research Fellowship Program and the NERRS System-Wide Monitoring Program. The sections below briefly describe the national context for these programs as well as the history and current status of the programs in the SFE.

Graduate Research Fellowship Program

The NERRS established a Graduate Research Fellowship (GRF) program in 1997 to encourage and enable talented young scientists to contribute to scientific knowledge, to provide science to support effective coastal decision making, and to train future coastal scientists and policy-makers. The GRF program provides funding to graduate students for research projects conducted within the NERRS. Projects are based on local needs, national research priorities of the NERRS, as well as the students' own interests. Since the designation of SF Bay NERR in 2003, the Reserve has supported GRF students investigating topics ranging from the synergistic effects of nutrients and invasive invertebrates to the demographics and ecology of rare plants. Opportunities for GRF support are advertised on the Reserve’s website (http://sfbaynerr.org).

System-Wide Monitoring Program

SF Bay NERR supports physical and biological monitoring to supply long-term datasets for use in estuarine research and resource management. These monitoring efforts reflect both national and regional priorities for data collection. At a national level, the NERRS established the System-Wide Monitoring Program (SWMP) with a primary mission to:

> Develop quantitative measurements of short-term variability and long-term changes in the water quality, biotic diversity, and land-use / land-cover characteristics of estuaries and estuarine ecosystems for the purposes of informing effective coastal zone management.

This program was initiated in 1995 and developed in consultation and partnership with several other national monitoring efforts including the National Status and Trends Program of the National Oceanic and Atmospheric Administration (NOAA), the U.S. Environmental Protection Agency Environmental Monitoring and Assessment Program, the National Park Service Inventory and Monitoring Program, and the National Science Foundation Long Term Ecological Research Program. Since then, the conceptual framework for SWMP has been periodically updated and revised (most recently in 2011). Long-term monitoring activities and iterative habitat assessments that are conducted as part of SWMP are intended to improve understanding of the temporal and spatial dynamics of estuarine processes, and to provide baseline information for evaluating change in ecosystem function in response to natural and anthropogenic perturbations. Data are subjected to quality control and assurance procedures at the individual reserve level and through the NERRS Centralized Data Management Office with coordination and support from NOAA’s Estuarine Reserves Division of the Office of Coastal

Resource Management. All of these data and associated metadata are publically accessible through the online database (http://nerrsdata.org) and can be sorted and downloaded to meet specific data needs of individual users. Additionally, telemetered monitoring stations provide near-real-time data that is queried and made available through the same website as well as other sites such as the Central and Northern California Coastal Ocean Observation System (http://www.cencoos.org). Standardized monitoring protocols employed in all 28 reserves around the country allow for comparisons of estuarine processes within and across biogeographic regions and different coasts.

SF Bay NERR initiated SWMP in 2005 and gradually expanded to become fully operational in 2008. Recent revision of the national SWMP Plan in 2011 provided a more systematic and comprehensive structure to the various monitoring protocols and activities undertaken throughout the NERRS. Many of the intended components of this coordinated program are not yet operational nationwide, but progress is being made at the individual reserve level as resources and funding become available. SF Bay NERR utilizes its own staff, graduate students, and scientific colleagues from around the region to undertake a variety of monitoring efforts that contribute to the larger vision of SWMP (Table 1). For example, meteorological data are collected every 5 seconds with a 6-meter weather station (Campbell Scientific CR1000) positioned on the edge of the marsh at Rush Ranch (Figure 4). Measurements of air temperature, relative humidity, barometric pressure, wind speed and direction, photosynthetically active radiation, and precipitation are averaged over 15-minute intervals and automatically uploaded to the internet via satellite telemetry. More information about these efforts is available in the Reserve's management plan (SF Bay NERR 2010) and detailed descriptions of the primary abiotic monitoring efforts (water quality, nutrients, and weather) are available in the Reserve's annual metadata files archived by the Centralized Data Management Office (http://nerrsdata.org).

Table 1. Current categorization of the primary toolkits, components and elements of the national System-Wide Monitoring Program.

Long-term data collected through this program provide baseline information to support management and to complement and enhance other research and monitoring. Bold-faced elements are required of all reserves where applicable and are considered operational throughout the NERRS as of 2011. Additional elements will be deemed operational on a system-wide basis only after programmatic funding has been secured to ensure proper measurement and long-term support. Non-operational sampling designs and methodologies are in various stages of development around the country. Additional toolkits are available to guide data analysis and synthesis, education and translation, and application to management.

Toolkit	Component	Element
Abiotic	Weather	**Meteorological station***
	Water quality	**Sonde station***
		Water chemistry*
		Water column radiation
	Hydrology	**Groundwater wells**
		Hydrodynamics*
	Sediment analysis	Total suspended solids**
		Sediment chemistry
		Pore water chemistry**
		Accretion / erosion rates**
Biotic	Vegetation†	**Emergent marsh****
		Submerged aquatic vegetation
	Benthic invertebrates	Decapods***
		Sessile invertebrates*
	Plankton	Zoo-, phyto-, bacterio- (or size based)
	Nekton	Fishes, invertebrates*
	Birds	Secretive marsh birds**
		Shorebirds and waterbirds
Mapping	Imagery	**Watershed scale maps*****
		Reserve scale maps***
	Elevation mapping	Vertical control***
		Elevation products

† Denotes monitoring via field surveys (e.g., quadrat sampling along permanent transects)
* Presently implemented by SF Bay NERR technicians
** Presently implemented by external scientists working in the Reserve sites of China Camp and Rush Ranch
*** Presently implemented by both SF Bay NERR technicians and external scientists

Monitoring water quality

Monitoring by Reserve technicians is focused primarily on estuarine water quality and nutrients at both China Camp and Rush Ranch as a core component of SWMP. Regularly calibrated data loggers (YSI 6600-EDS and 6600-V2 sondes) deployed at each of four water-quality stations (two per site) measure a variety of parameters every 15 minutes: salinity, temperature, depth, pH, dissolved oxygen and turbidity. In addition, replicate discrete water samples are collected monthly at all four monitoring stations and analyzed for a suite of nutrients (nitrate, nitrite, ortho-phosphate, silicate, ammonium, and urea) as well as chlorophyll *a*. Each month a single day of higher frequency samples are collected with an automated sampler (ISCO 6712) over a complete, semidiurnal tidal cycle to capture diel variation in concentrations of nutrients and chlorophyll *a*. In response to the recognized ecological significance of ammonium in the estuary (e.g., Dugdale et al. 2007), SF Bay NERR research technicians utilize a rigorous fluorometric determination of ammonium concentration in all water samples and account for variable matrix effects over time and between sites (Taylor et al. 2007).

Data from these stations are valuable to researchers working within the sites and to educators, students, and decision makers. However, at the current time the Reserve's efforts are only one contribution to larger and longer-term monitoring programs in progress throughout this large, diverse estuary. Status and trends of estuarine water quality as determined by other ongoing programs was recently synthesized in the The State of San Francisco Bay (2011) report, and a few typical features of current water quality in the estuary are briefly summarized below:

- *Salinity*: The SFE is a well-mixed estuary, with a strong salinity gradient in the North Bay extending from the Golden Gate northward towards the Sacramento-San Joaquin Delta. Typically, X2 (the location where salinity equals 2 psu) lies near the town of Collinsville, well east of the Rush Ranch reserve site. After winter storms with very heavy precipitation, the estuary may become vertically stratified for several days.

- *Water temperature*: There is a strong marine influence in the SFE and Pacific Ocean temperatures along the California coast are generally low year round. Therefore, water temperatures within the estuary are also typically quite low (10-20°C).

- *Depth*: The SFE experiences mixed semidiurnal tides with an average tidal range of 1.8 meters. Average depth of San Francisco Bay is 4.3 meters (http://www.bay.org/about-the-bay/at-a-glance). Average depth of San Pablo Bay sub-region (where China Camp is located) is 1.1 meters and average depth of Suisun Bay sub-region (where Rush Ranch is located) is 1.8 meters (http://sfbay.wr.usgs.gov/sediment/sfbay/geostat.html). A deep channel extends from the Golden Gate, through Raccoon Strait in Tiburon, and northwards; the deepest point within the Bay is under the Golden Gate Bridge (about 91 meters deep). Hydraulic mining for gold in the Sierra foothills brought massive amounts of fine sediments into the SFE and altered the estuary's bathymetry dramatically.

- *pH*: Variability in pH within the estuary is largely driven by local productivity and exhibits regular diurnal variability. Low-pH or acidified conditions associated with upwelling along the California coast are known to affect estuaries just north of the SFE (e.g., Tomales Bay) but the importance of this phenomenon in the SFE remains unclear.

- *Dissolved oxygen*: Technical improvements and regulation of wastewater discharge has reduced the threat of low dissolved oxygen events in the estuary. Tidal mixing, typical lack of stratification, and relatively cold temperatures also limit the occurrence of low dissolved oxygen. Periodic hypoxic events do occasionally occur in northern parts of the estuary and in areas of restricted tidal flushing, and in some cases these events are associated with fish kills.

- *Turbidity*: Delivery of suspended sediment to the estuary is essential for marsh accretion and has decreased in recent decades due to clearing of sediment derived from hydraulic mining and retention of sediment behind dams. Even with reductions in sediment supply, however, the SFE remains a turbid estuary. High turbidity has been implicated as one factor limiting phytoplankton productivity in the estuary over the past century.

The primary management concerns related to water-quality within the estuary are freshwater inflow, pollutants, and sewage treatment.

- *Freshwater inflow*: The SFE receives 90% of its freshwater from the Sacramento and San Joaquin rivers. Historically, peak freshwater flows from these rivers, which together drain 40% of the land surface of the state of California, would have occurred during the spring when snow melts in the Sierra Nevada mountains. However, dams on the major rivers and diversion of freshwater away from the estuary for use as drinking water or for agricultural irrigation have led to significantly less freshwater inputs to the estuary, and future reductions in winter snowpack associated with climate change are expected to further reduce freshwater inflow. The report on The State of San Francisco Bay (2011) concluded that there is an "urgent need for greater efforts to improve freshwater inflow conditions as part of a comprehensive program to improve the health of the Bay."

- *Pollutants*: California now has strict pollution controls in place to protect the SFE, yet there are still unsafe levels of pollutants in the estuary's water and sediments. Trash is currently the primary pollutant that continues to enter the estuary via surrounding watersheds and significant shipping traffic within the estuary also presents a constant threat of oil spills. Legacy pollutants remain a major management concern throughout the estuary. Methylmercury, most of which is derived from mercury introduced during hydraulic gold mining, poses a significant threat to the estuary's fish, birds, and other life. Methylmercury concentrations have remained stable over the last 40 years but restoration of tidal marshes may lead to an increase in methylmercury production. Due primarily to legacy pollutants like polychlorinated biphenyls (PCBs), methylmercury, and dioxins, there are now strict guidelines regarding the quantity, size, and type of fish from the SFE that can be safely consumed by humans.

- *Sewage treatment*: With a human population of more than seven million, the San Francisco Bay Area generates massive amounts of sewage and other waste. Elevated levels of fecal coliform bacteria sometimes result in beach closures or health warnings in the summer and during wet periods. Concern for human health is typically related to bacterial counts, yet inorganic substances released in wastewater also can have significant effects on estuarine life. For example, ammonium nitrogen, which is the primary form of nitrogen in secondary level wastewater treatment, has been shown to negatively affect diatom production in the estuary (Wilkerson et al. 2006, Dugdale et al. 2007) and has even been suggested to play a role in large-scale reorganization of the estuarine foodweb (Glibert 2010).

Other site-based research and monitoring

Subsequent chapters in this site profile summarize many ecological investigations in the Reserve. Notable ongoing studies being conducted within the Reserve (but led by scientists from outside the NERRS) include long-term monitoring of sediment dynamics, water level, vegetation (including species composition, abundance, distribution, biomass and productivity), birds, mammals, and patterns of habitat use by various species. Coordination of these projects by Reserve staff has helped to reduce impacts on natural resources by facilitating communication between researchers studying sensitive species (such as secretive marsh birds) and other scientists working in areas used by those sensitive species, by reducing project overlap in heavily used areas such as the cobble beaches of China Camp, and by identifying alternate (non-Reserve) locations for research to limit impacts of collections, researcher activities, or equipment deployment, when appropriate.

Wealth of existing research and regional data

In addition to the Reserve-based research and monitoring described above, there have been many hundreds if not thousands of scientific studies conducted in the SFE and, as a result, there exists a wealth of information on the history, natural resources, physical and biological changes and management concerns facing the estuary. Some regional monitoring programs have already persisted for several decades, including regular sampling of water quality by the U.S. Geological Survey and benthic animals by the California Department of Fish and Game. Other long-standing monitoring programs are supported by non-profit organizations such as the San Francisco Estuary Institute and PRBO Conservation Science.

At the end of the 20th century a broad collaboration of scientists, consultants and resource managers published two comprehensive reports about the region's intertidal habitats: *Baylands Ecosystem Habitat Goals: A report of habitat recommendations* (Goals Project 1999) and *Baylands Ecosystem Species and Community Profiles: Life histories and environmental requirements of key plants, fish, and wildlife* (Goals Project 2000). In 2010, a similar process concluded with a focus on 50-year recommendations for conservation and management of habitats and communities below the surface of the water: *San Francisco Bay Subtidal Habitat Goals Report: Conservation Planning for the Submerged Areas of the Bay* (Goals Project 2010). The following year a cross-cutting report on the overall health of the estuary was published (The State of San Francisco Bay 2011) and includes detailed evaluations of numerous ecological metrics, status and trends regarding a range of parameters, habitats and species within the SFE. Nearly all of the analyses in that report were based on publically available data and a series of technical appendices describe in detail the process by which the assessments and recommendations were made. These types of comprehensive and goal-oriented publications summarize an immense amount of environmental and ecological data, evaluate complex and critical barriers to effective natural resource management, and articulate specific goals and recommendations for prioritizing research, restoration and management activities around the estuary. Additionally, many years of effort by numerous researchers and resource managers has been directed at synthesizing and disseminating information about the estuary through articles and reviews, agency reports, conference proceedings, books, internet resources, and publication of an open-access peer-reviewed journal dedicated to science of the region (http://escholarship.org/uc/jmie_sfews).

1.3 Summary

The NERRS is a network of integrated research reserves where estuarine ecosystems are monitored and studied in a coordinated manner around the country. In addition to the local and regional benefits that the NERRS provides in support of coastal zone management, much potential lies within the reserve system to follow national trends, to make regional comparisons, and to serve as sentinel sites for detecting and responding to the effects of climate change on our nation’s estuaries. SF Bay NERR sites of China Camp and Rush Ranch contain some of the last remaining historic tidal marshes in the estuary and serve as reference sites for design and evaluation of other restored and created wetlands. Long-term monitoring and research are supported in these sites by the NERR and complemented by many other scientific efforts throughout the region. Overall, this site profile aims to review the existing state of knowledge for the Reserve’s research and monitoring activities, at China Camp and Rush Ranch as well as within a broader regional context, and to provide guidance for future research needs.

Site profile overview

The collection of chapters within this ecological profile of SF Bay NERR reinforces and expands upon the vast collection of publications noted above. Most of the chapters focus on emergent tidal wetlands and the channels or sloughs that permeate them, as those are the dominant estuarine habitats present at both Reserve sites. Several general and important conclusions emerge from these chapters. First, climate change and sea level rise pose immediate and severe threats to tidal marshes around the estuary. Future research, monitoring, restoration and management must consider these unavoidable and imminent changes. Second, the physical structure and resultant ecological function of tidal marshes is more important than mere acreage, and restoration efforts therefore should be designed and evaluated with this functionality as a central goal. Third, listed species (those that are officially considered rare, threatened or endangered at the state or federal level) live in and around tidal marshes and provide important incentives for conservation, restoration and adaptive management. However, there remain many uncertainties about the basic biology and ecology of these species, leaving conservation and recovery actions less than fully effective. Finally, more environmental research and monitoring is needed to distinguish short-term variability from long-term change and to guide sustainable management of natural resources in the estuary.

Additional topics

In addition to tidal marshes and the species they support, other important habitats and species exist within the Reserve sites and in the estuary as a whole. Brief mention of these topics is presented below and more detailed accounts can be found in comprehensive reports such as The State of San Francisco Bay (2011) and the Subtidal Habitat Goals Project (2010).

Pelagic communities

Open water habitats of the SFE support a wide variety of plankton and nekton that are influenced by the drivers of water quality noted above and are the focus of many past and present investigations in the estuary. One recent unifying theme of many of these studies is the acknowledgement of a significant "pelagic organism decline" (POD) over recent decades. The causes and solutions for observed declines in abundance and diversity of pelagic organisms remain in debate and a funding initiative was created to foster research and collaboration on this topic (http://www.water.ca.gov/iep/pod/). These efforts have been motivated by documented declines in several important species of fish, and a number of trophic connections involving plankton and benthic invertebrates have been implicated in these large-scale declines. A review of this topic including interpretations and questions about the role of plankton in the POD is available (http://www.water.ca.gov/iep/docs/FinalPOD2010Workplan12610.pdf) and a final report from this interagency initiative is expected to be released by 2013.

In general, phytoplankton primary productivity in the estuary is typically low despite relatively high nutrient concentrations. The main factor limiting phytoplankton growth is light limitation due to high concentrations of suspended sediment. Consumption of phytoplankton by voracious filter-feeders like the invasive overbite clam (*Corbula amurensis*) also can limit primary productivity. The U.S. Geological Survey and Interagency Ecological Program routinely measure chlorophyll *a* (as a proxy for primary productivity) in the estuary, and complementary monitoring of chlorophyll *a* by SF Bay NERR adds to the data available for the region.

Zooplankton are also important members of pelagic communities within the SFE, although their diversity has declined in recent years. Common taxa include rotifers, ciliates, copepods, cnidarians, and larval fish and invertebrates, and much attention has recently been focused on invasive copepods (e.g., *Limnoithona* spp.) that are thought to play a role in the POD.

Despite the undeniable POD, there remain a number of rare, threatened and endangered species of fish in the estuary. These listed species include the Delta smelt, Longfin smelt, Sacramento splittail, Chinook salmon, and Steelhead, all of which are known to occasionally use tidal slough habitats at or near Rush Ranch. The status and ecological requirements of these species are detailed in the Appendix along with numerous references for more information.

Benthic communities

In addition to the tidal marshes and sloughs discussed in detail in this site profile, benthic environments in the SFE include sandy and cobble beaches, rock outcrops, beds of submerged aquatic vegetation and macroalgae, and tidal flats of unconsolidated sediment. These biotic and abiotic habitats support a variety of different species and many of them are thought to provide ecosystem functions that are critical to the health of the estuary. The recent Subtidal Habitat Goals Project (2010) details what is known about each of these habitats and identifies key uncertainties and pressing research questions and management issues that warrant immediate attention. That report also points to restoration of subtidal benthic communities and creation of "living shorelines" as high-priority goals for natural resource management in the estuary.

Although true subtidal habitats are rare or non-existent throughout much of the Reserve sites, native and non-native benthic invertebrates are important parts of biological communities in both intertidal and subtidal regions of tidal sloughs at Rush Ranch. In particular, a variety of amphipod species (including *Americorophium spinicorne*, *Americorophium stimpsoni*, *Corophium alienense*, *Gammarus daiberi*, and *Eogammarus confervicolus*) likely serve as important food resources for fish at that site (Teejay O'Rear, personal communication). Intertidal invertebrates are supported by a variety of benthic habitats at China Camp but little is known about their site-specific ecology, population dynamics, and significance to foodweb structure and ecosystem stability. There remains much to be learned about the significance of linkages between benthic and pelagic communities at both Reserve sites as well as around the SFE more generally.

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2. History of the San Francisco Bay Estuary and the Formation of its Surrounding Tidal Marshes

Frances Malamud-Roam[1] and **Michelle G. Goman**[2]

[1] *Department of Geography, University of California, Berkeley*
fmalamud@eps.berkeley.edu, (510) 643-4326

[2] *Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, NY*
mg254@cornell.edu, (607) 255-4726

ABSTRACT

The tidal salt marshes that exist around San Francisco Bay are largely remnants of a vast network of marshlands that existed prior to the modern post-Gold Rush occupation of California, circa 1848. The rapid sea level rise that followed deglaciation precluded tidal marsh formation; however, after 6,000 years ago the rate of sea level rise slowed dramatically and tidal marshes began forming around the edges of the Bay. Tidal salt marshes are ephemeral features, evolving in response to long-term trends in global climate that have marked the Quaternary period (the last 2 million years), and local crustal movement. Evidence contained in the sediments of the San Francisco Bay estuary show that earlier incarnations of the estuary existed during previous low stands in sea level, associated with previous interglacial periods. Over the several thousand-year history of the modern estuary, vegetation records show that tidal marshes have responded both to the long-term trend in rising sea level and to higher frequency variations in fresh water inflows from the major rivers that discharge into the system. Changes in plant species composition over time reflect either fresher or more saline estuarine conditions, principally controlled by climate variations. In particular, the tidal marshes of the San Francisco Bay are affected by climatic conditions that dominate the larger watershed region of the estuary; for instance during the Neoglacial, Medieval period and, most recently, the Little Ice Age (LIA). During the Medieval period, widespread and prolonged drought occurred throughout the watershed, while during the Neoglacial and LIA climate was generally cooler and wetter. The 20th century is notable for anthropogenic-derived changes to the system. Not only has the vast majority of tidal marsh habitat been lost to development, but the remaining marshes have also been impacted by upstream water management decisions that altered overall estuarine water quality and sediment supply.

KEY WORDS

Tidal salt marshes
San Francisco Bay estuary natural history
sea level rise
climate change

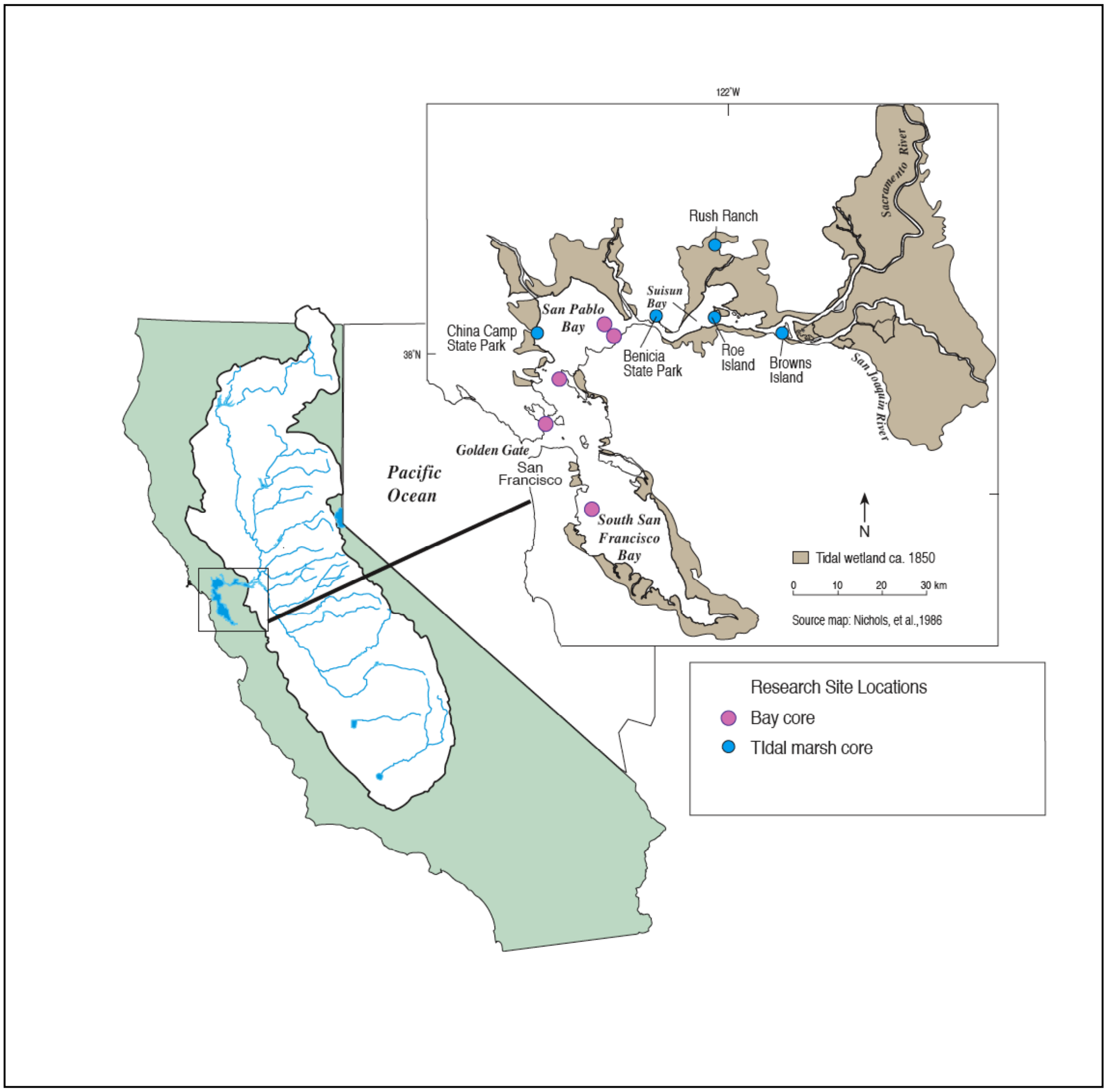
2.1 Introduction

On the central coast of California, a series of bedrock basins and narrow structural constrictions (straits) have produced what we recognize today as the San Francisco Bay estuary (Conomos et al. 1985; Goals Project 1999). Pacific Ocean water passes through the Golden Gate and enters the Central Bay of the estuary; from here saline water flows upriver with the tides into San Pablo Bay, through the Carquinez Strait, into Suisun Bay and finally into the Sacramento-San Joaquin delta (the Delta). This water mixes with the combined fresh water of the Sacramento and San Joaquin rivers (Figure 1) that flow westward through the Delta. Thus, the northern reach of the estuary experiences a gradient of generally decreasing salinity and tidal character with distance from the Golden Gate (Atwater et al. 1979, Malamud-Roam et al., 2006a). An additional basin exists to the south, the South Bay (Atwater 1979), but experiences significantly lower freshwater input so that a similar salinity gradient is not present here. The northern reach experiences a mean tide level 0.2 m higher than the southern reach, while the latter has a larger tidal range with 2.6 m in the South Bay, 1.7 m at the Golden Gate and 1.3 m at Suisun Bay (Conomos 1979; Conomos et al. 1985). This chapter reviews the natural history of the estuary and its tidal marshes, largely focusing on the period prior to European contact and subsequent environmental impacts. Other chapters of this site profile, however, address the modern setting as well as some of the changes in the estuary that have occurred as a result of human activities in the late 19th and 20th centuries.

2.2 Geologic History

The San Francisco estuary is the recurring product of a specific set of conditions resulting from global climate and sea level dynamics, and as such is an ephemeral feature of the California coast when considered on geologic timescales (Malamud-Roam et al. 2006a). The Quaternary period, covering the last ~2 million years has experienced large, regular oscillations in world climate between cool glacial phases, when large areas of the world’s high latitude continents were covered with thick ice sheets and global sea level was low, and warmer interglacial phases, such as today, when much of the continental ice sheets melted causing higher sea levels (Hays et al. 1977). These cycles, driven by astronomical forcing, generally occur on a 100,000-year scale, with long glacial periods (~90,000 years) and short interglacial periods (~10,000 years) (Shackleton and Opdyke 1976, Bassinot et al. 1994).

An estuary formed in the San Francisco Bay during at least the last 4 interglacial periods (Atwater et al. 1977, Sloan 2006). However, the stratigraphic evidence for earlier interglacial estuaries has largely been removed during glacial periods, when a wide river valley replaced the estuary and erosion dominated the landscape (Sloan 1992). A stratigraphic profile was constructed from a series of boreholes drilled along a transect between Alameda and southern San Francisco during the planning of a proposed “southern crossing” bridge and portrays the depositional history of the last several hundred thousand years (Figure 2, Sloan 2006). Layers of “Bay mud” (estuarine sediments) are interspersed with alluvium (river sediments deposited during glacial periods) representing several interglacial-glacial cycles in the San Francisco Bay. During the penultimate interglacial period, about 135,000 years ago, eustatic (global) sea level was about 6 m higher than the modern interglacial (Chen et al. 1991), resulting in a larger



Source map: Nichols, et al.,1986

Figure 1. Map of San Francisco Bay estuary and its watershed. Research sites on the tidal marshes and in the estuary are indicated by circles.

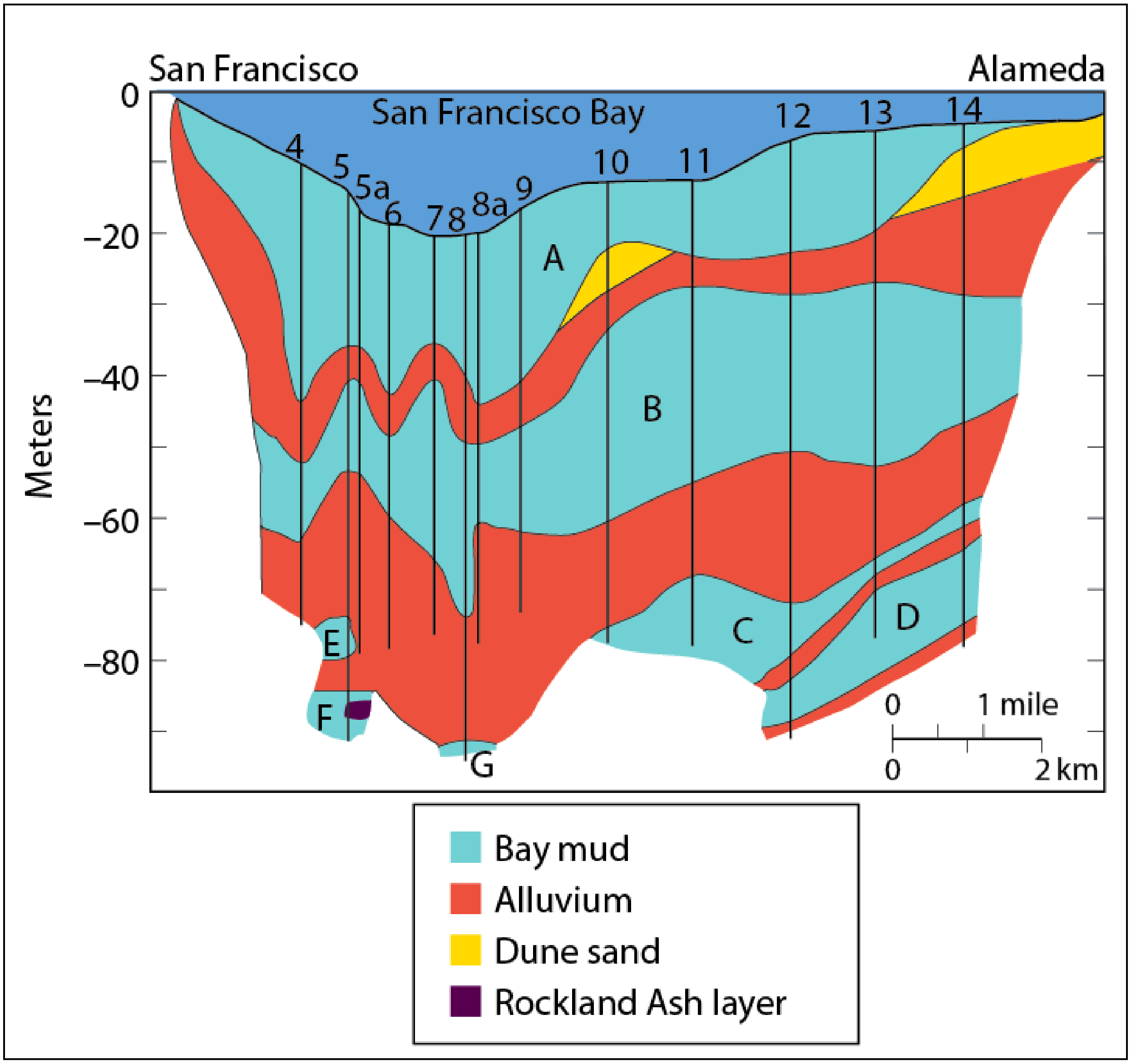


Figure 2. Sediment layers beneath the San Francisco Bay estuary between San Francisco and Alameda, the site of a proposed "southern crossing". Layer A contains the modern interglacial estuarine sediments (Bay mud), and layers B, C and D are previous interglacial estuary sediments; E, F and G may be associated with C and D. Alluvial sediments alternate between the estuary sediments, representing river-borne sediments deposited during glacial periods. Adapted, with permission, from D. Sloan, 2006.

estuary (Sloan 1992). Ingram and Sloan (1992) reconstructed a salinity history of this early incarnation of the estuary and found periods when conditions were significantly fresher than the modern estuary, which they attribute to climate fluctuations.

2.3 Sea Level Rise and the San Francisco Bay since the Last Glacial Maximum

A closer consideration of the rise of sea level in the San Francisco Bay since the last glacial maximum provides the context for a discussion of the history of tidal salt marsh formation around the edges of the Bay estuary. Two conditions, influenced by sea level rise, are critical for tidal marsh establishment and persistence: protection from severe storms (Zedler 2001, Mitsch and Gosselink 2000) and adequate sediment supply (Frey and Basan 1985, Pethick 1992, Trenhaile 1997).

Following the last glacial maximum, ca. 21,000 years ago (Kutzbach et al. 1998), eustatic sea level rise was at least 110-120 m (Figure 3; Ruddiman 2001, Fairbanks 1989), others calculate this rise to have been 130-140 m (Issar 2003, Clark et al. 2004). Local sea level changes differ due to crustal movement (e.g. Atwater and Hemphill-Haley 1997), subsidence (Patrick and DeLaune 1990, Watson, 2004) or diversions in glacial meltwater (e.g., Broecker et al. 1989, Fairbanks 1989). Tidal marshes most likely existed in small, fragmented pockets along the coastline even during glacial times, migrating with the changing shorelines as post-glacial sea levels rose (Atwater 1979, Malamud-Roam et al. 2006b). Sea level entered the river valley that would eventually become the current San Francisco Bay about 10,000 years ago (Figure 4, Atwater et al. 1977, Atwater 1979). The geologic constriction that forms the Golden Gate effectively buffers the coastal interior from high energy conditions along the California coastline (NOAA 2003), such that the newly forming Bay provided sheltered shoreline habitat.

Initially, the Bay filled rapidly (e.g., as measured in southern San Francisco Bay by Atwater et al. 1977) as the rate of sea level rise was on the order of 6-8 mm/year or more. The effect of this rapid rise was to preclude the development of extensive tidal marshlands along the edges of the Bay until the rate slowed to about 1-2 mm/year globally and locally, about 6,000 years ago (Fairbanks 1989; Atwater 1979, Goman and Wells 2000). The oldest extant tidal marshes in the San Francisco estuary became established following this global decline in the rate of sea level rise; however, most tidal marshes formed in the estuary within the last 5,000 years (Atwater et al. 1979, Byrne et al. 2001, Goman and Wells 2000, Malamud-Roam and Ingram 2004). Tidal marsh formation, health and stability are also affected by sediment supply. If sediment supply had been sufficient during the early Holocene (10,000-6,000 yrs ago), marshes could have become established even at the high rates of sea level rise. Indeed, tidal marshes in the South San Francisco Bay were able to persist during a period of rapid relative sea level rise that occurred in the last century as groundwater extraction caused rapid subsidence in the area (Patrick and DeLaune 1990, Watson 2004). In particular, Alviso Marsh experienced on average 3.9 cm yr^{-1} of accretion between 1955 and 1983.

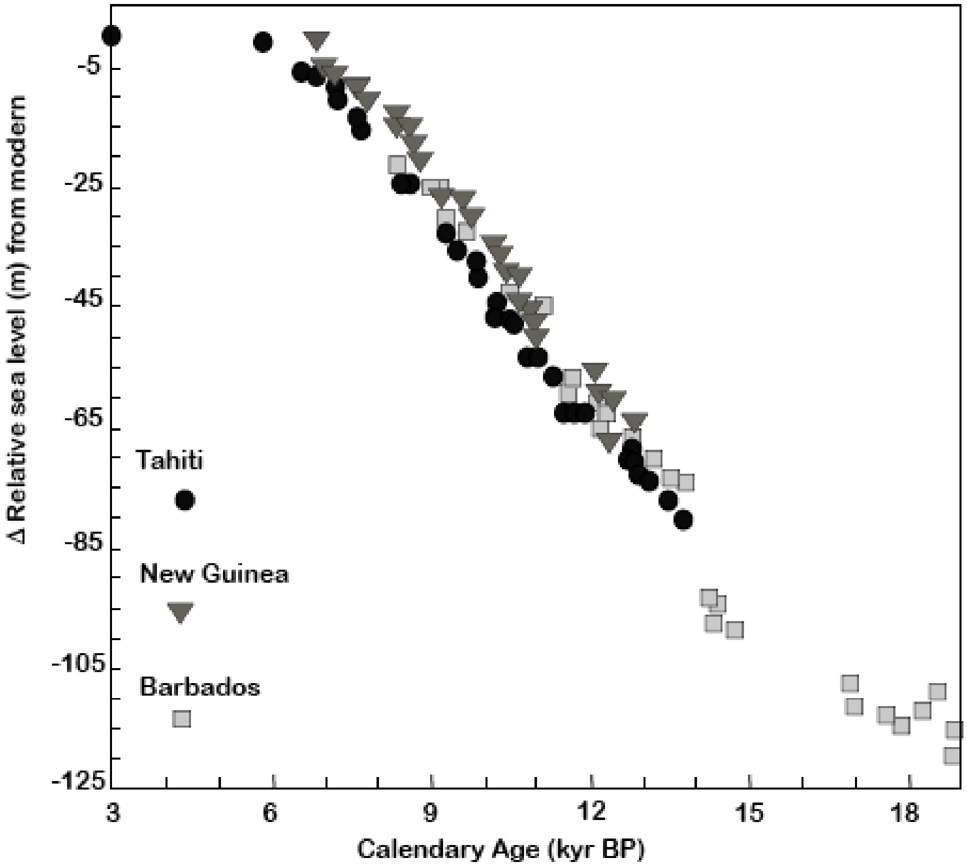


Figure 3. Sea level curve since the Last Glacial Maximum. Adapted from Quinn (2000), with source data from Fairbanks (1989), Chappell and Polach (1991), Edwards et al. (1993) and Bard et al. (1996).

A)

B)

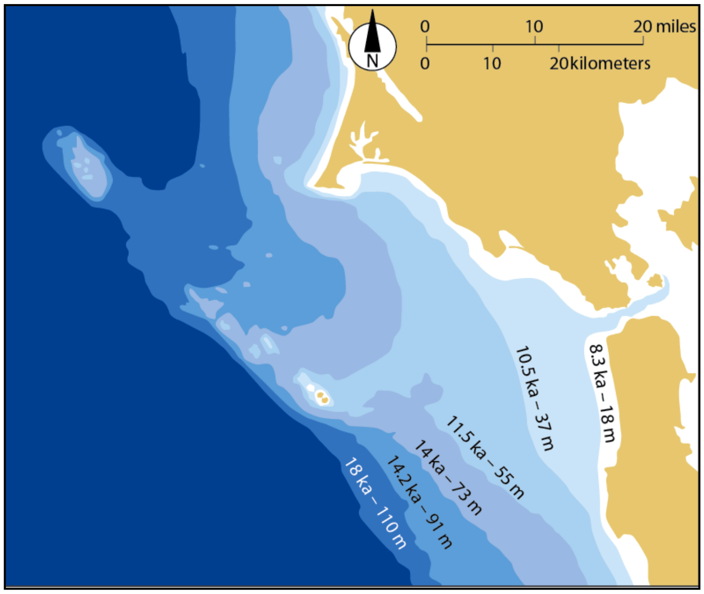


Figure 4. San Francisco Bay estuary formation. A) During glacial times, the shoreline is out beyond the Farallon Islands and a river valley occupies the site of the San Francisco Bay estuary. B) As global sea level rose since the height of the last glacial period, the shoreline gradually moved inland, passing through the Golden Gate approximately 10 thousand years ago. Adapted from Sloan, 2006 using data from Atwater 1979 and Atwater et al 1977.

2.4 Tidal Marsh Communities of the San Francisco Bay

Freshwater inflows and the tides strongly influence the composition and zonation of marsh vegetation along the estuary as well as within individual marshes through duration of tidal inundation or submergence and salinity (Mall 1969; Atwater and Hedel 1976; Goman 2001). On the marsh, plant zonation is not always well-defined because of spatial and seasonal variations in salinity and tidal inundation, and changes in marsh composition are gradual, forming a vegetation continuum within individual marshes and along estuary, rather than well-defined boundaries (Macdonald and Barbour, 1974, Chapter 4). The marked estuary-wide salinity gradient is clearly reflected in vegetation composition on the marshes, both in terms of plant assemblages and in terms of overall biomass, which increases eastward along the northern reach of the estuary as salinity declines (Conomos 1979; Goman 2001).

Tidal salt marshes are found in the northern reach of the estuary as far east as the western edge of the Carquinez Straits. These marshes are dominated by two species: Pacific cordgrass (*Spartina foliosa* Trin.), typically grows in near-monospecific bands at the interface between Bay waters and the marsh and pickleweed (*Sarcocornia pacifica*, formerly *Salicornia virginica* L.), typically dominates the rest of the salt marsh, with other species interspersed such as saltgrass (*Distichlis spicata* L.), fleshy jaumea (*Jaumea carnosa* (Less.) A. Gray) and marsh gumplant (*Grindelia stricta* D.C.) also present (Atwater et al. 1979; Goman, 1996; Malamud-Roam and Ingram (2001). Brackish marshes generally lie up-estuary of the Carquinez Straits and stretch as far east as the Delta. These marshes show an increase in biomass and in plant diversity within the tidal marshes as one moves up-estuary (Atwater and Hedel 1976). Brackish marshes are typically dominated by a variety of species of bulrush (*Scirpus* spp.); however, there is variability depending upon the local salinity regime. The tidal marshes close to the confluence of the Sacramento and San Joaquin Rivers typically experience fresher conditions than those further west in the estuary, although this varies over multiple timescales. In this region *Scirpus acutus*, *Typha angustifolia*, *T. latifolia* L. and *Phragmites communis* Trin. are able to tolerate frequent tidal inundation and so are found at the water's edge. For a more complete discussion of the plant communities of the tidal marshes in the San Francisco Bay estuary, see Chapters 4-6.

2.5 Freshwater Sources and Their Variability

Thus far we have primarily discussed oceanic influences on the San Francisco Bay estuary. The estuary is also influenced by riverine water sources. In fact, fresh water inflows to the estuary have a direct and immediate impact on estuarine salinity and thus on the ecosystems of the estuary, including tidal marshes (Atwater and Hedel 1976, Byrne et al. 2001, Goman 1996, Ingram et al. 1996a,b, Malamud-Roam and Ingram 2004, Peterson et al. 1989). The fresh water inflows derive from a large watershed (153,000 km^2) that encompasses the western slopes of the Sierra Nevada Range, the southern slopes of the southern Cascade Mountains, parts of the Klamath and Coast Ranges, and the Central Valley. In total this comprises about 40% of California (Conomos 1979, Conomos et al. 1985). Fresh water is delivered to the estuary primarily by the Sacramento River, which drains the northern part of the watershed and delivers over 85% of the total fresh water inflow, and by the San Joaquin River, which drains the southern watershed and delivers about 15% (Peterson et al. 1989). The two rivers merge to form the Sacramento-San Joaquin Delta, approximately 50 miles inland of the Golden Gate (Conomos et al.1985).

Each year, Bay-wide salinity fluctuations occur due to the seasonal nature of precipitation and snow melt in California (Cayan and Peterson 1993, Dettinger and Cayan 2003, Peterson et al. 1989, Knowles 2000); lower salinity occurs during the winter-spring wet season and is followed by increasing salinity through the summer-fall dry season. Salinity is also affected by year-to-year variations in climate, such as those associated with global phenomena like El Niño-Southern Oscillation (ENSO) (Mann 2000, Cayan and Webb 1992) and, on longer timescales, the multi-decadal Pacific Decadal Oscillation (Mantua et al. 1997; Benson et al. 2003) because of changes in precipitation over the watershed (Malamud-Roam et al. 2007). Superimposed on these natural climate fluctuations are recent increases in winter-spring temperatures (Cayan et al. 2001) and associated snowmelt and streamflow-timing trends (Roos 1991; Dettinger and Cayan 1995; Mote 2003; Stewart et al. 2005).

2.6 Holocene Freshwater Flows and Tidal Marsh History

Several reconstructions of paleo-salinity in the San Francisco Bay show that, while there has been a trend towards increasing salinity over the last 6,000 years due to sea level rise, there has also been considerable variability due to changes in fresh water inflows (Ingram and DePaolo 1993, Ingram et al. 1996a,b, Ingram and Sloan 1992, Schweikhardt et al. 2002). Long records of high-resolution year-to-year variations in salinity are difficult to generate using sedimentary records; however, dendroclimatological analysis of blue oak (*Quercus douglasii*) tree-ring chronologies from the foothills surrounding the Central Valley has been used to reconstructed annual changes in salinity of the San Francisco Bay for the past 400 year period (Stahle et al. 2001). Recent research has also demonstrated that shell fragments preserved in archaeological sites in the San Francisco Bay can produce seasonal records of salinity (Schweikhardt 2007). While variations in fresh water flows to the estuary do not impact the volume of water in the San Francisco Bay, the altered salinity of the Bay water results in local changes in estuarine and adjacent wetland ecosystems (Atwater et al. 1979, Byrne et al. 2001, Goman 2001, Josselyn 1983, Malamud-Roam and Ingram 2004, May 1999, McGann et al. 2002). To appreciate these ecosystem effects, we present some examples of past variations in estuary salinity and corresponding impacts on the vegetation of adjacent tidal marshes, focusing on 3 key periods in the watershed's climate history and the downstream tidal marsh responses. A discussion of the methodologies for reconstructing paleosalinity and past marsh vegetation assemblages is beyond the scope of this chapter; we refer the reader to a recent review (Malamud-Roam et al. 2006a).

The first key period occurred shortly after global rates of sea level rise declined and tidal marsh became established along the shores of the estuary. A period of cooler, wetter conditions commenced 4,000 to 3,500 years ago, known as the Neoglacial and reflected in mountain vegetation (e.g., Edlund and Byrne 1991, Anderson and Smith 1994), tree-line (LaMarche 1973), fire frequency (Brunelle and Anderson 2003) and lake levels (e.g., Benson et al. 2003). The cool and moist conditions over the state increased Sacramento and San Joaquin river flows and lowered salinity throughout the Bay estuary, as shown in reconstructed records from Bay sedimentary isotopic data (Ingram and DePaolo 1993, Ingram et al. 1996a,b) and marsh macrofossils and metal concentrations (Goman and Wells 2000). Reduced salinity resulted in more diverse plant assemblages with species that prefer fresher conditions, as seen, for instance, at China Camp (Goman et al. 2008). Pollen and stable C isotopes show the dominance of *Sarcocornia pacifica* and *Spartina foliosa* was replaced with a mixed assemblage that included *Typha* spp. and *Scirpus* spp. Further up-estuary, brackish tidal marshes (Figure 1) also saw a shift in plant species: at Peyton Hill, the fresh water bulrush *Scirpus americanus* became important over other, more salt tolerant species (Goman 2001, Goman and Wells 2000); at Browns Island, near the Delta, *Phragmites communis* and *Typha* spp. moved in (Goman and Wells 2000, Atwater 1980).

The second key period in the history of the estuary marshes came after the Neoglacial gave way to a drying trend punctuated by episodic, extreme droughts and floods (e.g., Schimmelmann et al. 2003, Malamud-Roam et al. 2007). The Middle Ages (ca. A.D. 900 to 1300), a period of unusual warmth throughout much of northern Europe (e.g., Hughes and Diaz 1994, NRC 2006, Osborn and Briffa 2006), brought dry conditions to California and the San Francisco Bay watershed (e.g., Hughes and Graumlich 1996, Meko et al. 2001). Two distinct “mega-droughts”, each lasting a century or so long, have been recorded throughout the state (e.g., Stine 1990, 1994) during this medieval period. In the San Francisco estuary, salinity levels were variable and included prolonged periods of higher than modern (i.e., prior to large-scale diversions of water from the Delta) salinity, a result of the droughts (Ingram et al. 1996a,b, Starratt 2004). Plant assemblages on the adjacent tidal marshes shifted to a less diverse community of salt tolerant species. For instance, at Rush Ranch, the relatively fresh-brackish marsh assemblage (including *Scirpus* spp., *Grindelia stricta*, some *Sarcocornia pacifica* and *Distichlis spicata*) of moister times rapidly transitioned to a marsh dominated by pickleweed (Byrne et al. 2001). Similar shifts were also experienced at Roe Island (May 1999) and down estuary at Benicia State Park marsh located in the Carquinez Strait (Figure 1, Malamud-Roam and Ingram 2004).

Most of the mineral sediments that maintain the tidal marshes are transported into the estuary via the Sacramento and San Joaquin rivers. During the mega-droughts of the medieval period, flows in these rivers were so reduced (Meko et al. 2001) that the downstream effect was not only to increase estuary salinity, but also to reduce the sediments delivered to the system. For instance, sediment accumulation rates calculated at China Camp declined during this period (to < 1 mm yr^{-1}) and several lines of evidence indicate the marsh was impoverished due to reduced inflow (Goman et al. 2008).

The final key period of interest began with an abrupt end to the Medieval period of unusual dryness in California: several paleoclimate records from California contain evidence of major floods that occurred at the termination of the droughts (Earle 1993, Schimmelmann et al. 2003, Stine 1990, Sullivan 1982, USBR 2002). These floods scoured sediments from the estuary floor (Ingram et al. 1996a), while depositing mud onto the marsh surface (Goman and Wells 2000). This period, known as the Little Ice Age, continued for the next several centuries with temperatures lower than modern (Graumlich 1993, Scuderi 1993, LaMarche 1973, 1974) and overall conditions less drought prone (Hughes and Brown 1992, Hughes and Funkhouser 1998). Tree-ring based reconstructions of the Sacramento and San Joaquin rivers shows that during this period, conditions were not the same over the two basins. San Joaquin river flow was unusually high for most of the Little Ice Age (Meko et al. 2002), while the Sacramento river had only a brief high-flow period, and otherwise remained generally close to, or below, its mean flow of the last 1200 years (Meko et al. 2001). Downstream in the estuary, these high flows brought generally fresher conditions, as well as episodic floods (Ingram et al. 1996a,b). On the tidal marshes, plant assemblages shifted to more diverse and less salt-tolerant species at many sites, such as Rush Ranch (Byrne et al. 2001), Roe Island and Browns Island (Malamud-Roam and Ingram 2004, May 1999) in Suisun Bay. China Camp in San Pablo Bay was also affected particularly during the latter half of the Little Ice Age when the variety of species on the marsh increased from near total dominance by *Sarcocornia pacifica* to a greater presence of *Distichlis spicata* (which is less tolerant of high salinity than *S. pacifica*) and *Scirpus* spp. (Goman et al. 2008, Malamud-Roam and Ingram 2004).

These three periods in the climate history of California demonstrate the sensitivity of tidal marshes surrounding the San Francisco Bay estuary not only to changes in sea level, but also to changes in climate conditions as they manifest themselves in altered fresh water flows. We feel, however, that a history of the estuary's tidal marshes is not complete without some discussion of what has arguably been the single most profound agent of change to this system: human land-use and development.

2.7 Human Impacts

Human occupation and modification of the estuary began many thousands of years before the discovery of gold in the watershed. Determining the extent of pre-European human-induced environmental changes is difficult; however, some details are known. For instance, the archaeologist Brian Fagan has described the estuary tidelands before 2,000 years ago as a "landscape of shell mounds" (Fagan 2003), where local populations of Native Americans built village-sized mounds as seasonal settlements on the marshes. The archaeology of these shell mounds is rich in information about cultural and anthropological (Lightfoot 1997) as well as environmental change caused in part by these early inhabitants, as evidenced by, for example, significant dietary shifts from an oyster-based diet to a clam-based diet (Jones et al. 1999, Ingram 1998).

Far more profound changes in the estuary have occurred since European contact. The discovery of gold in the mountains of the Sierra Nevada brought miners in from across the country seeking their fortunes, using a variety of techniques from panning to the highly destructive hydraulic mining. The scale and intensity of the mining efforts were devastating to natural ecosystems from the mountains downstream to the estuary (Goals Project 1999). In the early decades of the 20th century, the U.S. Geological Survey sent G.K. Gilbert to investigate the impacts of the extraordinarily high sediment fluxes caused by the mining and the effects of local agricultural activities (Gilbert 1917). For the most part, these sediments have passed through the system (Gilbert 1917, Cappiella et al. 1999, Jaffe, et al. 1998), though in some parts of the estuary (Suisun Bay and San Pablo Bay) shoaling has increased the area of tidal mudflats and tidal marsh (Nichols et al. 1986). The marsh at China Camp, for example, has prograded bayward, and the younger marsh is characterized by straighter channels compared to the sinuous channels of the older high marsh.

Other human impacts to the estuary and its ecosystems in recent centuries include local cattle-ranching, dam construction and water diversions, land development, urban and agricultural pollution and the introduction and spread of alien invasive species (Conomos 1979, Goals Project 1999, Hornberger et al. 2000, Jaffee et al. 1998, Nichols et al. 1986, Takekawa et al. 2006, Chapter 5, Chapter 9). The estuary's tidal marshes have been heavily impacted by modern human occupation of the region as well; not the least of these impacts has been the near total loss of tidal marsh habitat through diking and filling of the marshes for agriculture and development, such that only a small fraction of the pre-1850 tidal marsh areal extent remains today (Nichols et al. 1986). Perhaps more subtly, within the last 50 to 60 years, the vegetation on the remaining tidal marshes has shifted to a less-diverse, more salt-tolerant assemblage (Byrne et al. 2001, Malamud-Roam and Ingram 2004, May 1999), despite the fact that the average annual estuary salinity did not apparently change all that much throughout the 20th century (Fox et al. 1990). The vegetation communities may respond sensitively to the timing of freshwater inflows, which is now managed so as to reduce high spring flows and increase the later season flows (Knowles 2000).

Efforts are underway around the estuary to restore tidal marsh habitat (Goals Project 1999, Chapter 3); however, success could hinge on marsh responses to projected sea level rise. Tidal salt marshes are especially at risk as they rely more heavily than tidal fresh or brackish marshes on mineral sediments to maintain their elevation as sea level rises (Orr et al. 2003). Development around the estuary has blocked off most landward migration options for the estuary tidal wetlands (Goals Project 1999, Nichols et al. 1986, Orr et al. 2003). Thus unless significant action is taken to restore more open space for marsh expansion and to restore sediment supply, the tidal marshes of the San Francisco Bay estuary may face near extinction as global climate predictions and their ramifications come to pass.

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3. Tidal Wetland Restoration in San Francisco Bay: History and Current Issues

John C. Callaway[1], V. Thomas Parker[2], Michael C. Vasey[2], Lisa M. Schile[3], and **Ellen R. Herbert[2]**

[1]Department of Environmental Science
University of San Francisco
2130 Fulton Avenue
San Francisco, CA 94117
callaway@usfca.edu

[2]Department of Biology
San Francisco State University
1600 Holloway Avenue
San Francisco, CA 94132

[3]Department of Environmental Science, Policy and Management
University of California, Berkeley
137 Mulford Hall #3114
Berkeley, CA 94720-3114

ABSTRACT

Early restoration efforts in San Francisco Bay focused primarily on establishing appropriate elevations for plant recruitment, based on plant distributions in natural wetlands. Sites were graded and planted, and tidal connections were re-established with the expectation that restored wetlands would quickly resemble natural ecosystems. Over time, restoration efforts have evolved, with the realization that natural development of restoration sites is preferable, including a dense channel network and the accumulation of soils of appropriate texture. Bay restoration efforts also have grown substantially in size and scope. Whereas projects of 50 hectares were considered large in the 1980s, now many projects are 100s of hectares. Larger projects are on the scale of 1000s of hectares, with the largest approximately 6000 hectares (the South Bay Salt Pond Restoration Project). This massive increase in scale has brought enormous restoration opportunities, but it also has increased the complexity of restoration projects and highlighted the necessity of large-scale public involvement. Awareness of non-native plants at restoration sites is just one example of factors that have increased restoration complexity. Potential impacts of climate change also have moved to the forefront of restoration design, as sea-level rise and potential shifts in salinity are critical factors for long-term restoration planning.

KEY WORDS

climate change
invasive species
public outreach
regional planning
restoration
spatial heterogeneity

3.1 Introduction

Wetland losses to date have been enormous throughout the San Francisco Bay (hereafter, the Bay), ranging from 70 to 93% loss of historic area across regions (Table 1). Over 10,000 hectares of tidal wetlands remain in San Francisco Bay (north, central and south Bays), with over 5000 hectares in Suisun Bay (Table 1). Tidal freshwater wetlands in the Delta were impacted first, with substantial diking for agriculture occurring in the late 1800s (Mount 1995). While agricultural impacts also affected areas in eastern Suisun Bay, most of the tidal wetlands within the western part of Suisun Bay were converted to non-tidal wetlands for duck hunting and have been managed in this way since the late 1800s (Goals Project 1999). Wetlands in San Pablo Bay were diked for grazing and other agricultural uses, and large areas also were used for salt production. Similarly, salt pond construction, along with urban development, impacted large areas of tidal wetlands, in the south and central San Francisco Bay. Following the amendment of the Clean Water Act (CWA) in the early 1970s, wetlands became protected from further filling, diking, and dredging. Loss rates for tidal wetlands have been reduced in recent decades (Goals Project 1999), and the CWA, along with a growing understanding of the value of wetland ecosystems, has led to large-scale interest in wetland restoration around the Bay. In this article, we review the evolution of tidal wetland restoration in the Bay, including an evaluation of current and future challenges for Bay restoration.

Table 1. Historic and current area of tidal wetlands within the San Francisco Bay, including the number and area of restoration projects.

Data for historic and current area are from Goals Project (1999), and data on restoration projects are from the Wetland Tracker (*www.californiawetlands.net/tracker/*). The number and area of restoration projects incorporate all completed mitigation and non-mitigation projects from the Wetland Tracker, including projects that were enhancements of existing wetlands.

Region	Historic Area (Circa 1800) (Hectares)	Current Area (Circa 1988) (Hectares)	Number Of Restoration Projects	Restoration Area (Hectares)
Suisun Bay	26449	5488	12	850
North SF Bay	22288	6615	23	1381
Central SF Bay	5447	383	17	142
South SF Bay	22677	3778	44	1696

3.2 Early Restoration Efforts

Restoration within the Bay, and beyond, has evolved significantly over the last few decades and will face substantial challenges in the future. While some restoration occurred prior to the CWA, the initiation of significant restoration dates to the mid to late 1970s, and restoration efforts have been growing ever since. Throughout the 1980s and 1990s much of the restoration within the Bay focused on individual projects, motivated by mitigation under the CWA, although many projects have also been completed by public agencies interested in improving conditions and increasing wetlands within the Bay. A large number of individual projects have been completed (see the Wetland Tracker for a list of restoration projects around the Bay; *http://www.californiawetlands.net/tracker/*), with 96 estuarine restoration projects in the Wetland Tracker data base for the Bay, covering a total of more than 4000 hectares (Table 1). This value includes a mix of habitat creation and restoration, as well as enhancement of existing wetland habitat, so it cannot be interpreted as a direct increase in wetland area. Beyond the issue of wetland area, there has been debate on the relative effectiveness of mitigation wetlands, especially because of the difficulties in early attempts to establish *Spartina foliosa* in mitigation projects (Race 1985).

Early restoration projects within the Bay focused primarily on plants within salt marsh ecosystems, with few restoration efforts in brackish or freshwater tidal wetlands (see Williams and Faber 2001 for a more detailed review of early restoration efforts). Planting was not widespread because early practitioners assumed that by creating appropriate conditions, plants would establish on their own and that suitable habitat for native animals would develop. The models for these early restoration projects were well-established, natural wetlands. Plant distributions were surveyed across these natural wetlands, and target elevations were established for individual restoration projects.

The primary consideration for establishing appropriate conditions for plants was site elevation, due to its key role in determining tidal inundation rates, which in turn affects the degree of soil anaerobiosis and salinity (Mendelssohn and Morris 2000, Mitsch and Gosselink 2007). In order to establish the target elevations for plant establishment, restoration sites that were too low were filled with dredged material, and sites that were too high were excavated from uplands to intertidal wetland elevations. In some cases, native cordgrass, *S. foliosa*, and pickleweed (*Sarcocornia pacifica*, formerly *Salicornia virginica*) were planted from cuttings or seed (Josselyn and Buchholz 1984), although few other species were planted. Some projects were simply opened to the tides, regardless of elevation, with the expectation that they would accumulate sediment and build to appropriate elevations. While vegetation developed at these sites, many early restoration projects lacked complexity in terms of physical features or biological diversity, e.g., they had few relatively straight tidal channels with little branching and/or few plant species established in the early years post-restoration (see Williams and Faber 2001, Zedler 2001).

3.3 Evolution in Restoration Design and Planning

Over the last decade, restoration practitioners have acknowledged the lack of complexity in restored tidal wetlands and have begun to incorporate additional approaches into the design and implementation of tidal wetland restoration (Philip Williams and Associates Ltd. and Faber 2004). In particular, practitioners have focused on tidal channel development, using the approach of "over-excavating" sites or leaving them at slightly lower elevations than target elevations at natural sites (usually approximately 20 to 30 cm). At lower initial elevations, tidal energy is great enough to suspend and move sediment, and this energy leads to the development of a high density network of tidal channels in restored wetlands. In addition, many early restoration projects were built on excavated uplands or dredged material with coarser sediments than natural wetlands; coarse sediments at these sites led to problems with sediment nutrient concentrations and organic matter, which eventually limited plant productivity (Lindau and Hossner 1981, Langis et al. 1991, Zedler 2001). Initializing sites at slightly lower elevations allows restored wetlands to accumulate local sediment on the surface of the wetland, and these create conditions in the rooting zone that are more similar to natural wetland sediments, thereby avoiding problems associated with improper soil texture and nutrient status. One of the early projects in San Francisco Bay to use this approach was Sonoma Baylands (Figure 1). This site was a former wetland that had been farmed and subject to high rates of subsidence (1.5-2 m); dredged material from the Port of Oakland was used to fill the site, but it was left at elevations approximately 40 cm below target marsh plain elevations in order to maximize tidal channel development and ensure appropriate wetland sediment characteristics (Marcus 2000). While tidal flows and sedimentation rates initially were limited due to constrictions in the tidal connection at Sonoma Baylands, the site has developed into a vegetated wetland with a mix of habitats, and the approach of over-excavation has been adopted for many current or planned restoration projects within the Bay (Williams and Faber 2001, Philip Williams and Associates Ltd. and Faber 2004). In addition to promoting tidal channel development, topographic complexity has been incorporated into restoration sites through the creation of islands within restored sites (e.g., Sonoma Baylands and Crissy Field; Figure 1), primarily for nesting birds; however, areas with higher elevations also can reduce wind fetch and wind waves. Small areas of higher elevation habitats within a large low elevation restoration site also can serve as a nexus for plant establishment due to their lower rates of tidal inundation during the early phase of wetland development (Marcus 2000, Philip Williams and Associates Ltd. and Faber 2004).

Another substantial change for restoration planning efforts within the Bay has been a shift from the early focus on individual mitigation projects to a consideration of regional needs and opportunities for restoration. A major step in this regard was the development of the Habitat Goals Project (Goals Project 1999), which considered the importance of restoration issues for a broad range of wetland organisms and dynamics, among them: plants, invertebrates, fish, birds, mammals, hydrology, and sedimentation. The Goals Project developed detailed maps of priorities for restoration across the Bay and helped to identify the need to consider restoration planning at the landscape level (Goals Project 1999).

In addition to the broader scope for restoration planning, restoration efforts shifted from the early, relatively small projects to much larger projects over the last decade. For example, some of the large-scale early restoration projects in the Bay were Muzzi Marsh (52 ha in 1976), Cogswell Marsh (80 ha in 1980), and Warm Springs (80 ha in 1986; Williams and Faber 2001). By the 1990s the size of individual projects had grown with Pond 2A (220 ha in 1995) and Sonoma Baylands (120 ha in 1996; Figure 1). Current projects are considerably larger, with Montezuma Wetlands currently underway at 930 ha, close to 3000 ha in the Napa-Sonoma Salt Pond Project, and over 6000 ha being considered for restoration as part of the South Bay Salt Pond Project (data from the Wetland Tracker; *http://www.californiawetlands.net/tracker/*; Figure 1). These new projects are large enough that they will have landscape-level effects on the Bay. In addition, restoration has moved beyond the salt marshes of the Bay, with large-scale restoration and management efforts in brackish and freshwater tidal wetlands. CALFED (*http://calwater.ca.gov/*) and the Bay-Delta Conservation Plan (http://baydeltaconservationplan.com/) have been motivating factors for much of the freshwater wetland restoration within the Delta, with large projects such as Dutch Slough and Liberty Island. Within Suisun Bay, some of the recent projects involving brackish tidal

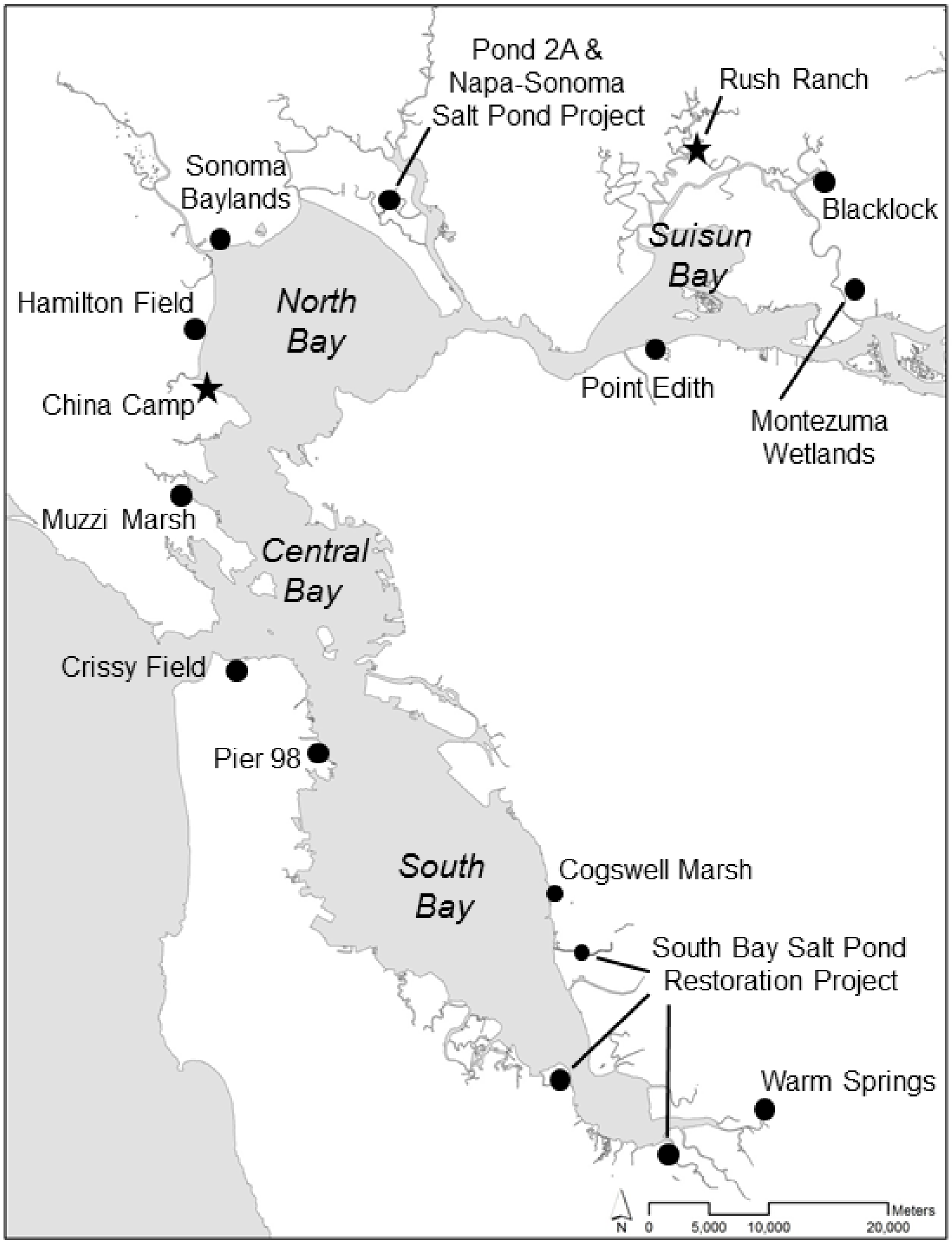

Figure 1. Location of major tidal wetland restoration projects in San Francisco Bay and the San Francisco Bay National Estuarine Research Reserve sites (China Camp State Park and Rush Ranch). Restored tidal wetlands are in the south Bay (Warm Springs, South Bay Salt Pond Restoration Project, and Cogswell Marsh), central Bay (Pier 98 and Crissy Field Marsh), north Bay (Muzzi Marsh, Hamilton Field, Sonoma Baylands, and Pond 2, which is a component of the Napa-Sonoma Salt Pond Project), and Suisun Bay (Point Edith, Blacklock, and Montezuma Wetlands).

wetlands include Montezuma Wetlands, Point Edith, and Blacklock (Figure 1). As with other regions, the design of sites within Suisun Bay has used natural tidal wetlands to provide input on restoration design including Rush Ranch, a component of the San Francisco Bay National Estuarine Research Reserve (e.g., Pearce and Collins 2004).

As larger projects have been initiated, there has been a push towards the incorporation of a stronger scientific basis for restoration. CALFED put substantial focus on the use of adaptive management in their restoration efforts (Brown 2003, Kimmerer et al. 2005, Zedler 2005). The South Bay Salt Pond Restoration Project also has explicitly incorporated science with reviews from both local and national science panels (see *http://www.southbayrestoration.org/science/*), and with the explicit use of adaptive management in the development and implementation of the project, including in the framework of the EIR (EDAW et al. 2007, Trulio 2007). In particular the South Bay Salt Pond Restoration Project has emphasized the identification of critical uncertainties that may limit restoration progress, as well as the development of experimentation and monitoring plans to address these uncertainties in the early phases of the project so that large-scale implementation in the future will be better informed (Trulio 2007).

3.4 Current Issues

Over the last decade, the importance of biodiversity has been recognized because of its role in retaining high levels of ecosystem functions (Hooper et al. 2005, Tilman et al. 2006, Hector and Bagchi 2007), and promoting them within restored ecosystems in particular (Naeem 2006). Much of the effort in evaluating the role of biodiversity for restored tidal wetlands has come from research in southern California wetlands, and this work has highlighted the importance of incorporating diversity into restoration sites in order to achieve a range of desired ecosystem functions (Zedler et al. 2001, Callaway et al. 2003, Sullivan et al. 2007). Despite the lack of research on this topic in San Francisco Bay, interest is growing in maintaining and restoring diversity in Bay wetlands (Baye et al. 2000). In the Bay, much of this interest has focused on transitional wetland-upland plant communities (e.g., restoration of *Suaeda californica* at Crissy Field and Pier 98; Figure 1), where much of the plant diversity in tidal wetlands is found (Baye et al. 2000).

Non-native, invasive plants are a major threat to biodiversity of Bay tidal wetlands (Grewell et al. 2007), and they will continue to be an on-going issue for tidal wetland restoration projects across the Bay. *Spartina alterniflora* and its recombinants with *S. foliosa* are particularly problematic as they currently are widely distributed, are prolific seed producers, establish readily from seed, and most importantly have substantial effects on native species and wetland ecosystem functions (Callaway and Josselyn 1992, Ayres et al. 2004, Neira et al. 2006), although large-scale efforts are underway to eradicate invasive *Spartina* spp. (see the Invasive Spartina Project, *http://www.spartina.org/*). Other problematic invasive plants include *Lepidium latifolium* in salt and brackish marshes, *Ludwigia hexapetala* and *Eichornia crassipes*, floating species that have recently been observed clogging entire channels in the western Delta, and *Egeria densa*, an aquatic weed that is widespread in the Delta (Andrew and Ustin 2009, Okada et al. 2009, Santos et al. 2011). Further upriver, *Ludwigia peploides* ssp. *montevidensis* has become a tremendous problem in Sacramento River oxbows and is dispersed down to the Delta. A large number of other non-natives are established in the Delta, including *Iris pseudacorus*, although it has not developed dense cover in most areas where it has become established. Impacts from invasive species are likely to be complicated by shifts in both wetland salinity and inundation rates associated with climate change, and these interactions are discussed in more detail below.

Beyond plants, non-native animals can have substantial effects on both restored and natural tidal wetlands and adjacent estuarine ecosystems, from burrowing isopods to benthic clams (Talley et al. 2001). As with plants, invasive animals are problematic when they substantially affect native species or ecosystem functions. Some native predators have also become concerns in natural and restored wetlands, in particular gulls and corvids, as well as introduced red foxes, all of which prey on bird eggs and chicks.

Contaminants have always been an issue for urban restoration projects, whether it is from watershed inputs (e.g., mercury, selenium, and other agricultural runoff), former military land use, (e.g., Crissy Field, Hamilton Air Field, Port Chicago/Concord Naval Weapons Station), or other land use issues (e.g., storage tank leakage, metals from chrome plating, solvent runoff, etc.). Mercury has been of particular interest recently in the Bay, in part due to elevated levels in the south Bay and the plans for large-scale salt pond restoration, as well as inputs from the larger watershed (Marvin-DiPasquale and Agee 2003, Miles and Ricca 2010, Gehrke et al. 2011). While elevated levels of mercury have existed for a long time in the Bay, managers are concerned that rates of methylation may increase once areas are converted from present subtidal, unvegetated conditions to vegetated wetland ecosystems (Choe et al. 2004, Conaway et al. 2008). Substantial research is presently underway to evaluate mercury biogeochemistry within a variety of habitats in order to better understand controls on methylation rates and potential impacts on wetland organisms, and the evaluation of this issue is a major component of the adaptive management approach of the South Bay Salt Pond Restoration Project.

Loss of elevation is a major factor affecting opportunities at many Bay restoration sites; subsidence of former wetlands from oxidation of soils is a major issue in the Delta (Rojstaczer and Deverel 1995, Mount and Twiss 2005), while water extraction and compaction of underlying aquifers presents an enormous challenge for the restoration of some sites in the south Bay (Poland 1988). Vegetation will only establish at sites when threshold elevations are met. This will either take many decades or could be expedited through fill with dredged material (e.g., Montezuma Wetlands) or the accumulation of organic matter through plant productivity, as has been tried experimentally at Twitchell Island in the Delta (Fujii et al. 2006, Miller et al. 2008).

3.5 Growing Complexity: Restoration Continues Evolving

The realization that wetland restoration is more complex than simply breaking down a levee and establishing plant cover has grown over time, with continuing focus on both physical and biological complexity within restored wetlands. In terms of physical heterogeneity, most of the focus remains on tidal channels and their role in providing connectivity between aquatic and wetland habitats, as well as the importance of tidal channels in affecting plant distributions in tidal wetlands (Sanderson et al. 2000). More recently, there also has been interest in restoring ponds and pannes (which typically do not hold water as long as ponds but remain unvegetated), with some consideration of how these habitats form in wetlands and how they might be sustained in both natural and restored wetlands (Collins and Grossinger 2004). The natural abundance of pannes across the Bay varies widely, with large numbers in Petaluma Marsh and historic accounts of large ponds in salt marshes on the east side of the south Bay (Collins and Grossinger 2004), but few at China Camp, a component of the San Francisco Bay National Estuarine Research Reserve (Figure 1; Baye in press). Within the context of the South Bay Salt Pond Restoration Project, there is special interest in restoring wetland ponds, as these may provide habitat for many bird species that currently rely on artificial salt ponds; however, the specific issues and methods for establishing and sustaining ponds within restored wetlands have yet to be identified.

Tidal restoration within the Bay has also moved beyond salt marsh restoration to consider a wide-range of habitats and functions along a gradient from mudflats to upland habitats and from salt marsh to freshwater marsh. Given this broader scope, some consideration of the trade-offs of different types of restoration is required. Simply maximizing the tidal area of every single restoration project within the Bay will not recreate the wide range of functions that natural ecosystems provide. There is increasing awareness of the important link between tidal wetlands and adjacent aquatic ecosystems through food web dynamics (Howe and Simenstad 2011). In addition, transitional upland habitats provide many benefits, as do lower elevations that are transitional from wetlands to unvegetated mudflats. The upland transitional sites have very high plant diversity with a large number of rare and threatened plant species (Baye et al. 2000). These areas have been overlooked in the past, primarily because they may not be counted as jurisdictional wetland habitats or as “in-kind” mitigation for tidal wetland impacts. These systems also have a large number of potential exotic plants that invade from adjacent degraded uplands, e.g., *L. latifolium* and many Mediterranean grasses, among others (Fetscher et al. 2010). Substantial challenges may exist in restoring these habitats (e.g., there are very few if any undisturbed reference sites to give us insight into what a “pristine” transitional habitat may have looked like and how it might have functioned). Transitional habitats also provide important buffers to reduce human impacts from adjacent urban and residential areas that commonly border wetlands around the Bay, and they provide refuge for wetland animals during extreme high tides (Goals Project 1999). Over the long-term, these transitional habitats also could provide substantial benefits as they could serve as critical areas for upland migration of wetlands in light of predicted increases in rates of sea-level rise.

Managers have realized that a range of wetland habitats can be highly valuable as different types of habitats will provide benefits for different species and also provide for a range of different ecosystem functions. However, making management decisions for priorities across different ecosystem types will be very challenging, as different ecosystems provide a range of functions with varying societal values. For example, how do we compare the benefits for different species or for different functions: water quality improvements from one type of wetland versus improved habitat conditions from a different wetland type? While science can provide input on individual benefits, evaluations of ecosystem functions and benefits presently are not available for most wetland and transitional ecosystems. In addition, decisions weighing the relative benefits across different wetlands ultimately will be based on economics, perceptions of benefits, and other social science issues, rather than individual measurements of ecosystem function.

A major issue for all tidal restoration projects around the Bay is the need to improve our understanding of the potential constraints on the development of restored wetlands, so that we can improve our abilities at predicting how future restoration projects may evolve, especially as larger and larger areas are restored. Some recent projects have not evolved exactly as predicted. For example, the development of a vegetated wetland at Sonoma Baylands occurred more slowly than expected, primarily due to restrictions on tidal flows at the site (Williams and Faber 2001). By learning from projects with varying success, we can identify potential constraints for future restoration, whether this is geomorphologic restrictions, limits on plant establishment, effects of non-native species, or other factors.

Finally, a major realization for wetland restoration over the last decade has been the need for improved public outreach and involvement. The restoration of Crissy Field in densely urban San Francisco in the mid-late 1990s had an enormous public outreach effort with the incorporation of 1000s of volunteers (Boland 2003). This effort highlighted the benefits of public involvement in restoration: citizens are much more likely to be supportive of projects if they actively engage in them. Similar efforts to improve public awareness of projects have been incorporated into the South Bay Salt Pond Restoration Project, which has worked to involve local citizens and organizations through "stakeholder forums" on a variety of issues and at many locations across the south Bay. Other large restoration projects have also made substantial efforts at public education and outreach, with the realization that publicly funded restoration efforts will only continue with strong on-going public support and involvement.

Other on-going restoration challenges include mitigating flood impacts, securing restoration funding, and incorporating landscape issues, such as habitat connectivity, propagule sources, large-scale questions of sediment availability, and potential impacts of restoration on sediment dynamics in existing ecosystems (Brew and Williams 2010).

3.6 Conclusions and Future Challenges

Although approximately 90% of Bay tidal wetlands have been lost (Table 1), current interest in restoring tidal wetlands in the region is great, with opportunities for large-scale projects that will substantially increase the present area within the Bay. For example in south San Francisco Bay, the South Bay Salt Pond Restoration Project may more than double the area of tidal wetland habitat in the south Bay, even though some former tidal wetlands will continue to be managed as ponds. Other Bay regions also could add thousands of hectares through current or future projects. Similarly, restoration has evolved from a simplistic approach that initially focused primarily on elevation, to a consideration of wetland complexity and regional ecosystem functions.

As the Bay Area population continues to grow and put pressure on natural ecosystems, future efforts at wetland restoration around the Bay will continue to face these same issues. Changing land use, increased water demand, greater pollution, and the potential input of new non-native species (in part through continued international trade) all act to constrain wetland health and limit restoration success. Because tidal wetland restoration is inherently unpredictable, new, unexpected challenges will arise as well (Williams and Faber 2001).

The greatest future challenge for tidal wetland restoration will be climate change (see Parker et al. Chapter 7). While specific impacts are unpredictable, some general trends are extremely likely: 1) there will be seasonal shifts in estuarine salinities with higher concentrations during the growing season due to reductions in snowmelt and shifts in the timing of watershed runoff (Knowles and Cayan 2002, Cayan et al. 2008); and 2) rates of sea-level rise will increase over the next century, although the magnitude of change is not certain (IPCC 2007, Rahmstorf 2007). Changes in salinity and inundation both will have large-scale effects on tidal wetlands in the Bay. Increases in salinity during the growing season are likely to cause more salt tolerant species to migrate up the estuary over the long term (Parker et al. Chapter 7). Tidal wetlands can keep pace with some increases in sea-level rise through increased mineral and organic matter accumulation (Morris et al. 2002); however, large-scale increases in sea-level rise are likely to lead to wetland loss. Kirwan et al (2010) reviewed a number of recent models of tidal wetland responses to sea-level rise and found that tidal wetlands could withstand conservative projections of increased sea-level rise with moderately high rates of suspended sediment, but higher rates of sea-level rise could lead to wetland loss.

Furthermore, recently restored wetlands are likely to be more sensitive than well-established, mature wetlands to impacts associated with climate change. Germination rates and the survival of newly established vegetation at restored wetlands are both very sensitive to increases in salinity and inundation rates (Callaway et al. 2007). In addition, newly restored wetlands with little or no vegetation will be more susceptible to sediment erosion associated with higher water levels, while at the same time they are in need of substantial amounts of sediment in order to build elevations from early restoration stages to conditions where plants can establish (Grewell et al. 2007). Beyond direct impacts, shifts in salinity and inundation associated with climate change also could cause unpredictable changes in restored Bay wetlands, including creating increased opportunities for invasive species, both plants and animals. Newly restored sites are highly susceptible to invasives due to their inherently disturbed condition, and climate change could allow for a different suite of invasive species to establish under new conditions within the Bay. Although these interactions are difficult to predict and evaluate, a number of recent articles have highlighted the potential for compounded problems between climate change and invasive species (Hellmann et al. 2008, Rahel and Olden 2008, Mainka and Howard 2010).

In order to maximize flexibility related to the uncertainties of climate change, potential restoration sites should be restored sooner rather than later, as vegetated wetlands are likely to be more resilient to climate change than unvegetated sites. Identifying restoration sites where adjacent uplands with shallow slopes could serve as locations for future wetland migration also would provide for increased flexibility, as wetlands that do not keep pace with sea-level rise could migrate to nearby higher elevations. More opportunities for wetland migration to adjacent uplands exist in the north Bay and Suisun Bay than in the south Bay, due to large scale urbanization in the south Bay. For example, opportunities to restore muted tidal wetlands at China Camp (Back Ranch and Miwok Meadows) and Rush Ranch (Spring Branch Creek) are promising restoration opportunities that would allow for wetland migration. However, if the magnitude of climate change impacts is high, long-term effects on tidal wetland ecosystems could be catastrophic, as these wetlands are unlikely to keep pace with rapid increases in rates of sea-level rise or large-scale shifts in salinity regimes.

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4. Tidal Wetland Vegetation in the San Francisco Bay-Delta Estuary

Michael C. Vasey[1], V. Thomas Parker[1], John C. Callaway[2],
Ellen R. Herbert[1], and **Lisa M. Schile[3]**

[1]*Department of Biology*
San Francisco State University
1600 Holloway Avenue
San Francisco, CA 94132

[2]*Department of Environmental Science*
University of San Francisco
2130 Fulton Avenue
San Francisco, CA 94117

[3]*Department of Environmental Science, Policy and Management*
University of California, Berkeley
137 Mulford Hall #3114
Berkeley, CA
94720-3114

ABSTRACT

We analyzed tidal wetland vegetation patterns in the San Francisco Bay-Delta Estuary (Bay-Delta) and discuss their significance for future conservation. Our objective was to conduct a balanced, random sample of six historic "remnant" tidal wetlands along a salinity gradient ranging from southern San Pablo Bay to the lower Delta. We also wanted to compare diversity among these sites at five different scales, ranging from small subplots to total species per site. We randomly established twenty 0.1-ha plots at each site and sampled ten 7-m^2 circular subplots (subplot scale) in each plot for species presence and cover. Total species per plot (plot scale) and total species per site (site scale) were calculated based on these subplot data. Importance values were calculated for each species found in subplots based on frequency of occurrence and proportion of total cover at each site. In addition, we recorded species found within the 0.1 ha plot but not sampled in subplots (plot_all scale) and calculated the total species for each site based on these plot_all data (site_all scale). Thus, richness at each site was evaluated at five different scales ranging from 7 m^2 to 20,000 m^2. We conducted a one-way ANOVA comparing mean richness among sites at three scales: subplot, plot, and plot_all. At Lower Estuary (San Pablo Bay) sites, richness values at all scales were much less than Upper Estuary (Suisun-Delta) sites. In Suisun-Delta sites, richness varied depending on the scale of sampling. Rush Ranch, a brackish wetland, had the highest average number of species per plot whereas Sand Mound Slough, a freshwater wetland, had the highest average number of species at the subplot scale and the most total species at the site-all scale. Sand Mound Slough also had the highest number of unique species (22) compared to the other sites. We found a strong negative correlation ($r^2=0.99$) between total species number and salinity (most in Delta at lowest salinity and least at China Camp with the greatest salinity). Our analysis suggests the following conservation recommendations: (1) restore habitat for freshwater plant species diversity in the Delta; (2) restore transitional brackish wetland habitat in salt marshes of the San Pablo Bay and San Francisco Bay; and (3) focus on control of pepperweed (*Lepidium latifolium*) in brackish marshes.

KEY WORDS

San Francisco Bay-Delta
tidal wetland vegetation
sampling scale
species richness
importance value
salinity gradient
conservation strategies

4.1 Introduction

At approximately 3400 km^2 (Atwater et al. 1979), the San Francisco Bay-Delta Estuary (Bay-Delta) is the largest and most complex embayment along the Pacific coast of North America. Over 55% of the historic tidal wetlands in California were originally located in this once vast estuary (Macdonald and Barbour 1974). Subsequently, approximately 95% of Bay-Delta tidal wetlands have been modified by various human practices (Atwater et al. 1979). Hardest hit was the freshwater Delta region that once covered ca. 140,000 ha (Atwater et al. 1979) and was diked and "reclaimed" for agriculture by the early 1920s. In the late 1800s and early 1900s, the margins of the Suisun, San Pablo, and San Francisco Bays were impacted by a variety of land use practices, including agriculture, creation of seasonal duck hunting ponds, salt pond production, and bay fill for urban development. By some estimates, thirty percent of the open water of the Bay-Delta has been lost through diking and filling (Goals Project 1999). During the 20th century, tidal wetlands began to regenerate in the Bay-Delta as levees degraded and former wetlands were reclaimed by natural processes. Wetland plant species colonized extensive outboard mudflats created by the legacy of sediments deposited by upstream hydraulic gold mining, so called "centennial marshes" (PWA and Faber 2004). This marsh recovery has been augmented in the latter part of the century by intentional restoration, at first for mitigation purposes (Josselyn 1982) and, as the ecological importance of tidal wetland habitats became more fully appreciated, through large-scale wetland restoration projects (Williams and Faber 2001, Chapter 3).

The floristic composition of Bay-Delta tidal wetlands is still poorly documented (Macdonald and Barbour 1974). Given the size and complexity of the Bay-Delta, difficulties of access, and the scale of historic human impacts, we have limited knowledge of tidal wetland species composition from relatively few localities (e.g., Atwater et al. 1979). In San Francisco and San Pablo Bays, transitional habitats between salt marsh plains and adjacent uplands have been so heavily impacted by human practices that their former species are now largely extirpated, and the flora of these transitional areas is not generally recognized as part of the Bay-Delta wetland ecosystem (Baye et al. 2000). The presence of upland-wetland transition habitats is one of the reasons China Camp State Park and Rush Ranch Open Space Preserve are valuable as they contain these habitats that are now extremely rare (Chapter 5, Chapter 6). Both of these sites are components of the San Francisco Bay National Estuarine Research Reserve (NERR) and the focus of this site profile.

Salt and brackish wetlands of Suisun Bay, San Pablo Bay, and San Francisco Bay have received the most study, while there has been much less focus on freshwater tidal wetlands of the Delta (e.g., Josselyn 1983, Goals Project 1999, Baye et al. 2000, Grewell et al. 2007). This focus on the more saline portions of the estuary has confounded a deeper understanding of the Bay-Delta wetland ecosystem as a whole. Today, Delta tidal wetlands are the poorest known element of Bay-Delta vegetation despite their former widespread extent and contribution to the broad intermingling of freshwater, brackish, and saltwater wetland species that occur in the Bay-Delta.

In this study, we employed a balanced, random quantitative analysis of six historic remnant wetlands that span the salt-to-freshwater gradient characterizing the Bay-Delta region (Table 1, Figure 1). While the goals and activities of our research are multiple, we present preliminary results of ongoing tidal wetland vegetation studies. Although these sites were selected for a variety of research purposes, they reflect the extent of historic remnant wetlands along the Bay-Delta regional salinity gradient. Different scales of vascular plant species richness were explored, and we used frequency of occurrence and proportion of total cover to calculate an importance value (IV) index to characterize dominance and diversity relationships for each individual species at each site. While we recognize that many factors influence local vegetation patterns other than ambient salinity regimes (e.g., duration of inundation; see Schile et al. in press), we focused on a regional scale at which salinity generally drives compositional shifts within the tidal wetland species pool throughout the Bay-Delta (Grewell et al. 2007). One of the primary concerns about rapid climate change is its potential to shift salinity gradients at a regional scale (Chapter 7). Based on our findings, we offer some recommendations for regional conservation actions that apply to Bay-Delta tidal wetland vegetation.

Table 1. Site codes, site names, site area, subregions, spatial coordinates, typical salinity regimes and salinity ranges for each site.

Salinity regimes are based on the Venice system (Anonymous 1959). Salinity ranges were obtained at tidal creek margins for each site during summer and fall 2008-2010.

Code	Site	Area	Subregion	Latitude	Longitude	Salinity	ppt
CC	China Camp	125 ha	San Pablo Bay	38° 0.745 N	122° 29.300 W	Polyhaline	28±4
PM	Petaluma Marsh	800 ha	San Pablo Bay	38° 11.315 N	122° 33.550 W	Polyhaline	27±4
CI	Coon Island	175 ha	San Pablo Bay	38° 11.630 N	122° 19.500 W	Polyhaline	21±3
RR	Rush Ranch	400 ha	Suisun-Delta	38° 12.000 N	122° 2.000 W	Mesohaline	6±2
BI	Browns Island	200 ha	Suisun-Delta	38° 2.350 N	121° 51.800 W	Oligohaline	4±2
SMS	Sand Mound Slough	25 ha	Suisun-Delta	38° 0.275 N	122° 37.400 W	Limnetic	0±0

4.2 Methods

We investigated six sites across the Bay-Delta salinity gradient: three sites in the Lower Estuary (hereafter referred to as San Pablo Bay) influenced by relatively high salinity regimes and three sites in the Upper Estuary (hereafter referred to as Suisun-Delta) influenced by brackish and freshwater conditions (Figure 1, Table 1). The San Pablo Bay sites included China Camp State Park (China Camp), Petaluma Marsh State Reserve (Petaluma Marsh), and Coon Island State Reserve (Coon Island). The Suisun-Delta sites included Rush Ranch Open Space Preserve (Rush Ranch), Browns Island Regional Shoreline (Browns Island) and Sand Mound Slough. China Camp, located in western San Pablo Bay, is the most saline of these tidal wetlands, and its vegetation is generally typical of Central and South San Francisco Bay wetlands (Josselyn 1983, Grewell et al. 2007). It is dominated by a large high marsh plain with fringing low marsh and an elaborate, dendritic network of channels. Petaluma Marsh occurs at the upper reaches of Petaluma River Slough, a major tidal slough that drains a watershed in northwestern San Pablo Bay and consequently receives seasonal freshwater influence. Petaluma Marsh is the largest remnant historic salt marsh in the San Francisco Bay Estuary and also has a well-developed system of tidal creeks. Coon Island is a brackish wetland in the tidally influenced portion of the Napa River that enters northeastern San Pablo Bay. The larger watershed of the Napa River provides more freshwater influence than that received by the Petaluma Marsh.

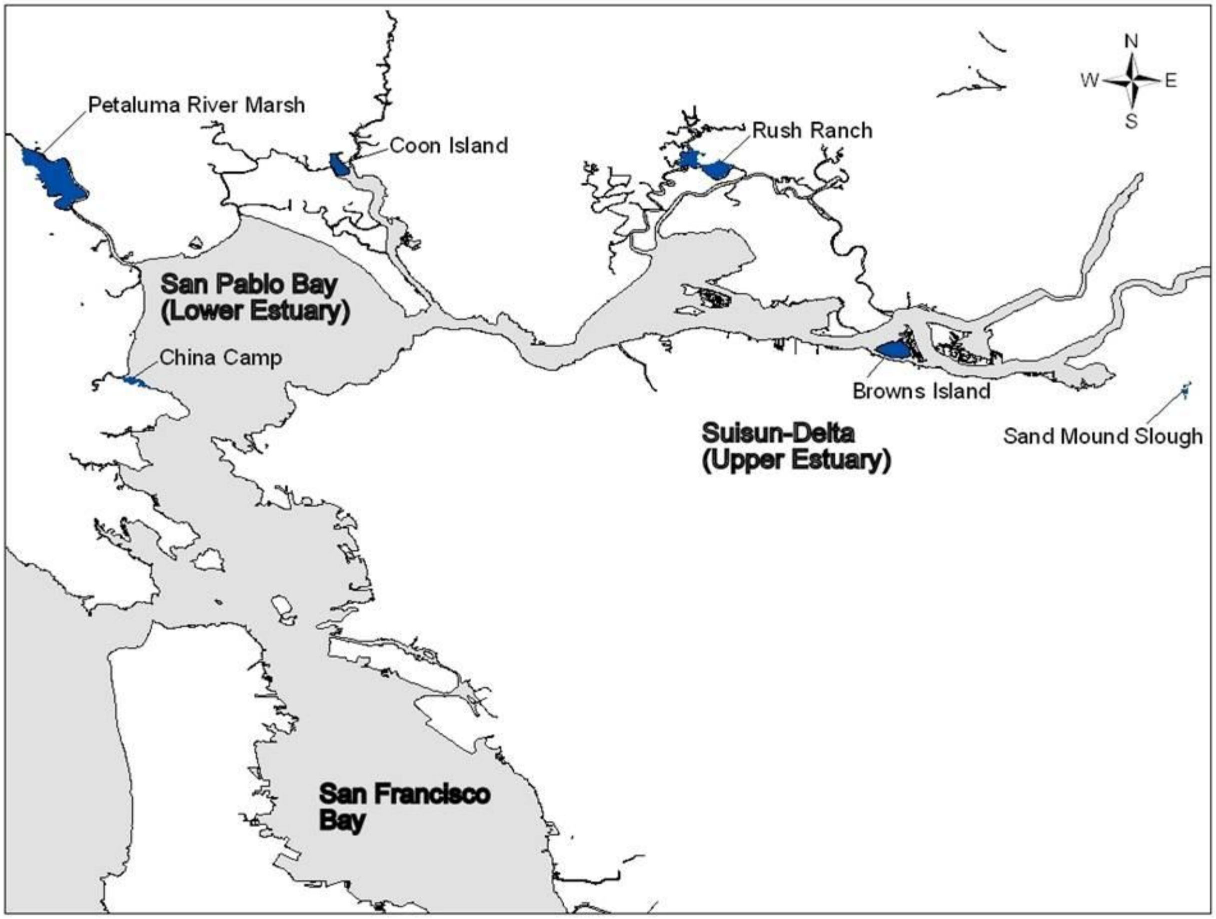

Figure 1. Distribution of six sample sites in the San Francisco Bay-Delta estuary. Different subregions are identified in bold font.

Of the three Suisun-Delta sites, Rush Ranch is the most saline and occurs along the upper reaches of Suisun Slough in the western Suisun Marsh. Rush Ranch is the largest remnant tidal wetland in the Suisun region. Browns Island is a large island at the margin of the eastern Suisun Bay and western Delta, while Sand Mound Slough is an archipelago of six small islands in the south-central Delta between diked former freshwater wetlands. Tidal creeks in the Suisun-Delta tend to be fewer and less dendritic than those in San Pablo Bay, and all three of these sites have lower annual salinity regimes than the three San Pablo Bay sites (Table 1).

For each of these six sites, we randomly chose pairs of spatial coordinates on ArcMap version 8.0 (ESRI Anaheim CA) using Hawth's tools (Beyer 2004). Sampling was not stratified by a preconceived vision of vegetation types because our intention was to randomly sample twenty 20 x 50 m plots at each site within intact natural wetland vegetation, incorporating less than 10%

open water, and with no obvious human disturbances. We navigated to sample sites using a hand held Garmin 76S GPS receiver (1-5 m accuracy), and established 20 x 50 m plots (0.1 ha) (long axis east to west). Within each 0.1 ha plot, all species present were identified; abundance was assessed using ten randomly positioned, 3-m diameter (~7.0 m^2) circular subplots employing a modified Daubenmire cover class approach (Daubenmire 1959). Sampling was conducted during the summers of 2007 and 2008. Teams of two to four people sampled each plot. Additionally, pore-water salinity concentrations were sampled at tidal creek margins from each site during late summer and fall 2008-2010 using a refractometer. Five to 12 readings were obtained from each site during this interval. Although salinity at these sites shifts annually and seasonally, the regional salinity gradient is generally consistent and provides a relatively robust context in which to compare species composition in these widely spaced sites.

Data from each wetland were analyzed at different spatial scales (see Figure 2 for design). Richness (i.e., the number of species per sample unit) was based on species presence-absence at each scale. We calculated the mean number of species per subplot (subplot scale =7.0 m^2), mean number of species per 0.1 ha plot using only subplot data (plot scale = 70 m^2), and total number of species per 0.1 ha plot (plot_all scale = 1000 m^2), including all species recorded in subplots as well as species found in the 0.1 ha plot but not in subplots). We then calculated the total number of species per site based on the 200 subplot data (site scale = 1400 m^2) and total number of all species found in the sites including those not found in the subplots (site_all scale = 20,000 m^2).

At each site, we added midpoint cover class values for all species in all subplots (n=200), summed these values for all species, and then divided each species total by the sum of the total cover for all species, yielding a proportion of total cover for each species (relative abundance). We then totaled the number of subplot occurrences for each species and divided this total by 200 to yield the relative frequency of occurrence for each species. An importance value (IV) was then calculated for each species as: (relative abundance + relative frequency) / 2 * 100. This IV index ranges from 0 – 100 and integrates both the proportion of total abundance and frequency of occurrence data for individual species so that, for example, widespread species with relatively low cover values (e.g., herbaceous dicots) are given greater weight than if only species abundance values were considered (Barbour et al. 1987).

Data were analyzed with JMP 8.0 (SAS Cary, NC, US) for differences between sites at subplot, plot, and plot_all scales by separate one-way ANOVAs, and differences among sites were estimated using a Tukey HSD test of *post hoc* contrasts. Prior to running the one-way ANOVAs, data were analyzed for normality. Plot and plot-all data met the assumptions of normality but sub-plot data required square root transformation. To explore the possible relationship between total number of species per site (site_all scale), salinity, and area, we ran two linear regression models with total species per site as the dependent variable and area or salinity as independent variables. In both models, residuals were normal and Cook's Distance values were less than one (i.e., there was no problem with outliers). Voucher specimens were collected of sampled species and deposited at San Francisco State University.

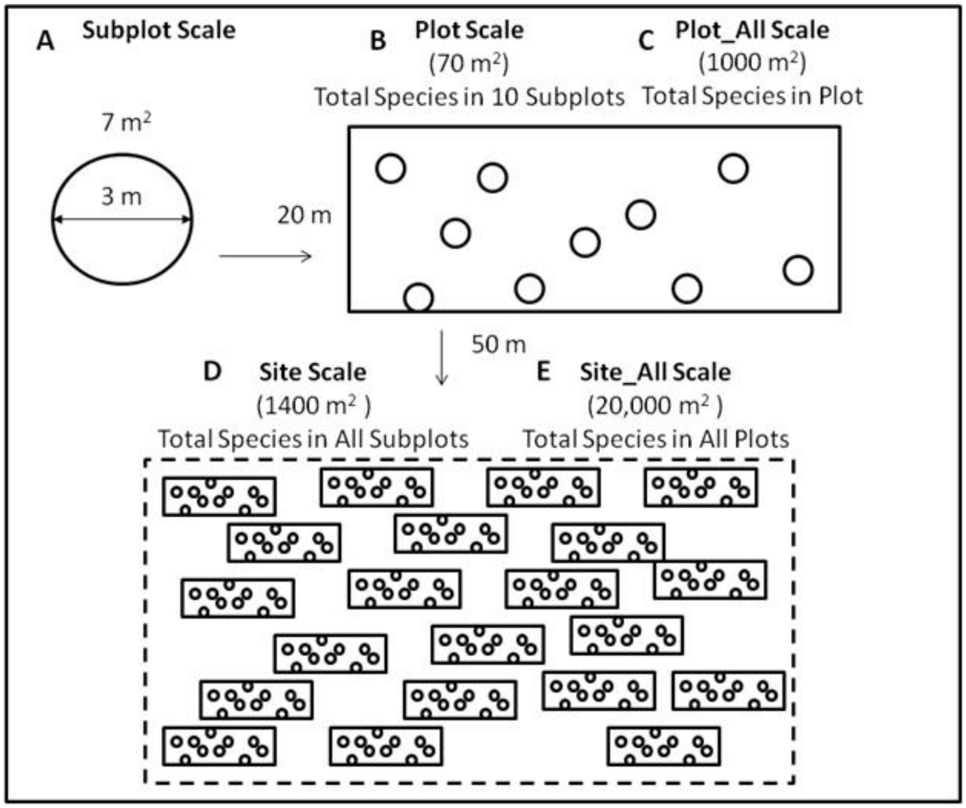

Figure 2. Sampling scales for species richness. A. Subplot scale: circular plots 3 m in diameter, 7 m^2 area; B. Plot scale: 10 subplots within 0.1 hectare plot, 70 m^2 area; C. Plot_all scale: all species found within 0.1 hectare plot, both in and out of subplots, 1000 m^2 area; D. Site scale: total of all subplots (200) within 20 plots at each site, 1400 m^2 area; E. Site_all scale: all species found in and out of subplots within 20 plots at each site, 20,000 m^2 area.

4.3 Results

The results of this analysis were generally consistent with past studies that include quantitative vegetation samples from the Bay-Delta (Atwater and Hedel 1976, Atwater et al. 1979, Watson and Byrne 2009). At all sampling scales, the more saline San Pablo Bay sites contained significantly fewer species than the Suisun-Delta sites (Table 2, Figure 3). For example, at the subplot (7 m^2), plot (70 m^2), and plot_all (1000 m^2) scales, San Pablo Bay sites contained slightly more or less half the number of species at Suisun-Delta sites. At the plot (1400 m^2) and plot_all scales (20,000 m^2), Coon Island in San Pablo Bay has about a third more species than the other two San Pablo Bay sites, yet Coon Island still has only about half the species of Rush Ranch, which has the least number of total species compared to the other two Suisun-Delta sites (Table 2, Figure 3). While the greatest contrast in species richness occurs between San Pablo Bay and the Suisun-Delta, there are more subtle contrasts between the three Suisun-Delta sites at different scales (Table 2). At the subplot scale, Sand Mound Slough averaged slightly more species than Rush Ranch, but not significantly so, yet significantly more than Browns Island. At the plot and plot_all scales, however, Rush Ranch averaged significantly more species than either Browns Island or Sand Mound Slough. Yet, at the site and site_all scales, Browns Island

and Sand Mound Slough contained more total species based on all twenty plots. Sand Mound Slough had the highest number of species recorded (56) for all sites, slightly greater than Browns Island (55). We found that there was no relationship between site area and total number of species per site. On the other hand, there was a significant relationship between salinity levels and all sample scales for richness. This relationship is the most robust at the site_all scale (total species per site) where the regression coefficient is $R^2 = 0.99$ ($P<0.0001$) (Figure 4).

Table 2. Mean and standard error values for species richness from six sites at subplot (7 m^2), plot (70 m^2), and plot_all (1000 m^2) scales.

Site (1400 m^2) and site_all (20,000 m^2) values represent total species from all subplots per plot and all species per plot (including species not found in subplots) respectively. Superscript letters for subplot, plot, and plot_all represent significant differences based on one-way ANOVA and *post hoc* Tukey HSD tests. *F* values and subscript df are provided where applicable.

Site	CC	PM	CI	RR	BI	SMS	*F* value	*P*
Subplot	$2.5^{ab}\pm0.1$	$2.8^{b}\pm0.1$	$2.3^{a}\pm0.1$	$5.2^{cd}\pm0.2$	$4.7^{c}\pm0.2$	$5.4^{d}\pm0.2$	$_{5,1191}=31.4$	<0.0001
Plot	$5.2^{a}\pm0.5$	$5.8^{a}\pm0.5$	$4.8^{a}\pm0.6$	$12.4^{c}\pm0.6$	$10.4^{b}\pm0.6$	$10.8^{bc}\pm0.8$	$_{5,\,114}=29.8$	<0.0001
Plot_All	$6.2^{a}\pm0.4$	$7.1^{a}\pm0.7$	$6.2^{a}\pm0.7$	$15.9^{b}\pm0.7$	$13.2^{b}\pm0.8$	$13.4^{b}\pm1.1$	$_{5,\,114}=32.4$	<0.0001
Site	10	14	21	39	48	44	NA	NA
Site_All	10	17	23	44	55	56	NA	NA

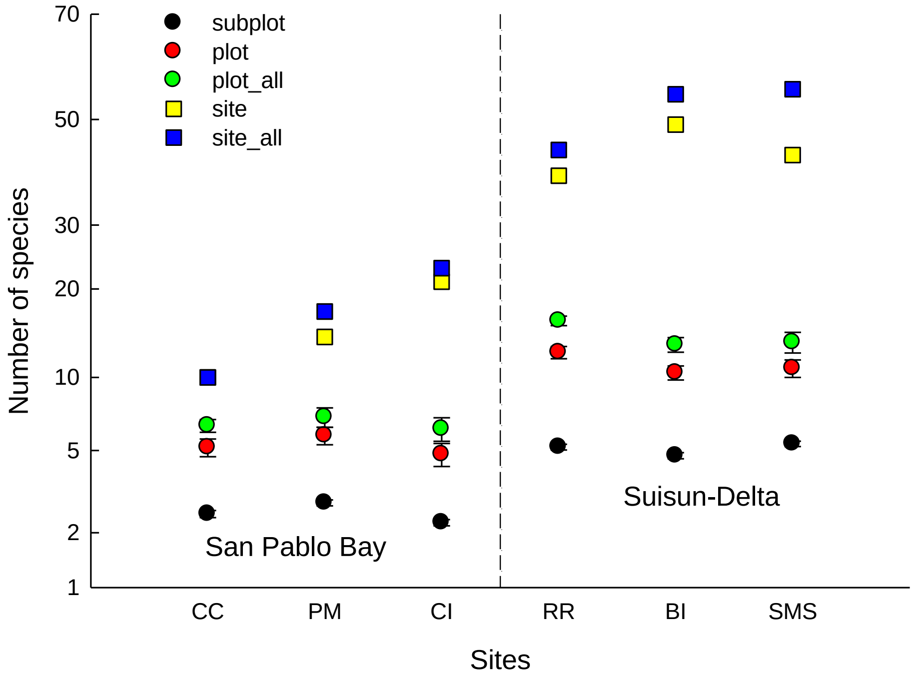

Figure 3. Mean (±SE)species richness at subplot, plot, and plot_all scales and total number of species at site and site_all scales for each site.

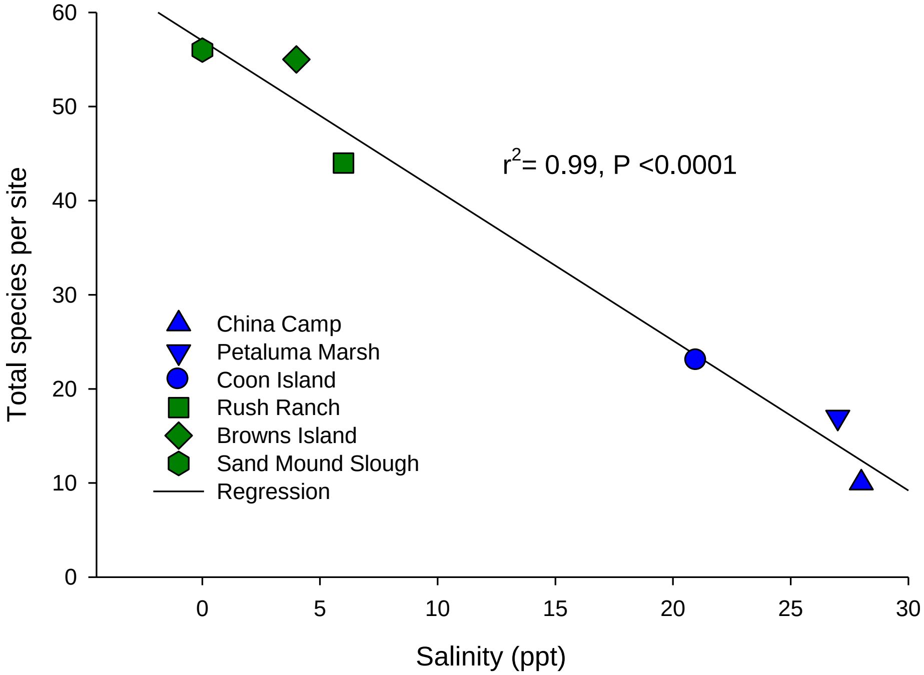

Figure 4. Linear regression comparing total number of species (site_all scale) as dependent variable and mean salinity (ppt) as independent variable.

The table of IV differences (Table 3) also illustrates the scope of the distinction between San Pablo Bay and Suisun-Delta sites. An IV value above 10 is relatively high (the species is either encountered relatively frequently or is relatively abundant wherever it is encountered). All three San Pablo Bay sites were dominated by pickleweed (*Sarcocornia pacifica*) that had IVs above 60. China Camp and Petaluma Marsh host four additional species that all had IVs greater than 10 – *Distichlis spicata, Jaumea carnosa, Grindelia stricta,* and *Cuscuta salina*) – all typical of high salt marsh plains. Tidal wetland vegetation in the three Suisun-Delta sites was more rich and diverse than in the San Pablo Bay sites. Both Rush Ranch and Browns Island retain species that are characteristic of the high marsh plain in San Pablo Bay (*Sarcornia pacifica, Distichlis spicata,* and *J. carnosa*); however, *D. spicata* had a higher IV than *S. pacifica* at these two Suisun-Delta localities, and *J. carnosa* had a higher IV than *S. pacifica* at Browns Island. An unusual tidal wetland species in the Bay-Delta found only at Browns Island during this survey, *Anemopsis californica,* was located in this high marsh habitat. The great majority of the tidal marsh plain in these two Suisun-Delta sites, however, is dominated by a middle marsh assemblage consisting primarily of *Schoenoplectus americanus* and species such as *Juncus balticus, Triglochin maritima, Euthamia occidentalis, Symphiotrichum lentum, Epilobium ciliatum, Eleocharis macrostachya,* and *Glaux maritima*. A listed species largely confined to Rush Ranch, *Cirsium hydrophilum,* occurs along shallow channels in this habitat. At the margins of deep channels and low areas where water stands, a third low marsh assemblage contributes to the heterogeneity of these sites. Here, species such as *Schoenoplectus acutus, Typha latifolia, Typha domingensis, Typha angustifolia,* and *Schoenoplectus californicus* provide a structural matrix in which species such as *Calystegia sepium, Persicaria maculosa* and *Samolus parviflorus* occur.

The eight species with highest IVs (> 10) at Sand Mound Slough in descending order were *Schoenoplectus acutus, Schoenoplectus americanus, Calystegia sepium, Phragmites australis, Typha latifolia, Rubus discolor, Salix lasiolepis,* and *Typha domingensis*. Together, these species create tall, dense thickets that are difficult for people to penetrate; however, many species such as the fern *Atherium felix-femina,* flowering plants such as *Potentilla palustris, Hibiscus lasiocarpus, Lycopus asper, Stachys albus* and *Mimulus guttatus,* emergent wetland species such as *Sparganium eurycarpum* and *Sagitaria latifolia,* sedges such as *Carex obnupta* and *C. pellita,* and other woody species such as *Cephalanthus occidentalis* and *Cornus sericeus* were interwoven within and between these dominants (Table 3).

In total, 82 species were found in the combined subplot samples for all sites (site scale, Table 3), and 94 species were observed in all 120 plots including those species not picked up in the subplot sampling (site_all scale, Table 4); therefore, although the site samples covered an area of only 1400 m^2 compared to the 20,000 m^2 for the site_all samples (i.e., about 7% of the total area surveyed), the subplot sampling picked up 87% of the total number of species observed in all plots per site. At the site_all scale (Table 4), five species (5%) were exclusively found in San Pablo Bay sites, including three natives (*Frankenia salina, Limonium californicum,* and *Spartina foliosa*) while the remaining species (95%) occurred both in San Pablo Bay sites and Suisun-Delta sites. Of these, 64 species (68%) were found only in Suisun-Delta sites. Another 12 species (13%) were shared among Coon Island and the Suisun-Delta sites but not with China Camp or Petaluma Marsh. There were no species found exclusively at China Camp, two (both exotics) at Petaluma Marsh, none at Coon Island, seven at Rush Ranch, five at Browns Island, and twenty two (23% of all species picked up in the survey) at Sand Mound Slough. There were far more native species in these wetlands than exotic species (81 native to 13 exotic; 86% to 14%; Table 4) and, with the exception of *Lepidium latifolium*, these all had low IVs (Table 3).

4.4 Discussion

At a regional scale, tidal wetland vegetation in the Bay-Delta is influenced by ambient salinity regimes (Figure 4). At different scales of sampling, species richness tends to increase from salt marshes (low richness) to mild brackish and freshwater wetlands (high richness; Table 2, Figure 3). In terms of frequency of occurrence and proportion of total abundance per occurrence, there is a distinct shift of species composition and dominance from a narrow suite of salt-tolerant species in salt marshes to a diverse array of species in brackish and freshwater tidal wetlands of the Suisun-Delta (Table 3). These findings have important implications for understanding patterns of plant species diversity in Bay-Delta wetlands and potentially for the future conservation management of Bay-Delta wetlands to maintain and increase this diversity in the face of rapid environmental change.

Table 3. Species codes, species names, and Importance Values (IVs) for species found in subplots at all six sites.

Relatively high IVs (above 10) are highlighted in bold. Species are generally arranged in descending ranks from highest IV to lowest IV at each site except where species are found in more than one site. Note that out of 82 species sampled, 57 were only sampled in the Suisun-Delta, 2 in San Pablo Bay, and 23 were found in both subregions.

	Code	Species	Status	CC	PRM	CI	RR	BRI	SMS
1	Sapa	*Sarcorcornia pacifica*	N	**85.4**	**86.5**	**64.9**	**28.9**	6.2	
2	Disp	*Distichlis spicata*	N	**20.6**	**17.5**	3.3	**34.1**	**30.2**	
3	Jaca	*Jaumea carnosa*	N	**17.5**	**18.7**	4.0	**13.7**	**11.7**	
4	Grst	*Grindelia stricta var. angustifolia*	N	**12.7**	9.9	6.2	**20.4**	2.5	
5	Cusa	*Cuscuta salina*	N	**15.0**	**23.3**		0.5		
6	Frsa	*Frankenia salina*	N	5.2	**16.1**				
7	Lica	*Limonium californicum*	N	6.5	1.1				
8	Cusu	*Cuscuta subinclusa*	N	3.0	3.7		1.3		
9	Boma	*Bolboschoenus maritimus*	N	1.6	2.3	**36.3**		0.3	
10	Spfo	*Spartina foliosa*	N	7.2		1.1			
11	Acmi	*Achillea millefolium*	N		2.2	0.3	2.1	1.0	
12	Lela	*Lepidium latifolium*	E		7.3		**12.6**	2.0	
13	Bapi	*Baccharis pilularis*	N		2.2				
14	Attr	*Atriplex triangularis*	N		0.8	1.9	**13.8**		
15	Rucr	*Rumex crispus*	N		0.3	0.3	0.8	0.3	0.8
16	Scam	*Schoenoplectus americanus*	N			11.0	**41.8**	**64.2**	**48.9**
17	Scac	*Schoenoplectus acutus*	N			6.5	4.1	**23.3**	**56.0**
18	Poan	*Potentilla anserina*	N			5.6	**15.7**	**14.4**	3.7
19	Tyan	*Typha angustifolia*	N			4.9	4.9		6.7
20	Juba	*Juncus balticus*	N			2.6	**36.5**	9.9	
21	Ardo	*Artemisia douglasiana*	N			1.3		1.2	
22	Scca	*Schoenoplectus californicus*	N			1.5		0.3	0.9
23	TySp	*Typha spp.*	N			9.0			5.7
24	Tyla	*Typha latifolia*	N			0.8	0.3	0.8	19.5
25	Tydo	*Typha domingensis*	N			0.8	6.4	**19.7**	**10.6**
26	Bado	*Baccharis douglasii*	N			0.3	0.9	0.3	
27	Chmu	*Chenopodium multifidium*	E			0.3			
28	Case	*Calystegia sepium*	N				**10.7**	**12.0**	**31.3**
29	Trma	*Triglochin maritima*	N				**16.4**	**15.5**	
30	Euoc	*Euthamia occidentalis*	N				4.0	**15.3**	0.3
31	Pepu	*Persicaria punctata*	N				4.0	1.9	6.1
32	Epci	*Epilobium ciliatum*	N				4.1	3.3	0.5
33	Plod	*Pluchea odorata*	N				1.3	2.1	0.3
34	Glma	*Glaux maritima*	N				8.4	1.5	
35	Asle	*Aster lentus*	N				6.8	0.8	
36	Elma	*Eleocharis macrostachya*	N				0.4	8.8	1.4
37	Sapar	*Samolus parviflorus*	N				0.8	1.5	0.8
38	Gatr	*Galium triflorum*	N				0.5	1.6	
39	Sysu	*Symphyotrichum subulatum*	N				0.5	0.3	
40	Ruca	*Rumex californicus*	N				0.3		
41	Apgr	*Apium graveolens*	E				3.0		
42	Sool	*Sonchus oleraceus*	E				1.0		
43	Trco	*Triglochin concinum*	N				2.0		
44	Asra	*Aster radulina*	N				0.8		
45	Sodo	*Solanum douglasii*	N				0.3		
46	Sasu	*Salicornia subterminalis*	N				0.3		
47	Cihy	*Cirsium hydrophilum*	N				0.3		
48	Heec	*Helminthotheca echiodes*	E				0.5		
49	Lyca	*Lythrum californicum*	N					2.7	0.3
50	Migu	*Mimulus guttatus*	N					5.5	
51	Lyam	*Lycopus americanus*	N					3.1	1.9
52	Caob	*Carex obnupta*	N					2.3	0.4

	Code	Species	Status	CC	PRM	CI	RR	BRI	SMS
53	Cape	*Carex pellita*	N					2.0	8.1
54	Hyve	*Hydrocotyle verticillata*	N					1.3	1.0
55	Lyas	*Lycopus asper*	N					1.4	0.8
56	Hyum	*Hydrocotyle umbellata*	N					1.2	0.3
57	Rudi	*Rubus discolor*	E					0.9	17.3
58	Peam	*Persicaria amphibia*	N					0.8	6.7
59	Lima	*Lilaeopsis masonii*	N					0.5	0.5
60	Mear	*Mentha arvensis*	N					0.6	1.9
61	Irps	*Iris pseudacorus*	E					0.3	2.6
62	Anca	*Anemopsis californica*	N					1.2	
63	Sisu	*Sium suave*	N					0.3	
64	Laje	*Lathyrus jepsonii var. jepsonii*	N					1.1	
65	Soam	*Solanum americanum*	N					0.3	
66	Dece	*Deschampsia cespitosa*	N					0.3	
67	Pema	*Persicaria maculosa*	N					8.3	8.9
68	Phau	*Phragmites australis*	N						**24.3**
69	Sala	*Salix lasiolepis*	N						**13.6**
70	Atfi	*Athyrium filix-femina*	N						8.5
71	Popa	*Potentilla palustris*	N						7.0
72	Salat	*Sagittaria latifolia*	N						6.8
73	Speu	*Sparganium eurycarpum*	N						6.5
74	Stal	*Stachys albens*	N						2.4
75	Lupe	*Ludwigia peploides*	N						1.4
76	Juxi	*Juncus xiphioides*	N						0.3
77	Cima	*Cicuta maculata var. bolanderi*	N						0.3
78	Hila	*Hibiscus lasiocarpos*	N						0.5
79	Cose	*Cornus sericeus*	N						0.9
80	Scmi	*Scirpus microcarpus*	N						0.8
81	Ceoc	*Cephalanthus occidentalis*	N						0.3
82	Hyra	*Hydrocotyle ranunculoides*	N						0.3

Table 4. Species codes, species names, status (N=native, E=exotic) and Importance Values for species found at all six sites and including those not recorded in the subplots (site_all scale). Presence of a species at a site is indicated by a "+".

	Code	Species	Status	CC	PRM	CI	RR	BRI	SMS
1	Frsa	*Frankenia salina*	N	+	+				
2	Lica	*Limonium californicum*	N	+	+				
3	Spfo	*Spartina foliosa*	N	+	+	+			
4	Cusu	*Cuscuta subinclusa*	N	+	+		+		
5	Cusa	*Cuscuta salina*	N	+	+		+		
6	Boma	*Bolboschoenus maritimus*	N	+	+	+		+	
7	Disp	*Distichlis* spicata	N	+	+	+	+	+	
8	Jaca	*Jaumea carnosa*	N	+	+	+	+	+	
9	Grst	*Grindelia stricta* var. *angustifolia*	N	+	+	+	+	+	
10	Sapa	*Sarcorcornia pacifica*	N	+	+	+	+	+	+
11	Chal	*Chenopodium multifidium*	E		+				
12	Coma	*Conium maculatum*	E		+				

Table 4. Species codes, species names, status (N=native, E=exotic) and Importance Values for species found at all six sites and including those not recorded in the subplots (site_all scale). Presence of a species at a site is indicated by a "+".

	Code	Species	Status	CC	PRM	CI	RR	BRI	SMS
13	Bapi	*Baccharis pilularis*	N		+	+			
14	Lela	*Lepidium latifolium*	E		+	+	+	+	
15	Acmi	*Achillea millefolium*	N		+	+	+	+	
16	Attr	*Atriplex triangularis*	N		+	+	+	+	
17	Rucr	*Rumex crispus*	N		+	+	+	+	+
18	Tysp	*Typha* spp.	N			+		+	+
19	Ardo	*Artemisia douglasiana*	N			+		+	
20	Tyan	*Typha angustifolia*	N			+	+		+
21	Bado	*Baccharis douglasii*	N			+	+	+	
22	Juba	*Juncus balticus*	N			+	+	+	
23	Scac	*Schoenoplectus acutus*	N			+	+	+	+
24	Poan	*Potentilla anserina*	N			+	+	+	+
25	Scca	*Schoenoplectus californicus*	N			+	+	+	+
26	Scam	*Schoenoplectus americanus*	N			+	+	+	+
27	Tyla	*Typha latifolia*	N			+	+	+	+
28	Tydo	*Typha domingensis*	N			+	+	+	+
29	Euoc	*Euthamia occidentalis*	N			+	+	+	+
31	Pomo	*Polypogon monspieliensis*	N				+		+
30	Sasu	*Salicornia subterminalis*	N				+		
32	Civu	*Cirsium vulgare*	E				+		
33	Sool	*Sonchus oleraceus*	E				+		
34	Loco	*Lotus corniculatus*	E				+		
35	Trco	*Triglochin concinum*	N				+		
36	Cihy	*Cirsium hydrophilum*	N				+		
37	Heec	*Helminthotheca echiodes*	E				+		
38	Glma	*Glaux maritima*	N				+	+	
39	Asle	*Aster lentus*	N				+	+	
40	Apgr	*Apium graveolens*	E				+	+	
41	Gatr	*Galium triflorum*	N				+	+	
42	Sysu	*Symphyotrichum subulatum*	N				+	+	

Table 4. Species codes, species names, status (N=native, E=exotic) and Importance Values for species found at all six sites and including those not recorded in the subplots (site_all scale). Presence of a species at a site is indicated by a “+”.

	Code	Species	Status	CC	PRM	CI	RR	BRI	SMS
43	Sodo	*Solanum douglasii*	N				+	+	
44	Ruca	*Rumex californicus*	N				+	+	
45	Sisu	*Sium suave*	N				+	+	
46	Trma	*Triglochin maritima*	N				+	+	+
47	Case	*Calystegia sepium*	N				+	+	+
48	Epci	*Epilobium ciliatum*	N				+	+	+
49	Pepu	*Persicaria punctata*	N				+	+	+
50	Plod	*Pluchea odorata*	N				+	+	+
51	Sapar	*Samolus parviflorus*	N				+	+	+
52	Lyca	*Lythrum californicum*	N				+	+	+
53	Elma	*Eleocharis macrostachya*	N				+	+	+
54	Anca	*Anemopsis californica*	N					+	
55	Laje	*Lathyrus jepsonii*	N					+	
56	Soam	*Solanum americanum*	N					+	
57	Dece	*Deschampsia cespitosa*	N					+	
58	Pema	*Persicaria maculosa*	N					+	
59	Migu	*Mimulus guttatus*	N					+	+
60	Lyam	*Lycopus americanus*	N					+	+
61	Caob	*Carex obnupta*	N					+	+
62	Carex	*Carex pellita*	N					+	+
63	Hyve	*Hydrocotyle verticillata*	N					+	+
64	Lyas	*Lycopus asper*	N					+	+
65	Hyum	*Hydrocotyle umbellata*	N					+	+
66	Rudi	*Rubus discolor*	E					+	+
67	Peam	*Persicaria amphibia*	N					+	+
68	Lima	*Lilaeopsis masonii*	N					+	+
69	Juxi	*Juncus xiphioides*	N					+	+
70	Cima	*Cicuta maculata* var. *bolanderi*	N					+	+
71	Irps	*Iris pseudacorus*	E					+	+
72	Mear	*Mentha arvensis*	N					+	+

Table 4. Species codes, species names, status (N=native, E=exotic) and Importance Values for species found at all six sites and including those not recorded in the subplots (site_all scale). Presence of a species at a site is indicated by a "+".

	Code	Species	Status	CC	PRM	CI	RR	BRI	SMS
73	Phau	*Phragmites australis*	N						+
74	Sala	*Salix lasiolepis*	N						+
75	Atfi	*Athyrium filix-femina*	N						+
76	Popa	*Potentilla palustris*	N						+
77	Salat	*Sagittaria latifolia*	N						+
78	Speu	*Sparganium eurycarpum*	N						+
79	Stal	*Stachys albens*	N						+
80	Lupe	*Ludwigia peploides*	N						+
81	Hila	*Hibiscus lasiocarpos*	N						+
82	Cose	*Cornus sericeus*	N						+
83	Scmi	*Scirpus microcarpus*	N						+
84	Ceoc	*Cephalanthus occidentalis*	N						+
85	Bila	*Bidens laevis*	N						+
86	Oesa	*Oenothera sarmentosa*	N						+
87	Vebo	*Verbena bonariensis*	E						+
88	Hyra	*Hydrocotyle ranunculoides*	N						+
89	Asle	*Aster radulina*	N						+
90	Eicr	*Eichornia crassipes*	E						+
91	Lesp	*Lemna* sp	N						+
92	Vela	*Verbena lasiostachys*	N						+
93	Vebo	*Verbena bonariensis*	E						+
94	Scga	*Scutellaria galericulata*	N						+

Patterns of Bay-Delta Tidal Wetland Plant Species Diversity

Despite the pioneering work by Atwater et al. (1979), there has been a persistent belief that brackish wetland vegetation of the Suisun Bay region is more diverse than the freshwater Delta. For example, Byrne et al. (2001, p. 66) state:

> Brackish wetlands are floristically distinctive and *contain a greater diversity of plant species* than either the salt marshes of San Francisco Bay or the freshwater wetlands of the Sacramento-San Joaquin Delta. (*emphasis added*)

A recent paper reiterates this perspective and argues that "increasing salinity may just move the center of diversity eastward" (Watson and Byrne 2009, p. 126). Yet, based on original wetland vegetation surveys by Atwater and Hedel (1976), Atwater et al. (1979, p. 363) states:

> Diversity generally increases from San Francisco Bay to the Delta. Whereas individual marshes around San Francisco Bay typically contain 13 or 14 species of native plants, specific sites in the Delta contain 40 species. Composite regional lists imply even greater differences in diversity: only 15 native species reportedly live in tidal marshes around San Francisco Bay but about 30 reportedly live around San Pablo Bay and Carquinez Strait, 40 around Suisun Bay, and 80 in the Delta.

Atwater et al. (1979, p. 369) continues:

> Tidal-marsh plants of San Pablo Bay, Carquinez Strait, and Suisun Bay provide an intricate, mutable transition between salt marshes of San Francisco Bay and freshwater marshes of the Delta … Species from opposite ends of the spectrum overlap to varying degrees in the middle,

These observations by Atwater et al. (1979) are consistent with our findings. While all of the Suisun-Delta sites are significantly richer than San Pablo Bay sites in terms of species richness, we record the greatest total species richness at Sand Mound Slough in the Delta (56) and Browns Island in the western Delta (55), and the least in the more brackish wetlands of Rush Ranch in the western Suisun Bay region (44) (Table 2, Figure 3D). We also found that Rush Ranch and Browns Island contain a rich mixture of species characteristic of the eastern San Pablo Bay site (Coon Island) as well as the Suisun-Delta sites, perhaps constituting the heart of the "intricate, mutable transition" vegetation described by Atwater et al. (1979) above. If Sand Mound Slough is a reasonable indicator of Delta plant species diversity compared to these other wetlands, and there is little data to suggest otherwise, many species that occur in Delta freshwater wetlands simply do not establish in more saline reaches of the estuary. For example, Sand Mound Slough had twenty-two species that were not found downstream (Table 4). This suggests that the species pool for vegetation in the Bay-Delta ecosystem is most rich in the Delta and progressively attenuates as higher levels of ambient salinity are encountered. The significant correlation ($R^2 = 0.99$, $p<0.0001$) between ambient salinity and total number of species per site in this limited study strongly suggests this relationship (Figure 4).

We suspect that the reason Watson and Byrne (2009) found more species at South Hampton Bay and Hill Slough in the Suisun Bay region compared to Sand Mound Slough in the Delta is that the amount of area they sampled at Sand Mound Slough was not sufficient to detect the greater number of species that we found there. Since their design was based on Atwater and Hedel (1976), who originally sampled a comparatively small transect at Sand Mound Slough compared to South Hampton Bay and Hill Slough, this is understandable. As pointed out, in a comparison of richness at the 1000 m^2 plot scale between Rush Ranch, Browns Island, and Sand Mound Slough, Rush Ranch had the highest richness, whereas at the site_all scale (20,000 m^2), Sand Mound Slough had 12 more species than Rush Ranch (Table 2). These data suggest that

Rush Ranch has more species that are frequently encountered at local scales, but that Sand Mound Slough has more species that are infrequently encountered at the larger site scale.

While our study provides evidence that the greatest number of tidal wetland plant species occurs in the Delta, this is not to say that the brackish wetlands of Suisun Bay are not diverse but rather that their diversity, compared to the Delta, may be more a function of species endemism than species numbers. Suisun Bay is well known for its concentration of local endemic plant species in Bay-Delta tidal wetlands. A good example is *Cirsium hydrophilum,* and there are other brackish wetland examples, such as *Lathyrus jepsonii* var. *jepsonii* and *Chloropyron molle* (CNPS 2009). Conversely, none of the species we encountered at Sand Mound Slough are classified as local endemics. Rather, the Delta species are more widespread freshwater wetland plants that present a greater diversity of life histories than Suisun wetlands including trees, shrubs, vines, ferns, floating aquatic species, and other more typical wetland herbaceous plants.

Another important source of Bay-Delta tidal wetland plant diversity that has been generally overlooked formerly occurred in the salt marshes of the historic San Pablo Bay and San Francisco Bay. As detailed by Baye et al. (2000), many locally rare herbaceous species today were once found in wetlands historically concentrated on the edges of tidal salt marshes where seasonal pools, freshwater springs and intermittent creeks created a system of small brackish, tidally-influenced wetlands. Unfortunately, most of these marginal wetland habitats are now gone as the Bay-Delta has been transformed by human activity in the post-European settlement era. Our tidal wetland sampling of the San Pablo Bay sites did not record any of these species, and clearly the more saline regions of the estuary would be regarded as a more diverse wetland ecosystem if these species were still present. This potential for incomplete sampling, and the previous discussion of brackish and freshwater wetlands, raises the issue of sampling methods that we address below.

The Benefits and Costs of Balanced, Random Sampling

In this study, we intentionally designed a balanced, random sample of tidally influenced vegetation at each historic wetland site representing a range of positions along the salinity gradient within the Bay-Delta (Figure 1, Table 2). The advantage of this approach is that it provides an unbiased estimate of species richness, relative abundance, and frequency of occurrence at a variety of scales to ensure an equal comparison among sites. As such, we can state with some confidence that species numbers in the Suisun-Delta are more likely greater than in San Pablo Bay and that there does appear to be a strong correlation between ambient (water column) salinity and numbers of species at tidal wetlands arrayed along the estuarine salinity gradient (Figure 4). One cost to random sampling, especially in a system with strong local gradients like tidal wetlands, is that it is inherently biased towards recording species that are relatively abundant and spatially well-distributed (Grieg-Smith 1983). Rare species that are patchily distributed, particularly in uncommon, specialized habitats, generally require large numbers of randomly distributed samples (Greig-Smith, 1983). For example, while the Coon Island tidal wetland is more species rich than either China Camp or Petaluma Marsh at the site scale, richness is obscured when viewed at smaller sampling scales such as subplots and plots (Table 2, Figure 3). This may be an example of how brackish species found more commonly in

Suisun Bay wetlands are more patchily distributed on Coon Island and therefore more likely to be missed in small-scale random samples. The balanced random sampling approach, for similar reasons, would not be effective at detecting fine-scale diversity of transitional brackish habitats such as those described by Baye et al. (2000). Consequently, for large-scale questions – such as those addressing potential effects of climate change on Bay-Delta plant species along the estuarine salinity gradient – the balanced, random approach is useful. However, for more local scale questions, and for questions involving species in specialized habitats, a more targeted approach is likely to be more effective (Parker et al., 2011).

Conservation Implications

Our study has implications for conservation of Delta tidal wetland vegetation. The Sacramento-San Joaquin Delta once encompassed approximately 260,000 ha of wetlands of which approximately 140,000 ha were tidally influenced (Atwater et al. 1979). According to Hart (2010), this Delta wetland habitat was not monolithic. The north Delta was shaped by powerful flows of the Sacramento River. Natural levees, six to seven meters high, were deposited by these flows, and colonized by tall gallery forests of valley oak, cottonwoods, sycamores, and alders. The south Delta was shaped by more moderate flows of the San Joaquin River, levees were lower, and riparian woodlands sparser. Behind these natural levees were extensive stands of freshwater wetlands characterized by tules, cattails, and other tidal wetland species that gradually gave way to seasonal wetlands, vernal pools, grasslands, and oak savanna. This mosaic of freshwater wetland plant diversity must have been extraordinary; however, as the Delta was "reclaimed", over 95% of this habitat was lost. Today, small remnants of this diversity persist in remote corners of the Delta, such as at Sand Mound Slough, and one compelling question is: if conditions in the Delta become more saline with sea level rise and potentially greater diversion of freshwater from upstream, where will these species go? At the moment, conservation alternatives are limited by lack of available habitat and restoration opportunities; however, a building restoration movement exists in the Delta, and we hope that the broader community of the public, scientists and policy makers recognizes that plant species diversity in the Delta is remarkable, despite its general appearance to the contrary (as one cruises by on a boat). While the vegetation of Sand Mound Slough may not be representative of the entire Delta, its high diversity compared to other historic wetlands in the Bay-Delta provides the impetus to recognize that future Delta restoration efforts should be viewed as an opportunity to recreate this diversity as well as provide for vegetation structure and ecosystem services that support other wildlife and microbial organisms.

This study also highlights the importance of the Suisun Bay region for plant diversity at a variety of scales. Tidal wetlands in the Suisun are a convergence between salt tolerant and freshwater dependent plant species, including several species that are endemic to this region. Although partially salt-tolerant species in the brackish portion of the estuary should be able to retreat upstream in the face of salinity intrusion (Watson and Byrne 2009), this presupposes that marsh plain habitat will be (or become) available to colonize. Of possibly greater conservation concern for Bay-Delta brackish wetlands is the spread of an invasive non-native species, *Lepidium latifolium*. We found that this species has a relatively high IV at Rush Ranch compared to other species, was well established at Browns Island and Petaluma Marsh, and also was present at Coon Island (Table 3, Table 4). *Lepidium latifolium* is particularly problematic at Rush Ranch where it dominates habitat in which *Cirsium hydrophilum* occurs. Invasive *L. latifolium* has become so well integrated into sensitive brackish wetland habitat that it poses a particularly onerous control challenge. Further research and pilot control studies are urgently needed.

Although our assessment did not sample the kinds of marginal brackish habitat in San Pablo Bay and San Francisco Bay that were highlighted by Baye et al. (2000) and that largely have been extirpated, it does underscore the importance of brackish habitat to greater plant diversity in the Bay-Delta. Landscapes with intact transition habitat at the margin of salt and brackish wetlands are highly limited and this is one of the reasons San Francisco Bay NERR components such as China Camp and Rush Ranch are so valuable from a conservation perspective. The greatest opportunity for large-scale habitat restoration in the Bay-Delta is currently focused on these more saline portions of the estuary. Given the importance of these marginal brackish habitats to plant diversity in the Bay-Delta as a whole, we advocate that more effort be made to establish conditions favorable for these marginal habitats in tidal wetland restoration projects in San Francisco Bay and San Pablo Bay. This could greatly enhance the overall plant diversity of the Bay-Delta.

4.5 Acknowledgments

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5. Flora and Ecological Profile of Native and Exotic Estuarine Wetland Vegetation by Hydrogeomorphic Setting at Rush Ranch, Suisun Marsh

Whitcraft, Christine[1,2], Brenda J. Grewell[3], and Peter R. Baye[4]

[1]San Francisco Bay National Estuarine Research Reserve
San Francisco State University

[2]California State University, Long Beach
1250 Bellflower Blvd.
Long Beach CA 90840
cwhitcra@csulb.edu, 562-985-4820

[3]USDA ARS Exotic & Invasive Weeds Research Unit
University of California, Department of Plant Sciences MS-4
Davis, CA 95694
USDA is an equal opportunity provider and employer.
bjgrewell@ucdavis.edu

[4]Annapolis Field Station
33660 Annapolis Road
Annapolis, CA 95412
baye@earthlink.net

The authors contributed equally to this work.

ABSTRACT

We profile the ecology and distribution of estuarine wetland vegetation at the Rush Ranch Open Space Preserve (Rush Ranch) component site of the San Francisco Bay National Estuarine Research Reserve. This site includes the largest remaining undiked tidal wetland within the Suisun Marsh region of the San Francisco Estuary. The brackish tidal wetlands grade into transitional vegetation and undeveloped grasslands of the Potrero Hills, and we describe diverse vegetation that reflects the estuarine position, land use history, and hydrogeomorphic complexity of the site. A detailed analysis of the distribution and abundance of both desirable native plant communities and exotic, invasive weeds is provided that will aid weed management planning and restoration efforts. There are four major estuarine geomorphic units supporting vegetation at Rush Ranch that are also widely distributed in the region: subtidal channel beds, fringing tidal marsh, tidal marsh plain and tidal marsh-terrestrial ecotone. These are distinguished by small variations in hydrology and elevation. We evaluate vegetation within each of these landforms, considering each vegetation community as a function of changing physical environment and biological iterations. Past land-use and exotic plant species invasions have substantially altered Rush Ranch tidal marsh vegetation patterns. Our results indicate 27% of the flora to be exotic species, and several are highly invasive. Despite these threats, the reserve's position in the landscape provides important and increasingly rare habitat linkages between the tidal marsh and upland grasslands, providing great potential for restoration and migration corridors for vegetation response to sea level rise and other climate change factors. We present a detailed flora and vegetation analysis by hydrogeomorphic setting to provide an ecological framework for future monitoring, research and adaptive conservation management.

KEY WORDS

Suisun Marsh
estuarine wetlands
tidal wetlands
brackish marsh
wetland flora
invasive species
plant community
vegetation
anthropogenic drivers

5.1 Introduction

The 425 hectares of estuarine wetlands at the Rush Ranch Open Space Preserve (Rush Ranch), a component site of the San Francisco Bay National Estuarine Research Reserve, are part of the largest extant tidal marsh within the brackish Suisun Marsh reach of the San Francisco Estuary (Figure 1). The tidal wetland at Rush Ranch is unique because of its areal extent, largely intact prehistoric marsh platform, hydrogeomorphic complexity, continuity between tidal marsh ecotones and undeveloped grasslands, and habitat provision for endangered and endemic plant populations.

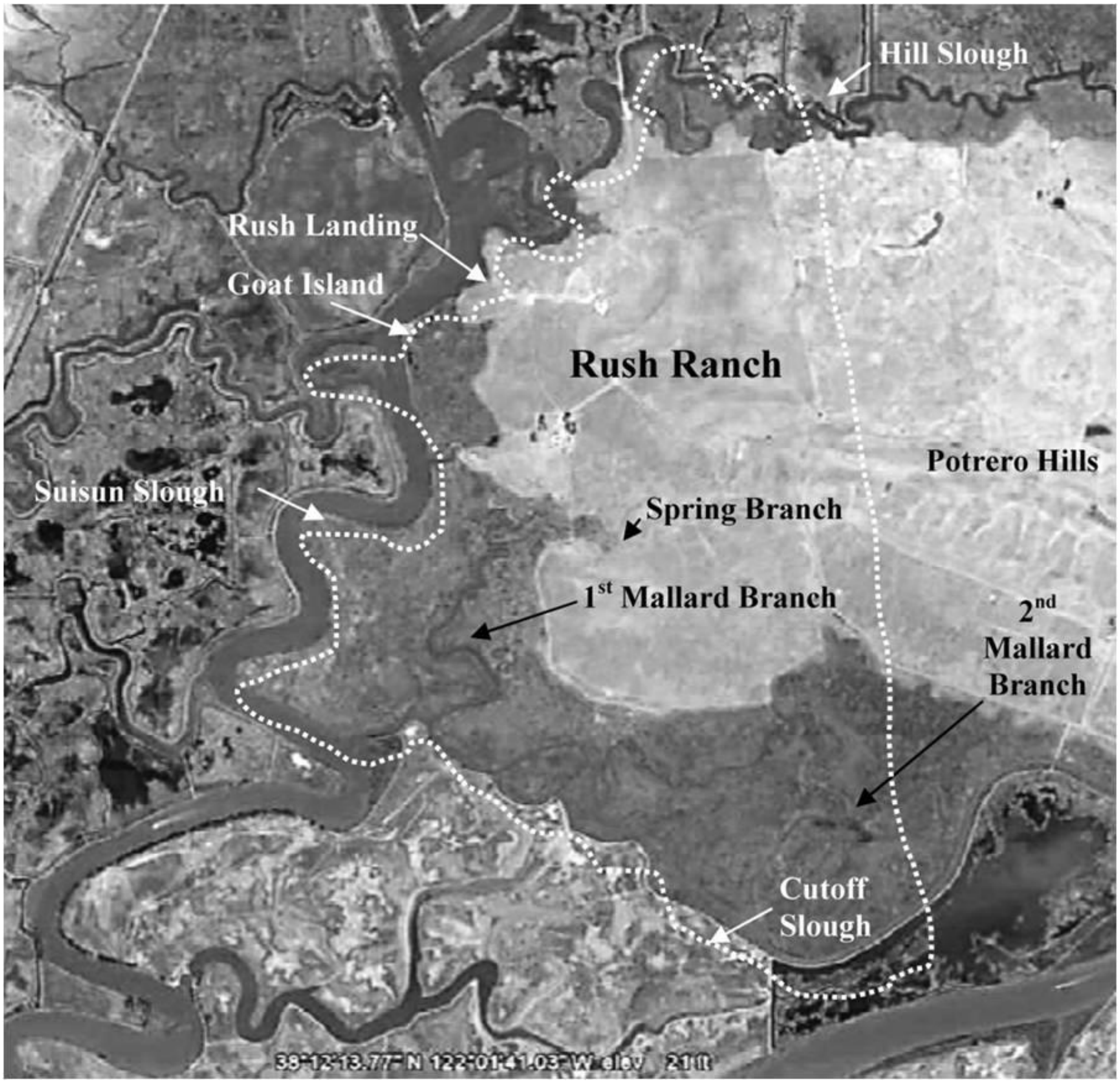

Figure 1. Location of the Rush Ranch Open Space Preserve (838 hectares, boundary in dotted line) (38°12′31.7″N Latitude, 122°1′31.9″W Longitude). Key areas tidal sloughs and landmarks within RROSP are identified. © 2011 Google.

Hydrology and geomorphology are fundamental determinants of the structure, dynamics, and productivity of wetland plant communities. The estuarine vegetation at Rush Ranch reflects hydrological influences on different spatial and temporal scales: (1) regional scale – location in the estuary; (2) temporal scale – historic land use; and (3) local scale - modern patterns of site-specific hydrogeomorphology. Rush Ranch is approximately 80 km up-estuary from the Golden Gate tidal inlet in the northern region of Suisun Marsh. Suisun Marsh is situated in between the extensive Sacramento-San Joaquin Delta and the North and South Bay reaches of the San Francisco Estuary. In this region, the hydrology and tidal mixing of fresh and salt water have been spatially and temporally dynamic, and historic variability in physical processes was a key driver of historic biological diversity (Moyle et al. 2010). At the regional scale, the diversity of vegetation within the entire Suisun Marsh and particularly at Rush Ranch results from a combination of and small variations in physical and geological factors, such as distance from the ocean, the magnitude of freshwater input from direct precipitation, watershed runoff, and Delta outflow, salinity pulses, storms, and the duration of tidal submergence (Atwater et al. 1979; Josselyn 1983). In contrast to wetlands in the Delta, vegetation at Rush Ranch is influenced by large annual and interannual ranges in salinity (Moyle et al. 2010). In recent times, key physical and chemical processes have been anthropogenically mediated by active management of Delta outflow and Suisun Marsh salinity regimes by state and federal water projects (Enright and Culberson 2009) that effectively reduce biologically-important environmental variation (Moyle et al. 2010).

The distribution and abundance of plant species and how these two factors change with hydrogeomorphic complexity are also influenced by the functional traits of plant species (Shipley 2010, Bonin and Zedler 2008). The site includes a rich estuarine flora that corresponds to unique hydrogeomorphic features within the marsh and supports estuary-dependent wildlife and complex food webs. This vegetation is quite different from graminoid-dominated tidal marshes of the North American Atlantic Coast, and the brackish plant community composition and structure is also floristically distinct from, and more diverse than, tidal marsh vegetation in San Francisco Bay or along the outer coast of California (Mason 1972, Baye et al. 2000, Grewell et al. 2007, Watson and Byrne 2009). While the tidal wetlands and terrestrial-ecotone vegetation at Rush Ranch are unique and largely intact as compared to most of the San Francisco Estuary, they have not been immune to change and do not represent a static, pre-development condition. They have a legacy of agricultural and ranching use, hydrologic modifications and alteration to vegetation (Wetlands and Water Resources, Inc. 2011). As a result of this anthropogenic activity, the flora of terrestrial ecotones between estuarine marshes and uplands has been significantly degraded, and native flora from these areas is now regionally rare or extirpated (Baye et al. 2000). Despite historic alterations, the estuarine plant communities at Rush Ranch are a significant natural resource that merit conservation attention. Rush Ranch has one of the only remaining gently sloping undeveloped lowlands (alluvial fan topography and soils lacking intensive agriculture or urban/industrial development) bordering undiked tidal marsh. This setting provides rare geomorphic accommodation space for estuarine transgression as sea level rises and a rare opportunity to conserve the high tidal marsh and its terrestrial ecotone.

Aspects of the tidal wetland vegetation of Suisun Marsh previously have been reviewed by Mason (1972), Atwater and Hedel (1976), Atwater et al. (1979), Josselyn (1983), Wells and

Goman (1995), Baye et al. (2000), Hickson et al. (2001), Byrne et al. (2001), Grewell et al. (2007), Watson and Byrne (2009), and Vasey et al. (Chapter 4). Floristic surveys and studies of plant ecology specific to Rush Ranch and contiguous tidal wetlands offsite have also contributed to our knowledge of the site (Wetland Research Associates 1990, Siegel 1993, Ruygt 1994, Grewell 1996, Grewell et al. 2003, Fiedler & Keever 2003, Fiedler et al. 2007, Grewell 2008a, Watson and Byrne 2009, Reynolds and Boyer 2010). These surveys and studies suggest the modern vegetation at Rush Ranch is typical of relict tidal wetlands elsewhere in the Suisun Marsh, and while rare species and plant assemblages occur, the Rush Ranch flora shares many elements of wetland flora with marshes elsewhere in the San Francisco Estuary and northern coastal California.

This profile presents historical context, descriptions and baseline data on the floristic composition and ecology of estuarine vegetation at Rush Ranch, the relationship of vegetation to hydrogeomorphic settings and associated hydrologic and other physical-chemical processes, as well as modern transformations of vegetation pattern. In addition, we provide a framework for future monitoring, research, and adaptive conservation management.

5.2 Geomorphic and Historic Development of Vegetation

Paleoecology and Historical Ecology

In addition to spatial scale differences in hydrology, past land use exerts great influence on hydrology and thus on present plant community structure. Paleoecological reconstructions of geology, climate, sedimentation, and vegetation change of the northern San Francisco Bay Estuary during the past 7,000 years have included site-specific studies of tidal wetlands ringing the Potrero Hills (including Rush Ranch) that are the ecological heritage of modern vegetation. The oldest tidal brackish and salt marsh sediments in the northern San Francisco Bay Estuary are associated with a slowing of post-glacial sea level rise rates as they approached modern sea level. This initial deceleration of sea level rise began 6000 yr before present (BP), and by approximately 4000 yr BP initiation of most modern tidal marsh plains began, although some emergent fresh-brackish estuarine marshes deposited discontinuously earlier (Wells et al. 1997, Malamud-Roam and Ingram 2004, Malamud-Roam et al. 2007). Studies of the stratigraphic record of microfossils (pollen, diatoms, foraminifera) and organic and inorganic sediments at Rush Ranch indicate that the wetland vegetation at Rush Ranch developed and has been subjected to a cycle of environmental variability over millennial and centennial scales, as well as climate-driven changes in hydrology and aqueous salinity (Wells et al. 1997, Malamud-Roam and Ingram 2004, Malamud-Roam et al. 2007). These climate variations occurred in a background of relatively slow and stable sea level rise rates. They corresponded with marked fluctuations in the composition of tidal marsh dominant vegetation, indicated by reversals in relative abundance and composition of pollen assemblages corresponding with low and high salinity regimes (Watson et al., Chapter 10).

Empirical reconstruction of Rush Ranch paleoecology clearly indicates that the existing mature marsh plain and sloughs, and corresponding development and evolution of marsh plant communities, have a relatively brief geologic existence – less than two thousand years – and underwent profound fluctuations in vegetation dominance and salinity regimes, as well as in precipitation (Byrne et al. 2001). The stratigraphic and pollen records do not support the assumption of an "equilibrium" or steady "natural" state in either Suisun Marsh or Rush Ranch (Byrne et al. 2001; Goman et al. 2008). These records have specific implications for special-status species conservation, particularly endemic Suisun Marsh species. Suisun Marsh historic endemic species, some of which are now endemic to Rush Ranch alone or nearly so, either persisted in refugial habitats within local salinity gradients of Suisun Marsh, or underwent range shifts very rapidly between Suisun Marsh, the western estuary, and the Delta. Stable suitable habitat likely did not persist at any one location at Rush Ranch for more than 1000 years.

Early anthropogenic influences on estuarine vegetation

Rush Ranch is located near some of the largest prehistoric Patwin (Wintun) village sites recorded in the Suisun Marsh region (Kroeber 1925, Johnson 1978, Fulgham Archaeological Resource Service 1990). Patwin utilized annual burning of grasslands and after-seed harvest in the lowland valleys for hunting, maintenance of favorable seed (pinole) and bulb production (Lightfoot and Parrish 2009, Johnson 1978, Lewis 1973, Bean and Lawton 1973). Annual burns likely influenced the character of tidal marsh edges and stream valleys, particularly in limiting the development of woody scrub. In addition to burning of tule stands to enhance growth , diggingand stem cuttingalso likely altered productivity and the ecology of tidal marsh vegetation in California (Anderson 2005). *Schoenoplectus acutus* (hardstem bulrush), *S. californicus* (California bulrush), *Juncus* species, *Carex barbarae* (basket sedge) and other sedge beds were harvested for textiles (house construction, reed boats, clothing, footwear, duck decoys, and basketry) as well as food (Anderson 2005, Johnson 1978). In the 1700s, Spanish explorers also introduced both non-native plants and fire into the system. All of these activities potentially influenced the structure of tidal marsh vegetation at Rush Ranch.

Photographs and other records from the late 19th and early 20th centuries suggest historic anthropogenic influences on Rush Ranch tidal marshes include: regional and local diking, (e.g. Suisun Slough and partial diking within marsh plain, Second Mallard Branch drainage), ditching to drain tidal marsh plains (mosquito ditching), haying and livestock grazing in tidal marsh, creation of tidal marsh pans and ponds, construction of slough dam and partial levees along marsh perimeters, and introduction of non-native animal and plant species. These alterations contributed to indirect ecological alterations such as increased terrigenous sedimentation from gullies and seasonal streams and slope failures of adjacent hillslopes, both subject to overgrazing.

Diking of historic tidal marsh in the Suisun region progressed from the late 1870s through the 1970s. The construction of full and incomplete dikes at Rush Ranch along slough borders of tidal marshes likely contributed significantly to local declines in tidal slough bank vegetation (including rare endemic plants) that was regionally decimated by early 20th century diking. Diking and ditching, and cattle manure in the tidal marsh, also likely facilitated the spread of invasive non-native species into the marsh. Diking of historic tidal marsh has greatly impacted estuarine ecotone transitions in the San Francisco Estuary by creating sharp boundaries between wetlands and terrestrial grasslands (Fieldler and Zebell 1995, Josselyn 1983). Mason (1972) and George et al. (1965) report accounts from "old timers" that prior to diking of wetlands in Suisun Marsh, there were extensive tidal marshes "where water stood on the land", and tall tules lined the margins in deeper water. This pattern of vegetation was also reported by DeAnza as he first explored Suisun by water in 1776. Historic reports also note that high marsh plains on Grizzly Island were covered with *D. spicata* which was dominant but associated with salt-tolerant species including *Sarcocornia pacifica* (syn. *Salicornia virginica*, *Salicornia pacifica*, perennial pickleweed) in poorly drained areas (George et al. 1965, Mason 1972).

In the 19th century, *Distichlis spicata* (salt grass) and *Schoenoplectus americanus* (chairmaker's bulrush) were both harvested as commodities and utilized as packing material by the Gladdin McBean Pottery Works in Lincoln (Frost not dated). Saltgrass hay bales were also loaded onto schooners at sites such as Rush Landing, and transported for sale as cattle feed (Mason 1957, 1972; George et al. 1965, and Frost not dated). Haying directly in tidal marshes also likely had acute and prolonged inhibitory effects on reproduction of what are now rare endemic high tidal marsh plants.

Grazing most likely had similar impacts as those discussed for haying. Grazing in marshes would likely have been most intensive in early summer, when hillslopes are dry and green forage is restricted to wetlands. Intensive grazing likely occurred during peak flowering periods of *Cirsium hydrophilum* var. *hydrophilum* (Suisun thistle) and *Chloropyron molle* subsp. *molle* (soft bird's beak), for example. Cattle grazing has been officially excluded from tidal wetland areas of Rush Ranch since the Open Space Preserve was established (Wetland Resource Associates 1990), but in the 1980s, prior to transfer of ownership to Solano Land Trust (SLT), grazing within the tidal wetland was pervasive (P. Moyle, pers. obs). Following removal of cattle from the marsh, the population endangered *C. h.* var. *hydrophilum* (presumed extinct) recruited and spread along tidal creek channels (Grewell, pers. obs, photo-documented Figure 2). Since SLT ownership, there has been both unintentional and intentional grazing of cattle and horses within tidal marsh areas, and the practice has recently (2011) been re-established (Poerner (SLT), pers. comm.). Cattle grazing has directly impacted endangered plant population in the tidal wetlands, and resultant trampling destroyed a historic population of endangered *C. molle* on the marsh (Grewell et al. 2003, Grewell 2005).

Historic hunting influences on Rush Ranch and surrounding private hunting clubs and public wildlife areas also influenced tidal wetland vegetation within Rush Ranch. Historically, much of the historically abundant native vegetation (e.g. *Sarcocornia. pacifica* and *Distichlis spicata*) in Suisun Marsh was considered "undesirable" for waterfowl (Rollins 1981), and early management of diked wetlands focused on production of non-native plants and some native species (particularly *Bolboschoenus maritimus* (alkali bulrush), *Scirpus robustus* misapplied) that were not naturally dominant in the region (Miller et al. 1975). Several plant species or novel genotypes of local species were introduced by duck clubs in California, who primarily purchased seed for waterfowl habitat from eastern and southern USA sources (Mason 1957).

Releases of exotic ring-necked pheasants and other game birds on adjacent hunting lands may explain the high density of pheasants at Rush Ranch where they are protected from hunting.

Figure 2. *In 1992, following cessation of historic cattle grazing in Rush Ranch tidal wetlands,* Cirsium hydrophilum *var.* hydrophilum *(previously considered extinct) rebounded and was observed as a robust, dominant plant species along first order tidal creeks at Rush Ranch. By 1995, the exponential spread of* Lepidium latifolium *was underway along the same tidal creek, and* C. h. *var.* hydrophilum *was reduced in stature and abundance within the community.*

Pheasants rely on plant seeds and insect food sources, and their foraging effects on Rush Ranch vegetation and native wildlife food webs are unknown. Feral pigs (*Sus scrofa*), relative of the European boar, are non-indigenous to North America and introduced for hunting; in recent years, they have invaded Rush Ranch tidal wetlands. Their impacts on tidal marsh vegetation are quite visible, but ecological effects have not been studied at Rush Ranch. Rooting and wallowing activities of feral pigs are a major source of unnatural disturbance in the marshlands. For example, large sections of *D. spicata*–dominated areas of marsh plains have been especially impacted at the Preserve (authors, personal obs.). Habitat destruction by feral pigs are a major threat to the long and short-term viability of endangered soft bird's-beak (Grewell et al. 2003) and endangered Suisun thistle (Fiedler et al. 2007) at Rush Ranch.

Exotic Plant Introductions

The introduction of exotic plant species and their subsequent spread and colonization as invasive weeds has degraded tidal wetlands of the San Francisco Estuary, and Rush Ranch has not been excluded from this impact. Interactions between exotic and native species alter the structure and function of wetland plant communities, profoundly affect the diversity and abundance of native flora, and pose significant challenges to the integrity and sustainability of current and proposed wetland restoration projects. At Rush Ranch, *Lepidium latifolium*, *Apium graveolens* and a suite of winter annual grasses (*Hainardia cylindrica* (barbgrass), *Parapholis incurva* (sicklegrass), *Polypogon monspeliensis* (rabbitsfoot grass, annual beard grass) have been particularly problematic and directly impact endangered native flora (Grewell et al. 2003, Grewell 2005, Fiedler et al. 2007, Grewell et al. 2007). Tidal wetland restoration sites are highly susceptible to weed invasion due to hydrochorous dispersal of weed diaspores, the disturbed condition of newly restored sites, and also because the implementation of restoration projects is proceeding prior to regional eradication of weeds to manageable levels. Exotic, invasive plant species of particular concern at Rush Ranch are discussed below, and additional exotic plants with potential for increased spread and impact are listed in the Supplementary Matieral.

Lepidium latifolium

L. latifolium (perennial pepperweed, white top) was first was first discovered in California in 1936 (Robbins 1941). *L. latifolium* began rapidly and aggressively expanding its range from 1986 to 1996 as water management and land use practices in the delta changed dramatically (Howald 2000, Mooney et al. 1986). In the early 1990s *L. latifolium* invaded and spread in tidal wetlands, along ephemeral stream corridors, and in disturbed upland areas at Rush Ranch (Grewell, pers. obs.). By 1995, *L. latifolium* had aggressively displaced formerly dense stands of endangered *Cirsium hydrophilum* var. *hydrophilum* (Grewell, pers. obs., photo documented Figure 2). At Rush Ranch, several plant and animal species including endangered endemic taxa co-exist with the weed as understory species (Spautz and Nur 2004, Reynolds and Boyer 2010). In 2003, *L. latifolium* was the third most frequent plant associate (85% frequency) of endangered *C. h.* var. *hydrophilum* at Rush Ranch (Fiedler et al. 2007). By 2005, *L. latifolium* had invaded 12% of a population of endangered soft bird's-beak that had been reintroduced at Rush Ranch in 2000 (Grewell 2005). This aggressive weed threatens the viability and recovery of endangered plant populations at Rush Ranch and elsewhere in San Francisco Estuary (Grewell 2005, Fiedler et al. 2007).

Apium graveolens

A. graveolens (celery), a horticultural/garden escapee native to Europe, has invaded estuarine emergent wetland plant communities at Rush Ranch, greater Suisun Marsh, and the Carquinez Straits. Jepson (1923) and Mason (1957) noted the naturalization of *A. graveolens* in marshes and along streams in the Sacramento Valley and Southern California. The species was described as common in the San Francisco Estuary more than 30 years ago (Atwater et al. 1979), but invasive spread has been recent. In its native European range (Spain), relative cover and elevational amplitude of *A. graveolens* are low relative to other salt marsh plant community members and the plant is restricted to high marsh (Sánchez et al. 1996). At Rush Ranch, *A. graveolens* is often closely associated with *Lepidium latifolium*, but it has a broader ecological amplitude than its co-invader and occupies a broader range of hydrogeomorphic settings than have been reported from its native range (Grewell, pers. obs). Within 4 years of an experimental restoration of *Chloropyron molle* subsp. *molle* to the Spring Branch restoration site at Rush Ranch, *A. graveolens* had invaded *C. molle* subsp. *molle* sub-populations and its frequency of occurrence was 18% (Grewell 2005). The frequency of *A. graveolens* with endangered *Cirsium hydrophilum* var. *hydrophilum* was as high (85%) as that of it co-invader, *L. latifolium*, at Rush Ranch (Fiedler et al. 2003). The invasive populations in the Potrero Hills region may be a source for new invasions westward in the Estuary. In 2009, *A. graveolens* first colonized the Southampton Marsh Preserve (Benicia State Recreation Area) in the Carquinez Straits, suggesting the need for greater recognition of this problematic invasive plant, and management and reduction of upstream source populations (Grewell 2010).

Exotic annual grasses

A suite of exotic, winter annual grasses are invasive on the high marsh plain near the terrestrial ecotone, and also in seasonal wetlands at Rush Ranch. *Polypogon monspeliensis* is native to Europe, Asia, and Africa. Evidence from adobe brick remains place *P. monspeliensis* introduction to California during the mid-19th century (Frenkel 1977). Seasonally low salinity levels imposed by winter and anthropogenic runoff into estuarine wetlands control the distribution and abundance of *P. monspeliensis* (Callaway and Zedler 1998) because germination percentages of seeds decrease with increasing salinity. Thus, salt applications may be a practical control method (Kuhn and Zedler 1997). *Hainardia cylindrica* (syn. *Monerma cylindrica*, thintail, hardgrass) and *Parapholis incurva* (curved sicklegrass) are taxonomically similar, European introductions. *H. cylindrica* is locally abundant in terrestrial ecotone and turf pans, Hill Slough and Rush Ranch tidal marshes (Baye and Grewell, pers. obs.). *P. incurva* is less common at Rush Ranch and other tidal wetlands ringing the Potrero Hills, but locally co-occurs with *H. cylindrica* (Baye and Grewell, pers. obs.).

The exotic cool season grasses all have a C_3 photosynthetic pathway, and the inherent lower photosynthetic rate suggests they will be competitively inferior in interactions with C_4 grasses such as native *Distichlis spicata* (Waller and Lewis 1979). At Rush Ranch, *D. spicata* is obviously more abundant than these exotic cool season grasses. However, competitive superiority and relative abundance are not the only criteria by which exotic species should be considered in a management context. At Rush Ranch, seeds of these exotic grasses germinate late November to February, and the exotic, annual grasses complete their annual growth cycle by late spring to early summer. During the pre-reproductive growth phase of the exotic annuals, the endangered hemiparsitic herb, *Chloropyron molle* subsp. *molle* (Figure 3) germinates and emerges as a seedling in exotic-grass occupied habitat and forms parasitic connections with the roots of the exotic grasses, the exotic hosts die back when *C. m.* subsp. *molle* is in seedling stage (Grewell 2004). In a field study at Rush Ranch and Hill Slough, nearest neighboring plant species (potential hosts) were shown to greatly affect *C. m.* subsp. *molle* seedling survivorship and the presence of winter exotic grasses (particularly *H. cylindrica*) in the community is highly correlated with premature mortality of the endangered plant seedlings while survivorship was highest when native *D. spicata* and *Sarcocornia pacifica* were nearest neighbors (Grewell et al. 2003, Grewell 2004). These results suggest that control of exotic winter grasses in estuarine vegetation at Rush Ranch and elsewhere, prior to restoration attempts, are essential for sustainable populations of *C. m.* subsp. *molle* (Grewell 2004, 2005). The negative impacts of non-native host plants suggest recovery of endangered hemiparasites must consider the costs of non-competitive mechanisms when prioritizing non-native species removal in estuarine wetlands (Fellows and Zedler 2005, Grewell 2005).

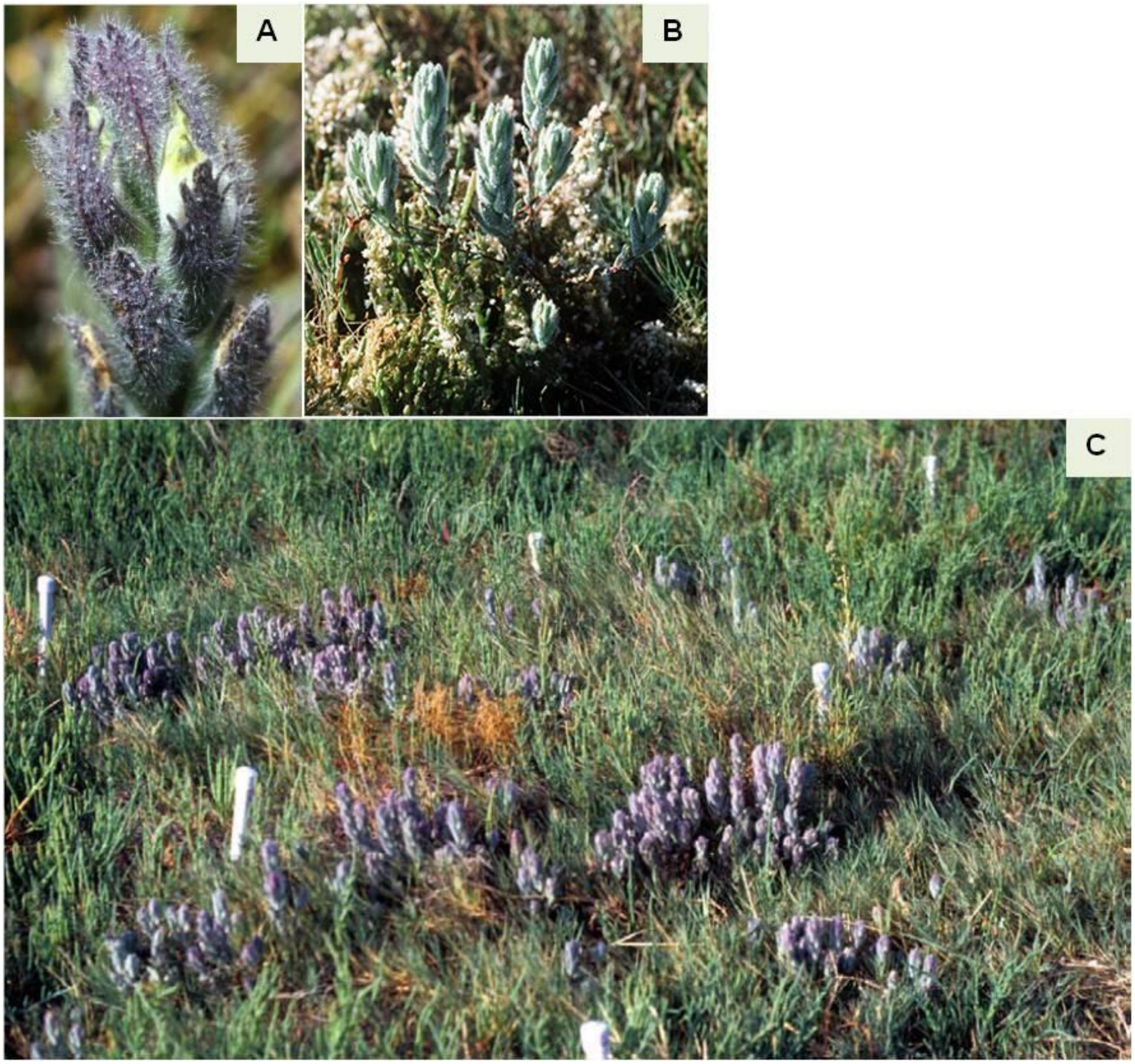

Figure 3. *The endangered hemiparasite* Chloropyron molle *ssp.* molle *(soft bird's beak, **A**) often occurs with the holoparasitic vine* Cuscuta pacifica *var.* pacifica *(salt marsh dodder), and is dependent on native halophytes such as* Sarcocornia pacifica *and* Distichlis spicata*, to complete its annual life cycle at Rush Ranch (**B-C**).*

Phragmites australis

Cosmopolitan *Phragmites australis* (common reed) is a large, perennial grass with creeping rhizomes and stolons that is found worldwide. Two recognized subspecies of *P. australis* (one native, the other exotic) are among the most misunderstood plant taxa in Suisun Marsh and at Rush Ranch. Fossil records dating to the Cretaceous and additional archeological records confirm a long presence of *P. australis* in North America as a minor native component of tidal wetland plant communities (Orson et al. 1987). In the past 150 years, a dramatic expansion of *P. australis* in North America has occurred to the point it is considered a nuisance in many estuaries. This aggressive spread by vegetative growth may have both environmental and genetic causes, and multiple karyotypes are involved (Chambers et al. 1999). Molecular studies have confirmed native, introduced and Gulf Coast North American *Phragmites* lineages are genetically distinct, and invasive introduced populations do not represent a hybrid population type (Saltonstall 2003a). Native individuals persist in many midwestern and western states including California, but introduced populations are also present and recently introduced genotypes largely dominant the Atlantic coast region (Saltonstall 2003b).

The typically non-invasive, genotype *Phragmites australis* (Cav.) Steud. subsp. *berlandieri* (E. Fourn.) Saltonstall & Hauber, native to California, is present at Rush Ranch, nearby Peytonia Slough Ecological Reserve, and other tidal wetlands in the Delta and Suisun Marsh (Grewell and Shapiro, pers. obs.). This native taxa serves as host plant for *Ochlodes yuma* (Yuma skipper), which is only associated with the native genotype while the exotic, invasive genotype *P. australis* subsp. *americanus* has been adopted by *Poanes biator* (broad-winged skipper, a large eastern Lepidopteran species (Shapiro and Manolis 2007). In disturbed environments, both native and exotic genotypes can spread and displace competing macrophytes, though aggressive spread is more typical of the more recent, exotic invader. Differences between the two subspecies can be subtle and may partially depend on ecological conditions, but there are distinguishing morphological characters (Swearingen and Saltonstall 2010). The assumption that all *P. australis* present is the invasive taxa can be problematic, as some stands at Rush Ranch have persisted for decades. The presence of the native genotype at Rush Ranch that supports native insect species should be considered in management plans.

Importance of vegetation presence and type

Coastal wetlands and their ecotones provide key ecological services and ecosystem functions (Emmett et al. 2000, Levin et al. 2001, Weslawski et al. 2004). Many of these services and functions are dependent on the composition and structure of plant communities (Bruno and Bertness 2001). In estuarine communities, vascular plants act as the major modifiers of the physical environment, provide primary energy and nutrient sources, and form most of the structural environment for other organisms. Critical marsh functions (such as nursery habitat provision, bank stabilization, runoff filtration, and trophic support) are directly and indirectly tied to the presence of vascular plants (Gleason et al. 1979, Warren and Neiring 1993). At Rush Ranch and elsewhere within San Francisco Bay estuary, vegetation type and structure, as well as marsh size and surrounding land use, are important in determining the distribution of multiple bird species (Spautz et al. 2006) and macroinvertebrate trophic relationships at nearby sites at Grizzly Island (de Szalay and Resh 1996). Thus, understanding and documenting the location and distribution of plants through time at properties like Rush Ranch is essential to effective management and preservation of these ecologically important habitats.

ContemporaryVegetation Patterns Relative to Hydrogeomorphic Settings

A wide range of environmental factors (i.e. hydroperiod, nutrient regimes, disturbance levels) and their interactions control the structure and composition of estuarine vegetation (Levine et al. 1998, Keddy 2000). Tidal submergence is a complex measure that serves as the primary control of the elevational ranges of tidal marsh plant species (Hinde 1954; Atwater et al. 1979; Macdonald, 1988; Byrne et al. 2001). Plant functional traits that convey stress-avoidance or stress-tolerance ability combine with competitive and facilitative interactions among plant species to influence estuarine plant species presence and abundance across environmental gradients (Keddy 1990, Bertness 1992, Pennings and Bertness 2001, Grewell et al. 2007, Grewell 2008a). At a local scale, environmental heterogeneity associated with hydrogeomorphic complexity combines with past land use and location to support distinct plant communities and assemblages. Vegetation patterns in oligohaline to brackish marshes like Rush Ranch are often more patchy (Crain 2008) than zonal, compared with tidal salt marshes. Thus we will discuss vegetation patterns in a geomorphic landscape unit context. Geomorphic units are planning areas delineated on the basis of topographic and geographic features. These landforms can serve as the basis of conceptual physical models for soil/vegetation distribution and dynamics, and are the major controls of habitat quality and spatial pattern of habitats over time. In addition, hydrogeomorphic units provide an appropriate context for description of the azonal nature of modern vegetation at Rush Ranch.

Rush Ranch includes 4 major estuarine geomorphic units: subtidal channel beds, fringing tidal marsh, tidal marsh plain and tidal marsh-terrestrial ecotone (Figures 4-7); and three major terrestrial geomorphic units (hillslopes, inactive and active alluvial fans). Our focus is on the diverse array of estuarine wetland vegetation and ecotonal vegetation at the margins of tidelands at Rush Ranch. Here we describe the plant communities of, subtidal channel beds, fringing tidal marsh, tidal marsh plain, tidal marsh ecotones, and tidal-terrestrial ecotones (including alluvial fans).

5.3 Tidal Channels (SAV)

Submerged aquatic vegetation (SAV) are rooted flowering plants that grow primarily below the water surface. The primary *Stuckenia pectinata* (syn. *Potamogeton pectinata*, sago pondweed) and *Ruppia maritima* (widgeongrass) beds in San Francisco Estuary are around islands and other shallow areas in Honker Bay, Suisun Cutoff, and Suisun Bay (Schaeffer et al. 2007, California State Coastal Conservancy 2010). *S. pectinata* and *R. maritima* have long been recognized as important waterfowl food plants in managed wetlands throughout Suisun Marsh (George et al. 1965, Miller et al. 1975). Important food plants from out-of-state sources were planted extensively by duck club managers on Honker and Suisun Bay islands and throughout Suisun Marsh (Miller et al. 1975), and novel genotypes of *S. pectinata* and other waterfowl food plants may have been introduced and dispersed into Bay shallows (Mason 1957). Most SAV in the vicinity of Rush Ranch occurs in diked managed wetlands with perennial ponds and ditches, which in some years support substantial stands of *S. pectinata*, *R. maritima*, and *Zannichellia palustris* (horned-pondweed) (Mason 1972). *Stuckenia pectinata* typically dies back when water salinity exceeds 15 ppt (Kantrud 1990) but reappears with the return of oligohaline conditions. *Ruppia maritima* is an opportunistic species that thrives in warm and less saline water (Kantrud 1991, Koch and Dawes 1991), yet also tolerates salinity fluctuations and marine conditions. In 2010, extensive beds of *S. pectinata* appeared in open subtidal beds of Suisun Slough near Goat

Island, possibly in relation to declining suspended sediment supply and turbidity (Ganju and Schoelhammer 2009) and aqueous salinity (Moyle et al. 2010).

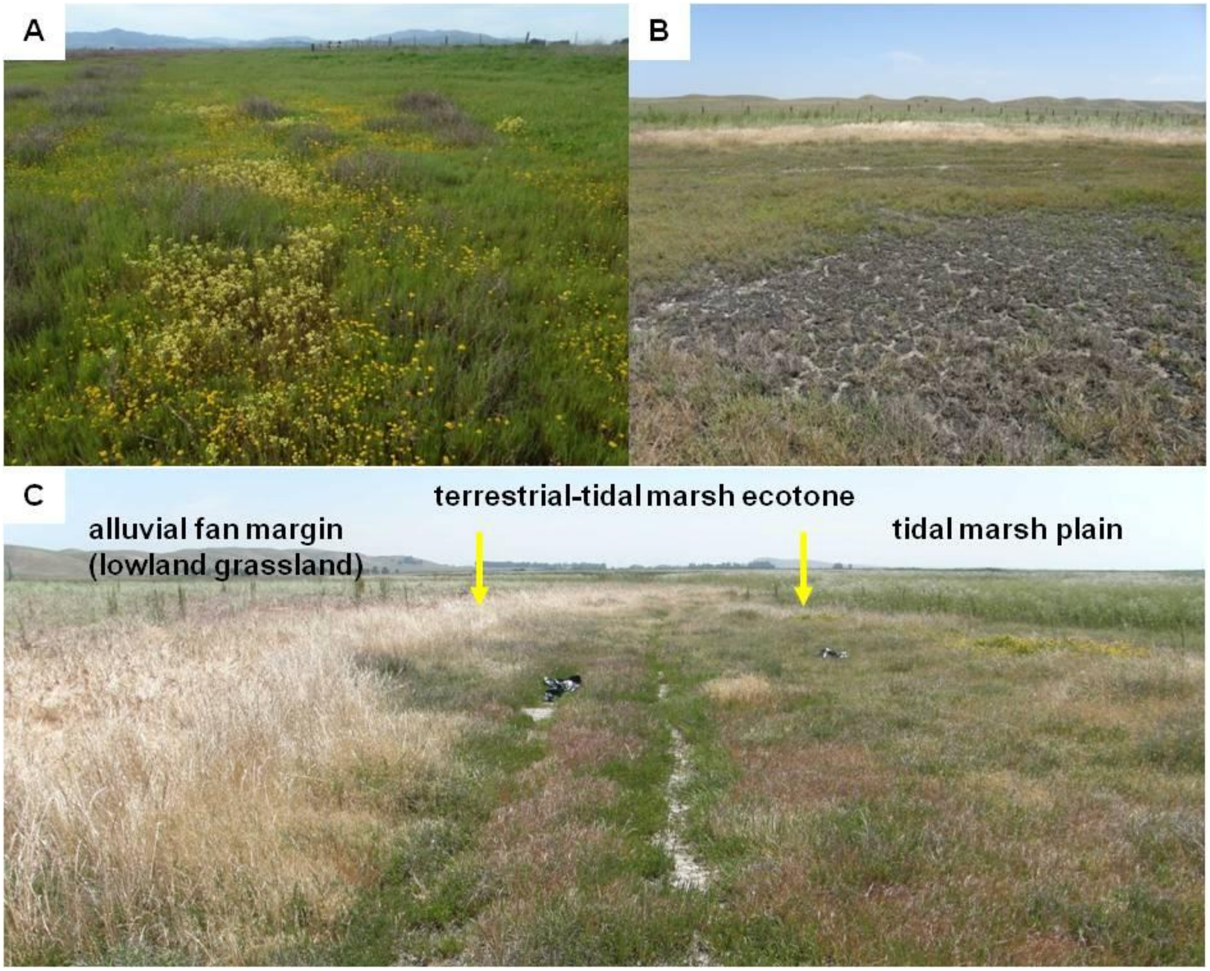

Figure 4. *High marsh-terrestrial ecotone along margins of alluvial fan dominated by lowland grassland south Rush Ranch (Cutoff Slough marshes), forming high marsh pans that are similar to shallow saline seasonal wetlands subject to extreme high tide flooding. Annual forbs* Lasthenia glabrata *(smooth goldfields), owl's-clover (*Triphysaria versicolor*) form conspicuous but ephemeral vernal wildflower displays (A). The ecotone desiccates in summer to (B) algal and cyanobacterial crusts and (C) dwarfed vegetation of turf pans (annual graminoids* Hordeum gussoneanum, Lolium perenne, Juncus bufonius, *with sparse low patches of* Triglochin concinna *and* Sarcocornia pacifica*).*

Figure 5. *Low tidal brackish marsh along mud banks of Rush Ranch tidal sloughs (First and Second Mallard Branches) are typically dominated by (**A-D**) tules (*Schoenoplectus californicus, S. acutus*) with cattails (*Typha latifolia, T. dominguensis*) that provide cover and foraging habitat for California clapper rails (**D**), but fringing marsh also supports colonies of Lyngbye's sedge (*Carex lyngbyei*) along Hill Slough (**E**) and upper Suisun Slough.*

Figure 6*. Fringing high marsh and terrestrial ecotone at Rush Landing, Suisun Slough (****A–C****). Shown here are diverse patches of clonal forbs and graminoids dominating the high marsh plain, including* Juncus arcticus *ssp.* balticus *(Baltic rush), silverweed (*Potentilla anserina *subsp.* pacifica*), gumplant (*Grindelia stricta*), and western goldenrod (*Euthamia occidentalis*), while terrestrial ecotone shifts towards dominance by clonal perennials* Distichlis spicata *(saltgrass),* Leymus triticoides *(creeping wildrye) and* Ambrosia psilostachya *(western ragweed), and fringing low marsh at channel's edge is dominated by tall bulrushes (*Schoenoplectus californicus *and* S. acutus*).*

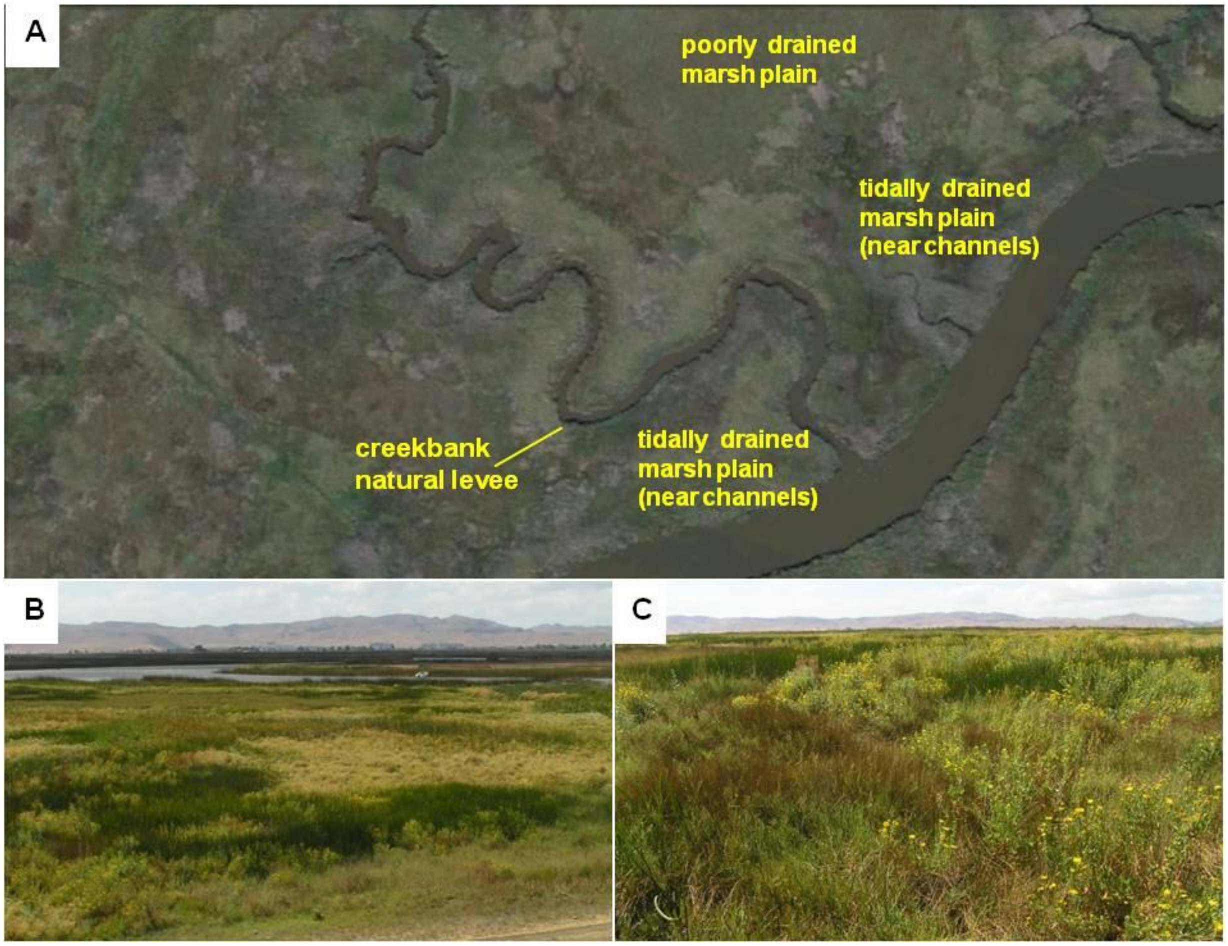

***Figure** 7. The high marsh plain (marsh platform) of Rush Ranch, show above in aerial, oblique, and ground view (**A-C**), is a complex and highly dynamic mosaic of vegetation patches. Tidally drained marsh plains near channels (**B**) support diverse assemblages of both tall and low-growing forbs, rushes and bulrushes – and also massive infestations of* Lepidium latifolium *(perennial pepperweed). Poorly drained marsh in the interior portions of the plain (**C**), remote from channels, support three-square bulrush, saltgrass, Baltic rush, gumplant, and pickleweed assemblages.*

5.4 Fringing tidal marsh

The fringing tidal marsh is positioned immediately above typically unvegetated subtidal channel beds (Figure 5, 6). This tidal marsh landform occurs as narrow bands on low edges of channels or at the edges of the marsh between "uplands" (hillslopes, scarps, alluvial fans) and tidal sloughs and appears to provide wave-damping, peat-forming, and sediment deposition functions comparable with high fringing marshes investigated in Maine (Morgan et al. 2009). This landform supports plant species diversity and richness similar to (and in some locations, exceeding) vegetation of many high marsh plain areas at Rush Ranch. In contrast to the wave-attenuating marsh plains, fringing marshes of Rush Ranch are generally exposed to wind-waves from open slough fetch from the west and northwest. Fringing marsh occurs as narrow bands along large, tidal sloughs Suisun Slough and Hill Slough, particularly where the sloughs abut levee banks. Fringing marsh is also present where tidal sloughs border the neighboring hills with abrupt changes in slope that preclude development of tidal marsh plains (e.g. the reach of Suisun Slough immediately north of Rush Landing).

In fringing or narrow tracts of tidal marsh, sinuous, complex tidal drainage networks are not able to develop due to the insufficient area available and the proximity of relatively steeper drainage gradients to the adjacent sloughs. Fringing marshes at Rush Ranch have developed extensively along the upland transition. Fringing marsh is also found in small, discontinuous segments that are directly exposed to wave action, forming dynamic peat slumps and scarps along slough edges. Fringing marsh may also be buffered by wave-damping, tule-dominated low marsh. These tule-dominated areas may also serve as a barrier that can limit the growth and spread of adjacent marsh vegetation species towards tidal sloughs. Fringing marshes at Rush Ranch appear to have no history of ditching or diking and are generally composed of mostly organic (peat or muck) fine sediment, except at edges of active or recently active alluvial fans where better-drained mineral sediments are found. In some locations, substantial sediment has deposited along the exterior of artificial levees allowing vegetation to colonize and expand outward for large distances into the slough. At Rush Ranch, fringing tidal marsh banks adjacent to dikes are steep scarps composed of primarily of fine-grained peaty sediments. Fringing marshes adjacent to active alluvial fans or subject to slow current support limited natural levees with overbank deposits. These natural levees include better-drained sediments that support vegetation less tolerant of long hydroperiods.

The fringing marsh at Rush Ranch is bordered by inundation-tolerant *Schoenoplectus* /*Typha* / *Carex* (bulrush/cattail/sedge) associations at lowest elevation. At middle to higher elevations, the fringe vegetation usually is composed of subshrubs, creeping perennial forbs and rushes, and grasses as well as bunchgrasses that are tolerant of brackish salinity conditions. Tall, shrubby *Grindelia stricta* var. *angustifolia* (syn. *G. hirsutula,* marsh gumplant) often borders tidal creek banks and provides dense emergent cover in mature tidal marshes (Baye 2007); it is also abundant in high fringing marsh. The vegetation typical of widespread well-drained, high banks of mature tidal creeks of Rush Ranch is also abundant in high fringing marsh, including tall, dense growth forms of *Sarcocornia pacifica*, *Frankenia salina* (alkali heath), *Potentilla anserina* var. *pacifica* (syn.*Argentina egedii,* silverweed cinquefoil), *Glaux maritima* (sea-milkwort), *Distichlis spicata* , *Deschampsia cespitosa* (L.) subsp. *holciformis* (tufted hairgrass), *Juncus arcticus* subsp. *balticus* (Baltic rush) and other associated sub-shrubs and forbs. In addition to these broadly distributed species, the high fringing marsh supports species with small habitat ranges and narrow salinity tolerances including *Sium suave* (water parsnip), the rare *Cicuta bolanderi* (Bolander's water-hemlock), *Helenium puberulum* (sneezeweed), *Eryngium heterophyllum* (coyote-thistle), *Oenanthe sarmentosa* (water parsley) as well as more widespred perennial brackish wetland forbs like *Euthamia occidentalis* (western goldenrod), *Ambrosia psilostachya* (western ragweed), and *Pluchea odorata* (marsh fleabane) . Slumps and scarps of wave-impacted fringing marsh locally support opportunistic colonizers *Lilaeopsis masonii* (Mason's lilaeopsis, western grasswort) and *Isolepis cernua* (low club-rush). Below freshwater seeps in wave-cut low bluffs, fringing marsh at Rush Landing supports distinctive stands of freshwater marsh species discussed in freshwater seepage landform section. In recent years, *Lepidium latifolium* has invaded fringing marsh at Rush Ranch but at present is infrequent in this geomorphic setting.

5.5 Tidal marsh plains

Typically, tidal marsh plains (platforms) at Rush Ranch are wide tidal landforms dissected by complex, sinuous dendritic channels. Compared to surrounding, diked areas in Suisun Marsh, Rush Ranch channels have been altered significantly less. However, regional and on-site ditching, partial diking and dam constructions have reduced sediment supply and thus altered the historic channel sinuosity. Internal landforms and vegetation zones of the tidal marsh plain (tidal creek banks and natural levees, artificial channels and dikes, tidally vs. poorly drained plains, ponds and turf pans) will be discussed individually.

Tidal creek banks and natural levees

Tidal creeks are a key feature of natural estuarine wetlands that dissect marsh plains and range from large creeks that rarely drain, to small creeks that are covered with vegetation (Leopold et al. 1993). The banks of these creeks are a distinct landform at Rush Ranch, formed by gradual overbank accretion of sediment and debris at stable bank positions. The vegetation present on these banks and levees is strongly influenced by subsurface drainage of the adjacent creeks (Figure 5). The tidal creek banks are regularly subjected to brackish tide water and support tall emergent graminoids and forbs such as *Schoenoplectus* spp., *Carex* spp., *Typha* spp. (cattails), as well as more diminutive plants such as *Lilaeopsis masonii*, *Isolepis cernua*, *Hydrocotyle verticillata* (water-pennywort) and *Triglochin striata* (three-ribbed arrow-grass). Hill Slough's low creek banks support extensive colonies of *Carex lyngbyei* (Lyngbye's sedge), an oligohaline tidal marsh species typical of the Pacific Northwest (Figure 5d). This is a disjunct population apparently unique in the San Francisco Estuary. At Rush Ranch, it is established at the lower end of the low tule marsh zone.

The more elevated upper creek banks are often a habitat for tall forbs and subshrubs such as *Grindelia stricta* providing dense flood refuge and cover for marsh wildlife. Upper creek banks also support rare or endangered plants, such as *Cirsium hydrophilum* var. *hydrophilum* , *Cicuta bolanderi* and *Lathyrus jepsonii* subsp. *jepsonii* (Jepson's Delta tule pea). Invasive non-native clonal forbs such as *Lepidium latifolium* also occupy this habitat. At Rush Ranch, the spread of *L. latifolium* is frequently along these tidal channels (Figure 8) and the upland margin of other tidal marshes near Potrero Hills (Grossinger et al. 1998, Boyer and Burdick 2010).

In fresh to brackish tidal areas, small *Lilaeopsis masonii* and *Triglochin striata* are found in the marsh ground layer below the canopy of tall emergent macrophytes along tidal sloughs and slumping banks of in-channel islands. The macrophytes may include *Scheonoplectus californicus, S. acutus, Typha domingensis, T. angustifolia, T. latifolia,* and *Phragmites australis*, either in mixed or in monospecific stands. Extensive marsh plains within the brackish marsh are dominated by *Distichlis spicata*. Where tidal creeks introduce complexity, we also find *Sarcocornia pacifica, Limonium californicum* (California sealavender) *Atriplex prostrata* (common spearscale), *Glaux maritima Jaumea carnosa* (fleshy jaumea), *Triglochin maritima* (seaside arrowgrass), *Isolepsis cernua, I. carinata* (keeled sedge), *Helenium bigelovii*, *Pluchea odorata, Deschampsia cespitosa,* and *Oenanthe sarmentosa*. Other rarer plants, such as *Symphyotrichum lentum* (Suisun Marsh aster), *Lathyrus jepsonii* subsp. *jepsonii, Cicuta bolanderi,* and *Eleocharis parvula* (dwarf spikerush) also occur in this zone. When the depth and duration of flooding increases during wet years, midzone diversity is reduced in Suisun Marsh as mosaics of more flood tolerant *Juncus arcticus* subsp. *balticus* and *Schoenoplectus americanus* expand (Grewell, unpublished data).

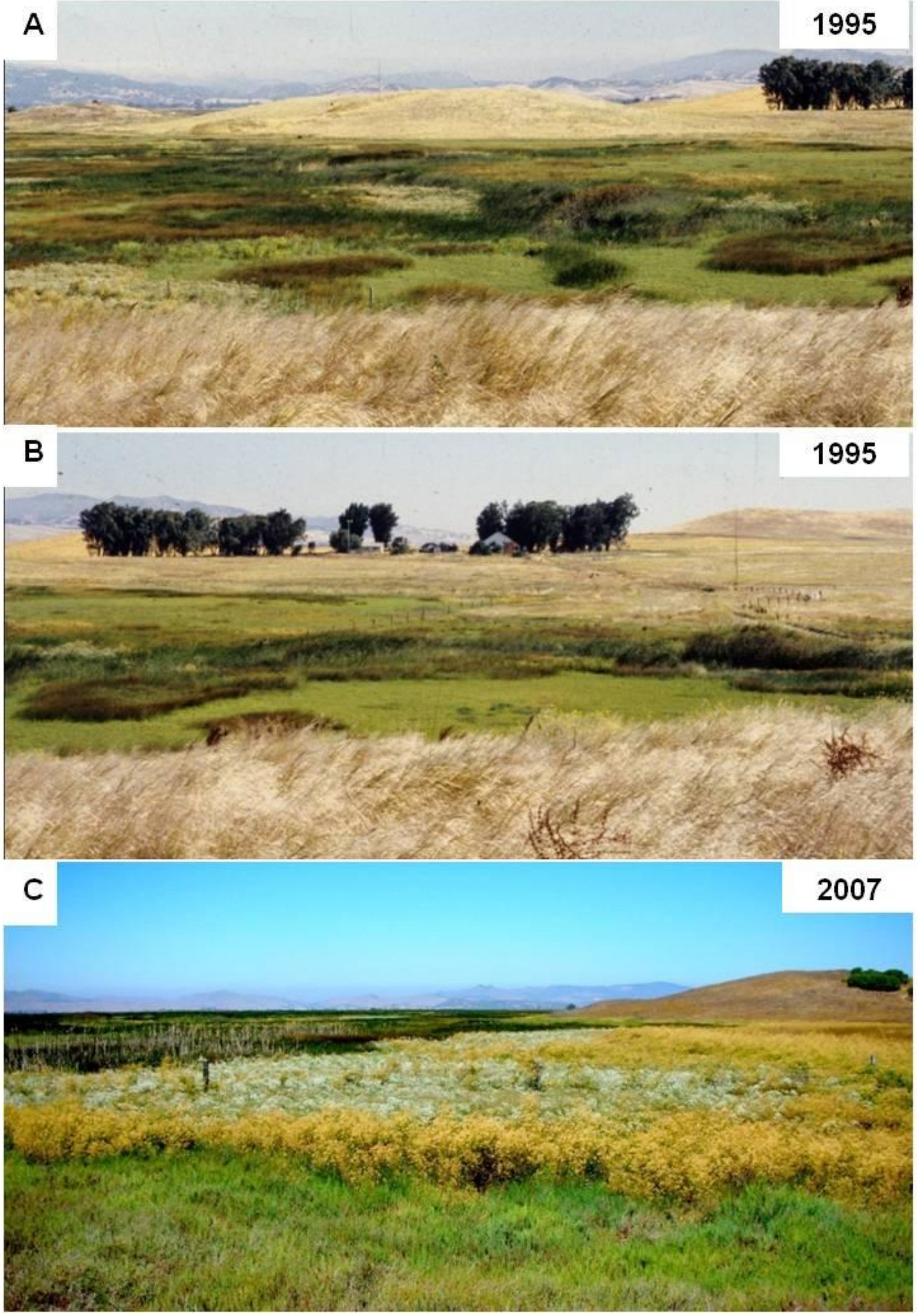

Figure 8. *Marsh view Upper First Mallard Branch during early phase of exponential spread of* Lepidium latifolium *(1995,* ***A-B****) and dense infestation 15 years following initial colonization (2007,* ***C****).*

Artificial channels and levees

The creation of channels and dikes at Rush Ranch most likely began in the late 19th century for agricultural purposes. Ditching of tidal marsh plains with poor drainage (mosquito ditches) or tidal marsh pans and ponds such as in the "Mallard Slough" vicinity created ponded habitats attractive to dabbling ducks (Wetlands and Water Resources, Inc. 2011). At Rush Ranch, non-engineered ditching extended and connected the distal ends of small tidal creeks. In addition, slough dams and partial dikes were constructed along the marsh perimeters on branches of Second Mallard Slough, Suisun Slough, and Hill Slough. The resultant steeply elevated berms line rectilinear channels, creating crests above the marsh plain that are only flooded at the most extreme high tides. Throughout most of Suisun Marsh, dikes (artificial levees) adjacent to tidal marshes have replaced much of the natural flood refuge habitats formerly provided by natural marsh levees or terrestrial vegetation. In this artificial and constantly changing ecotone, ruderal species, such as *Lepidium latifolium*, *Annagalis arvensis* (pimpernel), *Brassica* spp. (wild mustards), *Raphanus* spp. (wild radish), *Foeniculum vulgare* (fennel), *Helminthotheca echioides* (bristly ox tongue), *Conium maculatum* (poison hemlock), and *Rubus armeniacus* (Himalayan blackberry) thrive. These ruderal species are characterized by high reproductive abilities, fast growth rates, and short life spans and are thus capable of thriving on a frequently changing depositional area (Grime 1977).

Tidally drained marsh plain

This zone of the tidal marsh is influenced by surface and subsurface drainage of adjacent creeks and ditches which limits soil waterlogging, salt accumulation due to evapotranspiration, and ponding in contrast to poorly drained marsh plains (discussed below). The tidally-drained marsh plain at Rush Ranch is extensive, as compared to other relict tidal marshes with small to no remnant tidal plain habitats (Figure 7 a, b). This brackish landform at Rush Ranch is dominated by mixed creeping subshrub and graminoid species, such as *Distichlis spicata, Sarcocornia pacifica,* and *Lepidium latifolium*. Plants, such as *Glaux maritima* and *Senecio hydrophilus* previously common in this zone throughout the estuary, persist at Rush Ranch yet rarely occur on other similar properties. Within the well-drained marsh plain, there are middle and high elevation areas (high and mid marsh) occurring in a patchy mosaic distribution indicative of altered hydrology.

Traditionally, high marsh is defined as the area from approximately mean higher high water (MHHW) to extreme high water (occurring on spring tidal cycles) (Peinado et al. 1994, Josselyn 1983). Much of the marsh native plant and animal biodiversity, including regionally rare and endangered species, is found, in particular, in the high marsh. The common holoparasitic vine, *Cuscuta pacifica* var. *pacifica* (salt marsh dodder), and the endangered root hemiparasite, *Chloropyron molle* subsp. *molle*, suppress perennial dominants in the community and enhance plant species richness in the high marsh (Grewell 2008a, b). The marsh at Rush Ranch is primarily high marsh plain dominated by *Distichlis spicata*, *Sarcocornia pacifica*, *Frankenia salina* and, with locally abundant *C. p.* var. *pacifica* and *Grindelia stricta* var. *angustifolia* or *G.* ×*paludosa*. At Rush Ranch, *Arthrocnemum subterminale* (Parish's glasswort) is found in upper Spring Branch Creek, the emphemeral drainage in Suisun Hill Hollow below Suisun Hill spring, stock pond and Grizzly Island Road, and as small rare patches near terminus of first order tidal creeks associated with Second Mallard Branch Slough. Other co-occurring species include introduced *Cotula coronopifolia* (brass buttons) in areas where water occasionally pools and *Atriplex prostrata*. Endangered *C. m.* subsp. *molle* (Figs. 3, 5) also occurs along high marsh ecotones, drainage divides within marsh plains, and near high order tidal creeks. Similar to levee and berm habitats, the high marsh is also susceptible to invasion by many non-natives including *L. latifolium*, *Apium graveolens*, *Lotus corniculatus* (bird's foot trefoil), *Bromus diandrus* (ripgut brome), *Hainardia cylindrica* (barbgrass), *Parapholis incurva*, and *Polypogon monspeliensis*. *Rumex crispus* and *R. pulcher* (curly and fiddle docks) have been reported at the edges of brackish high marshes at Rush Ranch but are not believed to be invasive (Baye et al. 2000).

In slight depressional areas of the marsh plain that experience more extended hydroperiods, a number of marsh plants co-occur in a patchy mosaic distribution that reflects subtle changes in sediment characteristics and hydrology. Plant species here include *Juamea carnosa*, *Frankenia salina*, *Cuscuta pacifica* var. *pacifica*, *Triglochin maritima*, *Distichlis spicata*, *Juncus arcticus* subsp. *balticus*, and *Sarcocornia pacifica*. *Glycyrrhiza lepidota* (wild licorice), rare in tidal wetlands, is associated with *J. a.* subsp. *balticus* in the marsh plain adjacent to Hill Slough. In this zone, *S. pacifica* is often its tallest, most robust form among all habitats within the marsh (SEW 1996). Although Watson and Bryne (2009) found that *D. spicata* had been nearly replaced by *Schoenoplectus americanus* and *Bolboschoenus maritimus* in the mesohaline marshes including Rush Ranch, their sampling was limited to a single season. Historically and in modern times, *D. spicata* is the main dominant in this zone, also reaching its maximum height form in this habitat (Mason 1972). Well-drained peat sediments bordering first order tidal creeks and mosquito ditches dissect the plain support the endemic, federally endangered Suisun thistle (Figure 9, *Cirsium hydrophilum* var. *hydrophilum*) (Fiedler & Keever 2003, Fiedler et al. 2007), as well as *Senecio hydrophilus* (alkali marsh ragwort), *Pluchea odorata*, and *Grindelia*. spp.. The five most dominant plant species (measured as canopy cover) associated with endangered *C. h.* var. *hydrophilum* bordering tidal creeks have been native *Potentilla anserina* var. *pacifica*, *Schoenoplectus americanus*, *Juncus arcticus* subsp. *balticus*, and *Grindelia stricta*; and exotic *Lepidium latifolium* (Fiedler et al. 2003). In addition to these dominant species, results of a marshwide census at Rush Ranch indicate exotic *Apium graveolens*, *Atriplex prostrata*, and *Rumex crispus* also frequently occur with the endangered thistle though they are not dominant in the association (Fiedler et al. 2003). It is interesting to note that the dominant plant species associated with endangered *C. hydrophilum* var. *hydrophilum* are also recognized to be key indicator species for California black rail breeding habitat (particularly *S. americanus*) and California clapper rail breeding habitat (particularly *Grindelia stricta*) in Suisun and North Bay marshes (Evens and Nur 2002, Evens 2010).

Poorly drained marsh plain

Contrasting with tidally drained marsh plain, the poorly drained marsh plain habitat is remote from tidal channel drainage and is inefficiently drained primarily by slow overland sheeting flow or very slow infiltration and evapotranspiration. Elevated groundwater and soil salt accumulation due to evapotranspiration are important structuring processes in this marsh plain zone. Similar to the well-drained marsh habitats, this habitat is dominated by mixed creeping subshrub and graminoid species, such as *Distichlis spicata*, *Sarcocornia pacifica*, and recently, *Lepidium latifolium*. At Rush Ranch, patchy sections of non-native *Phragmites australis* occur in the poorly drained portions of the marsh plain habitats. Of all the zones on the well-drained marsh plain, the *D. spicata*-dominated zone is least invaded by *L. latifolium*, potentially as due to this poor drainage and resultant long hydroperiod (Whitcraft, unpublished data).

Figure 9*. Rush Ranch supports the last core population of the endangered* Cirsium hydrophilum *var.* hydrophilum, *Suisun thistle, formerly a widespread and abundant endemic species of Suisun Marsh (****A****, basal rosette,* ***B****, bolting shoot, and* ***C****, flower). Prior to* Lepidium latifolium *invasive spread at Rush Ranch, the rare thistle was part of a diverse emergent macrophyte community (****D****) occurring frequently with* Schoenoplectus americanus, Potentilla anserina *subsp.* pacifica, *and* Senecio hydrophilus *along first order tidal creeks (1992 photo, 1st Order Tidal Creek, First Mallard Branch drainage Rush Ranch).*

Marsh plain ponds

The ecogeomorphic origins of tidal marsh plain ponds (variously termed pools, ponds, pans or pannes in different regions and times; Harshberger 1916, Pethick 1974, and Adamowics and Roman 2005) in Suisun Marsh are not known, but may have structure and secondary origins similar to those in mature high peat tidal marshes of the northeast U.S. (Wilson et al. 2009, 2010). These ponded depressions in the tidal marsh plain are isolated from drainage networks, allowing them to maintain permanent standing water, except where they have been degraded or destroyed by marsh ditching (MacDonald et al. 2010). As a rare vegetation habitat at Rush Ranch, the ponds support *Stuckenia pectinata* and epiphytic green algae. The damped tidal ponds of Goat Island Marsh (diked marsh) also support stands of *S. pectinata* and the floating-leaved *Potamogeton nodosus* (pondweed).

High marsh pans (turf pans)

These high marsh pans occur on the upper edges of the high marsh to the lower edges of the alluvial fan. They are often poorly drained during high winter tides and dry in the summer neap tides. The vegetation on these pans is dominated by turf-like low or prostrate perennial and annual graminoids, forbs, and subshrub vegetation. They are similar in structure to playas (shallow-flooded, seasonally desiccated and hypersaline wetlands in arid or semi-arid flats or basins) or saline vernal pools and dominated by annual forbs, graminoids, perennial grasses, and prostrate subshrubs. These species include *Polypogon monspeliensis*, *Hainardia cyclindrica*, *Lasthenia glabrata* subsp. *glabrata* (goldfields), and *Juncus bufonius* (toad rush). Plants such as *Triphysaria versicolor* subsp. *versicolor* (butter and eggs) appear rarely in turf pans of south Rush Ranch tidal marsh in association with *L. glabrata, I. cernua*, and *J. bufonius*, as well as prostrate *S. pacifica*. This is an ecologically distinctive as the only reported occurrence of *T. versicolor* in a brackish tidal marsh; the species is typically found in the region within seasonal wetlands and alkali grasslands. *L. latifolium* appears to be consistently excluded from the summer-desiccated high turf pans, potentially by high porewater salinity or low porewater in general.

In contrast to many estuarine marshes, the high intertidal zone of San Francisco Estuary brackish wetlands can support the greatest richness of plant species in the marsh. However, at limited locations in the Suisun Marsh where the highest marsh elevation zone is still intact tides are muted, summer temperatures can exceed 38C, soil porewater can be hypersaline (> 40 ppt, and in places > 100 ppt) (Grewell et al. 2007, Grewell 2008a), and only *Arthrocnemum subterminale*, *Sarcocornia pacifica*, and *Cressa truxillensis* (alkali weed) are found.

5.6 Freshwater seepage sites

Unique communities can occur on the upper edge of brackish marshes, where salt water rarely reaches or where salt is diluted by fresh water seepage. *Oenanthe sarmentosa* can be relatively abundant in wet years particularly in or near freshwater seepages adjacent to low shoreline bluff scarps or drainages from upland swales. Other predominantly freshwater marsh species, including *Mimulus guttatus* (monkeyflower) and small-fruited sedge, appear anomalously in the middle marsh zone of fringing marshes at Rush Landing below seeps in the high marsh zone that support *Sisyrichium bellum* (blue-eyed grass) and mixed stands of *Carex barbarae* and *Leymus triticoides* (creeping wildrye).

5.7 Seasonal wetlands

The primary seasonal wetland at Rush Ranch occurs along the Spring Branch corridor between the South Pasture Trail and Grizzly Island Road. Prior to 19th century alterations, this area was an extension of the historic Holocene tidal wetland. The freshwater input at this site is inhibited by a stockpond and the road upstream of the site; in addition, the tidal flow within this area is restricted by a berm and by a culvert (pipe) under the trail at the west end of the area. Despite these waterflow restrictions, this area retains some plant species typical of a seasonal wetland habitat. This habitat is dominated by non-native grasses: *Hordeum marinum* subsp. *gussoneanum* (Mediterranean barley), *Lolium multiflorum* (Italian ryegrass), *Polypogon monspeliensis*, *Hainardia cylindrica* and *Parapholis incurva*. However, there is muted tidal influence from First Mallard Branch Slough, and in wetter years, the soil is inundated and saline as indicated by the presence of obligate wetland plants: *Arthrocnemum subterminale*, *Sarcocornia pacifica*, *Cressa truxillensis*, *Frankenia salina*, *Juncus arcticus*, and *Bolboschoenus maritimus*. These plant species persist within this habitat, occupying remnant channels and floodplain. Ephemeral vernal flora along the terrestrial ecotone at Upper Spring Branch also includes *Lepidium oxycarpum* (forked pepperweed) *Muilla maritima* (common muilla), *Lasthenia glabrata*, *Tyiphysaria eriantha* subsp. *eriantha*, *T. versicolor* subsp. *facucibarbata*, and in some years the rare *Lasthenia conjugens* (Contra Costa goldfields).

5.8 Diked marsh

Fringing marshes throughout the Suisun Marsh were frequently converted to diked marshes for hunting. At Rush Ranch, a muted-tidal impoundment of tidal marsh (diked marsh south of Goat Island) and hunter's cabin were added by the Rush family prior to 1900, and partial diking within the marsh plain also supported hunting pursuits on site. Today, the impoundment includes a more complete, but low levee along Suisun Slough, and two water control structures (at the north and south ends) allow limited inundation from the neighboring slough. Although the dikes and water control structures at Rush Ranch have not been thoroughly maintained, water levels within the diked marsh do not fluctuate to the full extent of the surrounding un-diked marsh. There is no levee on the eastern/landward side of the diked marsh. Here tall, robust stands of *Sarcocornia pacifica* and *Distichlis spicata* transition to grassland.

While sharing some of the dominant plant species with natural marsh areas, the altered hydrological conditions in the diked, non-tidal marshes does not support many of the rare or uncommon plant and animal species found in the more natural tidal marshes. Such is the case at Rush Ranch. The diked marsh is dominated by native cattails (*Typha latifolia*, *T. domingensis*) and bulrushes (*Schoenoplectus californica*, *S. acutus* var. *occidentalis*, *S. pungens*, *and S. americanus*) (PWA unpublished, pers. obs.). In addition, *Phragmites australis* has colonized the more disturbed areas along the south edge with observed spread into the more interior regions.

The artificial levee around the diked marsh supports an abrupt break in vegetation across a short and artificially steep slope, bordering a narrow fringing marsh. However, there are narrow bands of middle and high brackish marsh vegetation on the levee including *Distichlis spicata*, *Sarcocornia pacifica*, and *Grindelia stricta* var. *augustifolia*, as well as *Euthamia occidentalis* (western goldenrod) and *Calystegia sepium* (morning-glory). The upper zones of dikes are typically weedy and support a variety of introduced and invasive species, including *Rubus armeniacus* that frequently weakens the structure of the levee itself. The dike at the Goat Island Marsh at Rush Ranch is no exception, and contains a community dominated by *R. armenaicus*, annual forbs non-native forbs including *Lepidium latifolium* in small patches, *Raphanus sativus* (cultivated radish) as well as large colonies of *Phragmites australis* extending from the adjacent slough and diked marsh. Potential plans to restore tidal inundation to this area would dramatically alter the existing vegetation patterns.

5.9 Tidal Wetland– Terrestrial Ecotones

Lowland Grassland (sedge rush meadow)

Since grazing began to be restricted at Rush Ranch in the 1990s, the lowlands (sandy to silty alluvial fan edges near sea level) have regenerated extensive stands of a dominant native clonal perennial grass, *Leymus triticoides*, along the ecotone between alluvial fan edges and tidal marsh. *L. triticoides* forms extensive, spreading clonal colonies that coalesce and extend up to the fenceline that restricts grazing (currently less than 10-20 m above the highest tide lines). This grass also extends down to intergrading stands of *Sarcocornia pacifica*, *Distichlis spicata*, *Cressa truxillensis* and *Frankenia salina*. *Leymus triticoides* is abundant to dominant in floodplain grasslands and lowland swales and was a likely dominant element of lowland mesic or seasonal wetland grasslands in California (Holstein 2001). Its recent spread in areas where grazing pressure has been reduced at Rush Ranch, and elsewhere where agricultural crop production was abandoned suggests that it was a widespread, if not dominant, element of tidal marsh ecotones with lowland grasslands. The stands of *L. triticoides* at Rush Ranch may represent the most extensive and phenotypically diverse of any remnant tidal marshes in Suisun Marsh and the greater San Francisco Estuary (Baye and Grewell, pers. obs.).

Other clonal, graminoid species of seasonal wetland sedge meadows and grasslands have regenerated extensive, locally dominant stands at the tidal marsh ecotone of Rush Ranch following local restriction of intensive cattle grazing, including *Carex praegracilis* (field sedge; locally abundant at SE Rush Ranch tidal marsh edges), and *Carex barbarae*, particularly near seeps or swales with seasonally saturated or mesic soils.

Riparian bluffs

The north-aspect bluffs (wave-cut or channel-cut scarps in low sandstone hillslopes) of Suisun Slough and Hill Slough support remnants of native woody riparian scrub that are otherwise very scarce in swales of Rush Ranch and Potrero Hills, which are heavily grazed. The steep bluffs are inaccessible to cattle and likely have provided a natural refuge from grazing where slopes approach vertical and support shallow seeps. The ground layer of the riparian bluffs includes lowland grassland/sedge meadow elements (*Leymus triticoides, Carex barbarae*), and the patchy woody shrub thickets are dominated locally by *Rosa californica* (California rose), *Sambucus mexicana* (elderberry), *Toxicodendron diversilobum* (poison-oak), and *Baccharis pilularis* (coyote-brush). The lower branches of riparian scrub in some locations provide structural support for vines of the rare *Lathyrus jepsonii* var. *jepsonii* established in the upper tidal marsh edge below the bluffs. Large patches of *Rubus armeniacus* also occur in riparian bluffs of Hill Slough.

Active Alluvial Flats

The "hollows" of Suisun Hill and Spring Branch Creek (shallow ephemeral creeks and swales draining grasslands) develop low-gradient lower reaches that form braided alluvial fan distributaries with disturbed, fine slightly saline sands and silts (derived from marine sandstones), grading into tidal marsh edges. The alluvial flats are for the most part intensively grazed and trampled, and include barrens as well as herbaceous lowland grassland assemblages similar to those of tidal marsh ecotones, including *Lolium perenne* (ryegrass), *Distichlis spicata*, *Frankenia salina*, and *Cressa truxillensis*. Near low channel scarps and relatively well-drained edges, stands of *Hemizonia fitchii* (spikeweed) and *Arthrocnemum subterminale* are locally common.

5.10 Modern Transformations

Climate change

It is particularly noteworthy that the estuary's regional climate in the historic period (post-1850) has been relatively stable compared with the majority of the tidal marsh stratigraphic record, with most of the historic change in the salinity signal due to water diversion in the Delta (Byrne et al. 2001). The primarily fresh-brackish phase of Rush Ranch tidal marshes known from the early historic period is not a permanent or prevailing condition, but a long freshwater phase that began only 750 yr BP. Most significantly, perhaps, is that the entire geomorphic and ecological history of Rush Ranch tidal marsh plains occurred under a regime of slow sea level rise and gradual accretion of marsh peat (1.3 mm/yr) during the formation of the mature marsh plain (Byrne et al. 2001). No part of the marsh's history reflects the conditions that are expected in the 21st century: accelerated sea level rise rates significantly greater than 2 mm/yr and prolonged warmer climate with reduced delta outflows, and seasonal delta outflow limited to the wet season due to reduced or absent of Sierra snowpack. Modern operation of state and federal water projects dampen seasonal and annual outflow and salinity variability, yet climate change is the most powerful driver of long-term variability at Rush Ranch and regionally (Enright and Culberson 2009).

Over the past 30 years, the large annual ranges of channel salinity in Suisun Marsh have also had considerable temporal and spatial variation. This high interannual variability in salinity is likely key to a productive ecosystem that supports native biota (Atwater et al. 1979, Fox et al. 1991, Peterson et al. 1995, Byrne et al. 2001, Malamud-Roam et al. 2007, Moyle et al. 2010). Summer salinity is projected to increase in the Suisun Marsh because increasing spring air temperature is causing snowmelt runoff into the estuary to occur earlier in the year (Knowles and Cayan 2002).

Recent projections of areas vulnerable to sea level rise suggest variable effects at Rush Ranch that correspond to the magnitude of increases in water elevation (Knowles 2010). For example, with sea level increases of 50cm to 150cm relative to mean lower low water (MLLW), it is projected based on present day elevations that wetland elevations of the diked wetland and Hill Slough regions of Rush Ranch will drop to below MLLW tidal datum while the tidal marsh associated with Suisun and Cutoff Slough remains above MLLW. Projections of wetland elevation increases in the range of 100 to 150cm above MLLW suggest Rush Ranch tidal wetlands will be among extremely rare and isolated wetlands above MLLW relative to a largely inundated Suisun Marsh. However, these projections ignore the potential for vertical accretion and lateral migration of wetlands (Knowles 2010). Certainly, understanding how Rush Ranch vegetation may respond to predicted sea level rise will depend on understanding sediment supply and accretion (Orr et al. 2003, Callaway et al. 2007). At Rush Ranch, the average marsh accretion rate over the last 750 years has been approximately 1.5 mm/yr, close to the average rate of sea level rise at San Francisco for the period A.D. 1855-1986 (Lyles et al. 1988, Byrne et al. 2001). The actual changes in salinity and inundation regimes at sites such as Rush Ranch are difficult to predict and heterogeneous effects could result in increased plant species evenness (Watson and Bryne 2009). Some studies suggest increases in salinity and submergence of wetlands associated with sea level rise in Suisun Marsh will prompt local-scale declines in plant species richness and productivity (Callaway et al. 2007). If Rush Ranch tidal marsh plain accretion rates fall behind below rates of accelerated sea rise and hydroperiods increase, large-scale marsh vegetation zonation changes and dominance shifts within both the marsh plain and terrestrial ecotone would be expected (Watson and Byrne 2009). High marsh and terrestrial ecotone assemblages would be likely to shift landward and invade low-gradient stream valleys like Spring Branch Creek and Suisun Hill Hollow. Expansion of lower tidal marsh assemblages tolerant of prolonged flooding, such as tules, bulrushes, or sedges, would be expected to displace saltgrass, rush, and perennial forb assemblages within the tidal marsh platform. High marsh assemblages dominated by tall perennial forbs along tidal creek banks, internal to the marsh plain, would also be at risk of conversion to more flood-tolerant wetland graminoid assemblages.

Failed levees and expanded subtidal basins in the vicinity of Suisun and Montezuma Sloughs can result in a reduction of tidal range due to tidal prism increase. If such tidal damping interactions with sea level rise are significant at Rush Ranch, dominance by flood-tolerant wetland graminoid vegetation may be intensified. This condition may have parallels with the earliest vegetation history of Rush Ranch, evident in sediment cores showing foundering Cyperaceae and Poaceae-dominated marsh and mudflat in its early stages of formation prior to 1750 cal yr BP, prior to formation of the high marsh platform (Byrne et al. 2001).

Future research needs

Assembling information about the vegetation history and current status at Rush Ranch highlights gaps in our knowledge. Enumeration of such research gaps has been identified by the SF Bay NERR as a management priority in their 2011-2016 Management Plan in order to provide ideas for researchers (especially graduate students) as well as to facilitate cooperation among researchers. We see one major area of focus as the need to determine the types and levels of ecological impacts resulting from different management actions of the SLT (e.g., grazing, fencing locations, and stockpond management) that have the potential to impact estuarine vegetation communities on a large geographic scale. In addition, development of standardized and regularly occurring monitoring of submerged aquatic vegetation communities and rare plant populations would improve the ability to manage for their success and continued recruitment. In parallel with monitoring rare plant populations, it would be ideal to conduct research to support predictive modeling of non-native plants within the property and among neighboring properties. Successful modeling of potential ranges of a given plant species require growth parameters for each invasive plant through controlled field or greenhouse experiments. Several ecological restoration projects are being considered for Rush Ranch while surrounding tidal wetlands are heavily invaded with exotic plant species. Given the high numbers of exotic species in the estuarine flora at Rush Ranch, research is needed to support ecologically-based, comprehensive (multiple species) weed management strategies that will promote recovery of sustainable native plant communities. Restoration projects should be paired with research on short- and long-term responses of target weeds, native plant indicator species, and native plant communities to restoration and management actions. Research is needed to evaluate the range of variability in estuarine conditions (i.e., salinity, tidal flows) that will be needed to support more heterogeneous, native vegetation associated with specific hydrogeomorphic landform units (see Moyle et al. 2010). Focusing on these data gaps can inform adaptive management planning and actions for conservation and recovery of native plant communities at Rush Ranch.

Climate is changing across a range of scales, from local to global, yet ecological consequences of these predicted changes are difficult to understand and predict. Accurate predictions of the future impacts of climate change on plant diversity and distribution are critical to the development of conservation strategies and management plants. Incorporation of climate change factors, like sea level rise and subsidence, is essential to accurate predictions. Thus, one need is for manipulative experiments that address how life-history traits of species or processes such as migration might drive the ability of plant species to respond to climate perturbations. In addition, climate change is also predicted to interact with other drivers of biodiversity change such as habitat destruction and fragmentation, or the introduction of non-natives.

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5.13 SUPPLEMENTARY MATERIAL

PARTIAL FLORA OF ESTUARINE VEGETATION AT RUSH RANCH, SUISUN MARSH, SOLANO COUNTY, CALIFORNIA

VASCULAR PLANT SPECIES 2011

Peter R. Baye and Brenda J. Grewell

The following local flora of the tidal wetlands and their ecotones at Rush Ranch (Solano Land Trust) in Suisun Marsh, Solano County, California is compiled and adapted from multiple sources, primarily the unpublished plant lists, long term transect monitoring data, and field notes of Brenda Grewell (1990 – 2011), unpublished field notes of Peter Baye (1992-present), as well as published technical reports (Mason 1972, Ruygt 1994, Grewell et al. 2003, Fiedler et al. 2004, Grewell 2005), and journal articles (Fielder et al. 2007 and Grewell 2008). The geographic scope of the surveys was limited to estuarine wetlands and their terrestrial ecotones influenced by either periodic or episodic flooding by tidal waters, including extreme storm flooding events with wave runup above still-water elevations, indicated by remnant tidal debris.

Nomenclature and taxonomy, unless otherwise noted, follow Baldwin et al. (eds.) 2012, *In Press*, Jepson Manual, 2nd Edition (revisions published online 2011 (http://ucjeps.berkeley.edu/interchange.html). In some cases (noted), we follow Flora of North America (FNA, Flora of North America Editorial Committee 1993+) (http://www.efloras.org/flora_page.aspx?flora_id=1) for national and international alignment, and also refer to the USDA Plants Database (http://plants.usda.gov/). Common names in popular use in the Bay Area are included; provisional artificial common names are provided in brackets when no popular or folk names in use are known. Synonyms, particularly widely used and familiar synonyms in standard past California floras (Mason 1957, Munz and Keck 1959, Hickman et al. 1993) are also provided where recent taxonomic changes have occurred. Scientific names of plant taxa considered native to the region are distinguished by bold text.

MONOCOTYLEDONS

ASPARAGACEAE
Asparagus family

Asparagus officinalis L. Occasional in brackish high marsh, mostly along terrestrial edges or well-drained channel banks; conspicuous only after shoots expand to feathery tall masses. Often observed along Grizzly Island Road, and formerly cultivated in Suisun Marsh. Native to Europe (brackish marsh); escaped from cultivation. Not reported to be invasive in San Francisco Estuary tidal marshes, although it is locally common in some San Pablo Bay tidal marshes. Edible. Flowering late spring-early summer.

CYPERACEAE
Sedge Family

Bolboschoenus maritimus (L.) Pallas subsp. *paludosus* (A. Nelson) T. Koyama, ALKALI-BULRUSH, SALT MARSH BULRUSH. Uncommon, occasional in poorly drained depressions in tidal marsh plain, or slough banks at Rush Ranch. *B. maritimus* and *B. robustus* (as *Scirpus robustus*) have been widely confused in Suiun Marsh, where H. L. Mason 1957; and P. A. Munz 1959, 1968 treated *B. maritimus* as a synonym of *B. robustus* (as *Scirpus robustus*). In greater Suisun Marsh, *B. m.* subsp. *paludosus* is primarily found in managed diked wetlands where it has been planted for waterfowl food for decades (H. A. George 1963 as *Scirpus robustus*). Also locally abundant in tidal marshes of the northwestern estuary: western Suisun Marsh, Carquinez Straits, Napa-Sonoma Marshes and Petaluma Marsh. Putative hybrids *Bolboschoenus maritimus* × *B. robustus*, *B. fluviatilis* × *B. maritimus* occur in California (G. Smith, FNA) Flowering late spring-early summer.

Carex barbarae Dewey , BASKET SEDGE, WHITE ROOT. Uncommon but locally abundant upper edges of tidal marsh below steep bluffs and scarps along Suisun Slough and Hill Slough from Rush Landing northward and east to near the eastern end of Rush Ranch. Colonies usually occur in patches within riparian scrub of steep north aspect slopes with minimal or no cattle grazing access; primarily terrestrial, associated with seasonal seeps and swales. Locally associated with *Leymus triticoides*, forming dense turf above erosional scarps at Rush Landing's south-facing shoreline. Generally absent in cattle-grazed lowland grasslands and swales. Fruiting culms are produced at moderate density in summer. Aboriginal textile plant of high value: rhizomes were harvested for use in basketry, and preferred over most other species. Flowering late spring.

Carex lyngbyei Hornem. LYNGBYE'S SEDGE. Plants intermediate between *C. lyngbyei* Hornem (a species with occurring primarily in brackish estuaries of the Pacific Northwest and northern California coast) and *C. aquatilis* Wahlenb var. *dives* (Holm) L. Standley (a species with both montane interior and coastal wetland distribution) occur in extensive colonies along Hill Slough. Large monotypic colonies occur in brackish tidal creek and slough banks, and in brackish marsh plains, diminishing in size and frequency towards Suisun Slough, where scattered colonies occur. Hill Slough populations are identified as closer to *C. lyngbyei* rather than *C. aquatilis* var. *dives* based on a prevalence of achenes with slight compression or indentation, and minimal or lacking basal leaf sheath pigmentation, but the population may be consist of intermediates. West Delta populations identified as *C. aquatilis* var. *dives* have been collected from Browns Island (CAS856333) and near Bethel Island (CAS649708). *C. lyngbyei* is vegetatively similar in appearance to terrestrial *C. barbarae*, but occurring at the lowest intertidal marsh elevations with tule species *(Schoenoplectus* spp.). Rare disjunct populations are known from the Carmel River, Monterey County, and Giacomini Marsh (Lagunitas Creek Delta), Tomales Bay, Marin County. Flowering late spring-early summer.

Carex praegracilis W. Boott, MEADOW SEDGE, CLUSTERED FIELD SEDGE. Uncommon, known only from large lowland sedge meadow stands at the southeastern shoreline of Rush Ranch and adjacent California Department of Fish and Gameproperty in areas currently excluded from cattle grazing. It occurs in either monotypic stands or associated with extensive adjacent stands of *Leymus triticoides*, and extends above the upper limit of extreme tides Fruiting culms are produced at moderate density. Flowering spring (March-April).

Eleocharis macrostachya Britton, COMMON SPIKERUSH. Occasional, poorly drained brackish marsh plains, where it is easily overlooked among more abundant and common, morphologically similar (vegetative shoots) of *Juncus arcticus* subsp. *balticus*. Terrestrial leaf form (narrow, terete) is prevalent. *E. macrostachya* at Rush Ranch is more common in upland seasonal wetland stream channel and impoundments, where it develops typical emergent marsh shoot morphology (wide, spongy, hollow shoots). Flowering spring.

Isolepis carinata Hook. & Arn. ex Torr. KEELED CLUBRUSH. Uncommon or rarely distinguished from morphologically similar and more common *I. cernua*; similar habitats. Formerly known as *Scirpus koilolepis.* Flowering spring-fall.

Isolepis cernua (Vahl) Roem. &Schult. DWARF CLUBRUSH. Common in eroded marsh and channel banks, seeps in hillslope scarps bordering sloughs, in moist turf pans, and shaded in the ground layer of taller rush or bulrush vegetation. Co-occurs with *Lilaeopsis masonii* in ground layer of wave-scoured edges of fringing tule marsh along sloughs. Formerly know as *Scirpus cernuus.* Flowering spring-fall.

Schoenoplectus americanus (Pers.) Volkhart ex Schinz & Keller CHAIRMAKER'S BULRUSH, OLNEY'S THREE-SQUARE BULRUSH, THREE-CORNERED TULE. Widespread and abundant, dominating extensive stands in poorly drained marsh plains an depressions or shallow tidal channels, and in middle marsh zone of gently sloping slough banks. Commonly associated with breeding season occurrences of Califorrnia black rails at Rush Ranch and elsewhere in North Bay marshes (B. Grewell pers. obs.) Historically harvested as a textile plant by European Californian settlers. Historically harvested in Suiusun Marsh as packing material for Gladding-McBean Pottery Co. in Sierra Foothills. Formerly known as *Scirpus americanus* or *Scirpus olneyi*. Flowering summer.

Schoenoplectus acutus (H.L. Mühl. ex Bigelow) Á. Löve & D. Löve) var. ***occidentalis*** (S. Watson) S.G. Smith HARDSTEM TULE, COMMON TULE. Widespread and abundant to dominant in low brackish marsh of tidal slough banks. Hydridizes with *S. californicus* (S. G. Smith 1995). B. Grewell reports sterile, intermediate forms (potential hybrids with *S. californicus* at Rush Ranch. Mason (1972) also reported sterile forms in Suisun Marsh. Distinguished vegetatively by terete (rounded) shoots with grayish blue-green hue. Often emergent in water to 1.5 m. Aboriginal use as textile plant for mats, thatching, watercraft. Flowering summer.

Schoenoplectus californicus (C.A. Mey.) Soják CALIFORNIA TULE, CALIFORNIA BULRUSH. Widespread and abundant to dominant in low brackish marsh of tidal slough banks. B. Grewell reports sterile, intermediate forms (potential hybrids with *S. acutus*) at Rush Ranch. Distinguished vegetatively by subangular (slightly rounded three-corner) shoots and dark dull or olive-green hue. Formerly known as *Scirpus californicus*. Flowering summer.

IRIDACEAE
Iris family

Sisyrinchium bellum S. Watson BLUE-EYED GRASS. Local, persisting moist grassland seeps that have slumped and descended into extreme (spring tide) upper intertidal ecotones at eroding shorelines of Rush Landing, associated with *Leymus triticoides* and *Carex barbarae.* Flowering spring.

JUNCACEAE
Rush Family

Juncus bufonius L. TOAD RUSH. Widespread in turf pans and depressions with shallow seasonal pools and sparse perennial vegetation cover near terrestrial grassland edges of the tidal marsh and in low spots along Rush Ranch hiking trails. Also common in seasonal pools in upland depressions.

Juncus arcticus Willd subsp. ***balticus*** (Willd.) Trautvetter . BALTIC RUSH. Widespread, co-dominant to locally dominant over extensive areas of tidal marsh plains, sometimes forming large monotypic stands in poorly drained tidal marsh. Uncommon or absent in summer-desiccated terrestrial edges of the tidal marsh. Flowering summer.

Juncus arcticus Willd subsp. ***mexicanus*** (Willd. ex Roem. & Schult) Balslev. MEXICAN RUSH. Uncommon in tidal marsh compared with the similar *J. arcticus* subsp. *balticus*, and likely to be underdetected. Locally common in the wave-cut intertidal marsh bench at Rush Landing. Also present in terrestrial seasonal wetlands of drainages connected to tidal marshes. Flowering summer.

Juncus xiphioides E. Mey. IRIS-LEAF RUSH, occurs in brackish tidal marsh edges of Carquinez Straits and San Pablo Bay, and was reported historically from Suisun Marsh. It is expected to occur at Rush Ranch, but no confirmed localities are currently reported. Similarly, *J. phaeocephalus* Engelm. var. *paniculatus* Engelm. may also be expected at Rush Ranch, but has not been reported.

Juncus gerardii Loisel, BLACK RUSH, native to Europe and naturalized in northeastern Atlantic U.S. and Pacific Northwest tidal marshes, is invasive at three known eastern San Francisco Estuary localities, Martinez, Benicia and north Richmond (east of Point Pinole). It may be expected at Rush Ranch.

JUNCAGINACEAE
Arrowgrass family

Triglochin maritima L. SEA ARROW-GRASS. Widespread, locally common in poorly drained tidal marsh plains, sometimes forming colonies of conspicuous clumps. Also along Hill Slough, where it is locally abundant near freshwater discharges of upland swales and seeps. Flowering summer.

Triglochin concinna J. B. Davy. ARROW-GRASS. Occasional in tidal plains and especially near marsh – upland ecotone. At Rush Ranch, persistent near marsh edge First Mallard Branch drainage, and also persistent southeastern Hill Slough tidal marsh near upland edge where it occurs with endangered soft bird's-beak. *Triglochin concinna* separated from *T. maritima* based on lobing of ligule and smaller size of the *T. concinna* plants, and both variations have been observed near upland ecotone in First Mallard Branch drainage, and in tidal wetlands adjacent to Hill Slough. Perennial that spreads from rhizomes. Known to salt marshes, alkaline meadows, seeps and lake margins in coastal California, Great Basin, and Mojave Desert.

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Triglochin striata Ruiz. & Pav. STRIATE SEA ARROW-GRASS. Observed in low-growing, frequently submerged vegetation mats that include *Lilaeopsis masonii, Isolepsis cernua, Eleocharis acicularis* and *Hydrocotyl veriicillata* along north, central and eastern Suisun Marsh tidal sloughs, shorelines of islands in Suisun Bay, and along island shorelines and tidal sloughs throughout the Sacramento-San Joaquin Delta. At Rush Ranch, *T. striata* is emergent along Suisun and Hill Slough channel banks at low tides, an nearly always occurs with *L. masonii*. Regionally uncommon; found primarily in coastal river mouth lagoons Mendocino County and northward along Oregon Coast, where it occurs in low marsh of tidal channel banks, forming inconspicuous low creeping grass-like colonies resembling coarse, sparse stands of *Lilaeopsis.*

THEMIDACEAE
Themidaceae Family (traditionally within Liliaceae)

Muilla maritima (Torrey) S.Watson. This is the only bulb-forming perennial in the tidal marshes of Rush Ranch, occurring as a small population in the terrestrial ecotone of high marsh at the SE corner of Rush Ranch, in association with *Lasthenia glabrata, Triphysaria eriantha*, and dwarfed *Hordeum gussoneannum* and *Lolium perenne*. A small population also occurs locally in the alkali grassland of Suisun Hill Hollow below Grizzly Island Road, and possibly elsewhere; ephemeral spring flowers make detection difficult.

POACEAE
Grass Family

Agrostis stolonifera L. CREEPING BENTGRASS. Occasional, disturbed erosional shorelines at Rush Landing northward, occasional in tidal marsh plain near creek banks; infrequent or absent in marsh edges subject to summer desiccation (turf pans, terrestrial grassland ecotone). European; widely established in wetlands and moist grasslands of North America. Invasive in some freshwater and fresh-brackish wetlands. Not reported to be invasive in San Francisco Estuary tidal marshes. Flowering spring-early summer.

Crypsis schoenoides (L.) Lam. SWAMP TIMOTHY. Locally common in dried mud of brackish pools, diked marsh and occasionally in turf pans. Present in upper Spring Branch seasonal wetland near Grizzly Island Road. Primarily occurs in diked nontidal seasonal wetlands of Suisun Marsh, where it is managed for waterfowl forage, and has been intentionally seeded to diked managed wetlands throughout Suisun Marsh. European; widely established in wetlands and moist grasslands of North America. To date, typically not invasive in tidal marshes, though invasive spread observed in high tidal marsh, Napa Marsh region. Flowering spring-early summer.

Deschampsia cespitosa (L.) subsp. ***holciformis*** (J. Presl) W.E. Lawr.\ TUFTED HAIRGRASS. Locally common in wave-scoured fringing marsh, scarps, and sandstone outcrops from Rush Landing northward; occasional in tidal marsh plains and upper bank edges. Suisun Marsh populations have been variously referred to *D. c.* subsp. *cespitosa* (B. Grewell, Rush Ranch; Benicia locality, B. Crampton *7240*, UCR 135951) or subsp. *holciformis* (B. Crampton *9064*, UCD33869, Denverton locality). Rush Ranch populations are generally not glaucous, and have compact inflorescences; they are identified here as *D.c.* subsp. *holciformis*, which is prevalent in North Coast fresh-brackish tidal marshes. Eastern Suisun Marsh is the apparent inland limit of the species within the estuary. Flowering summer.

Distichlis spicata (L.) E. Greene SALTGRASS. Widespread, abundant, co-dominant or dominant almost throughout the tidal marsh plain, terrestrial ecotone, diked marsh, in all seasonally or perennial brackish soils; also present in alkali grasslands and seasonal wetlands far above tidal influence. Historically abundant in Suisun tidal marshes. Important in many plant assemblages at Rush Ranch, particularly with *Juncus arcticus* subsp. *balticus*, *Sarcocornia pacifica* (tidal marsh plain), *Frankenia salina*, and *Cressa truxillensis* (terrestrial ecotone). Flowering summer.

Elytrigia pontica (Podp.) Holub subsp. *pontica* TALL WHEATGRASS. Infrequent, local, southern shoreline of Rush Landing. Native to Europe, Asia; introduced as summer-active forage grass in alkali or saline soils. INVASIVE in the San Francisco Estuary, where it has been planted in the past for stabilization of artificial evees (local dominant at Mare Island dredge ponds, Palo Alto flood basin). Flowering spring-early summer.

Hordeum brachyantherum Nevski MEADOW BARLEY. Uncommon, locally present in brackish terrestrial edges of tidal marsh along Hill Slough; possibly underdetected elsewhere. [Not reported at Rush Ranch in 1990s (Grewell 1996); possibly established since, or undetected.] Numerous 20th century collections in Suisun Marsh by B. Crampton, W.L.Jepson, M.A. Nobs and H.L. Mason. Flowering spring.

Hordeum depressum (Scribner & J.G. Smith) Rydb. LOW BARLEY Native annual of low or seasonally wet alkali/subsaline soils and vernal pools. Single record from Rush Ranch, confirmation needed. Few records in Solano Co. Current local distribution, abundance unknown.

Hordeum marinum Hudson subsp. *gusssoneanum* (Parl.) Thell. MEDITERRANEAN BARLEY. Widespread annual invasive non-native weed, locally abundant in terrestrial ecotone, southern Rush Ranch tidal marshes. Flowering winter-spring.

Hainardia cylindrica (Willd.) Greuter. THINTAIL, HARDGRASS. Widespread annual invasive non-native weed of dense dried mud of seasonal brackish or alkali pools and disturbed wet grassland; locally abundant in terrestrial ecotone and turf pans, southern Rush Ranch tidal marshes and tidal reach of upper Spring Branch. Parasitized by *Chloropyron molle,* and correlated with high seedling mortality of the rare hemiparasite (Grewell et al 2003). Flowering spring.

Lolium perenne L. (incl. *L. multiflorum Lam.)* PERENNIAL RYEGRASS. Widespread short-lived perennial invasive non-native weed introduced as pasture grass. Locally common in brackish tidal marsh plains, particularly near areas influenced by freshwater runoff from upland grasslands or swales. Not reported as strongly invasive in brackish tidal marsh, but widespread and abundant to dominant in moist pastures, swales, seasonal wetlands in the Bay Area. Morphological intergrades between *L. perenne* and *L. multiflorum* are common or prevalent. Flowering spring.

Parapholis incurva (L.). C.E. Hubb CURVED SICKLEGRASS. Widespread annual invasive non-native weed of dense dried mud of seasonal brackish or alkali pools and disturbed wet grassland; locally present in terrestrial ecotone and turf pans, southern Rush Ranch tidal marshes. Apparently less common than, but locally co-occurs with the similar *Hainardia cylindrica*, Flowering spring-early summer.

Phragmites australis (Cav.) Steudel. COMMON REED. Locally dominant in the diked marsh west of the Ranch headquarters area, in the marsh and on its levees; also locally dominant along Suisun Slough, and present as small, sparse colonies of low stature in Hill Slough marsh plain. Some populations are presumably native to western North America, and the species was present but rare in the Sacramento-San Joaquin in and in California in the 19th century; Jepson collected the species in Suisun in 1891 (UC70791). Historical populations formerly recognized as *Phragmites communis* var. *berlandieri* support invertebrate fauna that do not frequent invasive haplotypes (A. Shapiro, personal communication). Modern invasive populations established in the late 20th century are likely genetically distinct (invasive M haplotype) European introductions. (Saltonstall, K. 2002, 2003). Flowering early summer.

Polypogon monspeliensis L. Desf. RABBIT'S-FOOT GRASS, ANNUAL BEARD GRASS. Widespread and locally abundant or co-dominant in poorly drained depressions within tidal marsh plains and disturbed marsh edges, turf pans. Endangered soft bird's beak forms host associations that result in high seedling mortality of the hemiparasite. Introduced from Europe. INVASIVE in brackish tidal marsh, particularly seasonal brackish pools or disturbed sediment. Flowering spring.

Leymus triticoides (Buckley) Pilg. CREEPING WILDRYE, ALKALI WILDRYE. Widespread in terrestrial grassland ecotones on alluvial fans throughout Rush Ranch, extending by clonal spread into adjacent intertidal high marsh. Relict stands are present on Goat Island and around seeps and springs in uplands. Locally abundant, spreading, and increasingly dominant in the terrestrial edges of tidal marshes where cattle grazing has been reduced or eliminated since 1990s. Also locally abundant in grazing-excluded bluff-top grasslands and headlands at Rush Landing north along Hill Slough. Strongly suppressed at fence-line grazing limits at tidal marsh/grassland edges, and at the Rush Ranch property boundaries. Both glaucous-leaf and green foliar forms are present. Sparse or absent in Rush Ranch tidal marsh edges in early 1990s.

Traditionally treated as a species in the genus *Elymus*, with which the rhizomatous genus *Leymus* may be again placed in synonymy. Flowering late spring.

Leymus ×multiflorus (Gould) Barkworth & D.R. Dewey. GIANT CREEPING WILDRYE. Coarse, taller, broad-leaf (up to 12 mm wide) putative natural hybrid (*L. condensatus*; not present) form of *L. triticoides*, distinguished by prevalence of 3 spikelets per node. Flowering spring.

POTAMOGETONACEAE
Pondweed family

Stuckenia pectinata (Linnaeus) Borner SAGO PONDWEED. Locally abundant in ponds and ditches within the diked marsh west of the Rush Ranch headquarters, and occasional in low-energy backwater areas in tidal sloughs and in pools associated with Hill Slough. Widespread in diked perennial brackish ponds in Suisun Marsh. W.L. Jepson field notes describe extensive sago pondweed beds in late 19th century Suisun Marsh ponds that were seasonally consumed by canvasback ducks. Several Suisun Marsh collections in California herbaria date from 1903-1904. Flowering summer, fruiting fall.

Stuckenia filiformis (Pers.) Börner (syn. *Potamogeton filiformis* Pers.) recently identified as dominant in young colonies in brackish subtidal beds of Montezuma Slough and western shores of Chipps Island, has not yet been detected at Rush Ranch, but may be expected in subtidal habitats of *S. pectinata* in years of low salinity.

RUPPIACEAE
Wigeongrass Family

Ruppia maritima L. WIGEONGRASS. Infrequent in ponded brackish depressions within the tidal marsh plain and diked marsh, possibly also in low-energy backwater areas in tidal sloughs. Widespread 20th century collection localities in Suisun Marsh (and one late 19th century Jepson collection), many likely from diked ponds. More tolerant of seasonally high salinity than the associated aquatic *Stuckenia pectinata*. Flowering summer, fruiting late summer-fall. (also treated as genus within pondweed family, Potamogetonaceae).

TYPHACEAE
Cattail Family

Typha angustifolia L. NARROWLEAF CATTAIL. Abundant in the diked marsh west of the Rush Ranch headquarters. Occasional in banks of tidal sloughs. European and invasive cattail species early introduced to North America, mistakenly treated as native in many North American floras. S. Watson (Botany of California vol. II, 1880) reported only two California localities prior to 1880, both in southern California, none from northern California. The earliest Solano County record is from near Dixon in 1949 (M.A. Nobs and S.G. Smith 743), and the oldest west Delta locality is from near Stockton in 1909 (J.C. Sanford, UC128663). Flowering late spring-summer.

Typha latifolia L. BROADLEAF CATTAIL. Common to abundant in the diked marsh west of Rush Ranch headquarters, and also common on banks of tidal sloughs, occurring with tules.
S. Watson (Botany of California vol. II, 1880) reported this species as "common in marshses from Sacamento northward" based on collections prior to 1880. Flowering late spring-summer.

Typha domingensis Pers. SOUTHERN CATTAIL. Present in the diked marsh west of Rush Ranch headquarters, and also along banks of tidal sloughs, occurring with tules. Native to California, but seldom collected and frequently misidentified as *T. angustifolia* or *T ×glauca*. Flowering late spring-summer.

Typha ×glauca Godron [HYBRID CATTAIL]. Spontaneous hybrid between native *T. latifolia* and exotic *T. angustifolia*, with inflorescence and leaf color traits approaching those of native *T. domingensis*; and forming intermediates with parent species in some North American populations; expected in Suisun Marsh.

ZANNICHELLIACEAE
Horned-Pondweed Family

Zannichellia palustris Linnaeus. HORNED PONDWEED. Historically known to benthic habitats of Suisun Marsh (Mason 1972), entirely submersed in brackish depressions, pools within marsh plains and diked ponds. Prior to extensive spread of tall emergent macrophytes in the diked pond at Rush Ranch, co-occurred with *Ruppia maritima* and *Stuckenia pectinata*. Likely overlooked, more widespread in Suisun Marsh region.

"DICOTYLEDONS"
AIZOACEAE
Carpetweed Family

Sesuvium verrucosum Raf. WESTERN SEA-PURSLANE. Infrequent at Rush Ranch, found at disturbed high tide lines and seasonally desiccated saline depressions. Typically occurring and locally common in drying mud of diked brackish seasonal wetlands in Suisun Marsh and in muted tidal areas of nearby Peytonia Slough Ecological Reserve. Flowering summer.

Carpobrotus edulis (L.) N. E. Br. and its hybrids are not known from Rush Ranch, but occur in tidal marsh terrestrial ecotones in San Francisco Bay.

APIACEAE
Carrot or Parsley Family

Apium graveolens L. WILD CELERY. Widespread and common, locally abundant in tidal marsh plains and drift-lines. Native to Europe, escaped from historical cultivation of celery. Invasive in brackish marsh, particularly disturbed soils. Highly invasive in tidal wetlands associated with Hill Slough, and invasion is increasing at Rush Ranch. Often co-invades near/with *Lepidium latifolium*. *A. graveolens* appears to be displacing endangered Suisun thistle of soft bird's-beak populations (Grewell, 2005).). Edible but can be confused with highly toxic congeners. Flowering late spring-fall.

Cicuta bolanderi S. Watson (*C. maculata* L.[misappl.] var *bolanderi* (S. Watson) Mulligan. BOLANDER'S WATER-HEMLOCK. Regionally rare, currently known in the San Francisco Bay estuary only from Rush Ranch. Observed in 2010 at only two subpopulations in fringing brackish marsh of Hill Slough and Suisun Slough near and within Rush Landing. This species was formerly abundant in Suisun Marsh, described as "abundant and conspicuous" in Suisun marshes only by Jepson (1911), and from Suisun and "Alvarado marshes" (Newark, Alameda County) by E. Greene (1894), who also described it (1892) as associated with Suisun thistle. Extensive population patches were also mapped at Rush Ranch in 1991 by P. Allen (DFG, unpublished maps), where it was often found with Suisun thistle. In 2003 it was reported to occur with 9% of endangered Suisun thistle population patches at Rush Ranch (Fiedler et al. 2003). Since invasive spread of *L. latifolium, C. bolanderi* has been rarely observed. Treated in the 1993 Jepson Manual and Second edition as *Cicuta maculata* L. var. *bolanderi* (S. Watson) G. A. Mulligan, but recent genetic analysis of North American *Cicuta* species (C. Lee & S. Downie. 2006) indicates that western North American *Cicuta* taxa are distinct from *C. maculata*, and likely belong to a well-supported monophyletic western clade that has not yet been resolved. Accordingly, the Suisun Marsh (type locality of *C. bolanderi*) populations are provisionally referred to the original named endemic taxon. Suisun type locality specimens were not analyzed by Lee and Downie (2006). Rush Landing specimens are indeed "conspicuous" due to large flowering shoots reaching heights exceeding 3 m, taller than any nearby plants except tules. *Cicuta* may be overlooked due to confusion with common and widespread *Sium suave*, which is much smaller but similar in aspect and gross morphology. *Cicuta* is reported to be among the most toxic vascular plants in North America, and extremely toxic to livestock. Flowering midsummer- early fall.

Conium maculatum L. POISON-HEMLOCK. Widespread and highly invasive European weed of levees, also occurring locally in terrestrial grassland edges of tidal marshes at Rush Ranch. Extremely toxic. Flowering summer, sporadically in fall.

Eryngium vaseyi J. Coulter & Rose. VASEY'S BUTTON CELERY Reported from Rush Ranch seasonal wetlands (historically tidal) by B. Grewell and by J. Ruygt. Found more extensively throughout Sacramento Valley and Delta. Typically occurring in inland alkali vernal pools, but occurs in a range of wetland – riparian habitats. Endemic to California.

Eryngium aristulatum Jeps. var ***aristulatum*** . COYOTE-THISTLE. Widespread but only occasional to uncommon in tidal marsh plains and fringing tidal marsh; locally common in fringing marshes along Suiusn Slough from Cutoff Slough to Suisun City. Flowering summer-fall.

Lilaeopsis masonii Mathias & Constance MASON'S LILAEOPSIS. Widespread but uncommon in banks of tidal creeks, ditches, and wave-scoured fringing marsh, where it forms creeping prostrate grass-like turfs or colonies that include *Hydrocotyl verticillata, Isolepsis cernua* and other low-growing emergents; occasionally occurring as an inconspicuous creeping component of the shaded ground layer vegetation in marsh plains or fringing tule marsh. At Rush Ranch, abundant on slumping channel banks of fringing marsh along Cutoff Slough, Suisun Slough and Hill Slough and less common along intertidal banks of First Mallard Branch. This species is possibly indistinct, a morphological variant and synonym of the more widespread but uncommon *L. occidentalis* J. M. Coult. & Rose. Virtually no nucleotide variation in the nuclear ITS II region was apparent among populations of *L. masonii*, or between it and its common congener, *L. occidentalis* (Fiedler and Zebell 1993, Fiedler et al. 2007). Flowering summer-fall. RARE (California state-listed).

Oenanthe sarmentosa C. Presl. WATER-PARSLEY. Widespread and locally common in brackish marsh plains and fringing marsh. *O. sarmentosa* is relatively more abundant in wet years, and near freshwater seepages adjacent to low shoreline bluff scarps or drainages from upland swales. Potentially overlooked in mixed stands with *Apium graveolens*. Flowering summer-fall.

Sium suave Walter. WATER-PARSNIP. Infrequent along tidal creek and slough banks at Rush Ranch, fringing marsh banks of Hill Slough and upper Suisun Slough; also in the nearby Lawler Ranch buffer ditch. In some years, observed from the Pasture Trail crossing over culverts at Spring Branch slough. More readily detected from boats along tidal creek banks of Rush Ranch. Flowering summer-fall.

ARALIACEAE
Aralia Family

Hydrocotyle verticillata Thunb. WATER-PENNYWORT. Uncommon to locally common in banks of tidal creeks, ditches, and wave-scoured fringing marsh. Often co-occurs with *L. masonii.* Flowering summer-fall.

ASTERACEAE
Aster Family

Achillea millefolium L. YARROW. Widespread but uncommon in well-drained tidal brackish marsh plains. Formerly common, but uncommon since displaced by invasive *Lepidium latifolium* along natural levees of tidal creek banks at Rush Ranch, forming small clonal colonies. Brackish marsh (salt-tolerant wetland) ecotypes of this typically upland species occur from western San Pablo Bay through the western Delta. Native. Flowering late spring-summer.

Ambrosia psilostachya DC WESTERN RAGWEED. Occasional, locally common in terrestrial grassland ecotones of tidal marsh, and along natural levees of tidal creek banks and fringing marshes. Abundant at E end Rush Landing high tidal marsh-terrestrial ecotone. Flowering summer-fall.

Artemisia douglasiana Besser WORMWOOD, MUGWORT. Occasional, natural levees of tidal creeks and fringing marsh, riparian scrub of N-facing bluff scarps of Hill Slough and Suisun Slough. Flowering summer-fall.

Baccharis douglasii DC. MARSH BACCHARIS. Occasional, terrestrial ecotone of diked marsh west of Rush Ranch headquarters, well-drained high tidal marsh plain, natural levees of tidal creeks. Flowering summer-fall.

Bidens frondosa L. MARSH-MARIGOLD. Occasional, local in disturbed patches of fringing marsh, especially in drift-lines and wracks. Flowering summer-fall.

Centromadia pungens (Hook. & Arn.) Greene SPIKEWEED. Occasional, terrestrial grassland ecotone of tidal marsh. Distinguished by lack of pappus on disc florets; otherwise similar to *C. fitchii*, with which it may be confused. Flowering summer-fall.

Centromadia fitchii (A. Gray) Greene FITCH'S SPIKEWEED. Occasional,terrestrial grassland ecotone of tidal marsh, especially alkali grassland of Spring Branch Creek alluvial fan.
Distinguished from *C. pungens* locally by disc pappus present. Flowering summer-fall.

Cirsium hydrophilum (E. Greene) Jepson *subsp.* ***hydrophilum*** SUISUN THISTLE. Very rare but locally common; historically endemic to Suisun Marshes, currently endemic to Rush Ranch and possibly extant at Peytonia Slough Ecological Reserve. At time of Solano Land Trust acquisition, believed to be extinct, but population rediscovered following removal of extensive grazing of tidal wetlands in early 1990s. Most subpopulations are in well-drained tidal marsh plains near banks of tidal creeks and 70% of subpopulations were found in along mosquito ditches (Fiedler *et al*. 2003, Fiedler et al. 2007). Present along tidal creeks tributary to Peytonia Slough prior to two fires and hydrologic alterations in the tidal marsh. No populations are recently confirmed from fringing tidal marshes of Suisun Slough northward through Hill Slough, despite apparently suitable habitat. Plant associates at Rush Ranch most commonly include *Apium graveolens*, *Atriplex triangularis*, *Distichlis spicata*, *Grindelia stricta*, *Jaumea carnosa*, *Juncus arcticus subsp. balticus*, *Lepidium latifolium*, *Potentilla anserina* subsp. *pacifica*, *Rumex crispus*, *Sarcocornia pacifica* and *Schoenoplectus americanus* (Fieldler et al. 2007), and the thistle is also found with *Senecio hydrophilus, Rumex occidentalis*, and non-native forbs such as *Cirsium vulgare* and *Helminthotheca echioides*. Historically associated with *Cicuta bolanderi* acc. E. Greene (1892), and more recently (Fiedler et al. 2007; Allen, unpublished data1991) but this association has been rare since invasive spread at *Lepidium latifolium* at Rush Ranch. On-going threats at Rush Ranch include expansion of *Lepidium latifolium* and *Apium graveolens* invasions, presence of a non-native biological control weevils *Rhinocylllus conicus*, uprooting and habitat destruction by feral pigs (*Sus scrofa*) (Fiedler et al. 2007). ENDANGERED (listed State, Federal). . Flowering early summer-fall.

Cirsium vulgare (Savi) Ten. BULL THISTLE. Locally common in well-drained marsh plains and natural levees bordering tidal creeks or ditches, sometimes in association with endangered *C. hydrophilum.* Invasive European weed. Flowering early summer-fall.

Cotula coronopifolia L. BRASS-BUTTONS. Widespread in many brackish marsh habitats, including turf pans, pools, disturbed patches and drift-lines in tidal marsh plains, and disturbed (trampled) terrestrial edges of tidal marsh. Amphibious, heterophyllous: develops grass-like submerged leaves. More abundant in diked seasonal marsh and ponds, in emergent mud, often ephemeral pioneer dominant in early mudflat succession in tidal or diked marshes. This early introduction first appeared in San Francisco in the 1850s from South Africa (Behr 1888, 1892), rapidly spreading through San Francisco Bay by 1901 (Jepson 1911), and was collected in Suisun

Marsh by 1903 (C.F. Baker *3225*, UC 84527). Considered an important waterfowl food source. Flowering late winter-spring, sporadically in summer.

Euthamia occidentalis Nutt. WESTERN GOLDENROD. Widespread but uncommon in well-drained tidal marsh and natural levees bordering tidal channel banks, fringing marsh scarps, and along terrestrial ecotones with freshwater seep or surface drainage influence. Previously more common at Rush Ranch prior to *Lepidium latifolium* invasion. Flowering late summer-fall.

Gnaphalium stramineum Kunth CUDWEED. Occasional in drift-lines and disturbed patches in high marsh or terrestrial grassland ecotones.

Gnaphalium palustre Nuttl. CUDWEED. Occasional in drift-lines and disturbed patches in high marsh or terrestrial grassland ecotones.

G. stricta DC. var. ***angustifolia*** (A. Gray) M.A. Lane, incl. *G.* × *paludosa***.** MARSH GUMPLANT. Currently treated as ***Grindelia hirsutula*** Hook. & Arn. (incl.) in Flora of North America. Locally abundant in well-drained tidal marsh bordering tidal creek and ditch banks, and on natural levees of tidal sloughs. Occasionally occurring in patches in well-drained tidal marsh plains farther from tidal creeks. The current taxonomic treatment in Flora of North America places *G. stricta* and all its varieties, as well as other and other species, in synonymy with *G. hirsutula* , *sensu lato*. Because of regionally strong ecological, geographic, and morphological discontinuity between *G. stricta* var. *angustifolia* of tidal marshes compared with other local taxa now placed in synonymy with *G. hirsutula*, the Lane treatment of *G. stricta* var. *angustifolia* in the Jepson Manual (Hickman *et al*. 1993) should be conserved in this region. E. Greene distinguished *G. paludosa*, which has been treated by Lane as a hybrid between *G. stricta* var. *angustifolia* and *G. camporum* (of terrestrial grasslands), which Greene described as "abundant in brackish marshes of Suisun Bay". Flowering mostly summer-fall, sporadic flowers all year. Important nectar plant, and associated with nesting California clapper rails at Rush Ranch and elsewhere in San Francisco Estuary.

Helenium bigelovii A. Gray BIGELOW'S SNEEZEWEED. Uncommon in fringing marsh along Suisun Slough, Hill Slough, and in wave-scoured bluff edges near seeps; possibly elsewhere in tidal marsh plains. Flowering summer-fall.

Helianthus annuus L. ANNUAL SUNFLOWER. Uncommon in natural levees of tidal creeks. Flowering summer.

Helminthotheca echioides (L.) Holub. (syn,. *Picris echiodes* L.) BRISTLY OX-TONGUE. Occasional, locally common to abundant near ditches and sporadically in well-drained high marsh plains. Invasive in endangered *Chloropyron molle* subsp *molle* habitat. Invasive in Spring Branch drainage of Rush Ranch. Native to Europe. Flowering spring-summer.

Jaumea carnosa (Less.) A. Gray FLESHY JAUMEA. Widespread and common in both well-drained and poorly-drained tidal marsh plains, fringing marshes. Flowering summer.

Lasthenia conjugens. CONTRA COSTA GOLDFIELDS. Populations observed at Rush Ranch (and elsewhere around Potrero Hills) bloom in April. Rush Ranch population site is west of Grizzly Island Road within a small vernal drainage area surrounded by grasslands. Has been observed with *Lasthenia glabrata, L. glaberrima,* and *L. fremontii.* Historical Suisun Marsh population known to Ledgewood Creek north of Cordelia Road extirpated by development in early 1990s. ENDANGERED (listed Federal)

Lasthenia glabrata Lindl. subsp. ***glabrata*** SMOOTH GOLFIELDS. Uncommon, local in turf pans, poorly drained landward edge of tidal marsh plain at the lower edge of the terrestrial grassland ecotone, often on terrigenous (alluvial fan) sediments, south Rush Ranch. Associated with *Isolepis, Juncus bufonius*, *Triphysaria*, as well as prostrate phenotypes of *Sarcocornia pacifica, Frankenia,* and sparse *Distichlis*. Flowering spring (March-May, rarely June).

Lasthenia californica DC. ex Lind. subsp. *californica* occurs in subsaline sandstone soils within the erosional drainage below the northern spring and impoundment on Grizzly Island Road, and may be expected in terrestrial ecotones of tidal marsh below; *L. conjugens* Greene has been reported by Grewell from vernal pools at Rush Ranch, and occurs in alkali/subsaline vernal pools and flats south of Highway 12 near Potrero Hill. Historical tidal marsh and salt pond edge populations of *L. conjugens* are known from South San Francisco Bay.

Pluchea odorata (L.) Cass. MARSH FLEABANE. Occasional, well-drained marsh plain, natural levees of tidal sloughs and creeks, and fringing marsh. Historically abundant in San Francisco Estuary, presently occasional to rare. Formerly more common at Rush Ranch prior to invasion of *Lepidium latifolium*.

Senecio hydrophilus Nutt. MARSH BUTTERWEED, MARSH RAGWORT. Uncommon but widespread in well-drained tidal marsh plains, natural levees of tidal sloughs and creeks, and fringing marshes of Rush Ranch. Often associated with Suisun thistle. Previously more common at Rush Ranch prior to invasion of *Lepidium latifolium*. Historically “abundant in the Suisun Marshes” (Jepson 1911).

Symphyotrichum lentum (Greene) G.L. Nesom. SUISUN MARSH ASTER, SUISUN ASTER. Uncommon but locally abundant in clonal colonies, particularly in fringing marshes, tidal creek banks, and tidal edges of bluff scarps along Suisun Slough and Hill Slough. Flower color variable from white to pink-purple. At Rush Ranch and elsewhere in Suisun Marsh, outer phyllaries length highly variable – some overlap with *S. chilense* (Fiedler and Grewell, personal obs.) Flowering late summer – fall, and occasionally flowering as late as December.

Symphyotrichum subulatum (Michx.) G.L. Nesom var. ***parviflorum*** (Nees) S. D. Sundberg. ANNUAL ASTER, SLIM ASTER Widespread annual (to short-lived perennial in favorable conditions) occurring sporadically in well-drained tidal marsh plains, natural levees of tidal creek banks, fringing marshes, drift-lines of terrestrial ecotones. Abundant in fringing marshes of the Sacramento – San Joaquin Delta. At Rush Ranch, abundant in fringing marsh along Suisun Slough and Hill Slough. Uncommon but present along First Mallard Branch. Occasional/rare along Second Mallard Branch. Rare along Rush Ranch reach of Cutoff Slough, but more abundant along Cutoff Slough near the confluence with Montezuma Slough. Also abundant along canals in diked marshes of Suisun Marsh, but scarce in the diked marsh at Rush Ranch. More abundant at Rush Ranch prior to invasive spread of *Lepidium latifolium*. Occasional in the Carquinez Straits and Napa River. This subspecies is native to California; other subspecies may be introduced in California. This appears to be one of the oldest botanical collections from Suisun Marsh (H. Bolander *2618*, UC31440). Flowering summer-fall.

Sonchus oleraceus L. SOW-THISTLE. Occasional, locally common to abundant near ditches and sporadically in well-drained high marsh plains. Native to Europe. Flowering spring-summer.

Sonchus asper L. Hill subsp. *asper* PRICKLY SOW-THISTLE. Occasional near ditches and sporadically in well-drained high marsh plains; less common than *S. oleraceus* in brackish marsh. Native to Europe. Flowering spring-summer.

Tragopogon porrifolius L. SALISFY, OYSTER-PLANT. Reported from Rush Ranch tidal marshes by B. Grewell. Localities unknown. Flowering spring-early summer.

Xanthium strumarium L. COCKLEBUR. Locally common in drift-lines, wracks, sometimes quite weedy in disturbed patches of poorly drained tidal marsh seasonal nontidal marsh. Flowering summer.

BORAGINACEAE
Borage Family

Heliotropium curassavicum L. WILD HELIOTROPE. Formerly observed in sandy disturbed shorelines near Rush Landing in terrestrial ecotone of high tidal marsh; current localities need verification. Few other western Suisun Marsh localities are known (Grewell obs. near railroad tracks west of Morrow Island and Goodyear Slough), but locally dominant on artificial levees of eastern Suisun Marsh (Montezuma Slough; Baye, unpubl. data). Occurs infrequently in terrestrial edges of tidal marsh in San Pablo Bay and San Francisco Bay. Flowering summer.

Plagiobothrys stipitatus and *P. greenei* were reported by B. Grewell from upland vernal pools/seasonal wetlands at Rush Ranch; these may potentially disperse and establish in tidal marsh edges below drainages).

BRASSICACEAE
Mustard Family

Brassica nigra L. BLACK MUSTARD. Occasional, terrestrial grassland ecotone, levee of diked marsh, and natural levees of tidal sloughs. European native; abundance in saline wetland soils is limited.

Lepidium latifolium L. BROADLEAF PEPPERWEED, PERENNIAL PEPPERWEED. Noxious Eurasian weed spreading locally by adventitious shoots on rhizome-like shallow roots. Widespread, abundant, and dominant or co-dominant (including monotypic stands, and mixed stands overtopping shaded pickleweed-saltgrass understories) in Rush Ranch tidal marsh plains. Present but not abundant (2010) along Rush Ranch fringing marshes of Suisun Slough and Hill Slough. Absent or rare in summer-desiccated terrestrial ecotones of tidal marsh bordering alkali grassland where dominance shifts to *Sarcocornia-Frankenia-Distichlis* or *Leymus-Bromus-Lolium*. *L. latifolium* was present in the northern San Francisco Bay Area and western Delta in the late 1950s and 1960s, and became conspicuous and widely dominant by the 1990s. It was first collected recorded in southern Marin County near railroad tracks in 1965 (Howell 1970), east of Dixon (west Delta) in 1959 (B. Crampton *5150*, UCD35699), Napa-Sonoma Marsh 5 miles east of Sears Point in 1958 (T.C. Fuller *1480-58,* CDA3836), and in Petaluma Marsh in 1970 (A. LaRose, CDA3804). In Suiusn Marsh, early observations *of L. latifolium* were in disturbed diked wetlands and man-made levees. The weed was present on Joice Island levees adjacent to Cutoff Slough by 1989, and along levees of private managed wetlands in Suisun Marsh. At Rush Ranch, the species was first observed along mosquito ditches in the Second Mallard Branch drainage in 1991 (Grewell personal observation), and the weed was rare at Rush Ranch in the early 1990s. Its abundance increased dramatically throughout Suisun Marsh following the very wet 1997-98 El Niño event, and it has spread progressively since then. It has progressively displaced *Baccharis pilularis* and several uncommon, herbaceous marsh forbs including *Achillea millefolium*, *Pluchea odorata*, *Senecio hydrophylus*, *Symphyotrichum subulatum* var. *parviflorum* and *Cicuta bolanderi* (B. Grewell, pers. observ.). Flowering May-early summer; repeat flowering occurs in late summer regrowth on plants lodged, cut, or mowed early in the growing season, if soil moisture and salinity support growth. Abundant seed are produced in early summer.

Lepidium oxycarpum Torrey & Gray. SMALL-FRUIT PEPPERWEED. This diminutive ephemeral winter native annual peppercress is rare in the San Francisco Estuary today. It occurs locally at high density at the edge of tidal-terrestrial ecotone vegetation below a low, bare, sandy scarp near the mouth of Spring Branch Creek, south side. It may occur in similar alkali grassland or turf pan and forb pan vegetation elsewhere at Rush Ranch.

Raphanus sativa L. WILD RADISH. Occasional, terrestrial grassland ecotone, and natural levees of tidal sloughs. Common along levees of diked marsh at Rush Ranch and elsewhere. In San Pablo Bay, *R. sativa* rapidly becomes dominant on freshly maintained (mud-capped) levees. European annual weed. Abundance in saline wetland soils is limited.

CARYOPHYLLACEAE
Carnation family

Spergularia salina J.S. Presl & C. Presl. (syn. *S. marina* (L.) Grisb. SAND-SPURREY. Occasional, drift-lines and disturbed patches in well-drained high tidal marsh. At Rush Ranch and elsewhere in Suisun Marsh, occurs with endangered *Chloropyron molle* subsp. *molle* (Mason 1972, Grewell et al. 2003) European annual native; not known to be invasive.

Spergularia maritima (All.) Chiov. (syn. *S. media* (L.) Grisb. SAND-SPURREY. Occasional in disturbed wetland transitional areas at Rush Ranch, and usually found in wetlands. Also known to Jepson Prairie in Solano Co. European annual native; in Richardson Bay (Central San

Francisco Bay, Marin County), locally dominant and invasive, forming monotypic stands in high mudflats.

Spergularia macrotheca was reported as an associate of *Distichlis spcicata, Frankenia salina* and *Chloropyron molle* (as *Cordylanthus mollis*) on historically prevalent saltgrass plains in the Suisun Marsh flora by H.L. Mason (1972). *Spergularia macrotheca* var. *leucantha* is historically reported from alkali grasslands of Solano County, and *S. macrotheca* var. *macrotheca* estuarine collection localities range east in San Pablo Bay to Richmond (Point Pinole). It may potentially occur at Rush Ranch, and could be masked by presence of similar non-native *Spergularia* species.

CHENOPODIACEAE*
Goosefoot Family

Arthrocnemum subterminale (Parish) Standley ALKALI PICKLEWEED, PARISH'S PICKLEWEED or PARISH'S GLASSWORT. Uncommon, local terrestrial ecotones of tidal marsh in alkali grassland of Spring Branch Creek and Suisun Hill Hollow subsaline alluvial fans, and rare in terrestrial ecotones in Second Mallard Branch drainages, in ephemeral drainage of Suisun Hill Hollow immediately west of Grizzly Island Road, sporadically elsewhere in terrestrial edges on saline/alkali soils. More often found in edges of non-tidal alkali seasonal wetlands than in tidal marsh. Treated in the 1993 and Second Edition Jepson Manual as synonym. *Arthrocnemum subterminale* (Parish) Standl. Visually distinguished at a distance by relatively dense and symmetric branching patterns of shoots; otherwise easily overlooked among more common pickleweed. Flowering late summer-fall.

Atriplex prostrata Boucher ex DC *(A. triangularis* Willd*; A. patula* L. *subsp. hastata* (L.) A. Gray misapplied. SPEARSCALE, FAT-HEN. Widespread, locally common in borders of depressions within the marsh plain, along drift-line debris of creek bank levees, terrestrial edges of tidal marsh. Also abundant (and actively managed) in diked brackish marshes of Suisun Marsh, where its seed production is valued for waterfowl foraging habitat. The taxonomy and geographic origin of this species has been long confused. *A. prostrata* is native to Europe, early and widely introduced and naturalized in North America. The earliest botanical observations in California are from H. Behr's 1850s San Francisco residency, later reported in his Flora of the Vicinity of San Francisco (1888) from "cultivated grounds" as a "ballast weed introduced from Europe", under the name *A. patulum (*syn. *A. patula* var. *hastata,* misapplied to *A. prostrata*). S. Watson (1880) Botany of California volume II described *A. patula* L. var. *hastata* Gray distribution in 1880 as "frequent in salt-marshes near San Francisco" only, and noted a Santa Barbara locality as an addition and correction to volume II. Jepson (1911, corrected edition of 1901 Flora of Middle Western California) also described the range of *A. hastata* (syn. *A. patula* var. *hastata*) as "Common at the edges of salt marshes about San Francisco Bay", but not "Suisun Marshes". E. Greene (1894) reported *A. hastata* as "common along the borders of brackish marshes at Petaluma, and elsewhere. The 1993 Jepson Manual (Hickman *et al*. 1993) treated California populations previously referred to *A. patula* L. var. hastata and *A. hastata* Hall & Clem. as misapplied to *A. triangularis*, which was erroneously presumed to be native to California and Europe. *A. triangularis* is currently treated in the second edition of the Jepson Manual (in prep.) and the Flora of North America as *A. prostrata,* native to Europe but widely naturalized in North America and elsewhere. This common species is widely but erroneously presumed to be native to California. It may be transiently abundant in disturbed marsh shorelines and in drift-lines or wracks. Regardless of its presumed provenance, often not dominant within diverse salt marsh communities. However, has been observed as highly invasive secondary invader following disturbance imposed by weed eradication efforts (*Spartina patens, Lepidium latifolium)* and in other local disturbances within brackish tidal marsh plains in Suisun Marsh and Carquinez Straits (Grewell 2010). Flowering spring-fall.

Atriplex semibaccata R. Br. AUSTRALIAN SALTBUSH. Infrequent in terrestrial edges of tidal marsh at scattered localities. Native to Australia. Regionally common levee weed, introduced by wildlife habitat managers in Suisun Marsh, locally invasive. Flowering spring-summer.

Beta vulgaris L. WILD BEET. Infrequent, locally common and often transient in drift-lines and wracks, levees, ditch and tidal creek bank edges. Native to Europe, escaped from cultivation of Swiss chard and beet. Edible. Flowering spring-summer.

Sarcocornia pacifica (Standl.) A. J. Scott . PICKLEWEED. Widespread and abundant to locally dominant or co-dominant in tidal marsh plains and their terrestrial ecotones, often increasing during periods of drought and elevated marsh soil salinity. Growth forms range from tall (0.5 m) highly branched subshrubs (typical of relatively well-drained tidal marsh banks and diked marshes) to prostrate and sparsely branched mats (high tidal marsh turf pans). Traditionally treated as synonyms *Salicornia virginica* L. or *S. pacifica* Standley. Flowering late summer-fall.

Salicornia depressa Standl. (*S. europaea* L., misappl.), a widely dispersed annual succulent native forb occurs sporadically and widely in disturbed high mudflats and marshes in the San Francisco Estuary, often as a pioneer colonizing species. Populations occur in eastern San Pablo Bay near the Carquinez Straits, and may be expected episodically at Rush Ranch.

CONVOLVULACEAE
Morning-glory Family

Calystegia sepium (L.) R. Br. subsp. ***limnophila*** (E. Greene) Brummitt. MARSH MORNING-GLORY. Occasional to common growing on tules along fringing marshes and banks of tidal sloughs. Native. Flowering summer-fall.

Convolvulus arvensis L. BINDWEED. Uncommon at Rush Ranch, but occasional observations in uplands areas and at tidal marsh transition by diked pond.

Cressa truxillensis Kunth. ALKALI-WEED. Common in terrestrial ecotones of tidal marsh and grassland and alkali seasonal weltlands, and occasional in well-drained high tidal marsh plains. Flowering summer.

Cuscuta pacifica var. ***pacifica*** Costea and Wright (syn. *Cuscuta salina* Engelm. var. *major* Yunker) SALT MARSH DODDER. Widespread and abundant or locally dominant in well-drained tidal marsh plains, typically associated with *Sarcocornia and Jaumea* (in which it can form dense mats, and cause significant thinning or large dieback patches). Also present in high marsh edge areas, and commonly associated with *Chloropyron molle* subsp. *molle.* Emerging in spring, abundant by late summer; flowering summer.

FABACEAE
Pea or Legume Family

Glycyrrhiza lepidoda Pursh. WILD LICORICE. Local in the high marsh plain and slough bank scarps of Hill Slough near the northern and eastern borders of Rush Ranch, associated with *Juncus arcticus* subsp. *balticus*, *Leymus triticoides*; forming shrubby colonies near interior tidal channel banks (natural levees). This riparian species has also been recently reported from Southampton Marsh, and may represent a recent range and habitat extension.

Lathyrus jepsonii Greene var. ***jepsonii*** JEPSON'S TULE PEA. Uncommon along Cutoff Slough and First Mallard Branch at Rush Ranch but occurring in locally abundant colonies, especially along Suisun Slough and Hill Slough. More abundant along Second Mallard Branch and along Cutoff Slough near Montezuma Slough. Endemic to tidal wetlands of the San Francisco Estuary. Occurs along tidal sloughs throughout the Sacramento – San Joaquin Delta. Uncommon, but present Carquinez Straits and Napa River marshes. Established mostly at steep, well-drained banks of high tidal marsh bordering taller vegetation (including tules, and riparian scrub) over which its glabrous, winged stems climb. Individual shoots can grow to more than 2.5 m in length (Fiedler et al. 2007). Most frequent along Hill Slough edges. Regionally rare. Flower color variable, ranging from pink to purple. Flowering summer-early fall.

Lotus corniculatus L. BIRD'S-FOOT TREFOIL. Locally abundant in well-drained high marsh plains and terrestrial ecotones. European native, invasive in high brackish marsh and seasonal wetlands. Flowering spring-summer.

Lotus purshianus (Benth.)Clem. & E.G. Clem. var. ***purshianus*** SPANISH-CLOVER. Formerly observed in high tide lines near Rush Landing. Annual, generally hairy. Flowering summer.

Melilotus indica (L.) All. SOURCLOVER. Locally common in high brackish marsh and adjacent terrestrial grassland ecotones, southern Rush Ranch. Flowering summer.

Trifolium wormskioldii Lehm. COW CLOVER. Locally common in well-drained brackish marsh plains and fringing marsh. Flowering summer.

FRANKENIACEAE
Frankenia family

Frankenia salina (Molina) I.M. Johnston ALKALI-HEATH. Widespread and common in well-drained marsh plains, natural levees of tidal creeks and sloughs, and terrestrial ecotones; also in alkali grassland. Flowering spring-summer. Important nectar plant.

LAMIACEAE
Mint Family

Stachys albens A. Gray MARSH HEDGE-NETTLE. Uncommon, high brackish marsh and well-drained edges of marsh scarps along sloughs. At Rush Ranch, locally abundant (particularly in wet, low-salinity years) along small tidal creek channels in Hill Slough, Suisun Slough, Second Mallard Branch drainage. Also uncommon, but consistently present, along the southern shore fringing marsh at Rush Landing. Flowering summer-early fall.

Lycopus asper E. Greene BUGLEWEED, WATER-HOREHOUND. Locally rare (or rarely detected) along high brackish marsh bank (scarp) edges of northern Suisun Slough at Rush Ranch, associated with *Stachys albens*; also in fringing high marsh south of Rush Landing, with *Frankenia, Ambrosia, Distichlis*; possibly overlooked and occurring elsewhere. Previous collection localities in Solano and Suisun Marsh by W.L. Jepson (*14901*, Benicia) and A.A. Heller (Suisun Marsh near Suisun) are from the late 19th and earliest 20th c.

LYTHRACEAE
Loosestrife Family

Lythrum hyssopifolium L. HYSSOP-LEAF LOOSESTRIFE. Common, occasionally abundant, in high marsh turf pans and drift-lines, occasional in tidal marsh plains, including poorly drained depressions. European annual or short-lived perennial, invasive in seasonal pools.

Lythrum tribracteatum Salzm. ex Spring. THREEBRACT LOOSESTRIFE. Rare exotic annual loosestrife native to southern Europe; occurs occasionally at Rush Ranch in high marsh pans and poorly drained depressions.

Lythrum californicum was reported as a member of intertidal plant communities in the Suisun Marsh by H.L. Mason (1957, 1972). While no observations exist for Rush Ranch, populations have been documented at Browns Island and on Ryer Island (Grewell 1992) in Suisun Bay; may be expected at Rush Ranch.

ONAGRACEAE
Evening-primrose Family

Epilobium ciliatum Raf. subsp. ***ciliatum*** WILLOW-HERB. Occasional in well-drained brackish marsh, natural levees of tidal creeks, terrestrial ecotones, and drift-lines.

OROBANCHACEAE
Broomrape family
(including hemiparasitic genera of traditional Scrophulariaceae)

Chloropyron molle (A. Gray) A. Heller subsp. ***molle*** (syn. *Cordylanthus mollis* A. Gray subsp. *mollis* SOFT BIRD'S-BEAK. Rare hemiparasitic annual, federally listed as endangered, endemic to San Francisco Estuary (north Bay and Suisun). Occurs in various tidal sub-habitats within Suisun Marsh, including natural levees of tidal creek banks, well-drained high tidal marsh, edges of turf pans, and terrestrial ecotones, usually associated with relatively sparse cover of dominant vegetation, including *Sarcocornia*, *Distichlis*, *Cuscuta*, and other high tidal marsh annuals, many of which serve as hosts. At Rush Ranch, extant localities correspond with the vicinity of mapped locations of natural and seeded (experimentally reintroduced) populations reported by B. Grewell (2003, 2005) near Spring Branch Creek. Annual populations may fail to emerge from seed banks but reappear at the same or proximate locations. A former natural population in the Second Mallard Branch drainage (Ruygt 1993) was destroyed by extensive cattle grazing within the marsh in 1999, and further damage by feral pigs later impacted the same area (Grewell et al. 2003). Sporadic, small patches of soft bird's beak have emerged in disturbance gaps in marsh plain at Rush Ranch, but do not persist. Long-distance natural colonization events are likely infrequent given current fragmentation and loss of suitable habitat. However, historic records of small isolated patches that do not persist suggest within-Estuary dispersal is possible, though colonization and persistence may be limited. ENDANGERED (listed Federal), RARE (California-state listed).

Triphysaria eriantha Benth. subsp. ***eriantha*** FALSE OWL'S-CLOVER. Rare and local in patches within the tidal-terrestrial ecotone at the extreme SE corner of Rush Ranch, immediately above the *Lasthenia glabrata* zone, in association with dwarfed *Hordeum gussoneanum* and *Lolium perenne*, but absent in adjacent terrestrial grassland. Large populations of this species occur in the lowland grasslands on the neighboring ranch, which drains to the southeastern corner of Rush Ranch through a culvert. In the tidal marsh, it appears not to co-occur with the *T. versicolor*.

Triphysaria versicolor Fisch. & C. . Mey. subsp. ***versicolor*** YELLOW FALSE OWL'S-CLOVER, BUTTER-AND-EGGS. Locally abundant but uncommon in tidal marsh forb and turf pans of south Rush Ranch tidal marsh within the terrestrial ecotone, in association with *Lasthenia glabrata, Isolepis cernua*, *and Juncus bufonius*, as well as prostrate *Sarcocornia*. This is an ecologically distinctive and noteworthy occurrence, the only reported occurrence of *T. versicolor* in brackish tidal marsh; the species is typically found in the region within seasonal wetlands and alkali grasslands.

Castilleja ambigua (Hook. & Arn.) occurs in one high brackish marsh locality at Benicia (a succulent-leaf, late spring/summer-flowering form with large white and yellow corollas, and seed coats similar those of subsp. *humboldtiensis*), and at Point Pinole, Whittell Marsh (non-succulent, early spring-flowering form with purplish foliage and post-anthesis corollas) in association with a former population of *Chloropyron molle* subsp. *molle* and large populations of *Lasthenia glabrata*, both of which occur at Rush Ranch. Regionally rare tidal marsh ecotypes of this species may occur at Rush Ranch in corresponding habitats.

PLANTAGINACEAE
Plantain Family

Plantago subnuda Pilger SEEP PLANTAIN. Occasional to locally common in brackish marsh plains and fringing marsh, and seeps in sandstone bluffs of Rush Landing within tidal range.

Plantago maritima L. (*P. maritima* var. *juncoides* (Lam.) A Gray SEASIDE PLANTAIN. Infrequent, reported by B. Grewell from Rush Ranch and Hill Slough (DFG) tidal marshes where it is rare and occurs with *Chlopyron molle* subsp. *molle*. No other collection localities are known from Suisun Marsh, but it was one of the earliest brackish marsh collections from the region by W.H. Brewer *997* (UC8020) at Martinez in 1862, where it was subsequently collected by J.B. Davy (*6670*) in 1900. The species is common in maritime salt marshes of west Marin and Sonoma Counties, and in Richardson Bay. Flowering summer.

Plantago coronopus L. , buck's-horn or rat-tail plantain, a non-native European halophyte that has become widespread and locally invasive in Marin and Sonoma County tidal marsh edges, has not yet been reported at Rush Ranch, but has been reported from railroad yard localities in Solano County as far back as the 1940s (JEPS6910, C.B. Heiser 1947), has been observed in tidal marsh adjacent to Cordelia Slough in western Suisun Marsh, and maybe is expected at Rush Ranch and vicinity

P. elongata Pursh, a diminutive linear-leaved annual of brackish flats and alkali vernal pools, has been historically collected at multiple locations near sea level in Suisun Marsh, may be expected in Rush Ranch tidal marshes. This species may be easily overlooked in turf pans.

POLYGONACEAE
Buckwheat Family

Persicaria punctata (Elliott) Small (syn. *Polygonum punctatum* Elliott) DOTTED or WATER SMARTWEED. Occasional and locally abundant in brackish marsh plains and fringing marshes, drift-lines of Hill Slough, Suisun Slough, and elsewhere at Rush Ranch. Mason (1972) also reported as associated with *Bolboschoenus maritimus* subsp. *paludosus* (as *Scirpus robustus*) and *Polygonum lapathifolium* in vernal rain pools and poorly drained sites in Suisun Marsh (syn. *Polygonum punctatum* Elliott. Flowering summer to fall.

Polygonum aviculare L. subsp. *depressum* (Meisn.) Arcang. DOORYARD KNOTWEED. Occasional to locally abundant in brackish marsh plains and fringing marshes, drift-lines, European annual weed. Flowering spring to summer.

Polygonum marinense T. Mert. & Raven MARIN KNOTWEED. Uncommon in turf pans below and within terrestrial ecotones, potentially in south Rush Ranch in 2010, though confirmation is needed, and possibly in the same habitats as *P. aviculare*. The identity of this putative rare native annual species, formerly believed to be endemic to western Marin salt marsh edges, is questionable. It has undergone rapid range expansion from isolated locations in west Marin salt marshes in the 1960s (where it was presumed to be endemic) to widespread occurrences in brackish marshes of the northern San Francisco Estuary, east at least to Martinez and Rush Ranch in recent years. Its pattern and rate of spread in the northern estuary has been more like an invasive species than a narrow endemic. Its origin and phylogeny are in need of further study (Costea et al. in prep.), and it was considered to be a potential synonym of *P. robertii* Lois., or related non-native species, according to the treatment in the 1993 Jepson Manual (Hickman *et al*. 1993). Further study is needed at Rush Ranch. Flowering late spring to early summer.

Rumex crispus L. CURLY DOCK. Occasional, well-drained brackish high marsh, natural levees of tidal creeks, drift-lines. European perennial forb, invasive in non-tidal fresh-brackish seasonal wetlands, but seldom invasive in tidal marshes. Flowering spring to early summer.

Rumex occidentalis S. Watson WESTERN DOCK. Common but not abundant above banks of tidal creeks and fringing marshes. Distinguished from non-native *Rumex* species in wetlands by lack of inflated valves around achenes when in fruit, and by large rosy immature fruits. Flowering late spring or early summer.

P. ramosissimum Michx. subsp. *ramosissium* Recent taxomomic revisions (Costea in Baldwin et al. 2011, in press) suggest *P. ramosissimum* subsp. *ramosissium*, now considered native to salt marshes in SF Estuary, may be mistaken for *P. marinense*. Now present at Southampton Marsh Preserve, Carquinez Straits, and presumed more widespread in San Francisco Estuary; expected at Rush Ranch, possibly present and undetected or misidentified. More study needed.

PHYRMACEAE Lopseed family
(includes former traditional Scrophulariaceae genera)

Mimulus guttatus DC. MONKEY-FLOWER. Occasional in brackish high marsh near banks of tidal creeks or fringing marshes, and around and drift-lines, particularly near freshwater discharges of seeps or upland runoff. In years with high freshwater inflow, it has been very common along Suisun Slough. Brackish marsh ecotypes are not known west of Suisun Marsh. Flowering summer, sporadically to fall.

PLUMBAGINACEAE
Leadwort family

Limonium californicum (Boiss.) A. Heller CALIFORNIA SEA-LAVENDER. Infrequent but locally common in well-drained high marsh plains and creek banks.

PRIMULACEAE
Primrose family

Anagallis arvensis L. SCARLET PIMPERNEL. Occasional in disturbed drift-lines and terrestrial ecotones. European annual weed. Flowering spring, soon withering.

Glaux maritima L. SEASIDE MILKWORT. Widespread, patchy, locally common in well-drained brackish marsh plains and fringing marshes. Historic changes in distribution noted (Baye et al 2000). Flowering summer. Native to Pacific and Atlantic North American coasts, and Europe. Ant-pollinated in European populations. Excretes salt from leaf glands.

ROSACEAE
Rose Family

Potentilla anserina L. subsp**.** ***pacifica*** Howell**.** PACIFIC SILVERWEED. Synonymous with *Argentina egedii* (Wormsk.) Rydb. Widespread, common, and locally abundant (often in association with *Juncus arcticus* subsp. *balticus*) in both drained and poorly-drained tidal marsh, forming clonal (stoloniferous) colonies. Often observed near channels. Mason (1972) reported as common member of Distichlis spicata plane community historically common throughout Suisun Marsh prior to diking for attempted agricultural production. (Syn. *Potentilla anserina* L. subsp. *pacifica* (Howell) Rousi).

Rosa californica Cham. & Schltdl. On levees of diked marsh, along Hill Slough spreading into tidal marsh edges, and in riparian scrub edges of tidal marsh in bluff scarps along Hill Slough. Also reported by Mason (1972) as typical along dikes, sloughs and ditches of Suisun Marsh.

Rubus armeniacus Focke (syn. R. discolor Weihe & Nees.). HIMALAYAN BLACKBERRY. Locally abundant to dominant on levees of the diked marsh west of Rush Ranch headquarters, and rooted in riparian scrub of bluff scarps bordering Hill Slough, spreading over tidal marsh edges. Noxious invasive Eurasian weed.

SALICACEAE
Willow Family

Salix lasiolepis Benth. ARROYO WILLOW. Uncommon, riparian scrub ecotones of tidal marsh bordering Hill Slough. Much more common in Sacramento – San Joaquin Delta than in Suisun Marsh.

SOLANACEAE
Nightshade family

Solanum physalifolium Rusby var. *nitidibaccatum* (Bitter) Edmonds (*S. villosum* (L.) Mill., *S. saccharoides* Sendtn. misapplied). Reported by B. Grewell (1996) in tidal marshes of Rush Ranch and Goodyear Slough, rare within marsh plain- upland ecotone communities in disturbed locations. Native to South America.

FLORISTIC ANALYSIS

Families	Number Of Taxa
[Monocots]	
Asparagaceae	1
Cyperaceae	10
Iridaceae	1
Juncaceae	3
Juncaginaceae	2
Themidaceae	1
Poaceae	14
Potamogetonaceae	1
Ruppiaceae	1
Typhaceae	3
Zannichelliaceae	1

Families	**Number Of Taxa**
[11]	[38]
[Dicots]	
Aizoaceae	1
Apiaceae	8
Araliaceae	1
Asteraceae	28
Boraginaceae	1
Brassicaceae	4
Caryophyllaceae	2
Chenopodiaceae	5
Convolvulaceae	4
Fabaceae	6
Frankeniaceae	1
Lamiaceae	2
Lythraceae	2
Onagraceae	1
Orobanchaceae	3
Plantaginaceae	2
Polygonaceae	5
Phyrmaceae	1
Plumbaginaceae	1
Primulaceae	2
Rosaceae	3
Salicaceae	1
Solanaceae	1
[23]	[85]
TOTAL 34 Families	**123 known species and infraspecific taxa**

Non-native species 33 (33/123 =26.8%)

Endangered species (Federal-listed ESA): 3 (Cirsium hydrophilum subsp. hydrophilum, Chloropyron molle subsp. molle, Lasthenia conjugens)

Rare Species (State-listed ESA): 1 (*Lilaeopsis masonii*)

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6. Tidal Marsh Vegetation of China Camp, San Pablo Bay, California

Peter R. Baye

Annapolis Field Station
P.O. Box 65
Annapolis, California 95412
baye@earthlink.net

ABSTRACT

China Camp (Marin County, California) preserves extensive relict stands of salt marsh vegetation developed on a prehistoric salt marsh platform and complex tidal creek network. Its tidal marsh retains physical gradients that support regionally rare examples of ecotones with adjacent terrestrial vegetation stands, including those of active stream valleys (riparian scrub and woodland, freshwater marsh, sedge-rush meadows) and hillslopes (annual and perennial grassland, oak woodland, and mixed evergreen forest). The low marsh along tidal creeks and the bay edge supports extensive native stands of Pacific cordgrass (*Spartina foliosa*), with intermittent, variable stands of alkali-bulrush (*Bolboschoenus maritimus*). Most of the extensive middle marsh plains support near-monotypic stands of pickleweed (*Sarcocornia pacifica*), interspersed with infrequent salt marsh forbs and graminoids. High marsh zones along tidal creek bank levees support nearly continuous linear stands of gumplant (*Grindelia hirsutula*) and saltgrass (*Distichlis spicata*). Salt pans with their submerged wigeongrass (*Ruppia maritima*) are scarce, local, and small. High marsh ecotones along terrestrial edges on south-aspect slopes with grasslands are locally dominated by Baltic rush (*Juncus arcticus* ssp. *balticus*) and creeping wildrye (*Leymus triticoides*). North-facing slopes support either grassland ecotones or woody canopies of scrub or oak woodland overhanging high salt marsh. Brackish marsh ecotones occupy wet valleys and seeps above ordinary high tides, supporting large clonal stands of sedges and rushes (*Carex praegracilis, C. barbarae, Bolboschoenus maritimus, Juncus phaeocephalus, Schoenoplectus acutus*), grading into non-saline wetland soils. Regionally rare salt marsh plant populations have not been reported from China Camp, but many species otherwise uncommon or rare in San Francisco Bay tidal marshes occur. To date, non-native tidal marsh plant invasions have been relatively minor and localized within China Camp.

6.1 Introduction

China Camp State Park (San Rafael, Marin County, San Pablo Bay, California (Lat.38"001N, Long. 122"301W)) includes a tidal salt marsh approximately 180 ha in area (Hopkins and Parker 1984). Tidal marsh vegetation at China Camp is well known for its "old-growth" component: it contains a large remnant prehistoric marsh area that escaped 19th and 20th century diking and agricultural reclamation, preserving a nearly continuous stratigraphic record of estuarine marsh peat and mud deposition during the late Holocene (Malamud-Roam and Ingram 2004, Goman 2004). In addition, the vegetation gradients (ecotones) between tidal marsh and adjacent terrestrial vegetation (oak woodland, valley grassland, freshwater marsh) at China Camp have also been relatively well-preserved with little direct human modification. Among San Pablo Bay's few relict tidal prehistoric tidal marshes (Petaluma Marsh (Petaluma River), Fagan Slough (Napa River), Whittell Marsh (Point Pinole)), China Camp retains the greatest extent and diversity of terrestrial (upland and wetland) ecotone vegetation with high native plant species diversity and complex vegetation patterns.

The following is a qualitative descriptive account of China Camp tidal marsh vegetation conditions based primarily on long-term field observations between 1991-2011, a period including prolonged intervals of drought and high rainfall associated with long-term marsh salinity fluctuations, and one extreme storm erosion event (1997-98 El Nino). The aims of this account are: (1) to identify qualitative relationships between vegetation and marsh landforms, substrates, topography, and drainage patterns; (2) to describe qualitative long-term trends or cycles in vegetation change; to summarize plant species composition of China Camp marsh vegetation in context of the regional variation in tidal marsh vegetation.

6.2 Historical and prehistoric tidal marsh units

The relict prehistoric tidal marsh platform and its terrestrial ecotones occur within interior and landward portions of the marsh, including the partially drowned alluvial valleys (Back Ranch, Miwok Meadow) that are enclosed by San Pedro Road and connected to tidal flows by culverts (Figure 1). The ancient marsh platform is associated with the original, highly sinuous tidal marsh creek networks that extend between drowned hills, forming hillslope islands and island-like peninsulas (Jake's Island, Turtleback Hill, and unnamed south shore knolls; Figure 1), that extend towards alluvial deposits of small intermittent stream valleys. The outer (eastern) portion of the tidal marsh, in contrast, consists of two younger and distinct marsh subunits developed in historical times: a broad, fringing high tidal marsh platform or terrace, bounded by an active or relict wave-cut marsh scarp; and a highly dynamic outer low tidal marsh belt that periodically extends into tidal mudflats. The simpler and more uniform patterns of vegetation, topography, and drainage of the younger, post-reclamation era marsh contrast with the more complex and diverse vegetation patterns of the old, interior tidal marshes at China Camp.

The physical landforms of the tidal wetlands provide an ecogeomorphic framework for marsh vegetation structure and many physical processes that influence it. The following description of the tidal marsh vegetation is organized in terms of its diverse landforms and depositional environments.

*Figure 1. Prograded modern high tidal salt marsh terrace (*Sarcocornia pacifica dominant*) with fringing low salt marsh spreading across mudflats below the relict erosional wave-cut scarp (*Bolboschoenus maritimus *and* Spartina foliosa dominant*), south end of China Camp Salt Marsh, 2006. View is north to Jakes Island (background). Note low marsh extending into few, simple straight shore-normal tidal channels.*

6.3 Vegetation of the modern high marsh terrace and fringing low marsh

Most of the outer tidal salt marsh vegetation at China Camp is readily distinguished by a broad and nearly flat terrace with relatively limited development of internal tidal channels or complex internal vegetation gradients and mosaics (Figure 2). The simplicity of the outer tidal marsh structure is particularly evident in the wider, southern half of the marsh south of Jake's Island. The outer salt marsh exhibits relatively simple shore-parallel vegetation patterns marked by sharp and discontinuous apparent zonation of low (*Spartina*) and high (*Sarcocornia*) marsh (Figure 3), with increasing channel density and decreasing marsh width towards Gallinas Creek. The outer marsh vegetation is historical in age; it formed seaward of the prehistoric tidal marshes in San Pablo Bay as a result of 1) tidal marsh progradation initially induced by Gold Rush hydraulic mining outwash under the influence of both tidal and wave deposition of fine sediment accumulated from hydraulic mining spoils discharged from the Sacramento River, and 2) later reduction of tidal prism due to diking and tidal marsh reclamation (Atwater *et al.* 1979). Net marsh progradation at China Camp continued throughout most of the 20th century, interrupted with marsh shoreline retreat episodes that began to prevail over progradation by the 1990s (Jaffe *et al*. 1998, Doane 1999).

Figure 2. Ground view of abrupt zonation at relict marsh scarp: tall, dense, nearly monotypic Sarcocornia pacifica *high marsh above the relict marsh scarp, prograding* Spartina foliosa *zone of low salt marsh below intermediate, variable narrow zone of* Bolboschoenus maritimus. *View to south, south end of China Camp Marsh. April 2011.*

Two vegetation subunits of contrasting age, structure and dynamics have developed in the prograded outer tidal marsh. The inner subunit comprises a relatively stable high salt marsh terrace with significant vertical accretion of stiff bay mud (silty estuarine clay; Reyes clay soils) and fibrous organic matter (Goman 2005), dominated by *Sarcocornia pacifica* (Hopkins and Parker 1984, Li *et al.* 2005*)*. The outermost unit comprises a broad, fringing low salt marsh formed by clonal spread of *Spartina foliosa* (Li *et al.* 2005*)* across younger, soft bay mud tidal flats, and it is subject to significant episodic storm erosion.

Figure 3. Extensive infestation of Sarcocornia*-dominated prehistoric salt marsh by annual parasitic* Cuscuta salina *during a drought year (July 2008). View southeast from Turtleback Hill. [photograph courtesy of Amelia Ryan].*

The nearly flat high marsh terrace is dominated most of the year by tall, shrubby growth forms of *Sarcocornia pacifica*, occurring in either monotypic or low-diversity stands (Hopkins and Parker 1984, Li *et al.* 2005, Ryan 2009). *Sarcocornia* is typically associated with the middle and high salt marsh zones, where it is often dominant in San Francisco Bay (MacDonald 1977, Peinado *et al.* 1994). The *Sarcocornia* vegetation develops variable but often highly seasonal and extensive "blooms" of the annual shoot-parasitic herb, *Cuscuta pacifica* var. *pacifica (*syn. *C. salina* var. *major)*. *Cuscuta* can dominate extensive areas of *Sarcocornia* on both the young high marsh terrace and prehistoric interior salt marsh, becoming subdominant to dominant at times (Figure 4). It forms conspicuous, brilliant orange mats that temporarily shroud or smother *Sarcocornia*, usually reaching peak abundance in mid- to late summer. *Cuscuta* mats are usually most frequent and extensive on the landward portions of the high marsh terrace. Extensive patches of *Sarcocornia* dieback may follow severe *Cuscuta* infestations some years, especially in successive years of drought. Because of the strong seasonality and interannual variability in *Cuscuta* cover, it has sometimes been underestimated as an important or seasonally co-dominant component of China Camp's tidal marsh vegetation (for example, Li *et al.* 2005*)*.

Figure 4. Tidal creek patterning of the prehistoric interior salt marsh plain vegetation: shrubby Sarcocornia *and* Grindelia *dominate high marsh bordering creek banks; patchy mosaics of* Sarcocornia *(dominant),* Distichlis*, and common salt marsh forbs compose the plain's vegetation. June 2006. View southeast from Turtleback Hill.*

Relatively few other common salt marsh plants occur sporadically in the high salt marsh terrace, including *Limonium californicum, Distichlis spicata, Frankenia salina,* and *Jaumea carnosa,* and *Atriplex prostrata*. Other species less frequently associated with the well-drained high marsh vegetation of the terrace include *Polypogon monspeliensis, Cotula coronopifolia, Spergularia salina,* and *Spergularia macrotheca.* These species occur more frequently near well-drained banks of tidal channels and ditches within the terrace. *Limonium californicum* appears to track the vegetation gaps associated with numerous, large, unstable, wracks (drifted litter mats of *Spartina* shoots and other organic debris smothering pickleweeed) deposited by waves overtopping the outer edge of the high marsh terrace. Other opportunistic colonizers, such as *Atriplex prostrata*, also rapidly establish in vegetation gaps in the outer marsh wrack zone. Very old, persistent large woody debris (persistent trunks and limbs of trees, wrecked docks and pilings) also provides topographic highs in the outer high marsh terrace, supporting erratic occurrences of upland weeds perched above the marsh, rooted in the decaying wood, such as *Bromus diandrus*.

The relative simplicity and homogeneity of the outer high marsh terrace is probably due in part to the deficiency of natural tidal channels and associated drainage gradients, a characteristic of prograded marshes subject to strong wave action along the north shore of San Pablo Bay (Atwater *et al.* 1979). Plant species diversity tends to increase locally around well-drained tidal channel and ditch banks of the terrace, similar to the vegetation those of the older tidal marsh slough banks.

Crests of tidal channel banks are conspicuously delineated by extensive, narrow stands of *Grindelia hirsutula* (syn. *G. stricta* var. *angustifolia*), frequent clonal patches of *Distichlis spicata, Jaumea carnosa,* and *Frankenia salina*, and tall, shrubby forms of *Sarcocornia pacifica*. The abundance and continuity of local channel bank *Grindelia* stands, and the size of individual plants, has been observed to decline markedly during drought periods of the 1970s-1980s (P.M. Faber, pers. comm.) and early 1990s.

Despite the presence of some tidal channels across the high marsh terrace, some extensive areas of *Sarcocornia*-dominated vegetation can nonetheless remain persistently flooded in stormy, wet winters. Significant storm-related tidal flooding and impeded drainage of the some portions of the marsh terrace appear to modify its vegetation in the following growing season. Large areas of *Sarcocornia* dieback (conspicuous "gray marsh" patches) invaded by the annual *Atriplex prostrata* in summer were evident on persistently waterlogged and wrack-rich segments of the China Camp marsh terrace in 1997-1998 El Niño years. The poorly drained portions of the high marsh terrace are largely devoid of distinct salt marsh pans, however.

The outer boundary of the high marsh terrace is marked by either an active or relict wave-cut scarp (near-vertical cliff typically less than 0.5 m high) cut in cohesive bay mud with high shear strength (due to high concentration of dense *Sarcocornia* root meshes; (Pestrong 1965)), or a sloping marsh erosion zone in various stages of post-storm recovery. The wave-cut scarp maintains a dynamic and relatively straight outer edge of the high marsh terrace vegetation, and a sharp discontinuity with the wide low marsh zone below it (Figures 1-3; Doane 1999).

Low-relief marsh berms, formed by wave deposition of sediment and debris, may temporarily form above the scarp crest. The well-drained marsh scarps and berms often support particularly dense, tall *Sarcocornia* vegetation after periods of stability, and occasionally support *Frankenia salina*, *Grindelia hirsutula*, *Limonium californicum,* and other high salt marsh forbs. These bay-edge high marsh vegetation stands are subject to erosion during scarp retreat during major storms.

Below the wave-cut scarp edge of the marsh, the intertidal profile may consist of temporarily barren mudflatfollowing severe storm erosion events.However, during low rainfall/high salinity years. it is usually dominated by a continuous and relatively uniform low marsh zone of pure *Spartina foliosa* (). During high rainfall/low salinity years, it is usually dominated by a matrix of *Spartina* interrupted by large (sometimes extensive and continuous) clonal colonies of *Bolboschoenus maritimus* along the higher, inner (scarp) edge of the low marsh belt. The *Bolboschoenus* zone associated with the relict marsh scarp is relatively well-differentiated from the *Spartina* zone at the south end of China Camp marsh, but this zone was not identified or distinguished from pure *Spartina* stands in the remote sensing analysis of vegetation by Li *et al.*

(2005). The low fringing marsh zone below the scarp narrows to the south, as the topographic relief of the relict or active high marsh terrace scarp increases, consistent with the apparent gradient of wave energy and width of wave-dissipating nearshore mudflats.

The intermittent active erosional marsh scarps at times appear to function as local sites of *Spartina* and *Bolboschoenus* recruitment by seedlings and clonal fragments. The scarps likely provide refuges for rhizomes of *Spartina* and *Bolboschoenus* following severe erosion events, enabling rapid clonal regeneration and spread during post-storm accretion of mudflats. *Spartina* or *Bolboschoenus* marsh progradation across the marsh/mudflat edge generally proceeds as a uniform linear front, rather than an irregular, diffuse patchwork of semi-circular colonies that is typical of seedling-initiated colonies on flat, wave-sheltered mudflats (*e.g.,* tidal restoration sites behind dikes). Direct colonization of the soft, unstable wave-disturbed mudflat surfaces by *Spartina* seedlings, in contrast, appears to be rare or precluded most years.

Bolboschoenus emergence in the fringing marsh is episodic, associated with years of high rainfall, late spring rains, and relatively low summer salinity. *Bolboschoenus* vegetation is typically associated with the middle marsh zone (MacDonald 1977; Peinado *et al.* 1994). It may fail to emerge in years of high salinity, but clonal populations may persist as dormant corms during high salinity periods for at least several years or longer (Pearcy and Ustin 1984). At China Camp mean winter and summer aqueous salinities in the 1970s were reported to range approximately from 20 to 30 ‰ (Atwater et al. 1979), which are inhibitory to growth of *Bolboschoenus maritimus*. Salinities near and below 20 ‰ were prevalent during the summer growing season during the late 1990s-mid 2000s period during which *Bolboschoenus* expanded significantly.

After long intervals with no intensive storm erosion, the inner edge of the low *Spartina/Bolboschoenus* marsh zone accretes vertically and regenerates scattered *Sarcocornia* patches. *Sarcocornia* readily invades accreted *Spartina foliosa* swards, and it may persist as a shaded understory layer below moderately dense *Bolboschoenus maritimus* stands as well. *Sarcocornia* rapidly replaces *Bolboschoenus* in drought/high salinity years that cause enforced dormancy (above-ground dieback) of *Bolboschoenus.* Continued accretion can obscure the relict high marsh scarp as older and younger stands of *Sarcocornia* coalesce. Gaps within *Spartina* infrequently support inconspicuous small populations of annual *Salicornia depressa*.

6.4 Vegetation of ancient slough-patterned prehistoric tidal marsh

The inner tidal marsh plain vegetation is developed on more complex environmental gradients and substrates associated with the ancient tidal marsh plain. The inner marsh plain is dissected by sinuous networks of stable prehistoric tidal creeks, and contacts terrestrial soils of alluvial valleys and hillslopes along its landward edges. The interior prehistoric marsh is late Holocene in age; the basal strata of the marsh developed since sea level stabilized near modern elevations during the last 4500 yr BP, but the modern upper marsh soil horizons are only a few centuries old (Goman 2005, Malamud-Roam and Ingram 2004). Pollen and sediment stratigraphy (long cores to depths up to 6 m below the modern marsh surface) reveals that most (67%) of the marsh's depositional history was dominated by relatively brackish tidal marsh conditions (Goman 2005; Malamud-Roam and Goman, Chapter 2) as well as alternating unvegetated mud and marsh deposition episodes, interpreted as disequilibrium phases of rapid sea-level fluctuations (Goman 2005). The stratigraphy of China Camp reveals that even in its brief (circa 4000 yr) late Holocene history, its vegetation has fluctuated markedly in response to climate and sea level (Malamud-Roam *et al*. 2007), and did not maintain a steady-state or classical "dynamic equilibrium" condition resembling familiar historical conditions.

Modern salt marsh vegetation on the ancient salt marsh plain is established on geomorphically mature landforms and soils (low-relief natural levees along larger tidal sloughs, nearly flat peaty marsh plains), but includes dynamic creek banks with high turnover of slump blocks and scarps (Gabet 1998, Fagherazzi et al. 2004). Nearly all of the prehistoric marsh plains of China Camp are devoid of marshplain salt pans, the shallow ponds between tidal creeks that were delineated in many U.S. Coast Survey T-sheet maps of San Pablo Bay tidal marshes of the pre-reclamation era. There is no indication that salt marsh pan features ever developed extensively at China Camp. The distribution of tidal marsh pans correlates with position along stream-influenced gradients of tidal sloughs in other San Pablo Bay tidal marshes (Grossinger 1995).

The middle salt marsh plain is a complex mosaic of *Sarcocornia* and associated common middle salt marsh zone forbs and grasses patterned around tidal drainages (Figure 4), including local subdominants *Distichlis spicata, Cuscuta pacifica* var. *pacifica, Jaumea carnosa,* and *Frankenia salina.* Infrequent species of the middle salt marsh plain include *Triglochin concinna*, *T. maritima*, *Spergularia salina, S. macrotheca*, *Polypogon monspeliensis, Limonium californicum, Cotula coronopifolia,* and *Atriplex prostrata*. The relative abundance of *Sarcocornia* and associated salt marsh forbs and grasses varies among years, typically with increasing relative abundance of *Sarcocornia* during years of low rainfall/high salinity. Abundance of common *Sarcocornia* associates on the middle marsh plain often increases with proximity to drainage influence of tidal channels.

Sarcocornia structure in the marsh plain is not uniform. It occurs as tall, shrubby patches, particularly in the vicinity of tidal creeks or topographic irregularities in the marsh with locally improved drainage. *Sarcocornia* also forms decumbent, low-growing turf-like patches with little branching of vertical shoots, a growth form more typical of maritime salt marsh on peaty or sandy substrates in West Marin.

One of the most conspicuous salt marsh vegetation patterns corresponds with drainage and local elevation gradients between creek banks and inner portions of the marsh plain. *Sarcocornia* height may reach 0.6 m or more along natural levees of larger tidal creeks. Narrow and often dense bands of robust, semi-evergreen *Grindelia hirsutula* (syn. *G. stricta* var. *angustifolia*), a perennial subshrub, delineate the banks of tidal creeks (Figures 4-7), but *Grindelia* is almost entirely absent on the marsh plain. It occurs in sporadic, discontinuous patches, often with low vigor, along high marsh ecotones bordering hillslopes. *Frankenia* and *Distichlis* stands are also robust and frequent near crests of channel scarps and natural creek levees.

Tidal creek bank vegetation conditions vary from near-vertical erosional scarps with overhanging dense *Sarcocornia-Distichlis-Frankenia* canopies, to dense *Spartina* low marsh (Figures 6-7). Erosional slump blocks are frequent along China Camp's mature tidal creeks, particularly after stormy winters. Cohesive, peaty slump blocks displace high salt marsh vegetation from bank tops and natural levees to intertidal elevations too low to sustain them, causing dieback and death. Slump blocks subsequently become colonized by *Spartina foliosa* (Gabet 1998) and trap fine sediment (Figure 7), causing localized cyclic salt marsh succession back to *Sarcocornia* and associated species (Gabet 1998). This process results in dynamic stability of creek banks, with high turnover of low and high marsh vegetation types, and unstable intermediate stages of conversion between them, at any given creek bank location.

During years of high rainfall and low channel salinity during the growing season, *Bolboschoenus maritimus* establishes or regenerates in sporadic but sometimes large (up to 5 m long) colonies within tidal slough banks.

Figure 5. Tidal marsh creek vegetation. Grindelia, Distichlis, *and* Sarcocornia *occupy high marsh above the bank crest.* Spartina foliosa *occupies the banks and slump blocks.*

Figure 6. Tall (>0.6 m), dense Sarcocornia *and* Grindelia *stands dominate the high marsh above a relict channel scarp along a large tidal creek.* Spartina foliosa *dominates the slump blocks below the scarp, accreting recent sediment deposits in the sheltered lee of the blocks and in the canopy.*

Figure 7. Brackish tidal marsh (choked tidal flows through culverts beneath San Pedro Road) exhibits a patchwork of Bolboschenus, Distichlis, *and* Sarcocornia*-dominated vegetation.* Grindelia *dominates channel and ditch bank crests. Oak woodland and valley grassland flank the marsh. Note riparian woodland and freshwater marsh in background, associated with alluvial fan of a small canyon stream. View to southwest. June 2006.*

6.5 Brackish tidal marsh

Areas of brackish tidal marsh occur in Miwok Meadow and Back Ranch Meadow, landward of N. San Pedro Road, where daily tidal flows are partially choked but maintained by culverts connected to tidal sloughs (Figures 1, 8-9a). Choked tidal flows and terrestrial freshwater discharges (groundwater and small streams) combine to damp tidal range and reduce salinity in the brackish marsh. The brackish marsh plain supports a mosaic of patches dominated by *Distichlis, Sarcocornia, Bolboschoenus,* and *Jaumea*, with *Grindelia* again dominating narrow zones bordering tidal creeks. During drought years, saline or hypersaline conditions can develop locally in the brackish marsh, causing dieback of *Bolboschoenus* and expansion of *Sarcocornia* stands. Brackish marsh and pans also support local or intermittently abundant stands of non-native *Cotula coronopifolia* and *Polypogon monspeliensis* that are otherwise minor elements in the fully tidal salt marsh.

Most local brackish marsh zones at China Camp lack the characteristic dominant coarse tules and bulrushes of low intertidal brackish marsh in northern San Pablo Bay, such as *Schoenoplectus acutus, S. californicus*, and *S. americanus*, even in areas occupied by *Typha latifolia* at Miwok Meadow and Back Ranch Meadow tidal marsh edges. At the south end of China Camp marsh, however, one extensive and fully tidal brackish marsh area supports a narrow and dense stand of sharply zoned hardstem tule (*Schoenoplectus acutus*) and *Bolboschoenus maritimus.* This disjunct occurrence of tule-bulrush tidal marsh (Figure 9b) occurs below a hillslope canyon drainage, terminating in one of the largest willow groves bordering the China Camp Marsh below N. San Pedro Road. Tule-bulrush marsh zones are otherwise found in San Pablo Bay only in upstream reaches of Napa Marsh, and very locally in Petaluma Marsh.

A few tidal marsh pans (marsh plain salt pans) occur in the brackish marsh landward of San Pedro Road (Figure 10) in the Miwok Meadow marsh, but pans are otherwise very rare in the fully tidal marsh below the road. Pan beds in the brackish marsh are persistently flooded for most of the year, flooded by spring tides and winter rainfall. They support dense stands of *Ruppia maritima* (submerged aquatic vegetation beds) in spring and early summer. *Ruppia* usually develops abundant epiphytic filamentous algal growth by summer, and goes dormant. The relatively stable marsh edges of brackish pans are associated with *Distichlis, Sarcocornia,* and *Jaumea. Bolboschoenus* marsh edges invade pan beds in years of low salinity. In contrast, the few small and shallow salt marsh channel pans (fully tidal marsh; Figure 10a) at China Camp lack *Ruppia*.

6.6 Terrestrial ecotones of tidal marsh

Where local terrestrial vegetation types (valley grassland, oak woodland, mixed evergreen forest, riparian woodland, and freshwater marsh; Howell 1970) contact or intergrade with tidal salt marsh, they form rare regional examples of tidal marsh ecotones, some of which support distinctive plant assemblages. Unlike at China Camp, dikes and diked former ecotones are prevalent in most of San Pablo Bay tidal marshes.

Figure 8. (a) Brackish high marsh plain vegetation with a broad terrestrial ecotone bordering freshwater marsh and riparian woodland, Back Ranch Marsh. Vegetation shown is a mosaic of Sarcocornia pacifica, Carex praegracilis, Juncus arcticus *ssp.* balticus, Distichlis spicata*, and* Typha latifolia *bordering* Salix lasiolepis *thickets. June 2006. (b) tule-bulrush-cattail (*Schoenoplectus actuus, Bolboschoenus maritimus, Typha latifolia*) brackish tidal marsh between tidal pickleweed salt marsh and willow grove, south end of China Camp Marsh, in association with seasonal stream drainage and perennial groundwater discharge.*

Figure 9. Tidal marsh pans at China Camp. (a, b). Small channel pans (relict cut-off segments of tidal channels) in fully tidal salt marsh lack Ruppia*. (c) brackish marsh pan with choked tidal hydrology supports continuous cover by* Ruppia *across the bed in spring 2008.*

Figure 10. High salt marsh ecotone with valley grassland of south-facing hillslopes is typically dominated by (a) co-dominant Leymus triticoides *and* Juncus lescurii. *(b)* Grindelia *abundance is typically confined to tidal creek banks rather than natural upland edges, but can locally dominate the lower edge of the high marsh zone. June 2008.*

Valley grassland is abundant along south-facing hillslopes of Turtleback Hill and surrounding areas to the south, dominated by *Nassella* spp. and non-native annual grasses. A distinct high tidal marsh zone is co-dominated by perennial, rhizomatous, dense sod-forming native rush and grass species *Juncus arcticus ssp. balticus* (in places intergrading morphologically with *J. lescurii*; Howell 1970) and *Leymus triticoides*, usually less than 2-3 m wide (depending on slope). This high tidal marsh zone forms a conspicuous ecotone between the upland hillslope bunchgrass/annual forb grassland, and the tidal marsh (Figures 11, 12). This *Leymus triticoides-Juncus arcticus* ssp. *balticus* assemblage recurs at other prehistoric tidal marsh edges in the San Francisco Estuary. The relative abundance of *Juncus arcticus* ssp. *balticus* increases in the vicinity of hillside seeps and road culverts, and on north-facing slopes; *L. triticoides* tends to dominate the assemblage otherwise. Both rhizomatous nonhalophyte species extend into the upper zone of *Sarcocornia-Distichlis* salt marsh, possibly aided by clonal integration (Evans and Whitney 1992). The *Juncus-Leymus* zone is notably poor in typical invasive non-native species widespread in tidal marsh levees of other Marin baylands.

The tidal marsh-terrestrial grassland ecotone along dry hillslopes at China Camp supports sporadic and small stands of *Grindelia hirsutula*, and upland shrubs such *Baccharis pilularis*, *Mimulus aurantiacus*, and *Toxicondendron diversilobum*.

Figure 11. Juncus lescurii *locally dominates the high salt marsh ecotone and intergrades with Distichlis-dominated salt marsh along the northwest slope of Turtleback Hill.*

Figure 12. Riparian woodland and brackish to fresh Cyperaceae-*dominated marsh (J*uncus lescurii, Carex praegracilis, Eleocharis macrostachya*) border tidally choked brackish* Sarcocornia-Distichlis *marsh west of N. San Pedro Road.*

Groundwater seepage from upland and alluvial slopes is evident in local patches or zones of brackish marsh ecotone vegetation along some hillslope and roadside locations in years of high rainfall. These are indicated by atypical high marsh zones co-dominated by *Bolboschoenus maritimus*, and supporting locally abundant *Distichlis spicata*, *Juncus bufonius*, and *Isolepis cernuus*, and occasionally *Triglochin maritima*. These low-growing graminoids are frequent on high brackish marsh edges that occur on gently sloping, terrestrial sandstone-derived soils of Miwok Meadow. At the south end of China Camp, seeps and culverted seasonal streams support willow woodland (*Salix lasiolepis*) with canopies that overhang the tidal marsh edge, fringed by *Bolboschoenus* stands extending into fully tidal *Sarcocornia* marsh.

The historical “willow-composite” riparian - high salt marsh ecotone species assemblage of San Francisco Bay, reconstructed by Cooper (1926), is scarcely and incompletely represented at China Camp. *Baccharis douglasii, Euthamia occidentalis*, and *Symphyotrichum chilense* (syn. *Aster chilensis*) occur locally in high brackish and salt marsh zones in San Pablo Bay, but have not been observed within tidal influence at China Camp. In contrast, woody riparian scrub elements, including *Umbellularia californica, Toxicondendron diversilobum, Sambucus mexicana, Scrophularia californica, Rubus ursinus, Rosa californica, Carex barbarae*, and *Baccharis pilularis*, have either persisted or regenerated spontaneously in local patches along hillslope edges of China Camp tidal marshes. These salt-intolerant species are rooted immediately above or even within the storm high tide line, marked by old drift-lines of estuarine plant litter. Riparian ecotones of tidal marsh edges at China Camp generally appear to be associated with seasonal seeps or locally elevated groundwater discharge zones, often marked by corresponding local increases in

Bolboschoenus maritimus density in the adjacent landward high marsh edge, as well as marginal seasonal wetland vegetation indicators in adjacent uplands. Willow groves (*Salix lasiolepis*) dominate terrestrial edges of brackish tidal marsh where perennial groundwater discharges maintain wet freshwater soil conditions most of the year, primarily at the mouths of seasonal surface drainages at the south end of China Camp Marsh, and along the upper limits of tidal flooding in Back Ranch Meadow.

Willow scrub, wetland sedge meadow, and oligohaline emergent (freshwater) marsh intergrade with tidally choked brackish marsh in the low-gradient alluvial valley of Back Ranch Meadow, landward of San Pedro Road (Figures 9, 13). These form an irregularly zoned ecotone that fluctuates in position and composition during drought and high rainfall cycles. Willow thickets (*Salix lasiolepis*) with ground layers dominated by *Carex praegracilis* grade into fresh-brackish high marsh assemblages dominated by thick rush-sedge meadows and emergent freshwater marsh, including *Typha latifolia, Carex praegracilis, Eleocharis macrostachya, Isolepis cernuus, Juncus arcticus* sspp. *balticus and mexicanus, J. effusus*, *J. phaeocephalus* and *Argentina egedii* (syn. *Potentilla anserina* ssp. *egedii*), contiguous with a brackish marsh plain dominated by *Sarcocornia, Distichlis*, and *Jaumea* (Figure 9a). This brackish-fresh wetland gradient is flooded during extreme high winter tides. During drought years, the *Typha* stands in the freshwater- oligohaline-brackish high tidal marsh ecotone below the willow thicket at Back Ranch Meadow die back, and is invaded rapidly by *Distichlis* and *Sarcocornia* (Figure 13). *Carex praegracilis* also expands in the willow ground layer when the canopy thins during droughts. Sedge-rush meadow dominated by *C. praegracilis* in the brackish ecotone, in contrast, appears to resist rapid displacement during droughts.

On north-facing slopes of Turtleback Hill, oak woodland canopies overhang or contact tidal salt marsh, creating dense shade and litter-dominated marsh edges. *Quercus agrifolia, Heteromeles arbutifolia, Baccharis pilularis, Toxicondendron diversilobum*, and *Umbellularia californica* rooted above the tide line extend branches up to 2 meters or more into tidal salt marsh at some locations where they dominate surface cover. On steep south-facing slopes of Jake's Island, which support coastal bluff scrub (*Artemisia californica, Castilleja foliolosa, Dudleya farinosa, Mimulus aurantiacus, Toxicondendron diversilobum* assemblages with non-native annual grasses), terrestrial ecotones are abrupt except where slope failures occur and spread terrestrial soil masses on the marsh plain, sometimes entraining vestiges of bluff scrub vegetation. *Galium aparine* (non-native annual forb, also present in European high salt marsh ecotones) and the native clonal perennial forb, *Ambrosia pycnostachya*, are associated with this local ecotone, in association with *Sarcocornia, Distichlis*, and *Grindelia*.

Within China Camp State Park, but south of the main China Camp Marsh, lies a pocket marsh and marsh berm (barrier beach deposited on top of a retreating wave-cut marsh peat scarp, capped with high marsh vegetation, mostly *Distichlis*) enclosed between Headlands north of China Camp Beach. This pocket beach and marsh encloses a small lagoon with no tidal outlet, overtopped by storm waves during extreme high tides. The lagoon, essentially a perennial salt pan dominating the marsh, supports almost continuous cover of *Ruppia maritima*.

Figure 13. Senescent, moribund stands of Typha latifolia *during drought years are rapidly invaded by* Distichlis *(a) and* Sarcocornia *(b) in the fluctuating fresh-brackish marsh ecotone*

6.7 Uncommon native tidal marsh plants

China Camp tidal marshes are not known to support rare or endangered plant species endemic to the tidal marshes of the estuary. Populations of *Chloropyron maritimum var. palustre (syn. Cordylanthus maritimus* ssp. *palustris;* northern salt marsh bird's-beak) have been reported from Bucks Landing, immediately north of China Camp, but this regionally rare plant has not spread into China Camp marshes. In San Francisco Bay, this historically widespread species is restricted to Marin County bayshores and one recently reported population in Newark, Alameda County. Rare tidal marsh ecotypes of *Castilleja ambigua*, historically known from Mill Valley, Corte Madera, and Novato tidal marshes (now extirpated; Baye *et al*. 2000, Howell 1970), have not been detected in remnant prehistoric tidal marsh at China Camp.

Glaucous-leaved salt marsh ecotypes of *Festuca rubra* are common in Drakes and Tomales Bay tidal marshes, but in the San Francisco Estuary they are unique to China Camp, where they occur locally in high salt marsh on the northeastern shore of Turtleback Hill. Terrestrial ecotypes of this species are otherwise locally common on dry grassland of hillslopes above salt marshes from San Rafael (Marin Islands) to Richardson Bay. The north shore of Turtleback Hill also supports two other species seldom reported from high tidal marsh edges of San Pablo Bay: *Lotus purshianus* (growing extensively among *Distichlis* and *Salicornia*) and a very small high tidal marsh population of *Zigadenus fremontii* that may be a vestige of the Marin halophytic population still recognized taxonomically as *Z. fremontii* var. *salsus* (originally described by W.L. Jepson; reported by Howell as "rare along the edge of salt marshes, as…near San Antonio Creek where it grows with *Distichlis* and *Salicornia*" (Howell 1970, Howell *et al*. 2007)). No other populations of this variety are currently known from San Pablo Bay tidal marsh edges.

Ambrosia psilostachya, a clonal perennial forb with moderate salt tolerance (Salzman and Parker 1984), occurs uncommonly in tidal marsh edges of San Francisco Bay and San Pablo Bay. One extensive, sparse colony occurs in the high marsh ecotone of the southern Turtleback Hill shoreline, and one other local occurrence is known from the sandy beach at south China Camp State Park.

Zeltnera trichantha (syn. *Centaurium trichantha*), a slender annual forb, occurs locally at several locations in the high tidal or brackish marsh zone of China Camp near Turtleback Hill and Back Ranch Meadow, bordering hillslopes and road fills. This is the only known current salt marsh location remaining in San Pablo and San Francisco Bays for this species, which was historically present in their tidal marsh edges (Baye *et al*. 2000).

The annual forb *Polygonum marinense* occurs locally in high brackish marsh edges of the north side of Miwok Meadow marsh, and at scattered locations at the southern shorelines of China Camp salt marshes. This putative native "rare" salt marsh annual is now widespread in San Pablo Bay, and may be a cryptic non-native introduced plant (Howell *et al.* 2007).

6.8 Exotic and invasive tidal marsh plants

Compared with most San Pablo Bay tidal marshes, China Camp has escaped – to date – the brunt of regional invasions by exotic salt marsh species, mostly from Europe and Asia. For example, perennial pepperweed (*Lepidium latifolium*), Mediterranean tarplant (*Dittrichia graveolens*) and Australian or Pacific bentgrass (*Agrostis avenacea*) have rapidly invaded disturbed levees and high tidal marsh edges in San Pablo Bay in recent years. *L. latifolium* is limited to local disturbed brackish marsh edges at the north and south end of China Camp, above and below San Pedro Road. The annual forb *Dittrichia graveolens* has to date remained very infrequent in roadside tidal marsh edges of China Camp. Recent invasion by a non-native Algerian sea-lavender (*Limonium ramossisimum*) in Richardson Bay has not yet spread to suitable habitat at China Camp. *Juncus gerardi*, an invasive clonal rush in brackish marshes in eastern San Pablo Bay and western Carquinez Straits (Point Pinole), has not yet been detected in China Camp or elsewhere in western San Pablo Bay.

Hybrid smooth cordgrass (*Spartina alterniflora* x *foliosa*), arguably the greatest invasive non-native plant threat to the estuary's tidal marshes, has established at least at Bullhead Flat in China Camp, but the full abundance and distribution of the population is difficult to determine because of the inherent uncertainties of identifying morphologically cryptic introgressant (hybrid backcross) genotypes. This invasive and often cryptic hybrid/introgressant swarm is subject to ongoing eradication efforts by the Invasive Spartina Project of the California Coastal Conservancy. Spread of introgressant *S. foliosa* with superior adaptive physiological, anatomical, and morphological traits of *S. alterniflora* (increased salt tolerance, mechanical stress tolerance, submergence tolerance, etc.) may alter the erosion and progradation patterns of the fringing marsh/mudflat zone, and ancient tidal creek morphology. Chilean *Spartina densiflora*, which has been nearly extirpated from San Rafael Bay/Corte Madera by the Invasive Spartina Project, has not been detected in or near China Camp salt marshes.

Many non-native wetland and upland weeds occur in or near drift-lines of the uppermost marsh edges, especially in the vicinity of road culverts and disturbed roadside fill. These species seldom become abundant or highly invasive in China Camp tidal marsh vegetation; they include *Atriplex prostrata, Bromus hordeaceus*, *Cotula coronopifolia, Hordeum gussoneanum, Lolium perenne, Lotus corniculatus, Lythrum hyssopifolium, Mentha pulegium, Polypogon monspeliensis*, *Parapholis incurva, Sonchus oleraceus*, and *Spergularia rubra*.

6.9 Conclusions

China Camp's tidal marshes conserve regionally rare and exceptionally well-preserved examples of prehistoric slough-patterned salt marsh plain vegetation, and multiple types of tidal marsh-terrestrial ecotones. Most other prehistoric tidal marsh remnants in the North Bay have agriculturally altered or reclaimed (diked) edges with largely artificial and often mostly non-native vegetation. In addition, China Camp's tidal marshes have suffered relatively little from regional invasions by non-native tidal marsh plants, even in recently formed (post-reclamation era) portions of its tidal marshes. For these reasons, it provides outstanding opportunities for research, and use as a regional model for tidal marsh management and restoration.

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7. Climate Change and San Francisco Bay-Delta Tidal Wetlands

V. Thomas Parker[1], **John C. Callaway**[2], **Lisa M. Schile**[3],
Michael C. Vasey[1], and **Ellen R. Herbert**[1]

[1]*Department of Biology*
San Francisco State University
1600 Holloway Avenue
San Francisco, CA 94132

[2]*Department of Environmental Science*
University of San Francisco
2130 Fulton Avenue
San Francisco, CA 94117

[3]*Department of Environmental Science, Policy and Management*
University of California, Berkeley
137 Mulford Hall #3114
Berkeley, CA 94720-3114

ABSTRACT

In addition to increases in atmospheric CO_2 concentration, warmer temperatures, and shifts in precipitation, climate change will impact tidal wetlands with higher rates of sea-level rise and higher concentrations of salt in brackish and freshwater tidal systems. In the San Francisco Bay-Delta, the areas most likely to be impacted, brackish and freshwater tidal wetlands, are also the sites with the majority of endemic plant species and the greater biodiversity and productivity. Impacts on the San Francisco Bay-Delta estuary are complex and difficult to predict, but a few things are clear. Biodiversity of the tidal wetland system in the San Francisco Bay-Delta region will decline, with subsequent impacts on ecosystem functioning and services. Altered plant production, physiological tolerances and shifts in rates of mortality will modify wetland plant communities in ways not yet predictable. Lower ecosystem productivity from salinity increases will impact both primary and detrital-based food webs. Such changes will cascade via the food webs into invertebrate, bird and pelagic systems. Tidal wetlands are especially sensitive to processes that climate change will alter. Several of these altered processes are exacerbated by water diversions from the Delta.

KEY WORDS

salt marshes
brackish tidal wetlands
freshwater tidal wetlands
climate change
salinity
sea-level rise
Mediterranean-climate

7.1 Introduction

Climate change will have significant global impacts on tidal wetland ecosystems. In addition to responses to changes in CO_2, temperature, and precipitation that all biotic communities will experience, tidal marshes also will experience shifts in salinity and sea level. The root causes of these global changes are increases in atmospheric greenhouse gasses like CO_2 (Meehl et al. 2007, Richardson et al. 2009). Plants will experience both direct effects from CO_2 increases as well as the indirect effects of CO_2-mediated climate change (Hayhoe et al. 2004, Meehl et al. 2007, Church et al. 2008). For example, because of different physiological adaptations, increases in CO_2 concentrations might favor some wetland species at the expense of others because of its role as a plant resource (e.g., C3 over C4 species, Drake and Rasse 2003, Rasse et al. 2005). CO_2-influenced climate change will impact plant respiration, rates of decomposition, soil carbon storage, soil nutrient cycling, mycorrhizal symbionts and herbivory. By itself, increases in sea level will account for some losses of tidal wetlands and, globally, estimates range from 22% to 70% loss of coastal wetlands (Nicholls et al. 1999, Najjar et al. 2000, but see Hughes 2004). As a consequence, the San Francisco Bay-Delta estuary is predicted to change dramatically under every scenario of future climate change and sea-level rise.

We will examine current patterns of global change in more detail as the context for analyzing potential future changes in tidal wetlands in the San Francisco Bay-Delta (Cayan et al 2008a, b). We will first consider scenarios of how California's climate and other processes are suggested to change in the near future. Using those changes as a framework, we will then examine potential plant responses. Wetland vegetation will respond in a complex manner to these shifting processes, but an underlying lack of knowledge about most plant species means that we have great uncertainty about any projection of climate-change related impacts. Some species favored by increases in atmospheric CO_2 concentration, for example, may not respond well to temperature increases in the growing season, while others may respond favorably. Productivity and survival of other species certainly will be reduced simply by salinity increases. Overall, there will likely be significant shifts in wetland composition, especially in the brackish and freshwater portion of the estuary.

7.2 Current patterns of tidal wetland vegetation

The salinity gradient formed by the mixing of freshwater from the San Francisco Bay-Delta watersheds and saltwater from the Pacific Ocean form the template for the distribution of a variety of wetland types. In freshwater areas, sites are dominated principally by large and very productive plants such as *Schoenoplectus acutus* and *Salix lasiolepis*. These wetlands are quite high in annual net productivity, exceeding 2000-2400 gm m^{-2} yr^{-1} (Atwater et al. 1979, Parker et al. unpublished data). Species richness is also quite high in freshwater tidal sites and we have found up to 58 different plant species in as few as ten 0.1 ha plots at Sand Mound Slough near the mouth of the Delta (Vasey et al. Chapter 4).

At the other end of the salinity gradient, salt marshes contain few species, and the marsh plains are dominated almost exclusively by *Sarcocornia pacifica* (formerly *Salicornia virginica*). Species like *Spartina foliosa* are found in low marsh sites or restricted to channel and/or upland edges, like *Grindelia stricta* var. *angustifolia*, *Jaumea carnosa* or *Distichlis* spicata. For example, a comparable random sample of ten 0.1 hectare lots at China Camp State Park, a remnant salt marsh in lower San Pablo Bay and part of the San Francisco Bay National Estuarine Research Reserve, yielded just ten tidal marsh species (Vasey et al. Chapter 4). Annual net productivity is low compared to freshwater wetlands of the Bay-Delta, ranging from 400-1200 gm m^{-2} yr^{-1} depending on site conditions (Mahall and Park 1976).

Between the salinity and freshwater extremes are a range of brackish marshes with intermediate and variable species richness and productivity dependent on patterns of salinity and inundation. Many of the endemic species of the San Francisco Bay-Delta, such as *Lathyrus jepsonii* and *Cirsium hydrophilum* var. *hydrophilum,* are restricted to brackish wetlands. All the tidal wetlands also connect with adjacent terrestrial and pelagic systems as a resource base for food webs in those ecosystems. Consequently, because of cross-boundary ecosystem subsidies (Polis and Herdt 1996, Harding 2002), the influence of climatic change is likely to be critical not only to tidal wetlands but also to the adjacent systems with which they are linked.

7.3 Changes in the composition of the atmosphere and subsequent impacts

In the last 20-30 years, concentrations of CO_2 and other greenhouse gasses have dramatically increased (Meehl et al. 2007, Richardson et al. 2009). Current levels of greenhouse gasses are already believed to have impacted global climates (Meehl et al. 2007). Models indicate these gasses may increase in the future; depending on assumptions, by 2100 CO_2 will increase to 400 ppm or up to near 1000 ppm (Meehl et al. 2007, Cayan et al. 2008b). Current rates of increase in CO_2 concentration are on a pace to reach the higher values (Richardson et al. 2009). Such increases will facilitate continued and dramatic climate change. For example, in California, models suggest that temperatures may rise significantly during the 21st century, from 1.5-7° C for a variety of scenarios involving increases in greenhouse gasses (Dettinger 2005, 2006, Cayan et al. 2008b).

Directly or indirectly, the changes resulting from increases in greenhouse gasses will impact both the physical dynamics of tidal wetlands, plants and their interactions within these wetlands, and animals that live in them or depend upon them. Most predicted changes for northern California, including increases in temperature, unpredictable impacts on precipitation, major losses in watershed snowpack, shifts in runoff patterns, and increases in the rate of sea-level rise, all will impact tidal wetland dynamics. Taking these processes together, critical changes in tidal wetlands will result in eventual increases in wetland salinity and duration of inundation (Figure 1). The rest of this chapter examines these probable impacts in the context of the San Francisco Bay-Delta estuary and its tidal wetlands.

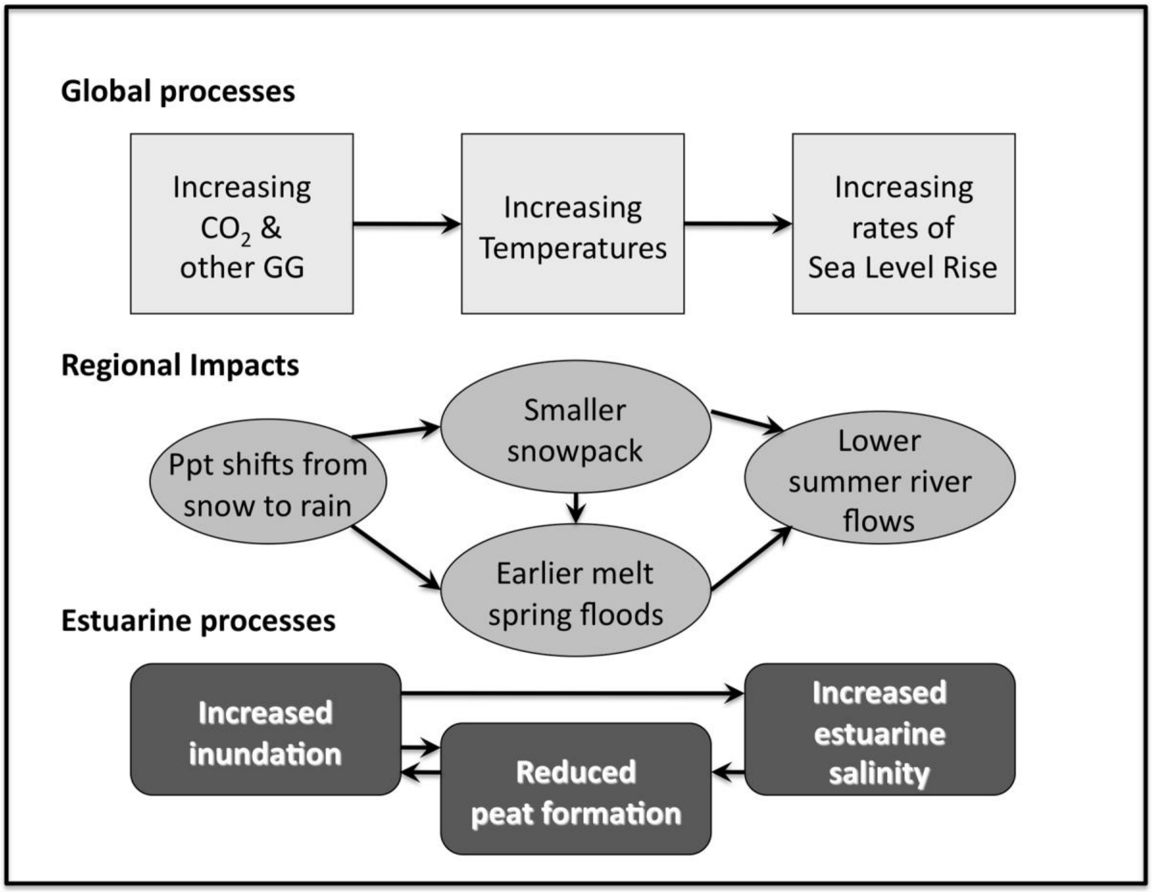

Figure 1. Principal processes governing impacts of climate change on the San Francisco Bay-Delta estuary. The first level containing CO_2 & greenhouse gasses, increasing temperature, and sea-level rise represent global processes. Below that are regional processes that are either the result of direct or indirect impacts of global processes on the Sacramento-San Joaquin watershed. The final level indicates processes within the estuary that will directly impact tidal vegetation in addition to the global and regional processes.

7.4 Impacts of rising temperatures on the Bay-Delta Estuary: Sea-level rise and salinity

Increasing temperatures will act globally, regionally and locally to impact wetlands (Figure 1). For example, temperature increases driving both thermal expansion of the world's oceans and melting of terrestrial ice sheets are believed to be primarily responsible for increases in rates of global sea-level rise, which has been close to 2-3 mm/yr over the last few decades (e.g., Stevenson et al. 2002, Meehl et al. 2007, Church et al. 2008). Historical rates before 1930 were generally less than 1 mm/yr, rising to 2 mm/yr between the 1930s to the 1950s, and declining during the 1960s and 1970s due to increases in global volcanic activities (Church et al. 2005). Increases in rates of sea-level rise are reported in most parts of the world (Hughes 2004, Holgate and Woodworth 2004, Cazenave and Nerem 2004, Church and White 2006), and recent re-evaluations of global data suggest even faster rates (Richardson et al. 2009). Rates are now over

3 mm/yr since around 1992 (Holgate and Woodworth 2004, Beckley et al. 2007, Church et al. 2008). The IPCC estimated sea-level rise of 10-59 cm by 2100 but later raised estimates to 18-79 cm (Meehl et al. 2007). The higher range would be more than a doubling of current rates, even though these rates are quite conservative because the IPCC did not include changes in the rates of melting of large ice sheets like Antarctica or Greenland. Melting has increased in the last decade (Rignot and Kanagraratnam 2006); therefore, rates of sea-level rise actually may increase much more than predicted (Rahmstorf 2007, Vermeer and Rahmstorf 2009). The most recent estimates of sea-level rise are suggesting more than a meter increase by 2100 (Richardson et al. 2009, Vermeer and Rahmstorf 2009); process models attempting to account for ice sheet melting are just beginning and bring uncertainty to these rates, which could be significant underestimates (Richardson et al. 2009, Vermeer and Rahmstorf 2009).

Historical rates of sea-level rise in the Bay-Delta have been similar to global averages, with the exception of localized regions or time periods of high subsidence rates, and future increases are also likely to mirror global predictions (Cayan et al. 2008a). Models of sea-level rise for the San Francisco Bay-Delta, however, are complicated by other forces. For example, during the negative phase of the Pacific Decadal Oscillation (PDO), climate change impacts on the rate of sea-level rise will be slowed, while a shift to the positive phase may result in an accelerated rise (Ramp et al. 2009, Largier et al. 2010). Combined with other processes (e.g., ENSO), fluctuations in sea level rise may have a greater impact on wetlands than a steady increase.

Locally, other influences from increased average temperatures will be just as great on estuarine wetlands (Figure 1). The primary impacts will result from several changes. One is the shift in precipitation toward an increase in rain at the expense of snow in the Sierran watershed (Lettenmaier and Gan 1990, Knowles and Cayan 2002, Miller et al. 2003, Hayhoe et al. 2004, Knowles et al. 2006, Cayan et al. 2008b). These changes in snowpack storage will shift timing of freshwater flows into the estuary, increasing flows in winter with potential flooding (Knowles and Cayan 2002, Miller et al. 2003, Hayhoe et al. 2004). The remaining smaller snowpack (Hayhoe et al. 2004, Cayan et al. 2008b) consequently will lead to reduced summer river flows entering the estuary. Lower flows will shift the freshwater-marine mixing interface eastward, progressively encroaching upon the Delta, and increasing salinity in brackish regions of the Napa River, Suisun Bay and potentially up into the western Delta (Goman and Wells 2000, Stahle et al. 2001, Byrne et al. 2001, Malamud-Roam et al. 2007). Current water management actions have not changed the net climatic influence on estuary salinity, and likely will not influence even greater future impacts (Enright and Culberson 2010). The net result of all of these changes will be an estuary with higher mean sea level, increased duration and frequency of inundation, and higher salinities.

Bay-Delta wetlands also are affected by Mediterranean-style summer droughts. Porewater in high marsh areas in salt marsh and brackish tidal wetlands significantly increases in salinity during the warmer, rainless growing season. Our monitoring of wetland soil salinities across the estuary indicates that by late summer salinity only a few meters away from channels is two to three times its concentration in adjacent estuarine waters (Parker et al, unpublished data). Increasing average temperatures (Meehl et al. 2007, Richardson et al. 2009), increased frequency of heat waves (Cayan et al. 2008b), and additional salt inputs due to sea-level rise will exacerbate these summer rises in high marsh salinity. As a consequence, gradual increases in salinity in the San Francisco Bay-Delta estuary will promote brackish wetlands converting to salt marshes, and intruding brackish waters impacting areas that are currently fresh.

7.5 Climate change impacts on Bay-Delta wetland vegetation

Among wetlands, freshwater and brackish tidal systems will exhibit the greater sensitivity with large shifts in plant composition and productivity in response to elevated salinity levels, impacts that will likely cascade into terrestrial and pelagic food webs. Currently, brackish wetlands are most prominent up the Napa River and in much of the Suisun region. These brackish wetlands transition to freshwater tidal systems farther up the Napa and into the Delta. Because so many processes are changing simultaneously, however, these tidal systems are likely to change dramatically with unpredictable increases or declines by multiple species.

The San Francisco Bay-Delta system currently experiences seasonal and annual variation in salinity (Fox et al. 1991, Peterson et al. 1995), and historically, the brackish zones have shifted across parts of the estuary (Atwater et al. 1979, Goman and Wells 2000, Byrne et al. 2001, Malamud-Roam et al. 2007). More recently, the brackish zones have experienced increased salinity due to water diversions upstream, with subsequent shifts in plant composition (Stahle et al. 2001, Malamud-Roam et al. 2007). Such a historical perspective leads to confidence that wetlands have some resilience in the face of global changes. The changes that will be experienced in the future, however, will be accompanied not only by increased salinity in the system, but also shifts in CO_2 concentrations, higher temperatures, accelerated sea-level rise, and increasing water diversions, all within the context of a highly urbanized estuary.

Decreases in summer-fall watershed freshwater flow and sea-level rise will shift the saltwater-freshwater mixing zone inland up the estuary, expanding saline influences and increasing wetland soil salinities through time (Figures 1, 2). Temperature increases will accelerate rates of evapotranspiration, also escalating soil salinities in areas not flushed daily by tides and further influenced by the dry-summer Mediterranean-climate compared to many temperate regions (Figure 2). Brackish wetland plant communities will shift towards plants with greater salinity tolerance, for example, *Sarcocornia pacifica*, *Spartina foliosa*, and *Distichlis spicata* (Mall 1969). The latter two, however, are C4 plants and may be at a metabolic disequilibrium with C3 plants that have some salinity tolerance. Further, these changes will be occurring simultaneously in the context of other globally shifting processes, such as increased frequency and duration of inundation due to sea-level rise (Figures 1, 2). We have found that *S. pacifica* produces biomass at very different rates throughout the northern Bay wetland system depending on frequency and duration of inundation along a salinity gradient (Schile et al. 2011). In well-drained areas, *S. pacifica* seems indifferent to changes in soil salinity and produces relatively high amounts of biomass. In poorly drained areas, plants are sensitive to salinity and decrease in productivity with increases in salinity. An estuary with increasing salinity will shift to more salt-tolerant species like *S. pacifica*, but if inundation frequency and duration increase due to a rising sea level, salt marshes in the lower Bay-Delta may actually be lost and overall estuarine productivity could decline considerably.

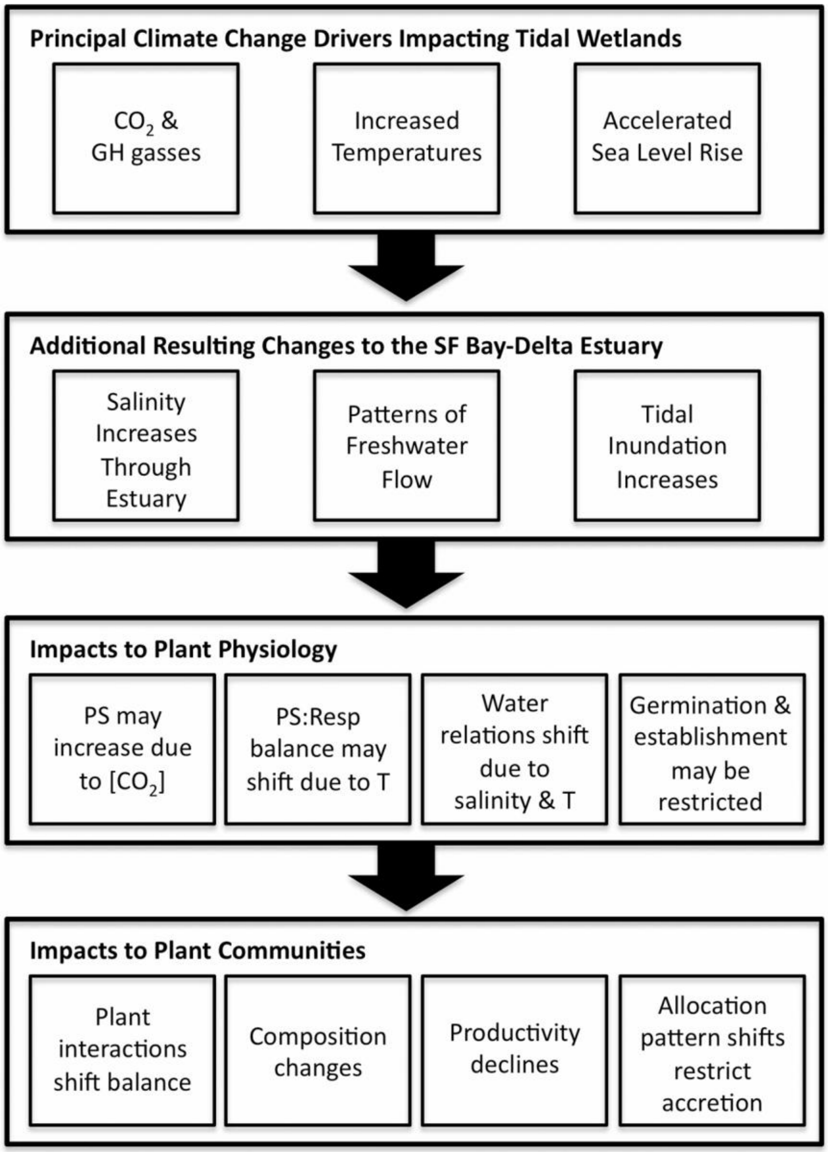

Figure 2. Cascading impacts of global climate change processes on tidal wetlands. Impacts of increased concentration of carbon dioxide (CO_2) and other greenhouse gasses (GH), increased temperature (T) and accelerated sea level rise (SLR) will directly and indirectly influence plant physiology and stress. Subsequently, changes will occur in the outcome of plant interactions due to shifts in physiological performance, for example, of photosynthesis (PS) and cellular respiration (RESP). Composition of wetlands will change, productivity will decline and these changes may restrict the organic component of vertical accretion.

These environmental shifts will not impact all species within tidal marshes equally. Changes in hydrology, salinity and other impacts of climate change will shift interactions among plants. CO_2, temperature and increased inundation and soil salinity will strongly influence plant metabolism (Figure 2). CO_2 is an essential plant resource required for photosynthesis (Figure 2). Long-term studies, particularly in the Chesapeake Bay, indicate that a number of ecosystem processes will be impacted by increased concentration of CO_2 alone, including photosynthesis, carbon storage and cycling and soil nitrogen fixation and nitrogen dynamics (Drake et al. 2003, Rasse et al. 2003, Johnson et al. 2003, Pendall et al. 2004, Rasse et al. 2005, Marsh et al. 2005, Hungate et al. 2005a, 2005b). Changes in the carbon composition of plants and their structural characteristics may reduce herbivore attack or their effects (Stiling et al. 2003, Cornelissen et al. 2004).

Experimental studies indicate that overall increases in CO_2 seem to differentially favor plants with C3 photosynthesis at the expense of those with a C4 metabolism (Rasse et al. 2005). While these studies found that some acclimation occurred, not all plants fully acclimated and still revealed increased rates of photosynthesis or plant density even after 17 years (Rasse et al. 2005). Other wetland research focused on C4 plants found that salt marshes are resilient to modest warming and large shifts in precipitation, although they conclude that interactive effects of multiple changes resulting from climate change may strongly affect wetland composition and function (Charles and Dukes 2009). While most of the species in the San Francisco Bay-Delta wetlands are C3 plants, *Spartina foliosa* and *Distichlis spicata* are C4 plants that are dominant in some parts of our wetlands and are likely to become comparatively less competitive.

At the same time, increasing temperatures will have both direct and indirect effects. Metabolic systems for any plant ecotype are adapted to limited ranges of temperatures, and enzymes involved in photosynthesis, respiration and other metabolic processes change in efficiency as temperature shifts away from their optimum. Generally, as temperature increases, photosynthesis and respiration rates both increase in an individual plant. At some point, photosynthetic enzymes reach a peak and photosynthesis declines past that threshold while respiration continues to increase (Figure 3). This will first affect productivity and later plant survival as increasing respiration rates consume stored carbon. Most studies of climate change impacts on ecosystems have focused on CO_2 concentration more than temperature (e.g., Rasse et al. 2005). Yet long-term research suggests that the shift in the balance between photosynthesis and respiration is already decreasing forest productivity (Clark et al. 2003). Unlike increases in CO_2, temperature shifts are more likely to favor C4 plants over C3, complicating our ability to predict the overall response of wetland vegetation to climate changes. Additionally, future climate scenarios suggest up to 7°C average temperature increases for California, significantly greater than average global increases (Dettinger 2005, 2006, Cayan et al. 2008b). Such extreme increases are more likely to reduce growth and increase mortality rates in wetland plant species.

Historically, wetlands maintain themselves against sea level rise by both accretion and upland retreat. A number of uncertainties exist about future rates of sea-level rise, such as estimates of glacial and icepack melt input (Meier et al. 2007, Vermeer and Rahmstorf 2009). The most recent model of estimated rates of sea-level rise for the San Francisco Bay-Delta indicate that the estuary has had historical rates equivalent to the global average (Cayan et al. 2008a). If the San Francisco Estuary continues to parallel global averages, this suggests a conservative estimate of a rise of 11-79 cm by 2070-2099 (Meehl et al. 2007), with the real possibility of 1 m to nearly a 2 m rise by 2100 (Richardson et al. 2009, Vermeer and Rahmstorf 2009). While wetland accretion in the San Francisco Bay-Delta has generally kept up with increases in sea level during the last several thousands of years (Goman and Wells 2000, Byrne et al. 2001, Orr and Williams 2003, Malamud-Roam et al. 2007), the amount of suspended sediment in Bay-Delta water suggests accretion rates may not be able to keep up with accelerated sea level rise and upland retreat is blocked by levees or development in many places. Clearly, the relationship between marsh accretion, inundation, and salinity will have variable impacts on tidal marsh species that are difficult to predict (Watson and Byrne 2009).

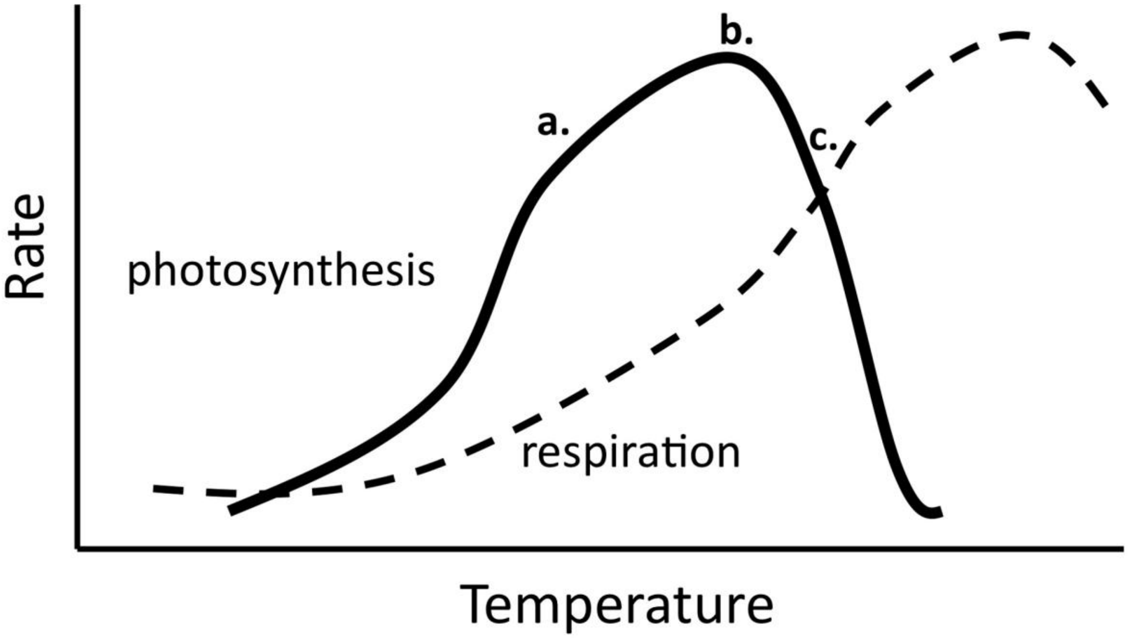

Figure 3. The potential impact of increasing temperatures on the relative balance between photosynthesis and respiration in wetland plants. Depending on their current temperature optima, any particular species might have a different balance in these metabolic rates. For example if these processes are currently at temperature a, *then the balance between photosynthesis and respiration will be weighted in favor of photosynthesis and further increases in temperatures in the short term will maintain or increase that ratio. At temperature* b *photosynthesis will have peaked and further increases in temperature means a decrease in plant productivity as photosynthesis declines but respiration continues to increase. Finally, at temperature* c, *the rate of respiration now exceeds that of photosynthesis and mortality will occur after carbon reserves are used.*

The future of tidal wetlands in this context of predicted sea-level rise is challenging (Stralberg et al. 2011). Because of human development on or near the Bay and Delta, areas for wetland retreat are limited, wave energy will increase, and wetlands are likely to erode in a shoreward direction (e.g., Crooks 2004). While wetlands likely could keep pace with moderate increases in sea level of up to 6 mm/yr (Patrick and DeLaune 1990, Orr et al. 2003), this may not occur with higher rates of sea-level rise that other researchers suggest may occur (Meier et al. 2007, Church et al. 2008, Richardson et al. 2009, Vermeer and Rahmstorf 2009). Suspended sediment in estuary waters may be insufficient for compensatory wetland accretion after a threshold rate of sea-level rise is reached (Orr and Williams 2003); past that threshold, only the organic contribution by plant growth remains as the driving mechanism for wetland accretion. Current models suggest that wetlands have a lag in response to rising sea level with a significant variation in productivity. Wetlands appear to be stable when the wetland surface is above the optimal elevation (Morris et al. 2002). Unless belowground plant productivity compensates with large increases in biomass production, the result will be increases in the frequency and duration of tidal inundation (Figure 2), leading to increased plant stress. Existing low marsh areas would be converted to mudflats, and low marsh plants would migrate into areas previously dominated by marsh plain vegetation (e.g., Donnelly and Bertness 2001). Depending on conditions along the wetland-upland border, wetlands would either migrate inland, or in many cases around the Bay-Delta, they would be restricted by adjacent dikes and development, a process often referred to as coastal squeeze (Titus 1991, French 2001), or because many wetlands are islands. Increased rates of sea-level rise will differentially impact the viability of restoration projects in the Bay-Delta region by reducing the opportunity for plants to establish in newly restored wetlands (see table in Callaway et al. 2007).

Another impact that is poorly understood is the combination of increases in estuarine salinity and rates of sea-level rise and reductions in plant productivity on the dynamics of physical-biological processes creating substrates within wetlands. Specifically, wetland substrates change in tandem with the salinity gradient. Within the freshwater tidal regions, the substrate is highly organic. These substrates become increasingly mineral in more saline areas, such that the salt marsh substrates have lower organic content than freshwater wetlands and are dominated by fine clays (e.g., Nyman et al. 1993). As the estuary increases in salinity and plant productivity declines, including in the rooting zone, even greater rates of mineral sediment inputs will be required for wetlands to remain stable with sea-level rise because of the reduction in belowground productivity and corresponding decrease in organic composition of substrates.

In addition to altered rates of growth as a result of climate shifts, other types of impacts will occur (Jin 2008, Figure 2). Increases in soil salinity and inundation will differentially affect germination and the physiological limits of species. For example, the salt marsh shrub *Grindelia stricta* var. *angustifolia*, while tolerant of high salinities, requires a considerable reduction in salinity for germination; complete inhibition of germination occurs by salinities at or above 23 ppt (Wayne 1995). Six years of drought in the late 1980s-early 1990s and corresponding salinity increases during germination resulted in more than a 90% reduction in population size at China Camp salt marsh (Parker, unpublished data). Such impacts on germination and survival will result in a shift in species composition through time, regardless of how environmental changes impact productivity. In salt marshes within the Bay-Delta, wetland productivity will only decline slowly without large composition or structural changes. However, in brackish and freshwater tidal marshes, changes in salinity of a few parts per thousand will have considerable impacts because the growth, productivity, and survival of most species are highly sensitive to any salinity, which could have significant impacts on the diversity and composition of these wetlands.

Lastly, as part of the California Floristic Province, the Bay-Delta presents relatively high levels of local species endemism, particularly in the brackish marshes of San Pablo Bay, Suisun Bay, and the lower Delta. As highlighted by Loarie et al (2008), local endemic species are highly susceptible to the forces of rapid climate change, particularly in cases where their dispersal is likely to be constrained by impermeable barriers. Endemic flowering plant species in the Bay-Delta (e.g., *Cirsium hydrophilum*) could be particularly susceptible to the kinds of changes described above.

7.6 Implications and Conclusions

In summary, global climate changes are differentially affecting tidal wetlands compared to temperate terrestrial ecosystems (Nicholls et al. 1999, Ellison 2000, Stevenson et al. 2002) and may already be shifting these ecosystems into novel states (Donnelly and Bertness 2001). Impacts on the San Francisco Bay-Delta estuary are complex and difficult to predict, but a few points are clear. Biodiversity of the tidal wetland system in the San Francisco Bay-Delta region will decline, with subsequent impacts on ecosystem functioning and services (e.g., Hooper et al. 2005). Changes in concentrations of carbon dioxide will impact plants directly, as well as increased temperatures, and their direct and indirect effects (Figure 1) will alter plant production, physiological tolerances and rates of mortality (Figure 2). The result of shifting tolerances and the changes in the balance among plant interactions will lead to altered wetland plant communities. The earliest recognizable changes in estuary wetlands will be due to salinity increases because even with current levels of water management, climate patterns govern shifts of salinity in the estuary (Enright and Culberson 2010). As summer temperatures rise and Sierra snowmelt decreases, we should expect saline ecosystems to increase in distribution and increase in area upstream, with losses principally in brackish and freshwater tidal wetlands and their local endemic species, leading to overall lower ecosystem productivity. Increases in sea-level rise will further shift plant distributions with an increase in species that are more tolerant of inundation (e.g., *Spartina foliosa*, *Schoenoplectus* spp., *Typha*) at moderate rates of sea-level rise and outright loss of wetlands at higher rates. These changes will impact both primary and detrital-based food webs and cascade via these food webs into invertebrate, bird and pelagic systems (e.g., Galbraith et al. 2002, Hughes 2004).

What is also clear is that long-term and appropriate management of the estuary will conflict with other resource demands of California under current policies and social perspectives. The San Francisco Bay-Delta Estuary is beginning to reverse a century of tidal wetland loss through large-scale wetland restoration projects across the estuary (Callaway et al. Chapter 3; Callaway et al. 2007), but current Bay and Delta development at low elevation and increasing demands on freshwater supply will emerge as major threats to the estuary, as will shifts in the overall sediment budget of the estuary. Globally, a consensus is emerging that policies need to accommodate and adapt to changes that will accompany climate change. Attempts to maintain and defend estuarine and coastal developments inevitably will become increasingly costly (Crooks 2004) at the expense of the estuarine ecosystem and the ecological services provided.

Great uncertainties underlie much of the modeling that suggests the future scenarios for the San Francisco Bay-Delta estuary. We did not consider predicted extreme events, such as longer series of hot or cold years, large earthquakes, severe storms, normal shifts in patterns of precipitation, increased frequencies in flooding or other changes that will occur as temperatures and sea-level rises (Cayan et al. 2008b). Changes in wetland vegetation will not follow simple gradient shifts because of these extreme events, but rather change opportunistically following episodic droughts or heat-waves that result in large diebacks or reduced growth after thresholds in salinity or heat tolerances are reached. These will undoubtedly have major impacts on the system as well. For example, spring 2001 experienced a brief heat wave early in the growing season that caused a temporary setback in the restoration of a newly formed marsh on the Petaluma River (Tuxen et al. 2008). Other uncertainties are more global, for example, rates of melting of Greenland or the Antarctic, disruptions of the Atlantic thermohaline circulation, shifts in decadal processes such as the El Niño-Southern Oscillation, or other "tipping points" that may cause rapid disruptions in our estuary (Lenton et al. 2008).

At present we need more research into a number of issues to fully understand the impact of climate change on the San Francisco Bay estuary so that appropriate policies and management actions can be developed (e.g., Sutherland 2004). Clearly, restoration of new wetlands needs to proceed rapidly so that their development will not be inhibited by increased erosive energy resulting from future increases in sea-level rise. Once established, restored marshes with well-developed vegetation are likely to be more resistant to impacts from sea-level rise or other environmental changes. However, restoration priorities need to focus on sites not subjected to potential coastal squeeze or else modify the site barriers to retreat along with the wetland restoration. In addition, there are a number of issues needing further research that are not discussed here such as the impact of invasive species. Changes in precipitation or temperature have already aided in the spread of wetland invasive species (Minchinton 2002, Loebl et al. 2006). Invasive invertebrates are eroding marshes in southeastern Britain at relatively rapid rates, and the increased temperatures of climate change may stimulate that process (Hughes 2004); ironically, the Bay-Delta has any number of plant and invertebrate invasive species that potentially will synergize with climate change to create an even greater impact on this ecosystem in the future. We are unsure exactly how our dominant wetland species will respond to the range of changes resulting from climate change. We lack information on the links between biodiversity in brackish and freshwater tidal wetlands and ecosystem functioning. Finally, we do not know the effectiveness of current conservation measures and policies governing human development and potential paths for biotic retreat in areas increasingly threatened in the near future. Natural ecosystems such as the Bay-Delta provide too many ecological services to society to be ignored or reduced in priority.

The San Francisco Bay-Delta estuary embodies a nexus of natural ecosystems and socio-economic policies that have come into conflict in the face of rapid environmental change. This icon of our region is at risk, as is the economic health and vitality of its dependent human society. As we shift into the enterprise of mitigating greenhouse gas emissions, we also must embrace a practice of adaptation to the suite of potential ecological changes described above. Innovative use of water storage and flows, land use policies that favor corridors and refugia to accommodate wetland migration, restricted infrastructure in or adjacent to wetlands, and many other measures will be needed to break the traditional pattern of ecosystem sacrifice in the interest of short-term gain. The manner in which we face this challenge realistically and act accordingly, will tell the tale.

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8. A Comparison of Water Column Nutrients and Pelagic Chlorophyll-*a* in Salt Marsh Sloughs and Main Channel Habitats of the Northern San Francisco Estuary

Alexander Parker[1] and **Risa A. Cohen**[2]

[1]*Romberg Tiburon Center for Environmental Studies*
San Francisco State University
3152 Paradise Drive
Tiburon, CA 94920
aeparker@sfsu.edu
(415) 338-3746

[2]*Department of Biology*
Georgia Southern University
P.O. Box 8042
Statesboro, GA 30460
rcohen@georgiasouthern.edu
(912) 478-1228

ABSTRACT

Tidal salt marsh habitats are thought to play an integral role in estuarine biogeochemical cycles. The paradigm in salt marsh biogeochemistry is that marshes act as nutrient sinks and organic matter sources. However, at present few published studies exist for nutrients and phytoplankton stocks in salt marsh sloughs of the northern San Francisco Bay Estuary. Two independent research and monitoring programs were initiated to fill this information gap by providing the basis for a comparison of nutrients and phytoplankton between salt marsh habitats and adjacent main channel habitats at several locations in the northern estuary, including locations near the San Francisco Bay National Estuarine Research Reserve site at Rush Ranch. Further process-based studies are needed to constrain the exchange of nutrients and phytoplankton between salt marsh habitats and the estuary; however, this summary of available data suggests that the potential flux of nutrients and phytoplankton biomass is likely site-specific and driven by local processes.

KEY WORDS

salt marsh
phytoplankton
nutrients
Suisun Marsh
biogeochemistry
Browns Island
Napa River

8.1 Introduction

Salt marshes play an important role in the biogeochemistry of estuarine and coastal ecosystems. The paradigm that emerged from marsh studies during the 1960s and 1970s (e.g., Teal, 1962; Valiela and Teal, 1979) is that salt marshes act as sinks for inorganic nutrients through the production of marsh plant biomass and act as organic matter sources through the export of detritus (Teal and Howes, 2002). While many studies support these early ideas, large amounts of site-specific variation in magnitude and direction of nutrient flux have been observed, most notably as a function of marsh age (Valiela and Teal, 1979; Childers and Day, 1990; Teal and Howes, 2002). As a result, some ecosystems models of salt marsh nutrient cycling based on generalization may not be applicable to specific systems (Nixon, 1980; Zedler, 1996).

Much of our understanding of nutrients and organic matter in salt marshes comes from Atlantic coast salt marshes (e.g. Teal, 1962; Valiela and Teal, 1979). Although studies of west coast marshes are becoming more available (e.g., Zedler, 1996; Boyle, et al., 2004), there has been little direct study of the biogeochemistry of salt marshes in the San Francisco Bay Estuary (SFBE) (Bucholz, 1982; Josselyn, 1983; Jassby, 1993). In light of the dramatic loss of salt marsh habitat in the SFBE during the late nineteenth and early twentieth centuries (Malamud-Roam and Goman, Chapter 2), and the more recent restoration of salt marsh habitats occurring today in the SFBE (Grenier and Davis, 2010), more detailed study of salt marsh biogeochemical function in the SFBE are needed.

Salt marshes are thought to intercept and transform nutrients, particularly nitrogen, between upland environments and coastal waters (Valiela and Teal, 1979; Teal and Howes, 2002; Koop-Jakobsen and Giblin, 2010). Groundwater, precipitation, N_2-fixation and tidal exchange all contribute to N inputs while N losses through tidal exchange with surrounding waters or to the atmosphere via denitrification are the primary N outputs (Valiela and Teal, 1979; Brin et al 2010) although few of these N processes have been studied directly in SFBE marshes (see Yorty, 2007). Because of assumed high denitrification rates in sediments, salt marshes can withstand large N additions (Teal and Howes, 2002) and have been used as natural tertiary 'treatment facilities' for municipal wastewater (Sherr and Payne, 1981; Peterson and Teal, 1996). For example, Bucholz (1982) studied N flux in a restored salt marsh adjacent to a wastewater discharge pipe in south SFBE and found that the marsh acted as a wastewater N sink.

Salt marshes can also act as organic matter sources, exporting detritus, algae and dissolved organic matter. Indirect evaluation and modeling in the SFBE suggest that less than 10% of estuarine organic matter has its origin in salt marsh habitats (Jassby, 1993) with much of the dissolved and detrital particulate organic matter being refractory in nature (Sobczak, et al., 2002; Sobczak et al., 2005). The organic matter that drives the SFBE estuarine food web is primarily from phytoplankton (Canuel et al., 1995; Jassby and Cloern 2000; Mueller-Solger, 2002) with some exceptions (Howe and Simenstad 2007), and high phytoplankton biomass in salt marsh sloughs is possible as a result of relatively long water residence times in tidal channels compared to the main estuary (Schroeter, 2007; Sommer et al., 2002). Additionally, shallow water depths in sloughs and tidally exposed benthic habitat allow for the presence of benthic diatoms that help to fuel ecosystem primary production (Bucholz, 1982; Lopez et al

2006; Cohen, unpublished). Phytoplankton production in salt marsh habitats is variable (Haines, 1979; Spiker and Schemel, 1979; Lucas et al., 2002), thus it is difficult to quantify the role of salt marsh phytoplankton population as food for higher trophic levels throughout the SFBE (Howe and Simenstad, 2007). However, phytoplankton stocks in salt marsh sloughs may be labile organic matter sources for the main estuary assuming that they are either exported there with the tides or consumed by estuarine fish and invertebrates foraging within the salt marsh habitat (Deegan and Garritt, 1997).

Between 2004 and 2007, two research and monitoring programs were completed independently by the authors, in part to address these information gaps. The programs, funded through CALFED's Integrated Regional Wetlands Monitoring Program and the UC Sea Grant / CALFED Science Fellowship Program, provide the basis for a comparison of nutrients and phytoplankton at several locations within both natural and restored northern SFBE salt marshes. While the studies were not designed specifically to address nutrient and phytoplankton flux associated with salt marsh restoration (Lopez et al, 2010), the information presented here provides a baseline characterization that may be used to understand future salt marsh restoration outcomes and gauge restoration success.

The two studies were carried out in the northern SFBE at locations in the western Delta, Suisun Marsh, and the Napa-Sonoma Marsh Complex and provide spatial and temporal information for sloughs within these salt marsh habitats. The results provide the basis to address the following expectations: 1) Spatial variation in nutrient and chlorophyll-*a* concentrations both between and within salt marsh locations are strongly influenced by local conditions such as municipal activity, salinity gradient, and dominant vegetation type. 2) Temporal variation in nutrients and chlorophyll-*a* are likely related to hydrologic conditions, with elevated nutrients in winter and spring and a delay in chlorophyll-*a* until summer and 3) Salt marsh habitats are generally sources of nutrients and chlorophyll-*a* to main channel deep water channel habitats of the adjacent subembayments of the northern SFBE.

8.2 Materials and Methods

Site Descriptions-

Three salt marsh locations were sampled including habitats in the low salinity western Delta, Suisun Marsh and the Napa River Marshes (Napa-Sonoma Marsh Complex). The western Delta sites were located at Browns Island and Sherman Lake, near the confluence of the Sacramento and San Joaquin Rivers east of Suisun Bay (Figure 1A). This region of the estuary is the focus of much research because this transition zone between fresh and saltwater is critical habitat for estuarine fish (Kimmerer, 2004; Sommer et al., 2007). Both of the western Delta locations contain tidally influenced brackish marshes. Browns Island is an 3.4km^2 natural reference, while tidal flow was restored to Sherman Lake (13.1km^2) in the 1920s (S. Siegel, pers. comm.). Browns Island and Sherman Lake are similar in that tidal channel sides are steep with little exposed mudflat area at low tide, and the dominant vegetation consists of *Scirpus* spp and *Typha* spp. rather than *Spartina* spp. However, the channels in Sherman are often clogged with several types of invasive macrophytes, including floating *Eichhornia crassipes* and submerged rooted

Cabomba caroliniana in the warmer months. Besides the occasional *C. caroliniana* fragments, these plants were not abundant at Browns Island. Human use of the two sites also differs. Sherman Lake is a popular site for duck hunting, fishing, boating, and water sports compared to Browns Island. As part of the Integrated Regional Wetland Monitoring Pilot Project (IRWM) each site was sampled during the growing season (Spring through Fall) in 2004 and 2005. Water temperatures in channels within the marshes were similar in both years of the study, ranging from 14 ^{o}C - 23^{o}C. Salinity measured was always low (i.e., $\leq$ 3, on the practical salinity scale, S).

Suisun Marsh occupies an area of 340km^2 to the north of Grizzly Bay (Brown, 2003) and is the location of one of the two research sites comprising the San Francisco Bay National Estuarine Research Reserve (SFBNERR)(Figure 1B). Nearly all of Suisun Marsh was diked by the 1930s; today roughly 10% of the original tidal wetlands remain (Brown, 2003). For the majority of Suisun Marsh, water flow is managed to support waterfowl and ranch land for raising livestock. Six open water slough locations were visited monthly between June 2007 and May 2008 (Figure 2). Three of the slough locations (Boyton, Peytonia, and Sheldrake Sloughs) are along the western boundary of Suisun Marsh; Boynton Slough is the receiving water for wastewater discharge from the City of Fairfield. Additionally, three slough locations were sampled along the northeastern edge of Suisun Marsh (Little Honker Bay, Denverton, and Nurse Sloughs). Salt marsh restoration, via a constructed breach, began in 2006 at the Blacklock restoration site adjacent to Little Honker Bay. Water temperatures in Suisun Marsh ranged from 8.8 ^{o}C - 22.0 ^{o}C over the study period and salinity ranged from 1.8 S to 8.5 S with lower values found in winter and spring.

The 154km^2 Napa-Sonoma Marsh Complex consists of tidally influenced wetlands associated with the Napa River approximately 20km east of the China Camp site of the SFBNERR in San Pablo Bay (Coastal Conservancy, 2005) (Figure 1C). Land use in the surrounding 1100 km^2 watershed is primarily agriculture associated with livestock and vineyards, as well as urban development. However many of the Napa wetlands were historically altered through levees to create commercial salt ponds (Williams and Orr, 2002). In recent years, many of the levees have been breached to return tidal flows, and the breached wetlands are in various states of restoration (Williams and Faber, 2001). The IRWM project focused on three estuarine wetlands in the Napa River region: two 'restoring' sites (Bull Island, 1950s and Pond 2A, 1995), and one natural reference site (Coon Island) (Figure 1B). Bull Island is the most upriver location followed by Coon Island in close proximity, while Pond 2A is the most downstream, separated by greater distance than Bull and Coon Islands (Howe and Simenstad, 2007). Water temperatures in channels within the marshes were similar in both years, ranging from 13.5 ^{o}C - 25.0 ^{o}C. Salinity ranged from 0.3 psu – 20.5 psu; low salinities were generally observed in spring at the upriver locations.

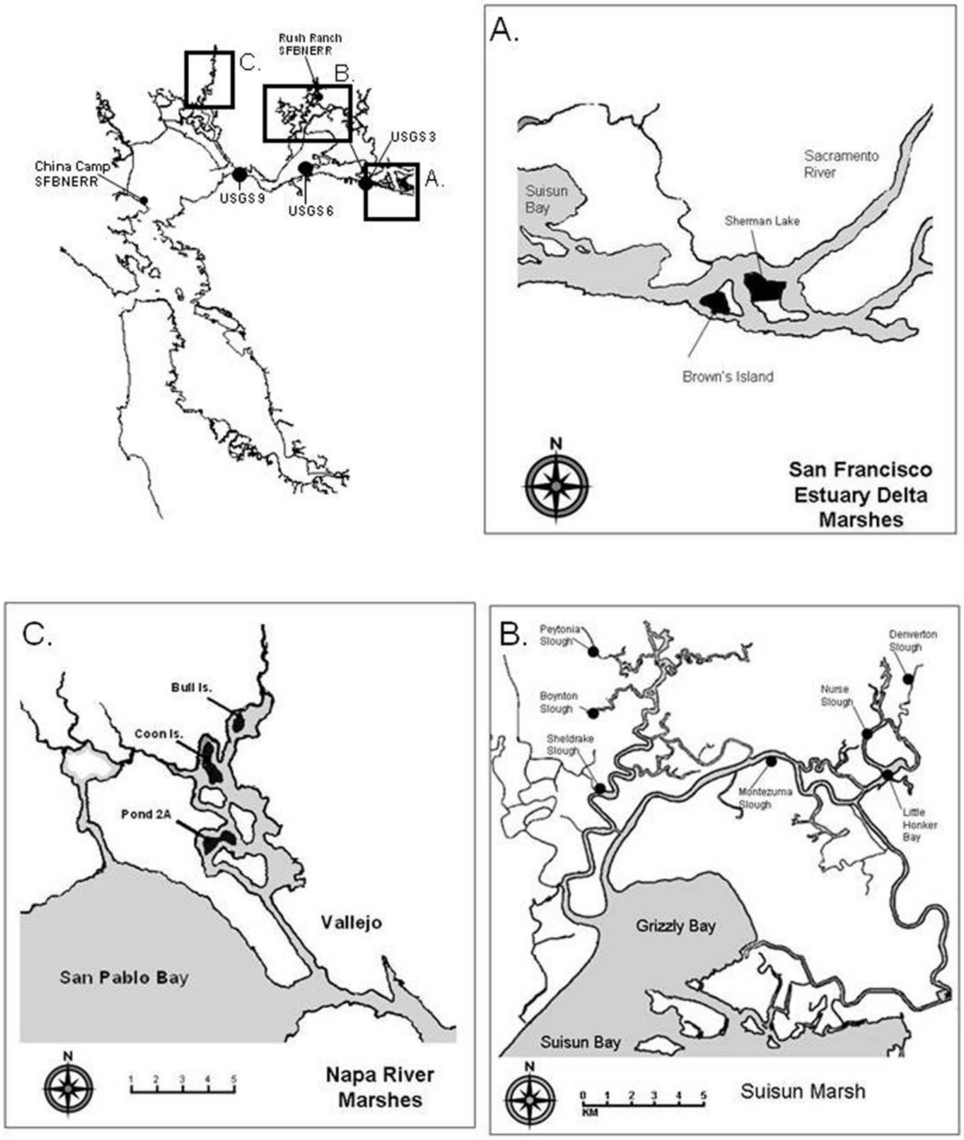

Figure 1. Map of northern San Francisco Bay Estuary salt marshes studied as part of the CALFED Integrated Regional Wetland Monitoring Pilot Project and UC Sea Grant - CALFED Science Fellowship Program. A) San Francisco Estuary Delta Marshes (Browns Island and Sherman Lake) B) Suisun Marsh was divided into stations in western sloughs (Boynton, Peytonia, and Sheldrake Sloughs) and eastern sloughs (Denverton and Nurse Sloughs and Little Honker Bay) C) three sites within the Napa River Marshes (Napa-Sonoma Marsh Complex). Closed circles indicate the approximate locations of the USGS main channel water quality monitoring stations. The locations of the San Francisco Bay National Estuarine Research Reserve's sites at China Camp and Rush Ranch are also shown.

The Salt Marsh sites were compared to long-term nutrient and chlorophyll-*a* records for the main channel sampling program carried out by the US Geological Survey (Water Quality of San Francisco Bay Website, http://sfbay.wr.usgs.gov/access/wqdata). The channel stations were selected based on proximity to the salt marsh locations listed above. USGS station 3 at Pittsburg (38° 03.0′N, 121° 51.7′W) is ~0.9 km from Browns Island and was selected for comparison with the western Delta sites. USGS station 6 at Roe Island (38° 03.9′N, 122° 02.1′W) is ~ 14km south of the sampling locations within Suisun Marsh and was selected for comparison with these sites. USGS station 9 at Benicia (38° 03.0′N, 122° 10.4′W) was selected for comparison with the Napa-Sonoma Marsh Complex and is located ~10km downstream of the salt marsh locations. Because only a limited number of data points were available from the USGS in 2004-2005, we pooled nutrient and chlorophyll-*a* USGS data from 2005-2010 for each of the three stations. We compared the 5-year means for each of the inorganic nutrients to the 2005 mean using t-tests, and no differences emerged ($p > 0.15$ for all nutrients analyzed). Comparison of mean chlorophyll-*a* from 2005 and 2005-2010 were made using Mann-Whitney U tests, and again no differences were detected ($p > 0.25$).

Sample collection, nutrient and chlorophyll-a analysis

Surface samples were collected by hand using an acid-cleaned bucket deployed from a small boat. Sampling was completed monthly. Sampling in the western Delta and in the Napa-Sonoma Marsh Complex was completed at the end of the ebb tide near slack low water. Suisun Marsh was completed during ebb tide and efforts were made to sample close to slack high water. Analytical methods for determining chlorophyll-*a* concentrations were the same for both of the salt marsh studies and nutrient analysis was completed in the same laboratory using the same methods. Nutrient samples were gently filtered through decontaminated (combusted 450 C, 4-hr) GF/F filters using a syringe filter. NO_3, PO_4, and $Si(OH)_4$ were analyzed using a Bran and Luebbe AutoAnalyzer II according to the procedures of Whitledge et al. (1981) and Bran and Luebbe for $Si(OH)_4$ (1999). NH_4 was determined from separate samples according to Solorzano (1969). *In vitro* chlorophyll-*a* was determined using the extraction protocol of Arar and Collins (1992); samples extracted from volumes of 25- 100 ml (determined by filtration times) were read on a Turner Designs fluorometer calibrated with commercially available chlorophyll-*a* standards (Turner Designs). Seasonal averages and standard error for nutrients and chlorophyll-*a* were calculated from a minimum of three data points for each season and combining results for two years. In the case of Suisun Marsh, stations were binned as either western (three sites) or eastern sloughs (three sites). Seasons were defined as follows: spring = March – May; summer = June – August; fall = September – November, winter = December – February, with samples collected in the Napa-Sonoma Marsh Complex and at the western Delta marsh sites occurring in all seasons except winter. To avoid giving a false sense of generality by employing inferential statistics, we took a descriptive approach of characterizing the variability and patterns in this system to promote further study.

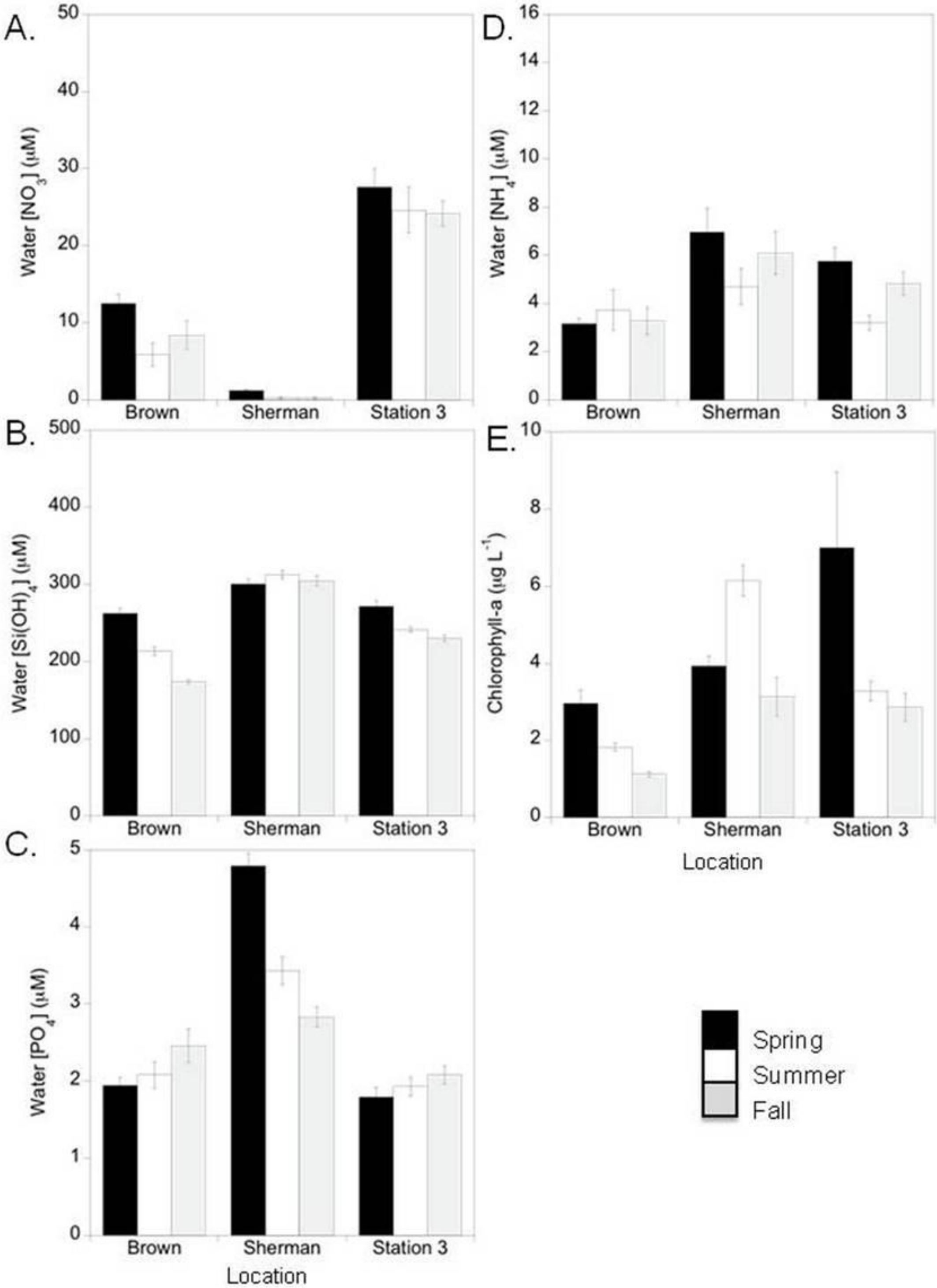

Figure 2. Mean (+/-se) seasonal inorganic nutrient and chlorophyll-a concentrations in salt marshes and adjacent main channel habitats in the western Delta of the northern San Francisco Bay Estuary. Salt marsh locations are Browns Island and Sherman Lake. Main channel site is the US Geological Survey water quality station 3. A) NO_3, B) $Si(OH)_4$, C) PO_4, D) NH_4 and E) chlorophyll-a.

8.3 Results

Browns Island and Sherman Lake

Nutrient and chlorophyll-*a* concentrations exhibited complex patterns at Browns Island, Sherman Lake and the associated main channel location, USGS station 3 (Figure 2), but a few interesting patterns emerged. Water column NO_3 concentrations at Sherman Lake were consistently low across seasons and potentially limiting, while station 3 had the highest concentrations (Figure 2A). In addition, Browns Island and station 3 appeared to have similar seasonal patterns in $Si(OH)_4$, PO_4 and chlorophyll-*a* concentrations compared to each variable at Sherman Lake (Figure 2B, C, E). Concentrations of NH_4 at Sherman Lake and station 3 were comparable in magnitude and seasonality and differed from concentration patterns at Browns Island (Figure 2D).

Suisun Marsh

Within each season, NO_3 and PO_4 concentrations were higher in the western sloughs compared to both eastern sloughs and the main channel site, USGS station 6 (Figure 3A, C). NO_3 concentrations averaged >100 µmol L^{-1} in the western sloughs for all but fall and were 4 to 5-fold higher than NO_3 in the eastern sloughs. Phosphate concentrations in the western sloughs ranged between 6.7 and 15.6 µmol L^{-1}compared to PO_4 concentrations of 0.38 – 4.7 µmol L^{-1} in the eastern sloughs in spring, summer and fall; during winter PO_4 concentrations were at times at or below detection limits. While there were spatial differences in NO_3 concentration between western and eastern sloughs and station 6, seasonal differences were not clear. Similarly, only spatial differences in PO_4 concentrations were apparent. NH_4 concentrations were different both spatially and temporally within Suisun Marsh and at station 6 (Figure 3D). NH_4 concentrations ranged between 0.62 and 4.70 µmol L^{-1} across all sloughs during spring, summer and fall and were highest in the western sloughs. During winter NH_4 concentrations were > 15 µmol L^{-1} across western and eastern sloughs. NH_4 at station 6 was also seasonally elevated during winter, but was lower than sites within Suisun Marsh. Both seasonal and spatial differences in $Si(OH)_4$ were evident across sites in Suisun Marsh (Figure 3B). Silicate concentrations were always >100 µmol L^{-1} in the Suisun Marsh sloughs but were lower $Si(OH)_4$ at station 6. Differences were observed for chlorophyll-*a* by location, but not seasonally (Table, Figure 3E). Chlorophyll-*a* concentrations in Suisun Marsh were always higher than average chlorophyll-*a* at USGS 6. During winter and spring, chlorophyll-*a* concentrations were similar in western and eastern sloughs, with spring chlorophyll-*a* concentrations 1.6 fold higher than winter values. During the summer and fall, chlorophyll-*a* values in the eastern sloughs increased slightly above spring values and were nearly 3-fold higher chlorophyll-*a* than western sloughs.

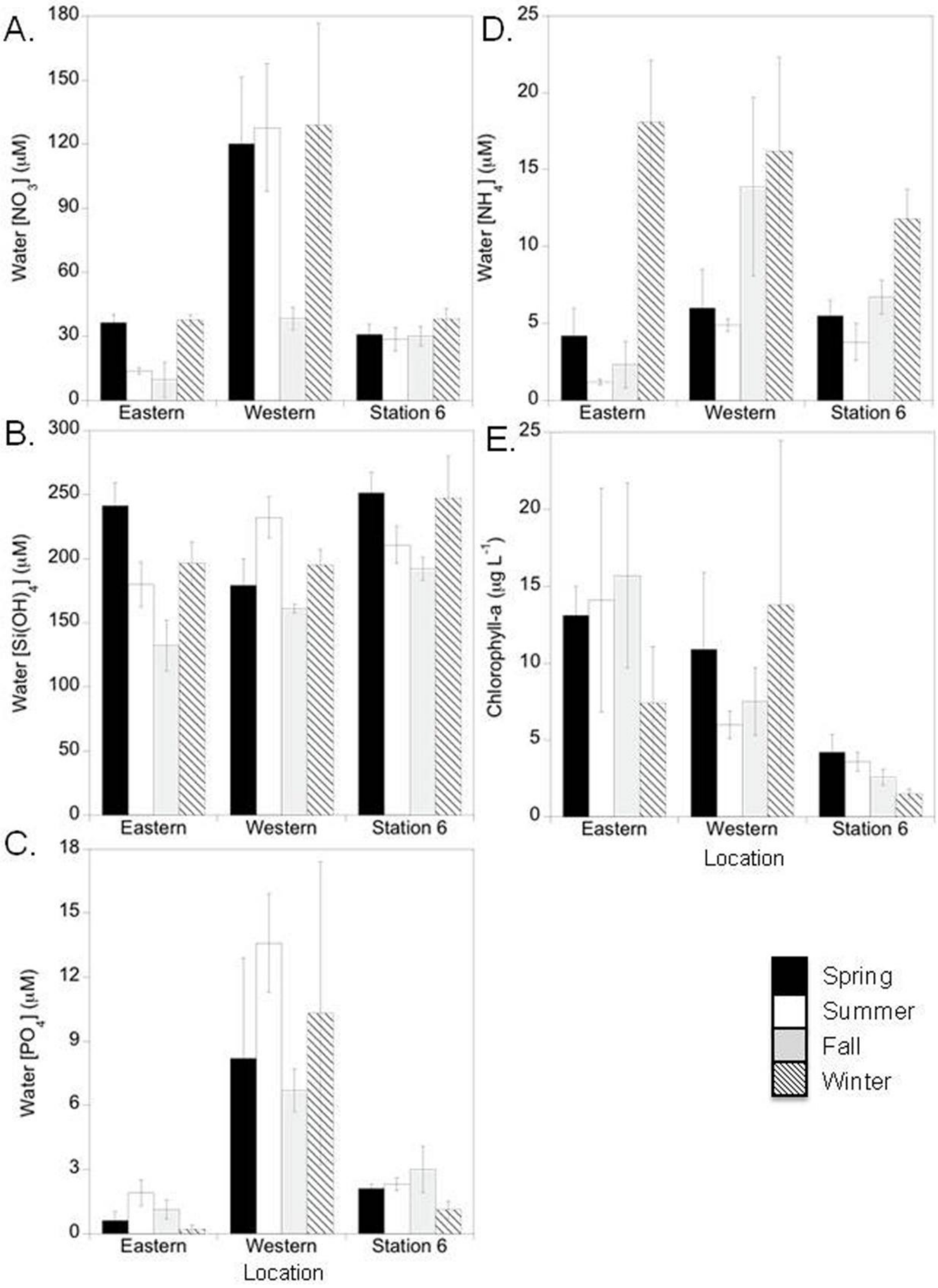

Figure 3: Mean (+/-se) seasonal inorganic nutrient and chlorophyll-a concentrations in Suisun Marsh and main channel habitats of Suisun Bay. Suisun Marsh sites were divided into western sloughs and eastern sloughs. Main channel site is the US Geological Survey water quality station 6. A) NO_3, B) $Si(OH)_4$, C) PO_4, D) NH_4 and E) chlorophyll-a.

Napa-Sonoma Marsh Complex

Few consistent spatial or temporal patterns in nutrient and chlorophyll-*a* concentrations emerged in marsh locations within the Napa – Sonoma Marsh Complex (Figure 4). Nitrate concentrations were highest at the upriver locations (Bull and Coon Islands) in the spring, and decreased by 10-fold at the most downriver site (Pond 2A). The main channel location, USGS station 9, had high NO_3 concentrations (~30 µmol L^{-1}) across all three seasons (Figure 4A). At Bull and Coon Islands, some similar seasonal patterns in nutrient concentrations emerged; $Si(OH)_4$ decreased in summer relative to spring concentrations and stayed low, while NO_3 and NH_4 concentrations decreased from spring and summer, followed by an increase in concentrations by the fall (Figure 4A,B,D). With the exception of NO_3, the nutrient concentrations at station 9 exhibited the same seasonal patterns as concentrations at the upriver locations. PO_4 showed the most consistent spatial and temporal patterns with highest values in the fall at Coon and Pond 2A (Figure 4C). Patterns in chlorophyll-*a* concentration were strikingly similar for Bull and Coon Island, with a maximum in the summer, whereas the downstream Pond 2A and station 9 sites had high spring chlorophyll-*a* concentrations, and similarly low summer and fall concentrations were observed (Figure 4E).

8.4 Discussion

A critical element of effective salt marsh restoration is the ability to demonstrate improvement to ecosystem function as result of management action. Such gains are often difficult to quantify particularly in places like the SFBE where baseline data on nutrients and organic matter flux as phytoplankton within salt marshes are largely unavailable. Based on this dataset it appears that seasonal patterns nutrient and chlorophyll-*a* concentration are not consistent across salt marsh landscapes in the northern SFBE and that factors driving seasonal patterns in these parameters are site-specific.

While direct nutrient and chlorophyll-*a* flux measurements are unavailable, first-order estimates of potential flux can be made using the differences in nutrient and chlorophyll-*a* concentrations in salt marshes and adjacent channel stations in the main estuary. Using this approach, the hypothesis that salt marsh habitats are a potential sink of inorganic nutrients and source of chlorophyll-*a* to the main embayments of the northern San Francisco Estuary was not always substantiated for the salt marsh locations surveyed here.

In the western Delta marshes NO_3 concentrations were higher at the more downstream natural reference site (Browns Island), while phytoplankton biomass was higher in the restored upriver (Sherman Lake) location across all seasons. A major difference between the two marsh locations was the submerged aquatic vegetation community composition. Floating and submerged aquatic macrophytes typically compete with phytoplankton for light and/or water column nutrients, which could explain the low NO_3 concentrations observed at Sherman Lake. However, the chlorophyll-*a* at Sherman Lake was highest during the summer when macrophytes were most abundant. Naturally senescing macrophytes in the late summer can contribute inorganic nutrients, particularly NH_4, to the water column (Landers 1982); therefore, high macrophyte biomass may actually support summer phytoplankton populations at

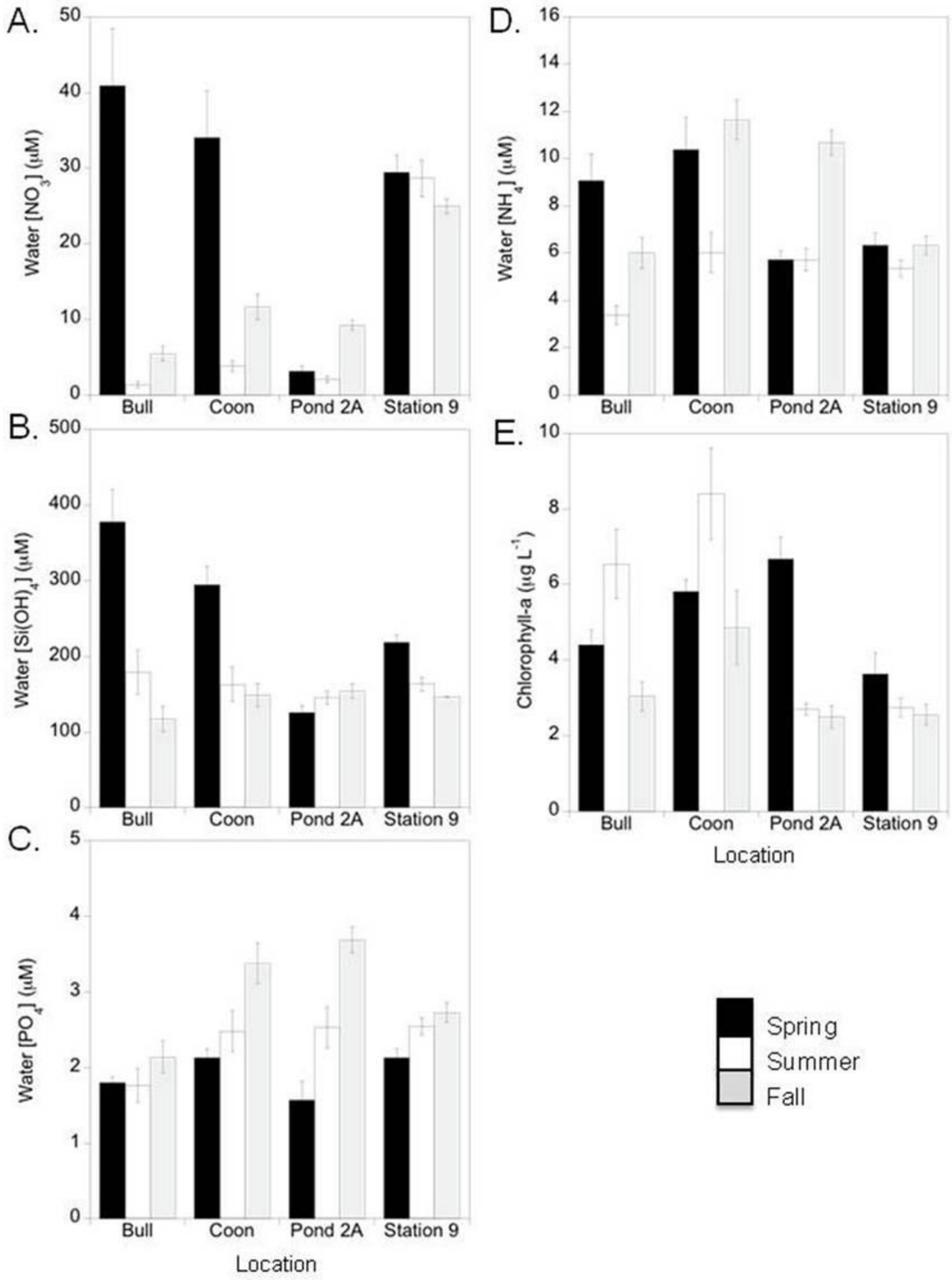

Figure 4: Mean (+/- se) seasonal inorganic nutrient and chlorophyll-a concentrations in the Napa-Sonoma Marsh Complex and main channel habitats of San Pablo Bay   Marsh sites were Bull Island, Coon Island and Pond 2A in the Napa River Main channel site is the US Geological Survey water quality station 6. A) NO_3, B) $Si(OH)_4$, C) PO_4, D) NH_4 and E) chlorophyll-a.

Sherman Lake (Cohen, unpublished). The two marshes also differed hydrologically. Tidal channels drained quickly at low tide at Browns Island, and relatively slowly at Sherman Lake (Siegel, pers comm.). The water in the tidal channels at Sherman Lake was slow moving, which is conducive to SAV growth. Within sloughs, the water was dark in color, likely due to tannic acids from breakdown of senescing vegetation, indicating longer water retention. These western Delta marshes did not appear to be a source of NO_3 or chlorophyll-*a* to the main channel habitats at USGS station 3 given that NO_3 concentrations were higher at station 3 in all three seasons, and spring chlorophyll-*a* concentrations there were at least twice those at Sherman Lake and Browns Island suggesting that at this time of year the salt marshes were not likely a source of phytoplankton to the western Delta.

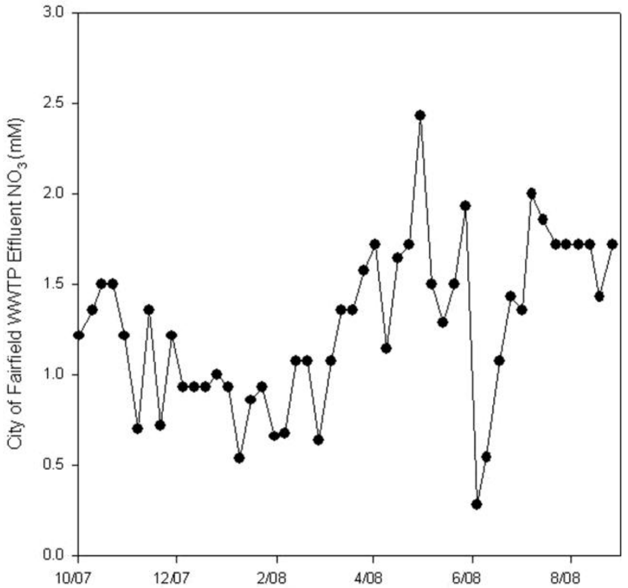

Figure 5: City of Fairfield daily wastewater NO_3 effluent load to the western Suisun Marsh. Effluent is discharged into Boynton Slough in western Suisun Marsh.

Not surprisingly, the highest nutrient concentrations found in Suisun Marsh were in western sloughs, likely as a result of their proximity to wastewater discharge activities. The City of Fairfield discharged between 3.9 and 33.5 million gallons per day of advanced secondarily treated sewage into one of the western sloughs (Boynton Slough) during the study period (Figure 5) with a mean annual concentration of 1.26±0.44 mmol L^{-1} (17.7±6.3mg L^{-1}) NO_3 (SFBWQCB, 2010). Thus the proximity of the SFBNERR site at Rush Ranch to western Suisun Marsh sloughs could lead to elevated NO_3 concentrations at the reserve site. During the fall, mean effluent NO_3 concentrations in the discharge were 35% lower than the annual mean which was likely in part responsible for lower western slough NO_3 concentrations measured during fall. Although not quantified during this study, increased emergent salt marsh vegetation biomass during the fall may have also contributed to lower NO_3 concentrations through N assimilation. The annual average NH_4 concentration in the City of Fairfield effluent was roughly three orders of magnitude lower than NO_3 concentrations, 8.6±9.0µmol L^{-1} (0.1±0.1mg L^{-1}) and these differences were reflected in the concentration of NH_4 relative to NO_3 in the western sloughs. It is unclear why NH_4 concentrations were higher in the eastern Suisun Marsh sampling locations. There is currently no information about water residence time for Suisun Marsh (P. Moyle, pers comm.), but it is likely that residence time is longer in the eastern sloughs than the western sloughs which are adjacent to the major hydrologic connection between Suisun Marsh and Suisun Bay. Longer residence times in the eastern sloughs have the potential to allow for the accumulation of NH_4 from nearby cattle ranching or through benthic regeneration of NH_4.

The elevated chlorophyll-*a* concentrations found in the eastern locations in Suisun Marsh may also be related to water residence time. An alternative explanation for the patterns in chlorophyll-*a* within Suisun Marsh is the presence of *Corbula amurensis* that is largely absent in the eastern sloughs but has been observed at high densities within western sloughs, including near the SFBNERR site (Shroeter, 2008). *Corbula* has high clearance rates in the main estuary and can effectively control the accumulation of phytoplankton biomass during the summer and fall (Alpine and Cloern, 1992) such that their abundance likely has a similarly strong influence on phytoplankton standing stock in the sloughs. Because NO_3, PO_4, NH_4, and chlorophyll-*a* were all higher in the western sloughs compared to station 6, Suisun Marsh should be viewed as a potential nutrient and chlorophyll-*a* source to the northern SFBE. However, without estimates of water exchange between Suisun Marsh and Suisun Bay it is not possible to quantify any subsidy of nutrients or chlorophyll-*a* from the marsh to Suisun Bay.

The patterns in nutrients and chlorophyll-*a* concentrations in the Napa-Sonoma Marsh Complex appeared to be related to riverine inputs and wetland location along the Napa River. In the spring, NO_3 and $Si(OH)_4$ concentrations declined with distance downstream and increasing salinity (i.e., from Bull Island to Pond 2A). This inverse relationship with salinity has been observed in other estuaries, and was more pronounced at low tide (Montani et al. 1998), which was when sampling in the present study occurred. Furthermore, increased nutrient availability associated with freshwater influx during late spring and early summer rains may also partly explain the summer chlorophyll-*a* maxima observed at Bull and Coon Islands. However, the much higher spring and fall NO_3 concentrations at station 9 relative to the marsh sites suggests that the major source of NO_3 to the main bay may not be the Napa River. In contrast to $Si(OH)_4$ and NO_3, PO_4 and NH_4 did not appear to be related to freshwater inflow. Concentrations of NH_4 in particular were higher at Coon Island and Pond 2A in the fall than at Bull Island, the most upstream location. Thus the high NH_4 concentrations we observed could have resulted from regeneration processes (Balls 1992, Page et al 1995, Montani et al 1998).

The role of salt marshes in mitigating nutrient loads associated with cultural eutrophication or as potential source of phytoplankton biomass for estuarine species has been used to bolster support for salt marsh restoration and conservation. Such ecosystem services have been demonstrated at nearby Elkhorn Slough, CA (Gee et al., 2010). However, at present, empirical evidence to confirm these paradigms for the SFBE have not yet been demonstrated. Despite the identified need for baseline monitoring of nutrients and chlorophyll-*a* prior to and after salt marsh restoration activities begin (Granier and Davis, 2010) little information about salt marsh slough nutrients or chlorophyll-*a* exist for the SFBE (Brown, 2004). Salt marsh restoration may influence inorganic nutrient supply to the SFBE, which in turn will influence overall estuarine productivity (Cloern, 1983; Dugdale et al, 2007; Glibert 2010) but the direction of nutrient and phytoplankton flow between the main estuary and salt marshes is not clear. The site-specific nature of nutrient and chlorophyll-*a* patterns observed during these studies suggests that developing a single effective model of nutrient and phytoplankton dynamics for salt marshes in the SFBE is unlikely (Lopez et al, 2006). Baseline data on nutrient and phytoplankton stocks along with process-based studies to identify important nutrient cycling pathways will be invaluable for assessing the effects of future salt marsh restoration efforts in the SFBE. The San Francisco Bay National Estuarine Research Reserve may be uniquely positioned to address these data gaps through future research and monitoring efforts at the China Camp and Rush Ranch reserve sites.

8.5 Acknowledgments

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Personal Communication

Peter Moyle, PhD
University of California at Davis
One Shields Avenue, Davis, CA 95616
Tel/fax:530-752-6355 / 530-752-4154

Stuart W. Siegel, PhD, PWS
President and Principal Environmental Scientist
Wetlands and Water Resources, Inc.
818 Fifth Avenue, Suite 208, San Rafael, CA 94901
Tel/fax 415-457-0250

9. San Francisco Bay Tidal Marsh Pollution by Persistent Organic Contaminants and Trace Metals

Hyun-Min Hwang, Peter G. Green, and **Thomas M. Young**

Department of Civil and Environmental Engineering,
University of California, Davis
One Shields Ave., Davis, CA 95616

Hyun-Min Hwang (Corresponding Author)
Phone: 530-752-1755, Fax: 530-752-7872
Email: hmhwang@ucdavis.edu

ABSTRACT

In San Francisco Bay (SFB), more than 80% of the original tidal marshes have disappeared over the last 150 years and the existing marshes are significantly fragmented and contaminated by numerous organic pollutants and trace metals that cause habitat quality degradation. Tidal marshes in SFB provide vital food and habitat for clams, crabs, and juvenile fish and offer shelter and nesting sites for waterfowl and shorebirds. These marshes also play a buffering role by retaining contaminants before they reach the estuarine waterbody, resulting in significant accumulation of contaminants in marsh sediments. Although concentrations of contaminants in the marsh ecosystem have been declining, they are still high enough to threaten the well-being of aquatic life and wildlife. Considering importance of tidal marsh, it is helpful to have an integrated review on temporal trends and current status of contaminants and their adverse effects in the tidal marsh ecosystem of SFB, which can be used as a reference to better understand tidal marsh habitat quality and implement marsh restoration projects. This review summarizes the geographical distribution and temporal trends of contaminants especially mercury, polychlorinated biphenyls (PCBs), and organochlorine pesticides, which are the most serious concerns for public health and environmental degradation in SFB. This review mainly focuses on these contaminants in marsh sediments and their bioaccumulations in birds inhabiting the marshes. Potential impacts of contaminants on the health of aquatic life and wildlife in the marsh ecosystems are also reviewed.

KEY WORDS

Mercury
Organochlorine pesticides
PCBs
Bioaccumulation
Biomagnification
Ecological impacts
Habitat quality degradation
Temporal trends

9.1 Introduction

San Francisco Bay (SFB) is comprised of diverse habitats. Tidal marshes are an important part of the SFB wetland ecosystem, which is the most biologically productive habitat in SFB. Tidal marshes in SFB, as a transition zone between upland and aquatic systems, play important roles in sustaining ecological diversity by providing vital food and habitat for clams, crabs, and juvenile fish as well as offering shelter and nesting sites for waterfowl and shorebirds (Goals Project, 1999). Tidal marshes also play critical buffering roles by slowing shoreline erosion and absorbing nutrients and contaminants before they reach the open bay. This buffering role, however, could lead to heightened accumulation of contaminants in marshes near urban and industrial areas. In fact, all contaminated marshes in SFB, including Stege Marsh, Peyton Marsh, and Castro Cove, are located downstream of creeks and rivers, which deliver various contaminants from urban and industrial areas.

San Francisco Bay is one of the most altered major bays in the world. More than 80% of historic tidal marshes in SFB have been diked, filled, or transformed into salt ponds, agricultural, residential and industrial lands during the last 150 years (Goals Project, 1999). The remaining marshes are highly fragmented (Figure 1), which makes them more vulnerable to human impacts. When these fragmented marshes are heavily contaminated by toxic chemicals, many marsh dwelling animals, which cannot migrate to less contaminated marshes, are likely to be more seriously stressed.

San Francisco Bay has experienced significant contamination due to population growth combined with mining and industrial activities over the last 150 years. Population in the SFB area increased from 0.1 million in 1860 to 2.7 million in 1950, and 6.8 million in 2000 (Bay Area Census, 2000). Since the mid-1800s, SFB has received enormous amounts of contaminants such as mercury, polychlorinated biphenyls (PCBs), organochlorine (OC) pesticides, and polycyclic aromatic hydrocarbons (PAHs) from historic gold and mercury mining, municipal and industrial wastewater treatment plants, urban and agricultural runoff, and oil spills (Connor et al., 2007; Davis et al., 2007; Heim et al., 2007).

Until the late 1960s, raw or minimally treated sewage containing a large amount of contaminants was dumped into San Francisco Bay. A significant decrease in contaminant loading occurred after the San Francisco Bay Regional Water Quality Control Board issued its first Water Quality Control Plan in 1975 for the fulfillment of the Clean Water Act (SFBRWQCB, 2000). Restrictions on the use of contaminants such as PCBs, OC pesticides, and lead also contributed to the decline of their levels in the SFB system (Hornberger et al., 1999; Venkatesan et al., 1999).

The SFB ecosystem is also highly vulnerable to damage by oil spills due to high traffic volume of marine vessels and geographical characteristics. More than a thousand oil tankers along with countless container ships travel across the bay each year. Numerous refineries and oil storage tanks on the shorelines also add the risk of oil spills. SFB is an enclosed bay and therefore spilled oils likely stay longer due to slow dispersion compared to open coastal areas. Sporadic oil spill accidents release tremendous amounts of contaminants such as PAHs and cause enormous ecological damage, including the death of thousands of birds and aquatic organisms.

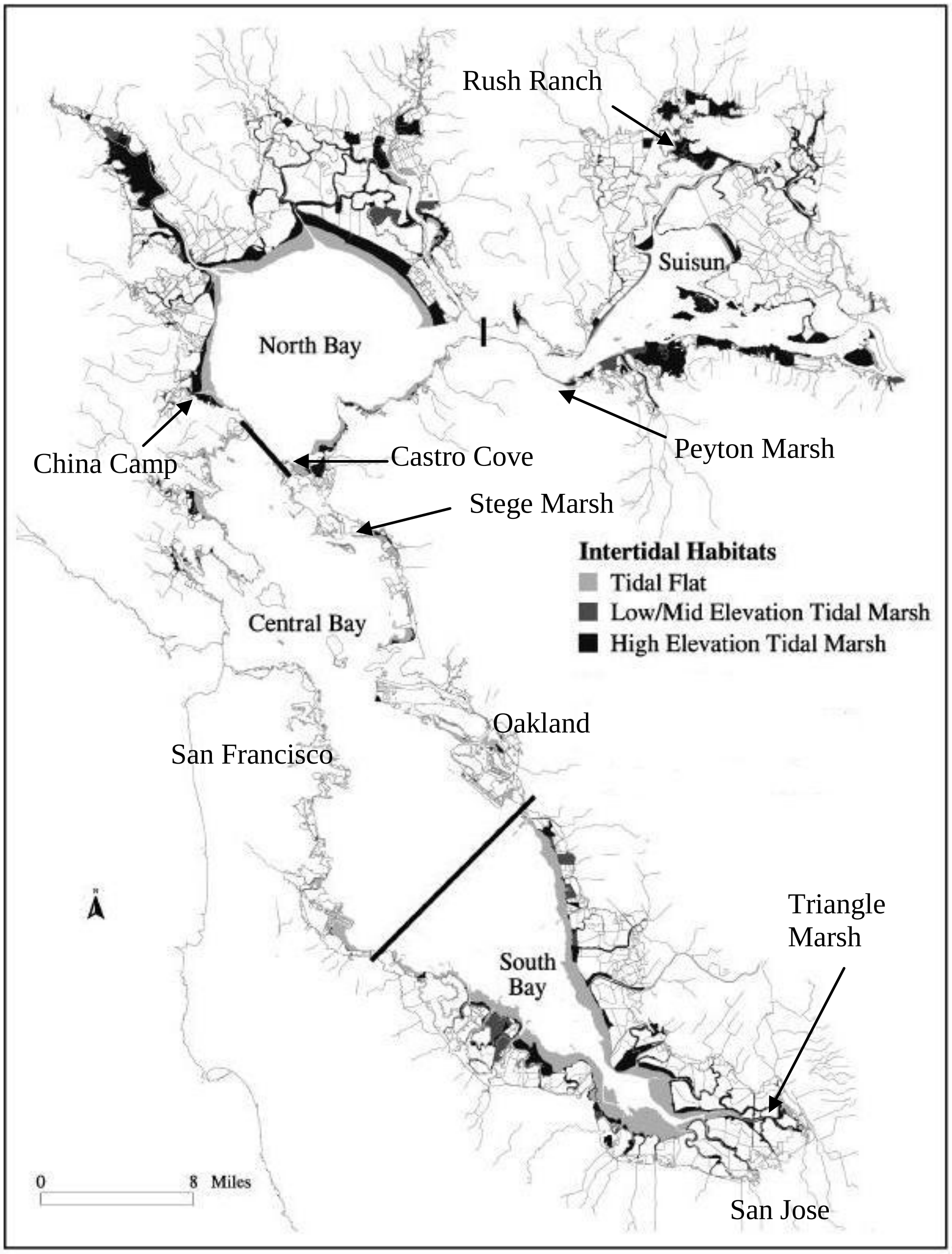

Figure 1. Tidal marshes in San Francisco Bay (adapted from Grossinger et al., 1998). China Camp and Rush Ranch comprise the San Francisco Bay National Estuarine Research Reserve.

Considering the importance of tidal marshes in restoring and sustaining SFB habitat quality, it is helpful to have an integrated review on temporal trends and current status of contaminants and their adverse effects in the tidal marsh ecosystem of SFB, which can be used as a reference to better understand tidal marsh habitat quality and implement marsh restoration projects. This review summarizes geographical distributions and temporal trends of contaminants, mainly mercury, PCBs, and OC pesticides, which are of the most serious concerns in the marshes of SFB. Toxic impacts of contaminants on the marsh ecosystem in SFB are also reviewed. Marshes in SFB have been less studied compared to the open bay and the lack of contaminant and toxic impact data hinders more comprehensive review. Some open bay data are used to suggest possible changes in marshes when reliable marsh data are not available.

9.2 Contaminants in sediment

Hydrophobic organic contaminants such as PAHs, PCBs, OC pesticides, dioxins and pyrethroids and many trace metals in the water column tend to be adsorbed onto suspended particles, which settle to the bottom (Schladow et al., 2004), making sediments a final repository for these contaminants (Fostner and Wittman, 1983). Surface and core sediments, therefore, can record geographical differences and temporal trends of local inputs of these contaminants. Seasonal variations of concentrations of surface sedimentary contaminants reported in the literature are much less significant compared to those in living organisms, which could be substantially affected by some factors such as reproduction cycles. Schladow et al. (2004) observed large seasonal differences of PAH concentrations in surface water samples but variation of total PAH concentrations in sediments was less than 20%. Insignificant seasonal variation is mainly due to surface sediment sampling methods, which typically collect up to about 3 to 5 cm deep, equivalent to a composite of several years of sedimentation. Therefore, unlike aquatic life and wildlife samples, in which toxic chemical body residues vary along with seasons, collection seasons of sediment samples do not need to be considered for the comparison among sampling sites.

Generally, levels of sedimentary contaminants in marshes adjacent to urban and industrial areas are much higher than SFB ambient sediment levels, while those in marshes near undeveloped areas are similar to the levels found in open bay ambient sediments (SFBRWQCB, 1998; Hunt et al., 2001; Schladow et al, 2004; Leatherbarrow et al., 2005; Hwang et al., 2006a, b; Heim et al., 2007). In comparison to San Pablo Bay and Suisun Bay, marshes in central and south SFB have been more severely contaminated by numerous toxic chemicals from wastewater treatment plants, historic mercury mines, and stormwater runoff (Schladow et al., 2004; Leatherbarrow et al., 2005). In addition, central and south SFB have very low freshwater input and low tidal exchange, resulting in lagoon-like static conditions that enhance quick deposition of particle bound contaminants. Marsh sediments were also contaminated by toxic chemicals such as PAHs from oil spills (Hostettler et al., 1992). Because of high levels of persistent organic contaminants and trace metals, some marshes such as Stege Marsh, Peyton Marsh, and Castro Cove (Figure 1) were classified as Toxic Hot Spots by SFBRWQCB (1999) and remediation has been implemented to restore habitat quality.

Conaway et al. (2004) and Hwang et al. (2008, 2009) showed a clear decline of contaminants and corresponding toxicity potential (e.g., probable effect level quotient, PELQ) in sediment cores collected from Triangle Marsh and Stege Marsh, respectively (Figure 2), that is a result of the restriction on the use of some contaminants and regulations on the discharge of wastewater. However, PAH concentrations in Stege Marsh core sediments have not declined due to continuous inputs primarily from vehicle emission (Hwang et al., 2008). The same temporal trends were also found in sediment cores collected from open water of SFB (Hornberger et al., 1999; Venkatesan et al. 1999), indicating that temporal decline of most persistent organic contaminants and trace metals is a bay wide trend. Although sediment core data are not available for other marshes, this trend is likely to be the same for those marshes. Assuming the declines of trace metal concentrations in Stege Marsh sediments continues at the current trends, Hwang et al. (2009) estimated that it might take 10, 2.5, and 25 years for silver, copper and zinc in surface sediments, respectively, to reach the San Francisco Bay ambient sediment levels (SFBRWQCB, 1998). In the case of lead, it is estimated to take 44, 82, and 153 years to reach the probable effect level (112 μg/g), the SFB ambient surface sediment level (43.2 μg/g) and the local baseline levels (5 μg/g), respectively.

Since the mid 1800s, SFB has received tremendous amounts of mercury from historic gold and mercury mining activities and became notorious for severe mercury contamination (Heim et al, 2007). The peak mercury concentration in marsh sediment cores collected from south SFB was found in layers deposited around the mid 1960s that is a substantial delay from the time (late 1800s) of the highest mercury production at New Almaden mines (Conaway et al., 2004). A similar delay was found in sediment cores from San Pablo Bay that was influenced by gold and mercury mining in the Sierra-Nevada (Hornberger et al., 1999). This delay is likely to be a result of slow hydraulic transport from source areas where mining activities occurred to the bay.

Among various mercury species, methylmercury (MeHg) is of the most concern due to its very high toxicity and bioaccumulation potential. Generally marshes filter inorganic mercury before they enter the open bay. However, deposited inorganic mercury in marsh sediment can be converted to MeHg more efficiently under anaerobic conditions principally by sulfate-reducing microbes (Gilmour et al., 1992) as well as iron-reducing microbes (Fleming et al., 2006). Methylmercury to total mercury ratios can represent the efficiency of mercury methylation. In SFB marsh sediments the ratios ranged from 0.01 to 0.04 (Figure 3), which are much higher than those (0.001-0.003) found in open bay sediments (Marvin-DiPasquale et al., 2003; Choe et al., 2004; Heim et al., 2007), making marshes major source areas of MeHg. Recognizing the importance of marshes as habitat for aquatic life and wildlife, large-scale plans, such as South Bay Salt Pond Restoration Project, are being formulated and implemented in SFB to restore marshes and enhance their quality. However, these restoration activities could increase the conversion of inorganic mercury to MeHg, which likely increases the exposure of wildlife to MeHg and consequent adverse effects on wildlife.

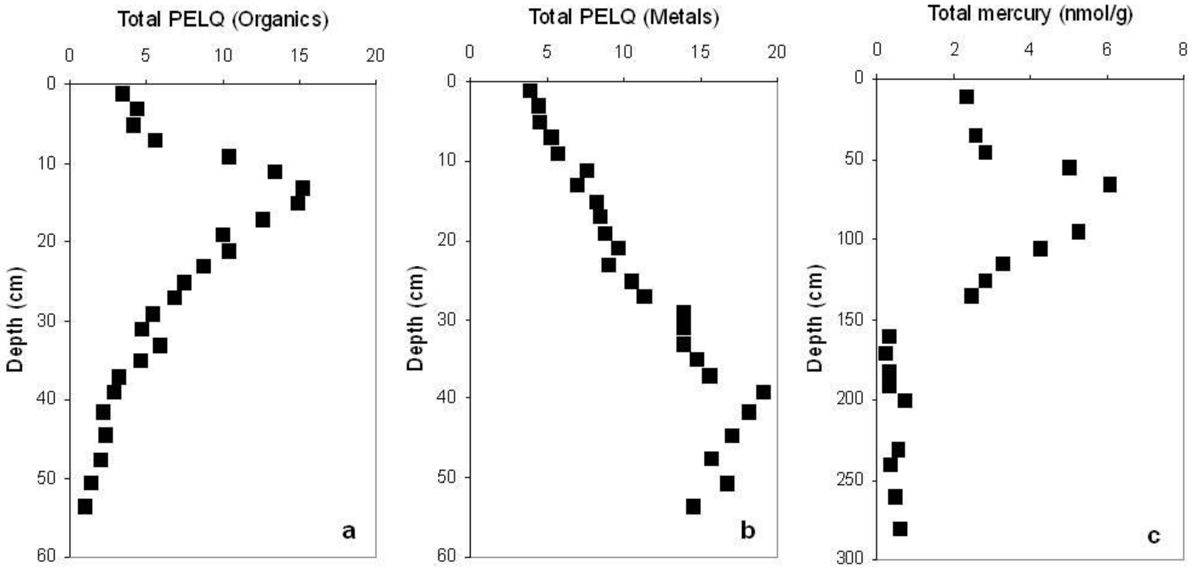

Figure 2. Depth profiles of toxicity potential of (a) organic contaminants and (b) trace metals in Stege Marsh sediment core (Hwang et al., 2008) and (c) total mercury concentrations in Triangle Marsh sediment core (Connaway et al., 2004). PELQ (Probable Effects Level Quotient) represents the degree of toxicity potential.

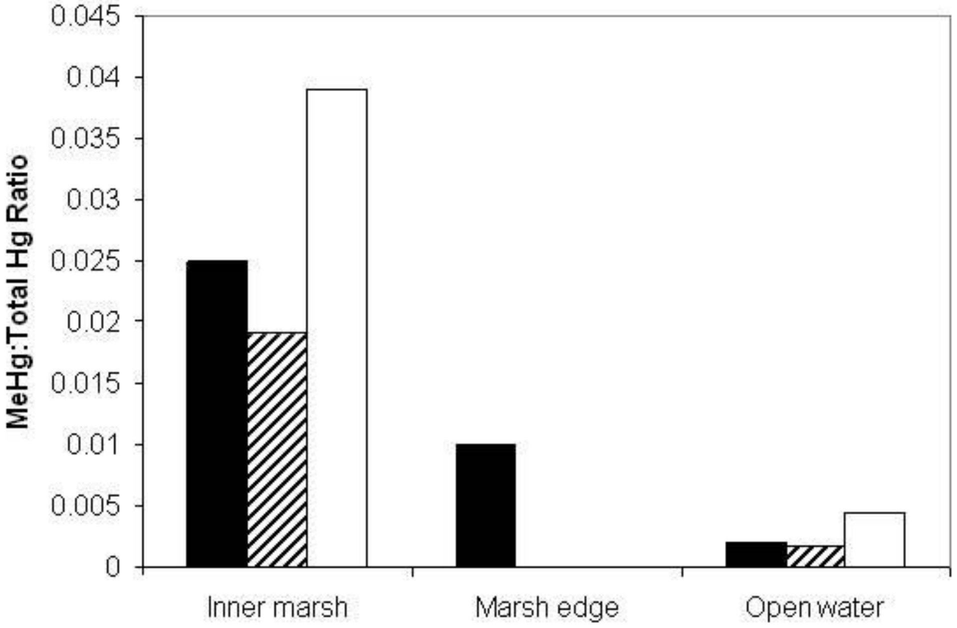

Figure 3. Efficiency of mercury methylation in marsh and open water sediments. Data are from Heim et al., (2007, solid bars), Marvin-DiPasqule et al. (2003, dashed bars), and Choe et al. (2004, open bars).

SFB is also well known for high levels of silver and nickel. Silver contamination especially in south SFB has been mainly associated with wastewater containing high levels of silver from photo development facilities that were operated until the mid-1980s in San Jose (Flegal et al., 2007). After the closure of these facilities and regulations on the discharge of silver from municipal wastewater treatment plants, silver levels in the bay system, including marshes, have declined significantly (Hornberger et al., 1999; Hwang et al., 2009). Nickel in SFB sediments is much higher compared to other urban estuaries. Unlike some toxic chemicals such as lead and PCBs, which have various anthropogenic sources, the majority of nickel in SFB has originated from natural sources (Hornberger et al., 1999). Soils in SFB watersheds contain nickel-rich source rocks such as serpentinite, in which nickel concentrations reach up to 3,000 $\mu g\ g^{-1}$ (Topping and Kuwabara, 2003) that is 150-fold higher than average continental crust in the range of 20 $\mu g\ g^{-1}$ (Taylor and McLennan, 1985).

Widespread occurrence of PCBs and OC pesticides, including DDTs, chlordanes, and dieldrin, in SFB is another environmental concern. Due to their hydrophobicity, a vast majority of these contaminants are introduced into the bay associated with sediments. Historically, municipal and industrial wastewater discharges were major sources of PCBs in SFB. Over the past decades, however, PCBs in treated wastewater effluents declined by three orders of magnitude and urban stormwater runoff became the primary pathway delivering PCBs to marshes in SFB (Davis et al., 2007). OC pesticides have been introduced to SFB from the Sacramento and San Joaquin Rivers, urban stormwater runoff, and regional tributaries (Schladow et al., 2004; Connor et al., 2007). After the restriction on the use of PCBs and the ban on the use of DDT and chlordane, their levels in SFB sediments have declined substantially (Hornberger et al., 1999; Venkatesan et al., 1999; Hwang et al., 2008). PCBs in marsh sediments along the coast of the central and southern portions of the bay are much higher than in other portions of the bay (Leatherbarrow et al., 2005). PCBs in highly contaminated Stege Marsh surface sediments were as high as 9,000 ng/g (Hwang et al., 2006a) and even higher in other locations (Hunt et al., 1999). DDTs and chlordanes in marsh sediments near the former agricultural chemical manufacturers were very high (Pereira et al., 1996; Hwang et al., 2006a).

High levels of dioxins and furans were found in stormwater collected from outfalls near petroleum refineries and other industrial areas in SFB (Wenning et al., 1999). Although no dioxin and furan data in marsh sediments have been reported, sediments in marshes adjacent to these stormwater outfalls likely contain relatively high levels of dioxins and furans. Dioxins and furans have very high tendency to be adsorbed onto particles, which quickly settle to the bottom. Data on emerging contaminants such as PBDEs, phthalates, and pyrethroids in SFB marsh sediments are very rare. Bis(2-ethylhexyl)phthalates in Stege Marsh sediments ranged from 280 to 32,000 ng/g (Hwang et al., 2006a). Kuivila and Datta (2004) found some current-use pesticides such as eptam and molinate at levels 0-20 ng/g (dry wt.) in Stege Marsh surface sediments but chlorpyrifos and pyrethorid pesticides such as bifenthrin and permethrin were not detected.

9.3 Contaminants in plants

Marshes in SFB are typically covered by euryhaline plants such as cordgrass (*Spartina foliosa*) and pickleweed (*Sarcocornia pacifica*) that are essential to maintain marsh structure. These plants also play critical roles in controlling geochemical fate and transport of toxic chemicals and introducing them into the estuarine food web (Weis and Weis, 2004). Marsh plants can uptake toxic chemicals from sediments and sequester them in their live and dead biomass (Masters and Inman, 2000; Weis and Weis, 2004; Zawislanski et al., 2001) and consequently reduce the levels of sedimentary toxic chemicals. The sequestration of trace metals in plant tissue is basic principle of phytoextraction for the clean-up of contaminated sediment in marshes. Accumulation of toxic chemicals in marsh plants, however, can also threaten wildlife such as detritivores or endangered herbivorous mice and voles that feeds on the contaminated plants. Marsh plants thus play two different (beneficial and harmful) roles simultaneously.

Literature reports on the role marsh plants play in controlling contaminant mobility in SFB are very rare. Jensen (2007) found total mercury (up to 30 ng/g) in cord grass shoots (especially growing tips) correlated with day-length, reflecting respiratory uptake of mercury from sediment pore-water. Green et al. (unpublished data) measured trace metals in cordgrass leaf salt exudate collected from Stege Marsh and found they were positively correlated with concentrations in sediments. Leaf salt exudate could be dissolved in sea water or rain water, which transport trace metals to open bay. These results support that marsh plants play important roles in mobilizing trace metals in marsh sediments. Additional in-depth studies are needed to better understand the roles of marsh plants in controlling contaminant mobility and cleaning up contaminated sediments.

9.4 Contaminants in invertebrates and small mammals

Long-term bivalve monitoring in SFB open water exhibited a significant decline of legacy organic contaminants and trace metals over the last decades (Gunther et al., 1999; Hornberger et al., 2000). Although no long-term biomonitoring in marshes is available, the decreasing trends found in the open bay are likely to be the cases in marsh invertebrates as supported by the decline of contaminants in marsh sediment cores (Conaway, 1997; Hwang et al., 2009).

Marsh invertebrates such as crabs and bivalves had been contaminated sporadically by oil spills and associated toxic chemicals such as PAHs. Mussels collected from shorelines of Alameda County after the *T/V Dubai Star* oil spill in 2009 accumulated PAHs up to about 20,000 ng/g (dry wt.), which is about 10 to 20 times higher than ambient background levels (Hwang et al., unpublished data). Although no contaminant data on invertebrates is available, it is reasonable to assume that marsh invertebrates were also exposed and affected by high levels of PAHs from other oil spills. Smalling et al (2010) detected many current use pesticides such as permethrin, dichloropropionanilide, *S*-ethyl dipropylthiocarbamate, fipronil, and others at levels ranging from not detected to 0.4 µg/g (lipid wt.) in crab embryos collected from Stege Marsh. Temporal trends on current use pesticides and emerging contaminants in marsh invertebrates of SFB are not available.

Due to tremendous habitat loss in SFB, the population of small mammals (e.g., salt marsh harvest mouse, vole) inhabiting marshes has declined significantly (Shellhammer, 1989). High levels of contaminants are also thought to have contributed to their population decline. However, it is very difficult to determine the association between exposure to contaminants and the decline of marsh mammal populations because data regarding body burdens of toxic chemicals in SFB marsh mammals and related health impacts are extremely rare. Clark et al. (1992) were able to marsh mammals such as salt marsh harvest mouse, deer mouse, and California vole, but their body residues were not high enough to cause adverse health effects.

9.5 Contaminants in birds

Marshes in SFB provide key habitats for various resident (e.g., California clapper rail) and migratory (e.g., American coot) birds. Populations of marsh birds, especially California clapper rail, in SFB have declined significantly due to drastic loss of marshes along with severe fragmentation. High levels of contaminants in their habitats and diets may also be a critical contributor to reduced bird populations. Many birds are at a high trophic level and thus biomagnification of contaminants results in much higher levels of contaminants in their body tissues, which makes them more vulnerable to adverse effects of contaminants.

This review covers not only marsh birds, such as California clapper rail and American coot, but also other birds, including avocets, herons, scoters, stilts, and terns, whose primary habitats include both marshes and non-marsh areas, due to lack of data on contaminants in marsh birds. Although non-marsh birds obtain their foods from marshes as well as non-marsh areas, geographical distribution and temporal changes observed in non-marsh birds can be used to infer those in marsh birds. To investigate impacts of contaminants in avian species, eggs were more commonly studied because eggs can be easily collected and contaminant residues in failed eggs can be linked directly to reproduction failure. Concentrations of contaminants in eggs can be also used as indicators of contaminant residues in their parents.

The most frequently measured contaminants in avian eggs include PCBs, OC pesticides, mercury and selenium (Ohlendorf et al., 1988; Schwarzbach et al., 2006; Ackerman et al., 2007). Mercury, especially MeHg, in some avian species is much higher than threshold for adverse effects such as reproductive impairment (Ackerman et al., 2006; Tsao et al., 2009). MeHg is much more toxic and has greater bioaccumulation potential than inorganic mercury. For example, MeHg accounts for almost all total mercury in birds of SFB (Tsao et al., 2009), indicating MeHg accumulates more efficiently than inorganic mercury. Mercury contamination is more severe in SFB marshes than in marshes of other areas (Figure 4). Mercury concentration in California clapper rail feathers in SFB marshes are still 4 times higher than in feathers of clapper rail in southern California (Schwarzbach, 2011). Levels of PCBs in black-crowned night heron eggs collected from SFB were comparable to those from Delaware Bay but lower than those collected from Boston Harbor, Cape Cod, New York Harbor, and Green Bay (Figure 5). This implies that PCBs in marsh birds of SFB may also not be higher than those in these areas.

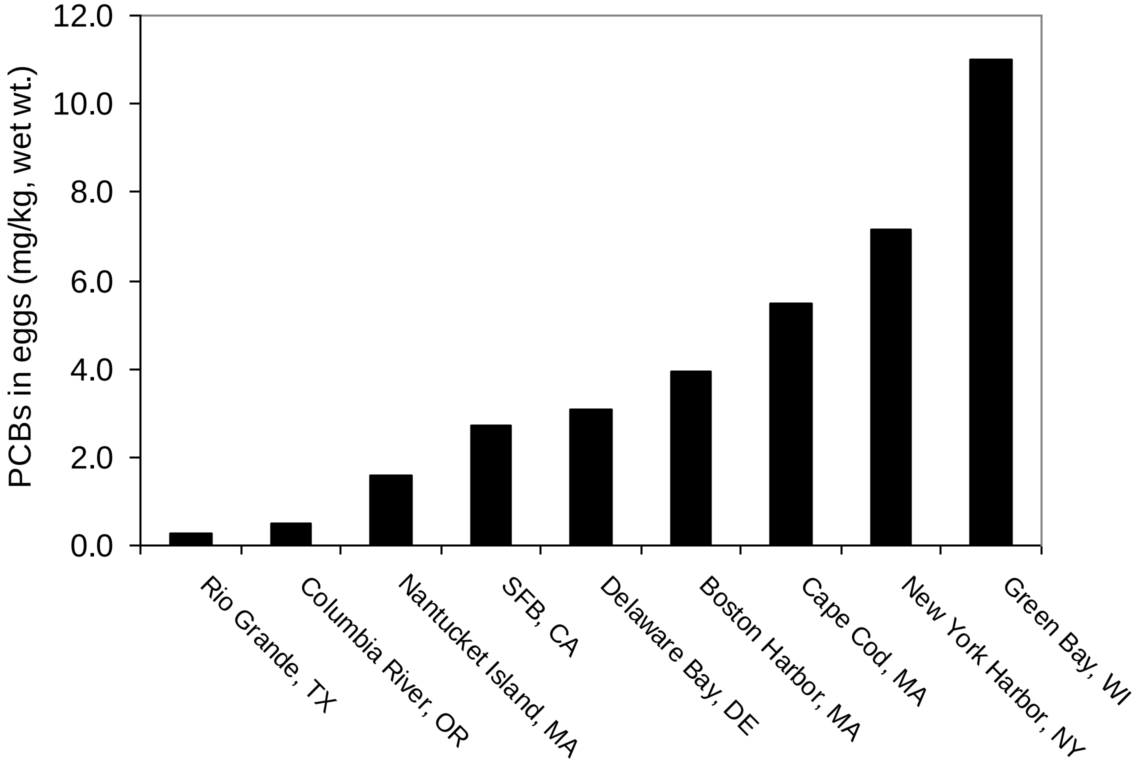

Figure 4. Mercury in clapper rail eggs collected from SFB and other areas. Data are from Lonzarich et al. (1992), Hui et al. (2002), Sutula et al. (2005), Schwarzbach et al. (2006).
Figure 5. Residues of PCBs in eggs of black-crowned night-herons collected from U.S. sites. Samples from the Rio Grande Valley (Wainwright et al., 2001) were collected in 1997 and samples from all other sites (Custer and Custer, 1995; Blus et al., 1997; Matz and Parsons, 2004) were collected between 1990 and 1993.

So far, studies on PBDE contamination in avian eggs in SFB are very rare (She et al., 2008). There have been many reports regarding die-off of avian species in other areas such as Chesapeake Bay due to exposure to organophosphorus pesticides (Rattner and McGowan, 2007), however, no such data have been published in birds in SFB. Because of susceptibility to metabolism, PAHs do not build up in birds and thus PAHs have not been measured in birds and their eggs.

Concentrations of organic contaminants and trace metals in birds and their eggs in SFB are highly variable and linked to factors such as collection sites (North Bay vs. South Bay vs. Central Bay), diets (fish eaters vs. insect eaters), collection time (pre-breeding vs. post breeding), sex (female vs. male), and age (clutch vs. adult) (Ackerman et al., 2006, 2007; Tsao et al., 2009). PCB residues were higher in birds and eggs collected from the southern portion of SFB than those from the central and northern portions of the bay, while DDE residues were higher in samples collected from the northern portion of the bay (Hothem et al., 1995; Schwarzbach et al., 2006; Ackerman et al., 2006). Greater PCB:DDE ratios were found in eggs of California clapper rail from South SFB (13:1) than North SFB eggs (2:1), due to more elevated input of PCBs and

DDE in the southern and northern parts of SFB, respectively (Schwarzbach et al., 2006). Mercury concentrations in blood of shorebirds (avocets, scoters, and stilts) captured in South SFB were much higher than those in North SFB (Ackerman et al., 2006) and the same trend is likely to be observed in marsh birds.

Body residues of contaminants in birds and their eggs can be also linked to their foods (Burger, 2002; Ackerman et al., 2006). Body residues of contaminants are much lower in marsh birds than in non-marsh birds. Levels of PCBs and DDE in eggs of marsh birds such as rails and coots, which are typically omnivorous species, are lower than in eggs of piscivorous species such as night herons and terns (Ohlendorf et al., 1988; Hothem et al., 1995; Schwarzbach et al., 2001, 2006). Eggs of American coots, which primarily eat plants, had the lowest levels of mercury among the investigated species (Davis, 2003). Ackerman et al. (2006) reported mercury concentrations in terns were much higher than those in avocets and stilts, which primarily eat invertebrates, that coincides with their trophic levels represented by nitrogen isotope ratios ($\delta^{15}N$); this indicates that diet is a critical factor influencing the body burdens of contaminants in birds.

Resident birds typically have greater body burdens than wintering migratory birds because resident birds are exposed to toxic chemicals continuously. During wintering seasons, contaminants such as mercury and PCBs in wintering birds increase due to consumption of contaminated food (Ohlendorf et al., 1991; Hothem et al., 1998). During and after breeding seasons, females of avian species generally have lower levels of contaminant body residues than males presumably because contaminants in female birds are translocated to eggs and this maternal transfer leads to significant decreases of body residues of contaminants in female birds. MeHg concentrations in blood of California black rails in SFB marshes were 2.7 times higher in males than in females (Tsao et al., 2009). Lewis et al. (1993) showed that about 15-24% of mercury in the bodies of female herring gulls was transferred to their clutch. Similar patterns might be observed in marsh birds.

Historical datasets show temporal trends of contaminants in some birds and their eggs collected in SFB. As levels of legacy contaminants, such as PCBs, OC pesticides, and mercury, in the SFB ecosystem have declined, body burdens of these contaminants in birds and their eggs also have declined concurrently. Concentrations of PCBs (0.65-5.01 μg/g) in failed California clapper rail eggs collected in 1992 from marshes of south SFB are about half of those found in 1975 (Schwarzbach et al., 2001, 2006; Lonzarich et al., 1992). Mercury levels in feathers of SFB California clapper rails from museum specimens dating to 1881 showed that mercury in SFB has declined over the last 130 years (Schwarzbach, 2011). A significant decrease of selenium was also found in California clapper rail eggs collected from the northern part of SFB (Schwarzbach et al., 2006). Unlike other legacy contaminants, mercury residues in birds and their eggs might increase in the near future in some marshes because marsh restoration likely elevates the production of MeHg.

9.6 Impacts of contaminants in marshes on aquatic life and wildlife

As described above, concentrations of contaminants in marshes of SFB have declined significantly and concurrent reduction of failed gamete production in clams and enhancement of the stability of benthic community structure have been observed (Hornberger et al., 2000; Thompson et al., 2002), which are the signs of the improvement of ecological conditions. However, concentrations of contaminants in many marshes are still high enough to be a cause of adverse effects found in aquatic life and wildlife (Hunt et al., 2001; Hwang et al., unpublished data; Schwarzbach et al. 2006).

Concentrations of sedimentary contaminants in many SFB marshes are much higher than background concentrations but chemical concentration itself is less meaningful unless such concentrations are linked to adverse effects. Levels of contaminants in sediments can provide insights into potential impacts on aquatic organisms when they are reasonably converted to a proxy for toxicity potential through comparison to numerical sediment quality guidelines. Converted data are then more toxicologically relevant and can be used in assessing the probable adverse effects of contaminants in sediments more accurately (Long et al., 1995; MacDonald et al., 1996). Concentrations of contaminants in many marsh sediments exceed sediment quality guidelines such as effects range-medians (ER-Ms) and probable effects levels (PELs), meaning that adverse biological effects are likely to be observed frequently (Long et al., 1995; MacDonald et al., 1996). PCBs and DDTs in many marshes in central and south SFB exceeded sediment quality guidelines 180 ng/g and 46 ng/g, respectively (Leatherbarrow et al., 2005, Hwang et al., 2008), indicating that organic contaminants in many marshes in SFB are still high enough to be a cause for concerns.

One way to assess the overall potential toxicity of multiple contaminants in sediments is calculation of the total ERM quotient (ERMQ) and PEL quotient (PELQ) that are sums of ERMQs and PELQs of individual contaminants, which can be obtained by division of sedimentary contaminant concentration of each contaminant by its ERM and PEL value, respectively, and mean ERMQ and PELQ, which are averages of ERMQs and PELQs, respectively, of all measured contaminants (Long et al., 2006). Total ERMQ and PELQ and mean ERMQ and PELQ values indicate tendencies about how often adverse effects are likely to be observed. The values of these parameters typically show good correlations with adverse biological responses in SFB marshes (Fairey et al., 2001; Hunt et al., 2001, Hwang et al., unpublished data). Schladow et al., (2001) observed a strong inverse relationship between total enrichment factors of metal and clam survival rates, indicating that the total enrichment factor (or possibly mean enrichment factor) could be also used as a tool for assessing the impacts of multiple contaminants.

In highly degraded marshes, contaminants in sediments were found to be linked to disturbance of benthic macroinvertebrate community. Hunt et al. (2001) and Thompson and Lowe (2004) reported that benthic assemblages in contaminated marshes exhibited signs of impairment. Reduced benthic species diversity and prevalence of opportunistic species were frequently observed in highly contaminated marshes. In many marsh sites, sediment porewater toxicity tests showed very low survival of amphipods and reduced fertilization of sea urchin embryos (Hunt et al., 2001; Hwang et al., unpublished data).

Contaminants deposited in sediment can be desorbed and accumulate in sediment dwelling organisms and eventually reach higher trophic level organisms such as fish and birds. A transplanted fish study (Hwang et al., 2008) showed that contaminants in Stege Marsh sediments were readily bioavailable and their levels in transplanted longjaw mudsuckers (*Gillichthys mirabilis*) were positively correlated with the levels in sediments. Contaminants in Stege Marsh are likely to be linked to population decline of indigenous longjaw mudsuckers. McGourty et al. (2009) observed slower growth and higher mortality rates in Stege Marsh compared to those found in clean marshes.

High levels of contaminants in the SFB system are also considered contributors to the decline of avian species. Hatching success of California clapper rails in SFB marshes are substantially lower compared to those in other areas (Schwarzbach et al., 2006). Predation and contamination were found to be the primary causes of the reduction in hatching success. In many cases, there has been speculation about possible impacts of contaminants using indirect evidence such as the presence of contaminants in bodies and eggs at levels higher than toxic thresholds. Current mercury concentrations in marsh birds such as rails breeding in SFB are still higher than threshold levels, which are known to be responsible for impairment of reproduction (Davis et al., 2003; Schwarzbach et al., 2006; Tsao et al., 2009). Additional indirect evidence is the level of contaminants in diets. When birds feed on diets containing contaminants at levels higher than threshold values, adverse effects are likely to be observed. Body burdens of PCBs (129-1,274 ng/g) and DDTs (67-162 ng/g) in transplanted fish (mudsucker; *Gillichthys mirabilis*) in Stege Marsh (Hwang et al., 2008) were higher than the wildlife criteria (160 ng/g for PCBs and 39.9 ng/g for DDTs) set for the protection of fish-eating birds (USEPA, 1997). This implies that sedimentary contaminants could eventually be transferred to fish-eating birds and possibly affect their health.

Through maternal transfer of contaminants, embryos are exposed to them and may experience hatching problems (Custer and Custer, 1995; Lewis et al., 1995). Levels of contaminant detected in avian eggs of SFB have been high enough to impair egg development (Ohlendorf et al., 1988; Hothem et al., 1995; Schwarzbach et al., 2001, 2006). Mercury concentrations were much higher in failed-to-hatch eggs than in normally hatched eggs. Cumulative effects of these responses over the long-term can eventually affect the population of birds, especially endangered species such as California clapper rails. Among contaminants measured in birds, DDT and its metabolites (DDD and DDE) were the most problematic due to their notorious eggshell thinning effect. Ohlendorf et al. (1988) found that levels of DDE in eggs were negatively correlated with eggshell thickness and thickness index in night herons and snowy egrets. A negative correlation was found between embryo weight and PCB residues in eggs of night-herons collected from Don Edwards San Francisco Bay National Wildlife Refuge, suggesting a possible impact of PCBs on the growth of embryos (Hoffman et al., 1986). Schwarzbach et al. (2006) found positive correlations between deformities and elevated concentrations of mercury in failed-to-hatch eggs.

Oil spills also cause severe damage in aquatic life and wildlife and degrade habitat quality. In 1998, about 1.5 million L of crude oil leaked from Shell storage tanks and was released into northern SFB, causing tremendous ecological damages. The spilled crude oil coated about 100 acres of Peyton Marsh, killed thousands of birds, and ruined valuable habitats for aquatic life and wildlife. Two recent oil spill accidents, *Cosco Busan* in 2007 and *T/V Dubai Star* in 2009, poured about 220,000 L and 3,200 L of fuel oil, respectively, into the bay. More than a thousand birds died due to acute toxicity of the spilled oil. Contaminants such as PAHs from oil spill accidents can also damage aquatic life such as crabs and bivalves in marshes. Mussels collected from shorelines of Alameda County after the *T/V Dubai Star* oil spill accumulated PAHs up to about 20,000 ng/g (dry wt.), which is about 10 to 20 times higher than ambient background levels. Concurrent measurement of lysosomal membrane destabilization exhibited that the mussels impacted by the spilled oil were less healthy (Hwang et al., unpublished data).

9.7 Conclusion

Overall, concentrations of persistent organic contaminants and trace metals in SFB marsh ecosystems have declined and habitat quality of existing marshes is being improved slowly. However, levels of contaminants in some tidal marshes are still high enough to be linked to adverse effects observed in aquatic life and wildlife species. Fragmented marshes are also a roadblock to recovery of healthy marsh ecosystems in SFB. To provide additional habitat and improve its quality, large-scale marsh restoration plans are being formulated and implemented. However, these restoration activities can increase the conversion of inorganic mercury to MeHg and thus restoration plans need to be implemented with caution to reduce unwanted increase of exposure of wildlife to MeHg.

This review finds that the environmental quality of many marshes of SFB does not fully support the health of the organisms; more studies are needed to better understand the roles of marshes in controlling the movement of contaminants and their impacts on the health of the marsh ecosystem. There is some evidence that persistent organic contaminants and trace metals deposited in sediments could be desorbed and affect the health of aquatic organisms. These contaminants eventually reach higher trophic level organisms such as birds and could provoke adverse effects on them. Most marsh studies, however, have not investigated overall impacts of contaminants, suggesting that more integrated studies are required to better support marsh management and restoration activities. It would also be desirable to further investigate the roles of marsh plants in controlling the fate and transport of contaminants and their possible usability for phytoremediation to clean up sedimentary contaminants. Lack of information regarding integrated impacts of simultaneous exposure to multiple contaminants also hinders accurate assessment of their overall adverse effects. Linking concentrations of individual chemicals in field samples to toxicity data may lead to underestimation of the combined toxicity potential of environmental contaminants. More studies are also needed for emerging contaminants such as PBDEs, phthalates, and pharmaceuticals.

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10. Distribution of Macroinvertebrates Across a Tidal Gradient, Marin County, California

April Robinson[1], **Andrew N. Cohen**[2], **Brie Lindsey**[3], and **Letitia Grenier**[4]

[1]*San Francisco Estuary Institute, Oakland, CA*
april@sfei.org
(510) 746-7344

[2]*Center for Research on Aquatic Bioinvasions (CRAB), Richmond, CA*
acohen@bioinvasions.com
(510) 778-9201

[3]*College of Atmospheric and Oceanic Sciences*
Oregon State University, Corvallis, OR
blindsey@coas.oregonstate.edu

[4]*San Francisco Estuary Institute, Oakland, CA*
letitia@sfei.org
(510) 746-7388

ABSTRACT

The distribution of macroinvertebrates across a tidal gradient is described from a study of invertebrate distribution across tidal marsh sub-habitats, a non-quantitative survey of epifauna on intertidal rocky substrate, and a few additional observations and records from China Camp State Park, Marin Co., California. In the tidal marsh study, invertebrates were sampled from distinct sub-habitat types: high-order channels, low-order channels, vegetated marsh plain, and natural levees adjacent to channels. Invertebrates were collected using a variety of trapping methods to account for capture biases associated with any one method. All common invertebrate taxa were significantly more abundant in a particular sub-habitat, and within each trapping method a few species accounted for most of the biomass. On intertidal rocks, 79% of the taxa identified to species or genus were exotic, but a few native species were common.

KEY WORDS

macroinvertebrate
intertidal
food web
tidal marsh
tidal gradient
salt marsh
exotic species
San Francisco Bay
China Camp State Park

10.1 Introduction

Intertidal habitats present a harsh physical environment for resident invertebrates. Twice daily tides subject terrestrial invertebrates to the risk of drowning and aquatic invertebrates to the risk of desiccation. Inundation periods and sediment properties vary across the intertidal gradient, and environmental conditions change rapidly with inundation and exposure. Physical and biological conditions change over small spatial scales, as slight changes in elevation translate to large changes in hydrology, geomorphology, and vegetation (Collins et al. 1986; Pennings and Callaway 1992).

Distribution of rocky intertidal invertebrates varies over both large and small spatial scales as a result of differences in dispersal, recruitment, and response to changes in microhabitat between species (Underwood and Chapman 1996). The small-scale zonation of rocky intertidal invertebrates results from a combination of physiological limitations and ecological interactions (Tomanek and Helmuth 2002).

Within tidal marshes, distinct sub-habitats – from large, high-order channels to small, low-order channels, to marsh plain and natural levee – are found adjacent to each other along the tidal gradient, sometimes changing abruptly from one meter to the next. Marsh invertebrate communities vary by sub-habitat, with many species showing a preference for particular elevations, vegetation zones or substrate types (Teal 1962, Davis and Grey 1966, Levin and Talley 2000).

Invertebrates constitute much of the secondary productivity in tidal marshes (Teal 1962) and play a critical role in transferring primary productivity up the food web, forming a substantial part of the diet of many resident marsh vertebrates (Grenier and Greenberg 2005). As there are few seeds and fruits in the marsh available for foraging terrestrial vertebrates (Greenberg et al. 2006), the distribution and diversity of invertebrates largely determines the food resources available for secondary consumers, and influences their foraging behaviors. Invertebrates constitute a substantial portion of the diet of many common marsh fish species as well (Visintainer et al. 2006).

This paper provides original data on the distribution of macroinvertebrates across a tidal gradient and reviews what is known about the diversity, distribution, and abundance of intertidal invertebrates at China Camp State Park in Marin County, California, a National Estuarine Research Reserve site[1]. Data from two studies, one of tidal marsh invertebrates and the other of rocky intertidal invertebrates, are presented here. Most of the previously available invertebrate data from China Camp focus on predation of invertebrates (Dean et al. 2005, Visentainer et al. 2006) rather than on their diversity and distribution. The implications of invertebrate distribution and diversity on the behavioral ecology of their predators are also briefly discussed.

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[1] The material in this article is also being published in the National Estuarine Research Reserve Special Issue of the journal *San Francisco Estuary and Watershed Science*, and in the book *Tidal Salt Marshes of the San Francisco Estuary: Ecology, Restoration, Conservation.*

10.2 Methods

Study Area

China Camp State Park contains 180 ha of tidal marsh, located on the western edge of San Pablo Bay in Marin County, CA (38°00′45″ N, 122°29′25″ W). San Pablo Bay is subject to semi-diurnal tides and a Mediterranean climate with mild, wet winters and warm, dry summers. The upper part of the intertidal zone, above roughly mean high water, is occupied by salt marsh, with mudflats below that. Rock outcrops and boulders are exposed on the low intertidal mudflats near a small island known as Rat Rock. The salt marsh is composed of a mix of ancient and centennial marsh, with the centennial marsh having accreted along the bayward edge over the last 150 years, likely due to the deposition of Gold Rush hydraulic mining sediments (Jaffe et al. 2007).

The salt marsh at China Camp includes several distinct sub-habitats along a tidal gradient, each with distinct vegetation and hydrology (Figure 1). The dendritic tidal conveyance network is comprised of high-order channels that receive tides twice daily and low-order channels that are smaller, at slightly higher elevation, and, thus, receive less frequent tidal inundation. Pacific cordgrass (*Spartina foliosa*) grows inside the banks of the high-order channels, while the low-order channels are unvegetated (though they may be overhung by pickleweed (*Sarcocornia pacifica*) or other vegetation). Low-order channels peter out into the marsh plain, which, in turn, receives less frequent tidal inundation than the channels. Marsh plain is the most extensive sub-habitat in the marsh, extending from mean high water to slightly above mean higher high water and dominated by pickleweed, a low-growing succulent halophyte, with other common

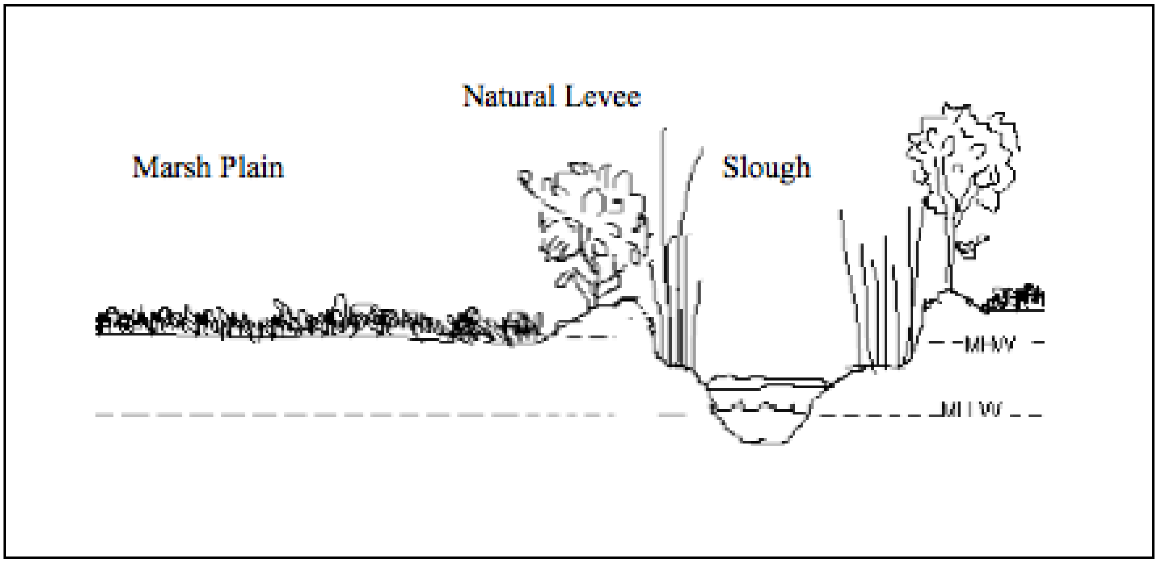


Figure 1. Sub-habitats of the China Camp tidal marsh. Channels are bordered by natural levees with vegetation dominated by Grindelia stricta *and* Sarcocornia pacifica. *The marsh plain adjacent the natural levee is slightly lower in elevation and is dominated by* S. pacifica.

marsh plants interspersed (primarily *Jaumea carnosa, Distichlis spicata* and *Frankenia salina*; Goals Project 2000). Natural levees build up along the edge of channels as coarse sediments are deposited by overbanking tides (Collins et al. 1986). These levees are dominated by gumplant (*Grindelia stricta*), a short woody shrub. Levees are higher and wider, and *Grindelia* is more abundant, along high-order channels. Consequently flood tides overflow low-order channels first, wetting the marsh plain near small channels more frequently and for longer periods than near large channels (Collins et al. 1986).

Tidal Marsh Invertebrate Study

Invertebrates at China Camp marsh were collected from the channels, marsh plain and natural levees as part of a food-web study reported in greater detail by Grenier (2004). Invertebrates were collected to investigate which taxa were available as potential prey items for the San Pablo Song Sparrow (*Melospiza melodia samuelis*), a tidal marsh obligate, and other marsh vertebrates; and to determine how macroinvertebrates were distributed across the tidal gradient. Because no single method was sufficient to account for all invertebrate locomotion types and habitat preferences, multiple trapping methods were used. The study was conducted in a 3.3 ha plot within the centennial portion of the marsh, characterized by the simple, less sinuous channels typical of a rapidly formed marsh.

Sample Collection

Sampling was conducted at low tide from May to July, 2001, and consisted of five capture methods: pit trap, sweep net, snail count, mud core, and sticky trap. Equal sampling effort was expended along high-order and low-order channels. For each channel type, random sampling locations were stratified across three sub-habitats: within the channel, on the natural levee adjacent to the channel, and on the nearby marsh plain. No samples were taken in standing water. The plant species within 10 cm of each trap were recorded.

Pit trap, sweep net, and snail count methods were conducted with equal effort in each of the sub-habitats. Pit traps were cylindrical plastic containers, 11 cm in diameter and 11 cm deep, buried in the sediment with the top of the trap level with the ground and no space between the container and the surrounding sediment. Traps were open for at least 3 hours. Sweep net sampling consisted of 10 strokes with a 15” diameter sailcloth net, sweeping new vegetation with each stroke. Snail counts consisted of counting all snails within a 22 cm x 22 cm quadrat.

Mud core and sticky trap methods were used only in the channels, because 1) on the natural levees and marsh plains pilot mud core samples consisted of dry, hard-packed sediment devoid of macroinvertebrates, and 2) pilot sticky trap samples replicated results from pit traps and sweep nets in natural levee and marsh plain habitats. Cores were 7.0 cm in diameter and 10 cm deep, and organisms were collected from them with a 0.5 mm mesh sieve. For each core, the relative abundance of roots was recorded on a scale of 0--3, with 0 indicating no roots and 3 indicating very dense roots. Sticky traps were a thin layer of *Tanglefoot* adhesive spread onto sheets of plastic (20 x 10 cm) that were placed on the sediment. The traps were set for at least three hours and checked frequently as the tide rose; if the traps were in jeopardy of flooding, they were moved to adjacent higher ground.

Sample Processing

Common invertebrates were identified to the lowest feasible taxonomic level with assistance from experts (see Acknowledgements). Average biomass was determined for large or common taxa (greater than 10 individuals per trap method) by weighing between 9 and 115 individuals per taxon, after drying at 55 degrees Celsius until a constant weight was achieved. Snails were weighed without their shells. Because planthoppers (*Prokelisia marginata*) had such low mass, they were weighed in groups of 10 individuals at a time. Masses for araneid spiders were estimated from lycosid spiders of similar size.

Data Analysis

Catch per unit effort (CPUE) was calculated as the number of invertebrates of the same taxon caught per trap hour for pit traps and sticky traps, and calculated as invertebrates per trapping event for all other capture methods. Differences in CPUE among sub-habitats were examined using nonparametric ANOVA (Kruskal-Wallis), which was also used to determine the relationship between CPUE and presence of roots, and CPUE and plant community composition. The relationship between CPUE and plant community composition was examined separately for each of the sub-habitats along the tidal gradient, because the vegetation varied dramatically among sub-habitats. Plant-invertebrate relationships in the channel sub-habitat were tested separately for large and small channels because *Spartina foliosa* was found only in large channels.

Rocky Intertidal Invertebrates

During low tide on November 15, 2005, organisms on and around a low intertidal rocky outcrop and boulders near Rat Rock at China Camp State Park were collected by hand and identified in the field by A. Cohen using a 10-power hand lens. The sampling was conducted as a component of ongoing surveys for the State of California's Marine Invasive Species Program, with the goal of characterizing and monitoring the distribution and abundance of exotic species in California's coastal waters. Some of these samples, along with quantitative samples from nearby quadrats, were preserved for identification in the laboratory. We report here only on the initial field identifications.

10.3 Results

Tidal Marsh Invertebrates

A total of 4597 invertebrates were captured in 787 trapping events, representing seven taxonomic classes and at least 14 orders (Table 1). Six of the 7 taxa identified to species (85.7%) were exotic (most of the arthropods were not identified to species). As expected, community composition of invertebrates differed notably by capture method, and one taxon dominated

Table 1. Number of invertebrates collected in the tidal marsh study by each capture method (* = exotic species).

						Number of Individuals Collected (by capture method)				
Phylum	**Class**	**Order**	**Family**	**Genus and Species**	**Common name**	**mud core**	**pit trap**	**sweep net**	**snail count**	**sticky trap**
Annelida	Oligochaeta				Oligochaete worm	655	-	-	-	-
	Polychaeta	Phyllodocida	Nereidae	*Neanthes succinea**	Polychaete worm	2	-	-	-	-
		Other Polychaetes			Polychaete worm	131	-	-	-	-
Mollusca	Gastropoda	Basommatophora	Ellobiidae	*Myosotella myosotis**	European marsh snail	1	3	22	886	2
	Bivalvia	Veneroida	Tellinidae	*Macoma petalum**		39	-	-	-	-
Anthropoda	Crustacea	Amphipoda	Corophiidae	*Corophium alienense**	Aquatic amphipod	195	3	-	-	-
			Corophiidae	*Grandidierella japonica**	Aquatic amphipod	98	-	-	-	-
			Talitridae	*Traskorchestia traskiana*		-	602	4	-	4
	Arachnida	Araneae	Araneidae		Orb spider	-	4	44	-	-
			Lycosidae		Wolf spider	-	26	2	-	-
		Other Arachnida			Spider	2	7	38	-	1
	Insecta	Coleoptera	Heteroceridae		Mud living beetle	41	3	-	-	-
			Curculionidae		Weevil	-	-	7	-	-
			Bembidion		Ground beetle	-	65	1	-	-
			Chrysomelidae		Spotted cucumber beetle	-	-	13	-	-
			Other Coleoptera		Beetle adult	1	5	17	-	-
					Beetle larvae	14	52	-	-	-
		Diptera	Dolichopodidae		Long legged fly	-	-	116	-	544
			Otitidae		Picture wing fly	-	-	25	-	-
			Other Diptera			-	-	86	-	99
		Homoptera	Delphacidae	*Prokelisia marginata**	Planthopper	-	-	703	-	1
			Other Homoptera		Leafhopper	-	1	11	-	-
		Hemiptera				-	-	9	-	-
		Lepidoptera			Moth	-	-	4	-	-
		Other Insecta			**Insect**	**1**	**1**	**6**	**-**	**-**

captures for most trapping methods. The amphipod *Traskorchestia traskiana* comprised 77% of the individuals caught by pit trap, while the planthopper *Prokelisia marginata* comprised 64% of the individuals caught by sweep net. Oligochaete and polychaete worms made up 67% of mud core captures and dolichopodid flies made up 83% of individuals caught by sticky trap.

Pit trap biomass was dominated by one species across all sub-habitats, while sweep net biomass was dominated by different taxa in each sub-habitat (Figures 2 and 3). Mass (+/- 1 SD) of common taxa ranged from 0.26 (+/- 0.07) mg/individual for *Prokelisia marginata* to 8.65 (+/- 6.70) mg/individual for *Traskorchestia traskiana* (Table 2). The mean biomass per quadrat for the snail *Myosotella myosotis* was 15.7 mg on the marsh plain and 25.5 mg on the natural levee, with no snails observed in the channels.

The abundance of common taxa differed by sub-habitat (Table 3). Channel size also influenced invertebrate community composition, with several common taxa being more abundant near either low-order or high-order channels (Table 4). The burrowing amphipod *Corophium alienense* was the only species whose abundance was related to the density of plant roots, being more abundant in areas with lower root density (Kruskal Wallis, H = 14.57, n = 72, p = 0.02).

The abundance of *Corophium* amphipods, *Macoma petalum* clams, and *Prokelisia* planthoppers were related to plant distribution. The burrowing amphipods and clams were more likely to be found in large channels where *Spartina foliosa* was not present (*C. alienense*: Mann-Whitney-U = 223.5, n = 36, p < 0.001; *M. petalum*: Mann-Whitney-U = 223, n = 36, p < 0.001), while planthoppers were more likely to be found in channels where *S. foliosa* was present (Mann-Whitney-U = 94, n = 36, p < 0.001).

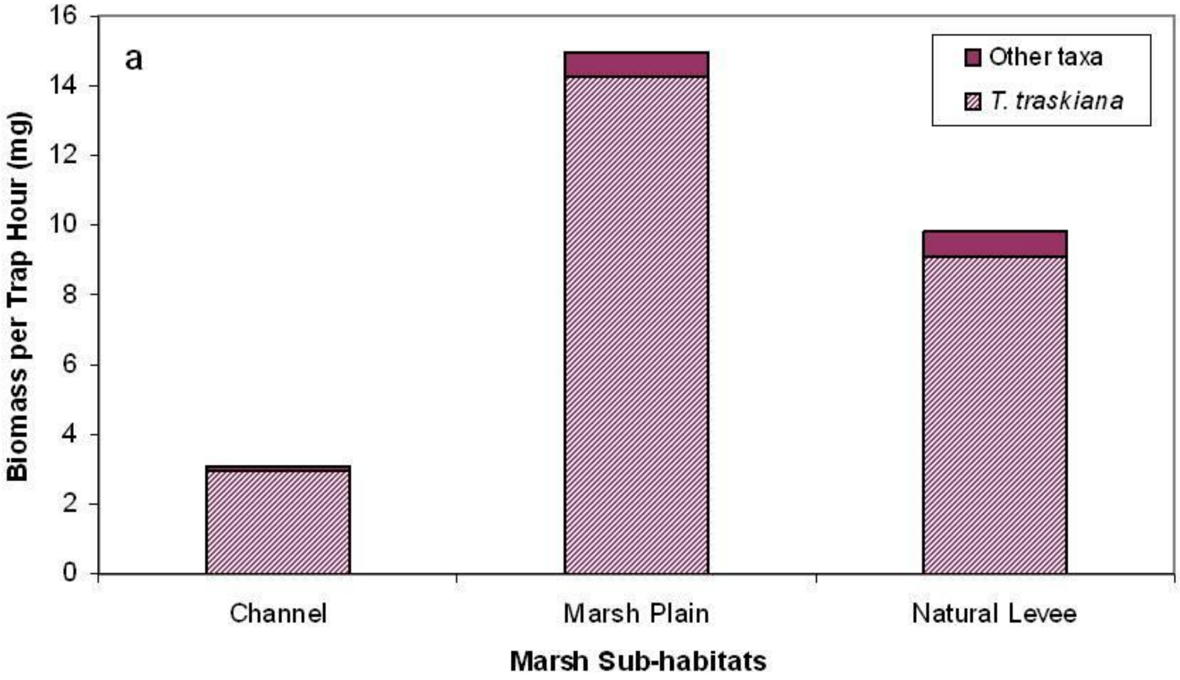
Rocky Intertidal Invertebrates

Invertebrates from nine classes and at least 16 orders were observed in the epifaunal survey (Table 5). Of the 28 taxa identified to genus or species, 22 (78.6%) are known to be exotic.

Additional Records

In addition to the taxa above, several invertebrates that had been seen but not captured during the quantitative tidal marsh study were hand-collected for identification. These taxa included the European green crab (*Carcinus maenas*), the yellow shore crab (*Hemigrapsus oregonensis*,), two species of shrimp (*Palaemon macrodactylus* and *Crangon franciscorum*), the Eastern mud snail (*Ilyanassa obsoleta*), stinkbugs in the family Pentatomidae, and mites in the family Tetranychidae.

Other invertebrates we commonly observed at China Camp include the isopod *Sphaeroma quoiana*, whose pencil-diameter burrows riddle the channel banks and may contribute to their slumping and erosion, and the small, commensal isopod *Iais californica*, which lives on *Sphaeroma*'s ventral surface. Both of these species are from Australia. The ribbed horsemussel *Geukensia demissa*, an import from the Atlantic, lives in the lower channels and at the marsh edge, attached by byssal threads to subsurface *Spartina* stems or other objects.



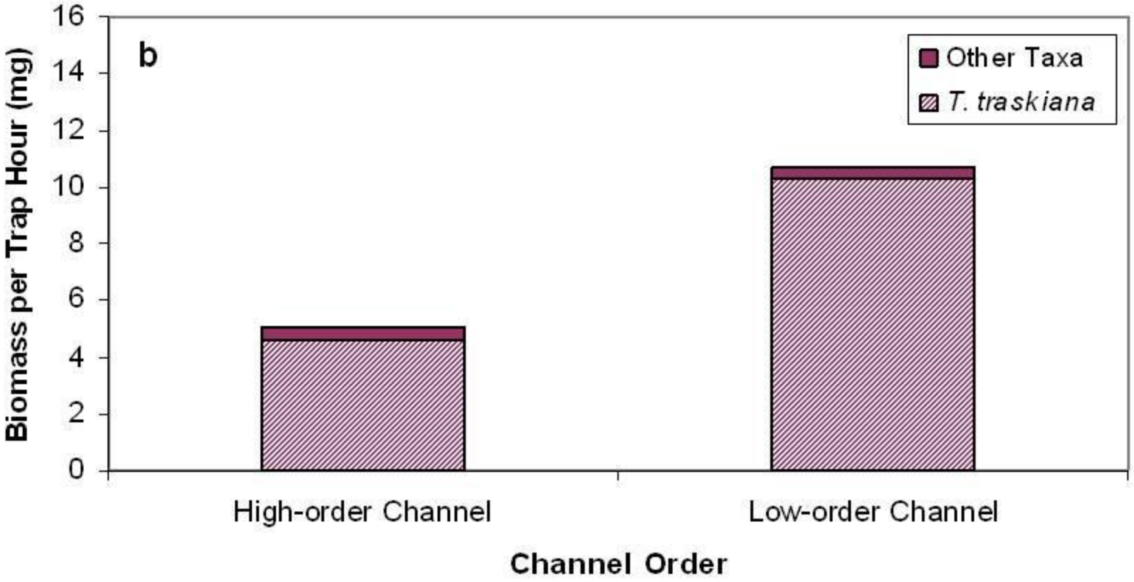


Figure 2. Mean biomass per trap hour for pit traps by a) marsh sub-habitat and b) channel order.

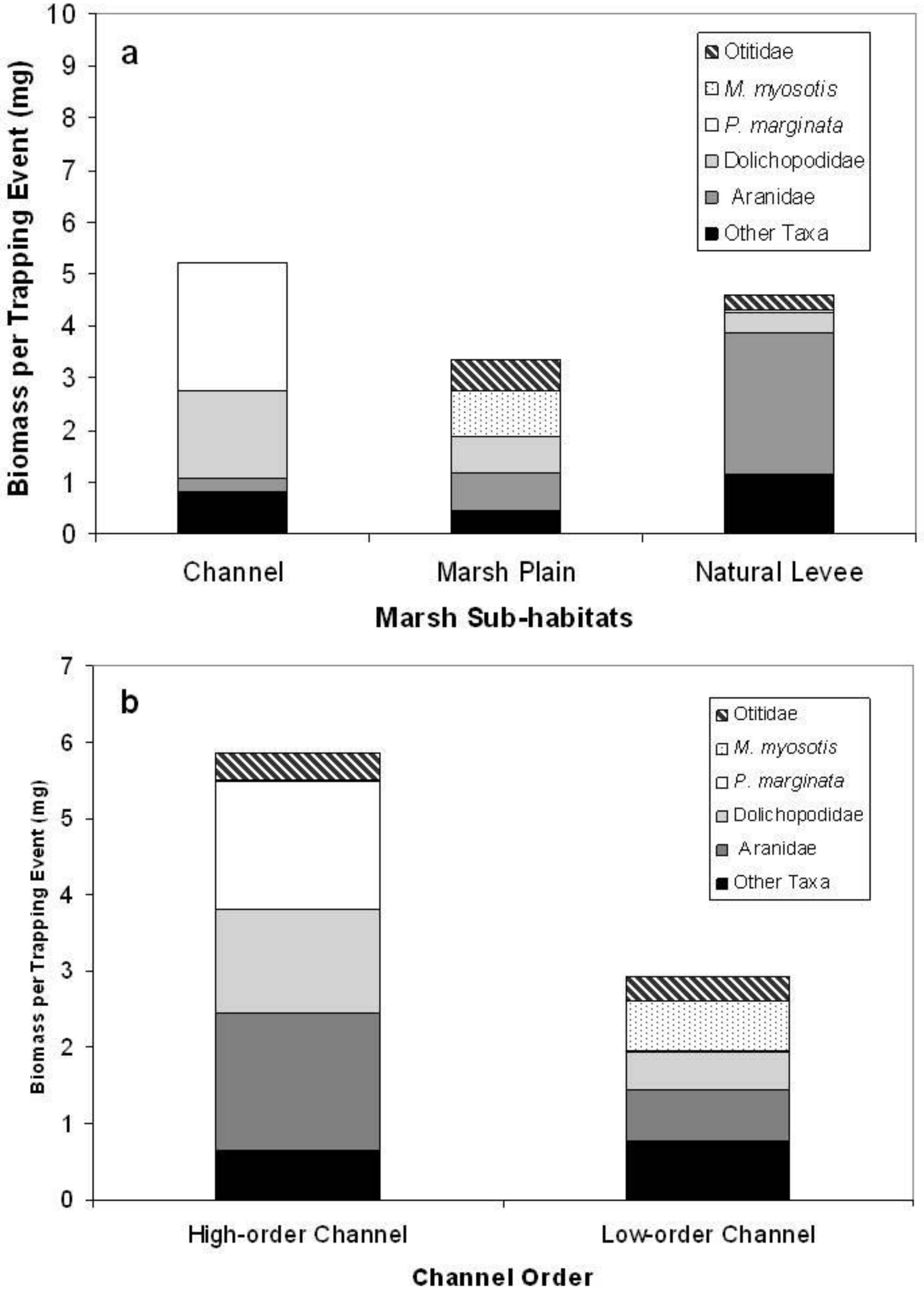


Figure 3. Mean biomass per trapping event from sweep netting by a) marsh sub-habitat and b) channel order.

Table 2. Individual mass (+/- 1 SD) for common taxa caught by sweep net and pit trap.

Taxon (Order)	$n_{weighed}$	Mean biomass (mg)	
T. traskiana (Amphipoda)	99	8.65	+/- 6.70
Chrysomelidae (Coleoptera)	26	7.15	+/- 2.06
Lycosidae (Araneae)	26	6.07	+/- 4.20
M. myosotis (Basommatophora)	60	3.35	+/- 1.44
Otitidae (Diptera)	25	2.85	+/- 1.16
Curculionidae (Coleoptera)	9	2.49	+/- 0.28
Heteroceridae (Coleoptera)	16	1.96	+/- 0.75
Dolichopodidae (Diptera)	113	1.73	+/- 0.61
Bembidion (Coleoptera)	42	1.68	+/- 0.42
Corophiidae (Amphipoda)	11	0.45	+/- 0.25
P. marginata (Homoptera)	40	0.26	+/- 0.07

Table 3. Catch per unit effort (CPUE) by sub-habitat for pit trap and sweep net samples. P-values are from Kruskal-Wallis tests (alpha = 0.05). Bold text indicates the zone with the highest CPUE.

Capture Method	Taxon (Order)	Total Count (# trap hours or trapping events)			
		Channel	Marsh Plain	Natural Levee	*p*
Pit Trap	Lycosidae (Araneae)	0 (234)	**13 (230)**	**13 (236)**	**0.001**
	Bembidion (Coleoptera)	0 (234)	**44 (230)**	21 (236)	**<0.001**
	T. traskiana (Amphipoda)	69 (234)	**318 (230)**	215 (236)	**<0.001**
	Heteroceridae Larvae (Coleoptera)	**52 (234)**	0 (230)	0 (236)	**<0.001**
Sweep Net	Chrysomelidae (Coleoptera)	1 (72)	3 (72)	**9 (72)**	**0.014**
	Aranidae (Araneae)	3 (72)	9 (72)	**32 (72)**	**<0.001**
	Otitidae (Diptera)	3 (72)	**15 (72)**	7 (72)	**0.002**
	P. marginata (Homoptera)	**689 (72)**	5 (72)	9 (72)	**<0.001**
	Dolichopodidae (Diptera)	**70 (72)**	28 (72)	18 (72)	**0.016**
Snail Count	*M. myosotis* (Basommatophora)	0 (72)	339 (72)	**547 (72)**	**<0.001**

Table 4. Comparison of catch per unit effort (CPUE) of common taxa by channel order, summed across all sub-habitats. P-values are from Kruskal-Wallis tests (alpha = 0.05). Bold text indicates the channel size with the greatest CPUE, where results are significant.

Capture Method	Taxon (Order)	Total Count (# trap hours or trapping events)		p
		Low-order Channel	High-order Channel	
pit trap	*T. traskiana* (Amphipoda)	**418 (349)**	187 (350)	**<0.001**
	Bembidion (Coleoptera)	37 (349)	28 (350)	0.673
	Lycosidae (Araneae)	12 (349)	14 (350)	0.91
sweep net	*M. myosotis* (Basommatophora)	**21 (108)**	1(108)	**0.01**
	Aranidae (Araneae)	12 (108)	**32 (108)**	**0.014**
	P. marginata (Homoptera)	11 (108)	**692 (108)**	**<0.001**
	Curculionidae (Coleoptera)	0 (108)	**7 (108)**	**0.007**
	Dolichopodidae (Diptera)	30 (108)	**86 (108)**	**0.013**
	Chrysomelidae (Coleoptera)	9 (108)	4 (108)	0.154
	Otitidae (Diptera)	12 (108)	13 (108)	0.827
mud core	Oligochaeta	**108 (36)**	19 (36)	**0.001**
	Polychaeta	**424 (36)**	231 (36)	**0.011**
	Heteroceridae (Coleoptera)	3 (36)	**38 (36)**	**0.035**
	C. alienense (Amphipoda)	26 (36)	72 (36)	0.801
	M. petalum (Veneroida)	13 (36)	26 (36)	0.822
	G. japonica (Amphipoda)	80 (36)	115 (36)	0.868
sticky trap	Dolichopodidae (Diptera)	278 (36)	266 (36)	0.83
snail count	*M. myosotis* (Basommatophora)	**641 (108)**	245 (108)	**<0.001**

Table 5. Marine invertebrates collected on intertidal rocks at China Camp in November 2005 and identified in the field (* = exotic species).

Phylum	Class	Order	Family	Species	Common Name
Porifera	Desmospongiae	Halichondrida	Halichondriidae	*Halichondria sp.* [1] *	sponge
		Haplosclerida	Chalinidae	*Haliclona sp.* [1] *	sponge
		Other Desmospongiae			sponge
Cnidaria	Hydrozoa				hydroid
	Anthozoa	Actiniaria	Diadumenidae	*Diadumene sp.* [2] *	anemone
			Diadumenidae	*Diadumene lineata**	Orange-lined anemone
					anemone
Annelida	Polychaeta	Phyllodocida	Nereidae	*Neanthes succinea**	pile worm
			Polynoidae	*Harmothoe praeclara* [3] *	scale worm
		Other Polychaeta			polychaete worm
Mollusca	Gastropoda	Cephalaspidea	Philinidae	*Philine sp.* [4] *	Tortellini snail
		Other Opisthobranchia		unidentified opisthobranch	sea slug
	Bivalvia	Ostreoida	Ostreidae	*Ostrea lurida*	Olympia oyster
		Mytiloida	Mytilidae	*Geukensia demissa**	Ribbed horsemussel
			Mytilidae	*Musculista senhousia**	Green bagmussel
			Mytilidae	*Mytilus galloprovincialis*/trossulus* [5]	Bay mussel
		Myoida	Corbulidae	*Corbula amurensis**	Overbite clam
			Myidae	*Mya arenaria**	Atlantic softshell clam
		Veneroida	Tellenidae	*Venerupis philippinarum**	Japanese littleneck clam
		Other Bivalvia		unidentified clam	clam
Arthropoda	Crustacea	Balanomorpha	Chthamalidae	*Chthamalus sp.* [6]	barnacle
			Balanidae	*Balanus glandula*	barnacle
			Balanidae	*Balanus sp.*	barnacle
		Isopoda	Sphaeromatidae	*Gnorimosphaeroma oregonense*	isopod
		Amphipoda	Gammaridae		amphipod
			Corophiidae or Aoridae	unidentified *Corophiid* or *Grandidierella japonica* [7] *	amphipod
		Decapoda	Portunidae	*Carcinus maenas**	Green shore crab
			Varunidae	*Hemigrapsus oregonensis*	Yellow mud crab
Bryozoa	Gymnolaemata	Ctenostomata	Nolellidae	*Anguinella palmata**	bryozoan
			Vesiculariidae	*Bowerbankia sp.**	bryozoan
		Cheilostomata	Membraniporidae	*Conopeum sp.**	bryozoan
			Cryptosulidae	*Cryptosula pallasiana**	bryozoan
			Schizoporellidae	*Schizoporella sp.* [8] *	bryozoan
Chordata	Ascidiacea	Pleurogona	Styelidae	*Botryllus schlosseri**	sea squirt
			Molgulidae	*Molgula manhattensis**	sea squirt

Taxonomic notes

[1] The sponges in San Francisco Bay in the genera *Halichondria* and *Haliclona* have been identified in many texts as the Atlantic species *Halichondria bowerbanki* and *Haliclona loosanoffi*, respectively, but some taxonomists have recently questioned these identifications.

[2] Of the four exotic *Diadumene* species in San Francisco Bay, this is the orange- or salmon-colored one that has sometimes been listed as *D. cincta*, but according to Dr. Daphne Fautin of the University of Kansas is not that species.

[3] Based on its abundance in other studies in San Francisco Bay, this is probably the Australian species *Harmothoe praeclara* and not the native (and primarily outer coast) species *H. imbricata*, but no morphological characters were examined that would distinguish the two.

[4] At least four exotic *Philine* species have been reported in Central California: *P. auriformis* from New Zealand and *P. orientalis* from the Philippines and Hong Kong in San Francisco Bay and other waters; and *P. aperta* from South Africa and *P. japonica* from Japan in other Central California bays. This seems an unlikely convergence of multiple species in this one genus from distant corners of the world, and we consider the taxonomy of exotic *Philine* species on the west coast of North America to be yet unresolved.

[5] The native species *Mytilus trossulus*, the Mediterranean species *M. galloprovincialis* and hybrids of the two have all been reported in San Francisco Bay. Characters were not examined to distinguish among these. Based on the frequency of the exotic or hybrid forms in San Francisco Bay, these specimens were counted as exotic (see Results).

[6] The native species *Chthamalus fissus* and *C. dalli* are both present in Central California; characters were not examined to distinguish between them.

[7] The Corophiidae reported in San Francisco Bay west of the Carquinez Strait are *Corophium alienense*, *C. heteroceratum*, *Monocorophium acherusicum*, *M. insidiosum* and *M. uenoi*, all of them exotic. The native Corophiidae reported in the San Francisco Bay watershed, *Americorophium spinicorne* and *A. stimpsoni*, are only found east of Carquinez Strait, usually in fresh water. The native *A. brevis*, once present in San Francisco Bay, is believed to be extinct south of Humboldt Bay. The Aoridae species *Grandidierella japonica*, from Japan, resembles the Corophiidae and is common in San Francisco Bay. Morphological characters were not examined to distinguish among these various species.

[8] The *Schizoporella* species in San Francisco Bay was formerly identified in many texts as the Atlantic species *S. unicornis*, but may comprise more than one species. We consider the taxonomy of *Schizoporella* in San Francisco Bay to be unresolved.

10.4 Discussion

The data presented in this paper demonstrate the unequal distribution of invertebrates across intertidal sub-habitats at China Camp State Park in San Francisco Bay. Relatively few species made up the majority of the invertebrate biomass in the tidal marsh, and the majority of both the rocky intertidal invertebrates and the tidal marsh invertebrates identified to species were exotic. The strong association of certain invertebrate groups to specific sub-habitats suggests that predators with different feeding specializations may forage primarily in one part of the marsh or another.

Invertebrate Diversity

Two general groups of intertidal invertebrates were collected at China Camp: those that belong to taxonomic groups that are primarily land dwelling (terrestrial-derived invertebrates), and those belonging to taxonomic groups that are mostly marine dwelling (marine-derived invertebrates). While only marine-derived invertebrates were found in the rocky intertidal habitat, both marine- and terrestrial-derived invertebrates were found in the tidal marsh. The terrestrial-derived invertebrates included spiders, insects, oligochaetes, and the pulmonate snail *Myosotella myosotis*, while the marine-derived invertebrates included sponges, cnidarians, polychaete worms, opisthobranch snails, bivalves, crustaceans, bryozoans, and sea squirts (Tables 1 and 5). As is typical of San Francisco Bay, many of the marine-derived invertebrate species at China Camp have been introduced from other parts of the world, including the coasts of the North Atlantic Ocean, Pacific Asia, and Australia (Cohen and Carlton 1995).

Invertebrate Distribution

Tidal Marsh

Most taxa in this study showed a preference for a particular sub-habitat or channel order. In addition, capture for most trapping methods was dominated by one taxon, reflecting whether the capture method was most likely to catch ground-crawling, flying, canopy dwelling, or benthic invertebrates. These results suggest clear niche partitioning. Competition, predation, food resources, and limits of physiological tolerance likely all play a role in maintaining this uneven distribution of invertebrates.

Each tidal marsh sub-habitat differs in the frequency and duration of tidal inundation and consequently varies in sediment moisture, oxygen and salinity; sediment particle size and organic content; and vegetation (Levin and Talley 2000). Levin and Talley (2000) suggest these interrelated factors influence invertebrate distribution in tidal marshes on different spatial and temporal scales. Parameters such as marsh age, salinity and elevation act over large time scales to determine which species are present in a marsh, while factors such as plant biomass and oxygen concentration affect invertebrates over shorter time and smaller spatial scales, determining where in the marsh certain species will be found. The results from this study are consistent with previous studies showing that the community composition of invertebrates differs by elevation and vegetation zone (reviewed in Levin and Talley 2000).

The channels, being most frequently inundated, support invertebrates that prefer moist environments. Our study found that benthic epifauna were more abundant in the channel than in the higher elevation sub-habitats. Similarly, studies of southern California tidal marshes have found benthic infauna to be most abundant at lower elevations (Levin and Talley 2000). Risk of desiccation increases at higher elevation for these invertebrates (Kneib 1984).

The channels also supported the greatest number of insects at China Camp, particularly homopterans and dipterans. Davis and Gray (1966) found that many marsh insects respond to tidal flooding and drying with behavioral rather than physiological adaptations. Even species able to withstand long periods of submersion in laboratory experiments preferred to escape the rising tide by flying, swimming, or running along the water surface whenever possible. The ability of flying and hopping insects, such as dipterans and homopterans, to quickly escape rising tide waters and predators may explain their abundance in the channels, despite being taxa of terrestrial origin. Heterocerid beetles, found in the channels at China Camp, are one of the few families of Coleoptera with marine representatives (Doyen 1976). Wyatt et al. (1986) suggest the shape of their burrows, which takes advantage of the surface tension effects of small air-filled openings, allows these beetles to protect their larvae from flooding in intertidal habitats.

Oligochaetes and polychaetes were most abundant in small channels, while heterocerid beetles, Dolichopodid flies and planthoppers were more frequently found in large channels. These invertebrates may be responding to physical differences among channel orders, or biotic differences in food resources, predation or competition. The narrow width and overhanging vegetation of small channels may reduce drying, limit temperature increases, provide protection from terrestrial predators, or affect food availability by changing the composition of microalgae. Whitcraft and Levin (2007) found more insects and fewer amphipods and oligochaetes in unshaded than shaded plots in a Southern California marsh, which they hypothesized was related to the presence of more cyanobacteria in unshaded plots and more diatoms in shaded plots. A similar mechanism could produce the trend seen at China Camp, if the smaller channels at China Camp are more shaded, which does seem to be the case based on personal observations of the authors.

While the inner banks of the small channels at China Camp were unvegetated, scattered stands of Pacific cordgrass, *Spartina foliosa,* grew inside the banks of large channels. Planthoppers specialize on *Spartina* sap (Denno et al. 1987), so it is not surprising that they showed a strong association with *Spartina*. *Corophium alienense* and *Macoma petalum* showed a significant negative association with *Spartina*. *Corophium* abundance was also negatively correlated with plant root density. Brusati and Grosholz (2006) found differences in the invertebrate community between the low elevation Spartina marsh and the nearby mudflat at China Camp and other San Francisco Bay marshes, with greater infaunal density in the mudflat overall, although invertebrate density was higher in the *Spartina* zone at China Camp in one year of their study. Previous studies in California marshes have attributed decreases in abundance of some taxa near marsh vegetation to either a reduced availability of suspended particulates due to reduced flow speeds near vegetation (Levin et al. 2006) or rhizomes interfering with burrowing (Brusati and Grosholz 2006). Flow of suspended particles would be important to both species that appeared to avoid *Spartina*, as *C. alienense* is a suspension feeder and *M. petalum* is both a suspension feeder and a surface deposit-feeder.

In contrast to the channels, the marsh plain receives relatively fewer inundation events. Ground-crawling invertebrates such as the amphipod *Traskorchestia traskiana*, *Bembidion* beetles, and lycosid spiders were most abundant on the marsh plain. *T. traskiana* is one of the few salt marsh species able feed on *Sarcocornia* detritus (Page 1997), which could explain its high population density and domination of invertebrate biomass on the marsh plain. *T. traskiana* was found in greater abundance in the marsh plain near smaller channels, suggesting that this species may prefer the more frequent wetting of this habitat either to remain moist or to find richer bacterial and algal feeding deposits.

The natural levee, with the least frequent inundation of the three sub-habitats, had the greatest plant diversity of all the sub-habitats, and featured the only woody plant in the marsh: gumplant (*Grindelia stricta*). *Myosotella* snails were most abundant on natural levees and were absent from the channels. These snails are lung-breathing like their upland relatives (Cohen 2005); their low mobility likely puts them at risk of drowning in rising tidal waters, and may increase their risk of predation in open areas. The natural levee, with its relatively high elevation and abundant vegetative cover, may provide these snails with refuge from both tides and predators. However, these snails show a preference for the natural levee and marsh plain near low-order channels where inundation is more frequent than near high-order channels, suggesting they prefer a moist environment despite their avoidance of channels. Araneid spiders were most abundant on the natural levee along large channels. The woody structure of the channel-side gumplant provides these spiders with support for their webs near channels where flying insects are most abundant.

Rocky Intertidal

A relatively diverse community of epifaunal invertebrates lives on low intertidal rocks near Rat Rock (Table 5), including a variety of attached filter-feeders (sponges, hydroids, anemones, oysters and mussels, barnacles, bryozoans and sea squirts) and a few mobile worms and crustaceans. A handful of clam species were also found in the sediment at this site. While exotic species dominate this community, some natives are common. The dominant barnacles are the white acorn barnacle *Balanus glandula*, and a small, brown barnacle in the genus *Chthamalus*, both of which are native. The small native shorecrab *Hemigrapsus oregonensis* and the native isopod *Gnorimosphaeroma oregonense* are both common on or underneath rocks, and *Hemigrapsus* can also be abundant in the marsh channels. Native Olympia oysters, *Ostrea lurida*, were abundant on these rocks in the fall of 2005, but low salinities during the subsequent unusually wet winter and spring apparently eliminated the population.

Invertebrates as Food Resources

Salt marsh invertebrate communities are typically species poor but may be biomass rich (Kreeger and Newell 2000). Only a few species comprised the bulk of macroinvertebrate biomass in the tidal marsh study (Figures 2a & b and 3a & b), although some other species not captured (e.g., *G. demissa* and *S. quoiana*) probably also accounted for significant invertebrate biomass in the marsh.

The strong association of certain invertebrate groups to specific sub-habitats suggests that predators with different feeding specializations may forage primarily in one part of the marsh or another. The distribution of invertebrates among the sub-habitats in our study suggests that the channels offer greater food resources for predators seeking aerial or benthic infaunal prey, while the marsh plain and natural levees offer the greatest resources for predators of surface-dwelling invertebrates. Studies of salt marsh Song Sparrow behavior and trophic ecology suggest that sparrows assimilate the majority of their carbon and nitrogen from invertebrates found on the marsh plain and natural levee (Grenier 2004). However, the dietary composition of most terrestrial marsh predators relative to the marsh sub-habitats has been little studied.

Marsh-feeding fish, on the other hand, have received slightly more attention. While high marsh invertebrates were found to be an important source of food for fish such as longjaw mudsucker and killifish *(Fundulus parvipinis)* in a Southern California tidal marsh (West and Zedler 2000), stable isotope data suggest that longjaw mudsucker at China Camp were not assimilating invertebrates from the marsh plain as a significant proportion of their diet (Grenier 2004). Visintainer (2006) found that copepods, amphipods, mysids and isopods made up a large portion of the diet of the most common fish species feeding in the China Camp marsh. They further found that stomach fullness and prey taxa richness in these fish varied with channel order in a species-specific way. This pattern supports the hypothesis from our tidal marsh study that unequal distribution of invertebrates by channel order may impact predator foraging patterns. Dean et al. (2005) suggest that China Camp is a sink for mysid shrimp, with large mature mysids being heavily preyed upon by marsh fish and birds. Further study is needed to better understand how invertebrate distributions influence both predation patterns and trophic transfer between the China Camp tidal marsh and adjacent upland and marine habitats.

Future Research

The results presented here contribute to understanding invertebrate diversity and distribution in the intertidal habitats of San Francisco Bay.. However these short-term studies do not shed light on seasonal and inter-annual variation in invertebrate community structure. Future field studies on the diversity, distribution, and ecology of the intertidal invertebrate community of San Francisco Bay in various seasons and over longer time scales would improve our understanding of this fauna and its significance in the food web.

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11. Avian Communities in Tidal Salt Marshes of San Francisco Bay: a Review of Functional Groups by Foraging Guild and Habitat Association

John Y. Takekawa[1,*], **Isa Woo**[1], **Rachel Gardiner**[1,2], **Michael Casazza**[3],
Joshua T. Ackerman[4], **Nadav Nur**[5], **Leonard Liu**[5], and **Hildie Spautz**[5,6]

[1]U. S. Geological Survey, Western Ecological Research Center
San Francisco Bay Estuary Field Station, 505 Azuar Drive, Vallejo, CA 94592. USA

[2]ICF International
630 K Street, Sacramento, CA 95816. USA

[3]U. S. Geological Survey, Western Ecological Research Center, Dixon Field Station,
6924 Tremont Road, Dixon, CA 95620. USA

[4]U. S. Geological Survey, Western Ecological Research Center, Davis Field Station
One Shields Avenue, University of California, Davis, CA 95616. USA

[5]PRBO Conservation Science, 3820 Cypress Drive #11, Petaluma, CA 94954. USA

[6]Current address: California Department of Fish and Game, Ecosystem Restoration Program
830 S. Street, Sacramento, CA 95811. USA

**Author for correspondence: email: john_takekawa@usgs.gov, phone: 707-562-2000, fax: 707-562-3001*

ABSTRACT

The San Francisco Bay (SFB) estuary is highly urbanized, but it supports the largest remaining extent of tidal salt marshes on the west coast of North America as well as a diverse native bird community. SFB tidal marshes are occupied by more than 113 bird species that represent 31 families, including 5 subspecies from 3 families that we denote as tidal-marsh obligates. To better identify the niche of bird species in tidal marshes, we present a review of functional groups based on foraging guilds and habitat associations. Foraging guilds describe the method by which species obtain food from tidal marshes, while habitat associations describe broad areas within the marsh with similar environmental conditions. For example, the ubiquitous song sparrows (Alameda *Melospiza melodia pusillula*, Suisun *M. m. maxillaris*, and San Pablo *M. m. samuelis*) are surface-feeding generalists that consume prey from vegetation and the ground, and they are found across the entire marsh plain into the upland-marsh transition. In contrast, surface-feeding California black rails (*Laterallus jamaicensis coturniculus*) are cryptic and generally restricted in their distribution to the mid and high marsh plain. Although in the same family, the endangered California clapper rail (*Rallus longirostris obsoletus*) has become highly specialized, foraging primarily on benthic fauna within marsh channels when they are exposed at low tide. Shorebirds such as the black-necked stilt (*Himantopus mexicanus*) typically probe in mud flats to consume macroinvertebrate prey and are generally restricted to foraging on salt pans within the marsh plain, ponds, or on mud flats during transitional stages of marsh evolution. The abundance and distribution of birds varies widely with changing water depths and vegetation colonization during different stages of restoration. Thus, tidal marsh birds represent a rich and diverse community in SFB marshes, with niches that may be distinguished by the food resources they consume and the habitats that they occupy along the tidal gradient.

11.1 Introduction

Development and human encroachment have greatly reduced the extent of tidal marshes in the San Francisco Bay (SFB) estuary and altered or fragmented its remaining wetlands. Nearly 80% of tidal marsh habitats have been lost and >13,000 ha of wetlands have been converted to salt evaporation ponds (Nichols et al. 1986, Goals Project 1999). Native bird communities that use these wetlands have been adversely affected, and populations of several species or subspecies are now threatened because of their reduced abundance and limited distribution (Harvey et al. 1992, Goals Project 2000, Greenberg et al. 2006a, Shuford et al. 2008).

In the past two decades, hundreds of wetland restoration projects have been initiated to restore historic estuary wetlands to tidally-influenced marshes, including conversion of former salt ponds (Goals Project 1999, Steere and Schaefer 2001). However, wetland restoration sites may not be functionally equivalent to natural marshes in terms of suitability for tidal marsh dependent wildlife. For example, Pacific cordgrass (*Spartina foliosa*) in a created wetland of southern California were less vigorous and failed to provide the vertical structure needed for nests of endangered light-footed clapper rail (*Rallus longirostris levipes*; Zedler 1993). Furthermore, tidal marsh birds face numerous threats (see Takekawa et al. 2006a) such as habitat fragmentation, invasive species, environmental contaminants, predation, and climate change. Sea-level rise may not result in a gradual upslope movement of tidal marshes to higher elevations because many tidal marshes are confined by levees in SFB. Sea-level rise and extreme tide events will likely exacerbate threats already faced by tidal marsh birds by reducing the amount of tidal marsh and upland refugia available (Greenberg et al. 2006b, Takekawa et al. 2006a).

At present, SFB tidal marshes support rich bird communities. Tidal marshes in SFB support at least 113 bird species that represent 31 families, including 5 subspecies from 3 families that are tidal-marsh obligates: song sparrows (Alameda song sparrow *Melospiza melodia pusillula*, Suisun song sparrow *M. m. maxillaris*, and San Pablo song sparrow *M. m. samuelis*), salt marsh common yellowthroat (*Geothlypis trichas sinuosa*), and California clapper rail (*Rallus longirostris obsoletus*). Greenberg et al. (2006b) noted that inhabitants of tidal marshes are disproportionately listed as endangered, threatened, or species of conservation concern more often than avian species in other habitats. Indeed, within SFB nearly 25% of species that use tidal marshes and 50% of tidal marsh-associated species are designated with special conservation status (Table 1).

Tidal marsh birds must be adapted to diurnal changes in tidal levels and salinity conditions. Birds that breed within tidal marshes typically elevate their nests to reduce the probability of flooding (Reinert 2006) but elevating their nests too high may result in increased visibility and predation (Greenberg et al. 2006b). Birds with small breeding home ranges like the California black rail (*Laterallus jamaicensis coturniculus*) select habitats in close proximity to high tide refugia sites such as upland levees or tall vegetation along channels (Tsao et al. 2009). In addition to behavioral adaptations to extreme tide events, tidal marsh birds are physically adapted to salinity. For example, American avocet (*Recurvirostra americana*) chicks hatch with relatively large nasal salt glands so that they can cope with their high salinity environment (Rubega and Oring 2004).

Some endemic species may be considered tidal marsh obligates if they are found principally in these salt marsh habitats and are potentially well-adapted to live in them. For example, passerines such as Belding's savannah sparrow (*Passerculus sandwichensis beldingi*) that are found in tidal marshes of the Pacific coast south of Point Conception do not possess salt glands, but their kidney structure (high volume of medulla) may allow them to concentrate salts (Goldstein 2006). SFB song sparrows are adapted to high salinities and can maintain their body mass in salt marshes, while riparian species such as the Marin song sparrow (*M. m. gouldii*) are less adapted for saline conditions (Basham and Mewaldt 1987).

Table 1. Avian species that use San Francisco Bay tidal marshes, the habitat elements they occupy, foraging strata, and special status designation.

Family	Common Name	Scientific Name	Habitat Association1	Foraging Guild2	Special Status3
Anatidae	Canada Goose	*Branta Canadensis*	UT, MP, CH	AQ	
	Gadwall	*Anas strepera*	MP, CH, P	AQ	
	American Wigeon	*Anas Americana*	MP, CH, P	AQ	
	Mallard	*Anas platyrhynchos*	MP, CH, P	AQ	
	Blue-winged Teal	*Anas discors*	MP, CH, P	AQ	
	Cinnamon Teal	*Anas cyanoptera*	MP, CH, P	AQ	
	Northern Shoveler	*Anas clypeata*	MP, CH, P	AQ, B	CSC
	Northern Pintail	*Anas acuta*	MP, CH, P	AQ	
	American Green-winged Teal	*Anas crecca carolinensis*	MP, CH, P	AQ	
	Canvasback	*Aythya valisineria*	CH, P	AQ, B	CSC S2
	Redhead	*Aythya Americana*	CH, P	AQ, B	
	Greater Scaup	*Aythya marila*	CH, P	AQ, B	
	Lesser Scaup	*Aythya affinis*	CH, P	AQ, B	
	Surf Scoter	*Melanitta perspicillata*	CH	AQ, B	
	Bufflehead	*Bucephala albeola*	CH, P	AQ, B	
	Common Goldeneye	*Bucephala clangula*	CH, P	AQ, B	
	Common Merganser	*Mergus merganser*	CH, P	AQ	
	Red-breasted Merganser	*Mergus serrator*	CH, P	AQ	
	Ruddy Duck	*Oxyura jamaicensis*	MP, CH, P	AQ, B	
Phasianinae	Ring-necked Pheasant	*Phasianus colchicus*	UT	S	
Podicipedidae	Pied-billed Grebe	*Podilymbus podiceps*	CH, P	AQ	
	Horned Grebe	*Podiceps auritus*	CH, P	AQ	
	Eared Grebe	*Podiceps nigricollis*	CH, P	AQ	
	Western Grebe	*Aechmophorus oreccidentalis*	MP, CH, P	AQ	
	Clark's Grebe	*Aechmophorus clarkii*	MP, CH, P	AQ	

Table 1. Avian species that use San Francisco Bay tidal marshes, the habitat elements they occupy, foraging strata, and special status designation.

Family	Common Name	Scientific Name	Habitat Association1	Foraging Guild2	Special Status3
Pelecanidae	American White Pelican	*Pelecanus erythrorhynchos*	P	AQ	
	Brown Pelican	*Pelecanus occidentalis*	CH, P	AQ	
Phalacrocoracidae	Double-crested Cormorant	*Phalacrocorax auritus*	CH, P	AQ	CSC S3, WL
Ardeidae	American Bittern	*Botaurus lentiginosus*	MP, CH, P	AQ	CSC S3
	Great Blue Heron	*Ardea Herodias*	UT, MP, CH, P	AQ	CSC S4
	Great Egret	*Ardea alba*	UT, MP, CH, P	AQ	CSC S4
	Snowy Egret	*Egretta thula*	UT, MP, CH, P	AQ	CSC S4
	Green Heron	*Butorides virescens*	MP, CH, P	AQ	
	Black Crowned Night Heron	*Nycticorax nycticorax*	UT, MP, CH, P	AQ, B	CSC S3
Cathartidae	Turkey Vulture	*Cathartes aura*	MP, UT	A	
Pandionidae	Osprey	*Pandion haliaetus*	UT, MP, CH, P	AQ	CSC S3, WL
Accipitridae	White-tailed Kite	*Elanus leucurus*	UT, MP	A	CSC S3, FP
	Northern Harrier	*Circus cyaneus*	UT, MP	A	CSC S3, BSSC3
	Sharp Shinned Hawk	*Accipiter striatus*	UT, MP	A	CSC S3, WL
	Cooper's Hawk	*Accipiter cooperii*	UT, MP	A	CSC S3, WL
	Red-shouldered Hawk	*Buteo lineatus*	UT, MP	A	
	Red-tailed Hawk	*Buteo jamaicensis*	UT, MP	A	
Falconidae	American Kestrel	*Falco sparverius*	UT, MP	A	
	Merlin	*Falco columbarius*	UT, MP	A	CSC S3, WL
	Peregrine Falcon	*Falco peregrines*	UT, MP, P	A	CSC S3, FD, CE, FP, BCC
Rallidae	Black Rail	*Laterallus jamaicensis*	UT, MP	S	CSC S1, BCC, FP, CT
	California Clapper Rail	*Rallus longirostris obsoletus*	MP, CH, P	B	CSC S1, FE, CE, FP
	Virginia Rail	*Rallus limicola*	MP, P	S	
	Sora	*Porzana Carolina*	MP, P	S	
	American Coot	*Fulica Americana*	MP, CH, P	B	
Charadriidae	Black-bellied Plover	*Pluvialis squatarola*	MP, P	S	
	Snowy Plover	*Charadrius alexandrinus*	MP, P	S	CSC S2, FT, BCC
	Semipalmated Plover	*Charadrius semipalmatus*	MP, P	S	

Table 1. Avian species that use San Francisco Bay tidal marshes, the habitat elements they occupy, foraging strata, and special status designation.

Family	Common Name	Scientific Name	Habitat Association1	Foraging Guild2	Special Status3
Recurvirostridae	Black-necked Stilt	*Himantopus mexicanus*	MP, CH, P	B	
	American Avocet	*Recurvirostra americana*	MP, CH, P	AQ, B	
Scolopacidae	Spotted Sandpiper	*Actitis macularia*	MP, P	B, S	
	Greater Yellowlegs	*Tringa melanoleuca*	MP, P	B	
	Lesser Yellowlegs	*Tringa flavipes*	MP, P	B	
	Willet	*Catoptrophorus semipalmatus*	MP, CH, P	B	
	Whimbrel	*Numenius phaeopus*	MP, CH, P	B	
	Long-billed Curlew	*Numenius americanus*	MP, CH, P	B	CSC S2, BCC, WL
	Marbled Godwit	*Limosa fedoa*	MP, CH, P	B	
	Red Knot	*Calidris canutus*	P	B, S	
	Sanderling	*Calidris alba*	MP, P	B, S	
	Western Sandpiper	*Calidris mauri*	MP, P	B, S	
	Least Sandpiper	*Calidris minutilla*	MP, P	B, S	
	Dunlin	*Calidris alpine*	MP, P	B, S	
	Short-billed Dowitcher	*Limnodromus griseus*	MP, CH, P	B	
	Long-billed Dowitcher	*Limnodromus scolopaceus*	MP, CH, P	B	
	Wilson's Snipe	*Gallinago gallinago*	UT, MP	B	
	Wilson's Phalarope	*Phalaropus tricolor*	CH, P	AQ	
	Red-necked Phalarope	*Phalaropus lobatus*	CH, P	AQ	
Laridae	Bonaparte's Gull	*Larus Philadelphia*	CH, P	AQ	
	Mew Gull	*Larus canus*	CH, P	AQ	
	Ring-billed Gull	*Larus delawarensis*	CH, P	AQ	
	Western Gull	*Larus occidentalis*	CH, P	AQ	
	California Gull	*Larus californicus*	CH, P	AQ	CSC S2, WL
	Herring Gull	*Larus argentatus*	CH, P	AQ	
	Glaucous-winged Gull	*Larus glaucescens*	CH, P	AQ	
Sternidae	Least Tern	*Sterna antillarum*	CH, P	AQ	CSC S2S3, FE, CE, FP
	Caspian Tern	*Sterna caspia*	CH, P	AQ	CSC S4, BCC
	Forster's Tern	*Sterna forsteri*	CH, P	AQ	CSC S4,
Rynchopidae	Black Skimmer	*Rynchops niger*	CH, P	AQ	
Columbidae	Mourning Dove	*Zenaida macroura*	UT	S	

Table 1. Avian species that use San Francisco Bay tidal marshes, the habitat elements they occupy, foraging strata, and special status designation.

Family	Common Name	Scientific Name	Habitat Association1	Foraging Guild2	Special Status3
Tytonidae	Barn Owl	*Tyto alba*	UT, MP	A	
Strigidae	Great Horned Owl	*Bubo virginianus*	UT, MP	A	
	Short-eared Owl	*Asio flammeus*	UT, MP	A	CSC S3, BSSC3
Trochilidae	Allen's Hummingbird	*Selasphorus sasin*	UT	A	
	Anna's Hummingbird	*Calypte anna*	UT, MP	A	
Alcedinidae	Belted Kingfisher	*Ceryle alcyon*	CH, P	AQ	BSSC3
Tyrannidae	Black Phoebe	*Sayornis nigricans*	UT, MP	A	
Corvidae	American Crow	*Corvus brachyrhynchos*	UT, MP	S	
	Common Raven	*Corvus corax*	UT, MP	S	
Hirundinidae	Tree Swallow	*Tachycineta bicolor*	UT, MP, P	A	
`	Violet-green Swallow	*Tachycineta thalassina*	UT, MP, P	A	
	Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	UT, MP, P	A	
	Cliff Swallow	*Petrochelidon pyrrhonota*	UT, MP, CH, P	A	
	Barn Swallow	*Hirundo rustica*	UT, MP, P	A	
Troglodytidae	Marsh Wren	*Cistothorus palustris*	MP	S	
Motacillidae	American Pipit	*Anthus rubescens*	UT, MP	S	
Parulidae	Saltmarsh Common Yellowthroat	*Geothlypis trichas sinuosa*	UT, MP	S	CSC S2, BCC, BSSC3
Emberizidae	Bryant's Savannah Sparrow	*Passerculus sandwichensis alaudinus*	UT, MP	S	BSSC3
	Savannah Sparrow	*Passerculus sandwichensis*	UT, MP	S	
	Golden-crowned Sparrow	*Zonotrichia atricapilla*	UT, MP	S	
	White-crowned Sparrow	*Zonotrichia leucophrys*	UT, MP	S	
	Fox Sparrow	*Passerella iliaca*	UT, MP	S	
	Alameda Song Sparrow	*Melospiza melodia pusillula*	UT, MP	A, S	CSC S2, BCC, BSSC2
	San Pablo Song Sparrow	*Melospiza melodia samuelis*	UT, MP	A, S	CSC S2, BCC, BSSC
	Suisun Song Sparrow	*Melospiza melodia maxillaris*	UT, MP	A, S	CSC S2, BCC, BSSC
	Lincoln's Sparrow	*Melospiza lincolnii*	UT, MP	S	
Icteridae	Western Meadowlark	*Sturnella neglecta*	UT, MP	S	

Table 1. Avian species that use San Francisco Bay tidal marshes, the habitat elements they occupy, foraging strata, and special status designation.

Family	Common Name	Scientific Name	Habitat Association1	Foraging Guild2	Special Status3
	Brown-headed Cowbird	*Molothrus ater*	UT, MP	S	
	Red-winged Blackbird	*Agelaius phoeniceus*	UT, MP	S	
Fringillidae	House Finch	*Carpodacus mexicanus*	UT, MP	A	
	American Goldfinch	*Carduelis tristis*	UT	A	
	Lesser Goldfinch	*Carduelis psaltria*	UT, MP	A	

[1] Habitat Association: UT = upland transition and high marsh plain; MP = mid and low marsh plain; CH = tidal creeks and channels; P = pans and ponds

[2] Foraging Guild: A = aerial; S = surface; B = benthic; AQ = aquatic

[3] Special Status: FE = Federal Endangered, FT = Federal Threatened FP = Federal Protected, FD = Federal Delisted, CE = California Endangered, CT = California Threatened; BSSC = Department of Fish and Game Bird Species of Special Concern, numeral following (1-3) indicates priority ranking;

BCC = Fish and Wildlife Service Birds of Conservation Concern; WL = Department of Fish and Game Watch List; CSC = California Species of Concern (California Department of Fish and Game); Natural Heritage Status Ranking at the S (subnational) level for California (S1 = critically imperiled, S2 = imperiled, S3 = vulnerable to extirpation or extinction, S4 = statewide population apparently secure, factors exist to cause concern)

11.2 Foraging Guilds

Diverse food resources are available in tidal marshes through terrestrial and marine food webs (Adam 1990, Kwak and Zedler 1997, Cloern et al. 2002), and tidal marsh birds are often omnivorous to take advantage of the various available food resources in these dynamic environments. Use of foraging guilds to describe bird communities reflects ecosystem productivity as it relates to a specific foraging community. Functional foraging guilds also help distinguish the way birds use the physical environment; here, we group birds into aerial, marsh surface, benthic, or aquatic foraging guilds (Table 1). Species can belong to more than one foraging guild based on flexibility in their diet and behavior.

Aerial foragers

Aerial foragers such as song sparrows prey within and above tidal marsh plant canopies. Virtually all of the passerines found in tidal marshes, including swallows (Hirundinidae), savannah sparrows (*Passerculus sandwichensis*), marsh wrens (*Cistothorus palustris)*, salt marsh common yellowthroat, and red-winged blackbirds (*Agelaius phoeniceus*) belong to this foraging guild. Aerial foragers commonly feed upon flying insects such as plant hoppers (*Prokelesia* spp., Delphacidae); leafhoppers (Cicadellidae); grasshoppers (Acrididae); mantids (Mantidae); bees and wasps (Hymenoptera); flies (Ephydridae, Dolichopodidae); moths and butterflies (Lepidoptera), such as the Western pygmy-blue (*Brephidium exilis*) and the inchworm moth (*Perizoma custodiata*); but they may also consume plant seeds (Goals Project 2000). Northern harriers (*Circus cyaneus*), white-tailed kite (*Elanus leucurus*), red tailed hawks (*Buteo jamaicensis*), and owls (Tytonidae and Strigidae) are all tertiary aerial consumers that forage on small mammals, other birds, or insects. The white tailed kite forages high above open marshes and grasslands (5-25 m above the ground) by rapidly beating its wings and hovering in place while scanning the ground for prey (Dunk 1995). The northern harrier has distinctive owl-like facial disks that help with directional hearing to locate prey (Rice 1982). When foraging, the northern harrier flies relatively close to the ground (<2 m) using both visual and auditory cues to capture prey (Rice 1982, Macwhirter and Bildstein 1996).

Marsh surface gleaners

Marsh surface gleaners such as the black rail forage primarily at the marsh surface on invertebrate prey such as beetles (*Cicindela* spp, *Bembidion* spp), spiders (*Pardosa* spp, *Phidippus* spp), amphipods (*Traskorchestia* spp), snails (*Myosotella* spp, *Assiminea* spp), shorebugs (Saldidae), isopods (Isopoda), and other items such as seeds (Takekawa et al. unpublished data). Many gleaners have bills adapted to capture a wide range prey resources. For example, song sparrows are gleaners that have longer and deeper bills than their closest non-tidal marsh relative (Grenier and Greenberg 2006), presumably as a response to selection for increased invertebrate diets over seeds that can be obtained on the sediment surface. Western meadowlarks (*Sturnella neglecta*) and red-winged blackbirds are also surface gleaners that are found in large flocks feeding on insects and seeds on the ground. Canada geese (*Branta canadensis*) are primarily herbivores that feed on a wide variety of plants and aquatic vegetation. Their diet may also include agricultural grains.

Benthic foragers

Benthic foragers consume prey within marsh and channel surface sediments. As tidal waters recede, foraging habitats become exposed for benthivores such as black-necked stilts (*Himantopus mexicanus*) and clapper rail. Typical benthic macroinvertebrates consumed by birds in the tidal marsh are: horse mussel (*Geukensia demissa*), clams (*Corbula* spp, *Macoma* spp), crustaceans (amphipods [*Corophium* spp], Cumaceae), and annelids (Capitellidae). Although horse mussels comprise the majority of the clapper rail diet (Moffitt 1941), the rail also consumes crabs (*Hemigrapsus* spp, *Carcinus* spp, *Pachygrapsus crassipes*) and spiders (*Phidippus* spp, *Pardosa* spp, Lycosid) -- one record reports a bird opportunistically fed on rabbit carrion (Moffitt 1941). In contrast, northern shovelers (*Anas clypeata*) are dabbling ducks that use their spatula-shaped bill to filter and strain plant material, mollusks, crustaceans, and other small invertebrates from the water column and benthos through their bills (Dubowy 1996).

Shorebirds are benthic foragers and are of special importance, because each year hundreds of thousands of shorebirds winter in SFB (Takekawa et al. 2001, Warnock et al. 2002). Based on these large shorebird populations, the estuary was designated as a Western Hemisphere Shorebird Reserve Network Site of Hemispheric Importance in 1989 (Morrison et al. 2001, WHSRN 2010). One of the reasons SFB tidal flats support these high numbers can be explained by resource partitioning between birds of different size with varied bill lengths and shapes. Some shorebirds are adapted to forage on the surface of mud flats (e.g., western sandpiper, *Calidris mauri*; American avocet), while others have long bills that can probe deeper into the substrate (long-billed curlew, *Numenius americanus*; marbled godwit, *Limosa fedoa*). American avocets have slightly upturned bills and primarily forage by scything: holding their bill open and moving it side-to-side on the surface of the sediment. They are reported to be generalists and consume most prey items of <63 mm (Robinson et al. 1997). Long-billed curlews are the largest North American shorebird and have a long, decurved bill that is adapted to probing and pecking for crustaceans and other benthic invertebrates deep (10-15 cm) below the sediment surface (Dugger and Dugger 2002).

Aquatic foragers

Aquatic foragers such as heron and egrets (Ardeidae) and terns (Sternidae), consume aquatic organisms that dwell in channels or ponds such as crabs, threespine stickleback (*Gasterosteus aculeatus*), silversides (*Menidia* spp), gobies (*Gobiidae*), prickly sculpin (*Cottus asper*), brine shrimp (*Artemia franciscana*), shrimp (*Palaemon* spp, *Crangon* spp), and aquatic insects including water boatmen (*Trichocorixa reticulate*; Goals Project 2000). Ducks (Anatidae), grebes (Podicipedidae), and cormorants (Phalacrocoracidae) are aquatic foragers that search for aquatic vegetation, crustaceans, mollusks, fish, and other invertebrates. Dabbling ducks (such as American wigeon, *Anas americana*) forage primarily at the surface on aquatic vegetation and consume insects, beetles, mollusks, and crustaceans during the breeding season (Mowbray 1999), while grebes, cormorants, and diving ducks (such as ruddy duck, *Oxyura jamaicensis*) submerge to forage underwater on pelagic or benthic prey. Pied-billed grebes (*Podilymbus podiceps*) nest in emergent aquatic vegetation and forage in the open water or amongst aquatic vegetation. They are opportunistic and feed on large crustaceans, fish, insects, and other invertebrates (Muller and Storer 1999).

11.3 Tidal-Marsh Habitats

In addition to functional foraging guilds, the diversity of tidal-marsh birds is reflected in their spatial use of different habitats along an elevation and tidal gradient. Associating birds to their habitats is fundamental in identifying the functions and structures of landscapes critical to a bird's life cycle (Wiens 1994, 1996; Walters 1998). Habitat use integrates movements and behavior (home range, foraging strategy, breeding requirements), and marsh structure (elevation and canopy complexity), with driving processes (tidal fluctuations, global climate change), and biotic interactions (prey consumption, predation, and competition). Tidal marshes are characterized by distinct vegetation zones based on the degree of tidal inundation and the salinity tolerance of marsh plants (Josselyn 1983, Goals Project 1999).

Tidal marsh habitats progress along a gradient from the upland-high marsh transition to the estuarine edge (as in Goals Project 1999). We group birds within these habitat types, reflecting our interpretation of how birds partition in tidal marshes. From higher to lower elevation, these habitats include: upland transition and high marsh plain, mid and low marsh plain, tidal creeks and channels, and pans and ponds. We then provide examples using four different species – song sparrows, black rails, clapper rails, and black-necked stilts – describing their association with tidal marsh habitats, foraging guilds, and habitat use.

Upland Transition and High Marsh Plain.

The upland transition demarcates the zone between the edge of the tidal marsh and the adjacent non-tidal habitat. In SFB, marshes are often bordered by transitional high-elevation levees that separate human development from the marshes. At the upper end of the tidal marshes, the high marsh plain is the bayland habitat within the historic tideline (Goals Project 1999) that is inundated infrequently above mean higher high water. The high marsh plain is dominated by common pickleweed (*Sarcocornia pacifica*, formerly *Salicornia virginica*) with coyote bush (*Baccharis pilularis*) and other characteristic vegetation extending across to the upland transition.

Song sparrows

Song sparrows in SFB marshes have differentiated into three subspecies, each of which is endemic and adapted to saline and brackish conditions (Marshall 1948, Marshall and Dedrick 1994, Chan and Arcese 2002). The three endemic subspecies segregate regionally: San Pablo song sparrow in San Pablo Bay (north of Sausalito on the west side and north of Point Richmond on the east side), Alameda song sparrow in the Central and South Bay, and Suisun song sparrow in Suisun Bay (including the Carquinez Strait, Figure 1). Each subspecies is phenotypically distinct, but their genetic differentiation is ambiguous, especially between the San Pablo and Suisun subspecies (Chan and Arcese 2002). Grinnell and Miller (1944) characterized the tidal marsh song sparrows as widespread and abundant throughout SFB. Population viability analyses and simulations indicated that the historic population size of the San Pablo song sparrow was likely three times larger than the present (Takekawa et al. 2006b), and larger populations may have been likely for other song sparrow subspecies (Spautz and Nur 2008a, 2008b, Chan and Spautz 2008).

SFB song sparrows are sedentary, year-round residents (i.e., non-migratory) except for the young of the year which disperse within and among marshes (PRBO unpublished data). Unlike salt marsh common yellowthroats or black rails, which are present in some tidal marshes and absent in others (Nur et al. 1997), song sparrows are ubiquitous throughout tidally-influenced marshes of SFB and have been documented in all tidally-influenced marshes (n > 80) where surveys have been conducted in the SFB (Spautz et al. 2006, PRBO unpublished data).

Systematic, repeated surveys of song sparrows during breeding seasons between 1996 and 2006 reveal population trends that differ by SFB region and thus subspecies (Figure 2). Their "apparent density" refers to detection per area, uncorrected for detection probability. In the absence of variation in detection probability among years or locations, apparent density provides a good surrogate for absolute density. Apparent density of song sparrows varies spatially, among bays, among marshes, and within marshes (Figure 3; Spautz et al. 2006, Stralberg et al. 2009). In the Central and South Bays, the apparent density of song sparrows has been increasing.

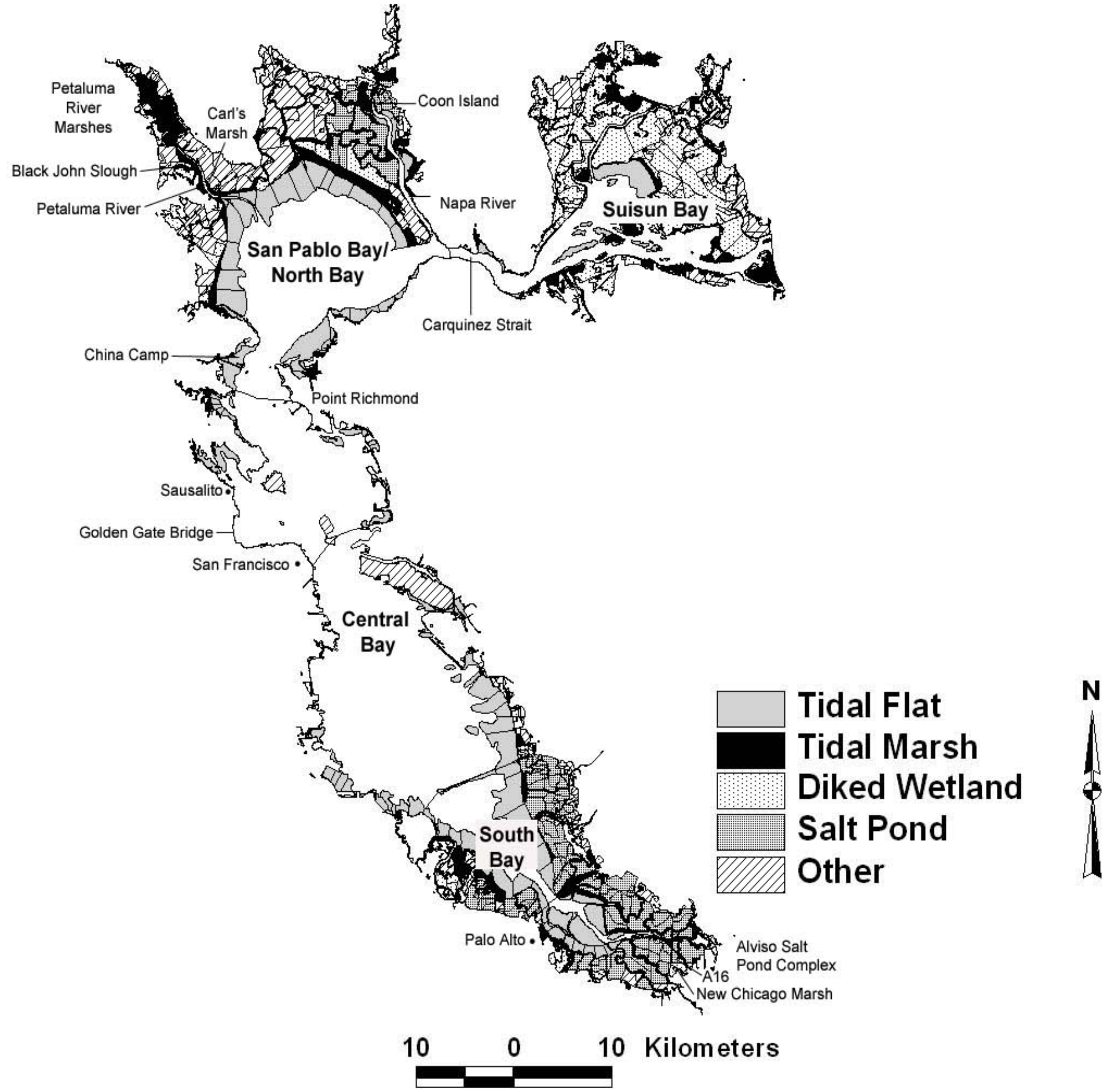

Figure 1. Mosaic of tidal salt marshes and related habitats within San Francisco Bay, including locations referenced within this paper. China Camp is part of the National Estuarine Research Reserve System. Habitat map created with EcoAtlas (SFEI 1998).

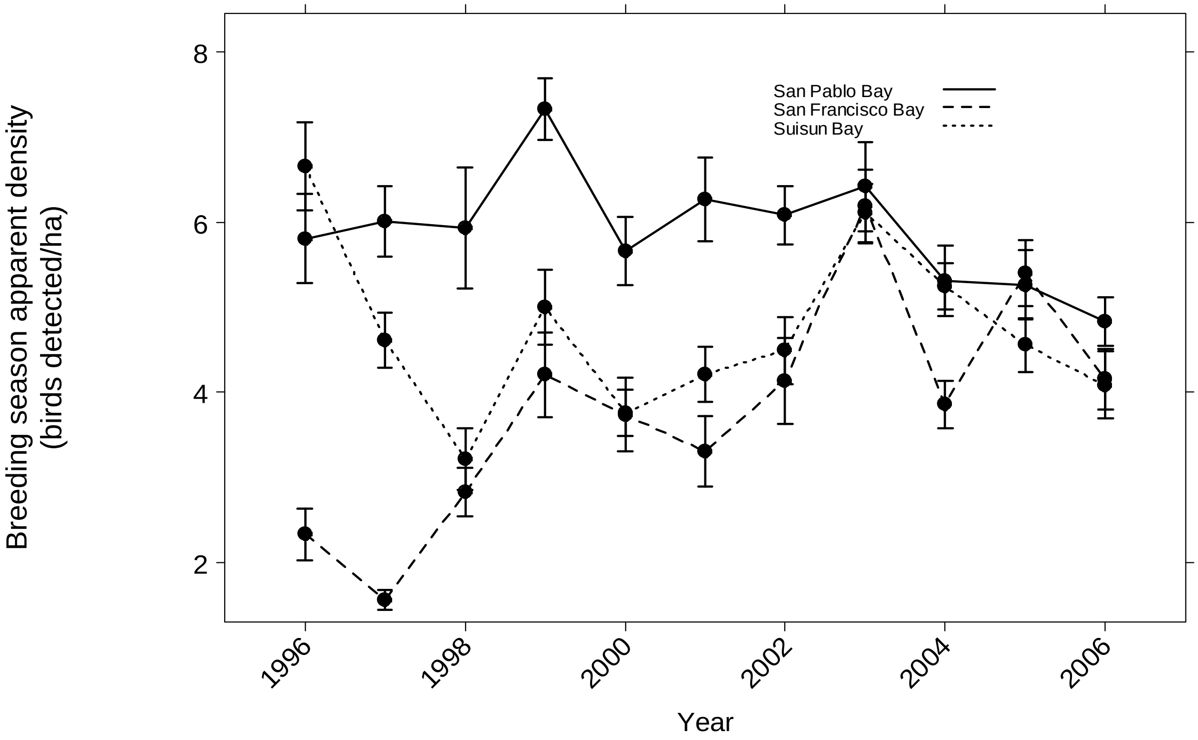

Figure 2. Song sparrow (Alameda Melospiza melodia pusillula*, Suisun* M. m. maxillaris*, and San Pablo* M. m. samuelis*) breeding season density indices in the San Francisco Bay region from 1996 to 2006 (Liu et al. 2007).*

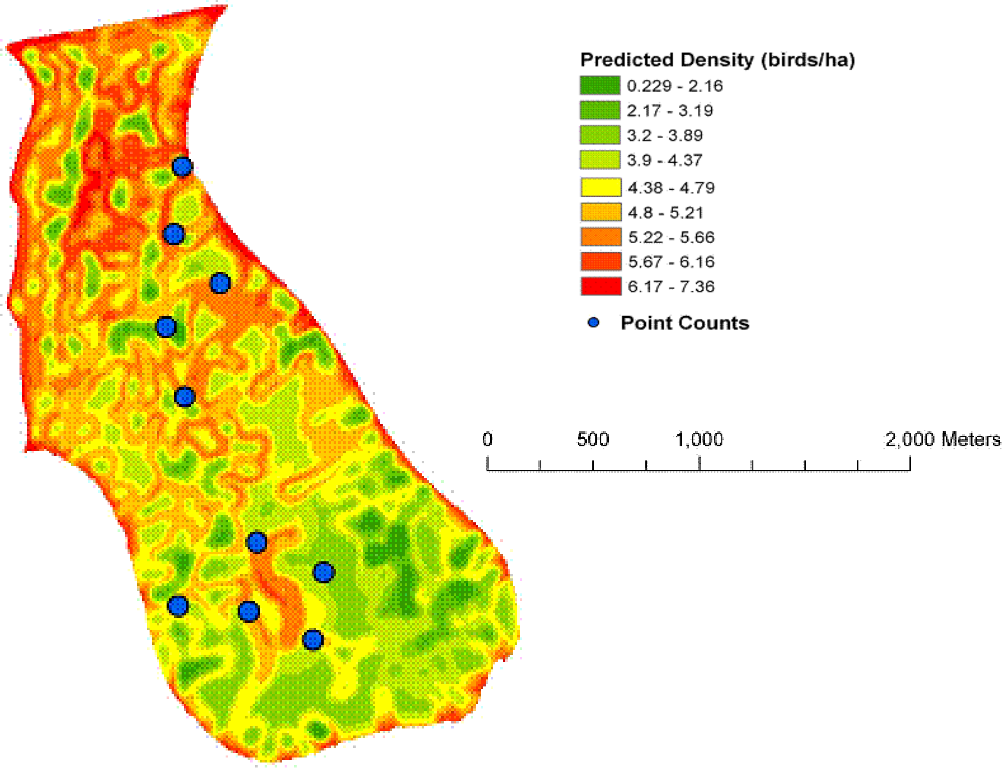

*Figure 3. Predicted density of San Pablo song sparrows (*M. m. samuelis*) at Coon Island, lower Napa River (Stralberg et al. 2010).*

The estimated density (after accounting for detection probability) of a particular song sparrow subspecies may vary two-fold among high and low density marshes. For example, in the spring of 2000, song sparrow density was estimated at 5.2 ± 0.5 birds/ha in Central and South Bay, 14.9 ± 1.2 birds/ha in San Pablo Bay, and 14.9 ± 1.8 birds/ha in Suisun Bay (PRBO unpublished data). Variation in density among marshes may reflect differences in habitat suitability, but other factors are also influential, including habitat preference, site fidelity, and reproductive success. Although it is valuable to identify habitat and landscape correlates of density, variation in density alone is not a sufficient indicator of habitat quality. Habitat quality requires determination of reproductive success, survival, and recruitment of young.

Song sparrows are commonly associated with marshes with higher elevation dominated by common pickleweed but are also found throughout lower marshes characterized by Pacific cordgrass. They require vegetation of sufficient height to establish nests that avoid tidal flooding (>30 cm: Marshall 1948). They primarily nest along tidal channels and sloughs and forage along channel edges and on the adjacent marsh plain consuming invertebrates such as snails, amphipods, and insects, as well as seeds (Grenier 2004). Tidal marsh song sparrows require fully-vegetated marshes yet avoid habitat where the vegetation is extremely dense (Marshall 1948).

Multivariate analysis of within-marsh and between-marsh variation in apparent density revealed that tidal-marsh song sparrows were most strongly and positively associated with gum plant (*Grindelia* spp), as well as with coyote bush (Spautz et al. 2006), while negatively associated with rushes (*Juncus* spp.), pond, and pan habitat types. In addition, apparent density of song sparrows was positively related to the size of the marsh (Spautz et al. 2006). However, this relationship demonstrated diminishing returns: the largest marshes (top 10% in size) did not necessarily have the highest density of birds, which suggest that additional factors influence song sparrow density or that densities may not always be optimal. Apparent density increased with distance from the water's edge (e.g., bayshore or river shore), consistent with their use of high marsh. Predictive models that included fine scale (1-m) vegetation indices and geomorphology suggested that song sparrow abundance was positively associated with salinity and tules (*Bolboschoenus* spp, and *Schoenoplectus* spp, formerly *Scirpus* spp; Stralberg et al. 2009). Statistical models that related species abundance to spatial habitat relationships suggested that breeding bird abundance was positively associated with vegetation productivity (Normalized Difference Vegetation Index) as well as channel area, density, and proximity which may reflect a preference for tall vegetative structure for nesting sites (Stralberg et al. 2009). Overall, models were successful in predicting song sparrow abundance (Stralberg et al. 2009).

Reproductive success also reflects variation in habitat and landscape characteristics. For example, song sparrow nests located in the invasive, non-native cordgrass (*Spartina alterniflora* and its hybrids) were less successful than nests in native plants (Nordby et al. 2009). Nests in non-native *Spartina* at lower elevation were likely more susceptible to flooding. However, nests that were placed too high in vegetation were more susceptible to predation (Greenberg et al. 2006b). Recent studies revealed that nest survival in tidal-marsh song sparrows was maximized when nest heights were 20-30 cm above the ground; nests closer to the ground were more susceptible to flooding and nests >30 cm were presumably more susceptible to predation (PRBO unpublished data).

Mid and Low Marsh Plain

The mid-marsh plain occurs between mean high water and mean higher high water and is inundated regularly. It is dominated by common pickleweed and also supports species that are less tolerant to inundation in the upper reaches of the marsh plain such as saltgrass (*Distichlis spicata*), fat-hen (*Atriplex triangularis*), and alkali heath (*Frankenia salina*; Goals Project 1999). Characteristic birds of the mid marsh plain include black rail, northern harrier, and song sparrow. Within the mid marsh plain, the habitat of black rail and song sparrow can be differentiated by the vertical strata they occupy. Black rails fly infrequently and spend most of their time within the marsh canopy. Song sparrows, especially males defending breeding territories, are more often found at the top of the vegetation.

The low marsh plain is found along tidal creeks and channels and is inundated daily during high tides. Low marsh vegetation is dominated by tall emergent species such as cordgrass or in more brackish waters by tules. Characteristic bird species of low marsh include clapper rail, willet (*Catoptrophorus semipalmatus)*, and marsh wren (*Cistothorus palustris*). Canopy architecture of tall emergent vegetation is a critical feature for nesting birds providing nest cover during high tides and flood tides. Sufficient plant height for nesting birds not only reduces the probability of nest flooding, but also provides sufficient cover against predators (Zedler 1993, Greenberg et al. 2006b, Reinert 2006).

California Black Rail

California black rails occur in two distinct regions: the Colorado River region and northern California (Conway and Sulzman 2007, Evens et al. 1991, Girard et al. 2010). Roughly 80% to 90% of the northern California population is found in SFB tidal marshes (Evens et al. 1991, Goals Project 2000). Black rails are listed as a state threatened species (California Department of Fish and Game 2008). Unlike song sparrows, black rails tend to run below and within wetland vegetation and seem reluctant to fly although short flights are common (Eddleman et al. 1994). Detection is challenging because of their highly secretive nature and the variation in detection is influenced by distance from observer, sex, breeding stage, and time of day (Legare et al. 1999). However, there appears to have been a drastic decline in black rail populations since the 1900s (Eddleman et al. 1994). This decline is largely due to the loss of 80% of historical tidal marshes and fragmentation of remaining tidal marshes. A recent increase in estuary-wide black rail populations (+3.2% annually from 1996 to 2008) may be a result of restoration efforts over the past 30 years -- rail density is positively correlated with years since restoration (Wood 2009). The black rail occurs primarily in large, contiguous marshes, dominated by common pickleweed or in mature vegetated freshwater marshes (Ehrlich et al. 1988, Evens et al. 1991, Evens and Nur 2002), but peripheral upland vegetation or tall vegetation along channel edges provides refuge from predation during extreme high tides (Evens and Page 1986, Goals Project 2000, Tsao et al. 2009).

Breeding black rails are found almost exclusively in mature, fully tidal marshes that are dominated by pickleweed and tules (Evens et al. 1991, Spautz et al. 2006), but younger marshes that are more prominently vegetated with cordgrass have been found to support rails during the non-breeding season (Evens et al. 1991). Breeding black rails require a dense pickleweed canopy and an open understory for nesting, foraging, and movement (Evens and Page 1983). Black rail nests consist of a bowl with a canopy of dead or living plant matter (Flores and Eddleman 1993) that is approximately 45-70 cm above the nest (Ehrlich et al. 1988). Some nests subject to inundation are thick (>12.7 cm) and comprise many layers due to frequent repair (Huey 1916). On the Petaluma River in northern San Pablo Bay, radio-marked black rails have relatively small breeding home ranges (average 95% fixed kernel home range of 0.65 ha; Figure 4; Tsao et al. 2009). Levees and channel edges lined with taller vegetation such as coyote bush and gum plant serve as areas of refugia for black rails during extreme high tides (Evens and Page 1986).

Habitat structure (vegetation height, stem density, percent cover, and vegetation productivity) rather than plant species composition seem to better explain black rail habitat selection (Tsao et al. 2009, Stralberg et al. 2009). Other local and landscape factors that are associated with black rails include nearby tidal marsh, natural upland, and agricultural habitats, channels <1 m wide, marsh size (>8 ha), proximity to creeks and rivers (especially the mouth), and limited access by predators (Evens and Nur 2002, Spaultz et al. 2006). Predictive modeling (Strahlberg et al. 2009) suggests that channel area and vegetation diversity were negative predictors of black rail abundance, perhaps because this species may select more mature marshes with taller vegetation to avoid nest flooding (Spautz and Nur 2002, Spautz et al. 2006, Tsao et al. 2009). Statistical models of habitat use support that black rails used areas dominated by pickleweed (Tsao et al. 2009) which tend to have low plant diversity. Because black rails require more mature habitat features, habitat use of restored marshes may depend on site specific processes of marsh development.

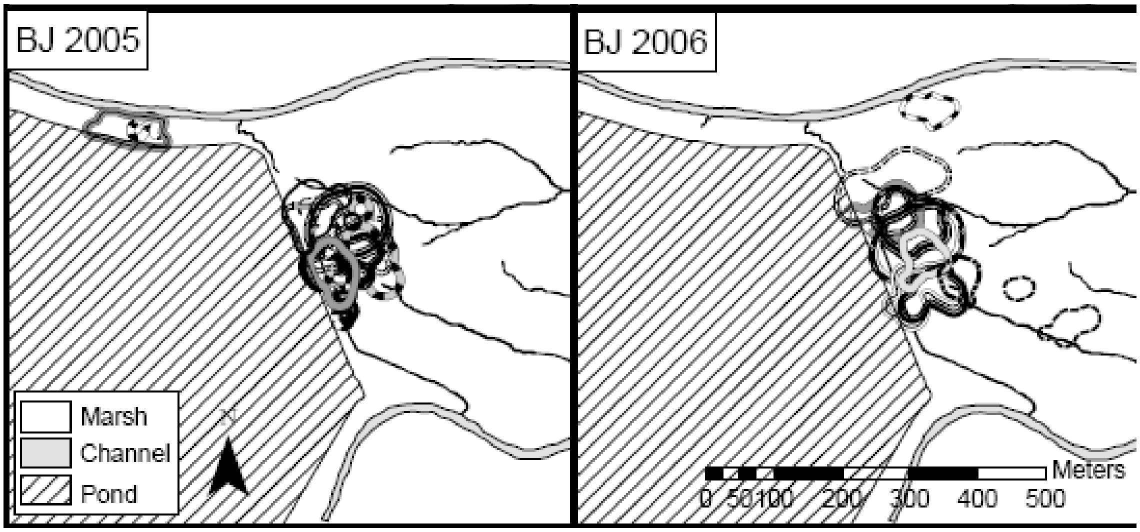

*Figure 4. Ninety-five percent fixed kernel home ranges of breeding California black rails (*Laterallus jamaicensis coturniculus*) at Black John Slough on the Petaluma River. Each polygon represent a unique individual in 2005 (n=10) and 2006 (n=10; Tsao et al. 2009).*

Black rails consume terrestrial insects, aquatic invertebrates and seeds (Ehrlich et al. 1988) typically found on the marsh surface. In the Petaluma River marshes of San Pablo Bay, black rail diet (regurgitated samples) comprised primarily of beetles and spiders (97% and 72% frequency of occurrence, respectively), with amphipods and snails found less often (44% and 28% frequency of occurrence, respectively; Takekawa et al. unpublished data). Other taxa detected include flies (Diptera), leaf hoppers (Cicadellidae), shore bugs (Saldidae and Macroveliidae), and seeds. Nematodes, Hemiptera, Heteroptera, Hymenoptera, Orthoptera, and shaft lice (*Menopon* spp.) were found in <5% of samples.

Black rails are vulnerable to extreme high tide events which may flood nests and increase the probability of predation as individuals are forced to retreat to upland margins or areas with less cover during flood events (Evens and Page 1986). Furthermore, black rails exhibit strong site fidelity and seem to select for elements that provide high tide refugia, such as tall vegetation (>1 m in height) near channels or proximity to upland areas (Tsao et al. 2009). Since most wetlands in this urbanized estuary are surrounded by levees with rather narrow upland transition zones, sea-level rise and extreme tide events might further reduce available high-tide refugia and lead to increased predation exposure and risk of nest-flooding.

Tidal Creeks and Channels

Tidal creeks and channels form a drainage network through low marsh and mid marsh plain areas within tidal marshes. Channels drain the marsh surface and serve as conduits for water, sediments, nutrients and channel biota, such as phytoplankton, zooplankton, nekton (small fish and shrimp), and benthic invertebrates. Some aquatic channel inhabitants can use the low marsh when it is flooded at high tide, including silversides, longjaw mudsuckers (*Gillichthys mirabilis*), and crabs. Herons and egrets are among the many waterbirds that feed on the small fish and benthic invertebrates found in tidal creeks, but perhaps no other tidal marsh bird uses tidal creeks and channels to the extent of the clapper rail, a tidal marsh obligate.

California Clapper Rail

The clapper rail is endemic to the tidal marshes of SFB and populations have been affected by habitat loss, habitat degradation, hunting, and predation. Historically, the clapper rail population was thought to have been abundant, as "thousands" were reported to have been killed in a single day in 1859 for consumption in San Francisco and to feed gold miners in the Sierra Nevada Mountains (Wilbur and Tomlinson 1976). Sport and market hunting drastically reduced clapper rail numbers, but with the passage of the Migratory Bird Treaty Act in 1913 (Wilbur and Tomlinson 1976) clapper rail numbers improved (Grinnell and Miller 1944). More recently clapper rail numbers steadily declined since the mid-1900s, and in 1970, the clapper rail became a federally listed endangered species (35 Federal Register 16047; 13 October 1970).

Although population estimates of clapper rails include some survey data gaps, the evidence suggests that declining trends were real. In the 1970s, surveys estimated 4,200-6,000 birds were present of which 55% resided in the South Bay (Albertson and Evens 2000). In the 1980s, clapper rail numbers had declined to 1,200-1,500 birds with 80% of the population in the South Bay (Harvey 1980). Based on surveys conducted in 1992-1993, the entire population of clapper rails was placed conservatively at <600 individuals (Collins et al. 1994). By 1988, the introduced red fox (*Vulpes vulpes regalis*) was identified as one of the primary reasons for the clapper rail population decline (Foerster et al. 1990). In 1991, a predator management program was initiated as the clapper rail population consisted of only 300-500 individuals (Albertson and Evens 2000). Clapper rail populations rebounded to over 800 individuals in 1993 largely attributed to the predator management program (Albertson and Evens 2000). In the early 2000s, the clapper rail population increased to almost 1,400 individuals with 75% of the population in the South Bay. However, surveys following removal of invasive cordgrass in southern SFB indicated declining populations.

The clapper rail uses tidal channels for foraging and as corridors for travel, and clapper rail numbers may be positively correlated with channel density (Albertson and Evens 2000). Clapper rails primarily occur within the tidal inundation zone in emergent marsh vegetation including pickleweed, Pacific cordgrass, invasive cordgrass, gum plant, tules, and jaumea (*Jaumea carnosa*; Grinnell et al. 1918, DeGroot 1927, Harvey 1988, Albertson and Evens 2000).

Much of their remaining habitat is characterized as being isolated and relatively small in size with a high edge to area ratio usually enveloped by industrial and urban areas (Albertson and Evens 2000).

Clapper rail habitat use is highly correlated with the presence of tidal sloughs and channels of varying widths and depths (DeGroot 1927, Harvey 1988, Foerster et al. 1990, Schwarzbach et al. 2006). Clapper rails use channels for movement through the marsh, as feeding areas, and as escape routes from predators (DeGroot 1927). Clapper rails have a relatively small annual home range (averaging <3 ha), with a smaller breeding home range (average <2 ha: Albertson 1995; U. S. Geological Survey, unpublished data). Radio-telemetry observations of clapper rails in several South Bay tidal marshes indicate that intra-daily movement (Figure 5) may be greater than inter-daily movements (Overton unpublished data), because movement between feeding, nesting, and roosting areas during varying tidal cycles accounts for the extensive intra-daily movements. Thus, rails may use a larger proportion of their seasonal or annual home range on a daily basis than otherwise might be expected.

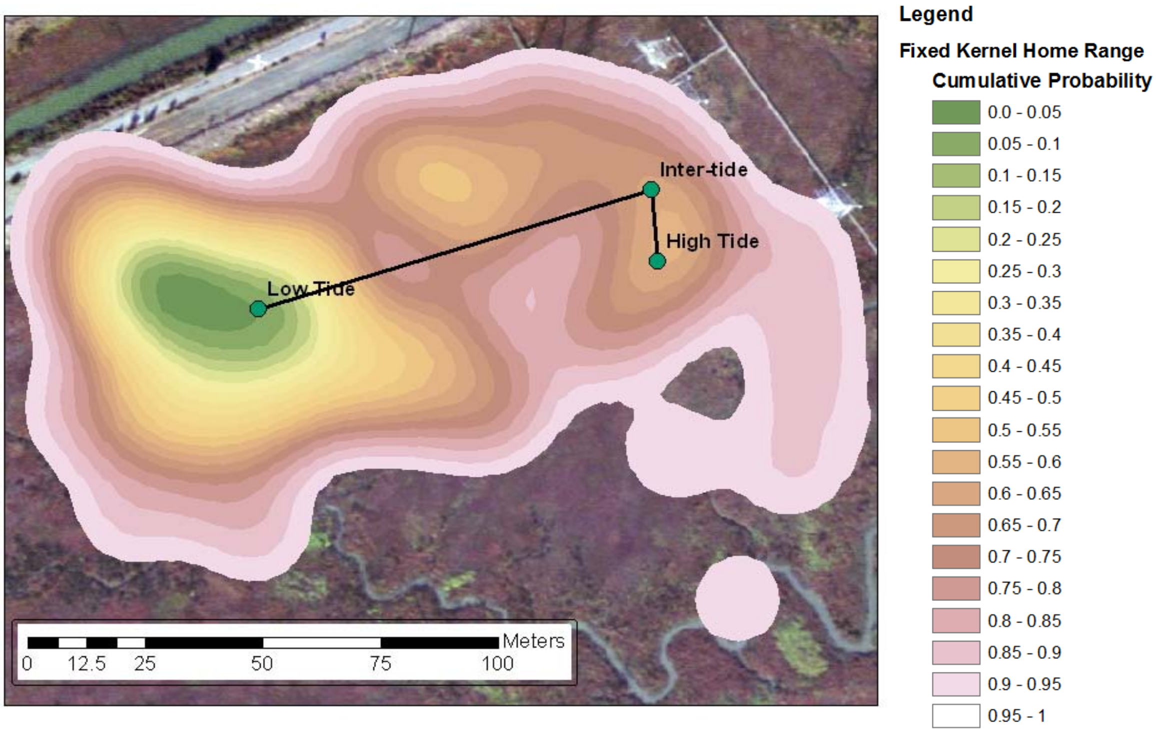

*Figure 5. Example of an intra-daily movement of a California Clapper rail (*Rallus longirostris obsoletus*) within its annual home range (95% adaptive kernel, CVH smoothing parameter; Overton, C. and M. Casazza unpublished data).*

Clapper rail nests consist of a nest bowl and canopy, and are commonly found close to tidal channels (<10 m width; DeGroot 1927, Zucca 1954, Harvey 1988, Foerster et al. 1990). The nest bowl is built on top of a platform that is approximately 18 cm high and often contains woven cordgrass stems (Harvey 1988). The nest canopy is on average 57 cm tall and is commonly constructed of pickleweed, cordgrass, gum plant, and tules so that the nest platform is concealed. Although recent foraging studies have not been attempted in SFB, previous research indicated rails primarily forage in the benthic zone on animal matter including the introduced horse mussel, crabs, clams (*Macoma balthica*) and spiders (Williams 1929, Moffitt 1941). Plant matter, primarily *Spartina* seeds, made up less than 15% of the food items by bulk found in 18 stomach samples collected near Palo Alto (Moffitt 1941). Current diet may be affected by more recent non-native invasive species commonly found in the estuary such as the overbite clam (*Corbula amurensis*).

Pans and Ponds

Salt pans are shallow depressions that fill with rain water or during highest tides. Salts are concentrated through evaporation and vascular plant growth is inhibited, resulting in bare and exposed areas (Mitsch and Gosselink 2000). Salt pans vary in size and some are large enough to support ponds with submerged vegetation, while others dry up entirely, forming completely bare patches within the tidal marsh. Natural salt pans were first developed into industrial salt ponds in the mid 1800s (Goals Project 1999). By the mid 1900s, almost half of the South Bay's historical tidal marshes had been converted into salt ponds and approximately 4,050 ha of salt ponds were created in the North Bay. At peak production, salt ponds covered approximately 14,580 ha in SFB (California Research Bureau 2002). Many waterfowl and shorebirds use salt ponds, especially as stopover sites during migration (Takekawa et al. 2000, Takekawa et al. 2001, Takekawa et al. 2005) to consume the rich supply of invertebrates such as brine shrimp (*Artemia franciscana*) and brine flies (*Ephydra* spp). Shorebirds such as American avocet and black-necked stilt also use salt ponds for breeding (Robinson et al. 1999). Here we focus on the black-necked stilt, because the species often nests in or near salt pans within the tidal marsh plain.

Black-necked Stilt

Historically, black-necked stilts (hereafter stilts) were uncommon residents of SFB (Grinnell et al. 1918, Grinnell and Wythe 1927). Presently, stilts are common wintering and breeding residents in the Bay, possibly due to the expansive creation of artificial salt evaporation ponds from tidal marsh between the 1930s and 1950s (Gill 1977, Goals Project 1999). Stilt abundance in SFB is highest in the fall (about 6,239 birds), followed by early winter (5,104), and the spring (1,088 birds; Stenzel et al. 2002). Stilts are the second most abundant breeding shorebird in SFB after American avocets, and SFB represents the largest breeding area for stilts on the Pacific coast (Page et al. 1999, Stenzel et al. 2002, Rintoul et al. 2003). Stilts are most abundant in the South Bay (Stenzel et al. 2002), where the breeding population has been estimated at 590 pairs (Rintoul et al. 2003).

Stilts in SFB breed predominantly in marshes but use salt ponds heavily for foraging during the breeding season. For example, during the pre-breeding, breeding, and post-breeding seasons, radio-marked stilts primarily used managed marshes (49%, 66%, and 63%) and salt ponds (32%, 22%, and 20%), followed by uplands (14%, 8%, and 9%), tidal marshes (2%, 3%, and 2%), sloughs (2%, <1%, and 1%), lagoons (1%, 1%, and 5%), and tidal flats (<1%, <1%, and <1%), respectively (Figure 6; Ackerman et al. 2007, Ackerman et al. unpublished data). Similarly, Hickey et al. (2007) found that habitat use by radio-marked stilts captured on nests in the South Bay was highest in salt ponds (57%), followed by diked wetlands (20%), tidal marsh (12%), tidal flats (6%), and other wetlands (6%). Compared to habitat availability, both diked marshes and salt ponds were selected by stilts (Hickey et al. 2007). During South Bay breeding surveys, Rintoul et al. (2003) observed stilts predominantly used salt ponds (55%) and marshes (29%) followed by other wetland types (14%) and tidal flats (1%). Stilts are mainly aquatic foragers, consuming invertebrates such as brine shrimp and brine flies when foraging within ponds or pans, but they will also consume small fish and some seeds (Hamilton 1975, Robinson et al. 1999).

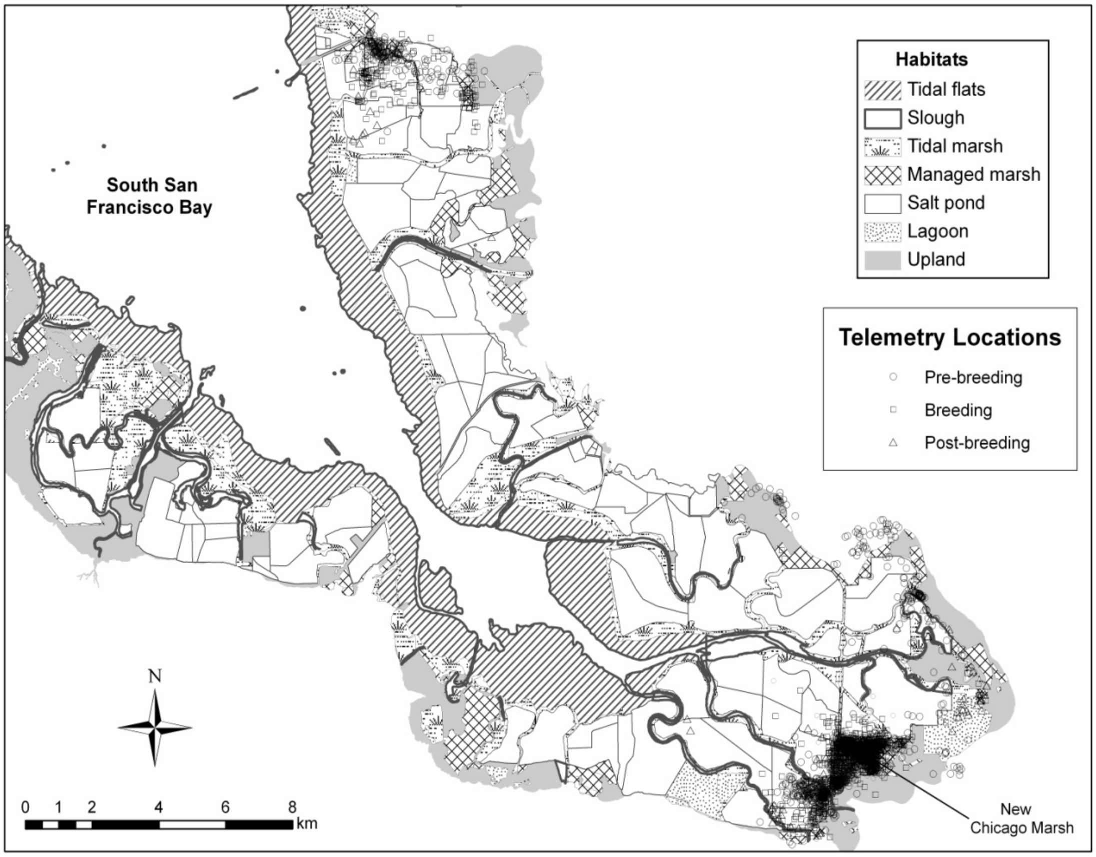

*Figure 6. Locations of black-necked stilts (*Himantopus mexicanus*) radio-marked during the pre-breeding seasons in 2005 and 2006, South San Francisco Bay, California. Symbols depict the breeding stage in which the location was obtained, including pre-breeding (open circles), breeding (open squares), and post-breeding (open triangles; Ackerman et al. 2007, Ackerman et al. unpublished data). Habitat types depicted include salt ponds, managed marshes, tidal marshes, tidal flats, uplands, and open bay (SFEI 1998).*

Stilts generally nest in managed and diked marshes within short emergent vegetation, bare areas, or vegetated margins (Robinson et al. 1999). Of 385 stilt nests monitored in the South Bay in 2006, 88% were in marshes, 12% were on islands within salt ponds, and <1% were on peninsulas within salt ponds; notably, no nests were found along salt pond levees (Ackerman unpublished data). Accordingly, 95% of the nests were associated with vegetation within 1 m of the nest bowl with an average height of 15.2±8.9 (SD) cm (Ackerman unpublished data). A particularly important nesting area for stilts in SFB is New Chicago Marsh (Rintoul et al. 2003, Ackerman et al. 2007), which is adjacent to the Alviso Salt Pond Complex. Nest monitoring efforts in New Chicago Marsh detected 101, 302, and 183 stilt nests in 2005, 2006, and 2007, respectively, although search efforts varied among years (Ackerman unpublished data). In 2005, radio-marked stilt chicks that were hatched in New Chicago Marsh moved toward the adjacent A16 salt pond when brine flies were abundant, but this pattern was not observed in 2006 after A16 was breached and salinity levels and potentially invertebrate abundance decreased (Ackerman unpublished data). Few other studies have monitored stilt nests in SFB, but Rintoul et al. (2003) observed that of 137 stilt nests found in the South Bay, 21% were in marshes, 69% were around salt ponds, and 9% were in other wetland habitats.

11.4 Restoration Stage

The SFB landscape is rapidly changing due to tidal marsh restoration efforts, and avian communities vary widely in response to those changing conditions. Multi-species management in this urbanized estuary has become a difficult balancing act that requires weighing the costs and benefits of converting habitats for threatened tidal-marsh species with reduced habitat for numerous species that depend on salt ponds (Stralberg et al. 2009). Tidal marsh restorations represent transitional habitat types as subtidal areas become suitable for vegetation colonization with adequate sediment supply (Woo et al. 2007, Athearn et al. 2009). Subsequently, the habitat use by different foraging guilds or nesting birds may reflect the habitat succession associated with restoration stage. For example, newly inundated aquatic areas become available to diving ducks and dabblers and will transition to tidal flats within a few years or decades with adequate sediment inputs. Tidal flats are heavily used by foraging shorebirds during low tide and are also used by diving benthivores (i.e., greater scaup *Aythya marila*, lesser scaup *Aythya affinis*, and ruddy duck) when the flats are submerged by the tides.

In sediment rich areas, continued sedimentation favors plant colonization in the tidal flats. As a low marsh habitat develops dominated by tall emergent cordgrass, tules, or sedges (Cyperaceae), increased vegetative structure allows for greater habitat and foraging partitioning for aerial foragers at the expense of foraging opportunities for benthic foragers. For example, vegetative marshes have greater habitat availability for nesting marsh wrens and song sparrows (Marshall 1948), but growth of denser vegetation then supports few shorebirds (Stralberg et al. 2003, Patten and O'Casey 2007, Stralberg et al. 2009). Small mammals found within the marsh plain can colonize and subsequently provide prey resources to raptors that soar above the marshes. In marshes with greater vegetative cover and height, black rails may colonize the marsh plain, as long as suitable high marsh and upland transition zones are nearby. Finally, establishment of channel networks and tall vegetative cover in more mature marshes will result in available foraging habitat and conditions suitable for clapper rails (Foin et al. 1997).

Song sparrows are ubiquitous within both young restoration sites and older historic marshes alike. Their relative abundance is not influenced by vegetation composition or obvious microhabitat features (percent channel, width of channel, or distance to water) but is positively related to vegetation cover (Nur et al. 1997). Nest survival for song sparrows varies by year and is influenced by edaphic and hydrologic conditions as well as species interactions. In an unseasonably wet spring, song sparrow nest success at Carl's Marsh, a relatively young marsh (breached in 1994), was over twice that at China Camp, a historic tidal marsh. Over 50% of nest failures at China Camp were due to flooding compared to only 21% at Carl's Marsh (Liu et al. 2007). On the other hand, nest failures due to predation were greater at Carl's Marsh (45%) compared to China Camp.

Black rails are found almost exclusively in mature marshes that are dominated by pickleweed and tules (Evens et al. 1991, Spautz and Nur 2002), although some younger marshes vegetated with Pacific cordgrass have been found to support rails during the non-breeding season (Evens et al. 1991). Since their breeding home ranges are relatively small (0.65 ha; Tsao et al. 2009), varied topography providing dense pickleweed canopy and an open understory for nesting, foraging, and movement seem to be preferred (Evens and Page 1983), as well as are areas with more complex habitat structure (vegetation height, stem density, and percent cover: Tsao et al. 2009). Tidal marsh restoration with particular attention to upland transition zones will increase habitat availability for black rail.

Clapper rails inhabit the most mature tidal salt marshes with well-developed cordgrass, vegetative cover, and creek and channel networks. Clapper rails are not usually found in young restoration sites, and it can take years or decades for the appropriate emergent vegetative cover and channels to develop (Foin et al. 1997). Considerable time may be needed for creek and channel networks to develop naturally (Wallace et al. 2005, Woo et al. 2007) or for constructed channels to equilibrate (Zeff 1999, Williams et al. 2002). Clapper rail recovery efforts can be difficult because it may take multiple years before colonization, and detections and densities can vary from year to year (Foin et al. 1997, Liu et al. 2007). Other factors can contribute to clapper rail reproductive success, including contaminants, predation, and flooding events (Schwarzbach et al. 2006).

Black-necked stilts have benefited from the existing habitat mosaic of salt pond and tidal marsh. Although they were rather uncommon in SFB historically, today they are the second most abundant breeding shorebird in SFB (Stenzel et al. 2002, Rintoul et al. 2003). Stilts forage in salt ponds yet primarily nest in adjacent managed and diked marshes and to a lesser extent islands within salt ponds (Robinson et al. 1999, Ackerman unpublished data). Large scale restoration and conversion of salt pond to tidal marsh will increase available nesting habitat for stilts at the expense of available foraging habitat. For species that depend on multiple habitat types such as stilts, the overall population response to restoration is not clear. Landscape scale analyses of population viabilities may help determine an extent of tidal marsh restoration that benefits multiple species.

Restoration effectiveness relies on a site's ability to provide suitable prey resources, cover, and for breeding birds, habitat for successful reproduction. Restoration is also a process of succession dynamics with habitats in transition. Habitat availability for wildlife will vary through time, depending on foraging strategies, prey availabilities, cover requirements, and habitat use during species' life stages. Understanding the mechanisms that govern habitat use and habitat requirements should improve restoration designs to maximize wildlife use of habitat mosaics through time.

11.5 Conclusions

Birds have distinct niches in tidal marshes of SFB based on their foraging guilds and habitat associations. Rather than representing a singular, monotypic habitat type, birds respond to a composite of different resources within the tidal marsh. In addition, species show distinct responses to habitat features that vary with the evolution of a site. Urbanization and flood protection have resulted in a much more static system and perhaps a less diverse avian community that may not be able to respond to the combined threats of sea-level rise, habitat degradation and fragmentation, invasive species and predation, and other environmental stressors.

Despite the severe loss of historic marshlands, restoration has resulted in an increase in tidal marsh habitat and generally a large response by birds (i.e., waterbirds). However, the avian community in early restoration is mostly transitional, and the species abundance and diversity will likely decrease over time in favor of endemic tidal marsh birds such as the black rail and the clapper rail that require mature marshes. Although the historical mosaic of tidal marshes in SFB has changed through time providing a wide range of habitats, current conditions are more restricted because regional development now surrounds tidal marshes. Rather than upslope migration of marshes to higher elevations, sea-level rise may eliminate tidal marshes and upland refugia zones adjacent to urban development. Thus, conservation of tidal marsh birds will require protection of existing marshes or expansion into new areas. Future research should be directed at predicting habitat alteration and fragmentation in tidal marshes caused by sea-level rise and linking them to changes in vital rates of bird populations, thereby identifying which species are most at risk.

11.6 Acknowledgments

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12. Abundance, Diversity, and Demography of Tidal Marsh Birds at China Camp State Park, Marin County, California

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Julian Wood[1], **Len Liu**[1], **Nadav Nur**[1], **Mark Herzog**[1,2], and **Nils Warnock**[1,3]

[1]PRBO Conservation Science, 3820 Cypress Dr. #11
Petaluma, CA 94954

[2]Present address: U.S. Geological Survey, Western Ecological Research Center
1 Shields Ave
University of California, Davis, CA 95616

[3]Present address: Audubon Alaska
441 West Fifth Avenue
Anchorage, AK 99501

ABSTRACT

Extensive habitat loss and degradation have likely resulted in decreases in populations of tidal marsh breeding birds in the San Francisco Estuary in the past 150 years. We conducted point count surveys and nest monitoring at China Camp State Park from 1996 through 2007 to assess marsh bird abundance, species richness and reproductive success over time. We found overall species richness to be similar compared to other San Pablo Bay sites. We present relative abundance for three focal species that are of conservation concern: San Pablo Song Sparrow *Melospiza melodia samuelis,* California Black Rail *Laterallus jamaicensis coturniculus,* and California Clapper Rail *Rallus longirostris obsoletus*. There was no apparent trend in Song Sparrow abundance during the study period. We determined Song Sparrow nest survival probability using the Mayfield method and found that nest survival at China Camp varied markedly among years, from >30% in 1996 to 6% in 2006. However, in 2007, nest survival was the second-highest observed, c. 29%. The main causes of nest failure were tidal flooding and predation.

KEY WORDS

Song Sparrow
California Clapper Rail
California Black Rail
nest survival
saltmarsh

12.1 Introduction

Tidal salt marsh is critical habitat for the persistence of many bird species (Burger 1985) and supports many endemic species or subspecies (Greenberg and Maldonado 2006). While diversity is generally low in salt marsh habitat, many of the species that rely on this habitat type are highly specialized (Chapman 1977). North America supports the highest number of terrestrial vertebrate species with subspecies endemic to tidal salt marsh (Greenberg and Maldonado 2006) and birds compose the majority of these endemic subspecies. On the west coast of the United States, the majority of these subspecies occur in the San Francisco Bay.

The San Francisco Bay and Delta contain the largest area of tidal marsh (162 km^2) along the Pacific Coast (Nichols et al. 1986). It is the most important site along the Pacific Flyway for wintering and migrating shorebirds and is also important for migratory waterfowl (Josselyn 1983, Page et al. 1999, Warnock et al. 2002). The San Francisco Bay also supports populations of endemic subspecies such as the federally endangered California Clapper Rail *Rallus longirostris obsoletus*, and the State of California threatened California Black Rail *Laterallus jamaicensis coturniculus*. Other endemic subspecies include the following State of California Bird Species of Special Concern: the Salt Marsh Common Yellowthroat *Geothlypis trichas sinuosa*, and three subspecies of Song Sparrow: Suisun Song Sparrow *Melospiza melodia maxillaris*, Alameda Song Sparrow *M. m. pusillula*, and San Pablo Song Sparrow *M. m. samuelis* (Shuford and Gardali 2008).

China Camp, located on the eastern shore of Marin County in San Pablo Bay, is one of the largest ancient marshes in San Pablo Bay, containing 99 ha (based on USGS aerial photos) of tidal marsh habitat. The marsh plain is dominated by perennial pickleweed *Sarcocornia pacifica* and characterized by complex dendritic networks of channels lined with gumplant *Grindelia stricta*. The outward edge of the marsh is dominated by bulrush *Schoenoplectus maritimus* and Pacific cordgrass *Spartina foliosa* (Atwater et al. 1979). China Camp marsh is an ancient marsh formed 2,000 to 6,000 years ago (Atwater 1979) and has been used as a reference site for evaluating the condition of restored, degraded and managed marshes (Williams and Orr 2002). In addition, the natural interface between tidal salt marsh and protected uplands that exists at China Camp is now rare elsewhere in San Francisco Bay. China Camp's extensive, undisturbed and ancient marsh plain and its upland transitional zone all contribute to making this area an important NERR site for researchers.

Extensive bird research has been conducted at China Camp including studies of species abundance and distribution (Nur et al. 1997, Takekawa et al. 2006), trophic adaptations (Grenier 2004), and genetic structure (Chan and Arcese 2002). While many of the above studies focused on the Song Sparrow, earlier studies were conducted on Clapper Rail (Gill 1979) and Black Rail (Evens et al. 1991, Evens and Nur 2002). PRBO Conservation Science (PRBO) initiated a long-term tidal marsh monitoring program in 1996 and has used China Camp as a key reference site in describing bird abundance, distribution and demographics in relation to local and landscape-level characteristics (Spautz et al. 2006, Greenberg et al. 2006).

The objectives of this study were to summarize bird species richness, abundance and demographic parameters at China Camp using data from 1996 to 2007. Although we provide richness and abundance data on all species, we provide analysis of abundance, demography, and habitat use for the three most common species, Black Rail, Clapper Rail, and Song Sparrow, found throughout San Francisco Bay tidal marshes. For the Song Sparrow, we examined trends in abundance and nesting success and compared results to those at other long-term monitoring sites in San Pablo Bay.

12.2 Methods

Study Area

Bird monitoring data were collected in tidal salt marsh habitat within China Camp State Park, Marin Co., CA (Figure 1). Point count stations, nest plots and territory mapping plots were placed throughout the site non-randomly in an effort to sample the range of habitat conditions at China Camp. Point count stations were located at least 50 m from the upland and bay edges. Nest plots were placed in areas with high focal species densities and included channel features. Sub-tidal mudflats and upland areas within and adjacent to China Camp were not surveyed as part of this study.

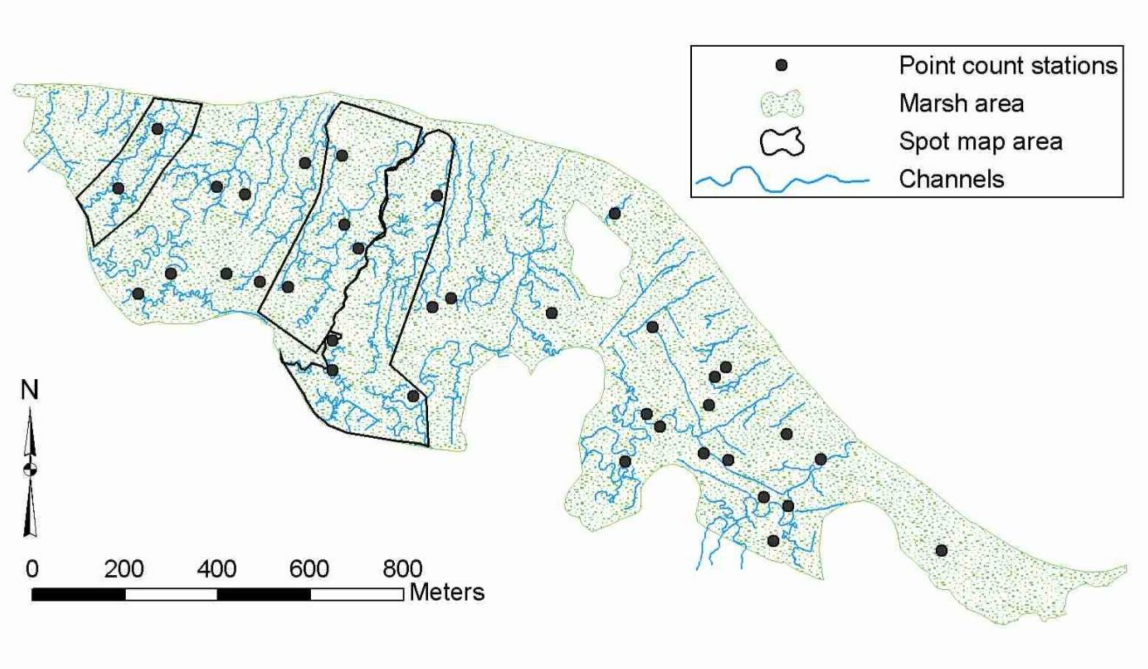

Figure 1. Map of the China Camp study site showing spot map areas, nest monitoring plots, and all PRBO point count stations conducted during 1996-2007. In any given year, only a subset of points was sampled.

General Point Count Survey

Point count surveys were conducted each year at 7 to 23 marshes in San Pablo Bay during spring (late March through May) between 1996 and 2007. Survey points (or stations) were placed 150-200 m apart, with 10 points surveyed at China Camp in most years and 5 to 13 points per site at other San Pablo Bay sites, depending on marsh size. In nearly all cases 2 surveys were conducted at each station and successive rounds were conducted at least 3 weeks apart. At each station, a trained field biologist recorded all birds detected by sight and sound for 5 minutes. For detections within 100 m from the observer, distance was estimated within 10 m bands (Reynolds et al. 1980; Ralph et al. 1995; Nur et al. 1999). Based on prior analysis of detection rates at various distances (Nur et al. 1997), we restricted the data used in the results to detections within 50 m of the observer. Within this area, we did not need to assume 100% detectability. For purposes of analysis, however, we did assume that there was negligible variation in detectability across sites and years based on previous analysis (Nur et al. 1997). Thus, the results obtained are not true density estimates, but instead an index of relative density (or abundance), as described by Ralph et al. (1995) and Nur et al. (1999). The indices were calculated for each 5-minute point count survey and averaged over the 2 visits and for Table 1, were averaged across years. Final average estimates were then divided by the proportion of tidal marsh within the 50 m radius. We defined species richness at the point level as the total number of unique species detected across both surveys within each year. Marsh areas were calculated using information on marsh delineation provided by the State Coastal Conservancy's Invasive Spartina Project, the San Francisco Estuary Institute's Bay Area EcoAtlas Version 1.50b4, and USGS aerial photographs.

Clapper Rail Point Count Survey

Clapper Rail surveys were conducted 3 times each year between January and March from 2005 through 2007. Passive Ten-minute surveys were conducted at 7 points, at least 200m apart, during a two-hour period surrounding sunrise and/or sunset. All Clapper Rail vocalizations were recorded with the time, direction and distance from the point. If the number of birds calling was uncertain, an estimate of the range was recorded (e.g., "2 – 4 birds") following Liu et al. (2009). Therefore, most surveys resulted in a minimum and maximum estimate for the number of unique birds detected.

For each point, we first selected the survey visit with the highest maximum number of Clapper Rail detections observed in any of the 3 visits. We then used the minimum and maximum number of detections from that visit to calculate the mean for each point. The mean number of Clapper Rails at each point was then used to calculate relative abundance expressed as birds/hectare. Detectability of Clapper Rail vocalizations decreases at 200 m (PRBO unpub. data), so relative abundance was calculated using detections within 200 m and based on the area covered by marsh within 200 m.

Territory Mapping

The breeding territories of Marsh Wrens and Black Rails were mapped within three plots, totaling 15.3 ha, from 2001 through 2005 following Verner (1985). The territory mapping plots were ideally visited weekly from March through July although some areas of the plots were visited as few as four times during the breeding season: twice during the first half of the season to produce mid-season maps (before May 1) and at least twice during the late season, between May 1 and June 30.

Nest Monitoring

Nest searching and monitoring was conducted at China Camp annually from 1996 through 2007 by trained observers following standard protocol as described in Martin and Geupel (1993) and Nur et al. (1997). Nest searching and monitoring allows measurement of a number of parameters associated with reproductive success (e.g., clutch size, initiation date) and provides information on population health and sustainability (Martin and Geupel 1993). Nests were located during all stages (construction, egg-laying, incubation, and nestling periods) and visited every two to four days to record nest contents. We also recorded nest substrate: the plant species upon which the nest was constructed. The ultimate outcome of each nest (fledge or fail) was determined based on nest condition and parental behavior. For Song Sparrow, we calculated daily nest survival rates using the method described by Mayfield (1975) and then estimated overall nest survival as the product of the daily nest survival rates over the 23-day nesting period (Johnson 1979, Nur et al. 1999). To compare with other studies, we also calculated apparent nest success as the fraction of detected nests that successfully fledged at least one nestling. Apparent nest success, however, is a biased estimator of nest survival, unlike the Mayfield method (Johnson 1979).

Analytical Methods

We present analyses of abundance of Song Sparrows with respect to year (1996 to 2007) for China Camp, and pooled for all other San Pablo Bay marsh sites. Change in abundance over time is shown non-parametrically using the LOESS procedure (Cleveland 1979) implemented in STATA 10.0 (StataCorp. 2007). In addition, we analyze change in abundance with respect to linear, second-order (i.e., quadratic) and third-order functions (Nur et al. 1999). In these analyses we used mean values (for China Camp or San Pablo Bay sites) for each year, weighted by the inverse of the standard error of the mean. For these parametric analyses we log-transformed abundance. The resulting linear trend in log-abundance implies a constant percent change in abundance over time (Nur et al. 1999). We used a similar approach to analyze overall nest survival in China Camp over the study period as well as at other San Pablo Bay sites for 1996 to 2007.

Table 1. Bird species detected at China Camp, breeding status and abundance index (mean number of individuals detected/ha).

Species	Breeding Status	Abundance Index	Species	Breeding Status	Abundance Index
Acorn Woodpecker		*	Marsh Wren	CO	0.17
Allen's Hummingbird	PO	*	Mourning Dove	CO	*
American Crow		*	Northern Flicker		*
American Goldfinch	CO	0.06	Northern Harrier	PR	*
American Robin		*	Osprey		*
American Wigeon		*	Pacific-slope Flycatcher		0.01
Anna's Hummingbird	PO	*	Red-shouldered Hawk		*
Barn Swallow		0.02	Red-tailed Hawk	PR	*
Black Rail	CO	0.26	Red-winged Blackbird	PO	0.26
Black-necked Stilt		0.08	Ruddy Duck		*
Brown-headed Cowbird	CO	*	Say's Phoebe		*
California Towhee		0.01	Snowy Egret		0.90
Canada Goose		*	Song Sparrow	CO	7.57
Clapper Rail	CO	*	Spotted Towhee		*
Clark's Grebe		0.05	Tree Swallow		0.07
Cliff Swallow		*	Turkey Vulture		*
Common Raven		0.05	Violet-green Swallow		0.02
Common Yellowthroat	PO	*	Virginia Rail		*
European Starling		*	Western Bluebird		*
Gadwall	PR	*	Western Grebe		0.01
Great Blue Heron		*	Western Gull		*
Great Egret		*	Western Meadowlark		*
Greater Yellowlegs		*	Western Scrub-Jay		*
House Finch		0.09	White-breasted Nuthatch		*
Killdeer		0.01	White-crowned Sparrow		*
Least Sandpiper		0.01	White-tailed Kite	PO	*
Lesser Scaup		0.01	Willet		*
Mallard	CO	0.04	Wilson's Snipe		0.05

Notes: * Abundance index < 0.01 birds/ha

Breeding status: CO = confirmed (nest found, nesting activity observed), PR = probable (pair or permanent territory throughout breeding season in suitable nesting habitat), PO = possible (detected during breeding season in suitable nesting habitat). Data from March through May 1996-2007 point count surveys and incidental sightings (excludes flyovers and species only detected in the bay).

12.3 Results

The most common species breeding at China Camp were Song Sparrow, Marsh Wren, and Black Rail. We confirmed breeding for an additional five species that bred infrequently or in very low numbers (Clapper Rail, Mallard, American Goldfinch, Mourning Dove and Brown-headed Cowbird, a brood parasite associated with upland and pasture habitats; Table 1).

Bird Species Richness

We detected 56 bird species during point count surveys at China Camp (Table 1). Bird species richness per point at China Camp showed no marked trend among years and ranged from 1.5 in 1997 and 2000 to 4.7 in 2007 (Figure 2). In most years China Camp was slightly lower than the average values for San Pablo Bay sites. Species richness was slightly higher in 2005 through 2007 for both China Camp and the San Pablo Bay average but still within the range of annual variation.

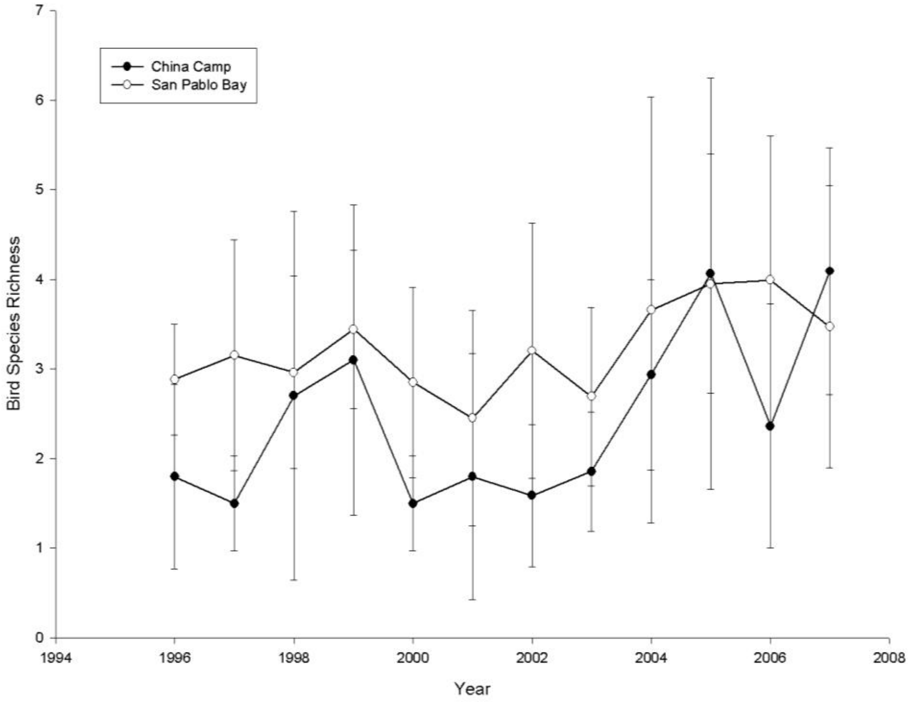

Figure 2. Mean marsh bird species richness per point at China Camp and San Pablo Bay using point count data (1996-2007).

Relative Abundance and Territory Density

For the 56 bird species detected, mean relative abundance ranged from <0.01 birds/ha to 7.57 (Table 1). Song Sparrow relative abundance at China Camp ranged from 4.69 birds/ha (SE ± 2.28) to 10.74 (SE ± 3.15), across the 11 years, and was slightly higher than the average of all San Pablo sites that ranged from 4.61 birds/ha (SE ± 0.28) to 7.20 (SE ± 0.36). No significant linear or non-linear (i.e., quadratic or cubic) trends were found at China Camp (Figure 3) or the rest of San Pablo Bay marsh sites (Figure 4). Year-to-year change at China Camp was not correlated with year-to-year change in Song Sparrow relative abundance at other sites.

Clapper Rail relative abundance averaged 0.24 birds per ha using point count survey data from 2005 through 2007. The average minimum number of Clapper Rails detected at China Camp over all surveys was 11.67 and the average maximum was 12.67. Marsh Wren territory density averaged 0.37 territories/ha (as determined by territory mapping from 2001 through 2005) and ranged from 0.26 in 2003 and 2004 to 0.52 in 2001. Black Rail territory density at China Camp averaged 0.43 territories per hectare and ranged from 0.33 in 2003 to 0.52 in 2001 and 2004.

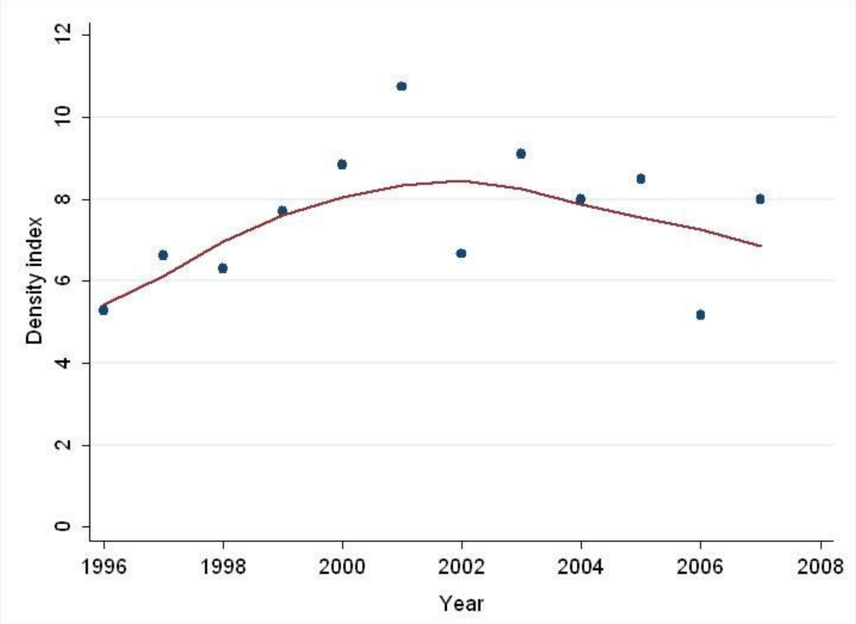

Figure 3. Mean Song Sparrow relative abundance (number of individuals detected/ha) at China Camp based on point count data from 1996 through 2007. Shown is LOESS smoothed data (see text). No significant linear, quadratic, or cubic trend was detected.

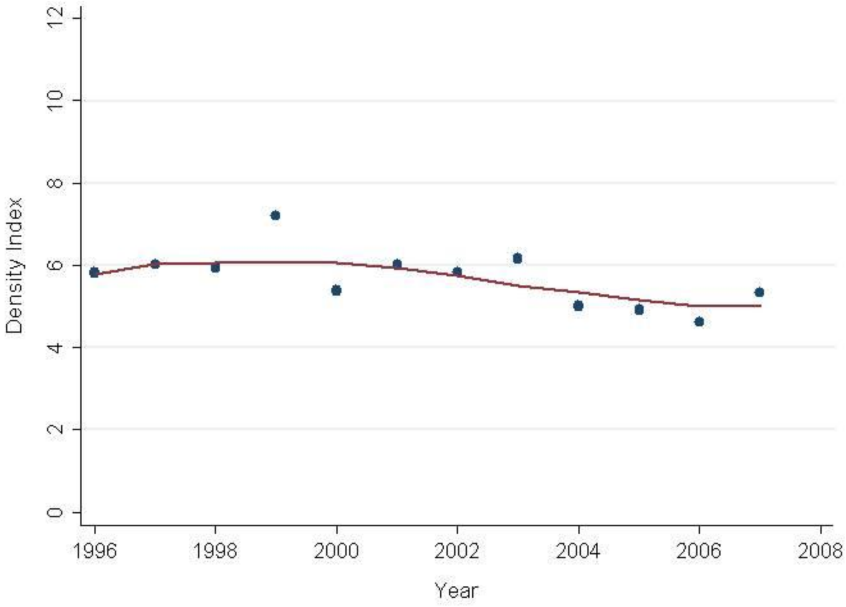

Figure 4. Mean Song Sparrow relative abundance (number of individuals detected/ha) at all San Pablo Bay sites based on point count data from 1996 through 2007. Shown is LOESS smoothed data (see text). No significant linear, quadratic, or cubic trend was detected.

Demography

The average Song Sparrow nest survival probability from 1996 through 2007 was very similar between China Camp (16.3%) and the rest of San Pablo Bay (16.0%). Apparent nest success was 24% at China Camp and 27% at other San Pablo sites. Nest survival at all sites was characterized by high annual variation. At China Camp, Song Sparrow nest survival varied from 6% in 2006 to 32% in 1996 (Figure 5). No significant trends (linear or non-linear) were found at China Camp or the rest of San Pablo Bay. Year-to-year changes in nest survival at China Camp were not correlated with year-to-year changes in nest survival at other San Pablo sites.

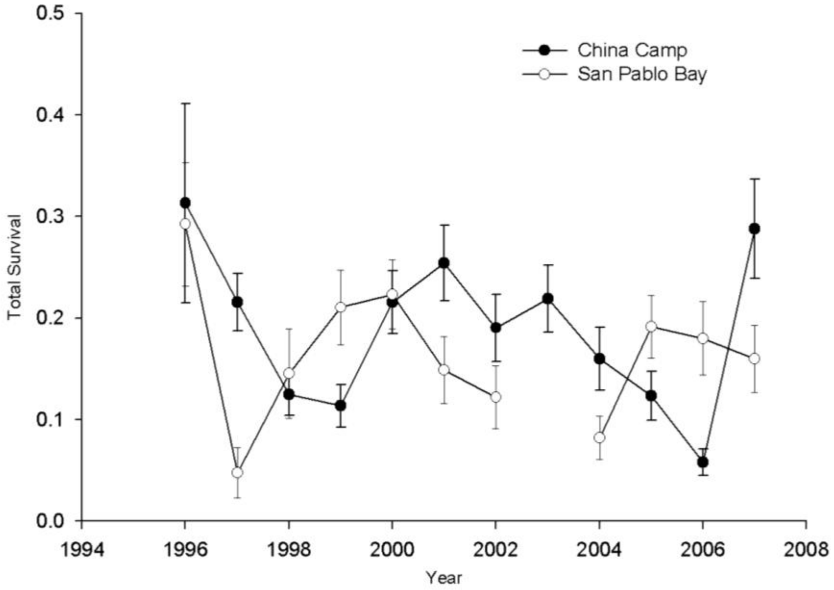

Figure 5. Song Sparrow nest survival (total survival) at China Camp and at all other San Pablo Bay sites, 1996-07. No nest monitoring was conducted at other San Pablo Bay sites in 2003. Error bars represent one standard error. No significant trend in nest survival was found.

For Song Sparrows, the most common nest fate at our sites was predation (Figure 6). Nest fates were similar between China Camp and the rest of San Pablo Bay sites with the exception of the percent of flooded nests (by spring and storm tides), which was twice as high at China Camp (16%) than at other San Pablo Bay sites (8%).

Of the 16 Black Rail nests monitored at China Camp from 1999 through 2007, 6 were confirmed successful (fledged at least one young), 6 were preyed upon by unknown predators, 2 were abandoned and the fate of 2 nests was unknown.

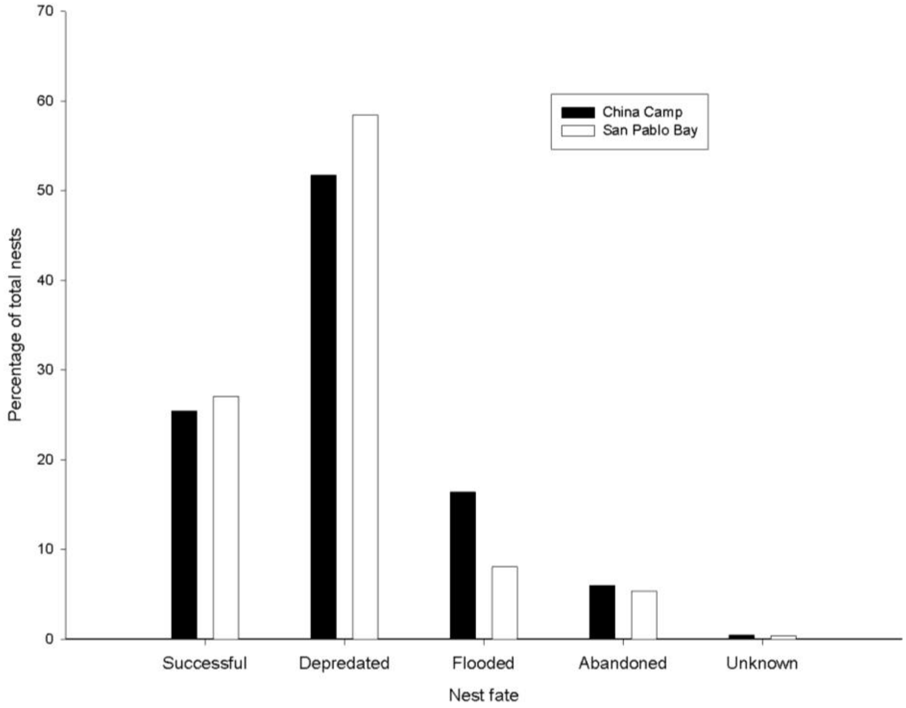

Figure 6. Song Sparrow nest fate at China Camp (n=1537) and all other San Pablo Bay sites (n=1088), 1996 - 2007.

Nesting Habitat Use

Song Sparrows used three species of plants on which to build their nests at China Camp (Figure 7). At other sites in San Pablo Bay, Song Sparrows used a greater variety of nesting substrates, and more nests were found in pickleweed and fewer nests were found in gumplant than those at China Camp (Figure 7).

Black Rail nests at China Camp were found in two plant species at China Camp (ten nests in gumplant and two nests in saltgrass *Distichlis spicata*). For four nests, the plant substrate was not recorded. All 25 Clapper Rail nests found at China Camp and all other San Pablo Bay sites used pickleweed.

12.4 Discussion

Bird Species Richness

Bird species richness at China Camp was lower compared to northeastern Atlantic coast salt marshes (Hanson and Shriver 2006), which ranged from 3.9 to 8.4 per survey point. China Camp bird species richness was slightly lower than that of other sites in San Pablo Bay. The slightly higher species richness observed at other San Pablo sites was due in part to habitat complexity. San Pablo Bay sites included areas of taller vegetation associated with brackish conditions (cattail, *Typha* spp.) and low marsh characterized by early-successional bulrush favored by Marsh Wrens and Common Yellowthroats. At China Camp, bulrush was most common on the outward edge of the marsh where Marsh Wren territories were clustered. Many San Pablo Bay sites also contained salt pans and other open areas that attracted shorebirds and other waterbirds adding to bird species richness. While overall bird species richness per survey point was slightly lower at China Camp, this site epitomizes a healthy ancient tidal salt marsh. While low in species richness, China Camp supported all species that have evolved to specialize in this harsh environment. In fact, many of the other San Pablo Bay marsh fragments lacked Black Rails and Clapper Rails (Evens and Nur 2002, Spautz et al. 2006).

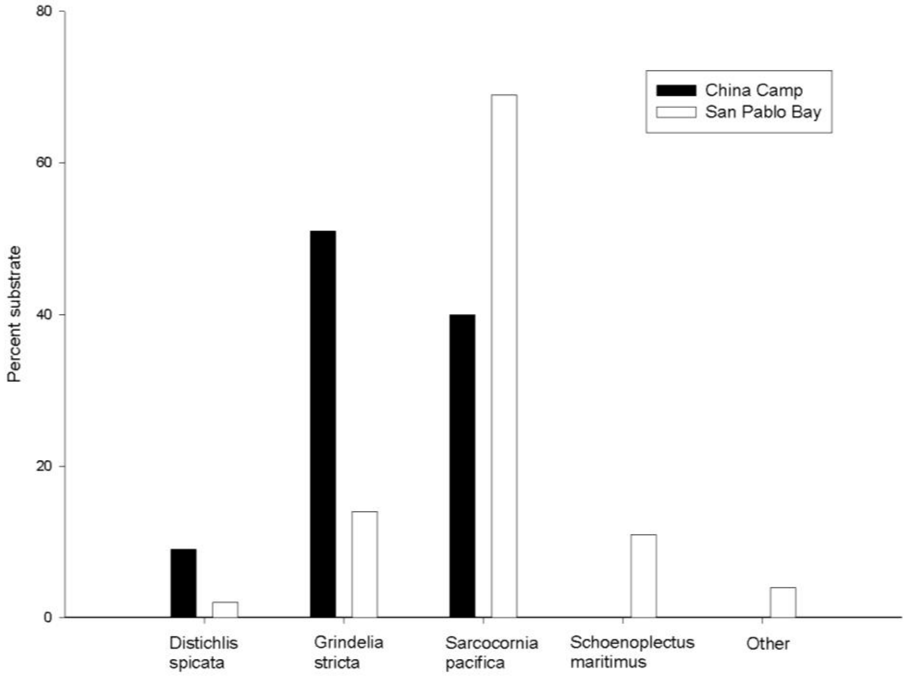

Figure 7. Nest substrate for Song Sparrow at China Camp (n=1537) and other San Pablo Bay sites (n=1088), 1996-2007.

Relative Abundance and Territory Density

Song Sparrows were the most abundant species at China Camp and had higher relative abundances than most San Pablo Bay sites. Bird-habitat analyses have shown that Song Sparrows are positively correlated with gumplant, an abundant shrub that lines channels at China Camp, and negatively correlated with rushes, ponds and pans (Spautz et al. 2006) that are lacking at China Camp. In addition, marsh size is an important predictor of Song Sparrow abundance in San Francisco Bay with larger marshes, such as China Camp, supporting higher densities (Spautz et al. 2006). Hanson and Shriver (2006) also determined that larger marshes had higher densities of salt marsh-obligate sparrows.

Nest Survival

Nest success of *Ammodramus* sparrows (Seaside Sparrow *A. maritimus* and Saltmarsh Sharp-tailed Sparrow *A. caudacutus*) from four Eastern U.S. salt marshes averaged 41.5% (Reinert 2006) and was higher than both China Camp and San Pablo (24% and 27%, respectively). Greenberg et al. (2006) found that 47% of San Francisco Bay Song Sparrow nest failures were due to predation and only 12% due to flooding. In Northeastern salt marshes, flooding was the main cause of nest failures for 6 of 11 studies of *A. maritimus* and *A. caudacutus* (Reinert 2006). Potential predators found in San Francisco Bay salt marsh habitat include the gopher snake (*Pituophis catenifer*), Northern Harrier (*Circus cyaneus*) and Short-eared Owl (*Asio flammeus*), Brown-headed Cowbird, corvids, river otter (*Lontra canadensis*), and raccoon (*Procyon lotor*). Other potential nest predators include the vagrant shrew (*Sorex vagrans*), California ground squirrel (*Spermophilus beecheyi*), California vole (*Microtus californicus*), House mouse (*Mus musculus*) and Norway rat (*Rattus norvegicus;* Johnston 1956a, Josselyn 1983).

Nesting Habitat Use

In San Pablo Bay, Song Sparrow nests have been found in pickleweed, saltgrass, cordgrass, and gumplant (Johnston 1956a). Spautz et al. (2006) have shown that Song Sparrow abundance is positively correlated with the amount of gumplant within the survey area. In our study, Song Sparrow territories were mostly located along gumplant-lined channels that Johnston (1956b) identified as an important marsh feature for foraging. However, Grenier (2004) found that Song Sparrows at China Camp also foraged in areas dominated by pickleweed that were outside their defended territories. In addition, habitat use may vary with marsh age within China Camp marsh. Additional data from different age classes (e.g., centennial and ancient marsh) would be required to explore habitat use and marsh age within China Camp.

Song Sparrows tended to nest in gumplant and in other substrates as high as possible to avoid flooding while still allowing for adequate cover from above. In the Northeastern U.S., *Ammodramus* sparrows nested primarily in cordgrass *Spartina sp.* that is taller than gumplant and may allow sparrows to nest above high tide levels and still provide concealment from above (Greenlaw 1983, Marshall and Reinert 1990). This may help explain the lower observed predation rate among east coast sparrows compared to west coast sparrows.

12.5 Conclusions

China Camp with its expansive ancient marsh buffered by natural uplands and younger outward marsh has provided researchers the opportunity to study the natural history and ecology of salt-marsh dependent birds in a setting that approximates historical conditions. China Camp supports a stable population of Song Sparrows and also harbors populations of California Black Rails, listed as state of California Threatened, and California Clapper Rails, a federal and state listed endangered species. These populations face many threats including sea level rise, invasive species (e.g., smooth cordgrass *Spartina alterniflora/* hybrids, and Chinese mitten crab *Eriocheir sinensis)*, pollution, and non-native predators. Rising sea levels threaten to alter and reduce marsh habitat as plant species that are less tolerant of inundation disappear, and as the outward edges of the marsh are eroded by rising waters and wind-wave erosion (Stralberg et al. in press, Duncan et al. 2008). The frequency and severity of storm surges may also increase (Cloern et al. 2011) resulting in higher nest losses due to flooding and increased exposure to predators, as nests placed higher in vegetation will be less concealed from above. While rails and other wildlife may seek refuge from high water in the upland buffer, they may also become more exposed to predation. In addition, sea level rise may adversely affect resident and migratory shorebirds that rely on tidal mudflats for foraging.

The myriad of threats to China Camp's bird community warrants continued monitoring to provide early detection of decreasing trends in abundance and nest success before populations become imperiled. Furthermore, long-term viability of tidal marsh populations cannot be assessed without information on survival of adults and juveniles. Early detection of decreasing trends in abundance or changes in nest success will allow time to identify threats and design conservation actions (e.g., restoration, improved management, predator control) to reverse downward trends. Research and monitoring should encompass multiple sites that represent the range of sizes, ages, configurations, and management regimes of marshes throughout the San Francisco Bay. In this way, we can better understand the role China Camp marsh plays within the broader context of the San Francisco Bay as a whole.

12.6 Acknowledgements

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13. Population Studies of Tidal Marsh Breeding Birds at Rush Ranch: A Synthesis

Hildie Spautz[1], **Leonard Liu**[2], **Sarah Estrella**[3], and **Nadav Nur**[2]

[1] *California Department of Fish and Game, Ecosystem Restoration Program*
830 S. Street, Sacramento, CA 95811. USA
email: hspautz@dfg.ca.gov

[2]*PRBO Conservation Science*
3820 Cypress Drive #11, Petaluma, CA 94954

[3]*California Department of Fish and Game*
Bay Delta Region (Region 3)
4001 N. Wilson Way Stockton, CA 95205

ABSTRACT

Rush Ranch, with the largest contiguous area of fully tidal marsh remaining in northern Suisun Bay, is critical habitat for a number of endemic bird species that breed in brackish tidal marsh. In spite of the abundance of non-native invasive plants (particularly perennial pepperweed, *Lepidium latifolium*) and altered hydrology, it is the best remaining representative in Solano County of the tidal marsh that once covered more than 27,000 ha (67,000 acres) in Suisun Bay. The most common breeding bird species are Suisun song sparrow (*Melospiza melodia maxillaris*), common yellowthroat (*Geothlypis trichas*), marsh wren (*Cistothorus palustris*), red-winged blackbird (*Agelaius phoeniceus*), and California black rail (*Laterallus jamaicensis coturniculus*). Bird populations have been studied at Rush Ranch for the last 30 years, and most intensively monitored for the last 10 years. This chapter presents a synthesis of these studies.

KEY WORDS

California black rail
California clapper rail
Geothlypis trichas
Melospiza melodia maxillaries
Laterallus jamaicensis coturniculus
Lepidium latifolium
perennial pepperweed
Rallus longirostris obsoletus
common yellowthroat
Suisun song sparrow

13.1 Introduction

Rush Ranch, with the largest contiguous area of fully-tidal marsh remaining in northern Suisun Bay, is a critical area for a suite of endemic breeding bird species adapted to brackish tidal marsh habitat. Birds using this tidal marsh habitat are the focus of the present chapter, with some mention of the species using the adjacent upland edges, grasslands, and human-occupied areas.

In spite of an abundance of invasive plants (particularly perennial pepperweed, *Lepidium latifolium*), high predation rates likely due to non-native predators and other human-associated predators (such as raccoons and skunks), an altered upland edge, and altered hydrology, Rush Ranch is the best representative of the tidal marsh remaining in Solano County that once covered more than 27,000 ha (67,000 acres) in Suisun Bay (Goals Project 1999). For this reason it has been included in a number of bird studies of Suisun Bay tidal marshes in the last three decades.

The most common bird species in the tidal marsh at Rush Ranch are Suisun song sparrow (*Melospiza melodia maxillaris*), a California Species of Special Concern (CDFG 2008; Spautz and Nur 2008); common yellowthroat (*Geothlypis trichas*), probably an inter-grade with the salt marsh sub-species (*G. t. sinuosa*), a California Species of Special Concern (Evens and Gardali 2008); marsh wren (*Cistothorus palustris*); red-winged blackbird (*Agelaius phoeniceus*); and California black rail (*Laterallus jamaicensis coturniculus*), a state-listed Threatened and fully-protected species (Trulio and Evens 2000; CDFG 2008). Recent surveys for California clapper rail, a federally and state-listed Endangered and fully-protected species (CDFG 2002, 2003, 2004a, 2005, 2006, 2007, 2008b) have resulted in two clapper rail detections at Rush Ranch, down from the numbers detected in the late 1970s through the early 1990s (Harvey 1980, Collins et al. 1994).

13.2 Bird Studies at Rush Ranch

Studies of birds at Rush Ranch have included focused surveys for special status species (including CDFG 2002-2008, Collins et al. 1994, Evens et al. 1991, Spautz et al. 2005, Herzog et al. 2005, Liu et al. 2006) and general bird surveys, both standardized (e.g., Herzog et al. 2005, Liu et al. 2006, Spautz et al. 2007) and non-standardized (e.g., Christmas Bird Counts and Breeding Bird Surveys conducted by local chapters of the National Audubon Society). Results from all of these studies have contributed to the development of a bird list for Rush Ranch (Table 1). We list these studies in chronological order below.

Table 1. Rush Ranch Bird List.

Common Name	Scientific Name	Notes[b]
Grebes		
pied-billed grebe	*Podilymbus podiceps*	
Clark's grebe	*Aechmophorus clarkii*	
western grebe	*Aechmophorus occidentalis*	
Pelicans and allies		
American white pelican	*Pelecanus erythrorhynchos*	
double-crested cormorant	*Phalacrocorax auritus*	
Herons and allies		
American bittern	*Botaurus lentiginosus*	
great blue heron	*Ardea herodias*	
great egret	*Ardea alba*	
snowy egret	*Egretta thula*	
cattle egret	*Bubulcus ibis*	
green heron	*Butorides virescens*	
black-crowned night-heron	*Nycticorax nycticoarx*	
Ducks and Geese		
tundra swan	*Cygnus columbianus*	
greater white-fronted goose	*Anser albifrons*	
snow goose	*Chen caerulescens*	
Canada goose	*Branta canadensis*	
wood duck	*Aix sponsa*	
green-winged teal	*Anas crecca*	
mallard	*Anas platyrhynchos*	nests in tidal marsh
northern pintail	*Anas acuta*	
cinnamon teal	*Anas cyanoptera*	
northern shoveler	*Anas clypeata*	
gadwall	*Anas strepera*	
Eurasian wigeon	*Anas penelope*	
American wigeon	*Anas americana*	
ring-necked duck	*Aythya collaris*	
greater scaup	*Aythya marila*	
lesser scaup	*Aythya affinis*	
common goldeneye	*Bucephala clangula*	
bufflehead	*Bucephala albeola*	

Table 1. Rush Ranch Bird List.

Common Name	Scientific Name	Notes[b]
hooded merganser	*Lophodytes cucullatus*	
ruddy duck	*Oxyura jamaicensis*	
Vultures		
turkey vulture	*Cathartes aura*	
Hawks, eagles and falcons		
osprey	*Pandion haliaetus*	
white-tailed kite	*Elanus leucurus*	
bald eagle	*Haliaeetus leucocephalus*	
northern harrier	*Circus cyaneus*	nests in tidal marsh / upland edge
sharp-shinned hawk	*Accipiter striatus*	
Cooper's hawk	*Accipiter cooperi*	
Swainson’s hawk	*Buteo swainsonii*	
red-tailed hawk	*Buteo jamaicensis*	
ferruginous hawk	*Buteo regalis*	
rough-legged hawk	*Buteo lagopus*	
golden eagle	*Aquila chrysaetos*	
American kestrel	*Falco sparverius*	
merlin	*Falco columbarius*	
peregrine falcon	*Falco peregrinus*	
prairie falcon	*Falco mexicanus*	
Pheasants and quails		
ring-necked pheasant [a]	*Phasianus colchicus*	nests in tidal marsh & upland
California quail	*Callipepla californica*	
Rails and allies		
Yellow rail		
California black rail	*Laterallus jamaicensis coturniculus*	nests in tidal marsh
California clapper rail	*Rallus longirostris obsoletus*	nests in tidal marsh
Virginia rail	*Rallus limicola*	nests in tidal marsh
sora	*Porzana carolina*	
common moorhen	*Gallinula chloropus*	
American coot	*Fulica americana*	
Shorebirds		
black-bellied plover	*Pluvialis squatarola*	

Table 1. Rush Ranch Bird List.

Common Name	Scientific Name	Notes[b]
killdeer	*Charadrius vociferus*	
black-necked stilt	*Himantopus mexicanus*	
American avocet	*Recurvirostra americana*	
greater yellowlegs	*Tringa melanoleuca*	
lesser yellowlegs	*Tringa flavipes*	
willet	*Tringa semipalmata*	
long-billed curlew	*Numenius americanus*	
marbled godwit	*Limosa fedoa*	
ruddy turnstone	*Arenaria interpres*	
western sandpiper	*Calidris mauri*	
least sandpiper	*Calidris minutilla*	
dunlin	*Calidris alpina*	
long-billed dowitcher	*Limnodromus scolopaceus*	
Wilson's snipe	*Gallinago delicata*	
Gulls and terns		
Bonaparte's gull	*Larus philadelphia*	
ring-billed gull	*Larus delawarensis*	
California gull	*Larus californicus*	
glaucous-winged gull	*Larus glaucescens*	
Caspian tern	*Sterna caspia*	
Forster's tern	*Sterna forsteri*	
Pigeons and doves		
rock pigeon [a]	*Columba livia*	
mourning dove	*Zenaida macroura*	
Owls		
barn owl	*Tyto alba*	
great horned owl	*Bubo virginianus*	
western burrowing owl	*Athene cunicularia hypugea*	
short-eared owl	*Asio flammeus*	
Hummingbirds and swifts		
white-throated swift	*Aeronautes saxatalis*	
Anna's hummingbird	*Calypte anna*	
Allen's hummingbird	*Selasphorus sasin*	

Table 1. Rush Ranch Bird List.

Common Name	Scientific Name	Notes[b]
Kingfishers		
belted kingfisher	*Ceryle alcyon*	
Woodpeckers		
downy woodpecker	*Picoides pubescens*	
northern flicker	*Colaptes auratus*	
PASSERINES		
Flycatchers		
willow flycatcher	*Empidonax traillii*	
Pacific-slope flycatcher	*Empidonax difficilis*	
black phoebe	*Sayornis nigricans*	
Say's phoebe	*Sayornis saya*	
western kingbird	*Tyrannus verticalis*	
Larks		
horned lark		
Swallows		
tree swallow	*Tachycineta bicolor*	
violet-green swallow	*Tachycineta thalassina*	
northern rough-winged swallow	*Stelgidopteryx serripennis*	
cliff swallow	*Petrochelidon pyrrhonota*	
barn swallow	*Hirundo rustica*	
Corvids - jays, crows and ravens		
western scrub-jay	*Aphelocoma californica*	
yellow-billed magpie	*Pica nuttalli*	
American crow	*Corvus brachyrhynchos*	
common raven	*Corvus corax*	
Bushtits		
bushtit	*Psaltriparus minimus*	
Wrens		
Bewick's wren	*Thryomanes bewickii*	
house wren	*Troglodytes aedon*	
marsh wren	*Cistothorus palustris*	nests in tidal marsh
Kinglets		
ruby-crowned kinglet	*Regulus calendula*	

Table 1. Rush Ranch Bird List.

Common Name	Scientific Name	Notes[b]
Bluebirds		
western bluebird	*Sialia mexicana*	
mountain bluebird	*Sialia currucoides*	
Thrushes		
American robin	*Turdus migratorius*	
varied thrush	*Ixoreus naevius*	
Pipits		
American pipit	*Anthus rubescens*	
Mockingbirds		
northern mockingbird	*Mimus polyglottos*	
Shrikes		
loggerhead shrike	*Lanius ludovicianus*	
Starlings		
European starling [a]	*Sturnus vulgaris*	
Warblers		
orange-crowned warbler	*Vermivora celata*	
yellow warbler	*Dendroica petechia*	
yellow-rumped warbler	*Dendroica coronata*	
black-throated gray warbler	*Dendroica nigrescens*	
Townsend’s warbler	*Dendroica townsendi*	
common yellowthroat	*Geothlypis trichas*	nests in tidal marsh
Wilson’s warbler	*Wilsonia pusilla*	
Tanagers		
western tanager	*Piranga ludoviciana*	
Sparrows		
spotted towhee	*Pipilo maculatus*	
California towhee	*Pipilo crissalis*	
vesper sparrow	*Pooecetes gramineus*	
lark sparrow	*Chondestes grammacus*	
savannah sparrow	*Passerculus sandwichensis*	nests in tidal marsh / upland edge
grasshopper sparrow	*Ammodramus savannarum*	
Suisun song sparrow	*Melospiza melodia maxillaris*	nests in tidal marsh
Lincoln's sparrow	*Melospiza lincolnii*	
golden-crowned sparrow	*Zonotrichia atricapilla*	

Table 1. Rush Ranch Bird List.

Common Name	Scientific Name	Notes[b]
white-crowned sparrow	*Zonotrichia leucophrys*	
dark-eyed junco	*Junco hyemalis*	
Cardinals and grosbeaks		
black-headed grosbeak	*Pheucticus melanocephalus*	
Blackbirds and allies		
red-winged blackbird	*Agelaius phoeniceus*	nests in tidal marsh
tricolored blackbird	*Agelaius tricolor*	
western meadowlark	*Sturnella neglecta*	
Brewer's blackbird	*Euphagus cyanocephalus*	
brown-headed cowbird	*Molothrus ater*	
Bullock's oriole	*Icterus bullockii*	
Finches		
purple finch	*Carpodacus purpureus*	
house finch	*Carpodacus mexicanus*	
lesser goldfinch	*Carduelis psaltria*	
American goldfinch	*Carduelis tristis*	
Old World sparrows		
house sparrow [a]	*Passer domesticus*	

Sources: Robin Leong, Napa-Sonoma Audubon Society; PRBO Conservation Science (unpubl. data); and eBird (2010)[a] Nonnative species [b] Species documented nesting in tidal marsh at Rush Ranch are noted.

13.3 Surveys for California black rail and California clapper rail, 1978 – 1993

Northern Suisun Bay was not historically considered to be within the range of the California clapper rail (Gill 1979). Harvey (1980) and Evens and colleagues (Evens et al. 1991, Evens and Collins 1992, Collins et al. 1994) conducted regional surveys for California clapper rail and California black rail that included portions of Rush Ranch and several other tidal marshes in Suisun Bay, as well as numerous marshes throughout San Pablo Bay and San Francisco Bay. These surveys took place in 1978-1979 and 1992-1993 (California clapper rail), and 1986-1989 (California black rail).

During these surveys, California clapper rails were detected from several locations at Rush Ranch including 1st and 2nd Mallard Branches and Cutoff Slough. Between 3 and 25 individuals were detected each survey year, with populations slightly higher in the winter, implying post-breeding dispersal from other portions of the estuary (Harvey 1980, Evens and Collins 1992, Collins et al. 1994). Variability in population sizes may be related to fluctuations in salinity and associated vegetation (Albertson and Evens 2000), but it may also be due to irregular colonization and extinction events in these small outlier habitat fragments in the regional meta-population, as well as survey variations and overall detectability of this cryptic species.

Surveys for California black rail conducted in and around Rush Ranch in the same areas surveyed for clapper rails indicated that California black rails are moderately to highly abundant: 0.65 – 1.90 rails per hectare (Evens et al. 1989; Nur et al. 1997). Habitat associations at Rush Ranch and other areas in Suisun Bay included higher marsh elevation, and denser vegetation associated with freshwater influence, particularly stands of *Schoenoplectus* spp. (Evens et al. 1989).

13.4 PRBO Conservation Science Tidal Marsh Bird Project, 1996 – 2007

PRBO Conservation Science initiated a regional program for the study of tidal marsh breeding birds in 1996 that has become one of PRBO's long-term data collection efforts in the western United States (Nur et al. 1997). Rush Ranch was chosen as one of the sites representative of Suisun Bay tidal marsh habitat, and was a reference marsh used as a comparison with tidal marsh restoration sites in several studies in Suisun Bay (Nur et al. 1997, 2003, 2004, 2005). Studies conducted at Rush Ranch have included standardized point count surveys conducted during the breeding season, and for some years also during winter and migration periods (breeding season 1996 – 2007, winter 2002-2003; Spautz et al. 2003, Liu et al. 2007), standardized surveys for black rail (2001-2002; Spautz and Nur 2002, Spautz et al. 2005), and nest monitoring (1996 – 2006; Spautz et al. 2001, Chan et al. 2002, Abbaspour et al. 2005a, 2005b, Liu et al. 2007). Most of these studies included collection of vegetation and other habitat characteristics in the field, and/or generation of landscape characteristics based on analysis of aerial photography using a Geographic Information System (GIS) for the development of statistical models of habitat selection. These models were developed to identify factors that may be useful in predicting bird distribution, abundance, and reproductive success, and ultimately, to help inform tidal marsh habitat restoration efforts in Suisun Bay and the San Francisco Estuary as a whole (Nur et al. 1997, Chan et al. 2002, Spautz et al. 2003, Spautz and Nur 2004, Spautz et al. 2006).

At Rush Ranch, standardized point count surveys were conducted for all bird species at 10 – 20 stations placed at least 107 m apart in tidal marsh habitat (Nur et al. 1997, Liu et al. 2007; Figure 1). Density indices for all species varied greatly across years at Rush Ranch, as well as in the rest of Suisun Bay and throughout the estuary from 1996-2006 (Liu et al. 2007, Pawley and Nur in prep.). Suisun Bay had the highest density indices for common yellowthroat (approximately 1 to 2.5 birds per ha) and marsh wren (approximately 1 to 4 birds per ha) between 1996 and 2006, relative to the estuary as a whole (including San Pablo Bay and San Francisco Bay; common yellowthroat: < 0.5 birds per ha; marsh wren: < 3 birds per ha; Pawley and Nur in prep). This is likely related to the strong association of these two species for the generally taller vegetation found in brackish tidal marshes (such as those in Suisun) rather than the shorter vegetation typical of more saline marshes in other portions of the estuary. Plant associations in Suisun include cattail (*Typha* spp.), various tule species, primarily alkali bulrush (*Schoenoplectus maritimus*) and three-square (*S. americanus*), and perennial pepperweed (Nur et al. 1997, Spautz and Nur 2004, Spautz et al. 2006). Research has shown a positive trend between common yellowthroat presence and the presence of perennial pepperweed, while for other bird species the association with pepperweed is probably neutral or only mildly positive (Spautz and Nur 2004).

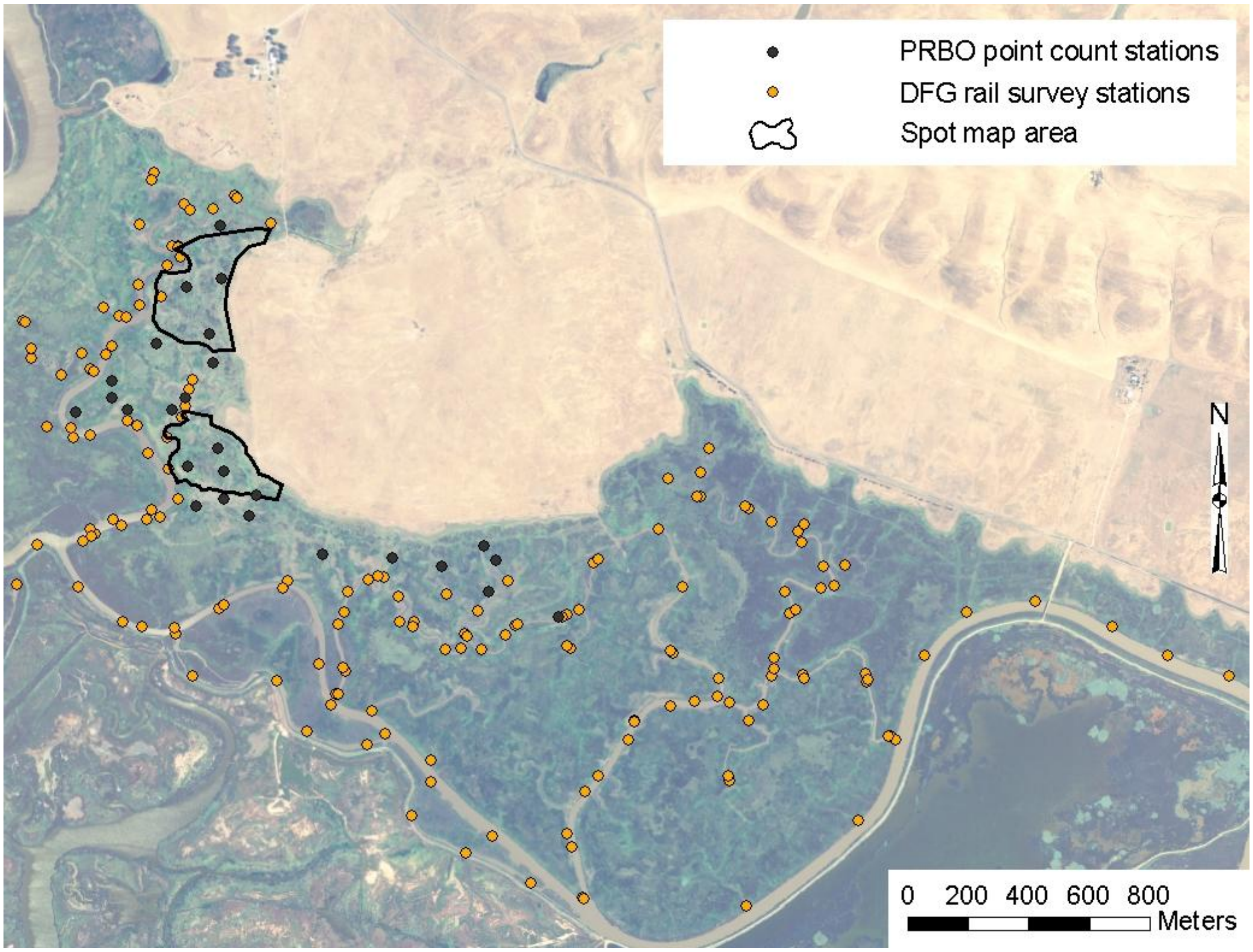

Figure 1. Map of Rush Ranch study areas. Density indices for Suisun song sparrow in Suisun Bay were approximately mid-way between San Pablo populations (Samuel's song sparrow, M. m. samuelis*) and San Francisco Bay populations (Alameda song sparrow,* M. m. pusillula*; Liu et al. 2007, Pawley and Nur in prep). From 1996-2006, song sparrow density indices ranged from approximately 3 to 7 birds per ha in Suisun, approximately 5 to 8 birds per ha in San Pablo Bay, and 2 to 6 birds per ha in San Francisco Bay. Habitat associations for song sparrows throughout the estuary included the proportion of shrubs (marsh gumplant,* Grindelia stricta*, and coyote brush,* Baccharis pilularis*, neither of which are as common in Suisun Bay as they are in more saline areas), proportion of surrounding natural upland, and proximity to upland edge (Spautz et al. 2006). There has been a statistically significant downward trend in song sparrow density at Rush Ranch and Suisun as a whole (-3.5 %; Pawley and Nur in prep; Figure 2). In San Pablo Bay there is a downward trend as well, although it is not statistically significant, while in San Francisco Bay the trend is positive (+ 4.1%), although it is marginally statistically significant (p = 0.07; Pawley and Nur in prep.).*

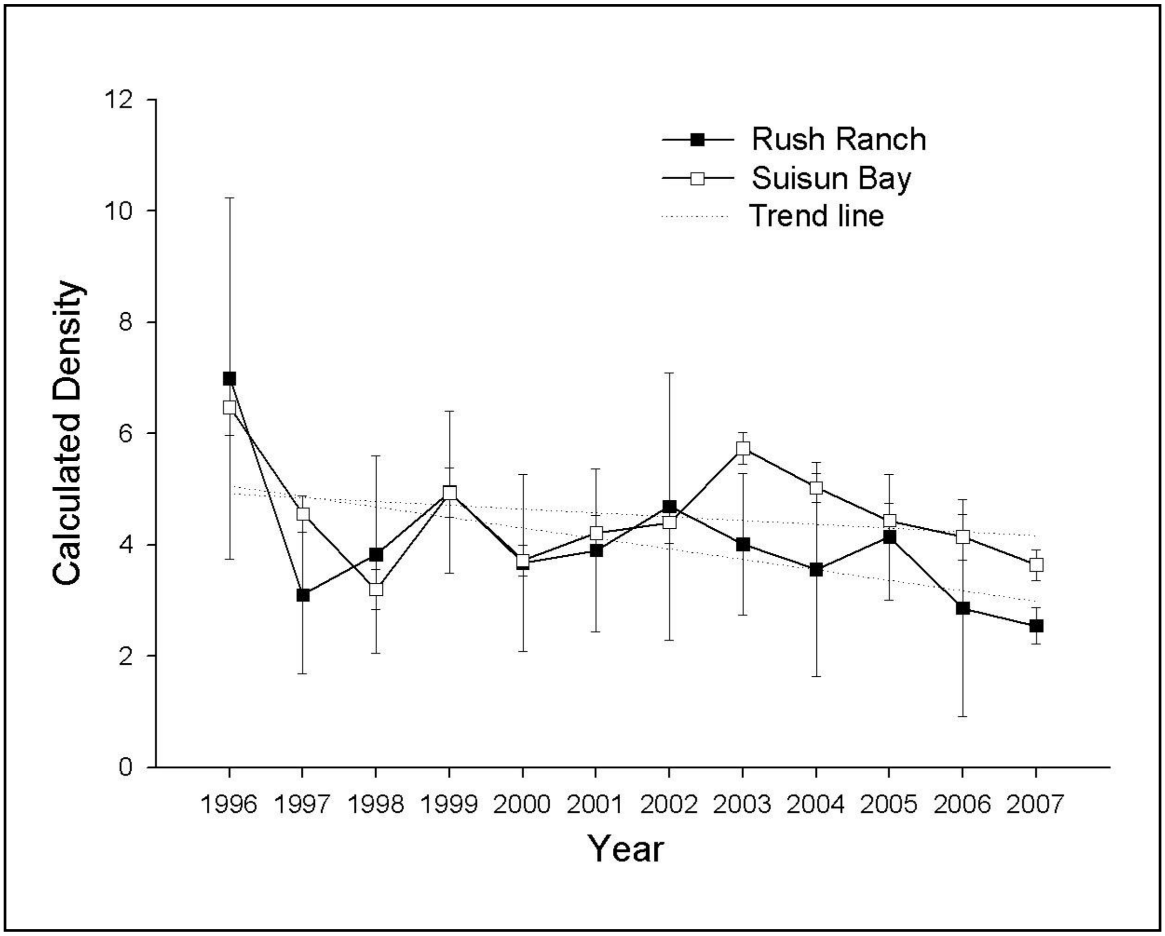

Figure 2. Suisun song sparrow density trends. Rush Ranch and all sites in Suisun Bay, 1996 – 2007 (PRBO unpublished data).

Abundance of California black rail was 0.85 birds/ha in 1996 (Nur et al. 1997) and 0.97 birds/ha in 2001 (Spautz and Nur 2002). In an earlier study in the same area of Rush Ranch, abundance was somewhat lower: 0.65 birds/ha (Nur et al. 1997). Habitat associations for California black rail, from an analysis of data for the entire Estuary, included higher proportion of vegetation cover (all plant species), higher channel density, proximity to channels, proximity to the next closest marsh patch (a measure of patch isolation), and the proportion of natural upland in the surrounding area (Spautz et al. 2006). The correlation of black rail density with marsh size (i.e., more rails per ha in larger marshes) was significant in one study (Spautz and Nur 2003), but not significant in another study (Nur et al. 1997).

Intensive nest monitoring at Rush Ranch from 1996 - 2005 has produced data for several hundred Suisun song sparrow nests (Figure 3). Each year a few nests of other species were found, including those of common yellowthroat, marsh wren, black rail, red-winged blackbird, and northern harrier (*Circus cyaneus*). Song sparrow nests have been found in virtually every type of plant at Rush Ranch, the most common being *Schoenoplectus* spp. (41%) and perennial pepperweed (13%) (Spautz and Nur 2004, PRBO unpublished data). There was no indication that nests built in pepperweed had a failure rate that was different from nests built in other vegetation (Spautz and Nur 2004). California black rail nests were most commonly built in *S. americanus* (n = 2; Spautz and Nur 2002).

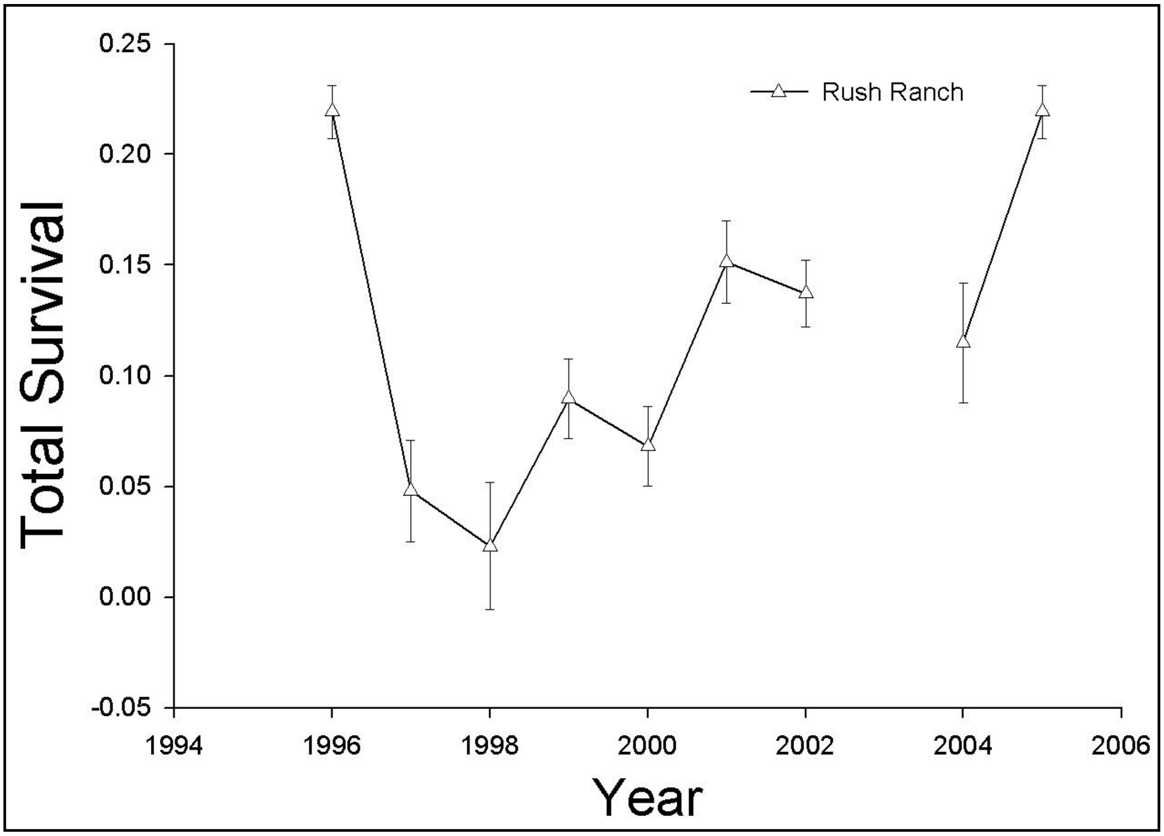

Figure 3. Suisun song sparrow nest survivorship trends. Rush Ranch, 1996 – 2006 (PRBO unpublished data).

During nine years of nest monitoring studies (1996-2002, 2004, and 2006), song sparrow annual nest survivorship was lower at Rush Ranch than at any other site monitored for four years and lower than the average of all sites for the remaining five years (Liu et al. 2007). High predation rates were the main cause of nesting failure (Spautz and Nur 2004, Greenberg et al. 2006). Predation was also the most common fate of song sparrow nests in other parts of the estuary, although at other tidal marsh study sites a moderate proportion of nests were also lost to flooding during high tides; these sites have greater tidal ranges, and a higher likelihood of tidal flooding on the marsh plain (Greenberg et al. 2006). For tidal marsh breeding birds, including song sparrows in the San Francisco Estuary, there is a trade-off between loss of nests to predation and flooding by high tides: nests built higher off the ground are depredated more often than nests built lower to the ground, but if they are lower to the ground they are more likely to be lost during high tides (Spautz et al. 2004, Herzog et al. 2005, Greenberg et al. 2006).

Potential nest predators at Rush Ranch include mammals (particularly rodents), snakes, and northern harrier. One hypothesis for higher predation rates at Rush Ranch than at other sites studied is that the combined factors of higher vegetation and reduced tidal inundation rates (relative to more saline marshes closer to the Golden Gate) contribute to small mammalian predator populations that are not periodically inundated, and thus are not kept in check. However, this hypothesis has not been tested.

We do not know how the increase in perennial pepperweed is impacting the ecology of Rush Ranch, nor do we know the ramifications of the possible affinity for it demonstrated by common yellowthroats. For example, we do not know whether spatial and temporal differences in plant structure and plant species makeup are impacting (directly or indirectly) other species that are part of the food web, and how those differences might be affecting food availability, vulnerability to predation, and overall survivorship for yellowthroats and other bird species. A NERR-sponsored study is currently underway at Rush Ranch to examine differences in the food web between areas that have and have not been invaded by perennial pepperweed (Whitcraft unpubl. data). This study has been expanded to include birds, and results are expected in 2011.

13.5 CDFG Rail Surveys, 2002 – 2008

The California Department of Fish and Game (CDFG) Bay-Delta Region has conducted breeding season (January-May) call-count surveys for the California clapper rail in Suisun Marsh annually from 2002 to 2008 (CDFG 2002-2008b; Figure 1).

In 1981, the U.S. Fish and Wildlife Service (USFWS) issued a Section 7 Biological Opinion (BO) for the implementation of the Suisun Marsh Plan of Protection (California Department of Water Resources (DWR) 1984, USFWS 1981). In the BO, the USFWS included recommendations for monitoring existing California clapper rail populations every three years and for increasing potential habitat. Following a 1994 survey by DWR and CDFG for a biological assessment (BA), construction and maintenance activities in some areas of Suisun Marsh became restricted at certain times of the year based on breeding season detections (USFWS 1994). These areas were designated: Rush Ranch (Spring Branch), Joice Island, Mothball (Reserve) Fleet (Benicia), Cutoff Slough (including 1st and 2nd Mallard Branches), and Hill Slough. Both the Rush Ranch location and the Cutoff Slough location are within the boundaries of Rush Ranch. From 2002-2008, the areas sampled by CDFG consisted of these five areas where California clapper rails were last known to have breeding sites. The goal was to re-document presence in these areas. In addition to these areas, sampling took place in areas where populations may occur based on suitable habitat or past breeding-season or non-breeding-season detections. Survey locations varied from year to year.

Most listening stations were established every 200 meters (depending on marsh characteristics) along waterways in, or adjacent to, marsh areas. Additional stations were located at the same intervals along marsh features such as existing trails, levees, or roads. These features were chosen to minimize observer impact on intact marsh vegetation and disturbance to rails.

Surveys were conducted using standardized breeding season call count methods for California clapper rail, which included a passive listening phase followed by the broadcast of a taped call (USFWS 2005). Calls from California black rail, Virginia rail (*Rallus limocola*) and sora (*Porzana carolina*) were also recorded.

As few as seven clapper rails were detected during these breeding season surveys in Suisun Marsh in seven survey years; however, eight were detected in fall by clapper rail biologists during other field studies. In the breeding season, two were within Rush Ranch and five were elsewhere. In fall, six were within Rush Ranch and two were elsewhere.

During the passive listening phase, the three other rail species were recorded. California black rails were less vocal early in the year, reaching a peak in April (Figure 4). By contrast, Virginia rails and soras were most often detected in January and February (Figures 5 and 6).

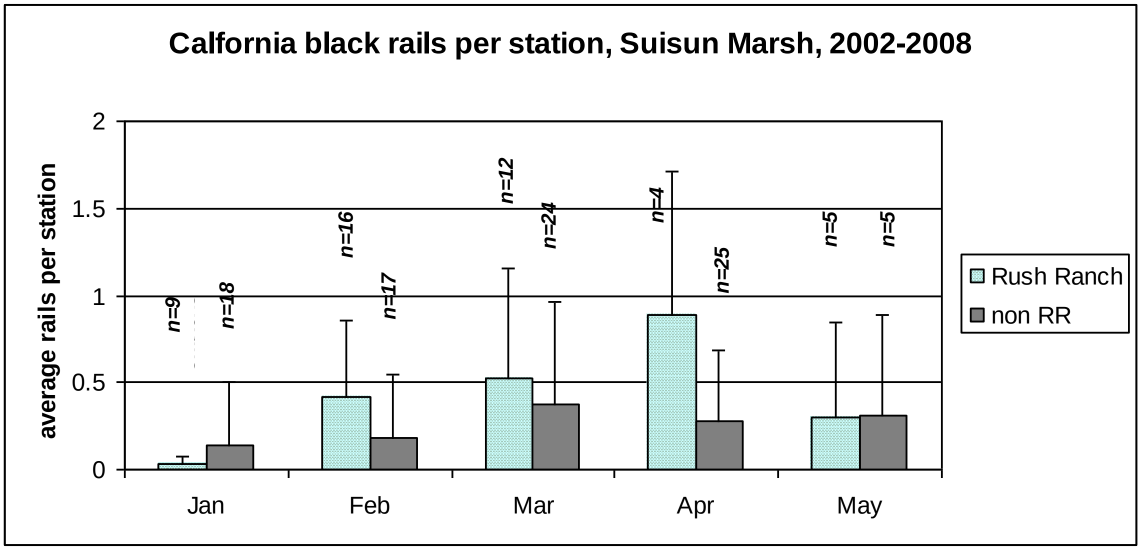

*Figure 4. Average number of California black rails (*Laterallus jamaicensis coturniculus*) detected per CDFG survey station from 2002 to 2008 at Rush Ranch locations and non- Rush Ranch locations in Suisun Marsh.*

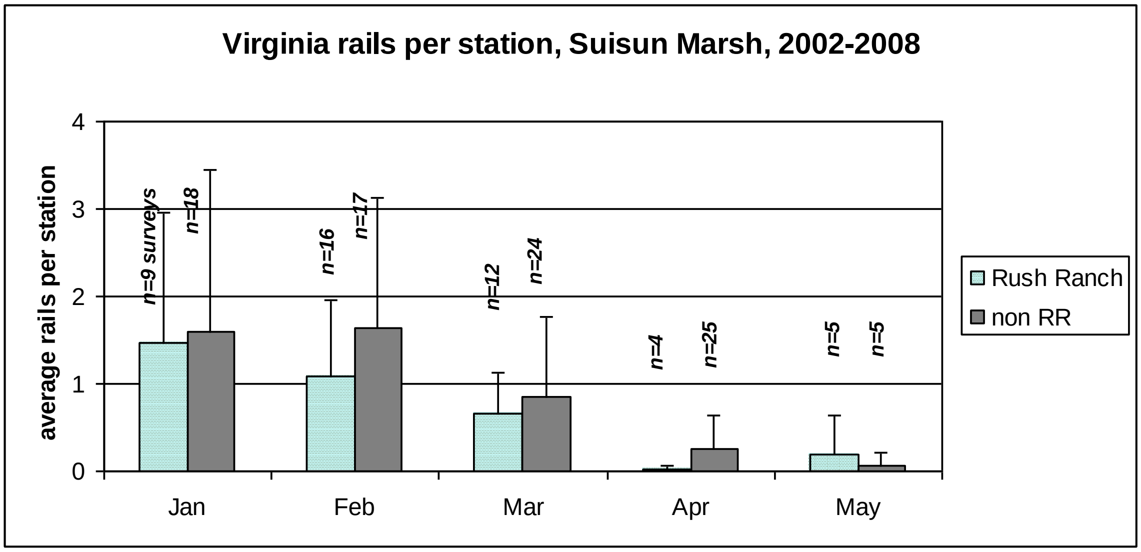

*Figure 5. Average number of Virginia rails (*Rallus limocola*) detected per CDFG survey station from 2002 to 2008 at Rush Ranch locations and non- Rush Ranch locations in Suisun Marsh.*

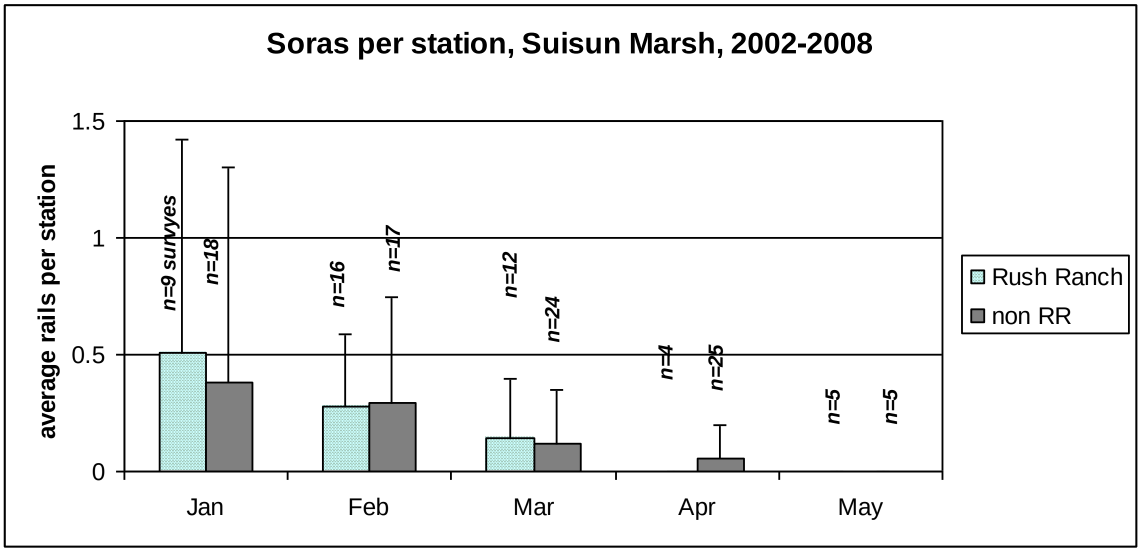

*Figure 6. Average number of soras (*Porzana carolina*) detected per CDFG survey station from 2002 to 2008 at Rush Ranch locations and non- Rush Ranch locations in Suisun Marsh.*

The Wildlife Habitat Data Analysis Branch (WHDAB) of CDFG conducts periodic vegetation surveys of the Suisun Marsh north of the Solano County line. The process uses aerial photograph interpretation in conjunction with ground verification, and geographic information systems (GIS) editing and processing. According to the photo interpretation, California clapper rails in Suisun Marsh were found primarily in vegetation which includes silverweed (*Potentilla anserina*), tule (*Schoenoplectus acutus* var. *occidentalis*), threesquare, California bulrush (*S. californicus*), and cattails (*Typha* spp.: CDFG 2000, 2004b).

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14. Mammals of China Camp State Park and Rush Ranch Open Space Preserve

Howard Shellhammer

San Jose State University and H. T. Harvey and Associates
Los Gatos, CA
hreithro@pacbell.net

ABSTRACT

China Camp State Park is primarily a forested area with a fringing saline marsh while the Rush Ranch Open Space Preserve has large brackish marshes backed by grass-covered hills. The emphasis of this chapter is on small mammals common to both areas, i.e. endangered salt marsh harvest mice and several rare shrews. Both China Camp and Rush Ranch contain significant stretches of intact marsh-upland ecotone that provide refuge for small mammals during periods of high water. This refuge habitat will become even more important as accelerating sea level rise increases marsh inundation and reduces other available cover. Future efforts to conserve populations of salt marsh harvest mice and shrews around San Francisco Bay should focus on protection and expansion of the marsh-upland ecotone.

14.1 Introduction

China Camp State Park and Rush Ranch Open Space Preserve are components of the San Francisco Bay National Estuarine Research Reserve. While both areas contain marshes they are quite different in their overall plant cover. China Camp is predominately a forested area in the hills of the Marin Peninsula and is located on the saline San Pablo Bay while Rush Ranch is composed of marshes and grasslands located on the more brackish Suisun Bay. The objective of this chapter is to summarize what is known and what needs to be known about terrestrial mammals that live at each site. The mammals of the two areas are listed in Table 1. Some of the smaller mammals, especially the endangered salt marsh harvest mouse (*Reithrodontomys raviventris*) and several rare shrews (*Sorex* spp.), will be discussed in considerable detail in the sections on the two areas.

Table 1. Land Mammals of China Camp State Park and Rush Ranch

Genus/Species	Common Name	China Camp[1]	Rush Ranch	Status[2]
Didelphis virginiana	Virginia opossum	+	+	***
Sorex vagrans sonomae	Fog shrew	+		
Sorex trowbridgii	Trowbridge’s shrew	+		
Sorex ornatus californicus	Ornate shrew	+	+	
Sorex ornatus sinuosis	Suisun shrew	+		
Scapanus latimanus	Broad-footed mole	+	+	
Tadarida braziliensis	Brazilian free-tailed bat	+		
Eumops perotis	Western mastiff bat		+	
Antrozous pallidus	Pallid bat	e	+	
Plecotus townsendii	Lump-nosed bat		+	
Corynorhinus townsendii	Townsend’s big-eared bat	e		
Eptesicus fuscus	Big brown bat	e	+	
Lasiurus blossevilli	Western red bat	e	+	
Lasiurus cinereus	Hoary bat	e	+	
Lasiurus noctivagans	Silvery-haired bat	e	+	
Pipistrellus hesperus	Western pipistrelle		+	
Myotis californicus	California myotis	e	+	
Myotis evotis	Long-eared myotis	e	+	
Myotis leibii	Small-footed myotis	e	+	
Myotis lugifugus	Little brown myotis	e	+	
Myotis thysanodes	Fringed myotis	e	+	
Myotis volans	Long-legged myotis	e	+	
Myotis yumanensis	Yuma myotis	e	+	
Lepus californicus	Black-tailed jackrabbit	+	+	
Sylvilagus audubonii	Audubon cottontail	+	+	
Erethizon dorsatum	Porcupine	+		

Table 1. Land Mammals of China Camp State Park and Rush Ranch

Genus/Species	Common Name	China Camp[1]	Rush Ranch	Status[2]
Thomomys bottae	Botta's pocket gopher	+	+	
Microtus californicus	California vole	+	+	
Mus musculus	House mouse	+	+	***
Neotoma fuscipes	Dusky-footed woodrat	+		
Ondatra zibethicus	Muskrat	+	+	
Peromyscus maniculatus	Deer mouse	+	+	
Peromyscus boylii	Brush mouse	+		
Peromyscus truei	Pinyon mouse	e		
Rattus norvegicus	Norway rat	+	+	***
Rattus rattus	Black rat	+	+	***
Reithrodontomys megalotis	Western harvest mouse	+	+	
Reithrodontomys raviventris	Salt marsh harvest mouse	+	+	
Sciurus griseus	Western Gray squirrel	+	+	
Sciurus niger	Eastern fox squirrel		+	
Tamias sonomae	Sonoma chipmunk	+		
Spremophilus beecheyi	California ground squirrel	+	+	
Dipodomys heermanni	Heermann kangaroo rat	+		
Canis latrans	Coyote	+	+	
Canis domesticus	Domestic and feral dog	+	+	***
Urocyon cinereoargenteus	Gray fox		+	
Vulpes vulpes	Red fox	+		***
Felis silvestris	Domestic cat and feral	+	+	***
Puma concolor	Mountain lion	e		
Lynx rufus	Bobcat	e	+	
Mephitis mephitis	Striped skunk	+	+	
Spilogale putorius	Spotted skunk	+	+	
Lutra canadensis	River otter	+	+	
Mustela vison	Mink		+	
Mustela frenata	Long-tailed weasel	+	+	
Castor canadensis	Beaver		+	
Taxidea taxus	Badger	+	+	
Procyon lotor	Raccoon	+	+	
Odocoileus hemionus columbianus	Black-tailed deer	+		
Sus scrofa	Wild pig	+	+	***

[1] expected, [2] non-native species

Neither of the two areas has a list of documented mammals. The nearest park or management unit with a mammal list to China Camp is Point Reyes National Seashore (http://www.nps.gov/pore/naturescience/mammals.htm) and while it is on the other, i.e., the western, side of the Marin Peninsula, that list offers some idea of what mammals can be found in China Camp. Based on that list and the type of vegetation present at China Camp, a number of the mammals listed for China Camp in Table 1 are listed as "expected". A similar situation exists for Rush Ranch. A list of mammals has been prepared by the Suisun Marsh Natural History Association and is available online (http://www.suisun.wildlife.org/mammal.html). It is assumed that the mammals on that list are present on Rush Ranch especially since the ranch has a small grove of eucalyptus trees and several barns or barn-like buildings. Those structures make it likely that the bats listed for the area on Table 1 can be found at Rush Ranch, at least occasionally.

It is likely that some of the mammals listed in Table 1 are not common in the two areas, and this is especially the situation with the shrews. Only one species of mammal, however, is listed as endangered by both California Department of Fish and Game and the U. S. Fish and Wildlife Service, and that is the salt marsh harvest mouse.

14.2 China Camp State Park: Unique marshes, a changing forest and a dearth of information.

Mammals of the park

While the marshes of China Camp State Park are somewhat unique the forests of the park are very much like those in other parts of the Marin Peninsula. Most of the 1,640 acre park is made up of hillsides covered with mixed evergreen forest, oak woodland, and chaparral plus some native grassland. The upper portion of the park is a ridgeline covered by mixtures of chaparral and dry woodland containing manzanita, madrone, coast live oak and California black oak. The forests and other upland areas provide habitats for a diversity of mammals while the marsh provides the home for an endangered mouse and a rare shrew (see Table 1).

The changing forests of China Camp

The forested areas at China Camp are complex and diverse and they support a considerable variety of mammals. The forest of the park is changing, however, with the advent and spread of Sudden Oak Death (SOD) within it. Tempel, Tietje and Winslow (2006) and Tempel and Tietje (2005) studied the risk to small mammals and other species of SOD in San Luis Obispo County but there are not any published studies on the actual effects of SOD on mammals in China Camp. If many of the oaks die in China Camp the small mammals that eat acorns as part of their diet likely will decline in numbers and the carnivores that prey on those small mammals will also decline. Apigian et al. (2005) studying SOD in nearby Sonoma county suggested that the response to SOD by small mammals in coastal live oak woodlands in the San Francisco Bay Area may be varied, e.g., with wood rats being found only in the most heavily affected sites while the apparent response of deer mice and related species was varied. Deer mice were most common in heavily affected sites while Pinyon and brush mice were more common is less affected sites. The authors, however, noted that the apparent patterns of abundance could have been caused either by aspects of the SOD damage or to factors unrelated to

SOD. It is also likely that without the larger trees in the forest many of the bats now present in China Camp's forest will move elsewhere with concomitant changes in the numbers and diversity of insects. The impact of SOD is very heavy in some portions of the park. What the actual effects of SOD on China Camp will be in the longer run await time and scientific study.

The marshes of China Camp

The marshes of both China Camp and Rush Ranch are of special interest to the author because they contain the only endangered mammalian species in either area, i.e., the salt marsh harvest mouse, as well as several rare to very rare shrews. Much of the discussion of the marshes of both China Camp and Rush Ranch will concentrate on these species.

The marshes of China Camp are more or less unique in that they have transition areas connecting them to the grasslands above them and there are few other marshes around the San Francisco Bay that (1) have grassland adjacent to them and (2) have an ecotone between the highest zone of the marsh and the grassland. There are three primary regions of marsh separated from one another by Turtleback Hill and Chicken Coop Hill. For the location of these features and others at China Camp see the map on the California State Parks website (http://www.parks.ca.gov/). There is a wide, broad marsh with an extensive marsh plain that extends north and westward from Turtleback Hill to beyond the mouth of Gallinas Creek to the west. A second and smaller marsh is between Turtleback Hill and Chicken Coop Hill with the smaller Bullet Hill located between them. The third of the primary marshes extends east from Chicken Coop Hill and disappears before Buckeye Point. There are a few very small pocket marshes to the east of Buckeye Point but beyond the park boundaries there are no marshes around San Pedro Point and westward to the northeastern suburbs of San Rafael. This break in marshes between China Camp and the marshes east of Larkspur (and south of the Corte Madera Channel) is significant in the case of the salt marsh harvest mouse (SMHM). The more southern subspecies of this endangered species (*Reithrodontomys raviventris raviventris*) occurs south of the break and the northern subspecies (*R. r. halicoetes*) occurs to the north.

There has been some trapping for SMHM in the marshes in or near China Camp but it has not been either recent or extensive. The oldest trapping records are those of George Fisler, who did a major study of the SMHM in the early 1960s and wrote the monograph on the species (Fisler 1965). He trapped the southern, or *raviventris*, subspecies as far north as the marshes east of Larkspur, in what is today the Corte Madera Marsh Ecological Reserve. The farthest south he trapped in the range of the northern, or *halicoetes*, subspecies was on the south side of Gallinas Creek at its mouth, a point approximately a half mile to the west of the western boundary of the park. He captured 24 SMHM at the Gallinas location but he did not indicate the trap effort.

The park or the marshes near the park have been trapped three times. Cummings (1975) trapped in the general vicinity where Fisler trapped in 1965, i.e., the south side of Gallinas Creek and somewhat east of the mouth, but he captured just one SMHM in 100 trap nights, a trap night being one trap set for one night. Shellhammer and Simons

(1980) trapped in the marsh off the northeast side of Turtleback Hill and captured 2 SMHM in 200 trap nights.

The character of the marsh extending from the mouth of Gallinas Creek eastward to the park at the west side of Turtleback Hill is, as mentioned previously, almost unique around the San Francisco Bay as it exists today, so it seems unusual that so few SMHM have been captured there since the area was trapped by Fisler in1965. Little is known about SMHM populations in the China Camp marshes in the 2000s but it is likely that the large marsh extending westward from Turtleback Hill is still a productive habitat for SMHM. It is also possible that some SMHM move occasionally from that marsh into the two marshes in China Camp east of Turtleback Hill.

Although the Gallinas Creek/China Camp marsh is wide and broad in comparison with the smaller marshes within the park, most all of them are bisected by North San Pedro Road which limits marsh transgression. Turtleback Hill, Chicken Coop Hill, Bullitt Hill and Jake's Island are exceptions in that they have complete marsh-upland ecotones. The transition zone between marsh and grassland is narrow and steep on the sides of the smaller pocket marshes on the bay side of the road crossing them. The two marshes on the upland side of the road have gentler slopes and broader transition zones, features needed by SMHM as escape cover (Shellhammer 1982, 1989) when tides are high. Tides flow in and out of the upper part of each of those two marshes via culvert pipes beneath the road. The road bed and its barren edge is 20 feet wide where it crosses the marshes, a barren band that is likely to preclude SMHM from crossing the road (Shellhammer 1982, 1989) and hence the only likely access to the upper portions of these marshes is through the culvert pipe. These two smaller, brackish marshes could be improved as SMHM habitat if the present culvert pipes were removed and replaced with larger openings that would allow vegetation to grow on most of their surfaces and hence allow for the movement of SMHM beneath the road for a greater part of each tidal cycle, i.e., not just when the tides are low.

Little is known of the "fog" shrew (*Sorex vagrans sonomae*) that might inhabit these marshes. Cummings (1975) reported no shrew captures nor did Fisler (1965). Shellhammer and Simons (1980) captured no shrews at China Camp in 200 trap nights but Simons captured 19 shrews of various species in 2,986 trap nights at 6 of the 20 locations he trapped in the marshes around San Pablo Bay (Simons, pers. comm.). It is assumed that shrews still exist in the China Camp marshes but only intensive trapping or fortuitous observation could verify if they are present. Trapping for shrews involves demanding trapping protocols including checking traps several times each night or using fewer, specially-designed shrew traps (e.g., those described in Hays 1998) that contain food to keep the shrews alive through the night. It is also necessary to bait the traps with baits other than those used to trap SMHM. For these reasons there is seldom the support available to trap for shrews and hence little of it is done and little is known of their presence or their numbers anywhere around the Greater San Francisco Bay.

14.3 Rush Ranch: Harvest mice and shrews in a changing marsh.

Rush Ranch Open Space Preserve is very different ecologically compared with China Camp State Park in that approximately half of its 2,070 acres is marsh and brackish rather than saline, and is a mixture of tidal, muted tidal and diked marsh conditions. The rest of Rush Ranch is composed of the Potrero Hills covered by grazed annual grasses. The only trees, mostly non-native eucalyptus, are those found around the preserve headquarters, the former home of the Rush family.

The subspecies of the salt marsh harvest mouse (SMHM) found in the Suisun Marsh, as well as the marshes of San Pablo Bay is *R. r. halicoetes.* The mouse was originally described by Dixon (1908, 1909) who described the species as being restricted to salt marshes and primarily to areas of pickleweed (*Sarcocornia pacifica*). Fisler (1965) indicated that the *halicoetes* subspecies was found in both salt and brackish marshes, although the brackish marshes he trapped were described as being "characterized by the presence of the cattail (*Typha latifolia*) and several species of *Scirpus. Salicornia* and *Distichlis* are found in depressed areas, which are scattered throughout the marshes even to the landward edges…Natural and artificial levees support growth of *Grindelia cuneifolia* and *Baccharis pilularis*"**.** That expectation as to the preferred habitat of the mouse being primarily saline vegetation continued until the late 1990s when approximately 1,300 acres of SMHM conservation areas were established in the Suisun Marsh on California Department of Fish and Game (DFG) land.

Researchers from the DFG and the California Department of Water Resources (DWR) began monitoring those conservation areas starting in 1998 and continue today. In addition to pickleweed and upland grasses, some of the vegetation in the mouse reserves, and in Rush Ranch, which they trapped in 2002, 2003 and 2004, however, was composed of a mixture of halophytes including *Atriplex triangularis, Frankenia salina, Distichlis spicata, Juncus balticus* and *Schoenoplectus americanus*. In some areas of the Suisun marsh their trapping grids were placed in monocultures or near monocultures of *Schoenoplectus* species, usually *S. americanus*, Olney's three-square bulrush. Because the trapping grids were sometimes placed in either tidal or diked areas when the soil surface was flooded, they began to place their traps within or on top of, the vegetation or thatch layer over two feet off the ground (L. Barthman-Thompson pers. comm.). They consistently trapped SMHM in these brackish vegetative conditions and have shown that SMHM use the complex stands of *Schoenoplectus americanus* as well as pickleweed and other halophytes. Their studies are summarized and analyzed in Sustaita et al. (2011). They demonstrated that the thickness and complexity of the vegetation, be it pickleweed, mixed vegetation or the layer of thatch in *Schoenoplectus* stands or in stands of *Schoenoplectus* mixed with *Juncus* , is important in promoting mouse numbers by providing cover from predators and refuge from high waters. Similarly, H. T. Harvey (2007) found SMHM in the deep thatch in mature alkali bulrush (*Schoenoplectus robustus*) in the southern-most end of the South San Francisco Bay.

Researchers at DFG and DWR often found many more SMHM in the Suisun Marsh than other investigators and trappers have found in marshes elsewhere in the greater San

Francisco Bay area. The average capture efficiency (C.E.) of SMHM for all 252 projects they carried out in the Suisun Marsh between 1998 and 2007 as calculated by the author of this chapter was 4.4 (i.e., the number of animals captured divided by the total number of traps set times 100), although some of their surveys were conducted in upland habitats where SMHM was not the targeted species. This index has been used for decades in SMHM trapping studies before modern computer-aided density estimation programs were available. The sources for these and the following capture efficiencies are their various yearly reports to their agencies and the database for SMHM trapping projects developed by the current author (Shellhammer) and available from the San Francisco Estuary Institute (http://legacy.sfei.org/ecoatlas/smhm). That database shows that most of their trapping efforts in the Suisun Marsh (in mouse conservation areas, on Rush Ranch and other State and county properties) had C.E.s below 10.0, although some were in the low 20s and one effort that yielded a C.E. of 25.0 (i.e., one mouse for every four trap nights). For comparison, the 201 projects carried out in South San Francisco Bay yielded an average C.E. of 1.4 while 74, or 36.8%, of them yielded no SMHM. Few of these projects had capture efficiencies of 10.0 or more.

During 2002, 2003 and 2004, Sustaita et al..(2011) carried out a SMHM study investigating habitat use and demography in different vegetation types. Two of the study sites were tidal, one of which was Rush Ranch, and two were managed diked areas. Three different vegetation types were trapped at each site: pickleweed dominated, mixed-wetland marsh vegetation dominated by species other than pickleweed, and upland grasses dominated. Two trap grids were located in each vegetation type at each site. They captured 648 SMHM in 9,384 trap nights carried out in the mixed-wetland trapping grids for a C.E. of 6.9. In contrast they captured 441 SMHM in 9,288 trap nights in the pickleweed-dominated trap grids for a C.E. of 4.7. The Rush Ranch capture efficiencies were comparatively lower than at most of the sites; at Rush Ranch they captured 117 SMHM in 2,352 trap nights in mixed-wetland vegetation for a C.E. of 6.9 and 59 SMHM in 2,304 trap nights in pickleweed-dominated vegetation for a C.E. of 2.6. The mixed-wetland areas in two of the three other sites had higher capture efficiencies than Rush Ranch (7.4 and 11.1), while one site was lower (C.E. 4.2), and all of the pickleweed dominated areas in the other sites were higher (3.7-6.4).

The fact that this study, as well as their annual monitoring, yielded high capture efficiencies in mixed-wetland areas within the Suisun Marsh suggests that the habitat requirements for the northern subspecies of the mouse should be modified. These results further suggest that presently Rush Ranch has valuable mouse habitat. When more trapping is done in alkali bulrush areas in the southern end of the South San Francisco Bay, we expect that perceived habitat requirements for the southern subspecies of the mouse will also be modified.

Much has been learned about SMHM use of various habitats because of the DFG and DWR trapping studies, and specifically Sustaita et al. (2011), but there are aspects that still need to be examined. For example, relatively little is known about the feeding ecology of SMHM. Fisler (1965) suggested that mice of the two SMHM subspecies will eat seeds but “prefer a great amount of either green or dry vegetation”. He suggested that they will eat salty vegetation while the upland *R. megalotis*, the western harvest mouse, will not. Little more is known about the breadth of their diets other than the statement by Fisler (1965) that "the three forms will eat a variety of food natural to their habitat as well as many artificial foods". We assume that the SMHM at Rush Ranch eat parts of various *Schoenoplectus* species and other halophytic species. Barthman-Thompson (pers. comm.) noted that SMHM were captured repeatedly in stands of *Schoenoplectus*, and sometimes a hundred yards or more in one night from patches of pickleweed, suggesting that mice were not moving back to areas of pickleweed to eat, instead eating the vegetation of bulrushes and other brackish species.

Suisun Shrews

Suisun shrews have been found historically in tidal and brackish marsh communities from Sonoma Creek in Sonoma County to Collinsville in Solano County (Rudd 1955, Brown and Rudd 1981). Ornate shrews are found in the grasslands above tidal and brackish marshes throughout the range of the Suisun Shrew, and because the two forms are so similar externally (except for coloration) it is difficult to differentiate between these two shrews in the field. Rudd (1955) suggested that Suisun Shrews typically inhabit Pacific cordgrass (*Spartina foliosa*) and pickleweed in tidal salt marshes and bulrush species and cattails (*Typha spp.*) in brackish water marshes. Rudd noted, however, that *structure* rather than species composition of the plant community determines the preferred habitat of these shrews. He suggested that dense, low-lying, plant cover where invertebrates are abundant was optimum habitat for shrews. Rudd also suggested that driftwood and other litter above the mean high-tide line were essential for both nesting and foraging. Such litter helps maintain the moist conditions needed by the invertebrates that the shrews eat. Hadaway and Newman (1971) reported that these shrews were most often captured at the ecotone between marshes of pickleweed and upland levees vegetated by coyote brush (*Baccharis* spp.) and grasses. In that sense Suisun shrews have problems similar to the salt marsh wandering shrew (*Sorex vagrans halicoetes*) found in the southern parts of the San Francisco Bay as the latter shrew needs increasingly rare marsh areas that are not flooded on a regular basis by tidal waters (Johnston and Rudd 1957, Goals Project 2000). In addition to the great loss of marshes over the last century there has been a dramatic reduction in both the width of most tidal marshes (i.e., from upper edge to mudflats) and in the loss or great reduction in the breadth of the zones of vegetation within those marshes. This latter phenomenon is much more obvious in tidal salt marshes, which historically had a low marsh zone of cordgrass, a middle zone of pickleweed and an upper zone of peripheral halophytes that blended into the grasslands above the marshes (Shellhammer 1982, 1989). In most of the San Francisco Bay today, and especially in the South San Francisco Bay, diking and filling of marshes has reduced the middle zone by half or more and reduced the upper zone from a band between hundreds of meters to as much as two kilometers wide to a band of two meters or less. The grasslands above the marshes and the ecotone between the marshes and grasslands have disappeared along almost the entire edge of the San Francisco Bay (Shellhammer 1982, 1989). There is little to no escape cover of almost any kind remaining and little to no litter or debris. Hence both the vagrant shrew and Suisun shrew have suffered greatly.

Trapping for marsh-dwelling shrews is not the same as trapping for SMHM, i.e., SMHM traps are not necessarily placed in the most appropriate locations for shrews nor are they baited appropriately to attract shrews. There have been, however, a few studies of Suisun shrews carried out in the northern Suisun Bay in the 1980s. Williams (1983) trapped along 26 transects in the Grizzly Island area using pitfall traps and captured fifteen house mice and one ornate shrew. Another shrew was found dead near one of the trapping transects. Hays and Lidicker (2000) were much more productive as they captured 161 shrews in the marsh ecotone in the southern portion of Rush Ranch in 1989 and 1990. They used a custom made live trap that reduced trap mortality to 1% (Hays, 1998). Their study area was dominated by pickleweed, jaumea (*Jaumea carnosa*), saltgrass, arrowgrass (*Triglochin maritinum*), perennial peppergrass (*Lepidium latifolium*) and dodder (*Cuscuta salina*) and was located between ungrazed annual grassland and undiked tidal marsh. Their study area was located in the center of a marsh ecotone that was 20 to 70 m wide and about 8 km long at the time of the study. It was flooded completely only a few times a year but remained moist throughout the period of their study. The plants of their trapping area formed a dense layer of matted vegetation that was riddled with runways most likely created by California voles. The tidal marsh below the ecotone was 100 to 500 m wide and dominated by bulrushes, arrowgrass and jaumea. The other common species of small mammal in their study area was the SMHM.

In summary it appears that Suisun shrews may be rare in some parts of their range but potentially more common in much of the marsh ecotone of Rush Ranch. It is likely the low numbers in other parts of their range are due to the lack of appropriate habitat, which is still decreasing in the South San Francisco Bay (Shellhammer 1982, 1989). The vegetative conditions of the Rush Ranch ecotone favor Suisun shrews. Maintaining an adequate band of ungrazed grassland above the ecotone is important as it is the home of the closely-related ornate shrew, with which the Suisun shrew can interbreed. Hays and Lidicker (2000) note that "interbreeding with the subspecies californicus may be caused by invasion of the marsh by this upland form, and not the reverse. It may be that provision of adequate upland and marsh habitats permits co-existence of both shrews with minimal contact between them". The combination of extensive marsh ecotone and a wide band of ungrazed annual grassland above it are extremely rare. The maintenance of these two bands of vegetation at Rush Ranch is therefore extremely important.

The changing environment

While Rush Ranch is presently a productive area for SMHM there are potential changes that may reduce mouse numbers in the future. One change is the increasing coverage by perennial peppergrass. H. T. Harvey (2007) found SMHM in mixtures of peppergrass and alkali bulrush but the patch sizes of pure peppergrass were small enough even in areas dominated by this species to make it difficult to ascertain if the mice were consistently using pure stands of peppergrass for extended periods of time. The same general situation appears to be the case at Rush Ranch. Peppergrass has spread throughout the brackish portions of the southern part of the San Francisco Bay and is expanding rapidly at Rush Ranch. The density and area covered by peppergrass varies yearly but the direction has consistently been towards increased coverage. Studies are needed to find out if SMHM and Suisun shrews use large monocultures of peppergrass on a regular basis.

The other factor that bodes ill for both the mice and the shrews is sea level rise due to world climate change. Mean sea level in the San Francisco Bay is predicted to rise at least an additional 1.0 to 1.4 meters by the year 2100 (Cayan et al. 2009). Even a 0.5 m rise in sea level will likely be devastating to SMHM as most all of the marshes in the region, including one area at Rush Ranch, are backed by steep-sided dikes. The diked marsh at Rush Ranch has extensive uplands above it as do the tidal marshes along the southern border of the property. This is not the case, however, in most of the Suisun Marsh where roads and houses restrict the upward movement of marshes. As sea levels rise dikes will have to be raised and for economic restrictions it is likely that the new dikes will be just like the present ones, only higher, i.e., steep-sided dikes that are initially barren of vegetation. The new dikes will likely provide even less escape cover from tides for the salt marsh harvest mice or habitat for Suisun shrews. The diked marshes of Rush Ranch and the rest of the Suisun Marsh, however, may have an increasingly important role with respect to SMHM in a warmer world with higher sea levels. Barthman-Thompson and Quickert found high numbers of SMHM in diked, brackish marshes where water management has been effectively practiced. As sea levels rise, and if they rise slowly and do not rise more than about a meter, then the diked brackish as well as diked saline marshes throughout the San Francisco Bay are likely to become increasingly more important refugia for the mice. Should a more catastrophic sea level rise occur, it will be likely that much to most of the Suisun Marsh and most of the Suisun shrews will disappear while SMHM will decrease in numbers and distribution.

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15. Ecological Issues and Challenges Facing the San Francisco Bay National Estuarine Research Reserve

Matthew C. Ferner

San Francisco Bay National Estuarine Research Reserve
San Francisco State University, Romberg Tiburon Center for Environmental Studies
3152 Paradise Drive, Tiburon CA 94920

15.1 Ecological Issues Facing the Reserve

The diversity of topics reviewed in the preceding chapters of this site profile illustrates the natural complexity of the San Francisco Estuary (SFE), the impacts of modern civilization on the estuary, and the challenges for estuarine resource management in the 21st century. Ecological issues and challenges facing the San Francisco Bay National Estuarine Research Reserve (SF Bay NERR, or Reserve) can be loosely categorized according to the nature of their origin:

> *Physical*: sea level rise; decreasing sediment supply; increasing erosion; increasing temperatures; changes in storm frequency, intensity and timing; shoreline hardening; subsidence in diked wetlands; deterioration of levees; upstream diversion of freshwater
>
> *Chemical*: ocean acidification; increasing atmospheric carbon dioxide; eutrophication (especially due to inputs of nitrogen); legacy contaminants; emerging contaminants
>
> *Biological*: invasive species; declining native species; habitat loss for special status species and migratory species; trophic collapse (e.g., pelagic organism decline); harmful algal blooms

These issues and others have been widely acknowledged as important to the SFE (e.g., Goals Project 1999, Goals Project 2010, Suisun Marsh Plan EIS/EIR 2010, The State of San Francisco Bay 2011, SFBJV 2011) and are debated and discussed annually at long-standing regional conferences run by the Delta Science Program (http://www.deltacouncil.ca.gov/science-program, formerly known as the CALFED Bay-Delta Program: http://calwater.ca.gov/), the San Francisco Estuary Partnership (http://www.sfestuary.org/pages/home.php) and the Interagency Ecological Program (http://www.water.ca.gov/iep/). The preceding chapters in this site profile reviewed the ecological status of the estuary in general and SF Bay NERR sites in particular, and elaborated on specific management issues that have not yet been adequately addressed in the region. As noted in Chapter 1, an important role of SF Bay NERR is to encourage and support scientists in addressing these management issues through coordinated research and long-term monitoring in the Reserve sites of China Camp State Park (China Camp) and Rush Ranch Open Space Preserve (Rush Ranch). Following from the Reserve's recently completed management plan (SF Bay NERR 2010), it is useful to organize the most pressing ecological concerns as they relate to the four issue areas around which specific activities of the Reserve will be organized from 2011-2016: climate change, species interactions, water quality and habitat restoration. Additional needs for research are outlined in the final section of this chapter, and periodic updates to this information can be found at http://sfbaynerr.org/.

Climate change

Climate change is affecting all of the world's ecosystems, including the SFE (Cayan et al. 2009, Kimmerer and Weaver 2010, Knowles 2010, Chapter 7). Although natural fluctuations in weather patterns and climate regimes are expected, the current pace of rapid change is driven by anthropogenic inputs of greenhouse gases to the atmosphere (IPCC 2007). In the SFE and its watershed, climate change is anticipated to cause increases in coastal flooding due to sea level rise; changes in amount and timing of rainfall, snowpack, and snowmelt; increases in air and water temperatures; and increases in acidity of the estuary's waters. Sea levels are expected to rise at least 0.5 to 1.4 meters by the year 2100 (Cayan et al. 2009), potentially rising as much as several meters in that time, and will almost certainly have severe economic impacts on the San Francisco Bay Area (Heberger et al. 2009). In addition, the sources cited above predict that snowpack within the Sierra Nevada mountains will decline and freshwater diversion by humans will increase, resulting in less freshwater entering the estuary and overall higher salinities. The associated changes in hydrodynamics are expected to affect current and wave patterns, which in turn will affect sediment transport to, within, and from the estuary. Together these changes will likely alter the structure, composition, and distribution of estuarine habitats, including the landward transgression of tidal marshes (Chapter 7). As estuarine habitats and species respond to these significant stressors and changes, the surrounding human communities will need to adapt to and mitigate the effects of climate change in multiple ways.

China Camp. Marine influences are substantial at China Camp due to its close proximity to the Pacific Ocean. During future periods of intense upwelling, acidified and corrosive water may enter the estuary and challenge calcifying organisms such as the native Olympia oyster, which is an important foundation species in the cobble and rocky intertidal habitats at China Camp. An important issue of concern regarding tidal marshes is the need for estuarine transgression to higher elevations, particularly if marsh accretion cannot keep up with sea level rise. Although the marsh-upland ecotone at China Camp is relatively intact, natural movement of the marsh is still limited by a road, as well as steep hills in some areas (Chapter 6).

Rush Ranch. Rush Ranch is further up the estuarine gradient within the brackish Suisun Marsh and is subject to additional challenges related to sea level rise. First, the brackish vegetation at Rush Ranch will experience a net increase in salinity over time, causing a shift toward marshes dominated by more salt-tolerant species (Chapter 5, Chapter 7, Appendix). This change will lead to reduced plant diversity and concomitant changes in insect diversity and food resources for higher trophic levels. Belowground productivity and rates of accumulation of organic matter are also likely to be negatively affected. Second, because the majority of Suisun Marsh has been diked and managed primarily for duck hunting, wetland subsidence and weakening of levees increase the risk of widespread flooding as sea levels continue to rise. If catastrophic flooding occurs, there would be indirect effects on Rush Ranch in terms of regional habitat loss, shifts in water quality, and changes in resource availability and population connectivity. However, gradual estuarine transgression is possible in several areas of Rush Ranch due to the gently sloping hills and lack of development in the marsh-upland ecotone and low lying grasslands.

Species interactions

Intraspecific and interspecific interactions are of central importance to the structure and function of the estuary. Species interactions influence ecological processes such as production and consumption, nutrient cycling, and habitat change. Understanding the mechanisms and implications of these interactions is a critical step toward mitigating effects of invasive species, encouraging recovery of rare or threatened species, and reducing the extent of future declines in species diversity. The relationships between native species assemblages and ecosystem function can be disrupted by non-native and invasive species, potentially in ways that cascade to multiple trophic levels. The SFE has been called the most invaded estuary in the world, and an important issue at both Reserve sites is the influence of invasive plants and animals on habitat quality, food resources for consumers, and species diversity. Most scientific work conducted at SF Bay NERR is focused to varying degrees on species interactions, and this broad category of research is likely to remain a central focus of research and monitoring into the future.

China Camp. Invasive species are a challenge for marsh management at China Camp. Perennial pepperweed (*Lepidium latifolium*) along the upland edge has been actively controlled for many years. In 2010 the first confirmed clone of invasive hybrid cordgrass (*Spartina alterniflora* / hybrid with *S. foliosa*) was discovered in the marsh. Difficulties in distinguishing native and hybrid cordgrass present serious challenges for effective detection and control of hybrids in the marsh. Common invasive invertebrates such as European green crabs also may be a problem, having the potential to alter food webs and impact native species. Conversely, China Camp is also home to two federally endangered species (California clapper rail and salt marsh harvest mouse) that rely on tidal salt marsh habitat and are reasonably well studied at China Camp (Chapter 12, Chapter 14). As with threats posed by invasive species, the direct impact of human activity in the marsh is also a serious issue for habitat integrity and protection of sensitive species like secretive marsh birds and mammals. In addition to authorized researchers and mosquito-control personnel working in the marsh, unauthorized access by visitors, classes of students, and even undocumented researchers disturbs wildlife, creates persistent trails through vegetation, and accelerates channel slumping at convenient crossing points.

Rush Ranch. Ecological impacts of invasive species are also an important concern at Rush Ranch. Perennial pepperweed has expanded throughout the tidal marsh in recent decades, displacing native vegetation and limiting suitable habitat for rare plants, secretive marsh birds and the endangered salt marsh harvest mouse (Chapter 5, Chapter 14, Appendix). The high abundance of pepperweed in the marsh is likely to have important consequences for trophic interactions as well. Additionally, grazing by cattle and horses presents another threat to marsh species, particularly in the sensitive marsh-upland ecotone. Although short periods of grazing along the marsh edge has been a common strategy for weed control at the site, grazing also can result in damage to sensitive channel banks and destruction of native vegetation. Effective management of invasive plants and domestic animals at Rush Ranch is an ongoing challenge for stewardship and management of sensitive habitats and species (e.g., Whitcraft and Grewell in press).

Water Quality

As a result of human activities and land-use decisions throughout the watershed, the quality of water in the SFE decreased dramatically in the late 1800s and despite tight pollution controls remains impaired (State of the San Francisco Bay 2011). In large part these changes have been due to sedimentation associated with the Gold Rush, development of dams, reservoirs, and canals that divert freshwater away from the estuary for irrigation and drinking water, non-point source pollution from extensive and intensive urban development and agriculture, and year-round discharge from sewage treatment plants along the estuary’s shoreline. Further water quality changes in the estuary are expected to include elevated salinities due to rising sea levels and freshwater diversion, as well as continuing inputs of nutrients and emerging contaminants through sewage outfalls and stormwater runoff.

China Camp. An adequate supply of suspended sediments to the marsh is necessary for marsh elevation to increase at a similar rate to sea level rise. Ongoing studies of sediment dynamics (deposition, erosion, accretion) in the marsh should continue in order to track marsh responses to changing sediment supply and water level. Wastewater inputs from Gallinas Creek just north of China Camp may impact the marsh. Monthly measurements in that slough have shown elevated concentrations of urea compared to water at the southern end of the site. The balance between marine and freshwater influences on water quality at China Camp is also an issue of concern. Marine influences should increase with sea level rise, potentially bringing effects of ocean acidification, but large spring storms that may become more common with climate change can reduce salinities at China Camp low enough to decimate native oyster populations.

Rush Ranch. Pollution and nutrient inputs from stormwater and wastewater are the most pressing water-quality concerns at Rush Ranch. Hypoxic events in the tidal sloughs in autumn months occasionally result in fish kills. Nitrogen loading from wastewater treatment can alter phytoplankton dynamics and, in particular, ammonium has been included in a recent analysis of toxic stressors in the northern part of the estuary (Brooks et al, in press) where Rush Ranch is located. Furthermore, grazing of horses and cattle on the uplands of Rush Ranch and an expanding landfill just upstream in the watershed also exert negative influences on water quality. Water temperature and salinity in the marsh at Rush Ranch can vary with water management practices, especially diversion of freshwater away from the estuary and Sacramento-San Joaquin Delta, and will likely shift with continuing sea level rise and climate change (Chapter 5, Chapter 7, Appendix).

Habitat restoration

Degradation and conversion of tidal marsh habitat has long been a critical issue in the estuary, and wetland restoration on various scales is reversing the trend of habitat loss. Sea level rise threatens the long-term success of these restoration projects, making it especially important to restore the marsh-upland ecotone so that estuarine transgression can occur. Contemporary large-scale restoration projects face different challenges than previous smaller-scale restorations, including uncertainties about how to manage invasive weeds on a large scale while at the same time allowing for colonization by native plants. The Reserve sites play an important role in regional restoration efforts because the remnant historic marshes at China Camp and Rush Ranch are often used as reference sites to compare functioning of the “natural” habitat with that of a restored area. Even within the Reserve, however, there are areas in need of restoration.

China Camp. Culverts at the upland edge of the marsh at China Camp are too small, restricting tidal exchange with low-lying areas further west. Raising the road along the marsh or widening the culverts would at least partially restore tidal flow to what is now a mix of brackish and freshwater wetland. A variable and often dense population of native oysters could benefit regional restoration efforts through supply of larvae, but if oyster diebacks persist to the point of preventing reestablishment then there may be benefit in restoring oysters at the site as well.

Rush Ranch. Two wetland areas are particularly attractive candidates for habitat restoration at Rush Ranch. Spring Branch Creek drains much of the adjacent uplands, including stock ponds and a large active landfill further up the watershed. Where the creek would naturally enter the tidal marsh, however, narrow culverts under an access road greatly restrict water exchange and have resulted in a mostly stagnant, freshwater wetland upslope of the culvert. The gradual elevation gradient in this small drainage area makes the site a prime candidate for estuarine transgression if tidal flow could be restored; plans for this project are currently underway (Chapter 5). Another more impacted marsh was originally diked and managed as waterfowl habitat. Now the marsh surface has subsided and invasive weeds are rampant. Restoring tidal action to the site will require substantial engineering and dredging of a new channel, but initial plans for the work have been approved (Appendix).

15.2 Operational Resources and Management Constraints in the Reserve

Important assets for both Reserve sites are regional partnerships with land owners, researchers, conservation groups, restoration practitioners, regulatory agencies and policy makers. These stakeholders play a key role in continuing conservation practices and scientific study of the marshes at China Camp and Rush Ranch. San Francisco State University, the administrative state agency for the Reserve, offers many resources in support of the Reserve’s activities, including laboratory and office space at the Romberg Tiburon Center for Environmental Studies, funding for programs and staff, vehicles and boats for accessing Reserve sites, and academic colleagues and collaborators with similar commitments to understanding the estuary and informing its conservation and management. Physical facilities at the Reserve sites are limited but include: a fishing pier, picnic areas, campground and kayak access at China Camp; and a nature center, camping and residential space, small boat, and an all-terrain vehicle at Rush Ranch. Staff from California State Parks (China Camp) and the Solano Land Trust (Rush Ranch) maintain all facilities at their respective sites, manage recreational access and use of the sites, and actively manage natural resources at the sites (e.g., through weed control). Sufficient stewardship and conservation of these sites will continue to depend on the dedication and abilities of the organizations that own and care for the properties.

Site-specific management constraints

In addition to the constraints outlined in the previous section, numerous other factors challenge and constrain natural resource management and stewardship in the Reserve. The Reserve is faced with limited funding and staff support, and the estuary as a whole is faced with an ever-growing human population, extensive shoreline development, and threats of earthquakes and large-scale oil spills. A persistent site-specific challenge in continuing effective management of natural resources at both Reserve sites is balancing the desire for acquiring more data on physical and biological processes in the estuary against the need to limit access to sensitive habitats and to minimize impacts to sensitive species.

China Camp. At the date of this publication, funding for the California State Parks is currently in jeopardy with the looming threat of park closure in summer 2012. Although park closure is not expected to limit access for research or long-term monitoring activities, any degree of closure could limit or exclude public access and greatly reduce opportunities for education and outreach. Illegal entry and use by the public also could result in deterioration of exiting trails and roads, unauthorized trail creation, accumulation of trash, and unchecked destruction of sensitive habitats. Even with the park open and fully staffed it is difficult to regulate access because of the extensive trail systems and a county road extending along the entire edge of the marsh. The finite extent of tidal wetland is regularly visited by researchers and any excursions by the public add to the impact of foot traffic, sometimes resulting in persistent trails through the marsh. Furthermore, opportunities for restoring tidal flow to the marshes with restricted tidal exchange are severely limited by the presence of the county road. The road floods with saltwater during winter high tides, and this is a problem that will only be exacerbated by sea level rise. The cost and regulatory hurdles involved with raising the road or widening the underlying culverts is a formidable obstacle to effective flood control and habitat restoration.

Rush Ranch. As the premier property of the Solano Land Trust, Rush Ranch is a site with many different and potentially conflicting uses. The grasslands are leased for cattle grazing and the ranch headquarters near the edge of the marsh are used for animal boarding and breeding. There are many users of the ranch in addition to scientists: a non-profit group currently provides horse-drawn wagon rides along the marsh to people with limited mobility; multiple classes of elementary students visit the site each month during the school year; and a variety of nature enthusiasts and ranch volunteers frequent the nature center area and trails along the marsh. Despite a long-standing commitment to the property by the Solano Land Trust, there is limited salary support for stewardship, conservation, and regulation of visitor access. No trained ecologists are currently employed by the Solano Land Trust, so a voluntary advisory team of regional scientists is occasionally consulted on issues relating to resource conservation. Even with expert advice, however, a number of external constraints limit what can be achieved. Invasive weeds are a rampant problem throughout the mosaic of managed wetlands in the broader Suisun Marsh that surrounds Rush Ranch (Chapter 5, Appendix), providing a source of unwanted propagules that germinate in the Reserve. Water management presents another significant constraint on management options. The amount of freshwater released through dams into the estuary and the operation of salinity control gates in Suisun Marsh are dictated by state agencies responding to a variety of economic and political pressures. These actions have unintentional but unavoidable effects on key environmental factors in the marsh such as water level, temperature and salinity.

15.3 Research and Monitoring Needed in the Reserve

In general, research that addresses one or more of the four main issue areas outlined in section 15.1 is of value to the Reserve and its neighboring resource managers. Specific research and monitoring needs in the Reserve change over time and projects should be conducted or at least considered in light of past and existing projects within the Reserve sites and the SFE more broadly. Other regional organizations have articulated more extensive lists of priority research questions (e.g., SFBJV 2011) and new needs for applied research arise regularly. Broad gaps in basic understanding also should be addressed, but these topics may first require incremental study and may not provide the immediate benefits to management that more applied and clearly defined questions could. There is abundant research and monitoring ongoing at both Reserve sites, but additional and complementary work is still needed in the following areas:

Climate change

- long-term monitoring of vegetation, elevation, water level, and animal populations*
- precise measurements of sediment elevation and water levels done in conjunction with long-term monitoring projects
- relationships between suspended sediment concentration and rates of marsh accretion
- strategies for affordable and sustainable conversion of managed marshes to restored tidal marshes within Suisun Marsh (Rush Ranch)
- effects of increased freshwater diversion on estuarine ecology
- effects of coastal upwelling and ocean acidification on Olympia oysters (China Camp)

Sensitive species

- distribution and ecology of rare, threatened and endangered species, including: California clapper rail, salt marsh harvest mouse, black rail, Suisun thistle (Rush Ranch), soft bird’s beak (sub species *molle*, Rush Ranch), Chinook salmon (Rush Ranch)
- effects of pesticides and other contaminants on non-target species

Invasive species

- methods for reliable detection and ecologically sustainable control of hybrid cordgrass (China Camp)
- effects of perennial pepperweed on rare plants and other native species
- methods for ecologically sustainable control of perennial pepperweed (Rush Ranch)

Grazing

- effects of grazing on upland grasslands, marsh-upland ecotones, water-quality, and marsh function (Rush Ranch)
- effects of changing species of grazers (horses, cows, sheep) and timing of grazing on the habitats and factors listed above (Rush Ranch)

- strategies for effective use of grazing to control weeds in the marsh-upland ecotone (Rush Ranch)

Human impacts

- direct impacts of humans (including researchers, resource managers, school groups, and public visitors) on marsh habitats and species
- indirect impacts of visitor access and infrastructure (e.g., trail systems) on natural resources, including in reference to potential changes in management of China Camp (park closure) and planned restoration projects at Rush Ranch

Water quality

- oceanic (tidal) drivers of water quality (including temperature, salinity, and pH)
- wastewater and stormwater inputs of nutrients and sediments to the estuary

Rocky intertidal and subtidal habitat

- basic ecology of estuarine rocky intertidal and subtidal habitats (China Camp)
- ecological role and ecosystem services of Olympia oysters (China Camp)

There are also urgent restoration needs within the Reserve sites, including:

- Restoration of Goat Hill Marsh at Rush Ranch, with emphasis on use as a demonstration of conversion of managed marsh into tidal marsh (Rush Ranch)
- Restoration of full tidal flow to Spring Branch Creek (Rush Ranch)
- Restoration of upland grasslands with a focus on the role of grazing (Rush Ranch)
- Restoration of full tidal flow to marshes on upland side of North San Pedro Road (China Camp)

*Unless otherwise indicated, specified research or monitoring is needed at both Reserve sites.

15.4 Conclusion

The SFE is the largest estuary on the west coast of North America, containing a wide range of subtidal, intertidal and transitional habitats. In the past, these habitats supported diverse native flora and fauna, provided essential nurseries for commercially important fish and invertebrates, filtered sediment and pollutants that washed into the estuary, and protected the shoreline from flooding. The estuary has been irreversibly altered for development and agriculture, invaded by non-native species from all over the globe, and challenged by numerous anthropogenic threats to ecosystem health and stability. SF Bay NERR sites of China Camp and Rush Ranch represent rare remnants of habitats that were once common, including native grasslands, tidal marsh, tidal marsh-upland transition zones, tidal flats, and rocky subtidal and intertidal areas. Both China Camp and Rush Ranch have been used as reference sites for evaluating wetland restoration and enhancement projects around the estuary, and both sites also have restoration needs and opportunities. This site profile reviewed the existing state of knowledge for the Reserve's research and monitoring activities, and identified needs for future research to address pressing ecological issues that continue to challenge resource managers and the ecosystems they are charged to protect.

Sea level rise is perhaps the most immediate and unresolved threat, particularly if marsh accretion is not able to keep up. More frequent and persistent flooding of the marsh will alter soil salinities and biogeochemical processes, leading to shifts in vegetation communities and changes in habitat availability for marsh animals. A formidable challenge to management of the marsh at China Camp and most tidal wetlands around the estuary is how to accommodate future sea level rise with only very limited potential for estuarine transgression. An important management challenge at Rush Ranch is the urgent need to balance priorities for conservation, recreation and grazing. SF Bay NERR will continue to support conservation and management of these sites and the greater SFE through coordinated long-term monitoring and integrated research, education, stewardship and training programs. The cooperative support of resource managers and local communities will be especially critical for future survival of the SFE.

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Appendix

Wetlands and Water Resources, Inc.

818 Fifth Avenue, Suite 208
San Rafael, CA 94901
Tel/Fax 415.457.0250
www.swampthing.org

Rush Ranch Existing Conditions Final Report

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Prepared for:
Solano Land Trust
1001 Texas Street, Suite C
Fairfield, CA 94533
www.solanolandtrust.org

Prepared by:
Wetlands and Water Resources, Inc.
818 Fifth Avenue, Suite 208
San Rafael, California 94901
www.swampthing.org

with

Peter Baye, Ph.D.

and

Vollmar
CONSULTING
NATURAL RESOURCE SPECIALISTS

Project No. 1156

Planning **Assessment** **Design** **Implementation** **Applied Science**

Rush Ranch Existing Conditions Report

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Rush Ranch Existing Conditions Report

1 Introduction

Rush Ranch, an open space property owned by the non-profit Solano Land Trust (SLT), is a 2,070-acre site within the northern portion of Suisun Marsh, one of the largest estuarine marshes in the United States (Figure 1). The property includes 1,050 acres of tidal brackish wetlands, 80 acres of diked wetlands, and 940 acres of upland grasslands that include multiple seasonal streams and ponds. The site's tidal wetlands comprise the largest remaining piece of tidal marsh within Suisun Marsh. In 1988, SLT acquired Rush Ranch with the support of the California Coastal Conservancy (Conservancy). In 2003, San Francisco Bay National Estuarine Research Reserve (NERR) officially designated Rush Ranch as a component site in a nationwide network of research reserves. In 2007, SLT completed construction of a Nature Center, with support from the National Oceanic and Atmospheric Administration (NOAA) and the Conservancy, to educate the public and provide an on-site research station for visiting scientists. Rush Ranch Educational Council, an all volunteer non-profit group, has provided historical and environmental education to local school groups and the public for many years. Access Adventure, centered at Rush Ranch, provides education and outdoor recreation to people with limited mobility.

1.1 Rush Ranch as a Regional Ecological Resource

The tidal marsh at Rush Ranch provides a home for numerous federally and state-listed threatened and endangered species, including the last known meta-population of the Suisun thistle (*Cirsium hydrophilum* var. *hydrophilum).* In 2007, the U.S. Fish and Wildlife Service (USFWS) designated much of the marsh at Rush Ranch as critical habitat for Suisun thistle and soft bird's beak (*Chloropyron molle* ssp. *molle*, syn. *Cordylanthus mollis* ssp. *mollis*), another listed plant. Rush Ranch also provides important habitat for listed species such as salt marsh harvest mouse (*Reithrodontomys raviventris*), California clapper rail (*Rallus longirostris obsoletus*), and other rare and special status species. First Mallard Slough, a natural tidal channel at the center of the marsh, has been shown to harbor among the highest counts of splittail (*Pogonichthys macrolepidotus)* and tule perch (*Hysterocarpus traski)* in Suisun Marsh. Diadromous fish include NOAA-trust species such as Chinook salmon (*Oncorhynchus tshawytscha*), as well as striped bass (*Morone saxatilis)* and American Shad (*Alosa sapidissima)*. Other listed fish include delta smelt (*Hypomesus transpacificus*) and longfin smelt (*Spirinchus thaleichthys*).

Rush Ranch has a rich legacy of (literally) unique biological diversity in its prehistoric tidal marsh and terrestrial transition zones. Because of historic degradation and climate change, it also has important restoration and enhancement opportunities. Its position in the landscape provides important and increasingly rare habitat linkages between the tidal marsh, supratidal wetlands, seasonal and ephemeral streams, swales, hillslope bluffs and valley grasslands. It also provides opportunities for expanded research and education in the coming years. However, the tidal marsh at Rush Ranch has been impacted by regional water management, extensive ditching and disturbance in decades past, and more recent infestations of perennial pepperweed (*Lepidium latifolium*), and other wetland weeds, and faces future threats from continued changes in water management, climate change, and sea level rise.

1.2 Master Planning Process, the Existing Conditions Report, and Conceptual Modeling

In 1990, SLT completed a Rush Ranch Management Plan with support from the Conservancy. That plan has guided marsh restoration, public use, and grazing management of Rush Ranch for many years. In the ensuing years, SLT and its partners have completed a tidal marsh restoration project, species re-introduction, and facilitated important research into threatened and endangered species. In 2008, the Conservancy provided grant funds to SLT for preparation of a revised Master Plan, Land Stewardship Program, and five conceptual restoration designs. The purpose of the Rush Ranch *Master Plan, Land Stewardship Program, and Restoration Designs* Project is to provide a framework to conserve the unique natural communities and habitats at Rush Ranch in an ecosystem context, maintain appropriate agricultural and public uses in a sustainable manner, and foster a greater understanding of the culture, history, and environment of Suisun Marsh within the general public and scientific community.

In 2009, SLT hired a team comprised of staff from Wetlands and Water Resources and Vollmar Consulting along with independent coastal wetland ecologist Dr. Peter Baye to assist with preparation of the Master Plan, Land Stewardship Program, and conceptual restoration designs. One of the primary tasks under our scope was to generate an updated Existing Conditions Report that summarizes and synthesizes the impressive amount of existing data describing environmental conditions at Rush Ranch. The purpose of this report is not to simply repeat what is already known about Rush Ranch – rather, its purpose is to integrate information about existing conditions and key factors influencing site conditions (both historically, in the present-day, and in the future) into a *conceptual model* of site ecological forms, functions, and processes. The primary goals of these conceptual models are to:

1. Synthesize historic and contemporary evidence on the natural range of site-specific geomorphic variability inherent in the marsh, with emphasis on primary physical and ecological controls, to guide formulation of conceptual restoration designs

2. Identify hydrological and ecological functions (special-status species habitats) associated with specific landscape units
3. Assess the degree to which habitats at Rush Ranch have been or continue to be altered or constrained by historic or contemporary anthropogenic conditions

The basis of these conceptual models is the extensive research literature relevant to Rush Ranch and Suisun Marsh, a data library provided to WWR by SLT in early 2010, limited field reconnaissance, the input of noted experts on local ecology and physical processes, and the project team’s considerable experience within Suisun Marsh and its associated environs.

2 Summary of Key Findings and Inferences

2.1 Existing Conditions

Uncommon terrestrial invertebrate fauna and habitats. Alkali flats and grasslands of Spring Branch Creek, and their ecotones with tidal marsh, support important and limited habitat for many uncommon (and some possibly undescribed) invertebrate taxa, including disjunct populations of species and genera found in interior alkali desert habitats or coastal shoreline habitat, such as tiger beetles (Cicindelidae), staphylinid and anthribid beetles, mutilid wasps, and numerous aquatic and terrestrial coleopteran beetles. The seasonally wet, naturally flood-disturbed alkali flats, washes, and depressions of active alluvial fans are likely refugia for significant invertebrate biodiversity. These habitats are likely maintained by extreme flood events of Spring Branch Creek, alternating with droughts. Sparsely vegetated and unvegetated substrates such as erosional scarps and sandstone bedrock outcrops in terrestrial settings are also important microhabitats for insect diversity.

Seasonal streams and alluvial fans. Incision of seasonal channels in upland drainages and a high degree of bank instability appears to be related to concentrated cattle trampling within moist drainages (seasonal wetlands) that provide water and green forage into the dry season. Trampling and grazing in seasonal wetland of the drainages appears to inhibit growth, spread, and dominance of native sedge, rush, spikerush, and perennial grasses within channels and seasonally moist swales, which are dominated by pasture grasses. Sedimentation in alluvial fan alkali flats is supported by erosion in the upper drainages.

Endemic and rare vascular plants. Rush Ranch's southern tidal marsh plains support the last known populations of Suisun Thistle (*Cirsium hydrophilum* ssp. *hydrophilum*, federally listed as endangered), large natural and artificially established populations of soft bird's-beak (*Chloropyron molle* ssp. *molle*), and the only known contemporary San Francisco Estuary (type locality, Suisun Marsh) population of Bolander's water-hemlock (*Cicuta bolanderi*, syn. *C. maculata* var. *bolanderi*), a globally rare plant. Suisun Thistle and Bolander's water-hemlock were historically associated with one another. They both occur mostly on deep, tidally well-drained brackish marsh peat soils bordering well-drained banks. These local rare plant populations occupy a relatively small portion of what appears to be suitable sub-habitats more widely distributed around Rush Ranch. In addition, Rush Ranch supports numerous other uncommon or regionally rare species and disjunct plant populations, including Suisun aster and Lyngbye's sedge.

Submerged aquatic vegetation. Rush Ranch subtidal habitats support beds of submerged aquatic vegetation (SAV), including sago pondweed (*Stuckenia pectinata),* in portions of Suisun

Slough, and potentially other tidal sloughs that have not been surveyed for SAV. SAV, historically abundant in Suisun Marsh's brackish tidal marsh ponds, is an important aquatic habitat for estuarine fish, and for diving and dabbling ducks.

2.2 Drivers of Future Change

Sea level rise: long-term cumulative effects on estuarine and terrestrial ecotone habitat distribution, abundance, and quality. Rush Ranch's tidal marsh plain supports mature high marsh habitats developed under relatively low rates of sea level rise (< 2 mm/yr) within the last 2000 yr, before which it was primarily low marsh or unstable tidal flats and low marsh. The distribution of high tidal marsh habitats associated with many special-status species is closely associated with the extensive tidal drainage (creek and ditch) networks within the marsh plain.

The marsh plain, as a vegetated geomorphic feature, may be able to persist at rates of accelerated sea level rise significantly greater than those under which it formed during the late Holocene, rather than "drown" as mudflat. The dominant vegetation of the marsh plain and high marsh bordering creeks and ditches, however, may become vulnerable to major shifts. Reduced regional supply of suspended estuarine sediment and rates of sea level rise significantly greater than 2 - 3 mm/yr, however, may cause upper intertidal marsh accretion rates in particular to lag behind rising sea level.

Lagging high marsh accretion rates (particularly in El Niño years with punctuated rises of sea level tens of centimeters above the "smoothed" sea level rise curve) makes high marsh habitats within the marsh plain vulnerable to conversion to middle marsh zones with different dominant plant assemblages, such as bulrush. Similarly, poorly-drained marsh plains farther from overbank sediment supplies of tidal channels may be subject to conversion to low marsh if marsh accretion rates lag significantly behind rising sea levels.

In general, high marsh habitats on the peaty marsh platform, dependent on marsh accretion to keep pace with accelerated sea level rise significantly above long-term average rates, are at high risk of instability. These interior high marsh habitats support most of the rare or endangered tidal marsh plants and wildlife at Rush Ranch, including the endemic Suisun Thistle. Conversion of high brackish marsh to lower brackish marsh zones dominated by bulrush may also constrain the growth and spread of some dominant non-native invasive plants in well-drained marsh plains or high marsh, such as broadleaf pepperweed (*Lepidium latifolium*).

In contrast, high marsh zones fringing the terrestrial ecotone below the extreme high water line, are independent of marsh accretion and form directly on antecedent slopes as sea level rises. This fringing high marsh and terrestrial ecotone is not confined by dikes or development at Rush Ranch, and is capable of natural landward estuarine transgression with sea level rise, particularly in valleys (active alluvial fans) with very gentle topographic gradients. The landward-edge linear fringe of existing high marsh on terrestrial mineral soils, however, provides limited habitat for wildlife species that must nest and forage in relation to tidal creeks, and may not provide equivalent substrate or hydrology for rare plants associated with high marsh vegetation of peaty tidal creek banks and natural levees.

Cumulative effects of sea level rise on tidal marsh vegetation of Rush Ranch will likely include significant interactions with direct and indirect influences of climate change, including long-term shifts in salinity (annual average and seasonal variability, extreme events), tidal range (tidal damping effects of planned or unplanned unrepaired breaches of levees of subsided diked baylands of Suisun Marsh, or the Delta), and especially rainfall. Rush Ranch tidal marsh vegetation has in the past undergone long-lasting (multiple centuries) shifts in dominant vegetation in relation to long-term variability in rainfall and delta outflows.

3 Regional Overview

Suisun Marsh encompasses 116,000 acres of managed brackish wetlands, tidal marsh, upland grasslands, and subtidal bays and sloughs within the San Francisco Estuary (Figure 2). One of the largest estuarine marshes in the country, it was formed by Holocene-era (~10,000 years bp to present) estuarine flooding of a broad embayment in between the narrow channels of the Carquinez Straits and the Sacramento – San Joaquin Delta (Atwater 1979). The marsh is bordered On the east by the Potrero Hills, on the west by the inner Coast Range, and in the north by Suisun City and the broad flatlands and abundant seasonal wetlands of the Jepson Prairie.

The marsh is a complex matrix of habitats in the middle of the San Francisco Estuary in which both tidal inundation and salinity are temporally and spatially variable. Direct precipitation, watershed runoff, Delta outflow, and the operation of a complex salinity management system (see below) turn the marsh into a primarily freshwater system during the winter-spring rainy season. During the dry season, the attenuation of freshwater inputs transitions the marsh into a brackish system. Suisun vegetation communities, therefore, must be able to tolerate and thrive in a broad range of salinities. Vegetation communities and dependent wildlife also vary based on elevations relative to tidal datums, distance from tidal sources, substrate conditions, and the extent to which habitats have been modified by human activities. In the late 1800s and early 1900s, most of the formerly extensive tidal marshes throughout the Suisun system were diked and managed as duck clubs. At the same time, copious amounts of sediment from hydraulic mining activities in the Sierra Nevada washed down through the Delta and into the marsh. The combination of decreased tidal prisms (from diking) and increased suspended sediment concentrations (from hydraulic mining) resulted in the infilling of many smaller tidal channels within the marsh, and the constriction of larger channels. In subsequent years, activities such as mosquito ditching and the development of adjacent areas such as Suisun City further altered the character of the marsh. By the end of the 20th century, the nature of wetland habitats within the Marsh had changed dramatically. The amount of tidal marsh decreased from 67,000 to 8,000 acres (Figure 3), and populations of endemic plant and animal species dependent on tidal marsh habitats (such as Suisun marsh aster, Suisun thistle, and Suisun shrew) were almost eliminated (Goals Project 1999). Today, Rush Ranch provides some of most critical habitat remaining for these species.

The intensive manipulation of water resources within the Delta and Suisun Marsh has also had a profound impact on marsh habitats. Water diversions in the Delta for municipal and agricultural supply have drastically reduced the amount of freshwater flowing from the Delta into the Suisun system, especially during the winter-spring rainy season. At the same time, changes in runoff patterns and wastewater discharges from development adjacent to the marsh have altered the timing and nature of local freshwater inputs. To decrease the impact that salinity intrusions could have on Suisun Marsh habitats, DWR and USBR constructed a series of infrastructure elements (such as canals and tidegates) in the 1970s and 1980s aimed at manipulating circulation patterns within the marsh. These efforts culminated in 1988 with the construction of the Suisun Marsh Salinity Control Gates at the southern end of Montezuma Slough. The gates are managed to allow lower-salinity water from the Delta to enter the slough during an ebb tide, and to prevent higher-salinity water from Grizzly Bay entering the slough on a flood tide. The gates are typically operated from October through May to replicate the fresher conditions that historically existed in Suisun Marsh during the rainy season. During the dry season, the gates are not operated, and tidal flows are freely exchanged between Montezuma Slough, Grizzly Bay, and the Delta.

Water management within the duck clubs is one of the most significant controlling factors on the quality and distribution of habitats within Suisun Marsh. Water levels within the duck ponds are managed through a complex series of canals, tidegates, culverts, and other structures. Most managed wetlands are dry during the summer and early fall months when land managers carry out maintenance activities. The wetlands are then flooded during the fall, typically through a series of one or more flood-drain-flood cycles. Water circulates through the wetlands during the winter until the ponds are drained at variable times in the spring. The fall flood-up cycle can result in the creation and release of waters with low dissolved oxygen (DO) levels into tidal sloughs, which can in turn kill at-risk fish species and impair valuable fish nursery habitat. Pond releases are also rich in organic matter, which increases biological oxygen demand (BOD) and further lowers DO in receiving waters. Low-DO environments within the ponds and sloughs of Suisun Marsh are suspected of producing methylmercury (often denoted as “MeHg”), a bioaccumulating neurotoxin that adversely affects fish and wildlife species and poses a health risk to humans. The state Department of Water Resources, Suisun Marsh Conservation District, and others are currently engaged in an effort to understand how changes to duck club water management regimes can affect the frequency, severity, and duration of low-DO events and, potentially, MeHg production and export (DWR in-prep).

The investigation into low DO and MeHg production is one of many research studies that have been or are currently being implemented in Suisun Marsh. The marsh’s location within the estuarine gradient, broad range of habitats, and dynamic physical/ecological processes have made the marsh, and Rush Ranch in particular, a focal site for research on wetland habitats and long-term geomorphic evolution.

4 Geology, Soils and Geomorphology

Rush Ranch is situated on the west end of the Potrero Hills and extends into the adjacent marshes and sloughs of Suisun Bay. The Potrero Hills serve as the geologic foundation for the site, forming the hillslopes in the east as well as the underlying substrate upon which younger alluvium and marsh sediments have accumulated in the west. Figure 4 is a map of the geologic formations underlying the Potrero Hills and Rush Ranch.

The Potrero Hills are an east-west trending anticlinal ridge deformed by numerous faults and composed of a series of Tertiary-age sedimentary sandstones and shales (Graymer et al. 2002). The top of the anticline subsequently eroded away or collapsed, leaving a trough along which Spring Branch Creek currently drains. Regionally, the Potrero Hills are an isolated Coast Range feature with the same structural alignment and sedimentary formations as the Medanos Hills south of Suisun Bay. They are separated from the Vaca Mountains west of Vacaville by a broad expanse of alluvium in the Fairfield-Suisun region (Graymer et al. 2002). Pleistocene-age alluvium, eroded from the adjacent hills, overlays older rocks throughout much of the western terrestrial portions of the site (USDA 1977). Younger, Holocene-age alluvium occurs along the site's active creek floodplains. The estuarine areas also consist of a mix of Holocene-age alluvium and accreted sediments with a shallow peat veneer.

The soils on Rush Ranch reflect the underlying geology and include a mix of loams, sandy, silty and clay loams, and clays in the terrestrial areas and mucks, mucky clays and silty clays in the estuarine areas. Table 1 lists the specific soil types that occur on the site and their key characteristics. Figure 5 displays the distribution of these soils on the site in relation to topography.

The site geology, soils and related topography form the basis for a distinct set of terrestrial and estuarine geomorphic units, each with characteristic soils, plant communities, and habitat structures. These units serve as a key component of the conceptual model presented in this report and are described in more detail in Section 8 below. The terrestrial geomorphic units include Hillslope, Older Inactive Alluvial Fan, and Recent Active Alluvial Fan. The estuarine geomorphic units include Subtidal Channel Bed, Fringing Tidal Marsh, Tidal Marsh Plain, and Tidal Marsh-Terrestrial Ecotone. Figure 6 displays the distribution of these units on the site. Table 2 displays the relationship between soil type and geomorphic unit.

5 Topography and Hydrology

The interactions between topography, surface flows (both tidal and fluvial), and groundwater are among the primary drivers of ecosystem form and function within Rush Ranch. This section describes site topography, hydrology, and brief summaries of their influence on the Rush Ranch landscape.

5.1 Topography

Elevations at Rush Ranch range from approximately +4 to +8 ft NAVD within the site's estuarine habitats, and from +8 to +220 ft NAVD within the site's uplands (Figure 7). While the site's upland habitats have been adequately characterized using LiDAR (Light Detection and Ranging) technology, this technique is not as effective in wetlands, where tall vegetation can result in significant (up to 4 ft) errors in reported elevations (Figure 8). Therefore, it is important to note that Figure 7 displays only ***estimated*** marsh plain elevations; these data cannot be used to make inferences about precise elevations or elevations relative to the tidal frame (see Section 6.2 below). Exceptionally thorough ground-based elevation surveys would be necessary to accurately characterize wetland topography.

5.2 Tidal Hydrology

Like most tidal areas within the San Francisco Estuary, tidal habitats within Rush Ranch are inundated by *mixed diurnal tides*: for every lunar day (24.84 hours), there are two high tides and two low tides of unequal value (Walters 1985). *Tidal datums* describe average tidal elevations: Mean Higher High Water (MMHW, the average of all higher high tides), Mean High Water (MHW, the average of all high tides), Mean Tide Level (MTL, the average of all tides), Mean Low Water (MLW, the average of all low tides), and Mean Lower Low Water (MLLW, the average of all lower low tides). Since no entity thus far has performed proper tidal datum reckoning (according to NOAA standards) for the tidal sloughs bordering Rush Ranch, we are using calculated datums at Bradmoor Island as a surrogate for estimated Rush Ranch tidal datums (Table 3). Bradmoor Island is to the east of Rush Ranch, within the Nurse Slough complex, and is located at a similar distance from tidal sources.

Estuarine morphology increasingly distorts tidal waves with distance into the estuary, especially in natural tidal marshes such as those at Rush Ranch (Malamud-Roam 2000). These distortions have a profound influence on the inundation regime within the marsh and, in turn, the tidal marsh functions that are dependent upon the inundation regime. Tides primarily reach Rush Ranch through Suisun Slough, though there is likely some tidal exchange with Montezuma Slough, especially in the eastern portion of the site. Rush Ranch is located approximately 10 miles (16 km) upstream from the mouth of Suisun Slough in Suisun Bay, and as a result, the tidal signature there is significantly different from that observed in the open tidal embayment of Suisun Bay (the Port Chicago station).[1] Rush Ranch experiences a relatively broader tidal range than Suisun Bay, with a MHHW approximately half a foot higher than that of the open bay.

In San Francisco Estuary, the sequence of tidal extremes is irregular, and may be unique among tidal systems (Malamud-Roam 2000). The lower of the twice-daily low tides (LLT) follows the higher of the two daily high tides (HHT) irregularly, though about four times as often as the reverse. As a result, the Estuary is strongly ebb-dominant, with faster ebb currents that are responsible for much of the transport of sediment and chemical/biological constituents within and between tidal systems. The sequence of diurnal tidal patterns is also very consistent from year to year; net change in the annual sequence of the diurnal tidal pattern is about 1.09 days per year.

Typically, *intertidal elevations* are defined as the tidal range between MHHW and MLLW. The locations of these elevations on the landscape are frequently used to define the extent of tidal habitats at a given site. However, the extents and nature of tidal habitats are also influenced by short-term, periodic increases in tide levels due to spring tides, storms, and other events. In addition, tidal inundation patterns throughout a site can vary with distance to flood/drainage channels. Tidal inundation regimes are characterized by measuring the frequency, magnitude and duration of inundation of tidal habitats. Typically, areas farther from channels take longer to flood and drain, and therefore experience a vastly different inundation regime than areas immediately adjacent to channels. Differences in inundation regimes often leads to significant differences in substrate characteristics (grain size, % mineral content, etc.) as well as vegetation communities and even topography. The effects of different inundation regimes on habitat structure and function are discussed in-depth in Section 8 below.

5.3 Fluvial Hydrology

Multiple small watersheds drain the upland hillslopes of Rush Ranch. The largest of these watersheds is that of Spring Branch Creek (SBC), which drains into tidal marsh in the southwestern portion of the preserve. SBC drains much of the Potrero Hills east of Rush Ranch with a watershed of approximately 2,670 acres (measured at Grizzly Island Road). Wetlands Research Associates (1990) calculated SBC peak flows at 2-, 10-, and 25-year recurrence intervals to be 340, 520, and 610 cfs, respectively. Much of the original creek channel upstream of the road has been dammed to form a series of stock ponds; downstream of the road, the channel is diverted out of its historic channel and disconnected from its natural floodplain

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[1] WWR referenced tidal datums for Port Chicago to NAVD as part of restoration planning efforts for the Montezuma Wetlands Restoration Project (WWR 2004).

through a series of levees and non-functioning culverts. These anthropogenic factors have eliminated much of the gradual tidal-fluvial-upland ecotone that historically existed along the creek alignment, with associated impacts to dependent vegetation and wildlife communities (see Sections 8 and 9 for detailed descriptions of these communities). The stock ponds in line with SBC fill up during the wet season and the gradually shrink in response to evapotranspiration during the dry season. The main pond immediately upstream of Grizzly Island Road apparently maintains enough water from year to year to support a small population of stickleback, however, annual mortality of these fish is likely high due to the gradual drying and draw-down of riparian habitats upstream of the pond.

Other smaller local watersheds drain the northern portions of Rush Ranch uplands to form similar (and often, similarly impacted) fluvial-tidal ecotones to SBC. One of these watersheds is located north of the main ranch complex, and drains into the diked marsh near Goat Island. This “Goat” watershed is the location of a historic quarry whose material might have been used to construct the levees around the existing diked marsh. A small impoundment in line with this channel is formed by a pedestrian trail that crosses the ephemeral channel floodplain. A second watershed north of the “Goat” watershed drains into a relatively unimpacted portion of tidal marsh near Deadman Island. This tidal-fluvial ecotone is one of the least impacted throughout Rush Ranch and provides a valuable reference site for heavily impacted systems such as Spring Branch Creek.

5.4 Groundwater

Past groundwater monitoring efforts at Rush Ranch (WRA and PWA 1990) have encountered groundwater in the alluvium of saline marine sediments with elevated salt concentrations. Groundwater salinity is strongly influenced by precipitation and its attendant soil saturation: one well higher in the watershed had summer salinities up to 11 pt and winter salinities of around 7 ppt, while a well relatively lower in the watershed had a summer salinity of 3.5 ppt and a winter salinity of only 1 ppt. Several small, ephemeral springs are located in the hillsides within the SBC watershed. Water from these springs is held in the Tertiary marine Domengine Formation and occasionally appears at contacts with other, non-permeable formations (WRA 1990).

6 Historic Ecology

Rush Ranch and the greater Suisun Marsh region have been subjected to numerous anthropogenic disturbances and other changes that have significantly altered the 'natural' ecological state within both the estuarine and terrestrial landscapes. Most of these changes have been intentionally or incidentally wrought by European settlers beginning in earnest in the 19th century. However, other changes have occurred as a result of both natural long-term climate change and sea level rise, and Native American hunting and land use practices. Cumulatively, these effects indicate a system that has been subject to continual, directional long-term change that complicates defining the 'natural' ecological state of the region.

This section of the report gives a brief overview of the ecological changes that have occurred on the site and surrounding region over the past 15,000 years as well as the prevailing 'natural' conditions prior to European arrival in the region. The estuarine, fluvial (seasonal creek) and terrestrial landscapes are treated separately here and throughout the report since they are so distinct. In reality, however, these landscape units are all closely interconnected in terms of physical processes and ecological function and together should be viewed as a single tidal marsh-upland ecosystem.

6.1 Overview of Prehistoric Conditions and Changes

The area now known as Rush Ranch and the Suisun Marsh were dramatically different, even unrecognizable, 15,000 years before present (bp). At the time, the region was just beginning to emerge from the last ice age with substantially colder temperatures and higher rainfall levels, sea level was approximately 120m lower than at present (Gornitz 2007), humans were just arriving in North America for the first time along a migratory path from Asia across the Bering land bridge (Jacobs 2001), and there was a grazing and browsing mammalian megafauna, with associated large predators, distributed throughout present-day California, rivaling that of present-day southern Africa (Edwards 2007). At the time, the continental edge was west of the Farallon Islands, the San Francisco Bay was a river valley draining through the notch in the Coast Ranges now known as the Golden Gate, and the present-day grassland areas in the region likely supported or were dominated by more woody scrub, woodland and/or forest communities (Bartolome et al. 2007). The site of Rush Ranch was, at the time, an unremarkable wooded or open hillslope on the western end of a local ridge (the currently named Potrero Hills), miles from any tidal influence.

From 15,000 to the present, natural climate change caused a shift from a more mesic Pleistocene environment to a drier, more fully Mediterranean climate (Edwards 2007). This, in some combination with Native American hunting, caused the extinction, by about 10,000 bp, of most of the large mammals that occurred in the California region such as mammoth, bison, giant ground sloth, camel, horse, lion, and cheetah (Edwards 2007). The loss of these megafaunal species, especially the grazers and browsers, may have had a significant effect on the grassland and scrub communities of the time due to a reduction in grazing pressure and a shift in grazing animal species. The remaining megafaunal species included tule elk, deer, pronghorn antelope, mountain lion, grizzly bear and black bear. In addition numerous small mammals and birds inhabited the grassland and influenced its structure through grazing. Burning by Native Americans may have also had significant effects on grassland communities. Under natural conditions, fires due to lightening strikes likely occurred every 5-20 ten years on a given site in lower elevation areas of central California (Greenlee 1990). It is unclear when Native Americans began to introduce fire but by the time of European arrival, burns were conducted frequently (perhaps every 1-3 years) within the Coast Range grasslands based on observations recorded by early Spanish missionaries and explorers (Anderson 2007). On-going climate change also resulted in a rising sea level, warmer temperatures, and lower rainfall levels, leading to a gradual warming and drying of the environment that favored more arid grassland and forb communities within the terrestrial landscape.

By 6,000 bp, sea level was within approximately 2m of the present-day elevation (Gornitz 2007), Suisun Marsh was at an incipient level of formation, and the rate of sea level rise began to slow significantly. By the time of European arrival in the early 16th century, sea level was roughly at the present-day elevation, Suisun marsh roughly occupied its recent historical boundaries prior to diking and other anthropogenic disturbances initiated in the 1800s, and the terrestrial habitats on and around the Rush Ranch site were dominated by grasslands with scattered stands of coastal scrub. Blue oaks (*Quercus douglasii*) and other upland trees were probably absent since there is no current or historical evidence of their presence on or near the site. Local seasonal creeks like the currently-named Spring Branch Creek may have supported limited stands of woody riparian shrubs or trees though there is no current or historical evidence to indicate this.

6.2 Estuarine Landscape

This section describes the historic ecology of estuarine habitats with Rush Ranch. Much of this information can be extrapolated to describe the estuarine habitats of Suisun Marsh as a whole, but it is important to recognize how much of Rush Ranch escaped much of the 20th century diking and draining that has severely impacted its peers within the Marsh.

6.2.1 Paleoecology and Historical Ecology of Rush Ranch: A Synthesis

Embedded in the sediments of Rush Ranch tidal marshes are a complete stratigraphic record of microfossils (pollen, diatoms, foraminifera) and organic and inorganic sediments that trace its geomorphic and ecological origin, infancy, and development through its geologically brief existence (a few thousand years) in the variable climate of the late Holocene epoch. Teams of climate scientists and physical geographers from U.C. Davis and U.C. Berkeley have characterized the 7000 year geologic history of climate history, sedimentation, and vegetation change of the northern San Francisco Bay Estuary, including site-specific studies of Rush Ranch. Reconstructing the ecological development of the marsh is highly relevant to interpretation of its recent (post-European settlement) history, and to accurate qualitative conceptual models of its likely responses to future climate change. This body of research is selectively summarized below for applications to long-term management planning for Rush Ranch, with emphasis on implications for sea level rise and climate change adaptation.

6.2.2 Estuarine Paleoecology and Stratigraphy: Reconstruction of Regional and Rush Ranch Tidal Marsh Development

The oldest tidal brackish and salt marsh sediments in the northern San Francisco Bay Estuary are associated with a slowing of post-glacial sea level rise rates as they approached modern sea level. This initial deceleration of sea level rise began 6000 yr before present (BP), and by approximately 4000 yr BP initiation of most modern tidal marsh plains began , although some emergent fresh-brackish estuarine marshes deposited discontinuously earlier (Wells *et al*. 1997, Malamud-Roam and Ingram 2004). Prior to the initiation of tidal marshes, the early-mid Holocene climate was relatively arid and warm (Malamud-Roam *et al.* 2007). The period of initial and unstable tidal marsh development was associated with much higher delta outflows (fresher estuarine salinity regimes) punctuated with abrupt episodes of high salinity and drought, compared with historic times (Wells *et al*. 1997, Malamud –Roam et al. 2007). A long period of relatively wet, low salinity conditions with high delta outflows prevailed in the northern estuary for approximately two millennia, between 4000 and 2000 yr BP. Rates of sea level rise in the mid-late Holocene was relatively slow during early stages of tidal marsh formation and high delta outflows and precipitation, between 1.1-1.6 mm/yr (Goman and Wells 2000), and remained low until recent historic times.

Late Holocene climate in the last 2000 years of the estuary's development has been highly variable, including alternating periods of prolonged dry, warm, relatively saline phases, and cooler, wetter, fresh-brackish phases (Malamud-Roam and Ingram 2004, Malamud-Roam et al. 2007, Wells et al. 1997). Prolonged high salinity phases (decreased freshwater inflow from the Delta) occurred 1600–1300 yr B.P., 1000–800 cal yr B.P., 300–200 yr B.P., and ca. A.D. 1950 to the present. Prolonged low salinity phases (increased fresh water inflow) occurred salinity occurred before 2000 yr B.P., from 1300 to 1200 yr B.P. and ca. 150 yr B.P. to A.D. 1950. (Malamud-Roam and Ingram 2004). These climate variations occurred in a background of relatively slow and stable sea level rise rates. They corresponded with marked fluctuations in the composition of tidal marsh dominant vegetation , indicated by reversals in relative abundance and composition of pollen assemblages corresponding with low and high salinity regimes (proportions of salt-sensitive plant family pollen types, such as sedge and aster (Cyperaceae and Astereaceae) and relatively salt-tolerant plant family pollen types, such as goosefoot and grass (Chenopodiaceae and Poaceae) (Figure 9) It is particularly noteworthy that the estuary's regional climate in the historic period (post-1850) has been relatively stable compared with the majority of the tidal marsh stratigraphic record, with most of the historic change in the salinity signal due to water diversion in the Delta (Byrne *et al*. 2001).

The stratigraphic record of Rush Ranch tidal marshes (Byrne et al. 2001) is generally consistent with the long-term, large-scale patterns of climate and salinity from the rest of the northern estuary, but reflects some buffering and lag in response time due to distance from the main channel of the estuary (Malamud-Roam and Ingram 2004). Initial tidal marsh formation began at Rush Ranch only 2700 yr BP, oscillating between open tidal flats and low marsh under high salinity conditions before stable marsh established about 2500 yr BP. This depositional sequence occurs between 275 and 325 cm below the modern marsh plain surface. Low marsh peats (Cyperaceae) prevailed in the marsh under relatively fresher salinity regimes between 2500 and 1750 yr BP, extending up to elevations 175 cm below the modern marsh plain surface. The familiar geomorphically mature "high marsh plain" and the habitats structure that supports modern species did not establish until 1750 yr BP, during a period of relatively high salinity (abundant Chenopodiaceae pollen). This high salinity mature marsh phase continued until 750 BP, when fresh inflows increased and Cyperaceae and Asteraceae pollen (fresh-brackish marsh) dominated. This relatively fresh-brackish phase continued until approximately 1930 C.E. (A.D.), when dams and water diversions in the Sacramento-San Joaquin delta, and possibly drought as well, shifted the mature marsh to relatively more saline brackish marsh conditions that are known from the historic agricultural, waterfowl-managed, and diking era of Suisun Marsh. The modern historic salinity regime corresponding with diversion-reduced delta outflows is comparable with the long high salinity phase from 1750 to 750 yr BP. (Byrne *et al*. 2001).

The empirical reconstruction of Rush Ranch paleoecology clearly indicates that the existing mature marsh plain and sloughs have a relatively brief geologic existence – less than two thousand years – and underwent profound fluctuations in vegetation dominance and salinity regimes, as well as precipitation. The stratigraphic record does not support the assumption of an "equilibrium" or steady "natural" state in either Suisun Marsh or Rush Ranch. This record has specific implications for special-status species conservation, particularly endemic Suisun Marsh species. Suisun Marsh historic endemic species, some of which are now endemic to Rush Ranch alone or nearly so, either persisted in refugial habitats within local salinity gradients of

Suisun Marsh, or underwent range shifts very rapidly between Suisun Marsh, the western estuary, and the Delta. Stable suitable habitat likely did not persist at any one location at Rush Ranch for more than 1000 years. The primarily fresh-brackish phase of Rush Ranch tidal marshes known from the early historic period is not a permanent or prevailing condition, but a long fresh phase that began only 750 yr BP. Most significantly, perhaps, is that the entire geologic and ecological history of Rush Ranch tidal marshes occurred under a regime of slow sea level rise. No part of the marsh's history reflect the conditions that are expected in the 21st century: accelerated sea level rise rates significantly greater than 2 mm/yr and prolonged warmer climate with reduced delta outflows, and seasonal delta outflow limited to the wet season due to reduced or absent of Sierra snowpack. Section 11 discusses what these unprecedented conditions might mean for ecosystem forms, processes, and functions at Rush Ranch.

6.2.3 Prehistoric Anthropogenic Influences on Rush Ranch Vegetation

Rush Ranch is located near two of the largest prehistoric Patwin (Wintun) village sites recorded in the Suisun Marsh region, Hesaia and Yuiyui (Kroeber 1925)., both near the approximate locations of modern Suisun City and Rush Ranch (Kroeber 1925, plate 34). Village sites were associated with camp sites in the vicinity where hunting and gathering activities occurred. Patwin hunted waterfowl and fished, and collected shellfish, in winter months. Villagers on the Sacramento river used decoys to hunt waterfowl in nets, and also used nets and harpoons in fishing salmon. The majority of coastal and Central Valley tribelets (polities) utilized annual burning of grasslands in lowland valleys for hunting, maintenance of favorable seed (pinole) and bulb production (Lightfoot and Parrish 2009, Lewis 1973, Bean and Lawton 1973). Burning typically occurred after seed harvest. Annual burns likely influenced the character of tidal marsh edges and stream valleys (Spring Branch Creek floodplain), particularly in limiting the development of woody scrub.

Historical agricultural influences. Historic agricultural influences on late 19th and early 20th century Rush Ranch tidal marshes include the following activities and processes, indicated from historic records and photographs:

- Tidal marsh haying (harvest of marsh hay)
- Tidal marsh livestock grazing (continuing today at adjacent ranch land, reduced or ceased at Rush Ranch only in the last 20 yr)
- Ditching of tidal marsh plains with poor drainage (mosquito ditches) or tidal marsh pans and ponds (e.g. “Mallard Slough” vicinity – ponded habitats attractive to dabbling ducks)

- Slough dams and partial levee construction along marsh perimeters (e.g. branches of Second Mallard Slough, and Suisun Slough banks, Hill Slough marshes except one or two marsh islands)
- Local diking and non-tidal impoundment of tidal marsh (diked marsh south of Goat Island, Suisun Slough)
- Increased terrigenous sedimentation from gullies and seasonal streams subject to overgrazing and slope failures of adjacent hillslopes
- Introduction of non-native plant species in diked impoundments and agricultural lands
- Introduction of pigs and game birds

The construction of dikes at Rush Ranch, even incomplete dikes, along slough borders of tidal marshes likely contributed significantly to local declines in tidal slough bank vegetation (including rare endemic plants) that was regionally decimated by early 20th century diking. Cattle grazing and haying directly in tidal marshes also likely had acute and prolonged inhibitory effects on reproduction of what are now rare endemic high tidal marsh plants. Grazing in marshes would likely have been most intensive in early summer, when hillslopes are dry and green forage is restricted to wetlands. Intensive grazing likely occurred during peak flowering periods of Suisun thistle and soft bird's-beak, for example. Diking and ditching, and deposition of cattle manure in the tidal marsh, also likely facilitated the spread of invasive non-native species into the marsh.

6.3 *Terrestrial Landscape*

The terrestrial landscape on the site includes the upland hillslopes and older inactive alluvial fans around the base of the hills, extending down to the edges of and transitioning into the estuarine and fluvial landscapes (Figure 6). At the time of European arrival, this landscape was likely dominated by a mix of grassland communities and scattered stands of coastal scrub, as discussed below, though the relative cover and local distribution patterns of these communities is unknown. It appears that blue oaks and other upland trees were probably absent from the site given a lack of any current or historic indications of their presence within the Potrero Hills.

As is still the case today, the primary influences on species composition and distribution within the historic grassland and scrub communities included the mix of existing plant species that had colonized the site, geomorphology and soil, climate, grazing and fire. Geomorphology and soil provide the supporting framework for the plant communities and greatly influence the types of communities that can exist on a site and the composition and local distribution of species these communities within the limits of the available plant species. Upon this framework, climate was the overarching influence, with annual temperature and rainfall patterns varying significantly from year to year, and ultimately overwhelming the more temporary influences of grazing and fire (Bartolome et al. 2007). Nonetheless, on-going grazing and fire can maintain shifts in plant community composition and distribution patterns as long as they persist. For example, moderate to heavy grazing and/or fire generally favors grasslands over northern coastal scrub that otherwise would thrive under prevailing climate and soil conditions (Ford and Hayes 2007). The terrestrial communities on the site and surrounding region were likely subject to significant, on-going manipulation by Native Americans (Patwin Tribe) through frequent burning (Anderson 2006) and selective harvesting and nurturing of plants for food and other purposes (Anderson 2007). Native grazers including herds of elk, antelope and deer also likely had an on-going influence on the terrestrial plant communities, perhaps reducing or controlling scrub stands and influencing species composition and abundance in the grasslands much as domestic livestock do today. Given these significant anthropogenic and natural influences, it is problematic to ascribe a single ‘natural’ state to the communities that historically occurred on the site. Rather, it is critical to consider the influences of grazing and fire when characterizing historic community structure at Rush Ranch.

6.3.1 Plant Communities

The terrestrial landscape is currently dominated by non-native grasses with a subdominant component of weedy forbs introduced since the time of European exploration and settlement. These introductions, facilitated by some combination of the competitive advantage of the introduced species, intensive grazing by domestic livestock, effects of introduced pathogens, and other factors (Heady 1988, Malmstrom et al. 2005, Bartolome 2007), resulted in the extensive replacement of the original native grassland species by non-natives throughout the lower elevation coastal and valley regions of California.

The replacement was both rapid and widespread, generally thought to be largely complete by the late 1800s, before any serious scientific characterizations of the original communities had been conducted (Heady et al. 1992, Mensing and Byrne 1998). As a result, historical data is scarce but many nearly pristine reference sites exist that indicate the distribution and abundance of plant species within the native communities or variations in species and plant community composition across the landscape. The current prairies continue to support a high diversity of their original native species, albeit with typically a fairly low cover (Schiffman 2007) except in some areas with thin soils or during years with rainfall patterns that favor annual forbs (author pers. obs.).

Over the past several decades, various grassland ecologists have attempted to reconstruct the plant community characteristics of the original California grasslands both for pure academic interest and to provide a basis for attempting restoration of the original grasslands (Clements 1934, Heady 1988, Hamilton 1997, Holstein 2001, Bartolome et al. 2007, Schiffman 2007, Minnich 2008). Primary sources of information used for these reconstructions include observations and data from remnant native species and relict stands within the introduced grasslands, general observations recorded by early Spanish missionaries and explorers, and autecological characteristics of native grasses and forbs.

Initial characterizations of the original grasslands emphasized the dominance of perennial bunchgrasses, especially *Nassella pulchra* (purple needlegrass). Clements (1934) used an analysis of relict grassland stands to conclude that the original grasslands were dominated by various bunchgrass species (*Stipa (Nassella)*, *Poa*, *Koeleria*, *Melica,* etc.) with *Nassella pulchra* identified as the dominant within valley grasslands. This paradigm was generally accepted or promoted by grassland ecologists for several decades even into the present (Munz and Keck 1959, Burcham 1961, Heady 1988, Bartolome et al. 2007). While most of these authors recognized that forbs and other species were an important component of the native grasslands, they invariably highlighted perennial bunchgrasses as the most prominent component, in effect diminishing the importance or even dominance of other species, especially annual forbs. As an example, Heady (1988) boldly states that "*Stipa* (*Nassella*) *pulchra*, beyond all doubt, dominated the (native) valley grassland."

Several recent publications have criticized these earlier characterizations as emphasizing or promoting an overly simplistic view of the original grasslands as 'bunchgrass dominated'. Hamilton (1997) directly criticized Clements' (1934) methods and argued that the original 'grassland' areas were likely dominated by various species groups including perennial bunchgrasses, annual grasses, forbs and shrubs depending on the region and local site conditions. Holstein (2001) presented a compelling picture, based on available historic and current observations, that *Leymus triticoides* (creeping wildrye), a rhizomatous native grass, was the typical dominant on more low-lying alluvial fans and terraces. Schiffman (2007) argues that Clements did not adequately acknowledge the ecological importance and often dominant cover of annual and perennial forbs within native valley grasslands due to his focus on *Nassella pulchra* as the 'dominant' species. Together, these and other authors argue for a more nuanced view of the original California grasslands with several different potentially dominant series depending on local site conditions including native perennial bunchgrasses, native perennial rhizomatous grasses, native annual grasses, and native annual and perennial forbs. Many current grassland ecologists also prefer the term 'prairie' versus 'grassland' to describe both the original and current communities to emphasize the important and sometimes dominant or even exclusive component of native wildflowers, especially in the original 'grasslands' (Holstein pers. comm.).

Following the trend toward a more nuanced view of the grasslands, this author hypothesizes that there were at least five different dominant plant associations or series within the original grasslands on the site and that each was associated with distinct geomorphic and soil environments. These include:

- Mixed *Nassella pulchra*-forb dominated stands, concentrated on the drier upland hillslopes and perhaps extending to the upper and more elevated portions of the older alluvial fans; the relative cover of *N. pulchra* versus forbs undoubtedly varied across the site with *N. pulchra* likely favored in areas with deeper soils, and forbs (especially small annuals with shallower roots) favored on areas with thinner soils; the forbs likely included the large majority of species currently known from the site plus additional species that may have been locally extirpated though their historical patterns of distribution and cover are unknown; other perennial bunchgrasses (e.g. *Melica imperfect* and *Poa secunda*) may have occurred but are not currently known from the site;
- Forb dominated stands on limited areas with very thin soils over bed rock, such as convex slopes along the upper shoulders of the hillslopes and areas immediately surrounding exposed bedrock; the species that predominated in these areas are uncertain and probably diverse;
- *Leymus triticoides* dominated stands on the lower portions of the older alluvial fans, especially near the terrestrial-tidal marsh ecotone and perhaps extending to the mid or upper portions of the fans, as well as some of the valleys, saddles, and north-facing slopes in the upland hillslopes with seasonally wet or moist clay and clay loam soils; often in association with *Distichlis spicata* (saltgrass) on soils with elevated salinity.
- *Distichlis spicata* (saltgrass) dominated stands in areas of the older alluvial fans with both seasonally wet or moist soils and elevated soil salinity; this included some soils in the lower portion of the older alluvial fans and within low-lying valleys in the upper portions of the fans where alluvium is derived from marine sedimentary rocks with high inherent salinity;
- Scattered to dense stands of northern coastal scrub dominated by coyote brush (*Baccharis pilularis)* and silver lupine (*Lupinus albifrons*) whose occurrence and density depended on intensity of local grazing by elk, antelope and deer, and frequency of introduced fire by Native Americans; coyote brush in particular is an aggressive invader that tolerates a range of soil types. While some have speculated that it could have occurred across most of the site (Ford pers. comm.), this is highly unlikely based on historical evidence (Minnich 2008).

The justification for the hypothesized occurrence and distribution patterns of these plant associations comes from a variety of sources including the site's geomorphology, hydrology and soil characteristics, known autecological characteristics of native bunchgrasses, *Leymus triticoides*, *Baccharis pilularis*, *Distichlis spicata* and other native plants on the site, and observations by the author of the distribution patterns of remaining native grasses and forbs on this as well as dozens of other grassland sites throughout interior California over the past 20 years. Section 8 provides a detailed discussion of the current distribution patterns of native plant species on the site and the relationship of these patterns to site physical and land use conditions.

6.3.2 Wildlife

The terrestrial wildlife community of the region was also subjected to significant changes following the arrival of Europeans. By the late 1800s, many of the large mammals native to the region had been extirpated due to sport killing and overharvesting including tule elk, pronghorn antelope and grizzly bear (Williams 1986). The tremendous native bird populations, described in various historical accounts, were also greatly reduced by hunting, draining and diking of the marshlands, and disturbance of other habitats important for their existence. Furbearers were also an important component of the wildlife community such as beaver, otter, and mink. Populations of these species were also dramatically reduced through over trapping.

As with the grasslands, the changes in the wildlife community occurred before there were any serious scientific characterizations so that knowledge of the original community is based mostly on anecdotal observations of early explorers and settlers. Nearly all of these accounts focus on more charismatic or readily observable wildlife and species of commercial interest such as large mammals, large flocks of birds and furbearers. There is little to no information on smaller and more secretive mammal and bird species as well as most reptiles, amphibians and invertebrates.

Historical accounts make it clear that tule elk were abundant in the local region and undoubtedly grazed on and in the vicinity of the Rush Ranch site. In an 1832 journal entry, a traveler named Heather Davis who was traveling up the Carquinez Straits by schooner, recorded seeing hundreds of elk swimming from an island to the mainland in an area within southern Solano County. As the author describes, "(w)e came desperately close to crashing into several of these large animals, but after half-an-hour, we made our way through the herd safely". There are also various accounts of pronghorn antelope and grizzly bear around Suisun Marsh (Stein 2001) and the name of 'Grizzly Island', located just south of Rush Ranch, specifically derives its name from the occurrence of grizzly bears in the region. Stein (2001) relates, based on historical accounts, that "150 years ago, bears would regularly amble north across the relatively shallow bay and intervening slough from Mt. Diablo to Grizzly Island to nibble on the rose hips and wild blackberries growing there in great abundance”. Stein also relates an interesting anecdote from the subject of her book (Annie Alexander) about trapping “one interesting little mouse that is confined entirely to the salt marsh grass”, perhaps and an early reference to salt marsh harvest mouse (*Reithrodontomys raviventris*).

There are few historical accounts of avian use of the grasslands around Suisun Marsh. Most accounts focus on waterfowl species of interest to hunters and the large flocks of marsh birds historically prevalent in the region. It is assumed, however, that most bird species that currently breed or foraging in the grasslands also did so historically. Northern harriers, short-eared owls, grass sparrows, mallards, and other ground nesting birds likely nested heavily throughout the denser grass stands on the low alluvial fans near the marsh while numerous raptors and songbirds used the grasslands throughout the site for hunting and foraging.

It is difficult to assess the ecological effects to the grasslands from the loss of the native grazers and their replacement by domestic livestock since there was a simultaneous replacement of the native grassland plant species by non-native species. Together, these replacements represent a profound directional change to new ecological conditions at the site.

7 Landscape Units and Associated Plant Communities

The geomorphology of a site often provides a profound framework for understanding the overlying ecological process and functions including hydrologic patterns, distributions of plant communities and individual wildlife and plant species, and characteristics of important microhabitats utilized by rare and endangered species. Rush Ranch has an interesting geomorphic setting that directly and dramatically influences site ecology and species. This section provides a detailed description of the geomorphic landscape units and subunits that underpin site ecology and the current plant communities associated with these units.

7.1 Typology of Landscape Units

Physical processes (geomorphic and hydrological dynamics) and vegetation processes are inseparable in their effects on Rush Ranch habitats and ecosystem services that matter to land management and restoration planning. Classification and analysis of physical processes, geomorphology, vegetation, and habitat structure relevant to Rush Ranch, however, have developed separately as specialized sciences, each with sampling frameworks that apply different terms, concepts, and analytic approaches. This segregation of specialized disciplines that are mutually relevant can make practical, interdisciplinary integration challenging. For example, contemporary vegetation classification based on dominant species does not correspond with ecological frameworks based on hydrology (flooding, saturation, tidal elevation parameters), soil or sediment transport, or topography – all aspects of tidal marsh vegetation that area closely related for long-term planning, management, and monitoring.

The following working conceptual model of Rush Ranch landscape units attempts to unify dynamic geomorphology, hydrology and vegetation, and provide a comprehensive framework for integrating descriptions of dynamic “existing conditions” over long periods of time. The goal of a working integrated hypothesis of the long-term (late Holocene through modern) physical geography of Rush Ranch is to enable ecological and physical monitoring or observation in the short-term (“snapshots” in deep time) to share a conceptual framework with future analysis of climate change and sea level rise, and also paleoecological evidence of past vegetation responses to climate change. This is a coarse landscape ecological model applicable over geomorphic and ecological time (decades to centuries) in which more narrowly focused, specific ecological models or hypotheses covering shorter time-scales may be incorporated.

Major classes of vegetation/soil/geomorphic landform types are proposed for recent historical landforms with relatively homogeneous dynamic vegetation patterns and plant community composition identifiable from aerial photographs and “ground truthing.” The broad classification units are constructed to unify many diverse, fluctuating smaller units (such as individual objective plant assemblages with relatively short duration) that are likely to respond together to major environmental drivers of change. The “existing” landscape at Rush Ranch is the product of late Holocene landforms and vegetation remnants emerging through major climate fluctuations (Section 7; approximately 2,000 yr old mature marsh soil and topographic template) modified by prehistoric aboriginal land uses (principally grassland burning) and historic (post-1850) agricultural land uses and current agricultural and conservation land management.

Table 2 summarizes the geomorphic landscape units and associated subunits identified on the site. As shown, there are three hierarchical levels – primary units, primary subunits, and secondary subunits (i.e. Terrestrial Landscape > Hillslopes > Upper Convex Slopes). Figure 6 displays the distribution of the first two hierarchical levels on the site.

The identified units and subunits are based on differences in historical genesis and/or current ecological function and process and also reflect important ecological differences relevant to modeling of the site. The units and subunits were identified by the lead ecological team for the project based on knowledge of common topological landscape units within Bay-Delta landscapes augmented by in-depth experience with these landscapes over the past two decades.

The three primary units, terrestrial landscape, fluvial landscape and estuarine landscape, have clear and distinct differences in the overall physical and biological characteristics. The primary and secondary subunits reflect more subtle differences in historical genesis and/or current ecological processes that result in distinct geomorphic environments and associated plant communities within the primary units.

7.2 Terrestrial Landscape Units and Vegetation

The terrestrial landscape has three main subunits: hillslopes, older alluvial fans, and man-made basins (Figure 6). The hillslopes and fans are currently dominated by non-native grasses and forbs introduced since the time of European arrival. Still, these areas continue to support a low cover of numerous native grasses and wildflowers. The most common native grasses include purple needlegrass, creeping wildrye, and salt grass. The most common native wildflowers include narrow-leaved mule’s ears (*Wyethia angustifolia*), Great Valley gumplant (*Grindelia camporum*), white-leaf bush lupine (*Lupinus albifrons*), and California poppy (*Eschscholtzia californica*). There are also some scattered coyote brush shrubs growing on hills and fans near the marsh edge in the central portion of the site, mostly in areas excluded from grazing.

7.2.1 Primary Drivers of Terrestrial Plant Community Composition and Distribution

The primary influences on species composition and distribution within the current terrestrial plant communities include: 1) the mix of existing species that have colonized the site , 2) the underlying geomorphology and soils, 3) climate, 4) grazing, 5) fire, 6) disking or farming, and 7) topographic alterations. These include both relatively permanent influences beyond human control (geomorphology/soils, climate, and plant species not susceptible to management) that set the basic framework for the communities, and more transitory, controllable influences (grazing, fire, manageable plant species, farming and disking, and topographic alterations) that can alter community composition and distribution within the basic framework. There are other potential influences such as herbicide application, manual weed removal, and restoration planting, though these are all fairly expensive techniques generally applied to more limited areas and thus not considered potential ‘primary’ influences.

It is critical to understand the nature and potential range of effects from these influences since they underpin current ecological conditions within the grasslands and provide the basis for a conceptual model of future potential changes. Also, by understanding these influences, it becomes clear that there is no ‘natural’ mature ecological state within the grasslands - only the current temporary state that has resulted from the combination of these influences over historic and recent time.

Mix of Existing Species. The grasslands of California and western North America evolved over many millions of years and, just prior to European arrival, had come to be dominated by a mix of perennial grasses and perennial and annual forbs with, apparently, a fairly low cover and diversity of annual grasses (such *Vulpia* spp.). Yet, when European annual grasses were introduced (*Bromus* spp., *Hordeum* spp., *Avena* spp., etc.), they readily and rapidly colonized and largely replaced the natural grasslands. Obviously, these species were well-suited to the Mediterranean-style climate present in California but did not have the capacity to colonize the region until facilitated by human transport. An interesting question is why more dominant annual grasses had not evolved within the California region if the environment was apparently so suitable to their existence. It could be argued that the warming and drying trend coming out of the last ice age had created an ecological ‘pressure’ that made the eventual dominance by annual grasses somewhat inevitable via either evolution of new species or colonization by existing species.

The current mix of grasses and forbs present on the site include those non-native species that have been both introduced to the region and able to colonize the site within the prevailing environmental conditions as well as those native species that have been able to persist in competition with the non-native species. The various non-native species currently on the site arrived in California and subsequently spread at different times and rates over the past 400 years (D'Antonio et al. 2007). The three most common and threatening invasive terrestrial weeds currently on the site (other than the European annual grasses) are medusahead, yellow star-thistle and Harding grass. All of these species are believed to have arrived in California in the mid to late 1800s (D'Antonio et al. 2007) but have become widespread and aggressively invasive only in recent decades (Heady 1977). Non-native species can displace native species but can also have even deeper effects on site ecology that can allow them to become entrenched. As an example, the replacement of deep-rooted perennial bunchgrasses by shallow-rooted annual grasses may have left deeper water resources underutilized promoting the colonization of deep-rooted weeds such as yellow star-thistle (Davis et al. 2000, Enloe et al. 2001). Medusahead can form dense mats of thatch that effectively prevent the growth of any other species. Undoubtedly, additional non-native species will continue to arrive, and existing or new species may spread with the potential to significantly change the future species composition of the plant communities on the site.

Geomorphology and Soils. The site geomorphology and soils exert a strong influence on the distribution of different plant communities and the composition and distribution of species within these communities. The most important division is between the higher elevation hillslopes concentrated in the eastern portion of the site (but also including a few small hills in the west near the marsh edge), and the lower elevation older alluvial fans around the base of the hills and extending west down to the edges of the estuarine and fluvial landscapes (Figure 6).

From a broad perspective, the hillslopes have steeper, more well-drained and often loamier soils that derived from in-situ weathering of underlying marine sedimentary rocks. In contrast, the older alluvial fans have gentler, more seasonally moist loam and clay loam soils formed in alluvium from the sedimentary rocks. The hillslopes generally support true upland plant communities. Variations in plant species composition across the hillslopes largely follow variations in soil depth, texture and associated seasonal moisture. The upper hillslopes are zones of soil erosion with generally shallower soils, lower clay content and lower seasonal moisture levels. In contrast, the lower hillslopes and concave slopes in the upper hillslopes are zones of soil accumulation with generally deeper soils, higher clay content, and higher seasonal moisture levels. The gentle to flat hilltops tend to have deep, loamy soils. Other unique soil microhabitats include Altamont clay and Diablo-Ayar clay exposures, saddles and swales often with heavier soils, and limited rock outcrops. The older alluvial fans often have more mesic grassland communities. Also, most of the fans soils have moderately alkaline clay to clay loam subsoil typically within 12 inches of the surface (USDA 1977). The fans soils generally have higher seasonal moisture levels than the hillslope soils. Variations in plant species composition across the fans follow variations in elevation (upper drier versus lower moister fan areas) and the thickness of surface soils influencing the level of alkalinity affecting plant growth.

Climate. Climatic variations that impact the site include the amount and timing of rainfall and temperature, both of which vary greatly (USDA 1977). The annual patterns of rainfall and temperature can greatly influence species composition with non-native annual grasslands from year to year (Heady 1977, Bartolome et al. 2007) and perhaps also within non-native perennial grasslands (such as Harding grass) though this is less studied. These variations, however, do not generally result in permanent directional changes in species composition except, perhaps, during extreme weather events. As an example, some researchers point to extreme drought in the late 1800s combined with heavy grazing as perhaps a catalyst for the widespread replacement of perennial native bunchgrasses by non-native annual grasses throughout the Central Valley (Heady 1988, Bartolome et al. 2007). In modern times, extreme drought combined with overgrazing could cause certain weed species, such as yellow star-thistle (D'Antonio et al. 2007) to become more abundant. The high level of annual variation in climate, combined with the tenacity of most grassland species, tend to overwhelm temporary effects caused by grazing or burning, greatly constraining the ability to effect permanent changes through site management (Bartolome et al. 2007, Reiner 2007).

Grazing. Grazing can have a profound, though typically temporary, influence on species composition within annual and perennial grasslands. The effects of native grazers are largely unknown since both the historic grazers and native grasslands were replaced by introduced species before the native conditions had been studied. There has, however, been extensive research on the effects of domestic livestock grazing (mostly cattle) on the current grassland communities. Jackson and Bartolome (2007), both California range management experts, provide a good recent synopsis of the current known effects of livestock grazing on species composition and diversity within California annual and perennial grasslands. They highlight several important points relevant to grazing effects on the grasslands at Rush Ranch. First, manipulation of the timing and intensity of grazing in annual grasslands can have limited effects on species abundance but does not substantially change species composition over the long term. Second, careful manipulation of the timing and intensity of grazing can be used to promote native perennial bunchgrasses and forbs and reduce invasive weeds including yellow star-thistle and medusahead, though results can be neutral or even negative. Also, the application of a single grazing regime can simultaneously have both positive and negative effects depending on the species of interest (such as simultaneously reducing yellow star-thistle and purple needlegrass). The authors stress that climate variability can greatly influence or overwhelm the outcome of managed grazing efforts. They also stress that the success in achieving vegetation goals relies on the careful development and implementation of a site-specific grazing management plan. Severe overgrazing, especially when prolonged for several season, can allow invasive weeds to get a foothold on a site that then become a more dominant component of the plant community. It can also extirpate grazing-sensitive native plants and increase site erosion.

In spite of these very cautious statements, the site currently shows some very dramatic variations in species composition and cover along fence lines separating grazed versus ungrazed pastures, as discussed below. These conditions indicate that on-going, managed grazing can have a significant influence on the site grasslands. Also, two of the most prevalent weeds on the site – yellow star-thistle and medusahead – are among the most studied in relation to grazing management making the potential for successful control more likely. Ford and Hayes (2007) also point out that grazing reduces the cover and presence of coyote brush in favor of grasslands.

The current grazing lessee is Tim Wellman who has been grazing the site for at least thirty years. Over that time, he has maintained a fairly consistent cow-calf grazing operation with current stocking rates of roughly 100 cow-calf pairs on site November through June and a small number remaining the rest of the year (Wellman pers. comm.). This stocking rate leaves residual dry matter levels ranging from roughly 300 to 1,000 lbs/acre during light to medium rain years and 1,000 to 3,000 lbs/acre during heavy rain years (Poerner pers. comm.). The range of values during the light to medium rain years falls within recommend values for optimum range production and maintenance of range health (Bartolome et al. 2002). Mr. Wellman does not typically vary stocking rates in response to the annual variations in grass production (Poerner pers. comm.). From 1990 through 1998, the grazing management plan for the site precluded grazing in the pasture west of Grizzly Island Road and north of the headquarters access road, presumably to enhance waterfowl and raptor nesting on the site (WRA 1990). However, this resulted in heavy overgrowth of Harding grass, Italian thistle and other invasive weeds (Poerner pers. comm.). Mr. Poerner began grazing this pasture again in the late 1990s which has mostly eliminated Italian thistle and greatly reduced the stature of Harding grass.

Fire. Fire can also have a profound though typically temporary influence on species composition within annual and perennial grasslands. As with grazing, the effects of apparently frequent burning of the original grasslands by Native Americans are largely unknown since the practice stopped with the decimation of the Native Americans and the native grasslands that were the target of burning were replaced by non-native grasslands. There has, however, been significant research on the effects of burning on the current non-native annual grassland communities.

There appears to be little research on the effects of burning on more mesic perennial grasslands.

Reiner (2007), an expert on the effects of prescribed burning in California annual grasslands, provides a good recent synopsis of the current known effects of burning on species composition and diversity within California annual grasslands and associated perennial bunchgrasses. He highlights several important points relevant to the potential effects of fire on the grasslands at Rush Ranch. First, burning often increases the cover of native and non-native annual forbs at the expenses of non-native annual grasses. Repeated annual burning typically continues this trend though species cover will typically revert to the original conditions within 2-4 years. Burning also reduces the cover of woody species such as coyote brush. Second, seasonal timing of burns can influence which species are most affected, with late spring fires being most effective for reducing species with summer seed set, such as medusahead and yellow star-thistle. Seasonal timing is also important for positively affecting populations of purple needlegrass. Third, burning is generally regarded as a positive and increasingly preferred restoration and management tool within California’s non-native annual grasslands since it can be effective while emulating disturbances from natural, historic fire regimes. As with managed grazing, the success of managed burning relies on the careful design and implementation of a site-specific plan. The plan should also consider integrated effects with the site grazing regime.

Intentional burning has not been conducted on the site for many years or even decades (Poerner pers. comm.). Nonetheless, managed burning could likely have a significant influence on the grasslands, especially since two of most prevalent weeds on the site – yellow star-thistle and medusahead – have been effectively controlled by fire on other sites.

There have apparently been only two accidental fires on the site over the past 20 years (Poerner pers. comm.). Both fires were accidently started along Grizzly Island Road and extinguished by the County fire department. The first fire burned several hundred acres between Grizzly Island Road and the marsh boundary in the pasture south of the headquarters access road (Middle Pasture). The second fire burned approximately 300 acres in the northeast of the site starting at the corner of the site near Hill Slough and burning east and southeast. The current policy is to suppress or extinguish fires on the site as a matter of safety except in the far northwest pastures (Poerner pers. comm.). The very limited number and extent of fires on the site means that fire currently has no significant influence on the terrestrial plant community characteristics.

Disking and Farming. Farming can cause profound, often permanent changes in the composition and cover within grassland communities. Available data indicates that native perennial bunchgrasses are generally eliminated from farmed areas (Stromberg and Griffen

1996, Stromberg et al. 2007). Once farming is discontinued, the area is typically recolonized by non-native species often including a high component of weedy species that thrive in the disturbed soil. Species composition and cover can also be influenced by the species planted for farming. Some species, especially grains, can continue to persist after farming is discontinued as a component of the naturalized community (Poerner pers. comm.).

There has been no recent or current disking or farming on the site except for annual disking of fire break along both sides of Grizzly Island Road and the headquarters entry road. However, the pasture north of the headquarters access road (Harding Pasture) was disked and planted in Harding grass in the 1960s (Poerner pers. comm.). At the time, Harding grass was being promoted by the government as a good pasture cover crop. Farming has not been conducted since the 1960s but Harding grass continues to dominate this pasture. Also, it has slowly spread elsewhere on the site where conditions are favorable (Poerner pers. comm.). There are no available records but it is likely that most or all of the site was dry farmed for grains in the late 1800s and/or early 1900s based on an understanding of historic farming practices throughout the region (Poerner pers. comm., Wellman pers. comm.). Mr. Wellman has a photograph from the early 1900s showing extensive disking (presumably for dry farming) across the hills on the ranch just east of Rush Ranch (currently owned by the Ditmer family). Native perennial bunchgrasses would have been eliminated from these farmed areas.

Topographic Alterations. Topographic alterations can affect surface hydrology by creating berms or basins that can cause surface ponding and the establishment of man-made seasonal or perennial wetlands. Surface mining and road construction are the main topographic alterations that have changed the terrestrial plant communities in particular locations on the site. Quarry sites in the northwest portion of the old alluvial fans have become remnant shallow basins that have come to support seasonal wetlands plants including many vernal pool indicator species. Various graded dirt roads occur on the site that have more compacted soils and can also act as conduits for transport of and colonization by invasive weeds. Grizzly Island Road also bisects the ranch with a right-of-way along each side between the edge of the road and the adjacent pasture fence. These rights-of-way typically have disturbed soils, have ungrazed and otherwise unmanaged vegetation, and a high cover of invasive weedy species. As such, they serve as source locations for weed invasions onto the site.

7.2.2 Key Plant Species Components within the Terrestrial Plant Communities

The current terrestrial plant communities on the site include numerous dominant or otherwise important plant species or groups of species important to the site's ecological functioning and modeling (Table 4). These plant species components are related to the plant association approach used in *A Manual of California Vegetation* (Keeler-Wolf et al. 2008), which is the current standard for plant community classification in California, but are more closely tailored to the site ecological functions. Table 4 summarizes these key plant species components along with their local distribution patterns and susceptibility to short- or long-term change from natural or anthropogenic influences. Their distributions on the site are also summarized in the section below. These components are divided among the hillslope, older alluvial fan and man-made basin geomorphic subunits since the conditions within these subunits are so distinctive. Most of the components have distinct distribution pattern based primarily on geomorphology and soils and the current grazing regime. The distribution of Harding grass is also strongly influenced by past farming of the species in the pasture north of the headquarters. The distribution of the man-made vernal pools is an artifact of past mining. The abundance of species within each component can vary from year to year based on annual rainfall and temperature conditions but these variations generally occur within the context of the overall patterns set by local geomorphology, soils and grazing. Fire is extremely infrequent on the site and so exerts no significant influence on the current distribution patterns.

There has been considerable research into the competitive interaction among various plant species components within California grasslands: introduced annual grasses, perennial bunchgrass and rhizomatous grasses, native and non-native forbs, and key invasive weeds such yellow star-thistle and medusahead. There has also been considerable research on the effects of grazing, fire and other land management practices in shifting species composition and cover among these components and in restoring elements of the original grasslands. The recently published *California Grasslands: Ecology and Management* (Stromberg et al. 2007) provides an excellent summary of the current state of knowledge and most relevant research related to these topics. A synopsis of some of the key findings and concepts presented in this book and various supporting papers as they relate to Rush Ranch is presented below.

The key plant species components on Rush Ranch are presented in Table 4. Among these, the mixed non-native annual grass stands may exert the strongest influence on the current grassland community since they are ubiquitous and dominant throughout nearly the entire terrestrial landscape. Research has shown that these species are prolific seed producers and also tend to germinate 1-2 weeks earlier than purple needlegrass as well as many native forbs. This combination of factors means that seedlings of the annual grasses can aggressively outcompete seedlings of purple needlegrass by using up soil water reserves within the upper 60cm and shading the younger seedlings. This often results in a high mortality of needlegrass seedlings in an early growth stage as well as low survivorship in the summer since the plants are not robust enough and may not have deep enough roots to withstand the summer heat and water stress. Interestingly, the lack of recruitment of new needlegrass plants may be due to a lack of a sufficient seed bank to contribute seedlings to the competitive mix as much as the actual competition with the non-native grasses pointing to both seeding and reducing competition from annual grasses as key components to successful restoration of purple needlegrass stands. Once established, mature purple needlegrass plants are quite resilient and can survive indefinitely within a matrix of annual grasses though some studies have found reduced seed weight and number in mature plants and other studies have found a slow decrease in the number of adult plants over time. Purple needlegrass can withstand and even benefit from grazing and fire though it may be killed by 'hot' fires caused by an excess of thatch build up. Purple needlegrass has also been shown to effectively compete against yellow star-thistle.

An interesting outcome of the loss of purple needlegrass is that deeper soil moisture reserves are left underutilized. Most introduced annual grasses utilize water within the upper 60cm of soil while purple needlegrass can extend roots below 1.5m. Loss or reduction of purple needlegrass from a site may facilitate colonization by deep-rooted invasive species, especially yellow star-thistle. Seedling competition with annual grasses can exclude or minimize yellow star-thistle colonization of a site but once it becomes established, it utilizes different soil moisture depths than these grasses. Yellow star-thistle can exist in low density on a site for many years but then greatly increase due to site disturbance or change in management regime, such as severe overgrazing during a period of drought. Once established, it is can be reduced through careful grazing and fire regimes as well as targeted herbicide or biological control applications.

There have been few studies assessing competitive interactions between medusahead and more common introduced annual grasses. Medusahead competes for the same soil moisture as these species though it generally grows on more clay rich, seasonally moist soils. In an ungrazed or otherwise unmanaged condition, medusahead can form a dense thatch, often many centimeters thick that can strongly inhibit germination of other species resulting in essentially monotypic stands. Medusahead also has silica in its tissues making it unpalatable to livestock, especially in a more mature state. Thus, this species, if unmanaged, can greatly degrade the quality of grasslands for both livestock and other plant species. Like yellow star-thistle, medusahead can be effectively reduced through careful grazing and fire regimes.

Ungrazed or burned introduced annual grasses can reduce the cover of native forbs due to the same competitive pressures as described for purple needlegrass. Many studies have found that reducing the cover of these grasses, through grazing, burning or some combination of both, results in an increase in cover of both native and non-native forbs. While these outcomes seem promising for native forb cover, there can also be unintended outcomes such as colonization by undesirable invasive forbs.

There have been few studies on competitive interactions between Harding grass and native grasses and forbs. Some limited studies and anecdotal observations have found that both Harding grass and creeping wildrye are reduced or eliminated by grazing. Thus, it appears that one of the main management tools available on Rush Ranch for improving or restoring the grasslands on the older alluvial fans cannot be used to simultaneously reduce the invasive Harding grass and enhance the native creeping wildrye. Other, more multifaceted techniques will need to be devised to achieve these twin goals. Creeping wildrye does appear able to colonize, as the dominant species, ungrazed low-lying areas adjacent to the marsh without being intruded by Harding grass.

There are also few studies on the effects of grazing or fire on saltgrass. However, based on observations by the author at Rush Ranch and elsewhere, it appears that saltgrass is resistant to grazing since it is fairly widespread within existing grazed pastures. This resistance may be due to the low-growing, rhizomatous, perennial nature of the plant along with the salt crystals it exudes making it perhaps less palatable to livestock. Saltgrass also likely competes well against other plant species since it preferentially inhabits alkaline soils, often in barren areas with a low cover of other species.

Coyote brush currently occurs as a limited number of individuals or small stands on the site, mostly in ungrazed areas. Research and anecdotal observations clearly show that this species is reduced or eliminated from a site by grazing and fire, with more severe effects from more intensive grazing or more frequent fire. The presence of coyote brush in some ungrazed areas on the site and the near complete lack in grazed areas indicates that the species would likely colonize significant areas within the grasslands in the absence or minimization of both grazing and fire.

7.2.3 Current Plant Community Composition and Distribution

The current upland terrestrial plant communities (hillslopes and older alluvial fans) are heavily dominated by introduced annual and/or perennial grasses with a low cover (typical range of 0-5%) of native grasses and forbs during most years. There are a total of 30-40 individual bushes or small stands of coyote brush near the marsh boundary south and southwest of the site headquarters, mostly in areas excluded from grazing. There are no other shrubs or trees within the terrestrial landscape except eucalyptus (*Eucalyptus globulus*) and various horticultural and native plantings around the headquarters and a few planted valley oaks (*Quercus lobata*) along the entry road leading to the headquarters. All other woody vegetation on the site is associated with the seasonal creeks (fluvial landscape) or tidal marsh (estuarine landscape). Overall, the upland terrestrial plant communities, in their current condition, may be regarded as having a low to moderate ecological function based on the relatively low cover of native species and the relatively high cover of undesirable invasive weeds. Perhaps the best function of the current grasslands is a foraging and nesting habitat for a host of special-status and other birds.

The vernal pools in the man-made basins, on the other hand, are dominated by native seasonal wetland plants including many specialist vernal pool indicator species.

7.2.4 Hillslopes

The hillslopes are dominated by four introduced annual grasses – soft chess, ripgut, wild oats, and Italian ryegrass. These form the dominant matrix of the plant community. These species are widespread throughout the hillslopes with soft chess ubiquitous, ripgut and Italian ryegrass throughout most areas and wild oats the most patchy. Wild oats is most common on deeper soils where grazing appears less intense. Italian ryegrass is densest on more seasonally moist soils such as Altamont and Diablo-Ayar clays and around the bases of the hillslopes with heavier soils.

Within this matrix are a limited number of stands of native purple needlegrass and saltgrass. Nearly all larger stands of purple needlegrass are in midslope locations on Millsholm loam soils. The reasons for this distribution pattern are not clear but likely relates to a combination of soil depth (to bedrock), seasonal moisture level, and reduced competition from annual grasses. Perhaps the best stand on the site is on the west-facing hillslope just across from and north of the junction of the Grizzly Island Road and the entry road to the Rush Ranch headquarters. This stand extends across the entire midslope of the hill to just above the stock pond to the north. The average cover of purple needlegrass in this stand is around five percent. Other, smaller stands with comparable cover occur in a few other similar geomorphic locations in the hillslopes. The current limited distribution and lack of more purple needlegrass in the hillslopes may not necessarily reflect a lack of suitable habitat. Most if not all of the hillslopes may have been historically disked and farmed which would have eliminated the species. Saltgrass occurs in limited areas in the hillslopes, mostly on the lower slopes of hills with Diablo-Ayar clay and Altamont clay. Both of these soils have moderately alkaline subsoil which, when near enough to the surface, provides preferred habitat for saltgrass. Creeping wildrye is essentially absent from the hillslopes under current conditions.

Most of the identifiable ‘stands’ of native wildflower on the site are concentrated on the mid to upper ‘shoulders’ of the hillslopes. This is a common distribution pattern the author has observed elsewhere in bay region grasslands. This is a convex slope position, prone so soil erosion rather than deposition, which may result in thinner soils and reduce the growth and competition from introduced annual grasses. The most common wildflowers include narrow-leaved mule’s ears, Great Valley gumplant, white-leaf bush lupine and California poppy.

The most common weeds in the hillslopes are yellow star-thistle and medusahead. There are also scattered low-density stands of Italian thistle. Yellow star-thistle and medusahead both occur widely but are most concentrated on lower hillslopes with deeper, heavier soils. Yellow star-thistle also occurs densely on the deeper soils of some hilltops. Italian thistle appears to favor more protected or seasonally moist soils but is apparently kept mostly in check by the current grazing regime.

7.2.5 Older Alluvial Fans

The older alluvial fans are dominated by a mix of introduced annual and perennial grasses. Harding grass is a common dominant, especially in the pasture north of the headquarters where it was planted in the 1960s as a cover crop and continues to persist as the predominant species. Elsewhere, there are scattered to dense stand which may largely be the result of dispersal from the planted pasture. Grazing strongly reduces the cover and stature of this species. There are several fence lines crossing the older alluvial fans separating grazed from ungrazed pastures with Harding grass dominant or predominant on the ungrazed side and reduced to nearly absent on the grazed side. Soft chess, rip cut and Italian ryegrass are also a common matrix species in this area, generally forming a low understory beneath stands of Harding grass or the dominant matrix where Harding grass is absent. Italian ryegrass is a stronger component as compared with the hillslopes, especially on the lower fans, given the seasonally moister soils conditions.

Creeping wildrye is mostly restricted to a band along and extending down into the upper tidal marsh-terrestrial ecotone. It is conspicuously absent from the remainder of the fan areas and from all grazed areas. Where a fence line is near the marsh edge, it grows only on the ungrazed side right up to fence line but scarcely beyond. There are a few areas where very low gradient topography extends into ungrazed areas several hundred feet from the marsh edge (such as the area southwest of the headquarters and the southeast corner of the site). In these areas, creeping wildrye is often the dominant species, sometimes along with saltgrass. It was not observed in other ungrazed areas further up the fans (areas completely above tidal influence) and it is unclear if it could colonize these areas based on the available soil moisture regime, even in the absence of grazing or competition from other plants. Salt grass occurs more widely on the fans, often in dense stands near the marsh edge, and in low density stands within localized barren areas or as scattered individuals across portions the rest of the fans. The primary soil on the fans is Antioch-San Ysidro loam which has a moderately alkaline soil below about 12 inches which is likely the cause of the widespread occurrence of saltgrass. Purple needlegrass was observed in a few localized areas where a slight rise in the local topography apparently created deeper, more well-drained soils that allowed the species grow. The general lack of purple needlegrass on the fans may not be a good indicator of habitat suitability since most if not all of the fan areas were likely farmed in the past which would have eliminated the species.

Native wildflowers are largely absent from the older alluvial fans perhaps due to a combination of low habitat suitability, competition from non-native species and past disking and farming of the area. A few individuals of California poppy and some stands of Fitch's tarplant (*Centromadia fitchii*) were observed on the fans.

The most common weeds on the older alluvial fans are Harding grass, medusahead and yellow star-thistle. There are also stands of Italian thistle, milk thistle, fennel, and purple star-thistle but these are generally restricted to ungrazed areas near the marsh edge or road edges except Italian thistle which occurs in low density stands in scattered areas across the fans. The current grazing regime appears to be keeping these species in check. The distribution of Harding grass is described above. Medusahead and yellow star-thistle are both widespread on the fans, sometimes occurring as dominant species. Both species favor the heavier, seasonally moist soils of the fans. Medusahead is equally distributed across both the upper and lower fans. Yellow star-thistle typically has a higher density on the upper and mid fan regions but generally thins out nearer the marsh edge. There is some evidence that grazing affects the cover and distribution of these two species. Along the east-west fence line in the northeast of the site that separates a grazed and ungrazed pasture, medusahead (along with Harding grass) is much denser in the ungrazed pasture while yellow star-thistle is much denser in the grazed pasture, at least in the vicinity of the fence line.

7.2.6 Man-made Basins with Vernal Pools

The man-made basins within the old quarry sites are subject to prolonged shallow ponding during the rainy season. There are a total of 12 basins in two separate areas, all of which support seasonal wetlands with a mix of vernal pool indicator plants and more generalist seasonal wetland plants (Vollmar Consulting 2006). Maximum ponding depth ranges from 2 to 12 inches with most between 4 and 8 inches. Overall, these wetlands may be regarded as vernal pools given the dominance of vernal pool indicator species. These species include pale spikerush (*Eleocharis macrostachya*), stalked popcornflower (*Plagiobothrys stipitatus* var. *micranthus*), rayless goldfields (*Lasthenia glaberrima*), common mousetail (*Myosurus minimus* ssp. *minimus*), woolly marbles (*Psilocarphus brevissimus* var. *brevissimus*), maroon calicoflower (*Downingia concolor* var. *concolor*), and Vasey's coyote-thistle (*Eryngium vaseyi*). Common generalist seasonal wetland plants include meadow barley (*Hordeum brachyantherum*), bird's-foot trefoil (*Lotus corniculatus*), Harding grass, curly dock (*Rumex crispus*), blue-eyed-grass (*Sisyrhynchium bellum*), rabbit's-foot grass (*Polypogon monspeliensis*), brown-headed rush (*Juncus phaeocephalus* var. *phaeocephalus*), and spiny-fruited buttercup (*Ranunculus* *muricatus*). The pools also support some halophytic species indicating alkaline soil conditions including saltgrass (*Distichlis spicata*), brass buttons (*Cotula coronopifolia*) and alkali heath (*Frankenia salina*). No special-status plant species have been found within the pools and are unlikely to occur based on the results of past surveys and the artificial origin of the pools (Vollmar et al. 2006). Special-status species with low potential to occur include Contra Costa goldfields (*Lasthenia conjugens*), saline clover (*Trifolium depauperatum* var. *hydrophilum*) and alkali milk-vetch (*Astragalus tener* var. *tener*).

7.3 Alluvial Landscape Units and Vegetation

Alluvial landscape units include younger alluvial fans and their associated features such as braided channels and meander scarps, the seasonal stream channel and riparian zone, and impoundments (Figure 6).

7.3.1 Younger Alluvial Fans and Associated Features

Alluvial fans are depositional landforms that develop by turbulent hydraulic transport of coarse to fine sediments eroded from hillslopes during periods of high rates of runoff. Depositional structures develop where very shallow channelized flows of seasonal or ephemeral streams with high sediment loads spread into shallow distributary channels and sheet flow with low competence. In actively forming alluvial fans, the subaerial delta-like or splay-like depositional features are composed of a complex, often braided network of unstable small distributary channels, meander scars (scarps, pools) associated with abandoned channels. Sediment grading may occur in larger fans (like Spring Branch Creek), with relatively finer-grained sediments (silts, clays) concentrating in low-gradient (gently sloping or backwater areas between ephemeral or incised channels) low-energy environments within the fan. Alluvial fans also deposit salts where hillslope source rocks and soils (marine sandstones) contain alkali or salts, as at Rush Ranch. Coarser sediments (resulting in increased permeability and drainage) are associated with active channel beds and banks if they are eroded and transported from hillslope sources. Alluvial fans may be connected to existing drainage patterns and subject to periodic reactivation (sediment erosion, transport, deposition), but geologically older, relict fans may be disconnected from their original formative drainage patterns, and become relatively stable.

At Rush Ranch, Spring Branch Creek has a major active alluvial fan developed below the culverts on Grizzly Island Road. Portions of the creek floodplain above the road are also part of the alluvial fan head, but are constrained by the road as a distinct depositional sloping floodplain environment. The incised channel and stabilized channel position associated with the road culvert constrains depositional dynamics of the lower fan below the road (channel avulsion, meandering processes). The periodically reactivated depositional flats, sediment lobes and microtopography of the Spring Branch Creek alluvial fan maintain alkali flat microhabitats and shallow pool habitats. The active alluvial fan historically graded into tidal marsh to a greater extent than modern conditions allow with the berm and culvert across the fan mouth (former impoundment), which now allows choked tidal flows to reach over the lower fan. Extreme high tides formerly flooded a larger proportion of the alluvial fan.

The vegetation of the active depositional alluvial fan is influenced by periodic depositional and erosional events associated with major rainfall and runoff events (ENSO and PDO periodicity), relatively fine sediment deposition (mostly silts) and salts deposited in the fans derived from source rocks as well as former tidal incursions over the lower fan. The pre-agricultural vegetation of the lower fan is not known, but likely shared many or most dominant species known from seasonal wetland alkali grasslands that are still present: saltgrass (*Distichlis spicata*), meadow barley (*Hordeum brachyantherum*), alkali-heath (*Frankenia salina*), spikeweeds (*Centromadia fitchii, C. pungens*), tarweeds (*Hemizonia* spp.), seepweed (*Arthrocnemum subterminale*), cressa (*Cressa truxillensis*), toad-rush (*Juncus bufonius*). Moderately salt-tolerant wet meadow plants present elsewhere on Rush Ranch today also were likely components of some portions of the lower fan (especially on clay-rich deposits in depressions or flats between channels), particularly *Carex praegracilis*. Agricultural use introduced an additional and now dominant flora, including Mediterranean barleys *Hordeum marinum* ssp. *gussoneanum*, *H. murinum*, ryegrasses (*Lolium* spp.), and sicklegrasses (*Hainardia cylindrica*).

The lower alluvial fan at Spring Branch Creek, and probably other Rush Ranch drainages with similar features, supports alkali flats with sparse vegetation and relatively unconsolidated sediments, as well as cohesive unvegetated low scarps of intermittently active distributary channels. These features provide specialized sub-habitats for an exceptionally rich, localized and distinctive insect fauna at Rush Ranch; these species are described in detail below in Section 9.4.

Vegetation of inactive alluvial fans (relict Pleistocene fans) grade into tidal marshes and seasonal wetlands, but are otherwise terrestrial grasslands. Where grazing has been excluded for over a decade bordering tidal marsh, they have been rapidly recolonized by lowland clonal perennial grassland and sedge meadow dominants (Holstein 2000) *Leymus triticoides* and (locally at SE Rush Ranch) *Carex praegracilis*.

7.3.2 Seasonal Stream Channel and Riparian Zones

Channel incision has occurred in upper Spring Branch Creek reaches of Rush Ranch, forming distinct silty mud beds (pools, runs, becoming disturbed seasonal wetlands after the rainfall season) cut into parent sandstone-derived soils, and steep near-vertical banks and slump blocks. Highly active erosion associated with incision and slumping of partially unvegetated banks appear to be directly related to concentrated grazing and trampling by cattle, which directly destabilizes sediments and inhibits establishment and spread of widespread perennial clonal graminoids, as well as woody riparian species that currently lack local source populations. Sediment eroded from incised channels is apparently deposited in the stream valley floodplain/upper alluvial fan above Grizzly Island Road during overbank events (indicated by silt deposits, debris), and especially in the depositional lower alluvial fan below the road culverts. The incised single channel appears to concentrate flows, and presumably lowers local seasonal groundwater elevations in the adjacent floodplain during the wet season.

Channel pools support locally abundant populations of small stickleback (*Gasterosteus aculeatus*; likely non-resident, from upstream impoundments off the Rush Ranch property) concentrated at high densities in drawn-down pools in spring/summer. Stickleback likely prey on native invertebrates that would otherwise be free from fish predation in ephemeral or seasonal pool habitats isolated from permanent water bodies.

The bed and banks of the incised channel are dominated by non-native seasonal wetland weeds and pasture grasses, including rabbit's-foot grass (*Polypogon monspeliensis*), brass-buttons (*Cotula coronopifolia*) and ryegrasses (*Lolium* spp.). No woody riparian vegetation occurs in the riparian zone, even widespread, early-succession species with widely wind-dispersed seed (willows, coyote-brush). No significant stands of native dominant sedges, rushes, or perennial grasses typical of seasonally wet or mesic stream channels or riparian vegetation are present in the heavily grazed and trampled pasture that occupies the riparian zone of Spring Branch Creek, but small colonies or scattered individuals of widespread native marsh graminoids are present. A small, dense, ungrazed stand of Baltic rush (*J. arcticus* ssp. *balticus*) is established at the spring bordering the impoundment adjacent to Grizzly Island Road, where a single cottonwood was artificially planted. The successful establishment of the cottonwood (*Populus fremontii*) indicates that groundwater conditions are sufficient to support woody riparian vegetation at least locally within some riparian zones of Rush Ranch drainages.

7.3.3 Impoundments

Artificially impounded perennial ponds used for stock watering occur in Rush Ranch drainages. The impoundments store runoff early in the rainfall season before the spillway of the berm is overtopped, and stored winter flows represent discharges lost to recharge of groundwater in the alluvial fan bordering tidal marsh. The freshwater (alkali) marsh vegetation bordering the largest impoundment on Spring Branch Creek supports fringing marsh dominated by cattails (likely non-native *T. angustifolia*), common spikerush (*Eleocharis macrostachya*) and water-plantain (*Alisma plantago-aquatica*), below a nearly barren cattle-trampled mud zone below steep banks. Stickleback, found in seasonal channel pools above the pond, likely inhabit the artificial pond year-round. Native aquatic and amphibious insects of the pond are low in diversity, and consist entirely of widespread, fast-colonizing species (W. Ericson, pers. comm.. 2010). Past seining conducted of impoundments on the site by Chris Searcy of U.C. Davis and Cassie Pinnell of Vollmar Consulting found an abundance of Pacific chorus frog (*Hyla regilla*) tadpoles as well as some adults but other amphibian species. No California tiger salamander (*Ambystoma californiense*) adults, larvae or eggs have been found on the site. No current information is available on amphibian populations of the pond, but the presence of egg and larval predators (stickleback) and permanent deep water is not conducive to native amphibians (tree frogs, salamanders) adapted to seasonal wetlands of valley floodplains.

The man-made basins within the old quarry sites are subject to prolonged shallow ponding during the rainy season. There are a total of 12 basins in two separate areas, all of which support seasonal wetlands with a mix of vernal pool indicator plants and more generalist seasonal wetland plants (Vollmar 2006). Maximum ponding depth ranges from 2 to 12 inches with most between 4 and 8 inches. Overall, these wetlands may be regarded as vernal pools given the dominance of vernal pool indicator species. Common vernal pool indicator species include pale spikerush (*Eleocharis macrostachya*), stalked popcornflower (*Plagiobothrys stipitatus* var. *micranthus*), rayless goldfields (*Lasthenia glaberrima*), common mousetail (*Myosurus minimus* ssp. *minimus*), woolly marbles (*Psilocarphus brevissimus* var. *brevissimus*), maroon calicoflower (*Downingia concolor* var. *concolor*), and Vasey's coyote-thistle (*Eryngium vaseyi*). Common generalist wetland plants include meadow barley (*Hordeum brachyantherum*), bird's-foot trefoil (*Lotus corniculatus*), Harding grass, curly dock (*Rumex crispus*), blue-eyed-grass (*Sisyrhynchium bellum*), rabbit's-foot grass (*Polypogon monspeliensis*), brown-headed rush (*Juncus phaeocephalus* var. *phaeocephalus*), and spiny-fruited buttercup (*Ranunculus muricatus*). The pools also support some halophytic species indicating alkaline soils conditions including saltgrass (*Distichlis spicata*), brass buttons (*Cotula coronopifolia*) and alkali heath (*Frankenia salina*). No special-status plant species have been found within the pools and are unlikely to occur based on the results of past surveys and the artificial origin of the pools (Vollmar et al. 2006). Special-status species with low potential to occur include Contra Costa goldfields (*Lasthenia conjugens*), saline clover (*Trifolium depauperatum* var. *hydrophilum*) and alkali milk-vetch (*Astragalus tener* var. *tener*).

7.4 Estuarine Landscape Units and Vegetation

Estuarine landscape units include subtidal channel beds, fringing tidal marsh, tidal marsh plains, and the estuarine – terrestrial ecotone (Figure 6). Estuarine plant species currently found at Rush Ranch are described in Appendix B.

7.4.1 Subtidal Channel Bed

Subtidal habitats at Rush Ranch occur in beds of its largest sloughs, and consist almost entirely of unconsolidated bay mud (hypoxic, sulfidic, clayey silt mineral sediments with low percentage organic matter). These sediments are generally very low shear strength in shear strength in upper horizons, except where erosion exposes older, autocompacted bay mud, or where local submerged aquatic vegetation root masses occur. Small exposures of sandstone bedrock outcrops occur in subtidal slough beds along Suisun Slough's bluff scarps at Rush Ranch. Most subtidal beds are unvegetated soft benthos habitat supporting variable (presumably mostly non-native) benthic invertebrates, and bottom-feeding estuarine fish communities. Large stands of submerged aquatic vegetation, not yet diagnostically identified, but very likely sago pondweed (*Stuckenia pectinata*, syn. *Potamogeton pectinatus*) beds, occur in Suisun Slough near the diked marsh. Sago pondweed subtidal beds have not been surveyed at Rush Ranch, but are likely to occur in other low-energy subtidal environments, and are expected to increase in size and frequency when suspended sediment concentrations decline for successive months or years. Sago pondweed beds generally support rich invertebrate populations and small estuarine fish, and provide foraging habitat (invertebrates and vegetative matter, including carbohydrate-rich seeds, tubers, and foliage) for dabbling ducks (Kantrud 1990). Extensive subtidal pondweed beds have recently been discovered around Chipps Island, and represent a previously undocumented and probably ecologically important subtidal habitat (K. Boyer, San Francisco State University, C. Enright, California Department of Water Resources, pers. comm.. 2009).

7.4.2 Fringing Tidal Marsh

Fringing tidal marsh occurs as relatively narrow bands of gently sloping to planar tidal marsh between uplands (hillslopes, scarps, alluvial fans) and wide tidal sloughs, distinguished by either a lack of internal tidal channels, or minor simple, short, and unbranched tidal channels. Fringing marshes at Rush Ranch appear to have no history of ditching or diking, and represent relict prehistoric marshes. At Rush Ranch, fringing tidal marsh is generally composed of mostly organic peaty sediment, except at edges of active or recently active alluvial fans. Slough banks of fringing marsh exist as erosional scarps (unvegetated or sparsely colonized by *Isolepis cernuus* and *Lilaeopsis masonii*), or tule and cattail-dominated low marsh (*Schoenoplectus acutus, S. californicus, Typha domingensis, T. latifolia, T. angustifolia*) locally including Lyngbye's sedge (*Carex lyngbyei*) colonies at the outer edge of tules at Suisun Slough and Hill Slough, and possibly elsewhere. Mason's lilaeopsis (*Lilaeopsis masonii*) colonies also occur in edges of erosional fringing marsh. Fringing low marsh provides wave attenuation functions (wave energy damping, proportional with width, stem height, and density) and erosion buffering of fringing marsh scarps bordering wide, deep sloughs with westerly wind fetch.

The fringing marsh plain is generally well-drained high brackish marsh vegetation, and supports major populations of at least three rare plants, Bolander's water-hemlock (*Cicuta bolanderi*, syn. *C. maculata* var. *bolanderi*), Suisun Marsh aster (*Symphiotrichum lentum*), and Jepson's tule pea (*Lathyrus jepsonii var. jepsonii*). High fringing marsh supports very high native plant species diversity. It includes native dominants *Argentina egedii, Frankenia salina, Juncus arcticus ssp. balticus, Jaumea carnosa, Distichlis spicata,* and subdominants *Baccharis douglasii, Cuscuta salina*, *Glaux maritima, Euthamia occidentalis, Grindelia stricta,* and (locally) *Mimulus guttatus, Oenanthe sarmentosa, Pluchea odorata, Deschampsia cespitosa, Eleocharis macrostachya, Helenium puberulum, Lycopus asper, Rumex occidentalis,* and *Senecio hydrophilus*. This diverse, species-rich brackish marsh assemblage is relatively uncommon in the estuary (Baye *et al*. 2000) Although major invasive non-native wetland weeds are present in fringing marsh (*Lepidium latifolium, Apium graveolens*), they have at least not yet exhibited rapid rates of spread or dominance, in marked contrast with southern Rush Ranch marsh plain/slough systems. Suisun thistle is apparently absent in fringing marshes for reasons unknown, despite the local abundance of its historically associated species, Bolander's water-hemlock, and other likely indicator species of its microhabitat (*Senecio hydrophilus*).

Younger fringing marsh formed by progradation of wave-deposited coarse (organic and sandy) and fine suspended sediment (e.g. Rush Landing) is locally dominated by *Schoenoplectus americanus*, and includes patches of a distinctive glaucous-leaf form of *Scirpus microcarpus* as well as the largest population of Bolander's water-hemlock currently known at Rush Ranch. High fringing marsh-terrestrial ecotones with adjacent grassland are also notably high in native species richness and diversity, including *Ambrosia psilostachya, Frankenia salina, Leymus triticoides, Carex barbarae, Euthamia occidentalis, Cressa truxillensis*.

Fringing marsh edges are subject to erosional slumping and retreat. Slowly eroding banks appear to develop well-drained natural levee microtopography, but rapidly retreating fringing marshes appear to lack elevation gradients.

7.4.3 Tidal Marsh Plains

Tidal marsh plains comprise the largest marsh areas of Rush Ranch, and occur primarily along southern Rush Ranch (around Cutoff, First and Second Mallard Sloughs, and lower Suisun Slough), and Hill Slough east of the Grizzly Island Road bridge. Tidal marsh plains are dominated by dendritic tidal slough drainage networks, and are geomorphically mature (nearly 2000 year old features; Byrne *et al*. 2001). Most of the tidal marsh plain is dominated by high marsh flooded by tides at or above local MHHW (spring tides). Vegetation patterns evident in aerial photographs of the marsh plain trace of outlines apparent former marsh pans (undrained pond depression of interfluves) and are also implied by intensive historical ditching (to drain standing water breeding mosquitoes), and historic place-names “Mallard Slough” (proximate to broad shallow water and SAV habitat of dabbling ducks).

The tidal marsh plains support complex tidal marsh topography associated with sedimentation and drainage gradients patterned by tidal channel networks that transport sediment and flows. They support more topographic, habitat, and vegetation variability than fringing marshes, including complex internal distribution of contiguous channel bed, high marsh with tall vegetation (high tide cover, flood refuge habitat for wildlife).

The relatively well-drained deep peat banks bordering extensive internal networks of small (first order) tidal creeks in the marsh plain provide important habitat for high brackish marsh vegetation, including the endemic and endangered Suisun thistle (*Cirsium hydrophilum* var. *hydrophilum*). Relatively high density of flowering forbs and subshrubs in extensive channel-bank high marsh (e.g. *Frankenia salina, Grindelia stricta, Senecio hydrophilus, Pluchea odorata, Cirsium hydrophilum*) supports pollinator activity derived from insects nesting in terrestrial grassland habitats, foraging in the marsh when nectar sources are diminished in uplands during summer. The rare and endangered soft bird’s-beak (*Chloropyron molle ssp. molle*) is not currently known to occupy creekbank high marsh habitat at Rush Ranch, but it does so at Benicia (Southampton Marsh); this habitat should be presumed suitable where it consists of saltgrass, Frankenia, and dodder assemblages.

The tall creekbank high marsh vegetation, and the debris it traps, establishes the lowest flooding frequency and highest density of flood refuge habitat in the marsh. Creekbank high marsh vegetation is a core high marsh habitat for resident marsh mammals (salt marsh harvest mouse, *Reithrodontomys raviventris halicoetes*; Suisun shrew, *Sorex ornatus sinuosis*, a species apparently rarer than the endangered salt marsh harvest mouse). Creekbank high marsh and levees are also habitats for river otters (*Lutra canadensis*), nesting waterfowl, California black rails (*Laterallus jamaicensis coturniculus*), song sparrows (*Melospiza melodius samuelis*) and common yellowthroats (intermediate with salt marsh races; *Geothlypis trichas sinuosa*). California clapper rails (*Rallus longirostris obsoletus*), infrequent in modern Suisun Marsh, but likely past inhabitants during saline late Holocene phases of its development (and potential inhabitants of 21st c saline-brackish marsh conditions), also depend on high marsh of tidal creek banks for nesting and high tide cover. Peaty creek bank slump blocks and scarps provide basking habitat for resident populations of western pond turtles (*Clemmys marmorata marmorata*), particularly along Hill Slough.

Tidal marsh plains of southern Rush Ranch are not pristine (Byrne *et al*. 2001), and have a history of modification by extensive mosquito ditching (draining poorly drained marsh and pans between tidal channels, persisting today), partial diking and slough dams (subsided, eroded, and vegetated). Some of the fully tidal marshes present today may have regenerated from past episodes of partial diking and dike erosion. Tidal marsh plains are also generally composed of mostly organic (peat or muck) fine sediment 30-60% organic matter (Byrne et al. 2001).

Tidal marsh plains can be distinguished by vegetation and topography patterns into contrasting well-drained and poorly-drained areas. Well-drained high marsh plains form broad zones around tidal channels, and are generally heavily invaded by *Lepidium latifolium*, forming dominant canopies or dominating all vegetation layers. Uninvaded well-drained high marsh generally supports complex vegetation (including tall perennial forbs providing high spring tide cover) and high native species diversity, similar to fringing high marsh. Poorly-drained marsh plains occur in interfluves (topographic lows between channel drainages), and alternately act as evaporative basins during droughts (intermittent higher salinity brackish marsh; saltgrass, pickleweed vegetation prior to *Lepidium* invasion; Newcombe and Mason 1972), or middle marsh zones developing extensive low-diversity stands of bulrush (*Schoenoplectus americanus*) and rush-silverweed (*Juncus arcticus* ssp*. balticus-Argentina egedii*) during periods of relatively elevated sea level associated with El Nino events. The marsh plain rapidly underwent dominance shifts from prevalent saltgrass-baltic rush-pickleweed plains in the early 1990s to bulrush, rush, rush-silverweed and pepperweed-dominated plains following the 1998 El Niño event. Despite a subsequent drought cycle in the late 2000s, the marsh plain has retained extensive dominance by these post-El Nino assemblages (CDFG 2000).

Ditches (artificial channels) in tidal marsh plains consist of rectilinear excavated channels that cross or extend drainage networks, increasing drainage of poorly drained tidal marsh plain or historic ponds (pans). These features have persisted over the last half-century, and provide the majority of Suisun thistle habitat (Fiedler *et al.* 2004).

Persistent marsh plain ponds (pans) are not evident in the modern marsh plain, probably owing to extensive 20th century ditching. Ponds are potential mosquito habitats and were formerly drained by ditches and converted to marsh). Natural depressions in marsh plains, isolated from drainage networks, form permanent brackish ponds with permanently waterlogged soils and persistent standing water, flooded by infrequent (spring tide) overmarsh sheet flow. Analogs of natural ponds occur locally within the diked marsh along Suisun Slough, where they support dense beds of sago pondweed (*Stuckenia pectinata*), likely the primary SAV dominant of ponds. Archival descriptions of Suisun Marsh ponds by W.L. Jepson (Jepson 1904) indicate that they were extensive before diking and ditching of tidal marshes, and supported enormous quantities of both sago pondweed and canvasback ducks that seasonally exhausted most standing sago biomass.

7.4.4 Tidal Marsh – Terrestrial Ecotone

The high marsh ecotone (transition zone) with terrestrial vegetation types is variable at Rush Ranch, where some of the best remaining examples of undiked tidal-terrestrial ecotones remain in Suisun Marsh. Distinct ecotones occur with contacts between different geomorphic and drainage settings: relict inactive alluvial fans with terrestrial lowland grasslands, active alluvial fans with alkali grassland, and steep bluff scarp edges with riparian scrub.

Relict alluvial fan and gently sloping hillslopes are the prevalent tidal-terrestrial ecotone type at southern Rush Ranch. One distinct and widespread ecotone vegetation structure that has apparently regenerated since fencing excluded cattle grazing at the marsh edge is a nearly continuous patchy creeping wildrye stand (*Leymus triticoides*) extending into the high tidal marsh, as well as intermixed Mediterranean annual grass assemblages with dense, closed cover. A contrasting ecotone structure occurs where high marsh turf pans, dominated by nearly prostrate and sparse assemblages of saltgrass, pickleweed, cressa, occur over undrained but high elevation marsh. These develop cyanobacterial and algal mats that desiccate in summer, and support a distinctive and diminutive annual brackish marsh flora with affinities to playa, alkali grassland, and alkali vernal pools, including toad rush (*Juncus bufonius*), smooth goldfields (*Lasthenia glabrata* ssp. *glabrata*), butter-and-eggs (*Triphysaria versicolor*), and clubrush (*Isolepis cernuus*). This ecotone subtype likely supported federally listed endangered Contra Costa goldfields (*Lasthenia conjugens*), which occurs in highly similar estuarine-margin saline vernal pools bordering Hill Slough outside of Rush Ranch. Organic wrack deposits in the high marsh ecotone establish moisture refuges and cover that support dense populations of amphipods, an important potential prey base for insectivorous small mammals like Suisun shrew. Cover provided by debris wracks, locally dense pickleweed bordering hypersaline turf pans, and permanent tidal flood refuge cover in adjacent terrestrial grassland makes the tidal-terrestrial ecotone zone a potential primary subhabitat for the salt marsh harvest mouse. Unlike high marsh within the marsh plain, terrestrial-edge high marsh habitat equilibrates instantaneously with sea level rise because slopes are pre-existing, and do not depend on potentially lagging compensatory accretion rates.

The other distinct tidal-terrestrial ecotone type at Rush Ranch is formed at hillslope bluff scarps along upper Suisun Slough and Hill Slough. This “ecotone” is highly abrupt and sharp, not a gradient or typical “transition” zone. These bluffs locally intersect seasonal groundwater seeps, and are mostly north-aspect slopes sheltered from desiccation from onshore winds and southerly exposures. They support narrow, localized riparian scrub, including patchy dominants *Carex barbarae, Leymus triticoides, Sambucus mexicana, Rosa californica, Toxicondendron diversilobum, Baccharis pilularis, Ambrosia douglasiana,* and non-native invasive *Rubus armeniacus*. The lower edges of this riparian scrub ecotone, bordering fringing tule marsh, supports many or most populations of Delta tule pea. This riparian scrub ecotone may persist because most of the vertical slopes are inaccessible to cattle; less steep bluff slopes with cattle trails support minimal woody vegetation.

8 Special-Status Species

8.1 Fish

Suisun Marsh provides a broad range of habitat functions for fish, including serving as a spawning habitat, nursery, migratory corridor, foraging habitat, and refuge. Marsh geomorphology such as edge habitat, channel networks of varying complexity, and vegetated bank edges are known to be important habitat features for many fish species that utilize tidal marshes (Peterson and Turner 1994 and Visintainer et al. 2006). In areas of the Marsh other than Rush Ranch, levees prevent the development of edge habitat and obstruct hydraulic connectivity between tidal marshes and adjacent aquatic habitat. Rush Ranch's regionally unique morphology therefore makes it particularly well-suited to supporting fish species. The Spring Branch Creek corridor in particular harbors a high diversity and abundance of fishes (J. Durand, pers. comm. 2010). Despite these qualities, however, and likely due to factors that have little to do with estuarine habitat quality at Rush Ranch, fish species *of special concern* are rare in the Rush Ranch region of the Marsh. The life histories and habitat usage patterns of the few species that might make use of habitats within Rush Ranch are described below. Much of the information in this section is sourced from the draft species accounts for the Suisun Marsh Tidal Marsh and Aquatic Habitats Conceptual Model (Suisun Marsh Habitat Management, Restoration and Preservation Plan - Final Review Draft July 2010). Most of these species either use tidal marsh areas for foraging, or forage in subtidal aquatic areas on food exported from tidal marshes.

8.1.1 Delta smelt

Federally endangered Delta smelt (*Hypomesus transpacificus*), are an estuarine resident species that spawns in tidal freshwater (Moyle et al. 1992; Hobbs et al. 2007). They can briefly tolerate salinities as high as 19 psu (Swanson et al. 2000), but most individuals have been collected at salinities less than 2 psu as larvae (Dege and Brown 2004) and less than 5-6 psu as juveniles (Feyrer et al. 2007; Nobriga et al. 2008). They select waters that are well oxygenated and have relatively cool temperatures, usually less than 20-22 degrees Celsius (68-72 degrees Fahrenheit) in summer. Delta smelt are endemic to the upper San Francisco Estuary, and occur principally in the Delta and Suisun Bay (Moyle 2002). They have been found seasonally throughout Suisun Marsh in small numbers (Matern et al. 2002), but are currently very rare within the Marsh and even rarer near Rush Ranch (J. Durand, pers. comm. 2010). During high flow years they can spawn in the Napa River and be washed into San Pablo Bay, but do not establish permanent populations there. In all but high outflow years, the population has typically been centered in the northwest Delta in the Sacramento River during summer and fall. When not spawning, delta smelt tend to be concentrated near the zone where incoming salt water and out flowing freshwater mix (mixing zone). Channels in this area historically had the highest primary productivity in the Estuary and were where zooplankton populations (on which delta smelt feed) are usually most dense (Knutson and Orsi 1983, Orsi and Mecum 1986). The introduction of the overbite clam *Corbula amurensis* may be impacting populations and distributions of zooplankton within the marsh (Kimmerer and Orsi 1996), but a lack of historical data makes interpretation of existing zooplankton data unclear (J. Durand, pers. comm. 2010).

8.1.2 Longfin smelt

Longfin smelt (*Spirinchus thaleichthys*) is an anadromous state species of special concern that inhabits open waters of estuaries along the Pacific coast of North America. For juveniles through pre-spawning adults, optimum salinity ranges are typically 15 to 30 psu (Moyle 2002; Baxter et al. 1999), whereas during their spawning migration they prefer fresher water habitats where salinities are 0-2 parts per thousand. Spawning generally occurs from November until June, with the peak spawning period being from February through April, in areas that provide an adequate amount of rocks and/or submerged vegetation for eggs to adhere to. According to data from UC-Davis monitoring, longfin smelt can occur in the Marsh year-round, but they are mostly present during the larval stage when they use the brackish waters as nurseries. Longfin smelt abundance in the Marsh declined sharply in the early 1980s and has remained low since then (Matern et al. 2002). There has historically been a strong positive correlation between winter and spring Delta outflow and longfin smelt abundance during the subsequent fall (Jassby et al. 1995; Kimmerer 2002). High freshwater outflows increase the volume of low-salinity water rearing habitat required by larval and juvenile smelt. Historically, high freshwater flows also increased prey production for longfin smelt, but this changed after the introduction of the overbite clam (Kimmerer 2002). Salinity appears to have the greatest influence on larval distribution, and there is a strong relationship with X2, where the salinity gradient is 2 ppt (Kimmerer 2004). The center of larval distribution is correlated with X2, which is often centered in Suisun Bay (R. Baxter unpublished data). It is unclear why areas of the Marsh with high prey (zooplankton) populations do not support correspondingly high populations of smelt;

8.1.3 Sacramento splittail

The federally threatened Sacramento splittail (*Pogonichthys macrolepidotus)*, is a relatively large (>300mm in length) member of the minnow family. It is endemic to the San Francisco Estuary and watershed (Moyle et al. 2004). Juveniles and adults inhabit tidal fresh and brackish water in the Delta, Suisun Bay, Suisun Marsh, and lower portions of the Napa and Petaluma rivers and their marshes. They are abundant in moderately shallow (<4 m), narrow, turbid, sloughs lined with tules and other emergent vegetation (Feyrer et al. 2005; Moyle et al. 2004). In recent years, splittail have been most common in brackish tidal waters of Suisun Marsh and the Sacramento-San Joaquin Delta. Splittail exhibit significant use of floodplain and marsh habitats, so connectivity between channels and the marsh plain is an important habitat feature (J. Durand, pers. comm. 2010). The core of the distribution of adult splittail in summer lies between Suisun Bay and the west Delta. Juveniles and adults commonly inhabit salinities of 10-18 psu (Meng and Moyle 1995; Sommer et al. 1997), and adults can survive salinities up to 29 psu for brief periods of time (Young and Cech 1996). Splittail are found in waters with a broad range of temperatures from 5 to 24°C and can acclimate to temperatures up to 29-33°C for short periods. Splittail of all ages can tolerate low dissolved oxygen levels (<1 mg/L) (Moyle et al. 2004).

8.1.4 Chinook salmon

Chinook salmon (*Oncorhynchus tshawytscha*) follow the typical life cycle of Pacific salmon in that they hatch in freshwater, migrate to the ocean, and return to freshwater to spawn and die. Chinook salmon return to freshwater to spawn when they are three to eight years old (Healey 1991). Migration from the ocean to streams for spawning can be stimulated or inhibited by stream flow, atmospheric pressure, water turbidity, water temperature and dissolved oxygen (Allen & Hassler 1986). Chinook salmon runs are designated on the basis of adult migration timing; however, distinct runs also differ in the degree of maturation at the time of river entry, thermal regime and flow characteristics of their spawning site, and actual time of spawning (Myers et al. 1998). The different runs have been identified as Evolutionarily Significant Units (ESU), and the runs that have historically utilized Suisun Marsh are Central Valley fall and late-fall run (state species of concern), Sacramento River winter-run (federally endangered) and Central Valley spring-run Chinook salmon (federally threatened). Currently, Chinook salmon are rarely found in Suisun Marsh (J. Durand, pers. comm. 2010).

8.1.5 Steelhead

Steelhead (*Oncorhynchus mykiss*) generally follow the typical Pacific salmon lifecycle in that they hatch in freshwater, migrate to the ocean, and return to freshwater to spawn. However, steelhead are iteroparous, meaning they do not die after spawning and are capable of spawning more than once. Steelhead also exhibit greater variation than most anadromous fish in the time spent at each life stage. Steelhead from the tributaries of San Francisco Bay typically enter freshwater to spawn between November and April, with peak numbers occurring in January and February. Central California Coast and Central Valley steelhead are at, or near, sexual maturity when they enter freshwater and spawning occurs shortly after. Juveniles rear in freshwater for 1-4 years before migrating to the ocean as smolts. Emigration from natal streams occurs episodically during fall, winter, and spring high flows. Estuaries provide important transitional habitat for juvenile steelhead since they are used for rearing, foraging, freshwater to saltwater acclimation, and migration. The Distinct Population Segments (DPS) that have historically utilized Suisun Marsh are Central California Coast and Central Valley steelhead (both federally threatened). The DPS for Central California Coast steelhead pertinent to the Marsh includes all naturally spawned populations of steelhead in tributary streams to Suisun Marsh including Suisun Creek, Green Valley Creek, and an unnamed tributary to Cordelia Slough (commonly referred to as Red Top Creek). Suisun Marsh is the easternmost extent of their range. Currently, steelhead are rarely found in Suisun Marsh (J. Durand, pers. comm. 2010).

8.2 Estuarine Wildlife

Estuarine wildlife includes those species that primarily inhabit the estuarine landscape. Many of the species described in this section are dependent upon tidal marsh habitats; for these species, Rush Ranch provides the largest contiguous area of suitable habitat within all of Suisun Marsh. As above, much of the information in this section is sourced from the draft species accounts for the Suisun Marsh Tidal Marsh and Aquatic Habitats Conceptual Model. All of the species described below are target recovery species for habitat management and enhancement operations at Rush Ranch.

8.2.1 California clapper rail

The federally endangered California clapper rail (*Rallus longirostris obsoletus*) is a secretive, hen-like waterbird, indigenous to estuarine marshlands in the San Francisco Bay (Goals Project 2000). California clapper rails occur almost exclusively in tidal salt and brackish marshes with unrestricted daily tidal flows, adequate invertebrate prey food supply, well developed tidal channel networks, and suitable nesting and escape cover during extreme high tides. They once occupied coastal California tidal marshes from Humboldt Bay southward to Morro Bay, and estuarine marshes of San Francisco Bay and San Pablo Bay to the Carquinez Strait (SEW 2001). Resident populations are currently limited to San Francisco Bay, San Pablo Bay, Suisun Bay, and associated tidal marshes. Since most marshes in Suisun Marsh are diked, clapper rail presence in the Marsh is concentrated around the remaining tidal marsh habitats at Rush Ranch. Tidal marshes within Rush Ranch that are designated critical habitat for the rail include marshes in the Spring Branch area, and around First and Second Mallard Sloughs (CDFG 2009). Clapper rails have been monitored yearly in Suisun Marsh since 2002, and their variable presence in the Marsh may indicate that Suisun provides crucial habitat for this species (CDFG 2009). The rail has not been observed at Rush Ranch since 2003 (B. Wallace, pers. comm. 2010).

8.2.2 California black rail

The California black (*Laterallus jamaicensis coturniculus*) rail is listed as “threatened” by the state of California and is a federal species of concern. They occur almost exclusively in tidal marsh habitat (Evens et al. 1991, Manolis 1978, Nur et al. 1997), and the majority of the local species population is currently found in the historical marshes of San Pablo Bay, Suisun Bay, and the Carquinez Strait (Evens et al. 1991). The highest concentrations are in marshes associated with large rivers and sloughs (Petaluma River Marsh, Black John Slough, Coon Island, Fagan Slough, Napa River) (Evens et al. 1991, Nur and Spautz 2002); thus freshwater input to tidal marshes appears to correlate positively with black rail abundance. Within Suisun Marsh, black rails are found in both tidal and diked/muted tidal marshes. Surveys by PRBO, USGS, and CDFG have all found significantly high densities of California black rails in tidal marshes within Rush Ranch, especially near First and Second Mallards Sloughs (Nur and Spautz 2002, CDFG 2009, SLT correspondence with USGS 2009).

8.2.3 Yellow rail

The yellow rail (*Coturnicops noveboracensis*) is a small, reclusive rail that is currently a California species of special concern. Due to its secretive nature, its habitat preferences are not well documented, though it is known to inhabit wet meadows and coastal tidal marshes in winter. Though the species is extremely rare in California, recent surveys indicate that the species may be a regular winter visitor to Suisun Marsh (Sterling 2008 in Shuford and Gardali 2008). Surveys by the USGS in April of 2009 encountered two separate individuals in tidal S*cirpus/ Bolboschoenus* marsh at Rush Ranch, southwest of the ranch complex near the tidal portion of Spring Branch Creek (USGS 2009).

8.2.4 Suisun song sparrow

The Suisun song sparrow (*Melospiza melodia maxillaries*) is currently a federal species of concern. The Suisun song sparrow is a distinct subspecies of song sparrows completely endemic to Suisun Bay. Previous literature suggested that these birds are confined to undiked tidal marshes. However, field surveys by DFG and DWR have observed Suisun song sparrows along distribution ditches, permanent ponds, and other areas in diked wetlands of Suisun Marsh where required plant assemblages and brackish water conditions exist (Collins et al. 1994). Marshall (1948) and Cogswell (2000) point out that song sparrows use freshwater marsh, riparian vegetation along stream courses, coastal scrub, brackish marsh and salt marsh. Non-tidal seasonal wetlands may be used for foraging, but much less than fully tidal marsh. Suisun song sparrows are distributed over most of their original range, occurring in marshes from Martinez (Contra Costa County) eastward along the south bayshore of Suisun Bay to Pittsburg (Contra Costa County), then north of Suisun Bay throughout the extensive Suisun marshlands (Solano County). The reproductive success of the Suisun song sparrow was monitored at Rush Ranch and calculated to be approximately 27 percent. The density of Suisun song sparrows was estimated to be 11 birds per acre, with a total population estimated to be 22,000 to 53,000 (Nur et al. 1997).

8.2.5 Salt marsh common yellowthroat

The salt marsh common yellowthroat (*Geothylpis trichas sinuosa*) is a state species of special concern. It is a winter resident of tidal marshes but occurs in other habitats (often wetland ecotones) such as riparian thickets, freshwater marshes, marshy coastal forb vegetation, and brush or scrub near wetlands (Terrill 2000). Most breeding (60 percent in the San Francisco Bay region) occurs in brackish marsh, about 5 percent in salt marsh, and the remainder in other wetland or peripheral wetland habitats. Salt marsh common yellowthroats nest in a variety of habitats around San Francisco Bay wetlands and adjacent uplands; moisture appears to be the factor common to all types of breeding habitat. 2005 surveys by PRBO Conservation Science indicated that habitats at Rush Ranch support some of the largest populations of salt marsh common yellowthroat within the San Francisco Estuary; that same year Rush Ranch also supported one successful common yellowthroat nest (Liu et al. 2005). It is presumed that Rush Ranch continues to support salt marsh common yellowthroat breeding into the present-day.

8.2.6 Salt marsh harvest mouse

Federally endangered salt marsh harvest mice (*Reithrodontomys raviventris*) are small, native rodents endemic to the salt marshes and adjacent diked wetlands of the San Francisco Bay (Goals Project 2000). They are generally restricted to saline or subsaline marsh habitats around the San Francisco Bay estuary and mixed saline/brackish areas in the Suisun Bay area. The distribution of salt marsh harvest mice in Suisun is closely correlated with the abundance of mixed wetland vegetation (including native and non-native species such as fat hen, saltgrass, Baltic rush, Olney's three-square bulrush, and pickleweed) and pickleweed dominated vegetation. The salt marsh harvest mouse has been found throughout the Marsh in a variety of habitats. Current studies demonstrate that pickleweed is not necessarily the most "preferred" habitat as defined by the USFWS Draft Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California (USFWS 2010 DFG, DWR unpublished data) and their distribution is not restricted to pickleweed habitat. Ongoing genetic studies of the salt marsh harvest mouse in the Marsh show that the population is genetically diverse (Brown 2003). The Suisun Marsh has been extensively surveyed for salt marsh harvest mice since 1997 by DFG and DWR. Five tidal marsh areas (Peytonia Slough, Rush Ranch, Hill Slough, Joice Island, Lower Joice Island) in Suisun have averaged a much higher capture efficiency of than any other surveys conducted in the salt marsh harvest mouse's range. Locations in Rush Ranch with high salt marsh harvest mouse capture efficiencies are almost all in diked areas dominated by mature Olney's three-square bulrush with three to five feet of thatch; the mouse is infrequently encountered in areas dominated by tules or cattails (Shellhammer, pers. comm. 2010).

8.2.7 Suisun shrew

The Suisun shrew (*Sorex ornatus sinuosus*) is a federal and state species of concern with exceptionally narrow habitat requirements, primarily the ecotone between tidal wetlands and grassland uplands along Grizzly Island and the northern extremes of Suisun Marsh. Adjacent upland habitats are utilized by a close relative, *Sorex ornatus californicus* (Brown and Rudd 1981, Williams 1983). Due to its strict habitat requirements, Rush Ranch is one of the most important habitat epicenters for this small insectivore. Research by Hays and Lidicker (2000) indicated that the shrew has a unique ecology; it lives in distinct, rigid social groups comprised of a single adult male, multiple females, and subadults during the winter. Upon the arrival of the breeding season, these groups are invaded by numerous adult males, completely changing the social makeup of the groups. In additional, individuals also lose 30-40% of their body mass over the course of the breeding season, a phenomenon known as the Dehnel effect that is rare in temperate habitats such as those round in Suisun Marsh (Hays and Lidicker 2000). These unique behaviors may indicate that the Suisun shrew's genetic distinction could be impacted by habitat invasion by its upland cousin, *S. o. californicus*. Therefore, protection of adequate grassland and wetland habitat at Rush Ranch and similar areas is likely necessary to prevent interbreeding between the two species (Hays and Lidicker 2000, H. Shellhammer pers. comm. 2010).

8.3 Terrestrial Wildlife

Terrestrial wildlife includes those species that primarily inhabit or utilize the terrestrial or fluvial landscapes on the site rather than the estuarine landscape. **Table 5** contains an annotated list of special-status terrestrial wildlife species known or expected to occur on the site. As shown, all of the known or likely special-status terrestrial wildlife species are birds including seven raptor species and three songbird species.

The site is considered to be a regionally important nesting site for northern harrier and short-eared owl. These species nest primarily within tall grassland or marsh vegetation within the lower portions of the older alluvial fans and adjacent tidal marsh-terrestrial ecotone. Past nesting surveys conducted on the site found a high density of nests for both species within these habitats (McLandress 1987a and 1987b). Short-eared owls currently have fairly limited nesting areas within California, heightening the value of Rush Ranch for the species (Sloat pers. comm.). From approximately 1990-1998, grazing was discontinued in the pasture north of the headquarters (Harding Pasture) in an effort to protect and enhance nesting habitat for these species (Poerner pers. comm.). However, this resulted in tall, weedy growth of Harding grass, Italian thistle and other invasive weeds, likely reducing the quality of nesting habitats for these species. As a result, grazing was re-initiated after 1998.

The site is also considered to be an important foraging site for a broad range of special-status raptors and other, more common raptors. The intact grassland-marsh matrix provides a substantial prey base of the small mammals, birds and terrestrial invertebrates that are hunted by these species (see **Table 5**). More than a dozen different raptors have been documented on the site including seven special-status species (**Table 5**).

In the early 1990s, approximately 25 burrowing owls were released at Rush Ranch as part of a mitigation project; artificial burrows were constructed in and around the quarry area to house them. The burrows still exist, although there is little evidence of occupancy. Nonetheless, burrowing owls are observed almost every year on the property at locations including the quarry, the stock pond east of the quarry, the NE corner of the ranch, and the stock pond along Spring Branch Creek, all during the non-breeding season (B. Wallace, pers. comm. 2010). There was a recent sighting of a single adult western burrowing owl on the site near the entrance road to the headquarters. The owl was at a burrow and the sighting was in mid June, well within the breeding season (Scalf pers. obs). However, only one owl was observed, so it is not clear if the owl was actually breeding on sight.

The other special-status birds of note are songbirds. California horned lark is a ground nesting bird that nests and forages in primarily in grasslands. Loggerhead shrike nests in shrubs (which are mostly absent from the site) and forages in grasslands and scrub habitats. Both of these species have been observed on or in the immediate vicinity of the site. Tricolored blackbird is a colonial nester in emergent marsh and riparian scrub habitat that forages in surrounding marsh and terrestrial habitats, including grasslands. Data from the UC-Davis Tricolored Blackbird Working Group indicates that tricolored blackbirds have been consistently observed nesting on Rush Ranch from 2004-2008 (Sara Estrella, pers. comm. 2010).

8.4 Invertebrates

The lower alluvial fan at Spring Branch Creek, and probably other Rush Ranch drainages with similar features, supports alkali flats with sparse vegetation and relatively unconsolidated sediments, as well as cohesive unvegetated low scarps of intermittently active distributary channels. These features provide specialized sub-habitats for an exceptionally rich, localized and distinctive (including possibly endemic species and undescribed species; W. Ericson, STAT, pers. comm. 2010) insect fauna at Rush Ranch. The alkali flats, meadows, seasonal pools, and erosion scars are sub-habitats that support largest populations and diversity of Hymenoptera (wasps) and Cicindelidae (tiger beetles), particularly in bare or sparse sediment areas. These include:

- Hymenopteran bumblebee mimics, *Anthophora stanfordia*, in erosional scarps at alluvial fan and distributary channel margins (unvegetated, weakly cohesive vertical slopes in soft sandstone or sandy subsoil.
- Cicindelidae - tiger beetle family taxa. Adults hibernate; adults and larvae occur in/near fresh sediment deposits of unconsolidated or loosely consolidated, noncohesive silty or sandy sediment up to approximately 30 cm depth, avoiding dense root zones. They are also found among old rocks or old debris. Larvae occur under flooded pool beds. Maximum larval growth and survival apparently occurs in wet years. Adult populations peak around June. Regionally rare species present include *Cicindela haemorrhagica* (last detected at Rush Ranch circa 2003), a form that may be a morphologically distinct – possibly endemic – population or subspecies (W. Ericson, pers. comm. 2010). *C. senilis* (subspecies undetermined), regionally rare (Maffei 2000a,b) is observed consistently in alkali pools in the Spring Branch Creek alluvial fan (W. Ericson, pers. comm.. 2010). No Suisun Marsh localities of tiger beetles have been previously reported (Maffei 2000a, b).
- Staphylinid beetles, Anthribid beetles (family identification only). Rush Ranch is rich in taxa that are possibly undescribed species that inhabit playa-like, alkali flats of Spring Branch Creek alluvial fan. (W. Ericson, pers. comm.. 2010).
- Mutillidae (Mutilid wasps). Some known and some possibly undescribed species occur at Rush Ranch alkali pools, including:

  Sphaeropthalma edwardsii – specimens found in alkali pond, Spring Branch Creek circa 2000. This parasitic nocturnal species requires other ground-nesting hymenoptera for oviposition of eggs on wasp larvae.

  Photomorphus spp. – same life-history, habitat, and nocturnal habit as S. edwardsii.

  Dasymutilla aureola and *D. occidentalis* –These diurnal wasps run along dry bare sediment, including alluvial flats and foot trails around lower Spring Branch Creek. (W. Ericson, pers. comm. 2010).

- Coleopterid beetle – *Gyascutus* spp. (possibly undescribed species, disjunct population of a range extension for the genus otherwise found mostly in desert (washes, alkali), a biogeographic distribution comparable with Antioch Dunes endemic taxa. Unique Rush Ranch specimens appear to have affinities with *Gyascutus pacificus*. They occur on *Chenopodiaceae* sp. and *Frankenia* in the alluvial flats and also in tidal marsh. Genus Possible adult imitator of wasp *Cryptocheilus hesperus*. (W. Ericson, pers. comm. 2010)

- Sulifugae – camel spider/sun-scorpion. Previously undocumented high diversity of these taxa occurs at Rush Ranch, including possibly undescribed species, associated with alkali flat habitats of lower Spring Branch Creek alluvial fan and barren trampled trails. (W. Ericson, pers. comm. 2010)
- Dytiscidae and Hydrophilidae – Aquatic Coleopteran beetles are found in vernal pool and alkali vernal pool habitats of alluvial flats at Rush Ranch. Small depressional upland vernal pools, however, recently have the highest diversity of dytiscids. Alkali vernal pools in alluvial flats formerly supported high diversity, but population sizes and diversity collapsed following soil removal and peak (drought year salinity of early 2000s), when all larval instars were probably removed with excavated soil. These taxa are expected to be abundant in wet years, but were absent in the wet year 2010; only backswimmers (rapid colonizing widespread species) were found in former Dyatiscid and Hydrophilid habitats in the alluvial flats. Most common and prolific Dyticid genera at Rush Ranch are *Colymbetes, Dytiscus, Laccophilus, Abagus,* and *Thermonectus*. The most common and prolific Hydrophilid genera are *Berosus, Hydrochus, Hydrophilus, Enochrus,* and *Tropisternus.* (W. Ericson, pers. comm. 2010)
- Heteroceridae – mud-loving beetles with scissor jaws, occurring in the larger alkali vernal pools within the lower Spring Branch Creek alluvial fan.
- Wilcoxia spp. (robber-fly) – an undescribed form of this predator of bees and wasps is known only from Rush Ranch, where it occurs in alkali flats of the Spring Branch ck alluvial fan, and along barren soils of trails.

Populations of these invertebrate taxa have reportedly been adversely affected by past quarrying (soil removal circa 2001) within the alluvial fan, which was followed by rapid and acute declines or disappearance of Hymenoptera and Cicendelidae in excavated areas.

8.5 Plants

All of the special-status plants species currently known from the site occur within the tidal marsh or tidal marsh-terrestrial ecotone (estuarine landscape). The man-made vernal pools within the terrestrial landscape provide potential habitat for a few special-status plant species. However, none were detected during recent surveys (Vollmar et al. 2006) and are not expected to occur based on the lack of detection and the man-made nature of the habitat. The remaining habitats within the terrestrial and fluvial landscape are not particularly specialized and special-status species are not likely to occur.

8.5.1 Suisun thistle

Suisun thistle, *Cirsium hydrophilum* (E. Greene) Jepson var. *hydrophilum*, is a federally listed endangered species almost completely restricted in its modern geographic distribution to the southern tidal marshes plains of Rush Ranch, primarily between First and Second Mallard Slough. It was historically common generally in Suisun Marsh, where it was commonly associated with Bolander's water-hemlock (*Cicuta bolanderi* Watson), a formerly widespread tall, conspicuous marsh forb of Suisun Marsh that is also now rare and probably restricted mostly to Rush Ranch. Recent historic outlier populations at Peytonia Slough and upper Hill Slough (USFWS 2009) as well as its Suisun-wide historic distribution suggest that much suitable habitat at Rush Ranch is unoccupied.

Prior to 2004, few data were available on the population structure and size of Suisun thistle. In 1993, general surveys of Suisun thistle performed by Brenda Grewell throughout Suisun Marsh revealed only a few thousand plants, mostly from two main subpopulations occupying a cumulative area of approximately one acre (Fiedler et al. 2004). The 1993 surveys were performed following a prolonged multi-year drought. Fiedler sampled Rush Ranch marshes intensively to locate Suisun thistle populations following an extreme El Nino event (1998) and a series of relatively wet years except 2000. She detected a total of 209 patches (local populations or colonies), grouped into clusters of 47 subpopulations occupying 8.55 acres of tidal marsh. These included 45 subpopulations that were not previously detected. She estimated the 2003 population size to be roughly 137,500 individuals based on mean density, with an upper estimate population size upwards of 873,200 individuals based on maximum density. The 2003 population estimate was significantly greater than the 1993 (drought) estimate in size and local distribution, but the population remained narrowly distributed primarily along the banks of Suisun and Cutoff Sloughs, First and Second Mallard Branches and their tributaries (Fiedler et al. 2004). The long-term trends of Suisun thistle population size and structure among multiple El Nino Southern Oscillation Cycle (ENSO) events (rapid short-term sea level rise and increased rainfall amounts and seasonal distribution) and associated vegetation changes are not yet known.

Habitat associations of Suisun thistle at Rush Ranch were quantified by Fiedler et al. (2004). All colonies occurred in "high marsh" plain near small tidal sloughs and ditches. Most Suisun thistle colonies established on or near banks of small tidal channels, and most (70% frequency) were associated with artificial mosquito ditches. The majority (87.2%) of subpopulations were associated with deep, peaty Joice muck soils. Remaining subpopulations occur on Tamba mucky clay soils or transitional areas between the two soil types (Fiedler et al. 2003). Although Fiedler (2004) described these as "permanently saturated", the narrow local distribution of Suisun thistle along steep channel and ditch banks indicates a likely dependence on slow subsurface drainage and microaerobic soil conditions, and intolerance of prolonged, continuous flooding and waterlogging and sulfide accumulation typical of poorly drained marsh plains. No observers have reported Suisun thistle colonies growing on primarily mineral sediments associated with terrestrial tidal marsh edges, even at high marsh tidal elevations comparable with those in the marsh plain. No occurrences are reported from poorly-drained marsh plains distant from surface drainage channel features.

Suisun thistle species associations with widespread or dominant native non-native plants were also quantified by Fielder *et al.* (2004). The following brackish marsh species co-occurred with Suisun thistle between 72% (*Distichlis*) and 100% (*Argentina*) frequency in 2003: *Argentina egedii* (syn. *Potentilla anserina* ssp. *pacifica)*, *Schoenoplectus americanus*, *Lepidium latifolium* (non-native), *Apium graveolens* (non-native), *Atriplex prostrata* (non-native), *Rumex crispus* (non-native), *Sarcocornia pacifica, Juncus arcticus var. balticus, Jaumea carnosa,* and *Distichlis spicata.* "*Rumex crispus*" in the Fiedler study likely included some misidentified native *R. occidentalis*, which occurred in local abundance in at least one 2010 Suisun thistle colony, and "*Atriplex triangularis*" (*A. prostrata*) is a non-native plant (Flora of North America 1993+) erroneously treated as native in the 1993 Jepson Manual. These associations may include negative interactions (invasion and displacement, competition), facilitative, positive interactions (amelioration of local environmental conditions). Environmental indicator relationships (high correlation between co-occurring species) cannot be inferred from the sample, since plots included widely distributed species, but were placed only in occupied Suisun thistle habitat. Greene (1894) reported a conspicuous qualitative correspondence between Suisun thistle and Bolander's water-hemlock, and similar affinity between Suisun thistle and butterweed local habitat (*Senecio hydrophilus*) has been observed by Baye and Grewell (pers. comm. 2010) in recent decades. Wild celery (*Apium graveolens*) and broadleaf pepperweed (*Lepidium latifolium*), highly invasive marsh forbs that spread at high density along channel and ditch banks that are the primary habitat of Suisun thistle, are presumed to have strong negative influence on Suisun thistle seedling establishment and adult reproductive success, based on long-term qualitative field observations (B. Grewell, pers. comm. 2010; P. Baye, 2010, pers. comm; Fielder et al. 2004). Both these wetland weeds have expanded dramatically in Suisun Marsh since the 1998 El Nino event (B. Grewell, P. Baye, pers. comm. 2010).

The most frequent pollinator of Suisun thistle in 2003 was reported by Fiedler et al. (2004) to be the yellow-faced bumble bee (*Bombus vosnesenskii*). W. Ericson (pers. comm. 2010) reports *Bombus californicus* as the bumblebee with greatest preference for Suisun thistle working the marsh. The prevalence of *Bombus* pollination reported for Suisun thistle indicates a dependence on solitary bee habitat and populations in adjacent uplands, and suggests a threshold may exist for *Bombus* nectar plant abundance in the marsh to support foraging there during the flowering period of Suisun thistle. *Bombus* species also pollinate non-native bull thistle (*C. vulgare*), which co-occurs in Rush Ranch tidal marshes, also mostly near ditch and channel banks. Honeybees (*Apis mellifera*) have also been observed working *Cirsium* spp. flowerheads in Rush Ranch Suisun thistle populations (Baye, pers. obs.).

Although hybridization with bull thistle was once reported in the 1980s as a potential threat to Suisun thistle (USFWS 2010), no subsequent observation or analysis has confirmed either the existence of morphological intermediates suggestive of hybrids, or their spread. The relative importance of bull thistle as a competitor or nectar plant supporting bumblebee pollinator activity within the marsh has not been studied. The relative abundance and distribution of other bumblebee-pollinated flowering plants in the marshes during the period of Suisun thistle anthesis at Rush Ranch has not been investigated. The indirect and cumulative potential effects of bull thistle on pollinator abundance of Suisun thistle has not been investigated.

The weevil *Rhinocyllus conicus* is a seed predator of Suisun thistle at Rush Ranch, but its long-term impacts on Suisun thistle reproductive success have not yet been quantified. Variability in Suisun thistle annual flowering time is likely to influence the impact of weevil predation on seeds. Feral pigs (foraging, grubbing activities in the marsh) have been reported to have significant local adverse impacts on Suisun thistle sub-populations, at least intermittently (Fiedler et al. 2004, USFWS 2009).

The primary limiting factors for Suisun thistle at Rush Ranch are not known. Assessments of local population age-structure, density, and reproduction in occupied habitat by Fielder et al. (2004), historic distribution throughout Suisun Marsh, are consistent with the hypothesis that large areas of suitable unoccupied habitat exist at Rush Ranch. Suisun thistle has no specialized seed dispersal morphology, and may have become seed-limited and dispersal-limited rather than habitat-limited following the rapid diking of Suisun Marsh in the late 19th and early 20th century that must have eliminated most populations along tidal channel banks where artificial levees were constructed and the marsh plains and channels they enclosed. This conceptual model of Suisun thistle decline may explain why Rush Ranch, which had later and incomplete diking history compared with the rest of Suisun Marsh, became the last refuge of the species. If the seed dispersal limitation hypothesis is correct, facilitated dispersal (assisted colonization, AC) in suitable habitat (indicated by high frequency of closely associated species along brackish channel banks) may be an important practical tool for its recovery and re-occupation of historic distribution within Rush Ranch and beyond. Establishment of artificially seeded populations is recommended in the draft recovery plan for the species (USFWS 2009).

8.5.2 Soft bird’s-beak

Soft bird’s-beak, *Chloropyron molle* (A. Gray) A. Heller ssp. *molle* (syn. *Cordylanthus mollis* A. Gray ssp. *mollis*), is an annual hemiparasitic forb that historically ranged the northern San Francisco Bay estuary from Marin County to the vicinity of Antioch, inhabiting upper intertidal marsh habitats at both terrestrial edge and tidal slough bank positions in tidal marsh ecosystems (USFWS 2009). It is most frequently associated with native perennial high marsh forbs, subshrubs, grasses (*Sarcocornia pacifica, Distichlis spicata, Frankenia salina*, *Limonium californicum, Atriplex prostrata*), and the parasitic twining forb *Cuscuta salina* that establishes dieback patches that appear to facilitate colonization and persistence of soft bird's beak and other high marsh annuals (Grewell 2005, USFWS 2009). Soft bird's beak is an out-crossing species and floral visitors include *Bombus, Anthidium*, *Melissodes*, *Halictus*, and *Lassioglossum* bees (Grewell 2005, USFWS 2009). The rarity and endangered status of the species is due primarily to habitat loss and fragmentation (USFWS 1997, 2010). This species has been placed back in the distinct genus *Chloropyron* based on molecular (DNA) data sets (Tank *et al.* 2009).

Environmental factors apparently causing either short-term or long-term declines in Rush Ranch populations of soft bird's-beak include droughts, interference by non-native invasive plant species, disturbances by feral pigs, cattle overgrazing and trampling, and human trampling by recreational hikers and researchers working in the tidal marsh, and infrequent off-road vehicle trespass events (USFWS 2009, Grewell 2005). Natural seed predators of soft bird's-beak include song sparrows, granivorous small mammals (including the salt marsh harvest mouse), and moth larvae (*Saphinestra*), but it is not known whether these are significant threats to anthropogenically reduced populations of soft bird's-beak (Grewell 2005, USFWS 2009). The presence of a persistent seed bank in soft bird's beak buffers potential population effects of environmental perturbations (Grewell 2005, USFWS 2009).

Rush Ranch currently supports an extensive population of soft bird's-beak that was expanded by an experimental seeding project in 2000 (Grewell *et al*. 2003, 2005). Approximately 221 hectares (546 acres) of potential habitat have been surveyed at Rush Ranch. Population size of soft bird's-beak at Rush Ranch has fluctuated strongly since the first surveys in 1992, when population size was estimated at 44 plants. Estimated population size increased to over 2000 plants in 1993 following return of spring rainfall, but declined to 0 in the year 2000 (dry spring). Overall population size increased following artificial seeding experiments at Spring Branch Creek, reaching nearly 26,000 in 2002, and nearly 96,000 in 2004 (Grewell 2005). Some natural Rush Ranch subpopulations reported up to the 1990s, however, have declined or failed to emerge in recent years. Most of the population occurs along the terrestrial margins of high tidal marsh (terrestrial soils inundated by highest tides) along the north end of lower Spring Branch Creek (terrestrial edge high marsh), with most plants occurring in the artificially seeded population (Grewell 2005).

Fecundity of the reintroduced soft bird's-beak population declined sharply in 2004 (a moderately wet year) for reasons that are not clear, but reproductive success of the reference populations remained relatively stable. Reduced fecundity of the restored population was unexpected, as pre-dispersal seed predators (*Saphenista* moth larvae) were not prevalent within the population and seed predation rates were low (Grewell 2005). Extensive flowering and seed-producing populations of soft bird's-beak persisted at Spring Branch Creek upper tidal marsh edges in 2009 and 2010 (P. Baye, pers. obs.), but quantitative estimates of population size are not available. Populations remain restricted to sparsely vegetated upper tidal marsh edges (particularly near or in high brackish marsh turf pans), and are absent in dense, continuously vegetation of adjacent high tidal marsh west of the berm at the mouth of Spring Branch Creek.

Non-native invasive plant species are a significant threat to recovery and persistence of soft bird's-beak populations, particularly broadleaf pepperweed (*Lepidium latifolium*) and high marsh annual grasses (*Hainardia cylindrica, Parapholis incurva, Polypogon monspeliensis*). Wild celery (*Apium graveolens*) and sow-thistle (*Sonchus* spp.) have also been identified as invasive species occurring at high density in soft bird's-beak populations, and are potential threats. Non-native plants were present in 33% of soft bird's-beak populations patches investigated by Grewell (2005). Other recent non-native invasive plants with demonstrated potential for dominance in the terrestrial-high tidal marsh ecotone in San Francisco Bay, such as Algerian sea-lavender (*Limonium ramossisimum*) and European seashore goose-grass (*Puccinellia maritima*), have not yet dispersed to Suisun Marsh or impacted soft bird's-beak habitat.

The dramatic long-term increase in soft bird's-beak population size and extent at Rush Ranch following artificial seeding into unoccupied habitats determined to be suitable by expert judgment (supported by empirical data) indicates the potential for further recovery in unoccupied suitable habitat, particularly in terrestrial high marsh edges where sparse, low vegetation dominated by soft bird's-beak hosts are prevalent.

Draft recovery actions for soft bird's-beak (USFWS 2009) include tidal marsh restoration (de-embankment/dike breaching and removal), comprehensive site-specific and regional wetland weed management, managed pedestrian access to tidal marshes, exclusion of cattle and feral pigs, and experimental population augmentation (assisted colonization, facilitated dispersal).

8.5.3 Bolander's water-hemlock

Bolander's water-hemlock, *Cicuta bolanderi* S. Watson (syn. *C. maculata* L. var. *bolanderi* S. Watson), is a rare, coarse (up to 3.5 m tall at Rush Ranch) perennial marsh forb that is part of a western North American clade of *Cicuta* including *C. douglasii* distinct from *C. maculata* (Lee and Downie 2007). Suisun Marsh was the type locality for *C. bolanderi*. Until the status of the western North American *Cicuta* clade is resolved, the original rank of *C. bolanderi* may be validly applied over the incorrect *C. maculata* variety rank of *bolanderi*. The distinctiveness of nominal

C. maculata var. bolanderi from *C. douglasii*, in the absence of specimens from the type locality, is uncertain (Lee and Downie 2007). *C. douglasii* is also a regionally uncommon species in the coastal marshes of central and northern California, but old (late 19th c, early 20th c) are more frequent widespread in inland marshes.

The only recently confirmed locality of Bolander's water-hemlock in Suisun Marsh or the San Francisco Bay Estuary is at Rush Ranch fringing tidal marshes at Rush Landing and immediately south near Goat Island (P. Baye, unpublished data). The only other populations know in the Bay region are located at the head of Schooner Bay and diked freshwater marsh at Drakes Estero in Point Reyes National Seashore (Doreen Smith, Amelia Ryan, P. Baye, unpublished data). Other California localities are presumed extirpated. Bolander's water-hemlock is not currently federally or state-listed as threatened or endangered.

The historical distribution and abundance of Bolander's water-hemlock in Suisun Marsh was reported by Greene (1894) and Jepson (1911). It was conspicuous and abundant in Suisun Marsh, but not elsewhere in the region, in the 19th century, and it frequently associated with Suisun thistle (Baye *et al*. 2000, USFWS 2009). Its apparent extreme decline may likely be related to abrupt and extensive diking of Suisun tidal marshes in the early 20th century, since dikes were generally constructed along slough banks and outer bay marsh edges that appear to be the principal habitat of the species. The undiked and later incompletely diked tidal marshes of Rush Ranch likely provided a refuge for this species, as for Suisun thistle. If this hypothesis is correct, substantial suitable unoccupied habitat likely exists at Rush Ranch. It is unknown why Bolander's water-hemlock is apparently absent or undetected in the southern marsh plains of Rush Ranch.

The Rush Ranch population currently (2010) consists of approximately 50 adult (flowering and fruiting) and large vegetative plants, most of which occur in narrow fringing bulrush marsh at Rush Landing. The seedling population size is unknown. No seedlings or small juvenile plants were detected in 2010, but detection would be difficult in dense cover of bulrush (*Schoenoplectus americanus*) and its persistent leaf litter. The smaller subpopulation in fringing marsh near Goat Island consists of high marsh dominated by Baltic rush (*Juncus arcticus* ssp. *balticus*), silverweed (*Argentina egedii*), sea-milkwort (*Glaux maritima*), jaumea (*Jaumea carnosa*), and saltgrass (*Distichlis spicata*). Plants are conspicuous, taller than all surrounding vegetation except tules (*Schoenoplectus californicus, S. acutus*). *Cicuta* may be misidentified, however, as the morphologically similar water-parsnip *Sium suave*, which occurs in similar brackish marsh habitat, especially along tidal slough banks.

In summer-fall 2009 and 2010, the Rush Ranch populations produced abundant fully formed seeds, and appear to be fertile and fecund. No herbivory by insects or mammals was observed;

the genus is among the most toxic plants in North America. Cattle trampling caused damage and elimination of reproduction, but apparently not mortality, to several plants south of a gate access point that was left open in 2010, near an unauthorized trail leading to a popular local fishing point at the marsh edge. Recovery plan conservation recommendations for this species include surveys, seed banking, and protection (USFWS 2009). Since no estuarine populations were know to USFWS at the time of recovery plan preparation, assisted colonization was not known to be a feasible recommendation at that time.

8.5.4 Suisun aster

Suisun aster (Suisun Marsh aster), *Symphiotrichum lentum* (E. Greene) G.L. Nesom (syn. *Aster lentus* E. Greene), is a regionally and globally rare rhizomatous colony-forming perennial forb. It occurs infrequently in brackish tidal marsh shorelines (including levees), riparian freshwater marsh near the estuary, from northern San Pablo Bay east to the interior Sacramento-San Joaquin Delta marshes. At Rush Ranch, it occurs primarily scattered clonal colonies (locally abundant) in fringing brackish marshes along Suisun Slough and Hill Slough, particularly along upland bluff scarps and marsh scarp banks. It is scarce to absent along gently sloping terrestrial tidal marsh edges of southern Rush Ranch tidal marshes. Like most perennial asters, it is presumably an obligate outcrossing species, subject to fertility constraints (Allee effects) due to low neighborhood diversity of genotypes at very low population densities. Some populations may intergrade with the more widespread common aster*, S. chilensis*.

Conservation recommendations proposed by the U.S. Fish and Wildlife Service include (a) protection of existing populations in tidal marsh ecotones; (b) survey and inventory with taxonomic attention to natural variability among populations; (c) including Suisun Marsh aster and its habitat in tidal marsh restoration plans, using proximate source populations.

8.5.5 Jepson's tule pea

Jepson's tule pea, *Lathryrus jepsonii* var. *jepsonii*, is a relatively widespread but uncommon tall, clambering perennial forb that occurs primarily in the Sacramento-San Joaquin Delta, west to Napa River marshes. It occurs sporadically as relict and recent populations in Suisun Marsh, where it establishes in high brackish marsh along slough banks, levees, and steep, well-drained upland edges of tidal marsh. Presumably old relict populations occur at Rush Ranch primarily along the terrestrial edges of high brackish fringing tidal marshes bordering bluff scarps along Suisun Slough and Hill Slough, where it clambers over tules, bulrushes, and riparian scrub. Rush Ranch populations produce abundant flowers and seed, but small, young plants or colonies indicative of active colonization are not evident. This species is listed as a species of concern in the draft recovery plan for tidal marshes in northern and central California (USFWS 2010). It remains relatively rare in the San Francisco Bay Estuary, and occurs in limited, declining high tidal marsh edge habitats subject to erosion and sea level rise (indirect climate change impacts).

8.5.6 Mason's lilaeopsis

Mason's lilaeopsis, *Lilaeopsis masonii* Mason & Constance, is a creeping, rhizomatous, low-growing grass-like forb that can rapidly colonize erosional marsh peat scarps and gently sloping erosional marsh substrate near the leading edge of marsh vegetation bordering sloughs and bays. It can also establish in inconspicuous, shaded low-density colonies in the ground layer below brackish marsh vegetation canopies, especially near marsh edges. It is doubtfully taxonomically distinct from the more widespread (but uncommon) western lilaeopsis (*L. occidentalis;* Zebell and Fiedler 1996), a species with predominantly maritime (coastal lagoon, stream mouth) distribution. It may be an inland cline (morphological gradient) of that species (USFWS 2009). It ranges from the mouth of Tolay Creek (Sonoma County) to the sloughs of the Sacramento-San Joaquin delta. At Rush Ranch, it is found in sporadically in local abundance along unstable erosional marsh scarps. Because its detection is difficult and its habitat inherently unstable, its actual distribution and abundance may both highly variable and underestimated. It appears to be subject to rapid population turnover (local extirpation and recolonization) in response to erosion, exposure of shade-suppressed ground layer colonies, and recolonization. It has been treated as a species of concern (USFWS 2009), but it is relatively widespread, frequent, and capable of rapid population growth compared with most special-status estuarine plant species.

8.5.7 Lyngbye's sedge

Lyngbye's sedge, *Carex lyngbyei*, is a common and locally dominant colonial estuarine plant of North Coast stream mouth estuaries, ranging north to Alaska. It is regionally rare in the Central Coast, occurring as widely disjunct populations along the mud banks of the Lagunitas Creek delta (Tomales Bay), the Carmel River, and at Hill Slough low marsh edges near the Grizzly Island Road Bridge south to Suisun Slough. It may possibly occur elsewhere along Hill Slough and Suisun Slough. It was first detected in Hill Slough in 2010, and may have been previously undetected because of its overall morphological similarity to *C. barbarae*, a semi-terrestrial colonial wetland sedge that occurs nearby along Suisun Slough and Hill Slough in seeps in riparian scrub bluff scarps. As a disjunct population of a widespread plant (possibly an old relict population), Lyngbye's sedge at Rush Ranch has no special legal protected status, but has some significance to overall biodiversity conservation at Rush Ranch, as well as to conservation of the species during climate change.

9 Invasive Species

Invasive plant and wildlife species can severely alter or inhibit the natural ecological functions of a site through displacement or eradication of native species and changes to native plant community and habitat characteristics. Certain pest species, such as mosquitoes, can present a dilemma to land managers since they can carry human pathogens but also may be a natural component of the site ecology. This section identifies the invasive weeds known from the site with in-depth information on those weed species that present substantial current or potential future threats to the site ecological functions. It also discusses the primary invasive wildlife of concern – feral pigs and non-native clams.

9.1 Invasive Plants

Rush Ranch's terrestrial and tidal wetlands are invaded by a subset of the Bay Area's regional wetland weeds. Most wetland weeds are permanently naturalized and widely dispersed from region-wide vectors that rain propagules on Rush Ranch (waterfowl, wind, water-dispersed weed seeds), but some are local outlier populations with mostly localized dispersal. Some wetland weeds are known or highly likely major threats to conservation of native plant communities and recovery of sensitive plant species; others are conspicuous but often transient or non-dominant species (at least under current environmental conditions). The following brief accounts emphasize species that are interpreted to be major threats and priorities for future management to restrict their spread or reduce the severity or impacts of well-established naturalized populations. These species are summarized in Table 6, which also describes the species' ranking with the California Invasive Plant Council (Cal-IPC).

9.1.1 Species of Primary Concern

Broad-leaved pepperweed (*Lepidium latifolium*). This clonal forb is the most invasive plant in emergent marsh of brackish to oligohaline reaches of the estuary. It ascended from a common to widespread dominant weed in this region between the 1980s and 1990s, and abruptly increased in abundance and distribution following the 1998 El Nino event. It readily forms monotypic stands or similar monotypic canopies above shaded persistent antecedent marsh vegetation it invades. Broadleaf pepperweed is a dominant species of the southern marsh plains (slough system) of Rush Ranch, but has remained a frequent but marginal element of high fringing marsh vegetation along Suisun Slough and Hill Slough. It is not known whether its limited abundance in local fringing marshes is due to greater resistance to invasion, or circumstantial factors (timing, disturbance opportunities). Pepperweed control in brackish marshes is problematic because of many factors, including important native species diversity or special-status plants around or beneath pepperweed canopies, limited efficacy of most herbicide and surfactant combinations currently available for use in estuarine marshes, problematic indirect or non-target impacts of effective herbicides, and high clonal persistence of colonies. Pepperweed is apparently suppressed in seasonal wetlands of alluvial fans by intensive cattle grazing above Grizzly Island Road, and summer desiccation of saline/alkaline soils below the road, but little is known about factors controlling its spread in local terrestrial wetlands.

Yellow star-thistle (*Centaurea soltitialis*). This highly invasive, widespread annual or biennial can form dense stands and displace native vegetation and decrease the forage quality of rangelands (poisonous to horses). Seed is transported by human activities and animals. This species has a deep taproot (one meter or more) that grows quickly and can access and deplete deep soil moisture reserves in grasslands. It can strongly out-compete many other species in both stressed conditions and disturbed conditions (DiTomaso 2001, DiTomaso et al. 2006). Heavy infestations have been reported to use as much as 50% of annual stored soil moisture in loamy soils, and significantly reduce soil moisture reserves more than six feet deep (DiTomaso 2001). Grazing and fire can both influence the distribution and density of yellow star-thistle either positively or negatively depending on the timing and intensity of the regimes (D’Antonio et al. 2007).

Yellow star-thistle is currently wide-spread on the site, with the densest stands on heavier clay and clay loam soils around the lower hillslopes and the upper portions of the older alluvial fans.

The current grazing regime, combined with other factors may be influencing the extent and density of yellow star-thistle on the site. The east-west fence line in the northeast of the site separates a southern grazed from a northern ungrazed pasture. Yellow star-thistle has a 10-20% cover in the grazed pasture along with a dominance of introduced annual grasses (soft chess and Italian ryegrass) but is generally absent in the ungrazed pasture, at least near the fence line. Instead, the ungrazed pasture is dominated by Harding grass and medusahead both of which are largely absent in the grazed pasture. The single location provides only limited data but does indicate that the timing and intensity of grazing can influence that distribution and density of yellow star-thistle on the site though the outcome of reducing this species may mean that it is replaced by other undesirable species (such as medusahead and Harding grass).

Medusahead (*Taeniatherum caput-medusae*). This slender annual grass is a late-maturing annual that is highly competitive and is considered a major problem in rangelands, as well as communities degraded by overgrazing, fire or cultivation (Maurer et al. 1988). Medusahead can persist as a dense thatch layer that can prevent germination of other, more desirable species, contribute to fire danger and lock up nutrients (CalIPC 2010). This species prefers soils with high clay content and well-developed profiles (Ibid). Seed is dispersed by livestock, wind and water. Maintaining good stands of perennial vegetation, including perennial grasses, can help prevent the establishment of medusahead. Grazing and fire can both influence the distribution and density of medusahead either positively or negatively depending on the timing and intensity of the regimes (D'Antonio et al. 2006).

Medusahead is currently wide-spread on the site, with the densest stands on heavier clay and clay loam soils around the lower hillslopes and across the older alluvial fans. As with yellow star-thistle, the current grazing regime, combined with other factors may be influencing the extent and density of medusahead on the site. As described above, the east-west fence line in the northeast of the site separates a southern grazed from a northern ungrazed pasture. Medusahead is a dominant species in the ungrazed pasture but generally has a low cover in the grazed pasture at least near the fence line. This is not to say that grazing significantly reduces the species across the site since there are dense stands throughout many of the grazed pasture. However, the example from this location does indicate that the timing and intensity of grazing can influence that distribution and density of medusahead on the site though the outcome of reducing this species may mean that it is replaced by other undesirable species.

Harding grass (*Phalaris aquatica*). Harding grass is perennial, clump-forming grass that is a commonly seeded forage plant. It can form dense stands and is widely naturalized throughout lower elevations in California. This species provides nutritious forage (especially for sheep) and reseeds itself fairly well, providing green forage for a longer period than many annuals (Peterson 1988). However, this species is also known to cause neurological disorders in sheep, especially after environmental stresses cause the plant to wilt (Peterson 1988). Dense stands of Harding grass can threaten adjacent grasslands by providing a large source of seeds for colonization. Regular grazing and fire can both decrease Harding grass populations depending on timing (Peterson 1988, CalIPC 2010). This species produces an abundant seed bank and can withstand heavy grazing (mature plants are less palatable) and tolerate low moisture conditions (CalIPC 2010).

Harding grass is widespread in the pasture north of the headquarters (Harding Pasture) where it was planted in the 1960s as a cover and forage crop (Poerner pers. comm.). It has also colonized other portions of the site, mostly on the heavier soils of the older alluvial fans. The current grazing regime appears to significantly reduce the species distribution and density. There are a few locations on the site where Harding grass has a low to spotty cover within a grazed pasture and a dense to dominant cover in an adjacent ungrazed pasture.

9.1.2 Species of Secondary Concern

Italian thistle (*Carduus pynocephalus*). This vigorous annual thistle is widespread throughout lower elevation California. It occurs mainly in disturbed or ruderal areas, but also displaces forage in grasslands, reducing the value of hay and other crops. Italian thistle can rapidly colonize overgrazed or open, disturbed soils (i.e., fire breaks) (Pitcher 1986). It can also colonize previously grazed pasture if the grazing is discontinued (Poerner pers. comm.). The overwintering stage, basal rosettes, can severely reduce the establishment of other species (CalIPC 2010). Italian thistle relies on seed germination. Germination rate is high, with seeds germinating in a wide range of temperatures and seed bank persisting in the soil for multiple years (Ibid). This plant responds well to high nitrogen and high pH levels.

Italian thistle occurs in low-density widely scattered stands across the terrestrial landscape, mostly on deeper soils on more protected slopes or with higher seasonal moisture levels. Some of the densest stands are in areas excluded from grazing and lack of grazing generally appears to allow the species to increase. From about 1990 to 1998, grazing was stopped in the Harding Pasture in an effort to enhance habitat for ground nesting birds. However, as a result, the cover and stature of Italian thistle (along with Harding grass) greatly increased, most likely reducing the ecological functions of the grasslands for nesting birds and other species.

Purple star-thistle (*Centaurea calcitrapa*). This biennial (occasionally annual to perennial) thistle is often observed in recently or repeatedly disturbed areas, including pastures and overgrazed rangelands, along roads, ditches and fences (CalIPC 2010). Purple star-thistle prefers more mesic and heavier bottomland soils than yellow star-thistle (NWCB 2010). Purple star-thistle can replace palatable forage species and form dense stands that inhibit livestock movement. This species reproduces primarily by seed, which are mainly deposited below or near the plant. Conventional cattle grazing is not an effective control method, and can actually promote the species by grazing on competitor species (CalIPC 2010).

There are a few localized stands of purple star-thistle on the site, in disturbed areas, along fence lines, and low lying seasonally moist areas. The species distribution and cover is not likely to increase unless there are significant disturbances or severe overgrazing.

Fennel (*Foeniculum vulgare*). This naturalized, tall, perennial herb generally occurs in highly disturbed areas of low ecological quality (Bean 1985). This species does not generally establish lightly disturbed or undisturbed natural areas. Fennel is reported to be particularly aggressive in plowed areas or field subjected to medium or heavy grazing and recently abandoned (CalIPC 2010). Fennel's strong smell dissuades grazing. Fennel tends to prefer well-drained though seasonally moist, acidic soils and can tolerate a wide range of annual precipitation (Bean 1985, CalIPC 2010). Fennel can exclude or prevent the re-establishment of native species by out-competing for light, nutrients and water (CalIPC 2010). This species can quickly create a long-lived seed bank. Burning and grazing are generally not reported to be effective control measures (CalIPC 2010).

There are currently only limited stands of fennel on the site, mostly on disturbed sites near the marsh edge and along roadsides. The species distribution and cover is not likely to increase unless there are significant disturbances or severe overgrazing.

Milk thistle (*Silybum marianum*). This tall annual or biennial thistle will generally remain localized to disturbed site (unless disturbance becomes more widespread) (Bean 1985). It generally inhabits pastures, wastelands and irrigation banks, but requires disturbed, high fertility soils (including stock yards). This species reproduces solely by an effective wind dispersing seed and is not adapted to germinate in areas with high grass litter levels (Bean 1985). Milk thistle is reported to be toxic to stock animals, especially in wet weather or high soil moisture (Ibid). Over-grazing and fire encourage the spread of milk thistle (Bean 1985).

There are currently only limited stands of milk thistle on the site, mostly on disturbed sites within the older alluvial fans and along roadsides. The species distribution and cover is not likely to increase unless there are significant disturbances or severe overgrazing.

Russian wheatgrass (*Elytrigia pontica*). This is a coarse bunchgrass resembling a giant ryegrass with moderately high soil salt tolerance and drought tolerance, maintaining green foliage in summer. It was introduced as a forage and stabilization grass for subsaline soils in the western states. It has invaded and locally dominated high marsh ecotones and levees in San Pablo Bay and San Francisco Bay, and is established in small populations at multiple locations at Rush Ranch, mostly near Rush Landing. This species has the potential to dominate terrestrial tidal marsh ecotones and compete with native creeping wildrye and sedges. Because its local populations are currently small, it has high feasibility for low-cost control.

Sicklegrasses (*Hainardia cylindrica, Parapholis incurva*). Sicklegrasses are wiry, low-growing salt tolerant annual grasses of seasonal wetlands and tidal marsh edges, native to Europe. They are widespread in estuarine salt marsh edges and diked baylands. They are inconspicuous and low in dominance except in specific sub-habitats that special-status annual tidal marsh plants occupy, particularly hemiparasitic bird's-beak species like Chloropyron molle. At high density or dominance in turf pans of high marsh-terrestrial ecotones, they are likely to interfere with host relationships (haustorial connections) of hemiparasites, since grasses are poor hosts.

Black rush (*Juncus gerardii*). Black rush is native to Europe and naturalized in the U.S. North Atlantic and Pacific Northwest tidal marshes. It is established at Benicia and Pinole in brackish marshes, where it is spreading monotypic stands – indicating its potential for dominance as another invasive species. No occurrences at Rush Ranch or vicinity are known yet, but the rush disperses in water by abundant nearly microscopic seeds. It is a priority for early detection and exclusion from Rush Ranch, where it could readily be mistaken for many native rush-like plants.

Common reed (*Phragmites australis*). Common reed as a species is native to Suisun Marsh and the delta, but prevalent modern populations in the region are presumed to be invasive European haplotypes. Reeds are particularly invasive in recently prograded or disturbed brackish mineral sediments (bay muds), especially along dikes or nutrient-enriched areas or areas near nutrient-rich urban and agricultural freshwater discharges. At Rush Ranch, they are locally dominant on the perimeter dike of the diked marsh, and within the diked marsh.

Hybrid smooth cordgrass (*Spartina alterniflora* X *foliosa*). Known hybrid smooth cordgrass invasions are currently restricted to San Francisco and San Pablo Bay, but aggressive, invasive backcrossed (introgressant) *S. foliosa* phenotypes may potentially escape detection by analysis of relatively few molecular markers. Cordgrass colonization is likely to occur rapidly in Suisun during prolonged droughts or climate-driven salinity increase. Cryptic introgressant cordgrass should be rigorously analyzed for potentially invasive genotypes if it occurs at Rush Ranch.

9.1.3 Other Species of Concern

Wild celery (*Apium graveolens*). This widespread broadleaf forb is locally abundant to dominant large patches within specific brackish tidal marsh sub-habitats of sensitive species, including Suisun thistle and soft bird's-beak. Its abundance can be problematic in early stages of marsh succession (including restoration projects) if unmanaged at a local scale.

Brass-buttons (*Cotula coronopifolia*). This facultative annual to perennial salt-tolerant amphibious wetland forb has been regionally naturalized since the 1850s. It seldom persists as a dominant except in diked marshes with late drawdowns and saline pond beds. It can be an ephemeral dominant early in brackish marsh succession, and it may interfere with establishment or persistence of native annual tidal marsh forbs. It is otherwise not a threat to closed-cover perennial marsh vegetation.

Rabbit's-foot grass (*Polypogon monspeliensis*). This widespread naturalized wetland weed is locally abundant or dominant in disturbed fresh to brackish seasonal wetland depressions, but it is problematic for management primarily in local habitats supporting some special-status plants or annual plant species of local conservation concern, including Contra Costa goldfields, smooth goldfields, and soft bird's-beak. It is otherwise an ephemeral pioneer, early-succession dominant species that is displaced by strongly perennial marsh species developing closed cover.

Himalayan blackberry (*Rubus armeniacus*). This invasive riparian weed is locally dominant in tidal ecotone bluff riparian scrub bordering Hill Slough, and on the diked marsh levee, but is not invasive elsewhere.

Narrow-leaf cattail (*Typha angustifolia*). Narrowleaf cattail is widely established in diked and tidal brackish marshes. This species, which was known from only two southern California localities prior to 1880, is now widespread and abundant throughout the state. It is a European cattail species well-adapted to brackish soils, and readily achieves local dominance in disturbed or rapidly accreted marshes, like common reed. Its control is likely dependent on managed competition and differential colonization in early successional stages of marsh development.

9.2 Invasive Wildlife

There are two categories of invasive wildlife at Rush Ranch: wild pigs, which are known to disturb terrestrial and marsh habitats, and non-native clams, which impact the subtidal food web in tidal channels within the marsh. These species are discussed briefly below.

Feral pigs (*Sus scrofa*). Feral pigs are aggressive mammals that pose significant threats to the plant communities and rare plant habitats in the Suisun Marsh. These animals, which are present in significant numbers in the region, trample and root up large areas of vegetation, spread weeds and contribute to erosion. They also scratch and dig in wet ground to form wallows. Feral pigs can destroy nests of ground nesting birds. They prey on a wide variety of vegetation, as well as crayfish, frogs, snakes, salamanders, mice, the eggs and young of ground-nesting birds and young rabbits. Wallows can affect ponds and wetlands by increasing turbidity, creating algal blooms and lowering water quality (WDNR 2010).

Hunting is the main method used for eradicating feral pigs in California. Feral pig hunting is legal and regulated through the California Department of Fish and Game (CDFG 2001). Habitat destruction by feral pigs was fairly severe in earlier years on Rush Ranch, especially in upper marsh zones. Feral pig hunting is currently conducted as an organized management program on the site (Cuff 2006). This has greatly reduced but not eliminated feral pigs from the site.

Non-native clams. Two species of non-native, Asiatic clams are present within Suisun Marsh: *Corbula amurensis* and *Corbicula fluminea*. Within Rush Ranch, these species are generally low in abundance, though *Corbicula* can be found in higher densities on sediment bars along the inside bends of First Mallard Slough. Researchers from UC-Davis have been monitoring clam populations and their impact on aquatic productivity throughout the Marsh since 2006, and in general, these two species are thought to have minimal local impacts within First and Second Mallard Sloughs. Both these sloughs have high phytoplankton biomass above that of their downstream counterparts (e.g. Suisun and Montezuma Sloughs), so the relatively low populations of clams within the sloughs do not appear at this time to be sufficient to negatively affect higher trophic levels (Schroeter, pers. comm. 2010).

10 Conceptual Models

10.1 Key Drivers of Change

Suisun Marsh and Rush Ranch will experience several changes over the life of the Rush Ranch Master Plan and beyond that have great potential to change conditions in the Marsh: climate change, large-scale restoration, land use change within the watershed, and many more. Each of these topics is summarized here.

10.1.1 Climate Change: Sea Level Rise and Storm Frequency and Intensity

Climate change effects will affect California and the San Francisco Estuary in a number of ways. Climate change projections are sensitive to many future human actions and to highly complex atmospheric processes, making specific projections challenging at best. California is projected to retain its Mediterranean climate of cool and wet winters and warm and dry summers, including experiencing a high degree of variability in interannual precipitation amounts. Here we present two scenarios developed by a collective group of large studies funded by the California Energy Commission (CEC) under mandates of the Governor's Biennial Climate Change Report and utilized in early 2010 by the U.S. Environmental Protection Agency in its Climate Ready Estuaries pilot project for the San Francisco Estuary. A majority of the climate change projections presented here were developed by Cayan et al. (2009) based on projections from six leading climate models[2]. These models were selected based on their reasonable representation of historical simulation of seasonal precipitation, seasonal temperature, the variability of annual precipitation, and El Niño/Southern Oscillation (ENSO). All models were run with both a lower emission scenario (B1 SRES) and a mid-high emission scenario (A2 SRES) to capture a range of plausible future emission trajectories. Regional projections were developed by statistical downscaling.

For sea level rise projections in U.S. coastal locations, relative sea level rise may differ from global estimates due to a number of factors such as changes in local ocean circulation, ocean density, vertical land motion, erosion and sedimentation, gravitational effects, isostatic rebound, etc. Relative sea level rise in California has demonstrated similar rates of rise compared to global estimates (Cayan et al. 2008). Many California studies recommend using projections of global sea level rise estimates, which assumes California relative sea level rises continue at the same rate as global sea level rise. The "lower range" estimate is the mid-range

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[2] (1) NOAA Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1; (2) the National Center for Atmospheric Research (NCAR) Parallel Climate Model (PCM); (3) NCAR Community Climate System Model (CCSM); (4) the Max Planck Institute ECHAM5/MPI-OM; (5) the Center for Climate System Research of the University of Tokyo MIROC 3.2 medium-resolution model; and (6) the French Centre National de Recherches Meteorologiques (CNRM) models.

of Rahmstorf (2007) and high-end of IPCC TAR. The “higher range” estimate is the high estimate of Rahmstorf (2007). Table 7 presents these projections.

10.1.2 Large-Scale Tidal Restoration in Suisun and the Delta

Restoration of up to 7,000 acres of tidal marsh is anticipated in the Suisun Marsh Plan, and other planning efforts have called for up to 25,000 acres of tidal restoration in Suisun. The primary effect of this restoration, beyond all of its target benefits to ecosystem functions for native and migratory species, is the potential to alter tidal hydrodynamics within Suisun Marsh. Hydrodynamic modeling conducted by RMA for the Suisun Marsh Plan has demonstrated that restoring tidal action to large areas of subsided lands absorbs significant tidal energy and reduces tidal range in the near region. Some of the modeled scenarios suggest that mean lower low water may be up to one-half meter higher than it is with the current channel configuration. This raising of the low water level effectively makes some of the remaining intertidal land area shown in Figure 7 lower than indicated, relative to the tides. The exact magnitude of this effect on tides depends on where tidal marsh restoration efforts are located. As restoration sites accrete through mineral sedimentation and plant matter accumulation, their tidal prisms will decrease and these tidal effects will reverse.

10.1.3 Land Use Change in the Watershed

The cities of Fairfield and Suisun City continue to grow, converting open space, abandoned industrial sites, and agricultural lands into urban land uses. The primary effects of these changes are increases in impervious surfaces leading to greater stormwater runoff that could reaches Rush Ranch and a change in the nature of potential contaminant loadings associated with the land use changes. The other concern is that of mosquito control; more residences located near Suisun Marsh increases the demand for mosquito control in Suisun Marsh as a whole which could potentially include Rush Ranch.

10.1.4 Sediment Supply Regional-Scale Declines

The information in this section comes from the DRERIP sediment conceptual model (Schoellhamer et al. 2008) and a recent paper examining sea level rise and sediment supply changes in Suisun Marsh (Ganju and Schoellhamer 2010).

The watersheds that drain to the Sacramento-San Joaquin Delta have been heavily impacted by human activities since the discovery of gold along the American River in 1848. In general, human activities tend to increase the amount of sediment transported in rivers through soil erosion, but this increase can be offset by sediment retention in reservoirs, leading Syvitski et al. (2005) to conclude that the worldwide flux of terrestrial sediment to the oceans has decreased from pre-colonial conditions.

Probably the most significant anthropogenic driver, with respect to river sediment supply, is hydraulic mining. During the late 1800s and early 1900s, large deposits were washed into flumes using high-powered water jets in order to separate out gold. The mine tailings were routed into the rivers which dramatically increased the sediment supply. Gilbert (1917) estimated a 9-fold increase in sediment supply to San Francisco Bay during the mining period. Though the primary pulse of mining sediment has moved through the system, remnant terrace deposits remain in many of the watersheds (Meade 1982, James 1991). Also, recent estimates of river sediment supply to the Delta are substantially higher than Gilbert's pre-mining estimate, but have continued to decrease since the mid-1950s potentially indicating continued exhaustion of remnant mining derived deposits (Wright and Schoellhamer 2004).

Two major water supply projects have been constructed in the watersheds draining to the Delta, the Central Valley Project (CVP) and the State Water Project (SWP), with each project containing multiple large dams are reservoirs. Dams have also been constructed for other purposes, such as trapping hydraulic mining sediments. The U.S. Army Corps of Engineers National Inventory of Dams (http://crunch.tec.army.mil/nid/webpages/nid.cfm) contains 1,483 dams in California (see webpage for inclusion criteria) and Nilsson et al. 2005 classified the Sacramento-San Joaquin basin as “strongly affected” by dams in their recent study of flow regulation of the world's large river systems. The primary effect of dams on sediment supply is retention of sediment in the reservoir; the channel immediately downstream from the dam will erode to a new equilibrium (Porterfield et al. 1978) providing a short-term sediment source, but the long-term effect is decreased sediment supply (Williams and Wolman 1984). Dams also affect the flow regime, typically reducing high flows and increasing low flows (Singer 2007), which also has the effect of reducing downstream sediment supply.

The reduction of the hydraulic mining pulse and construction of dams led to a 50% decrease in sediment supply from the Sacramento River between 1957 and 2004 (Wright and Schoellhamer 2004). Exchange between estuarine sub-embayments may be more important in the coming century as watershed sediment loads continue to decrease (Ganju and Schoellhamer 2006). Decreased sediment supply to Suisun, San Pablo, and San Francisco Bays could over time result in the erosion of sediment from mudflats, converting them to subtidal flats. It could also reduce the amount of suspended sediment available for accretion in wetland restoration projects along diked, subsided baylands.

10.1.5 Delta Outflow and California Water Management

Water diversions from the Delta cause changes in the complex flow dynamics in the Delta and Suisun Marsh, which unnaturally affect migration and movement of fish and other aquatic organisms, limit access to suitable habitats, and alter water quality. Together, the CVP and SWP export facilities pump approximately 5 million acre-feet of water annually, and effectively reverse flows in Old and Middle rivers (Figure 2.7, Bay Institute, 1998; DWR 1995; DFG, 2008). Other water diversions and consumptive water use within the Delta (over 2,000 diversions) total an additional 1.7 million acre-feet (DWR 1995; Bay Institute, 1998; Healy et al., 2008; Herren and Kawasaki, 2001). Variability in the flow regime and seasonal flooding were historically important drivers of ecosystem structure and processes in the Delta and Suisun Marsh; native plant and animal species evolved under flow regimes of high inter- and intra-annual variability that differ strongly from the current managed regime. Water storage and flow control have dampened such variability across seasons and years, which has greatly changed estuarine hydrodynamics, circulation patterns and nutrient exchanges, and impacted resident species adapted to this natural variability.

As a result of the severe ecological impacts that have resulted from the large-scale replumbing of the Delta, a number of efforts are underway to improve the ecological sustainability of this intensely managed system. These efforts have numerous political and scientific complexities, and are unlikely to result in dramatic changes to existing Delta outflow regimes in the short-term. However, as these efforts mature into projects that are actually implemented on the ground, the status quo could very well change in the long-term. The mostly likely changes will be to the magnitude, duration, and timing of Delta outflow, which could have potentially significant impacts on habitats within Suisun Marsh. It will therefore be critical that ecological enhancement/restoration efforts in the Delta be integrated with similar efforts in Suisun Marsh to avoid negative impacts to Rush Ranch and other Suisun habitats.

10.1.6 Salinity Management of Suisun Marsh

Salinity management within Suisun Marsh is predicated upon the maintenance of primarily freshwater conditions within the Marsh to facilitate managed marsh/duck hunting operations. As increasing amounts of managed marshes are converted back to tidal brackish marsh, the need for salinity management within the marsh will change both spatially and temporally. Changes in salinity management operations could alter the salinity of tidal flows exchanged between Rush Ranch and its tidal sources, which could potentially change the structure of estuarine vegetation communities. The magnitude and timing of these changes will likely determine the magnitude of subsequent ecological change observed at Rush Ranch. Therefore, it is important that existing monitoring programs continue such that adequate “base lines” (characterizations of vegetation communities under current salinity management regimes) are established to allow for change detection over time.

10.1.7 Changes in Invasive Species Distributions

Changes in water/salinity management within the Delta and Suisun Marsh could potentially impact the distribution and composition of invasive species within Rush Ranch, especially those within estuarine habitats. Periods of salinity change in Suisun Marsh due to freshwater inputs have been linked to long-term or rapid changes to vegetation community composition (Beare and Zedler 1987, Clark 1986, Clark and Patterson 1985*)*. Decreases in tidal marsh salinity during seedling establishment can increase the spread of invasive plant species, such as the widespread non-native perennial pepperweed (*Lepidium latifolium*). Under normal conditions, salinity variation generally promotes dynamic plant community composition and diversity by influencing interactions of dominant perennial species and annuals or short-lived perennials which have adapted to varied levels of soil salinity (Callaway, Jones & Ferren 1990, Allison 1992). However, well established invasions can persist through less than favorable high salinity conditions (Zedler 1983).

Restoration of tidal areas within Rush Ranch and Suisun Marsh as a whole is expected to promote development of dynamic habitat structure and with this an associated plant community characterized by a high diversity of plants adapted to a variable environment. Additionally, such restoration will provide very significant tidal habitat for a number of special status and locally endemic species currently threatened by continued habitat loss and reduction. A persistent issue is the widespread extent of dominant invasives (*Cotula coronopifolia, Lepidium latifolium, Phragmites australis, Polypogon monspeliensis*) which have already established within a highly salinity regulated marsh system. Such species are expected to be a continued issue in restoration areas when nearby establishment of exotic invasives has previously occurred, which may continue to out-compete native and rare tidal wetland species. The Suisun Ecological Workgroup- Brackish Vegetation Subcommittee has suggested that periodic years of high salinity stress may prove to be an important factor in control the spread and establishment of invasive exotic species in Suisun Marsh (SEW 2001).

Within the terrestrial landscape, colonization by new invasive plant or wildlife species or the significant spread of existing species due to climatic events or changes in land management practices could significantly alter the species composition and ecological functions of the landscape. The specific changes that would occur are unknown and would be based on the characteristics of the specific invasive species.

10.1.8 Terrestrial Land Management Practices

As described in earlier sections of the report, there is no ‘natural’ mature ecological state within the terrestrial grassland and scrub communities on the site, only the current temporary state that has resulted from the combination of prevailing influences over historic and recent time.

Various land management practices including grazing, burning, herbicide applications, and habitat restoration can exert strong influences on the species distribution and composition within the terrestrial landscape. Grazing and burning mimic natural processes that have influenced the plant community characteristics for countless millennia and thus may be regarded as a continuation of these influences thought the timing and intensity may differed significantly from the historic natural conditions.

As a managed landscape, Solano Land Trust will undoubtedly develop a management regime for the terrestrial landscape that will favor certain desirable plant community elements such as native grasses and forbs and acceptable non-native species, and discourage certain undesirable elements, especially aggressively invasive weeds. The land management regime, if successful, would result in a shift in the current distribution and cover of plant species within the terrestrial landscape. Of course, this shift would only be maintained as long as the land management regime is continued. If the regime were discontinued or significantly changed, the distribution and cover of plant species would adjust based on the new conditions.

10.2 Conceptual Models and Key Inferences Related to Site Ecological Processes, Functions, and Dynamics

This section describes the conceptual models that explain the processes, functions, and dynamics within and between the landscape/ecogeomorphic units of Rush Ranch, key site disturbances, and the external drivers described above.

10.2.1 Conceptual Model of Unprecedented 21st Century Tidal Marsh Vegetation Change

The geomorphic and ecological development of Rush Ranch tidal marshes during the last 2500 years occurred over a period of consistently slow sea level rise and strongly fluctuating climate and salinity regimes (Byrne et al. 2001). The warm, dry, saline phases of its development lasting from decades to many centuries, may be comparable to forecast climate warming of the 21st century (Knowles and Cayan 2002), but interactions among higher salinity and temperatures with significantly accelerated sea level rise are likely to generate unprecedented, ecological conditions unprecedented in the Holocene paleoecological record (Malamud-Roam et al. 2007, Watson and Byrne 2009). Qualitative predictions of likely large-scale, long-term ecological responses of Rush Ranch tidal marsh vegetation to combined accelerated sea level rise, altered seasonal Delta outflows, and higher temperatures can be based on recent historic trends of vegetation change in the San Francisco Bay Estuary (Watson and Byrne 2009), and adapted to specific Rush Ranch conditions.

The following assumptions form the basis for a qualitative conceptual model of long-term 21st century vegetation change in Rush Ranch tidal marshes:

- Net deposition of fine suspended tidal sediment in the Suisun Marsh will continue to decline as sea level rises (Ganju and Schoellhamer 2009)
- Proportionally more tidal marsh accretion will depend on deposition of fine suspended sediment as sea level rise rates increase and marsh productivity declines with increasing submergence (Byrne et al. 2001)
- Increased summer salinity will result from decreased Sierra snowpack and melt water affecting summer delta outflows (Knowles and Cayan 2002)
- Low tidal marsh salinity increases will directly affect composition and productivity of low marsh vegetation (Watson and Byrne 2009)
- High tidal marsh (marsh plain) salinity will be offset by increased tidal immersion in tidally drained marsh plains (Watson and Byrne 2009)
- High tidal marsh salinity in poorly drained or undrained tidal marsh (pans, undrained interfluves) may increase due to higher salt loading during spring tides followed by evaporation.
- High tidal marsh salinity in tidal marsh terrestrial ecotones will increase due to reduced rainfall and prolonged evaporation following infrequent spring tide flooding episodes.
- Increased tidal marsh bank erosion (fringing marsh, slough banks, bay marsh edges) will occur due to increased tidal marsh prism per unit marsh area, and increased water nearshore water depths per unit wave fetch.
- Tidal sedimentation gradients associated with overbank deposition will concentrate suspended sediment and organic marsh peat accretion in high marsh near bank edges
- High marsh elevations bordering tidal channel sedimentation gradients will fall behind sea level rise more slowly than marsh plains distant from tidal channel sedimentation gradients.
- High marsh areas of terrestrial edges will keep pace with sea level rise depending on slope of alluvial fans subject to estuarine transgression, and alluvial sedimentation into rising tidal marsh.
- High marsh bordering bluff scarps (Suisun Slough, Hill Slough) will be subject to increased disturbance from bank slumping due to wave erosion and undercutting associated with sea level rise acceleration.

Low marsh (now tule-dominated) fringing channels is likely to respond to increased frequency and duration of high salinity by conversion to bulrush marsh (*Schoenoplectus americanus*) at lower brackish ranges of increased salinity, and alkali-bulrush marsh (*Bolboschoenus maritimus*) or even cordgrass (*Spartina foliosa*) at higher brackish ranges of increased salinity. These bulrush species do not grow below MTL, unlike tules that tolerate submergence at MLW and below. Bulrush low marsh conversion will therefore cause narrowing of low marsh zones, and reduced canopy height. Marsh width and shoot height are principal factors influencing wave energy attenuation. As fringing low marsh becomes narrower and lower, wave energy attenuation will decrease, providing positive feedback to marsh erosion response to bay deepening and increased wave energy associated with sea level rise. Because of frequent (daily) tidal inundation, the potential rate of sediment accretion in low marsh is relatively high in response to sea level rise.

High marsh (tall vegetation, natural levees) bordering tidal sloughs, one of the primary habitats for sensitive wildlife and plant species, is very infrequently flooded compared with low marsh, and is likely to suffer very low rates of sediment accretion in response to sea level rise. High tide flood refuge functions of slough banks within marsh interiors are likely to deteriorate, and increased horizontal slough bank erosion (slumping) due to increased tidal prism is likely to exceed vertical bank accretion. This internal loss of high marsh cover will decrease habitat suitability for resident rallid species and small mammals dependent on high tide refuge cover within their home ranges in the marsh plain. High tide wildlife cover/flood refuge habitat within the marsh plain may depend increasingly on scarce large woody debris or floating debris during extreme high tides. Tidal channels will widen but high marsh zones (natural levees) will narrow or disappear as erosion increases. This process will significantly reduce habitat for special-status high marsh species narrowly distributed along slough banks, such as Suisun thistle, soft bird's-beak, and Bolander's water-hemlock.

Most stable or persistent high tidal marsh zones will remain along the terrestrial edge of the marsh on low hillslope toes and alluvial fans composed of mineral sediment. Silty, low bulk density high marsh soils will be associated with active alluvial fan deposition. Higher bulk density soils will be associated with tidal marsh edges transgressing sandy clay loams of older alluvial fans. Peaty, well-drained high tidal marsh banks will become very scarce or eliminated in the marsh overall. Terrestrial edge high marsh may be dominated by low-growing species compared with tidal marsh slough banks, and may provide less cover during extreme spring high tides.

As peak summer salinity in channels increases, oligohaline (fresh-brackish) high tidal marsh species assemblages may become limited to areas of active terrestrial seeps (shallow groundwater discharge) or edges of alluvial fans with seasonal streamflow.

Tidal marsh plains are likely to increase in tidal drainage as channel networks erode headward in response to increased tidal prism. Vegetation of well-drained tidal marsh plains will increase in silverweed, bulrush and rush dominance. Extreme droughts associated with summer tidal channel salinity over about 18 ppt will increase pickleweed and saltgrass in marsh plains over bulrush (i.e., similar to current Napa Marsh). Increased tidal flooding and drainage of marsh plains will offset net increases in salinity from tidal sources, as predicted by Watson and Byrne (2009). Remaining poorly drained tidal marsh plains will revert to pans, and will exhibit increased peak summer salinity. Regenerated pans more than 30 cm deep may initially support sago pondweed *Stuckenia pectinatus*), but may become dominated by wigeongrass (*Ruppia maritima*) if summer peak salinities exceed 18 ppt)

The pace of marsh change is likely to be punctuated by abrupt increases in sea level (20 cm or more) associated with strong ENSO and PDO events, and extreme drought events. Extreme events may establish new patterns of marsh vegetation dominance that lag over recovery intervals in more average conditions, such as rapid expansion of bulrush stands in wet El Nino years with elevated sea levels, or expansion of saltgrass-pickleweed vegetation in extreme drought years.

Non-native invasive plant species that are widespread dominants in middle and high brackish marsh zones of the southern marsh plain, such as broadleaf pepperweed (*Lepidium latifolium*) and wild celery (*Apium graveolens*) are likely to endure increased competition from native dominant bulrush and rush species with higher flooding tolerance as sea level rise rates accelerate, and marsh accretion rates fall behind rising sea level. Impacts of these invasive species on sensitive rare native species in many interior marsh plain locations are likely to be reduced or nil, as habitat suitability for rare native species will likely be reduced or eliminated sooner than *Lepidium latifolium* is reduced by bulrush competition in submerging marsh plains. Wetland weed invasion pressure and impacts on terrestrial edge high marsh vegetation may increase as marsh zones ascend gentle topographic gradients as sea level rises. Pre-emption (invasion resistance) effects of antecedent vegetation in the shifting narrow landward high marsh gradients may become relatively more important for 21st century invasive species management. Wetland weed invasion of terrestrial tidal marsh edges may become limited by progressive expansion of widespread native clonal perennial graminoid species like *Leymus triticoides*, and to lesser extent, *Carex praegracilis* and *C. barbarae*.

In summary, 21st century tidal marsh vegetation changes important to management and conservation goals may be expected to include reduction or loss of high marsh bordering erosional tidal sloughs and marsh plain interiors, conversion of tule-dominated low marsh to narrower bulrush marsh, spread of bulrush and rush over marsh plains (extensive conversion of high marsh to middle marsh zones), increased channel density and extent in marsh plains partially offsetting vegetation impacts of net increases in channel, erosion of fringing marsh, salinity, and reduction of high marsh zones primarily to terrestrial edges, where species assemblages differ from slough bank high marsh. Some invasive species problems like *Lepidium latifolium* in marsh plains may literally be “drowned out” by marsh submergence combined with and bulrush and rush competition, but probably after special-status species habitats are degraded or lost. Special –status wildlife species dependent on high tide cover within home ranges on the marsh plain (mostly high marsh vegetation near slough banks) will suffer reduced high tide cover and loss of suitable habitat. Oligohaline tidal marsh vegetation may become restricted to small terrestrial-edge groundwater discharge zones.

10.2.2 Conceptual Model of Terrestrial Vegetation Responses to Key Drivers

As discussed above, the terrestrial plant communities on Rush Ranch have no ‘natural’ mature ecological state - only the current temporary state that has resulted from the combination of site influences over historic and recent time. In prehistoric time, primary influences included variations in natural climate patterns and cycles, grazing by native herbivores, and burning from either lightening strikes or intentional fires set by Native Americans. In modern times, primary influences include annual climate variations, livestock grazing, fire suppression, on-going invasion by non-native species, habitat restoration efforts, and, increasingly, the effects of anthropogenic changes in global atmosphere and climate. These influences can result in broad variations in plant species composition and cover across the site from year-to-year and over time. Some of these influences are more temporary, especially annual climate variations, grazing and fire, while others may be more directional or permanent, especially new invasions or spread by non-native species, successful habitat restoration, and global atmosphere and climate change.

Since there is no ‘natural’ mature ecological state, and two of the current primary influences – grazing and fire – are largely if not entirely anthropogenic in nature at this time, the terrestrial plant communities on the site essentially exist as managed landscapes with current community characteristics manipulated by these and other management activities within the context of the parameters set by more natural influences. A complete model of the site would consider the full range of outcomes from the combination of potential variations in the natural and anthropogenic influences. This model would be extremely complex and perhaps not too useful for the long-term maintenance and management of the site as an ecological reserve. On one end would be the complete cessation of all human inputs (grazing, fire, weed suppression, and habitat restoration) with the likely outcome that most of the site, except perhaps a narrow band adjacent to the marsh, would become overrun by invasive weeds with severely diminished ecological functions and extreme fire hazards. On the other end would be excessive grazing and fire inputs with the likely outcome of diminished plant species richness and insufficient cover for terrestrial wildlife such as ground nesting birds and small mammals.

Given this broad range of potential outcomes, the most useful ecological model would set targets for desired plant community and wildlife habitat characteristics, and then assess the potential natural and anthropogenic influences on the site to determine the range of land management strategies and activities that could be employed to achieve these targets.

Some of the targets that could be developed for the site include:

- Increasing the richness and cover of native grasses and forbs, especially purple needlegrass, creeping wildrye, and native wildflowers;
- Decreasing or eradicating the cover of ecologically harmful invasive species, especially yellow star-thistle, medusahead and Harding grass;
- Improving the habitat structure for key terrestrial wildlife species, especially ground-nesting short-eared owls and northern harriers, and the host of other birds that forage and nest on the site;
- Maintaining and improving habitat for small mammals, birds, reptiles and insects that constitute the prey base for raptors and other hunting birds that utilize the site;
- Increasing the density of coyote brush scrub near tidal marsh areas to provide a better habitat matrix for Suisun song sparrow;
- Improving habitat structure bordering the tidal marsh-terrestrial ecotone to provide good refugial habitat for Suisun shrew, saltmarsh harvest mouse, rails, and other marsh species during periods of excessively high tides.

While these targets are easy to articulate, they are much more difficult to achieve, especially in concert given the rather blunt management tools available (especially grazing and fire) and the fact they are generally applied simultaneously to all target species (both desired and non-desired) in a given area. Nonetheless, the combination of native plants and invasive weeds in the hillslopes appears amenable to management toward many of the targets outlined above. The most problematic invasive weeds are yellow star-thistle and medusahead, both of which have been effectively reduced through a carefully crafted and implemented integrated management plan involving grazing and burning. The grazing and fire regimes required to reduce these two weeds are also generally consistent with the regimes that would improve the cover of purple needlegrass and native forbs. It may be more difficult to achieve the management targets in the older alluvial fans, especially an increased cover of creeping wildrye across a larger portion of the fans. Grazing appears to greatly eliminate or reduce this species on the site. Yet, a lack of grazing over an 8-year period (1990-1998) in the pasture north of the headquarters did not result in a spread of this species up the fan but rather more weedy, dense growth of Harding grass, Italian thistle, and other invasive weeds. Greater cover of creeping wildrye may be achievable with more intensive restoration efforts, such as initial removal through heavy grazing of Harding grass, but the success of such efforts are far from certain.

The potential effects on California grasslands of on-going anthropogenic atmosphere and climate change are being increasingly studied but are as yet poorly understood. An excellent summary of the current state of knowledge and key research is presented in Chapter 19 (Dukes et al. 2005) of the recently published *California Grasslands: Ecology and Management* (Stromberg et al. 2007). A synopsis of some of the key findings and concepts presented in this chapter as they relate to Rush Ranch is presented below.

The most important potential effects of global atmosphere and climate change on California grasslands are as follows:

- Increased atmospheric CO_2 may change biomass production in certain species but studies completed so far have not indicated there will be drastic shifts in species composition; some weed species may become more competitive in a higher CO_2 environment but most studies are only suggestive and actual responses are not clear;
- Increased nitrogen inputs from atmospheric sources will likely increase soil fertility across the state which will likely favor introduced annual grasses over native and non-native forbs;
- Increased precipitation and a more prolonged rainy season from earlier in the winter to later in the spring may have a variety of effects including: an increase in overall above-ground biomass (though this above-ground increase can be offset by a decrease in below-ground biomass); an increase in the establishment of purple needlegrass due to the lessening of stress from summer drought; and an increase in the invasion and growth of woody species such as coyote brush (if not eliminated by grazing or fire);
- Increased average temperature may also have a variety of effects including: a slight increase in overall biomass production (based on the rather small predicted increases in average temperature) due to warmer winter temperatures; and earlier flowering of annual species with a potential consequent reduction in use of soil moisture reserves,

perhaps leaving more soil moisture for summer-growing species such as purple needlegrass.

While many of these potential effects have been tested individually, there have been very few experiments that tested all the potential effects in concert. Dukes and Shaw (2007) summarize perhaps the most comprehensive and long-term study yet conducted on the effects of global atmosphere and climate change on California grasslands. The Jasper Ridge Global Change Experiment, being conducted at the Jasper Ridge Biological Preserve near Stanford University in San Mateo County, was initiated in 1998 and continues to the present. This experiment has studied various potential effects of global atmosphere and climate change (CO_2 and N increases, temperature and precipitation increases, etc.) on multiple valley grassland plots. Some of the most important effects recorded included: increased warming accelerated the flowering of most grassland species though increased precipitation did not; increased CO_2 and N accelerated flowering in forbs but delayed it in annual grasses resulting in more synchronous flowering between these two groups; increased warming, precipitation and N all increased combined above and below ground biomass; increased CO_2 increased above ground biomass but decreased below ground (root) biomass. The level of many of these observed changes varied from year to year due, presumably, on changes in ambient weather conditions.

The relatively small changes from global atmosphere and climate change that have been experimentally demonstrated in California grasslands need to be weighed against the much larger changes that can occur on a more immediate basis from variations in annual climate and changes in the timing and intensity of grazing, fire and other land management practices. Also, California grasslands currently exist across a broad gradient of ambient rainfall and temperature conditions with often fairly minor variations in species composition and cover, at least from the standpoint of ecological functions. In many areas, geomorphology and soils are also more important than climate in determining the species composition and cover on a site. Given all these considerations, it seems unlikely that the on-going anthropogenic atmosphere and climate change will act as a dominant force on the community characteristics within the site grasslands, at least over the next few decades.

Rush Ranch provides a valuable site for on-going research into the effects of various management techniques on species composition and cover within California grasslands. It provides the geomorphic setting for two distinct grassland types of interest to California grassland biologists: mixed purple-needlegrass/introduced annual grass dominated upland grasslands; and creeping wildrye/salt grass dominated mesic perennial grasslands. It supports dense stands of yellow star-thistle, medusahead and Harding grass, three widespread invasive plant species that are all of great research and management interest to resource agencies and land managers. The grasslands also provide important regional nesting and foraging habitat for many raptors and other birds, important high-water refugia for a host of marsh-associated species including Suisun shrew, saltmarsh harvest mouse and rails, and the upland habitat component for the locally-endemic Suisun song sparrow. Solano Land Trust should leverage these characteristics to make the grasslands as important a component of the site research as the adjacent estuarine and fluvial habitats.

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Tables

Table 1. Site Soils (Source Data: USDA 1977)

Soil Type	Description	Site Distribution	Associated Geomorphic Unit(s)
Terrestrial			
Millsholm loam *(MmE, 15-30% slopes)*	Well-drained soils of upland hill slopes formed from weathered bedrock; loam underlain by sandstone at a depth of 10-20 in.; slightly acid to neutral throughout.	On steep hill slopes in the central eastern portion of the site.	Hillslope
Millsholm loam, moderately deep variant *(MnC, 2-9% slopes; MnE, 9-30% slopes)*	Well-drained soils of upland hill slopes formed from weathered bedrock; loam underlain by sandstone at a depth of 20-36 in.; slightly acid to neutral throughout.	On a few steep hill slopes in the southeastern portion of the site and a few scattered hills protruding above the marsh and low alluvial fans in the western portion of the site.	Hillslope
Gaviota sandy loam *(GaG2, 30-75% slopes, eroded)*	Well-drained soils of upland hill slopes formed from weathered bedrock; loam underlain by sandstone at a depth of 8-15 in.; slightly acid to neutral throughout.	On steep, generally south-facing hill slopes in the eastern portion of the site.	Hillslope
Altamont clay *(AcC, 2-9% slopes; AcE, 9-30% slopes; AcF2, 30-50% slopes, eroded)*	Well-drained soils on dissected terraces formed from weathered bedrock; clay, heavy clay loam surface, and clay subsurface underlain by siltstone at a depth of 25-40 in.; slightly acid to neutral surface, moderately alkaline below about 12 in.	Lower hill slopes, stratigraphically underlying Millsholm and Gaviota soils.	Hillslope
Diablo-Ayar clays *(DaE2, 2-9% slopes, eroded)*	Well-drained soils on dissected terraces; surface clay to 30 inches underlain by silty clay loam with weakly consolidated sediments extending to a depth of more than 60 in.; slightly acid to neutral surface, moderately alkaline below about 17 in.	On a few hills and valleys in the southeast of the site.	Hillslope
Clear Lake clay *(CeB, 2-5% slopes)*	Poorly drained soils of basins formed in mixed alluvium; clay extending to a depth of more than 60 in.; slightly acid to neutral surface, moderately alkaline below about 13 in.	Along some low-lying swales in the southeast of the site, bordered by both hill slope and alluvial fan formations.	Older Alluvial Fan (Inactive) (Pleistocene)
Antioch-San Ysidro complex *(AoC, 2-9% slopes)*	Moderately well-drained soils on terraces formed in alluvium from sedimentary rocks; loam and sandy loam surface underlain by clay, sandy clay loam and loam subsurface and substratum to more than 60 in; effective rooting depth of 12-20 in.; moderately alkaline below about 34 in.	In a few localized areas around the base of the hill slopes in the eastern portion of the site.	Older Alluvial Fan (Inactive) (Pleistocene))
Antioch-San Ysidro complex, thick surface *(AsC, 2-9% slopes)*	Similar to AoC soils but with an effective rooting depth of 20-30 in.; slightly acid to neutral surface, moderately alkaline below about 12 in.	Forms the large majority of the low alluvial fans in the western portion of the site and around the base of the hill slopes.	Older Alluvial Fan (Inactive) (Pleistocene)
Solano loam, dark surface variant *(Sm, nearly level)*	Somewhat poorly drained soils on terraces formed in alluvium from sedimentary rocks; loam surface (to about 7 in.), clay loam subsurface (to about 13 in.), and loam to loamy sand substratum to a depth of more than 60 in.; moderately to strongly alkaline thougout.	Along active and recent alluvial fans of modern creeks (such as Spring Branch Creek).	Recent Alluvial Fan (Active) (Holocene)
Borrow Pit (B.P.)	N/A	Two borrow pits in the northern portion of the site.	Older Alluvial Fan (Inactive) (Pleistocene)
Estruarine			
Joice muck *(Ja, nearly level)*	Nearly level, very poorly drained organic soils with a high mineral content; in salt and estuarine marshes formed from plant remains mixed with fine mineral sediments; saline black clayey muck to a depth of more than 60 in.; very strongly acid to about 40 in., moderately alkaline below.	Primary soil type within the tidal marsh plain and tidal marsh-terrestrial ecotone.	Tidal Marsh Plain, Tidal Marsh-Terrestrial Ecotone, some Fringing Tidal Marsh
Tamba mucky clay *(Ta, nearly level)*	Nearly level, very poorly drained organic soils with high organic content; in salt and estuarine marshes formed in alluvium from mixed sources and in hydrophytic plant remains; light to medium dark mucky clay surface (to about 10 in.), medium dark to black mucky clay subsurface (to about 42 in.), medium dark mucky clay substratum to more than 60 in.; very strongly acid to about 50 in., moderately alkaline below.	Formed along the edges of active tidal sloughs, typically along a band between the open water slough channels and the Joice muck soils.	Fringing Tidal Marsh and adjacent Tidal Marsh Plain
Reyes silty clay *(Re, nearly level)*	Nearly level, poorly drained, saline soils; in salt and estuarine marshes formed in alluvium derived from mixed sources; silty clay throughout; strongly acid to about 60 in., moderately alkaline below.	Formed along the edges of active tidal sloughs, restricted to few locations near the southern edge of the site.	Fringing Tidal Marsh and adjacent Tidal Marsh Plain
Open Water (*w*)	Open water within tidal sloughs.	Within active sloughs.	Subtidal Channel Bed

Table 2. Ecogeomorphic Units and Subunits on Rush Ranch

Landscape Units and Subunits	General Description	Geology, Soil and Hydrology Characteristics	Plant Community Characteristics
Terrestrial Landscape			
Hillslopes	True uplands on the site, steep to moderate slope hills mostly concentrated in the east but also occurring as small hills at or near the marsh edge in the west.	Underlain by uplifted marine sedimentary rocks (sandstones and siltstones); mostly well-drained loam soils often underlain by bedrock at 10-40 inches below the surface; surface hydrology features limited to very narrow, intermittent grassland swales in the lower hillslopes.	Dominated by introduced annual grasses with a subdominant component of invasive weedy forbs in some areas; a low cover of purple needlegrass and various native wildflowers also occur with distribution patterns related to local geomorphic characteristics.
Hilltops	Flat to gently crowned tops of hills.	Generally deeper soils than adjacent slopes, very well drained.	Dominated by introduced annual grasses but often supporting a subdominant cover of invasive weeds, especially yellow star-thistle and Italian thistle.
Upper Convex Slopes	Upper portions of the hillslopes; zones of soil erosion with typically thinner soils and lower seasonal moisture than lower concave.	Generally shallower soils than lower concave slopes, very well-drained.	Dominated by introduced annual grasses but often supporting a concentration of various native forbs such as narrow-leaved mule's ears, gumweed, and white-leaf bush lupine; invasive weeds not commonly dense on this landscape unit.
Lower Concave Slopes	Lower portions of the hillslopes and larger valleys in upper slopes; zones of soil accumulation with typically deeper soils and higher seasonal moisture content than upper convex slopes.	Generally deeper soils than upper convex slopes, well-drained.	Dominated by introduced annual grasses but often with moderate to dense mosaic patches of yellow star-thistle and medusahead; Italian thistle also occurs most commonly on this landscape unit as does the native perennial bunchgrass purple needlegrass.
Heavy Clay Soils	Exposed heavy clay soils with deep surface cracking along the hillslopes where Altamont clay and Diablo-Ayar clay occurs.	Altamont clay and Diablo-Ayar clay surface exposures, moderately drained, soil has high moisture-holding capacity.	Moderate to low vegetation cover including some bare areas; dominant species is typically Italian ryegrass.
Saddles and Swales	Flat to convex slopes between hills and along the lower portions of valleys.	Soils generally have a higher clay and seasonal moisture content.	Dominated by introduced annual grasses but sometimes supporting low-density stands of Harding grass.
Rock Outcrops	Small, localized sandstone outcrops in widely scattered areas on the lower hillslopes.	Sandstone rock exposures from underlying marine sedimentary rocks.	Rock outcrops often provide unique plant and wildlife microhabitats within grasslands depending on size, configuration and parent material of the rocks; the rock outcrops on the site are small and composed of a common parent material (sandstone) and thus do not present especially unique microhabitats.
Older Alluvial Fans	Older (Pleistocene age) alluvial fans around the base of the hillslopes and extending down to the edge of the estuarine and fluvial landscape units.	Formed in alluvium from sedimentary rocks; loam and sandy loam surface underlain by clay, sandy clay loam and loam subsurface and substratum to more than 60 inches; no underlying bedrock; moderately alkaline below about 12 inches in most areas.	Dominated by a mix of introduced perennial and annual grasses with a subdominant component of invasive weedy forbs grasses; very low cover and limited distribution of purple needlegrass and native wildflowers; intermittent band of creeping wildrye along the immediate marsh edge; saltgrass in scattered areas with alkaline to subalkaline soils.
Lower Fan Areas	Lower portions of the alluvial fans near the marsh boundary and extending up to the mid fan elevations.	Higher clay content and seasonal moisture level in surface soils than upper fan areas.	Often dominated or prone to be dominated by Harding grass; understory often includes a mix of soft chess, ripgut and medusahead; saltgrass often present as well; creeping wildrye sometimes intermixed along the lowest edge of the fan along the upper edge of the marsh-terrestrial ecotone but generally absent elsewhere within the fan.
Upper Fan Areas	Upper portion of the alluvial fans around the bases of the hillslopes.	Lower clay content and seasonal moisture level in surface soils than lower fan areas.	Generally dominated by introduced annual grasslands, especially soft chess; widespread dense to moderate patches of medusahead; yellow star-thistle widespread but generally density; Harding grass can occur in scattered to dense stands depending on level of grazing and soil moisture.
Areas with Elevated Soil Alkalinity	Scattered areas within the alluvial fans.	Likely in areas where surface soils are thin or absent and the moderately alkaline subsoils are closer to the surface; also along the immediate marsh boundary; typically clay to clay loam soils with elevated seasonal moisture.	Low to moderate cover of saltgrass often within bare soil patches; other associated plants inlcude

Table 2. Ecogeomorphic Units and Subunits on Rush Ranch

Landscape Units and Subunits	General Description	Geology, Soil and Hydrology Characteristics	Plant Community Characteristics
Terrestrial Landscape			
Man-made Basins with Vernal Pools	Approximately 12 man-made basins in low-lying areas within former quarry sites in the northwest of older alluvial fans; basins have come to support a dominance of vernal pool indicator plants and other seasonal wetland plants.	Basins subject to shallow ponding for several weeks during the rainy season; maximum ponding depth ranges from 2-12 inches.	Basins support seasonal wetland vegetation with a mix of vernal pool indicator plants, generalist seasonal wetland plants and some halophytic seasonal wetland plants.
Alluvial Landscape			
Distributary Channels	braided, reticulate, meandering shallow channels active during peak flow events within active depositional alluvial fans. Bank stability affected by cattle grazing and trampling.	intermittent flooding, brief seasonal or ephemeral high flows; small unstable channels and low banks subject to avulsion, meandering, switching; scour pools, scarps present; silty to clayey sediment	variable unvegetated or sparse vegetation following erosion, deposition events; bed instability influenced by cattle grazing, trampling – inhibits stabilization by perennial clonal graminoid vegetation (sedge, rush, spikerush, grasses)
Meander Scars	relict distributary channel scarps in abandoned (inactive) distributaries	steep (near-vertical) persistent low scarps, scarp or fan below	subject to cattle trampling
Lobes and Flats	sheetflow (braided) deposited sediment fans, very low gradient (flats)	clayey or silty flats, winter-saturated or shallow flooding, ponding; summer dessicated; cohesive to unconsolidated; subsaline or alkaline	alkali grassland or seasonal wetland, pool (including high salt marsh) plant species, including annual forbs, grasses
Impoundments (diked tidal marsh)	Artificial non-tidal perennial brackish to fresh-brackish marsh enclosed by bay mud levee	Impoundment of tidal inflows (tidegate) and upland runoff (swale drainage); predominantly fresh-brackish, perennial marsh, brackish to hypersaline upper edge	Common reed, cattail, chairmaker bulrush, Baltic rush-saltgrass-alkali heath upper edge; local SAV ponds (sago pondweed)
Impoundments (artificial pond)	artificially deep and ponds impounded by steep berms (dams); cattle watering ponds	persisting standing water or mud in summer, heavily trampled, disturbed silt, clay	freshwater marsh (cattail, water-plantain, spikerush), pondweed, bare mud
Estuarine Landscape			
Tidal Marsh Plains	Holocene tidal marshes underlain by thick mineral sedimentation and peat accumulation atop buried alluvial fans; dissected by branching, sinuous tidal slough network; extends to uplands with relatively "natural" edge through much of Rush Ranch	Predominantly organic peaty sediment in upper 1 m, underlain by thick mineral sediment over buried terrestrial alluvial fans	Middle and high marsh vegetation patterned along tidal drainage and elevation gradients; complex
Tidal Creek Banks	Steep or sloping channel side slopes, scarps, relict scarps, slump blocks	low marsh fringing banks – potentially high sediment accretion rates	tule, cattail, bulrush, mason's lilaeopsis; rarely Lyngbye's sedge
Tidal Slough Bank Levees	Microtopographic elevation gradient bordering larger tidal creeks, established by tidal sedimentation gradient	High marsh, enhanced subsurface tidal drainage; narrow zone of maximum suspended sediment deposition gradient during overbank flows	High vascular plant species diversity, including tall forbs; vulnerable to *Lepidium latifolium* dominance; maximum high tide cover; includes many rare plant populations
Dikes (Artificial Levees) and Slough Dams	Drained bay mud, oxidized, elevated above high spring tides	Minimal residual soil salinity; steep side-slopes	Terrestrial vegetation, mostly ruderal, non-native invasive species
Ditches (Artificial Channels)	Long rectilinear artificial channels cut across poorly drained marsh plain to reduce areas of persistent standing water (mosquito abatement)	Extension of tidal drainage network across natural drainage patterns; cross-section similar to smallest tidal creeks	Similar to well-drained marsh plain bordering small tidal creeks, but ditch side-cast disturbance facilitates weed invasion
Well-drained Marsh Plain	Zone bordering tidal creek sediment and detritus source,	Predominantly high marsh, peaty soil – near tidal surface and subsurface drainage; organic sediment accretion; narrow active suspended sediment deposition gradient during overbank flows	High vascular plant species diversity, including tall forbs; vulnerable to *Lepidium latifolium* dominance; includes rare plant populations
Poorly-drained Marsh Plain	Interior tidal marsh platform beyond tidal channels; potential pan or pond. Generally occurs distance from tidal sloughs	Predominantly middle to high marsh plain, peaty soil – remote from tidal creek sediment source, poorly drained, primarily organic accretion, slow. Evaporative concentration of salts in droughts; prolonged retention of standing water in wet years	saltgrass and rush; bulrush in depressions

Table 2. Ecogeomorphic Units and Subunits on Rush Ranch

Landscape Units and Subunits	General Description	Geology, Soil and Hydrology Characteristics	Plant Community Characteristics
Terrestrial Landscape			
Marsh Plain Ponds (Pans)	Depressions in poorly drained interior marsh plain with persistent shallow standing water winter-spring	Undrained tidal marsh, naturally impounded (no channel outlet); flooded by rainfall and overmarsh flows of spring tides. Minimized or eliminated by artificial ditching	SAV (pondweed, wigeongrass) ; may be invaded by tule, bulrush (converted to marsh)
High Marsh Pans (Turf Pans)	Playa-like barren to low, sparsely vegetated flats at landward edge of marsh plain or in terrestrial ecotone, lower edge of dense clayey to sandy alluvial fan sediments	Seasonally flooded or saturated with very shallow water; summer desiccated	prostrate forms of pickleweed, alkali-heath; clubrush, goldfields and low annual forbs, sparse saltgrass
Tidal Marsh Sloughs	Channel	Unconsolidated bay mud; rare outcrops of sandstone bedrock (Suisun Slough/Hill Slough)	SAV (pondweed, wigeongrass) , localized stands; tule, Lyngbye sedge (low marsh edge)
Bed (subtidal, intertidal)	Bottoms of tidal marsh sloughs are subtidal (larger sloughs) or intertidal (smaller sloughs)		Epibenthic and benthic invertebrate communities; may support aquatic vegetation; may support epibenthic algae
Tidal Creek Banks	Steep or sloping channel side slopes, scarps, relict scarps, slump blocks	low marsh fringing banks – potentially high sediment accretion rates	tule, cattail, bulrush, mason's lilaeopsis; rarely Lyngbye's sedge
Fringing Tidal Marsh	Narrow tidal marsh platform bordering large sloughs and uplands, lacking dendritic tidal channels	Thick peat soils with wave-cut scarp bank edges, generally well-drained	High vascular plant species diversity, including tall forbs; includes rare plant populations; At Rush Ranch, *Lepidium latifolium* present but not dominant despite suitable high marsh
Tidal Marsh-Terrestrial Ecotone	Predominantly terrestrial transition zone influenced by brief episodic extreme high tides flooding terrestrial or alluvial (terrigenous sediment) substrate	Variable terrestrial hydrology influence (xeric, seasonal seep, seasonal overland and channelized flow), terrestrial soils (non-peat); variable slope and drainage (including pans)	Intergrading terrestrial or alluvial grassland, tidal marsh, or riparian scrub vegetation
Upland Scarps	Hillslope erosion scarps, slump blocks, bordering tidal sloughs; stabilized or actively eroding banks	Sandstone-derived soils of hillslopes and old inactive alluvial fans; some bedrock cliffs (Suisun Slough); local seeps, slumps; some cattle trampling except steepest slopes	Riparian scrub elements – N aspect slopes (remnant old elderberry, rose, poison oak, coyote brush, basket sedge, monkeyflower, mugwort)

Table 3. Estimated Tidal Datums for Rush Ranch

Tidal Datums	**Bradmoor Island** [1] **ft NAVD88**	**Port Chicago** [2] **ft NAVD88**
MHHW	6.4	6.0
MHW	5.9	5.5
MTL	3.8	3.7
MLW	1.7	1.8
MLLW	0.9	1.1
range (MHHW - MLLW)	5.5	4.9

Notes:

1. Bradmoor Island tidal datum (NOS 941-4811) from DWR Blacklock Restoration Plan, based on April to July 2004 original data collected by National Ocean Service
2. Port Chicago tidal datum (NOS 941-5144) from www.tidesandcurrents.noaa.gov with WWR calculation of conversion to NAVD88 and verified by National Ocean Service staff in 2005

Table 4. Terrestrial Plant Species Components

Plant Species Component	General Description and Current Distribution	Susceptibility to Short- and Long-term Change
Hillslopes		
Dominant Non-native Annual Grasses		
Mixed non-native annual grass stands *(Bromus hordeaceus-Bromus diandrus-Avena barbata-Lolium multiflorum)*	Dominant matrix of non-native annual grasses throughout the hillslopes. Soft chess is the most common species. Wild oats is most abundant on deeper loamy soils. Italian rye is most abundant on heavier, seasonally moist soils. Rose clover, an introduced annual forb, is a common subdominant component of the matrix.	Local cover of individual species may vary with annual climate variations, but the stands are generally resistant to change under typical grazing or fire regimes. Cover could be reduced by invasion of weeds, especially yellow star-thistle and/or medusahead.
Native Grasses		
Purple needlegrass stands *(Nassella pulchra)*	Native perennial bunchgrass. Scattered, low density stands, mostly restricted to midslope areas on Millsholm loam soils. The basis for the distribution pattern is unclear. Total cover varies little from year to year since it is a perennial species.	Heavy competitive pressure from non-native grasses and forbs. Past farming of hillslopes would have eliminated most stands. No data available on whether stands are increasing or decreasing over time but cover could potentially be influenced positively or negatively under different grazing and fire regimes.
Creeping wildrye stands *(Leymus triticoides)*	Native perennial rhizomatous grass associated with seasonally moist to wet soils. Almost entirely absent from the hillslopes. A few individuals were observed on a west-facing mid slope on one of the isolated hills with Millsholm loam soil near the marsh edge and along a lower north-facing slope in the eastern hillslopes, also on Millsholm loam soil.	Significant stands of the species unlikely to become established in the hillslopes under any grazing or fire regime based on a general lack of suitable soil and moisture conditions and competition from non-native species.
Saltgrass stands *(Distichlis spicata)*	Native perennial rhizomatous grass associated with seasonally moist to wet alkaline to subalkaline soils. Within hillslopes, patchy low density stands restricted to lower slopes on Diablo-Ayar clay and Altamont clay soils, both of which have moderately alkaline subsoils.	Species generally appears resistant to influence under different grazing or fire regimes. Distribution will always be limited to areas with alkaline or subalkaline soils.
Native Forbs		
Native wildflower stands *(Wyethia angustifolia-Grindelia camporum- Lupinus albifrons-Eschscholtzia californica)*	Native wildflower stands include narrow-leaved mule's ears, Great Valley gumweed, white-leaf bush lupine and California poppy as the most common species. Identifiable stands are generally concentrated on convex to planar mid to upper slope areas on Millsholm loam and Gaviota sandy loam soils. These areas are prone to erosion (rather than deposition) and may have thinner soils and reduced competition from non-native species. Species abundance varies significantly under different annual rainfall and temperature patterns.	Heavy competitive pressure on the site from non-native grasses and forbs but cover within stands could increase or decrease under different grazing and fire regimes.
Native Shrubs		
Coyote brush stands *(Baccharis pilularis)*	15-20 scattered shrubs occur south and southwest of the site headquarters on the isolated hills with Millsholm soils. Most shrubs occur in areas excluded from grazing.	Stands are heavily impacted or eliminated under a typical grazing regime. Fire also reduces or eliminates stands. The species would likely become widely established across the hillslopes if grazing was discontinued or limited.
Special-status Plants		
(none)	No special-status plants are known or likely to occur with the hillslopes. This area presents fairly generic microhabitats not particularly suitable to any special-status species.	N/A
Invasive Grasses		
Medusahead stands *(Taeniatherum caput-medusae)*	Widespread but patchy within the hillslopes, concentrated on heavier, more seasonally moist soils including lower slopes with Diablo-Ayar clay and Altamont clay and north- and east-facing lower slopes of Millsholm loam.	Distribution and abundance can change annually and even directionally over the long-term due to grazing, fire and extreme climate conditions (excessive drought or rain). This species continues to spread throughout many regions in California (D'Antonio et al. 2007) and could continue to spread on the site under the current grazing and fire regimes. Stands could increase or decrease under different grazing and fire regimes.
Harding grass stands *(Phalaris aquatica)*	Limited stands mostly on the lowest hillslopes in areas with higher seasonal moisture. Stands occur on all soil types with the hillslopes. The dense cover in the pasture north of the site headquarters (Harding Pasture) is due to past farming of the species. It has since spread elsewhere on the site in areas with suitable soil conditions, including mesic soils in the lower hillslopes.	The current grazing regime greatly reduces the distribution and cover of the species, especially in areas with more marginal habitat such as the lower hillslopes. This is demonstrated in several locations where grazed and ungrazed pastures abut along a fence line and Harding grass is present or dominant only on the ungrazed side. Grazing and fire would likely decrease cover of the species in most areas.

Table 4. Terrestrial Plant Species Components

Plant Species Component	General Description and Current Distribution	Susceptibility to Short- and Long-term Change
Hillslopes		
Invasive Forbs		
Yellow star-thistle *(Centaurea solstitialis)*	Widespread throughout much of the hillslopes with densest stands on deeper, heavier soils especially on Altamont clay, Diablo-Ayar clay and the lowest slopes and some hilltops of Millsholm loam. Distribution and abundance can change annually and directionally over the long-term due to grazing, fire and extreme climate conditions (excessive drought or rain).	Distribution and abundance can be influenced by grazing and fire though annual climate fluctuations could overwhelm the effects from these activities.
Italian thistle *(Carduus pycnocephalus)*	Scattered low-density stands within the hillslopes, mostly on flat to north- or east-facing slopes with deeper soils.	Grazing generally reduces distribution and cover. Fire would also likely reduce distribution and cover.
Mediterranean lineseed *(Bellardia trixago)*	Low-density stands, primarily on thin Altamont clay soil exposures.	Potential influence of grazing or fire unknown.
Older Alluvial Fans		
Dominant Non-native Annual Grasses		
Mixed grass stands *(Bromus hordeaceus-Bromus diandrus-Lolium multiflorum)*	Dominant matrix of non-native annual grasses throughout the older alluvial fans except the lower margin adjacent to the tidal marsh. Soft chess and Italian rye are the most common species with Italian rye more abundant in heavier, seasonally moist soils.	Local cover of individual species may vary with annual climate variations but stands generally resistant to change under typical grazing or fire regimes. Cover could be reduced by invasion of weeds, especially yellow star-thistle, medusahead and/or Harding grass.
Native Grasses		
Purple needlegrass stands *(Nassella pulchra)*	Native perennial bunchgrass. Very limited stands within the older alluvial fans, mostly on slightly elevated areas with perhaps drier soils. Total cover varies little from year to year since it is a perennial species.	Significant stands of the species unlikely to become established on the older alluvial fans under any grazing or fire regime due to an apparent general lack of suitable or preferred habitat and competition from non-native species.
Creeping wildrye stands *(Leymus triticoides)*	Native perennial rhizomatous grass associated with seasonally moist to wet soils. Currently restricted to a narrow intermittent band along the upper edge of the terrestrial-tidal marsh ecotone. No occurrences of the species were observed further up the fans.	Species is typically eliminated under even moderate grazing pressure. This is demonstrated in several locations where grazed and ungrazed pastures abut along a fence line and creeping wildrye is present only on the ungrazed side. Grazing and fire would likely greatly decrease or eliminate the species.
Saltgrass stands *(Distichlis spicata)*	Native perennial rhizomatous grass associated with seasonally moist to wet alkaline to subalkaline soils. Within the older alluvial fans, the species occurs in dense stands along the marsh edge (often co-occurring with creeping wildrye stands) and in localized patches with alkaline or subalkaline soils within the upper portions of the fans.	Species generally appears resistant to influence under different grazing or fire regimes. Distribution will always be limited to areas with alkaline or subalkaline soils.
Native Forbs		
Native wildflower stands	There is a very low occurrence and cover of native wildflowers within the older alluvial fans.	Significant stands of native wildflowers are not expected to become established within the older alluvial fan under any grazing or fire regime based on a general lack of suitable conditions and competition from non-native species.
Native Shrubs		
Coyote brush stands *(Baccharis pilularis)*	15-20 scattered shrubs occur south and southwest of the site headquarters Antioch-San Ysidro soils. Most shrubs occur in areas excluded from grazing though there are 7-8 shrubs within a grazed pastured all of which show signs of heavy grazing damage.	Stands are heavily impacted or eliminated under a typical grazing regime. Fire also reduces or eliminates stands. The species would likely become widely established across the older alluvial fans if grazing was discontinued or limited.
Special-status Plants		
(none)	No special-status plants are known or likely to occur with the older alluvial fans. This area presents fairly generic microhabitats not particularly suitable to any special-status species.	N/A
Invasive Grasses		
Medusahead stands *(Taeniatherum caput-medusae)*	Widespread but patchy in moderate to dense stands across the older alluvial fans.	Distribution and abundance can change annually and even directionally over the long-term due to grazing, fire and extreme climate conditions (excessive drought or rain). This species continues to spread throughout many regions in California (D'Antonio et al. 2007) and could continue to spread on the site under the current grazing and fire regimes. Stands could increase or decrease under different grazing and fire regimes.

Table 4. Terrestrial Plant Species Components

Plant Species Component	General Description and Current Distribution	Susceptibility to Short- and Long-term Change
Hillslopes		
Harding grass stands *(Phalaris aquatica)*	Dense stand across the pasture north of the site headquarters (Harding Pasture) where the species was planted in the 1960s. Scattered to dense stands elsewhere across most of the older alluvial fans. Soil texture and moisture conditions are very amenable to this species.	Grazing appears to decrease the cover of this species as demonstrated in several locations where grazed and ungrazed pastures abut along a fence line and Harding grass is present or dominant only on the ungrazed side. Grazing and fire would likely decrease cover of the species in most areas.
`Invasive Forbs		
Yellow star-thistle *(Centaurea solstitialis)*	Widespread throughout much of the hillslopes with densest stands on deeper, heavier soils especially on Altamont clay, Diablo-Ayar clay and the lowest slopes and some hilltops of Millsholm loam. Distribution and abundance can change annually and directionally over the long-term due to grazing, fire and extreme climate conditions (excessive drought or rain).	Distribution and abundance can be influenced by grazing and fire though annual climate fluctuations could overwhelm these effects from these activities.
Italian thistle *(Carduus pycnocephalus)*	Scattered low-density stands within the hillslopes, mostly on flat to north- or east-facing slopes with deeper soils.	Grazing generally reduces distribution and cover. Fire would also likely reduce distribution and cover.
Milk thistle *(Silybum marianum)*	Limited to a few stands, in disturbed or roadside areas.	Current grazing generally eliminates the species from the site. The species became more widespread in the pasture north of the site headquarters (Harding Pasture) when grazing was discontinued (1990-1998). Fire could potentially increase the cover (Reiner 2007).
Prickly lettuce *(Lactuca serriola)*	Limited to scattered stands in ungrazed areas near the marsh edge.	Current grazing generally eliminates the species from the site. Species would likely become more widespread in areas with seasonally or intermittently moist soils if grazing were discontinued. Fire could possibly increase the species (Reiner 2007).
Fennel *(Foeniculum vulgare)*	Limited to scattered stands in ungrazed areas near the marsh edge and along roadsides.	Current grazing generally eliminates the species from the site. Species would likely become more widespread in areas with seasonally or intermittently moist or wet soils if grazing were discontinued. Fire could possibly increase the species (Reiner 2007).
Bellardia (Bellardia trixago)	Scattered low-density stands on thin exposed areas on Altamont clay soils.	Distribution and abundance likely resistant to grazing or fire.
Purple star-thistle *(Centaurea calcitrapa)*	A few localized stands around disturbed sites such as the troughs in the northeast portion of the site.	Current distribution limited to disturbed sites. Species could colonize areas of future disturbance. Also, fire or excessive grazing could cause the species to spread.
Man-made Basins		
Vernal Pool/Seasonal Wetland Plants		
Mixed Vernal Pool Indicator/Generalist Seasonal Wetland Species Stands *(Eleocharis macrostachya-Plagiobothrys stipitatus* var. *micranthus-Lasthenia glaberrima-Eryngium vaseyi/Hordeum brachyantherum, Lotus corniculatus, Phalaris aquatic-Rumex crispus/Distichlis spicata-Cotula coronopifolia-Frankenia salina*)	Mixed assemblage of annual and perennial vernal pool indicator plants, generalist seasonal wetland plants, and halophytic seasonal wetland plants. Occurs within 12 separate man-made basins within old quarry sites in the northwest of the older alluvial fans. Basins support seasonal wetlands that may be considered vernal pools based on the dominance of vernal pool indicator species.	Moderate grazing has been shown to maintain habitat conditions within vernal pools (Marty 2005). Fire would also likely help maintain habitat conditions by reducing the intrusion of mesic non-native annual grasses such as Italian ryegrass and Mediterranean barley (*Hordeum marinum* var. *gussoneanum*).
Special-status Vernal Pool Plants		
(none)	Special-status plant surveys were recently conducted within the vernal pool (Vollmar et al. 2006). No special-status species were found though the pools were determined to provide potential habitat for Contra Costa goldfields (*Lasthenia conjugens*), saline clover (*Trifolium depauperatum* var. *hydrophilum*) and alkali milk-vetch (*Astragalus tener* var. *tener*). However, these species are unlikely to occur based on lack of detection during the 2006 surveys and the man-made nature of the pools.	N/A

Table 5. Special-status Terrestrial Wildlife Species

Species	Status		
Raptors		Preferred Habitat(s)	Occurrence on Site
Cooper's hawk (nesting) *(Accipiter cooperii)*	CWL	Nests in trees, typically hunts in woodlands and forests; target prey is small to medium birds.	May occasionally forage over the site.
Golden eagle (nesting/foraging) *(Aquila chrysaetos)*	CWL CFP	Nests on cliffs or tall trees; hunts in open grasslands and other open habitats; target prey includes small mammals and birds	Known from general region and likely to forage in grasslands on site.
Short-eared owl (nesting) *(Asio flammeus)*	CSSC	Nests on the ground in grasslands and other tall herbaceous habitats; hunts in grasslands, marshlands and other open habitats; target prey is voles but also hunts other small mammals and birds.	Nests in significant numbers within the grasslands on the alluvial fans; Rush Ranch is considered a regionally important nesting site for the species; hunts within the grassland and marsh habitats.
Western burrowing owl (nesting) *(Athene cunicularia hypugea)*	CSSC	Nests in subterranean sites, especially California ground squirrel burrows but also under rip-rap piles, in culvert pipes, and other man-made features; prefers open to low grassland and open shrub habitats where it nests and hunts; target prey is small rodents and large insects.	At least one adult has been observed on the site during the breeding season (June) indicating the species may breed on site.
Swainson's hawk (nesting/foraging) *(Buteo swainsoni)*	CT	Summer nesting migrant; nests in trees; hunts in open grasslands and low agricultural fields (such as alfalfa); target prey is small mammals, birds and insects.	No documented occurrences on the site but common in the general region of eastern Solano County and likely to hunt on site, at least occasionally.
Northern harrier (nesting) *(Circus cyaneus)*	CSSC	Nests on the ground, typically in shrubby or tall herbaceous vegetation at the edge of a marsh; hunts in open grasslands and marsh habitat; target prey is small mammals, birds, reptiles, and insects.	Commonly observed hunting on the site; Rush Ranch is considered a regionally important nesting site for the species.
White-tailed kite (nesting) *(Elanus caeruleus)*	CFP	Nests in trees; hunts in open grasslands, marshlands, low agricultural fields and other open habitats; target prey is small mammals but will also hunt small birds, reptiles and insects.	Occasionally observed on the site hunting over the grasslands and marshlands.

Table 5. Special-status Terrestrial Wildlife Species

Species	Status		
Other Bird Species			
Loggerhead shrike *(Lanius ludovicianus)*	CSSC	Nests in shrubs; hunts in grasslands, open scrub, low agricultural fields and other open habitats; target prey includes insects, reptiles, and small mammals.	Known to forage on the site.
California horned lark *(Eremophila alpestris actia)*	CWL	Nests on the ground in grasslands; hunts primarily in grasslands; target prey includes insects and other terrestrial invertebrates.	Forages and likely nests on the site.
Tricolored blackbird (breeding colony) *(Agelaius tricolor)*	CSSC	Colonial nester within tall emergent marsh and riparian scrub habitat; hunts primarily in grasslands, riparian scrub, and some annual croplands; target prey is insects and other terrestrial invertebrates.	Known from the general region with potential to nest in emergent marsh habitat within the man-made stock pond along Spring Branch Creek and perhaps within the estuarine marsh habitats.

Table 6. Invasive Plant Species Known to Occur on Rush Ranch

Red-shaded rows indicate species that currently present a high threat to the ecological conditions or functions on the site and that are susceptible to control under different land use practices.

Species	Cal-IPC List[1]	Impact[2]	Invasiveness[2]	Distribution[2]
Cal-IPC 'High' Species				
Yellow star-thistle (*Centaurea solstitialis)*	High	A	B	A
Fennel (*Foeniculum vulgare)*	High	A	B	A
Perennial pepperweed (*Lepidium latifolium*)	High	A	A	A
Himalaya blackberry (*Rubus armeniacus*)	High	A	A	A
Hybrid smooth cordgrass (*Spartina alternaflora* X *foliosa*	High	A	A	C
Medusahead (*Taeniatherum caput-medusae*)	High	A	A	A
Cal-IPC 'Moderate' Species				
Slender oat (*Avena barbata*)	Moderate	B	B	A
Wild oat (*Avena fatua*)	Moderate	B	B	A
Black mustard (*Brassica nigra*)	Moderate	B	B	A
Ripgut brome (*Bromus diandrus*)	Moderate	B	B	A
Italian thistle (*Carduus pycnocepahlus*)	Moderate	B	B	A
Purple star-thistle (*Centaurea calcitrapa)*	Moderate	B	B	B
Bull thistle (*Cirsium vulgare*)	Moderate	B	B	B
Artichoke thistle (*Cynara cardunculus*)	Moderate	B	B	B
Bermudagrass (*Cynodon dactylon*)	Moderate	B	B	B
Cutleaf geranium (*Geranium dissectum*)	Moderate	C	B	A
Mediterranean barley (*Hordeum marinum* ssp. *guss.*)	Moderate	B	B	A
Wall barley (*Hordeum murinum* ssp. *lep*)	Moderate	B	B	A
Italian ryegrass (*Lolium multiflorum*)	Moderate	A	B	A

Table 6. Invasive Plant Species Known to Occur on Rush Ranch

Species	Cal-IPC List[1]	Impact[2]	Invasiveness[2]	Distribution[2]
Harding grass (*Phalaris aquatica*)	Moderate	B	B	B
Red sorrel (*Rumex acetosella*)	Moderate	B	B	A
Rose clover (*Trifolium hirtum*)	Moderate	C	B	B
Cal-IPC 'Limited' Species				
Mediterranean lineseed (*Bellardia trixago*)	Limited	C	C	C
Soft chess (*Bromus hordeaceus*)	Limited	B	C	A
Brass buttons (*Cotula coronopifolia*)	Limited	C	C	B
Redstem filaree (*Erodium cicutarium*)	Limited	C	C	A
Bristly ox-tongue (*Helminthotheca echioides*)	Limited	C	B	B
California burclover (*Medicago polymorpha*)	Limited	C	C	A
Rabbitsfoot grass (*Polypogon monspeliensis*)	Limited	C	C	B
Firethorn (*Pyracantha angustifolia*)	Limited	C	B	B
Radish (*Raphanus sativus*)	Limited	C	C	B
Curly dock (*Rumex crispus*)	Limited	C	C	A
Milk thistle (*Silybum marianum*)	Limited	C	C	A
Wild mustard (*Sinapis arvensis*)	Limited	C	C	C

Notes:

1. Cal-IPC (California Invasive Plant Council) Lists:
High: Severe ecological impacts on physical processes, plant and animal communities, and vegetation structure; moderate to high rates of dispersal and establishment; widely distributed ecologically.
Moderate: Substantial and apparent—but generally not severe—ecological impacts on physical processes, plant and animal communities, and vegetation structure; moderate to high rates of dispersal, though establishment is generally dependent upon ecological disturbance; distribution may range from limited to widespread.
Limited: Ecological impacts are minor on a statewide level or there was not enough information to justify a higher score; low to moderate rates of invasiveness; distribution is generally limited, but these species may be locally persistent and problematic.

2. Cal-IPC Ratings: *A*: Severe; *B*: Moderate; *C*: Limited; *D*: None

Species Not Listed By Cal-IPC But of Local Concern

Table 6. Invasive Plant Species Known to Occur on Rush Ranch

	Threats to:			
Species	**Special-Status Species**	**Native Species**	**Tidal Marsh**	**Diked Marsh**
Wild celery (*Apium graveolens*)	X		X	
Russian wheatgrass (*Elytrigia pontica*)		X	X	
Barbgrass-Sickelgrass (*Hainardia cylindrical*)	X	X	X	X
Black rush (*Juncus gerardii*)		X	X	
Sicklegrass (*Parapholis incurva*)	X			
Common reed (*Phgragmites australis*)				X
Narrow-leaf cattail (*Typha angustifolia*)			X	X

Table 7. Summary of Climate Change Scenarios: Averages for Mid 21st Century

Source: U.S. EPA Climate Ready Estuaries Pilot Project for the San Francisco Estuary

Metric		**“Lower Range” Scenario**	**“Higher Range” Scenario**
Temperature [a]	Annual average [b]	+2.8ºF (1.6ºC)	+3.5ºF (1.9ºC)
	Average increase of winter temperature [c]	+2.5ºF (1.4ºC)	+2.7ºF (1.5ºC)
	Average increase of summer temperature [c]	+4.0ºF (2.2ºC)	+4.5ºF (2.5ºC)
	Extreme heat days [d]	+10 days/year	+16 days/year
Precipitation	Annual change [e]	-4.5%	-7%
	Winter change	Reduced winter precipitation [f]	
	Heavy events	Decline in frequency of precipitation events (exceeding 3mm/day) but not a clear signal in changes of precipitation intensity	
Sea Level	Total increase for 2050 [g]	+30 cm	+45 cm
	Hourly sea level rise exceedances [h]	1343	1438
Storms and wind [i]		Tendency toward a decline in storms [j]. Projections suggest an increased frequency for heightened sea level events to persist for more hours. ENSO is not projected to increase in frequency or intensity.	
Snow pack change		For the Central valley watershed, April watershed-total snow accumulation projected to drop 64% by 2060 [k]	
Spring runoff		Spring runoff occurring earlier and reduced overall	
Seasonal changes in the amount of freshwater inflow to the Bay from the Delta in 2060 [l]		October through February: inflow +20% March through September: inflow -20%	

Notes:

[a] *Averages are for 2035-2064 projections relative to 1961-1990 baseline for B1 and A2 emission scenarios*

[b] *Approximate results using B1 and A2 emission scenarios and three global climate models (PCM1, GFDL CM2.1, and HadCM3) (CEC 2006)*

[c] *Results for Sacramento, CA. Warming projected to be more moderate along coastline (50km from coast) and rising considerably inland (Cayan et al. 2009). Averages are for 2035-2064 projections relative to 1961-1990 baseline for B1 and A2 emission scenarios*

[d] *Extreme heat days defined as daily maximum temperature exceeding 95th percentile of temperature from 1961-1990 historical averages of May-September days. 1961-1990 baseline approximately 8 days/year based on model runs. Results from Cayan et al. 2009 using three global climate models (CNRM CM3, GFDL CM2.1, and MICRO 3.2 with bias-corrected downscaling) for B1 and A2 emission scenarios. Mid-century projections suggest hot daytime and nighttime temperate increase in frequency, magnitude, and duration (Cayan et al. 2009). Extreme warm temperatures in California, historically a July and August phenomenon, will increase in frequency and magnitude likely beginning in Jane and may continue into September (Hayhoe et al. 2004; Gershunov and Douville 2008, Miller et al. 2008).*

[e] *Results are averaged across six global climate models using the grid point nearest to Sacramento (Cayan et al. 2009) for B1 and A2 emission scenarios*

[f] *CEC (2008)*

[g] *Sea level rise relative to 2000. DRMS (2007) also provides recommended 2050 global sea level rise estimates relative to 1990 of 11 cm (direct extrapolation of observed 20th century data), 20 cm (low end of Rahmstorf (2007) and approximate mid-range of IPCC TAR), 30cm (approximate mid-range of Rahmstorf (2007) and approximate high end of IPCC TAR), 41cm (high end of Rahmstorf (2007)).*

[h] *Hourly sea level exceedance defined as maximum duration (hours) when San Francisco sea level exceeds the 99.99th percentile level (140cm above mean sea level) (Cayan et al. 2009)*

[i] *Cayan et al. 2008*

[j] *Storm defined as sea level barometric pressure falling below 1005 millibar*

[k] *Knowles and Cayan (2004) “business-as-usual” scenario relative to 1995-2005*

[l] *Knowles and Cayan (2004) accounts for reservoirs, in-stream valley diversions, and in-Delta withdrawals and assumes no future management adaptation or altered demand patterns*

Figures

1:30,000; 1"= 2,500' at letter size

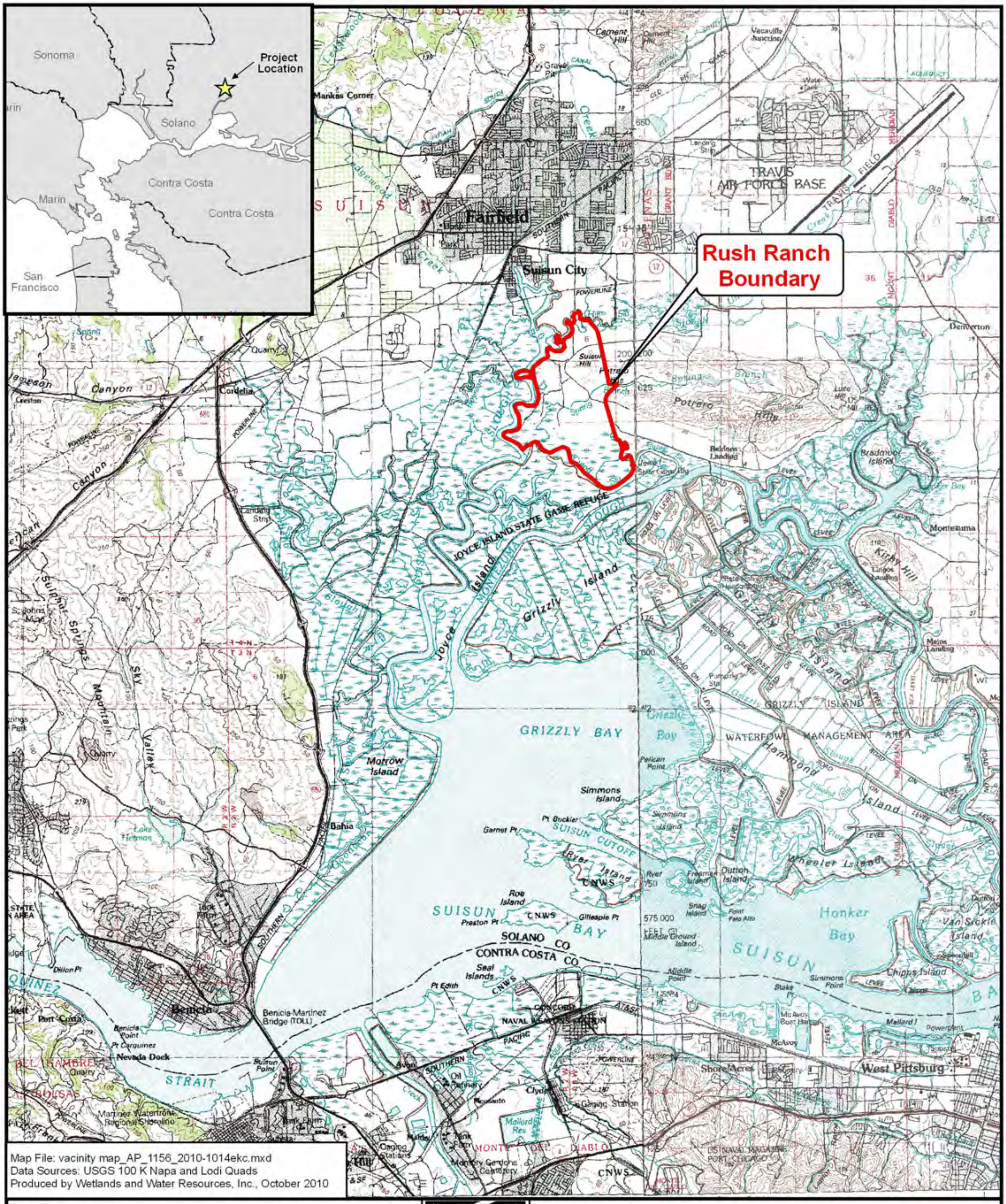
Data Sources: air photo(NAIP 2009); property boundary (SLT 2009)
Produced by Wetlands and Water Resources, Inc., October 2010
Map File: Location-map_AP_1156_2010-1015lee.mxd

WETLANDS AND WATER RESOURCES, INC.

LOCATION MAP

Rush Ranch Master Plan
Solano County, California
Solano Land Trust

October 2010	Project No. 1156	**Figure 1**



Map File: vacinity map_AP_1156_2010-1014ekc.mxd
Data Sources: USGS 100 K Napa and Lodi Quads
Produced by Wetlands and Water Resources, Inc., October 2010

1:150,000; 1"= 12,500' at letter size

0 5,000 10,000 20,000 Feet

0 2,600 5,200 Meters

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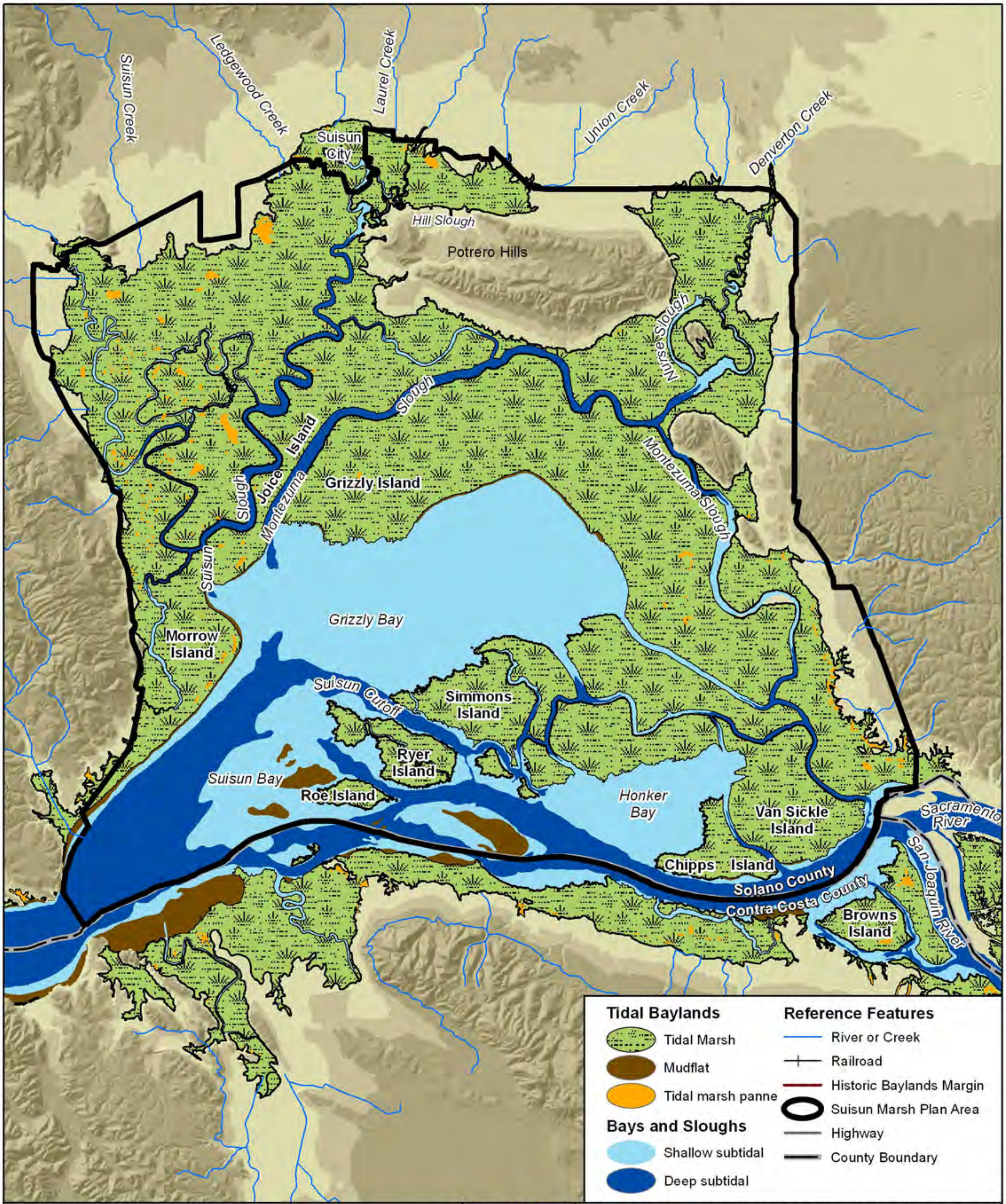
VICINITY MAP

Rush Ranch Master Plan
Solano County, California
Solano Land Trust

October 2010	Project No. 1156	**Figure 2**



1:150,000 (1" = 12,500' at letter layout)

0 1 2 mi

0 2 4 km

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Data sources: USGS (2009),
TIGER (2000), GAP (1998), Eco Atlas
(1998), DWR (Various), CDFG (2006-2007)
Produced by WWR, September 2010
map file: Historic-suisun-marsh_2010-0915lee.mxd

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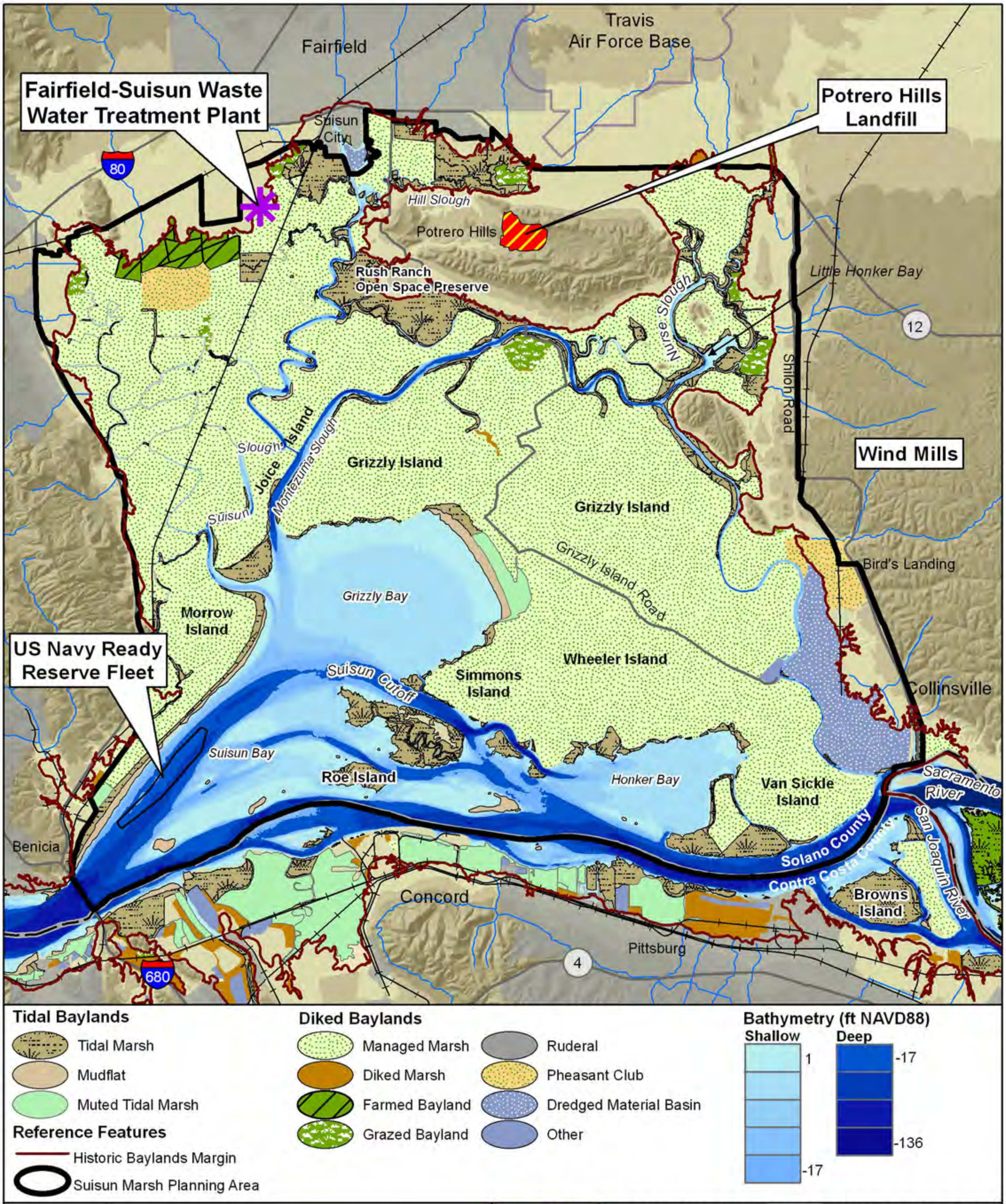
HISTORIC SUISUN MARSH HABITATS

Rush Ranch Master Plan
Solano County, California
Solano Land Trust

September 2010 | Project No. 1156 | **Figure 3A**



Data sources: USGS (2009), TIGER (2000), GAP (1998), Eco Atlas (1998), DWR (Various), CDFG (2006-2007)
Produced by WWR, September 2010
map file: land-use_Suisun_AP_1151_2010-0916lee.mxd

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EXISTING SUISUN MARSH HABITATS AND LAND USES

Rush Ranch Master Plan
Solano County, California
Solano Land Trust

September 2010 | Project No. 1156 | **Figure 3B**

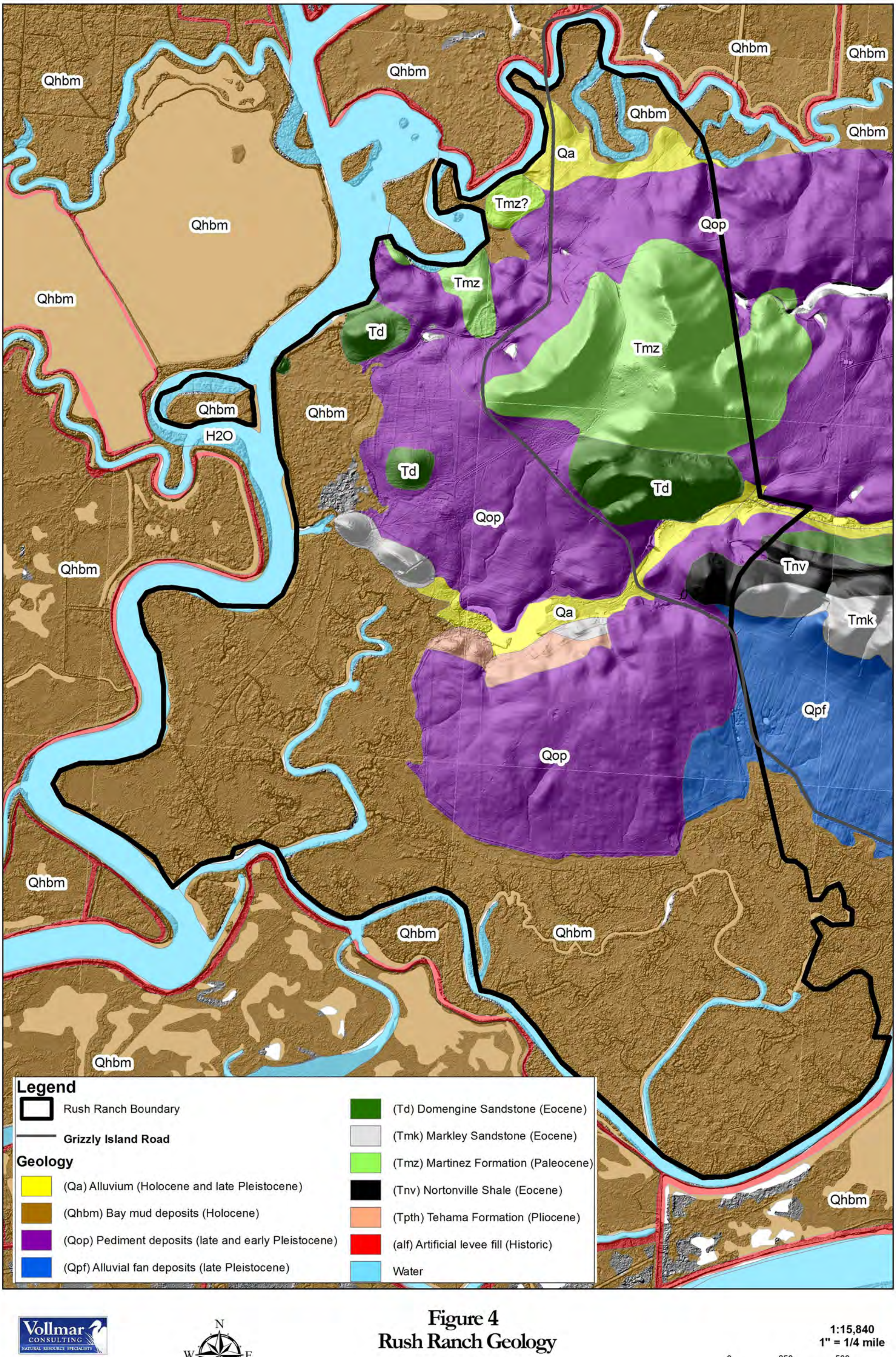

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Figure 4
Rush Ranch Geology

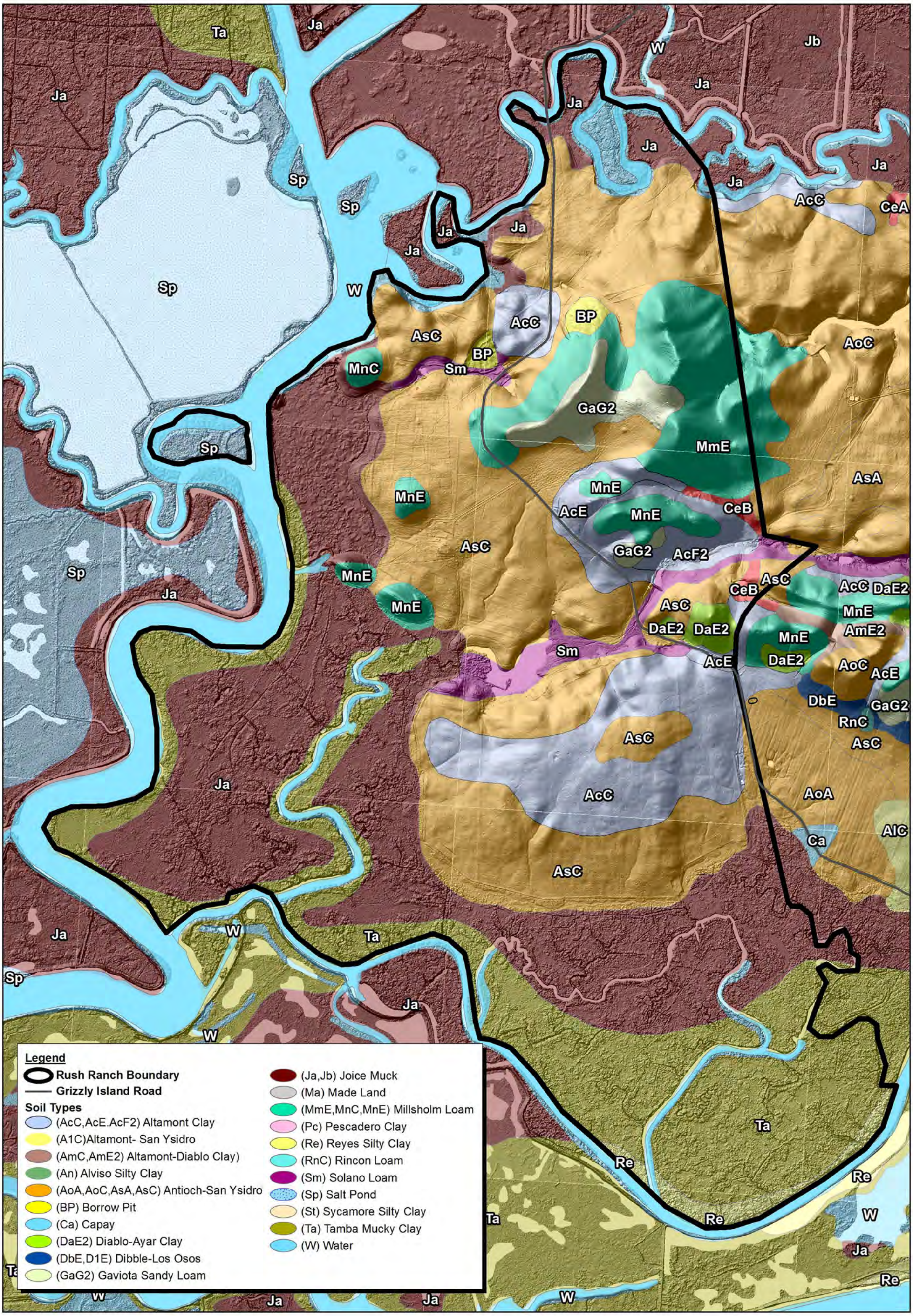
Solano County, CA

1:15,840
1" = 1/4 mile

0 250 500 Meters

0 0.125 0.25 0.5 Miles

Data Source:
USDA NRCS 2007; Solano Land Trust 2009
GIS/Cartography by Cassie Pinnell, October 2010
Map File: 220-Map_All-Soils_B-P_2010-1014.mxd



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Data Source:
USDA NRCS 2007; Solano Land Trust 2009
GIS/Cartography by Cassie Pinnell, October 2010
Map File: 220-Map_All-Soils_B-P_2010-1014.mxd

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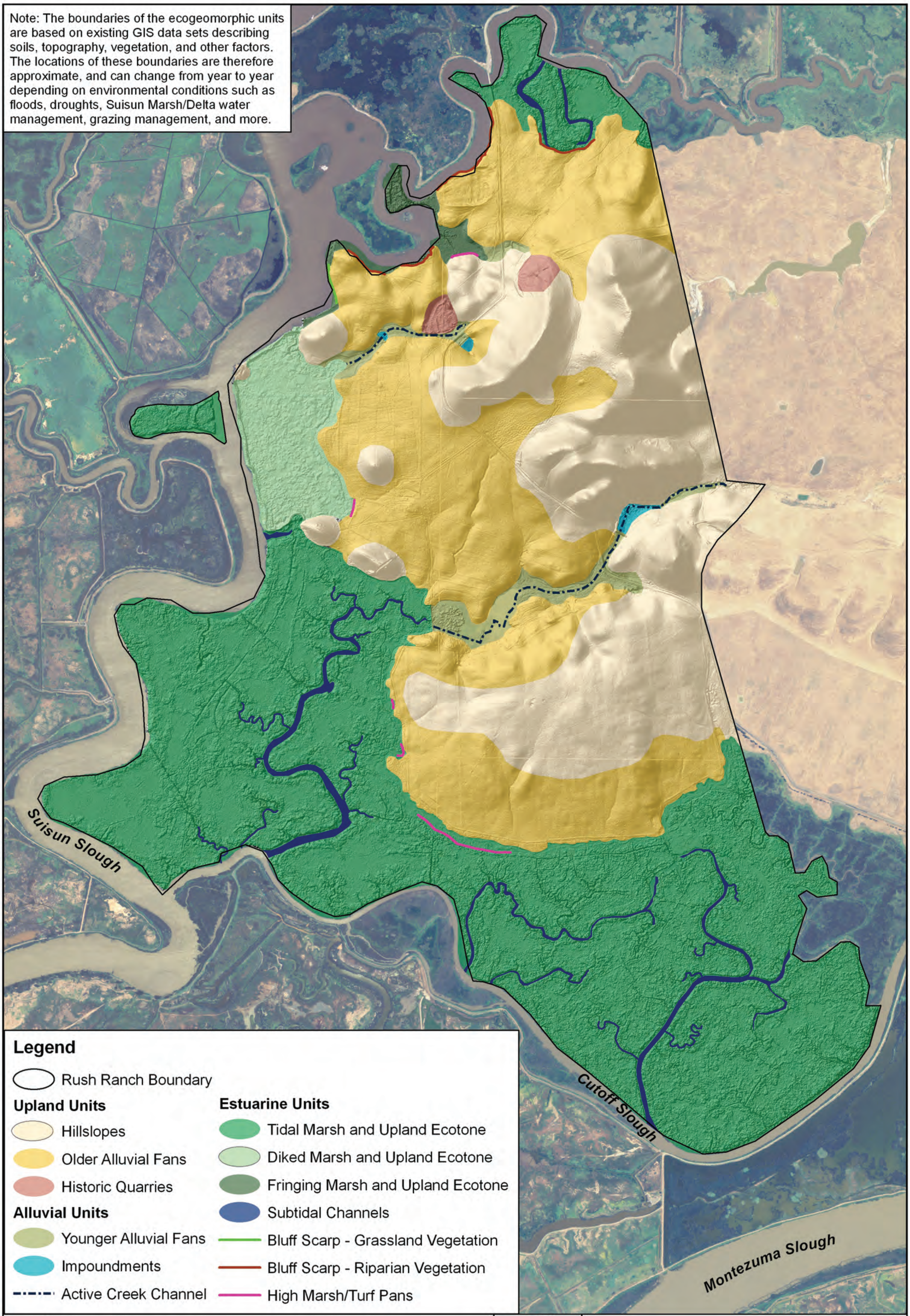
Figure 5
Rush Ranch Soils and Topography

Solano County, CA

1:15,840
1" = 1/4 mile

0 250 500 Meters

0 0.125 0.25 0.5 Miles



Note: The boundaries of the ecogeomorphic units are based on existing GIS data sets describing soils, topography, vegetation, and other factors. The locations of these boundaries are therefore approximate, and can change from year to year depending on environmental conditions such as floods, droughts, Suisun Marsh/Delta water management, grazing management, and more.

Legend

⬭ Rush Ranch Boundary

Upland Units

- ⬭ Hillslopes
- ⬭ Older Alluvial Fans
- ⬭ Historic Quarries

Alluvial Units

- ⬭ Younger Alluvial Fans
- ⬭ Impoundments
- -·-·- Active Creek Channel

Estuarine Units

- ⬭ Tidal Marsh and Upland Ecotone
- ⬭ Diked Marsh and Upland Ecotone
- ⬭ Fringing Marsh and Upland Ecotone
- ⬭ Subtidal Channels
- — Bluff Scarp - Grassland Vegetation
- — Bluff Scarp - Riparian Vegetation
- — High Marsh/Turf Pans

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1:18,000; 1 inch = 1/4 mile at B-size

0 0.25 0.5 Miles

0 250 500 Meters

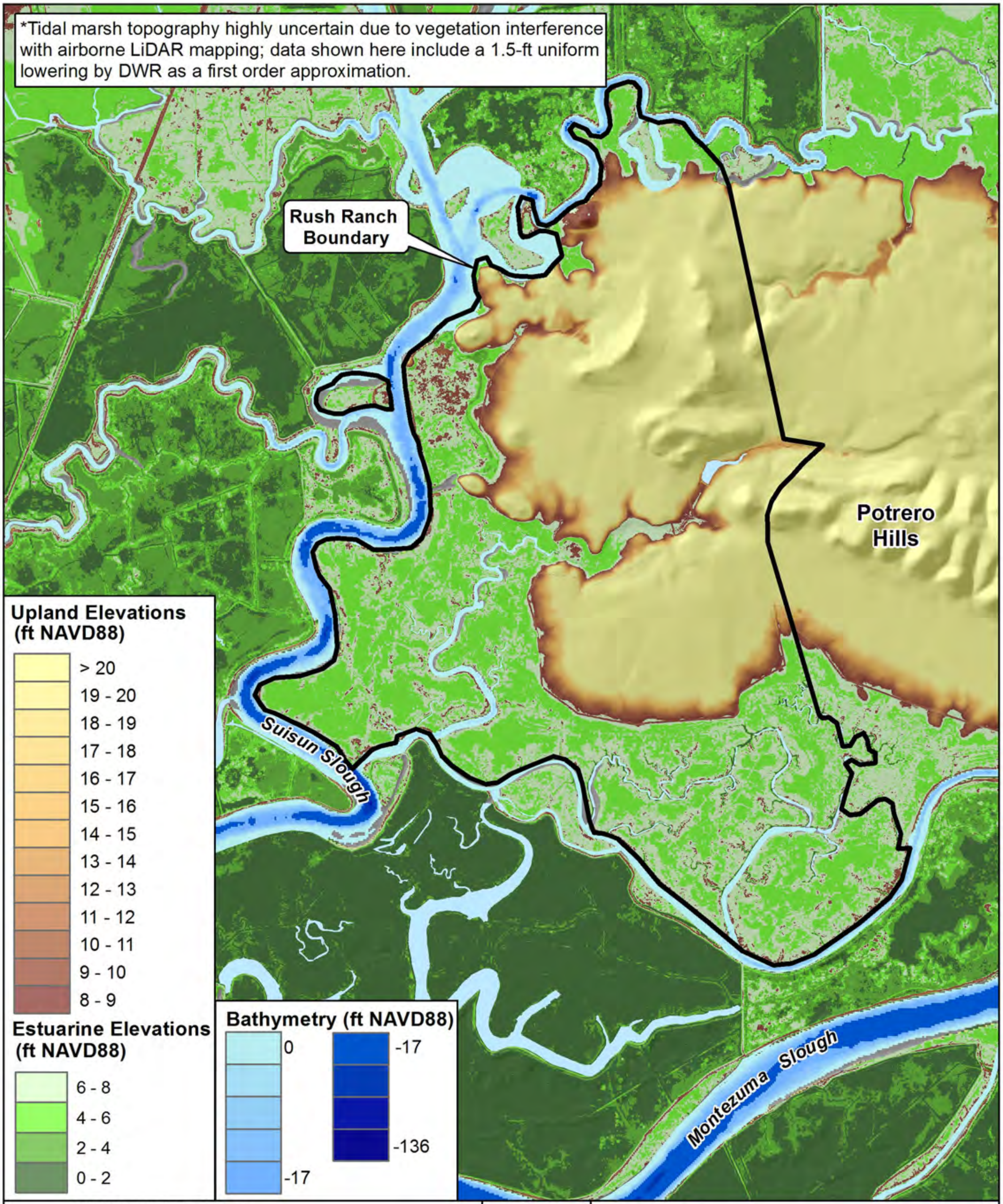
Data Sources: NAIP 2005 (air photo), WWR 2010 (data)
Produced by Wetlands and Water Resources, Dec. 2010
Map File: ecogoemorphic units_1156_BP_2010-1223ct.mxd

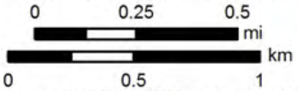
WETLANDS AND WATER RESOURCES, INC.

ECOGEOMORPHIC UNITS MAP

Rush Ranch Master Plan
Solano County, California
Solano Land Trust

December 2010 | Project No. 1156 | **Figure 6**





Data Sources: topo data (DFG 2005); bathymetry (USGS 2004); property boundary (SLT 2009)
Produced by Wetlands and Water Resources, Inc., October 2010
Map File: topography_project-site_AP_1156_2010-1015lee.mxd

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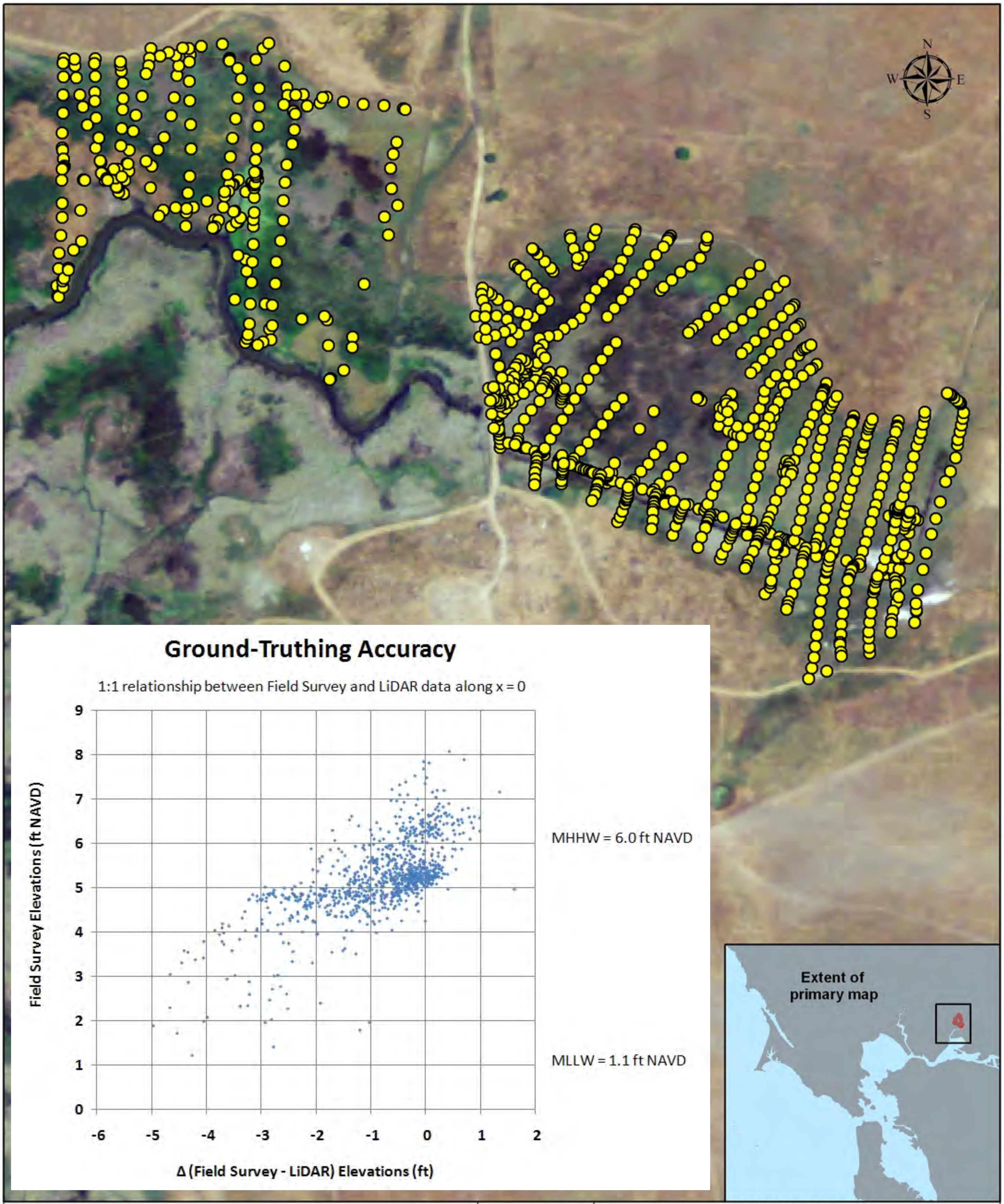
SITE TOPOGRAPHY

Rush Ranch Master Plan
Solano County, California
Solano Land Trust

October 2010	Project No. 1156	**Figure 7**



1:2,700 (1"=225' at letter layout)

Data Sources: USDA NAIP 2009,
Produced by WWR, December 2010
Map File: Field-survey-gt_AP_1156_201-1210mdl.mxd

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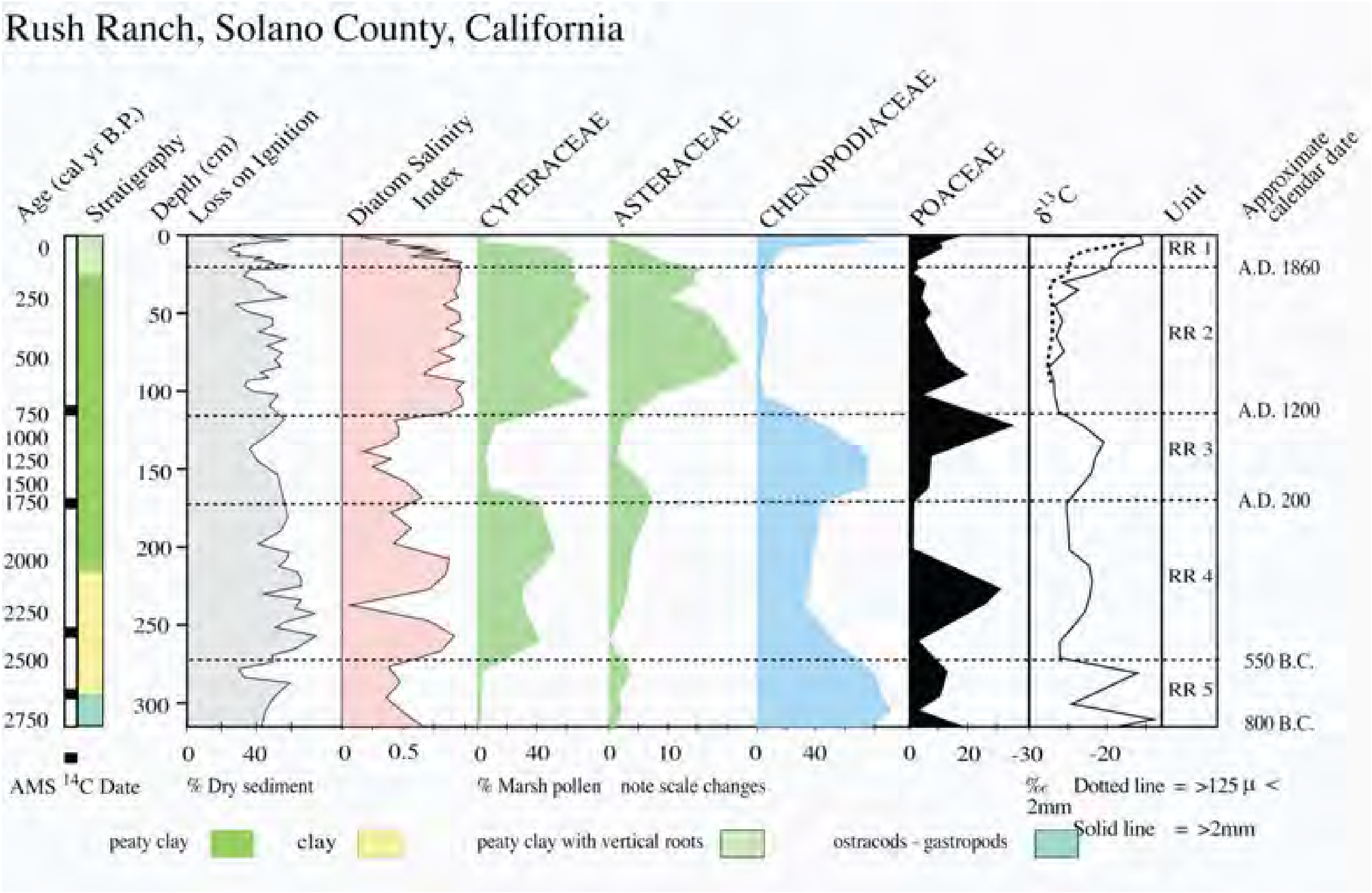
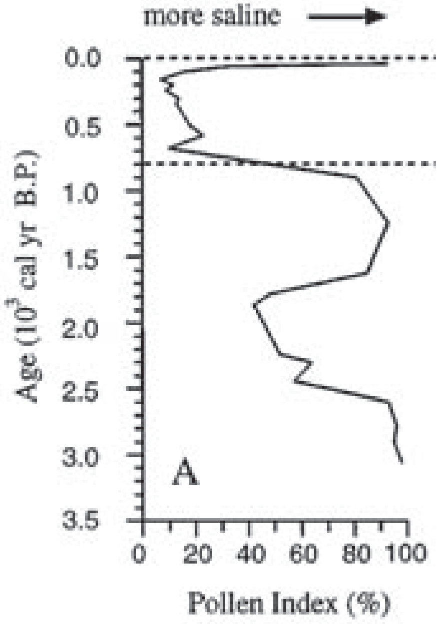
2010 SURVEY ELEVATION LOCATIONS

Rush Ranch Master Plan
Solano County, California
Solano Land Trust

December 2010 | Project No. 1156 | **Figure 8**

(R) Stratigraphy, chronology, Diatom Salinity Index, selected pollen taxa, and ±13C values from a Rush Ranch sediment core. Pollen represent percetages of total marsh pollen. From Byrne et al. 2001.





(L) Paleosalinity records from Rush Ranch. The index represents Chenopodiaceae plus Poaceae pollen as a percentage of Chenopodiaceae, Poaceae, Cyperaceae, and Asteraceae. From Ingram et al. 1996a.

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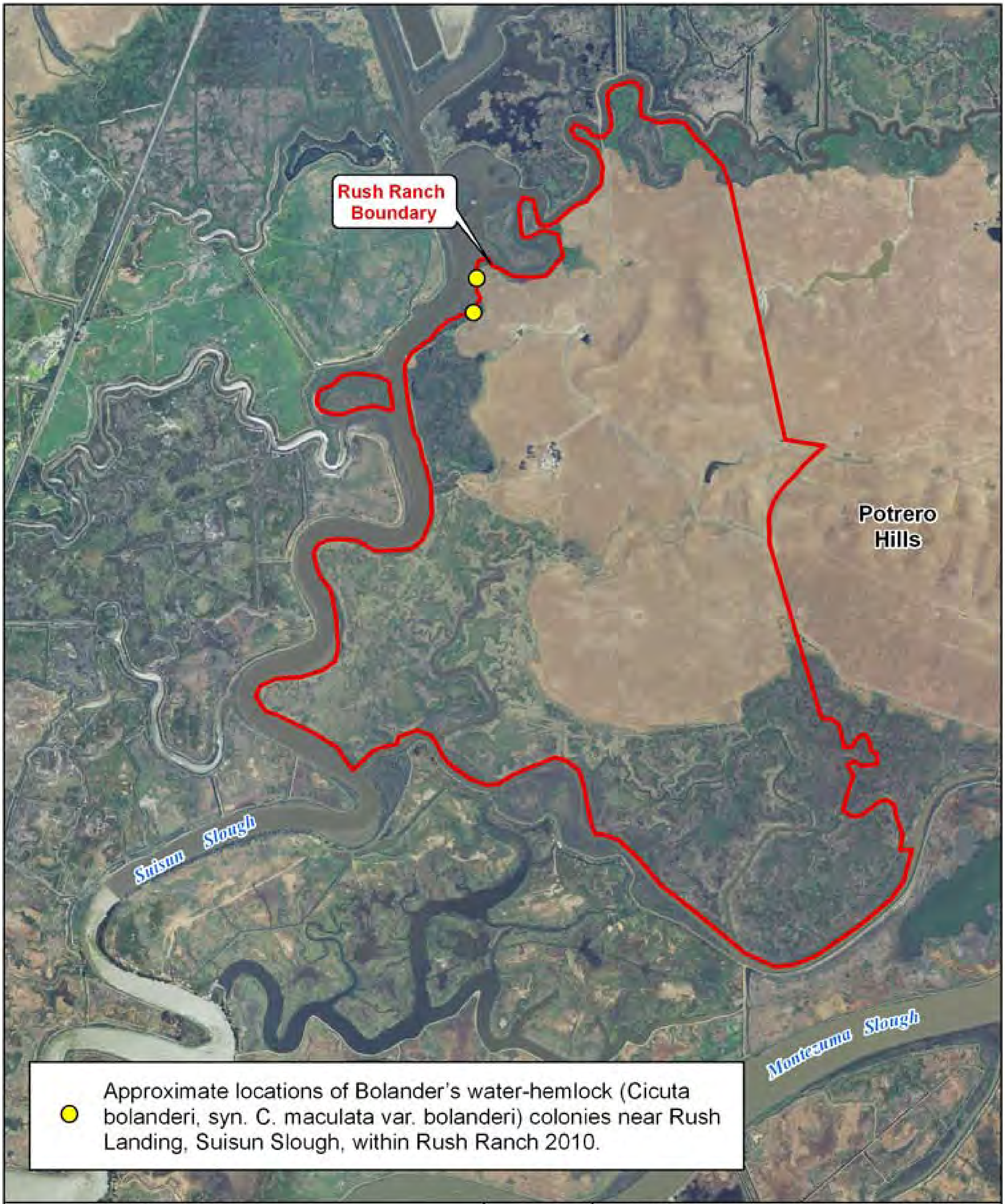
RUSH RANCH PALEOECOLOGY

Rush Ranch Master Plan
Solano County, California
Solano Land Trust

December 2010 | Project No. 1156 | **Figure 9**

Appendix A

Distribution Maps for Selected Special-Status and Invasive Species



● Approximate locations of Bolander's water-hemlock (Cicuta bolanderi, syn. C. maculata var. bolanderi) colonies near Rush Landing, Suisun Slough, within Rush Ranch 2010.

1:30,000; 1"= 2,500' at letter size

0 0.25 0.5 mi

0 0.5 1 km

Data Sources: air photo(NAIP 2009); property boundary (SLT 2009); Bolander's water hemlock locations (Baye 2010)
Produced by Wetlands and Water Resources, Inc., Dec 2010
Map File: BWH-map_AP_1156_2010-1210ct.mxd

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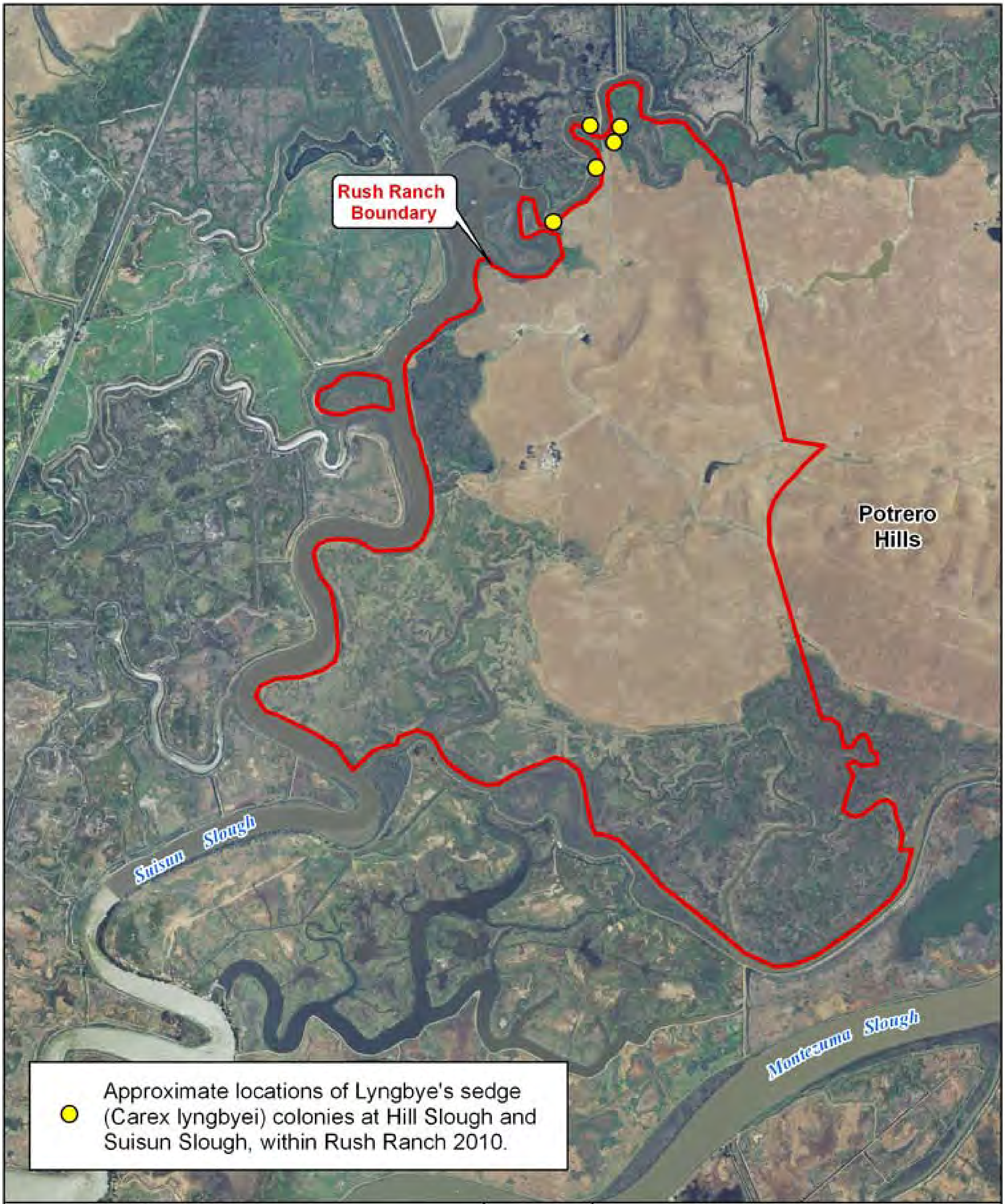
BOLANDER'S WATER HEMLOCK 2010 LOCATIONS, RUSH RANCH

Rush Ranch Master Plan
Solano County, California
Solano Land Trust

December 2010 | Project No. 1156 | **Figure A-1**



Data Sources: air photo(NAIP 2009); property boundary (SLT 2009); Lyngbye's sedge locations (Baye 2010)
Produced by Wetlands and Water Resources, Inc., Dec 2010
Map File: LS-map_AP_1156_2010-1210ct.mxd

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LYNGBYE'S SEDGE 2010 LOCATIONS, RUSH RANCH

Rush Ranch Master Plan
Solano County, California
Solano Land Trust

December 2010	Project No. 1156	Figure A-2

Data from Grewell 2005

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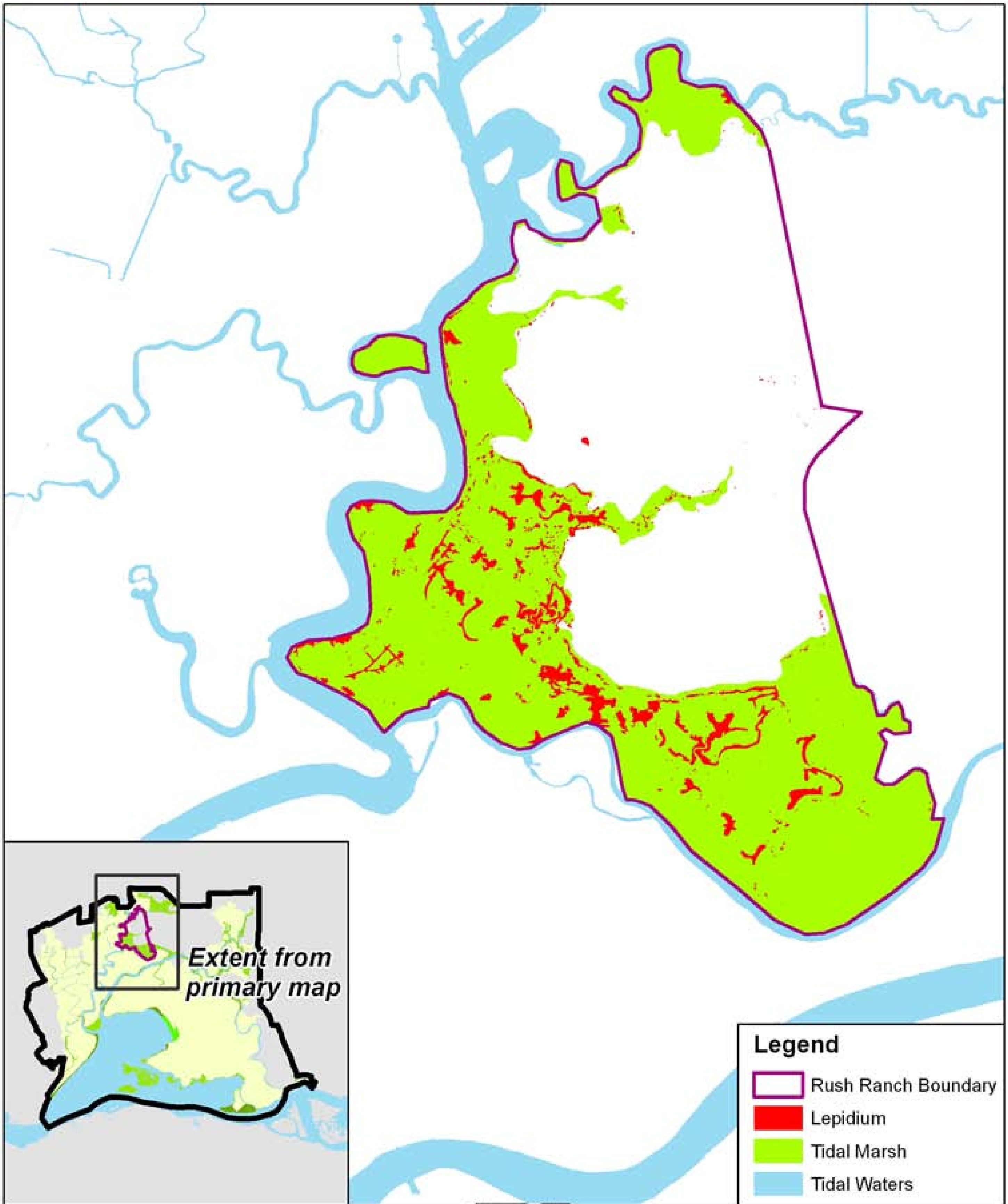
SOFT BIRD'S BEAK LOCATIONS AT RUSH RANCH

Rush Ranch Master Plan
Solano County, California
Solano Land Trust

December 2010 | Project No. 1156 | **Figure A-3**

Fig-A-3_SBB_1156_2010-1210ct.ai



1:30,000 (1" = 2,500' at letter layout)

0 1,500 3,000 Feet

0 500 1,000 Meters

N W E S

Data sources: vegetation (DFG 2006); marsh types (EcoAtlas 1998),
Lepidium data (Solano Land Trust 2009)
Produced by WWR, December 2010
map file: lepidium_AP_1156_2010-1210ct.mxd

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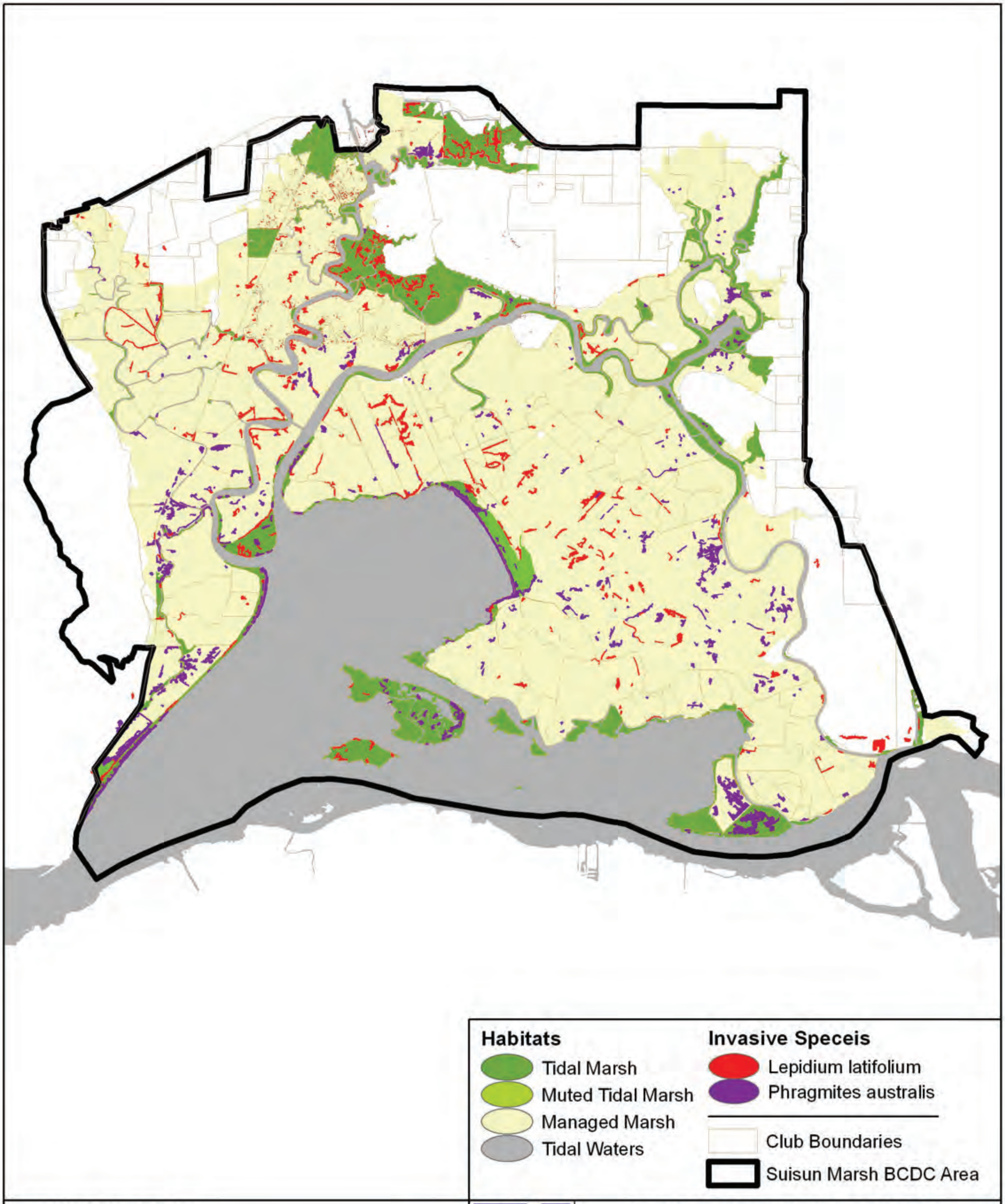
KNOWN EXTENT OF LEPIDIUM AT RUSH RANCH, 2009

Rush Ranch Master Plan
Solano County, California
Solano Land Trust

December 2010 | Project No. 1156 | **Figure A-4**



1;150,000 (1" = 12,500' at letter layout)

0 1 2 mi

0 2 4 km

N W E S

Data sources; vegetation (DFG 2006); marsh types (EcoAtlas 1998)
Solano Land Trust (2009)
Produced by WWR, December 2010
map file: invasive-plant-species_AP_1151_2010-1217mdl.mxd

WETLANDS AND WATER RESOURCES, INC.

PHRAGMITES AND LEPIDIUM EXTENT IN SUISUN MARSH

Rush Ranch Master Plan
Solano County, California
Solano Land Trust

December 2010 | Project No. 1156 | **Figure A-5**

Appendix B

Partial Estuarine Flora of Rush Ranch

Partial Estuarine Flora of Rush Ranch, Suisun Marsh, Solano County, California
Vascular Plant Species
Version 1.0 - 2010

The following local flora of the tidal wetlands of Rush Ranch(Solano Land Trust) in Suisun Marsh, Solano County, California is compiled and adapted from multiple sources, primarily the unpublished multiple plant lists prepared by Brenda Grewell (California Department of Water Resources, unpublished 1992 list and subsequent revisions, University of California, Davis), Fiedler *et al.* 2004, and unpublished field notes (Peter Baye, 1992-present).

The geographic scope of the surveys was limited to estuarine wetlands and their terrestrial ecotones influenced by either periodic or episodic flooding by tidal waters, including extreme storm flooding events with wave runup above still-water elevations, indicated by remnant tidal debris.

Nomenclature and taxonomy, unless otherwise noted, follow Flora of North America (http://www.efloras.org/flora_page.aspx?flora_id=1) for taxa covered by FNA in 2009; other taxa not covered in FNP follow Jepson Manual revisions published in the Jepson Interchange (http://ucjeps.berkeley.edu/interchange.html), or the USDA Plants Database (http://plants.usda.gov/). Common names in popular use in the Bay Area are included; provisional artificial common names are provided in brackets when no popular or folk names in use are known. Synonyms, particularly widely used and familiar synonyms in standard past California floras (Munz and Keck 1959, Hickman et al. 1993) are also provided where recent taxonomic changes have occurred.

CYPERACEAE
Sedge Family

Bolboschoenus maritimus (L.) Pallas ssp. paludosus (A. Nelson) T. Koyama, ALKALI-BULRUSH. Uncommon, occasional in poorly drained depressions in tidal marsh plain, slough banks; primarily found in managed diked wetlands of Suisun Marsh. Flowering late spring-early summer.

Carex barbarae Dewey , BASKET SEDGE. Uncommon but locally abundant upper edges of tidal marsh below steep bluffs and scarps along Suisun Slough and Hill Slough from Rush Landing northward and east to near the eastern end of Rush Ranch. Colonies usually occur in patches within riparian scrub of steep north aspect slopes with minimal or no cattle grazing access; primarily terrestrial, associated with seasonal seeps and swales. Locally associated with *Leymus triticoides*, forming dense turf above erosional scarps at Rush Landing's south-facing shoreline. Generally absent in cattle-grazed lowland grasslands and swales. Fruiting culms are produced at moderate density in summer. Aboriginal textile plant of high value: rhizomes were harvested for use in basketry, and preferred over most other species. Flowering late spring

Carex lyngbyei Hornem. LYNGBYE'S SEDGE. Lyngbye's sedge is distributed primarily from the North Coast of California (Mendocino County) north to Alaska, where it occurs in fresh-brackish marshes of tidal rivers. Rare disjunct populations are known from the Carmel River, Monterey County, and Giacomini Marsh (Lagunitas Creek Delta), Tomales Bay, Marin County. In the San Francisco Bay estuary, *C. lyngbyei* is known only from the vicinity of northern Rush Ranch, primarily in Hill Slough to near Suisun Slough, where it occurs in multiple large colonies on slough banks at the outer edge of low fringing tule marshes, and locally in patches within the marsh plain east of Grizzly Island Bridge. Fruiting culms are produced in summer at low density. Vegetatively similar in appearance to terrestrial *C. barbarae*, but occurring at the lowest intertidal marsh elevations with tule species *(Schoenoplectus* spp.). Flowering late spring-early summer.

Carex praegracilis W. Boott, MEADOW SEDGE, CLUSTERED FIELD SEDGE. Uncommon, known only from large lowland sedge meadow stands at the southeastern shoreline of Rush Ranch in areas excluded from cattle grazing. It occurs in either monotypic stands or associated with extensive adjacent stands of *Leymus triticoides*. Fruiting culms are produced at moderate density. Flowering spring.

Eleocharis macrostachya Britton, COMMON SPIKERUSH. Occasional, poorly drained brackish marsh plains, where it is easily overlooked among more abundant and common, morphologically similar (vegetative shoots) of *Juncus arcticus* ssp. *balticus*. Terrestrial leaf form (narrow, terete) is prevalent. More common in upland seasonal wetland stream channel and impoundments, where it develops typical emergent marsh shoot morphology (wide, spongy, hollow shoots). Flowering spring.

Isolepis carinata Hook. & Arn. ex Torr. KEELED CLUBRUSH. Uncommon or rarely distinguished from morphologically similar and more common *I. cernua*; similar habitats. Flowering spring-fall.

Isolepis cernua (Vahl) Roem. &Schult. DWARF CLUBRUSH. Common in eroded marsh and channel banks, seeps in hillslope scarps bordering sloughs, in moist turf pans, and shaded in the ground layer of taller rush or bulrush vegetation. Co-occurs with *Lilaeopsis masonii* in ground layer of wave-scoured edges of fringing tule marsh along sloughs. Flowering spring-fall.

Schoenoplectus americanus (Pers.) Volkhart ex Schinz & Keller CHAIRMAKER'S THREESQUARE BULRUSH. Widespread and abundant, dominating extensive stands in poorly drained marsh plains an depressions or shallow tidal channels, and in middle marsh zone of gently sloping slough banks. Historically harvested as a textile plant by European Californian settlers. Flowering summer.

Schoenoplectus acutus (H.L. Mühl. ex Bigelow) Á. Löve & D. Löve) var. ***occidentalis*** (S. Watson) S.G. Smith HARDSTEM TULE. Widespread and abundant to dominant in low brackish marsh of tidal slough banks. B. Grewell reports intermediate forms (potential hybrids with *S. californicus*). Distinguished vegetatively by terete (rounded) shoots with grayish blue-green hue. Aboriginal use as textile plant for mats, thatching, watercraft. Flowering summer.

Schoenoplectus californicus (C.A. Mey.) Soják CALIFORNIA TULE. Widespread and abundant to dominant in low brackish marsh of tidal slough banks. B. Grewell reports intermediate forms (potential hybrids with *S. acutus*). Distinguished vegetatively by subangular (slightly rounded three-corner) shoots and dark dull green hue. Flowering summer.

IRIDACEAE

Iris family

Sisyrinchium bellum S. Watson BLUE-EYED GRASS. Local, persisting moist grassland slump-blocks (terrestrial ecotone of tidal marsh) descended to intertidal elevations at Rush Landing, associated with *Leymus*, *Carex barbarae.* Flowering spring.

JUNCACEAE

Rush Family

Juncus bufonius L. TOAD RUSH. Widespread in turf pans and depressions with shallow seasonal pools and sparse perennial vegetation cover near terrestrial grassland edges of the tidal marsh. Also common in seasonal pools in upland depressions.

Juncus arcticus Willd ssp. ***balticus*** (Willd.) Trautvetter . BALTIC RUSH. Widespred, co-dominant to locally dominant over extensive areas of drained the tidal marsh plain, sometimes forming large monotypic stands in poorly drained tidal marsh. Uncommon or absent in summer-desiccated terrestrial edges of the tidal marsh. Flowering summer.

Juncus arcticus Willd ssp. ***mexicanus*** (Willd. ex Roem. & Schult) Balslev. MEXICAN RUSH. Uncommon in tidal marsh compared with the similar *J. arcticus* ssp. *balticus*, and likely to be underdetected. Locally common in the wave-cut intertidal marsh bench at Rush Landing. Also present in terrestrial seasonal wetlands of drainages connected to tidal marshes. Flowering summer.

Juncus xiphioides E. Mey. IRIS-LEAF RUSH, occurs in brackish tidal marsh edges of San Pablo Bay, and was reported historically from Suisun Marsh. It is expected to occur at Rush Ranch, but no confirmed localities are currently reported. Similarly, *J. phaeocephalus* Engelm. var. *paniculatus* Engelm. may also occur.

Juncus gerardii Loisel, BLACK RUSH, native to Europe and naturalized in northeastern Atlantic U.S. and Pacific Northwest tidal marshes, is invasive at two known eastern San Francisco Estuary localities, Benicia and north Richmond (east of Point Pinole). It may be expected at Rush Ranch.

JUNCAGINACEAE

Arrowgrass family

Triglochin maritima L. SEA ARROW-GRASS. Widespread, locally common in poorly drained tidal marsh plains, sometimes forming colonies of conspicuous clumps. Locally abundant near freshwater discharges of upland swales and seeps along Hill Slough. Flowering summer.

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Triglochin striata Ruiz. & Pav. [STRIATE SEA ARROW-GRASS]. Reported by B. Grewell. Regionally uncommon; found primarily in coastal river mouth lagoons Mendocino County and northward, where it occurs in low marsh of tidal channel banks, forming inconspicuous low creeping grass-like colonies resembling coarse, sparse stands of *Lilaeopsis*. No herbarium specimens are known from Sonoma, Napa, Solano, Sacramento, San Joaquin, or Contra Costa counties. Rush Ranch localities need verification.

Triglochin concinna Burtt Davy, a creeping, turf-forming sea arrow-grass, occurs infrequently on middle marsh plains of western San Francisco Bay and Pablo Bay in Marin County, and may be expected in Suisun Marsh. This species is abundant in maritime salt marshes of the West Marin coast.

LILIACEAE

Lily family

Asparagus officinalis L. Occasional in brackish high marsh, mostly along terrestrial edges or well-drained channel banks; conspicuous after shoots expand to feathery tall masses. Native to Europe (brackish marsh), escaped from cultivation. Widespread in northern San Pablo Ban tidal and diked marshes. Not reported to be invasive in San Francisco Estuary tidal marshes. Edible. Flowering late spring-early summer.

POACEAE

Grass Family

Agrostis stolonifera L. CREEPING BENTGRASS. Occasional, disturbed erosional shorelines at Rush Landing northward, occasional in tidal marsh plain near creek banks; infrequent or absent in marsh edges subject to summer desiccation (turf pans, terrestrial grassland ecotone). European; widely established in wetlands and moist grasslands of North America. Invasive in some freshwater and fresh-brackish wetalnds; not reported to be invasive in San Francisco Estuary tidal marshes. Flowering spring-early summer.

Crypsis schoenoides (L.) Lam. SWAMP TIMOTHY. Locally common in dried mud of brackish pools, diked marsh and occasionally in turf pans. Primarily occurs in diked nontidal seasonal wetlands of Suisun Marsh, where it is managed for waterfowl forage. European; widely established in wetlands and moist grasslands of North America. Not known to be invasive in tidal marshes. Flowering spring-early summer.

Deschampsia cespitosa (L.) P. Beauv. TUFTED HAIRGRASS. Locally common in wave-scoured fringing marsh, scarps, and sandstone outcrops from Rush Landing northward; occasional in tidal marsh plains and upper bank edges. Suisun Marsh populations have been variously referred to D. c. ssp**.** *cespitosa* (B. Grewell, Rush Ranch; Benicia locality, B. Crampton *7240,* UCR 135951) or ssp. *holciformis* (B. Crampton *9064*, UCD33869, Denverton locality). *D.c.* ssp. *holciformis* is prevalent in North Coast tidal marshes. Eastern Suisun Marsh is the apparent inland limit of the species within the estuary. Flowering summer.

Distichlis spicata (L.) E. Greene SALTGRASS. Widespread, abundant, co-dominant or dominant almost throughout the tidal marsh plain, terrestrial ecotone, diked marsh, in all seasonally or perennial brackish soils; also present in alkali grasslands and seasonal wetlands far above tidal influence. Important in many plant assemblages at Rush Ranch, particularly with *Juncus arcticus* ssp. *balticus*, *Sarcocornia pacifica* (tidal marsh plain), *Frankenia salina,* and *Cressa truxillensis* (terrestrial ecotone). Flowering summer.

Elytrigia pontica (Podp.) Holub subsp. ***pontica*** TALL WHEATGRASS. Infrequent, local, southern shoreline of Rush Landing. Native to Europe, Asia; introduced as summer-active forage grass in alkali or saline soils. INVASIVE in the San Francisco Estuary, where it has been planted in the past for stabilization of levees (local dominant at Mare Island dredge ponds, Palo Alto flood basin). Flowering spring-early summer.

Hordeum brachyantherum Nevski MEADOW BARLEY. Uncommon, locally present in brackish terrestrial edges of tidal marsh along Hill Slough; possibly underdetected elsewhere. [Not reported at Rush Ranch in 1990s B.Grewell list; possibly established since, or undetected.] Numerous 20th century collections in Suisun Marsh by B. Crampton, W.L.Jepson, M.A. Nobs and H.L. Mason. Flowering spring.

Hordeum depressum (Scribner & J.G. Smith) Rydb. LOW BARLEY Native annual of low or seasonally wet alkali/subsaline soils and vernal pools. Reported from Rush Ranch by B. Grewell. Few records in Solano Co. Current local distribution, abundance unknown.

Hordeum marinum Hudson ssp. ***gusssoneanum*** (Parl.) Thell. MEDITERRANEAN BARLEY. Widespread annual invasive non-native weed, locally abundant in terrestrial ecotone, southern Rush Ranch tidal marshes. Flowering winter-spring.

Hainardia cylindrica (Willd.) Greuter. HARDGRASS. Widespread annual invasive non-native weed of dense dried mud of seasonal brackish or alkali pools and disturbed wet grassland; locally abundant in terrestrial ecotone and turf pans, southern Rush Ranch tidal marshes. Flowering spring.

Lolium perenne L. *(incl. L. multiflorum Lam.)* PERENNIAL RYEGRASS. Widespread short-lived perennial invasive non-native weed introduced as pasture grass. Locally common in brackish tidal marsh plains, particularly near areas influenced by freshwater runoff from upland grasslands or swales. Not reported as strongly invasive in brackish tidal marsh, but widespread and abundant to dominant in moist pastures, swales, seasonal wetlands in the Bay Area. Morphological intergrades between *L. perenne* and *L. multiflorum* are common or prevalent. Flowering spring.

Parapholis incurva (L.). C.E. Hubb SICKLEGRASS. Widespread annual invasive non-native weed of dense dried mud of seasonal brackish or alkali pools and disturbed wet grassland; locally present in terrestrial ecotone and turf pans, southern Rush Ranch tidal marshes. Apparently less common than the similar *Hainardia cylindrica*. Flowering spring-early summer.

Phragmites australis (Cav.) Steudel. COMMON REED. Locally dominant in the diked marsh west of the Ranch headquarters area, in the marsh and on its levees. Some populations are presumably native to western North America, and the species was present but rare in the Sacramento-San Joaquin in and in California in the 19th century; Jepson collected the species in Suisun in 1891 (UC70791). Modern invasive populations established in the late 20th century are likely genetically distinct (invasive M haplotype) European introductions. (Saltonstall, K. 2002. Proc. Nat. Acad. Sci 99:2445-2449; Saltonstall, K. 2003. Estuaries 26: 441–451.). Flowering early summer.

Polypogon monspeliensis L. Desf. RABBIT'S-FOOT GRASS. Widespread and locally abundant or co-dominant in poorly drained depressions within tidal marsh plains and disturbed marsh edges, turf pans. Introduced from Europe. INVASIVE in brackish tidal marsh, particularly seasonal brackish pools or disturbed sediment. Flowering spring.

Leymus triticoides (Buckley) Pilg. CREEPING WILDRYE, ALKALI WILDRYE. Widespread in terrestrial grassland ecotones throughout Rush Ranch, extending by clonal spread into adjacent intertidal high marsh. Locally abundant, spreading, and increasingly dominant in the terrestrial edges of tidal marshes where cattle grazing has been reduced or eliminated since 1990s. Also locally abundant in grazing-excluded bluff-top grasslands and headlands at Rush Landing north along Hill Slough. Strongly suppressed at fence-line grazing limits at tidal marsh/grassland edges, and at the Rush Ranch property boundaries. Both glaucous-leaf and green foliar forms are present. Sparse or absent in Rush Ranch tidal marsh edges in early 1990s. Flowering spring.

Leymus ×multiflorus (Gould) Barkworth & D.R. Dewey . GIANT CREEPING WILDRYE. Coarse, taller, broad-leaf (up to 12 mm wide) putative natural hybrid (*L. condensatus*; not present) form of *L. triticoides*, distinguished by prevalence of 3 spikelets per node. Flowering spring.

POTAMOGETONACEAE

Pondweed family

Ruppia maritima L. WIGEONGRASS. Infrequent in ponded brackish depressions within the tidal marsh plain and diked marsh, possibly also in low-energy backwater areas in tidal sloughs. Widespread 20th century collection localities in Suisun Marsh (and one late 19th century Jepson collection), many likely from diked ponds. More tolerant of seasonally high salinity than the associated aquatic *Stuckenia pectinata*. Flowering summer, fruiting late summer-fall. (also treated in separate family, Ruppiaceae).

Stuckenia pectinata (Linnaeus) Borner SAGO PONDWEED. Locally abundant in ponds and ditches within the diked marsh west of the Rush Ranch headquarters, and occasional in low-energy backwater areas in tidal sloughs. Widespread in diked perennial brackish ponds in Suisun Marsh. W.L. Jepson field notes describe extensive sago pondweed beds in late 19th century Suisun Marsh ponds that were seasonally consumed by canvasback ducks. Several Suisun Marsh collections in California herbaria date from 1903-1904. Flowering summer, fruiting fall.

TYPHACEAE

Cattail Family

Typha angustifolia L. NARROWLEAF CATTAIL. Abundant in the diked marsh west of the Rush Ranch headquarters. Occasional in banks of tidal sloughs. European and invasive cattail species early introduced to North America, mistakenly treated as native in many North American floras. S. Watson (Botany of California vol. II, 1880) reported only two California localities prior to 1880, both in southern California, none from northern California. The earliest Solano County record is from near Dixon in 1949 (M.A. Nobs and S.G. Smith 743), and the oldest west Delta locality is from near Stockton in 1909 (J.C. Sanford, UC128663). Flowering late spring-summer.

Typha latifolia L. BROADLEAF CATTAIL. Common to abundant in the diked marsh west of Rush Ranch headquarters, and also common on banks of tidal sloughs, occurring with tules.
S. Watson (Botany of California vol. II, 1880) reported this species as "common in marshses from Sacamento northward" based on collections prior to 1880. Flowering late spring-summer.

Typha dominguensis Pers. SOUTHERN CATTAIL. Present in the diked marsh west of Rush Ranch headquarters, and also along banks of tidal sloughs, occurring with tules. Native to California, but seldom collected and frequently misidentified as *T. angustifolia* or *T ×glauca*. Flowering late spring-summer.

Typha ×glauca Godron [HYBRID CATTAIL]. Spontaneous hybrid between native *T. latifolia* and exotic *T. angustifolia,* with inflorescence and leaf color traits approaching those of native *T. domingensis*; and forming intermediates with parent species in some North American populations; expected in Suisun Marsh.

AIZOACEAE

Carpetweed Family

Sesuvium verrucosum Raf. WESTERN SEA-PURSLANE. Infrequent at Rush Ranch, disturbed high tide lines and seasonally desiccated saline depressions. Typically occurring in drying mud of diked brackish seasonal wetlands in Suisun Marsh. Flowering summer.

Carpobrotus edulis and its hybrids are not known from Rush Ranch, but occur in tidal marsh terrestrial ecotones in San Francisco Bay.

AMARANTHACEAE

Amaranth family

(including traditional Chenopodiaceae, Goosefoot Family)

Atriplex prostrata Boucher ex DC *(A. triangularis* Willd*; A. patula* L. *ssp. hastata* (L.) A. Gray misapplied. SPEARSCALE, FAT-HEN. Widespread, locally common in borders of depressions within the marsh plain, along drift-line debris of creek bank levees, terrestrial edges of tidal marsh. Also abundant (and actively managed) in diked brackish marshes of Suisun Marsh, where its seed production is valued for waterfowl foraging habitat. The taxonomy and geographic origin of this species has been long confused. *A. prostrata* is native to Europe, early and widely introduced and naturalized in North America. The earliest botanical observations in California are from H. Behr's 1850s San Francisco residency, later reported in his Flora of the Vicinity of San Francisco (1888) from "cultivated grounds" as a "ballast weed introduced from Europe", under the name *A. patulum (*syn. *A. patula* var. *hastata*, misapplied to *A. prostrata*). S. Watson (1880) Botany of California volume II described *A. patula* L. var. *hastata* Gray distribution in 1880 as "frequent in salt-marshes near San Francisco" only, and noted a Santa Barbara locality as an addition and correction to volume II. Jepson (1911, corrected edition of 1901 Flora of Middle Western California) also described the range of *A. hastata* (syn. *A. patula* var. *hastata*) as "Common at the edges of salt marshes about San Francisco Bay", but not "Suisun Marshes". E. Greene (1894) reported *A. hastata* as "common along the borders of brackish marshes at Petaluma, and elsewhere. The 1993 Jepson Manual (Hickman *et al*. 1993) treated California populations previously referred to *A. patula* L. var. hastata and *A. hastata* Hall & Clem. as misapplied to *A. triangularis*, which was erroneously presumed to be native to California and Europe. *A. triangularis* is currently treated in the second edition of the Jepson Manual (in prep.) and the Flora of North America as *A. prostrata*, native to Europe but widely naturalized in North America and elsewhere. This common species is widely but erroneously presumed to be native to California. Although it may be transiently abundant in disturbed marsh shorelines and in drift-lines or wracks, it is not reported as an invasive species regardless of its presumed provenance. Flowering spring-fall.

Atriplex semibaccata R. Br. AUSTRALIAN SALTBUSH. Infrequent in terrestrial edges of tidal marsh at scattered localities. Native to Australia. Regionally common levee weed, locally invasive. Flowering spring-summer.

Beta vulgaris L. WILD BEET. Infrequent, locally common and often transient in drift-lines and wracks, levees, ditch and tidal creek bank edges. Native to Europe, escaped from cultivation of Swiss chard and beet. Edible. Flowering spring-summer.

Sarcocornia pacifica (Standl.) A. J. Scott . PICKLEWEED. Widespread and abundant to locally dominant or co-dominant in tidal marsh plains and their terrestrial ecotones, often increasing during periods of drought and elevated marsh soil salinity. Flowering late summer-fall.

Sarcocornia subterminalis Parish ALKALI PICKLEWEED, PARISH’S PICKLEWEED or PARISH’S GLASSWORT. Uncommon, local terrestrial ecotones of tidal marsh in alkali grassland of Spring Branch Creek lower alluvial fan, sporadically elsewhere in terrestrial edges on saline/alkali soils. More often found in edges of non-tidal alkali seasonal wetlands than in tidal marsh. Treated in the 1993 and Second Edition Jepson Manual as synonym. *Arthrocnemum subterminale* (Parish) Standl. Visually distinguished at a distance by relatively dense and symmetric branching patterns of shoots; otherwise easily overlooked among more common pickleweed. Flowering late summer-fall.

Salicornia depressa Standl. (*S. europaea* L., misappl.), a widely dispersed annual succulent native forb occurs sporadically and widely in disturbed high mudflats and marshes in the San Francisco Estuary, often as a pioneer colonizing species. Populations occur in eastern San Pablo Bay near the Carquinez Straits, and may be expected episodically at Rush Ranch.

APIACEAE

Carrot or Parsley Family

Apium graveolens L. WILD CELERY. Widespread and common, locally abundant in tidal marsh plains and drift-lines. Native to Europe, escaped from cultivation of celery. Invasive in brackish marsh, particularly disturbed soils. Edible. Flowering late spring-fall.

Cicuta bolanderi S. Watson (*C. maculata* L.[misappl.] var *bolanderi* (S. Watson) Mulligan. BOLANDER’S WATER-HEMLOCK. Regionally rare, currently known in the San Francisco Bay estuary from Rush Ranch only, where it occurs at two subpopulations in fringing brackish marsh at and south of Rush Landing. This species was formerly abundant in Suisun Marsh, described as “abundant and conspicuous” in Suisun marshes only by Jepson (1911), and from Suisun and “Alvarado marshes” (Newark, Alameda County) by E. Greene (1894), who also described it (1892) as associated with Suisun thistle. Treated in the 1993 Jepson Manual and Second edition as *Cicuta maculata* L. var. *bolanderi* (S. Watson) G. A. Mulligan, but recent genetic analysis of North American *Cicuta* species (C. Lee & S. Downie. 2006. Can. J. Bot. 83:453-468) indicates that western North American *Cicuta* taxa are distinct from *C. maculata*, (which is likely a maternal progenitor species) and likely belong to a well-supported monophyletic western clade that has not yet been resolved. Accordingly, the Suisun Marsh (type locality of *C. bolanderi*) populations are provisionally referred to the original named taxon. Suisun type locality specimens were not analyzed by Lee and Downie (2006). Rush Landing specimens are indeed "conspicuous" due to large flowering shoots reaching heights exceeding 3 m, taller than any nearby plants except tules. *Cicuta* may be overlooked due to confusion with common and widespread *Sium suave*, which is similar in aspect and gross morphology. *Cicuta* is reported to be among the most toxic plants in North America, and extremely toxic to livestock. Flowering midsummer- early fall.

Conium maculatum L. POISON-HEMLOCK. Widespread and highly invasive European weed of levees, also occurring locally in terrestrial grassland edges of tidal marshes at Rush Ranch. Extremely toxic. Flowering summer, sporadically in fall.

Eryngium vaseyi J. Coulter & Rose. Reported from tidal marsh by B. Grewell. Typically occurring in inland alkali vernal pools of San Joaquin Valley and interior south coast ranges. Rush Ranch locations need verification.

Eryngium aristulatum Jeps. var ***aristulatum*** . COYOTE-THISTLE. Widespread but only occasional to uncommon in tidal marsh plains and fringing tidal marsh; locally common in fringing marshes near Rush Landing. Flowering summer-fall.

Hydrocotyle verticillata Thunb. WATER-PENNYWORT. Uncommon in banks of tidal creeks, ditches, and wave-scoured fringing marsh. Flowering summer-fall.

Lilaeopsis masonii Mathias & Constance MASON'S LILAEOPSIS. Widespread but uncommon in banks of tidal creeks, ditches, and wave-scoured fringing marsh, where it forms creeping prostrate grass-like turfs or colonies; occasionally occurring as an inconspicuous creeping component of the shaded ground layer vegetation in marsh plains or fringing tule marsh. This species is possibly indistinct, a morphological variant and synonym of the more widespread but uncommon *L. occidentalis* J. M. Coult. & Rose. Flowering summer-fall.

Oenanthe sarmentosa C. Presl. WATER-PARSLEY. Widespread and locally common in brackish marsh plains and fringing marsh. *O. sarmentosa* is relatively more abundant in wet years, and near freshwater seepages adjacent to low shoreline bluff scarps or drainages from upland swales. Potentially overlooked in mixed stands with *Apium graveolens*. Flowering summer-fall.

Sium suave Walter. WATER-PARSNIP. Infrequent along tidal creek and slough banks, fringing marsh banks, Hill Slough. Possibly recent re-establishment; not reported in 1990s plant species lists of B. Grewell. Flowering summer-fall.

ASTERACEAE

Aster Family

Achillea millefolium L. YARROW. Widespread but uncommon in well-drained tidal brackish marsh plains, natural levees of tidal creek banks, forming small clonal colonies. Brackish marsh (salt-tolerant wetland) ecotypes of this typically upland species occur from western San Pablo Bay through the western Delta. Native. Flowering late spring-summer.

Ambrosia psilostachya DC WESTERN RAGWEED. Occasional, locally common in terrestrial grassland ecotones of tidal marsh, and along natural levees of tidal creek banks and fringing marshes. Abundant at E end Rush Landing high tidal marsh-terrestrial ecotone. Flowering summer-fall.

Artemisia douglasiana Besser WORMWOOD. Occasional, natural levees of tidal creeks and fringing marsh, riparian scrub of N-facing bluff scarps of Hill Slough and Suisun Slough. Flowering summer-fall.

Baccharis douglasii DC MARSH BACCHARIS. Occasional, terrestrial ecotone of diked marsh west of Rush Ranch headquarters, well-drained high tidal marsh plain, natural levees of tidal creeks. Flowering summer-fall.

Bidens frondosa L. MARSH-MARIGOLD. Occasional, local in disturbed patches of fringing marsh, especially in drift-lines and wracks. Flowering summer-fall.

Centromadia pungens (Hook. & Arn.) Greene SPIKEWEED. Occasional, terrestrial grassland ecotone of tidal marsh. Distinguished by lack of pappus on disc florets; otherwise similar to *C. fitchii*, with which it may be confused. Flowering summer-fall.

Centromadia fitchii (A. Gray) Greene FITCH'S SPIKEWEED. Occasional, terrestrial grassland ecotone of tidal marsh, especially alkali grassland of Spring Branch Creek alluvial fan.
Distinguished from *C. pungens* locally by disc pappus present. Flowering summer-fall.

Cirsium hydrophilum (E. Greene) Jepson *ssp.* ***hydrophilum*** SUISUN THISTLE. Very rare but locally common; historically endemic to Suisun Marshes, currently endemic to tidal marsh plain of southern Rush Ranch. Most subpopulations are in well-drained tidal marsh plains near banks of tidal creeks and ditches (Fiedler *et al*. 2003). No populations are known from fringing tidal marshes of Suisun Slough northward through Hill Slough, despite apparently suitable habitat. Historically associated with *Cicuta bolanderi* acc. E. Greene (1892). Currently occurs in marsh dominated by *Distichlis, Juncus arcticus* ssp. *balticus*, *Argentina egedii*, often in association with *Senecio hydrophilus, Rumex occidentalis,* and non-native forbs such as *Cirsium vulgare* and *Helminthotheca echioides*. ENDANGERED (listed State, Federal). . Flowering early summer-fall.

Cirsium vulgare *(Savi) Ten.* BULL THISTLE. Locally common in well-drained marsh plains and natural levees bordering tidal creeks or ditches, sometimes in association with endangered *C. hydrophilum.* Invasive European weed. Flowering early summer-fall.

Cotula coronopifolia L. BRASS-BUTTONS. Widespread in many brackish marsh habitats, including turf pans, pools, disturbed patches and drift-lines in tidal marsh plains, and disturbed (trampled) terrestrial edges of tidal marsh. Amphibious, heterophyllous: develops grass-like submerged leaves. More abundant in diked seasonal marsh and ponds, in emergent mud, often ephemeral pioneer dominant in early mudflat succession in tidal or diked marshes. Early introduction first appearing in San Francisco in the 1850s from South Africa (Behr 1888, 1892), rapidly spreading through San Francisco Bay by 1901 (Jepson 1911), and collected in Suisun Marsh by 1903 (C.F. Baker *3225*, UC 84527). Flowering late winter-spring, sporadically in summer.

Euthamia occidentalis Nutt. WESTERN GOLDENROD. Widespread but uncommon in well-drained tidal marsh and natural levees bordering tidal channel banks, fringing marsh scarps, and along terrestrial ecotones with freshwater seep or surface drainage influence. Flowering late summer-fall.

Gnaphalium stramineum Kunth CUDWEED. Occasional in drift-lines and disturbed patches in high marsh or terrestrial grassland ecotones.

Gnaphalium palustre Nuttl. CUDWEED. Occasional in drift-lines and disturbed patches in high marsh or terrestrial grassland ecotones.

Grindelia hirsutula Hook. & Arn. (incl. ***G. stricta*** DC. var. ***angustifolia*** (A. Gray) M.A. Lane, incl. *G*. × *paludosa*). Locally abundant in well-drained tidal marsh bordering tidal creek and ditch banks, and on natural levees of tidal sloughs. Occasionally occurring in patches in well-drained tidal marsh plains farther from tidal creeks. The current taxonomic treatment in Flora of North America places *G. stricta* and all its varieties, as well as other and other species, in synonymy with *G. hirsutula* , *sensu lato*. Because of regionally strong ecological, geographic, and morphological discontinuity between *G. stricta* var. *angustifolia* of tidal marshes compared with other local taxa now placed in synonymy with *G. hirsutula*, the Lane treatment of *G. stricta* var. *angustifolia* in the Jepson Manual (Hickman *et al*. 1993) should be conserved in this region. E. Greene distinguished *G. paludosa*, which has been treated by Lane as a hybrid between *G. stricta* var. *angustifolia* and *G. camporum* (of terrestrial grasslands), which Greene described as “abundant in brackish marshes of Suisun Bay”. Flowering mostly summer-fall, sporadic flowers all year. Important nectar plant.

Helenium bigelovii A. Gray BIGELOW’S SNEEZEWEED. Uncommon in fringing marsh along Suisun Slough, Hill Slough, and in wave-scoured bluff edges near seeps; possibly elsewhere in tidal marsh plains. Flowering summer-fall.

Helianthus annuus L. ANNUAL SUNFLOWER. Uncommon in natural levees of tidal creeks. Flowering summer.

Helminthotheca echioides (L.) Holub. (syn,. *Picris echiodes* L.) BRISTLY OX-TONGUE. Occasional, locally common to abundant near ditches and sporadically in well-drained high marsh plains. Native to Europe. Flowering spring-summer.

Jaumea carnosa (Less.) A. Gray FLESHY JAUMEA. Widespread and common in both well-drained and poorly-drained tidal marsh plains, fringing marshes. Flowering summer.

Lasthenia glabrata Lindl. ssp. ***glabrata*** SMOOTH GOLFIELDS. Uncommon, local in turf pans, poorly drained landward edge of tidal marsh plain at the lower edge of the terrestrial grassland ecotone, often on terrigenous sediments, south Rush Ranch. Associated with *Isolepis, Juncus bufonius*, *Triphysaria*, as well as prostrate phenotypes of *Sarcocornia pacifica*, *Frankenia*, and sparse *Distichlis*. Flowering spring (March-May, rarely June).

Lasthenia californica DC. ex Lind. ssp. *californica* occurs in subsaline sandstone soils within the erosional drainage below the northern spring and impoundment on Grizzly Island Road, and may be expected in terrestrial ecotones of tidal marsh below; *L. conjugens* Greene has been reported by Grewell from vernal pools at Rush Ranch, and occurs in alkali/subsaline vernal pools and flats south of Highway 12 near Potrero Hill. Historical tidal marsh and salt pond edge populations of *L. conjugens* are known from South San Francisco Bay

Pluchea odorata (L.) Cass. MARSH FLEABANE. Occasional, well-drained marsh plain, natural levees of tidal sloughs and creeks, and fringing marsh.

Senecio hydrophilus Nutt. MARSH BUTTERWEED, MARSH RAGWORT. Uncommon but widespread in well-drained tidal marsh plains, natural levees of tidal sloughs and creeks, and fringing marshes. Historically “abundant in the Suisun Marshes” (Jepson 1911).

Symphiotrichum lentum (Greene) G.L. Nesom. SUISUN MARSH ASTER, SUISUN ASTER. Uncommon but locally abundant in clonal colonies, particularly in fringing marshes and bluff scarps along Suisun Slough and Hill Slough.

Symphyotrichum subulatum (Michx.) G.L. Nesom var. ***parviflorum*** (Nees) S. D. Sundberg. ANNUAL ASTER. Widespread annual (to short-lived perennial in favorable conditions) occurring sporadically in well-drained tidal marsh plains, natural levees of tidal creek banks, fringing marshes, drift-lines of terrestrial ecotones. Also abundant in diked marshes of Suisun Marsh, but scarce in the diked marsh at

Rush Ranch. This subspecies is native to California; other subspecies may be introduced in California. This appears to be one of the oldest botanical collections from Suisun Marsh (H. Bolander *2618*, UC31440). Flowering summer-fall.

Sonchus oleraceus L. SOW-THISTLE. Occasional, locally common to abundant near ditches and sporadically in well-drained high marsh plains. Native to Europe. Flowering spring-summer.

Sonchus asper L. Hill ssp. *asper* PRICKLY SOW-THISTLE. Occasional near ditches and sporadically in well-drained high marsh plains; less common than *S. oleraceus* in brackish marsh. Native to Europe. Flowering spring-summer.

Taraxacum officinalis Wigg. DANDELION. Reported from Rush Ranch tidal marshes by B. Grewell. Localities unknown. Flowering spring.

Tragopogon porrifolius L. SALISFY, OYSTER-PLANT. Reported from Rush Ranch tidal marshes by B. Grewell. Localities unknown. Flowering spring-early summer.

Xanthium strumarium L. COCKLEBUR. Locally common in drift-lines, wracks, and disturbed patches in poorly drained tidal marsh. Flowering summer. Cosmopolitan weed native to Eurasia; sometimes treated as native to N. America, but doubtful.

BORAGINACEAE

Borage Family

Heliotropium curassavicum L. WILD HELIOTROPE. Formerly observed in sandy disturbed shorelines near Rush Landing in terrestrial ecotone of high tidal marsh; current localities need verification. Few other Suisun Marsh localities are known. Occurs infrequently in terrestrial edges of tidal marsh in San Pablo Bay and San Francisco Bay. Flowering summer.

Plagiobothrys stipitatus and *P. greenei* were reported by B. Grewell from upland vernal pools/seasonal wetlands at Rush Ranch; these may potentially disperse and establish in tidal marsh edges below drainages).

BRASSICACEAE

Mustard Family

Brassica nigra L. BLACK MUSTARD. Occasional, terrestrial grassland ecotone, levee of diked marsh, and natural levees of tidal sloughs. European native; abundance in saline wetland soils is limited.

Lepidium latifolium L. BROADLEAF PEPPERWEED, PERENNIAL PEPPERWEED. Widespread, abundant, and dominant or co-dominant (including monotypic stands, and mixed stands overtopping shaded pickleweed-saltgrass understories) in Rush Ranch tidal marsh plains. Present but not abundant (2010) along Rush Ranch fringing marshes of Suisun Slough and Hill Slough. Absent or rare in summer-desiccated terrestrial ecotones of tidal marsh bordering alkali grassland where dominance shifts to *Sarcocornia-Frankenia-Distichlis* or *Leymus-Bromus-Lolium*. *L. latifolium* was present in the northern San Francisco Bay Area and western Delta in the late 1950s and 1960s, and became conspicuous and widely dominant by the 1990s. It was first collected recorded in southern Marin County near railroad tracks in 1965 (Howell 1970), east of Dixon (west Delta) in 1959 (B. Crampton *5150*, UCD35699), Napa-Sonoma Marsh 5 miles east of Sears Point in 1958 (T.C. Fuller *1480-58*, CDA3836), and in Petaluma Marsh in 1970 (A. LaRose, CDA3804). In Suisun Marsh, its abundance increased dramatically following the very wet 1997-98 El Niño event, and it has spread progressively since then. Flowering May-early summer; repeat flowering occurs in late summer regrowth on plants lodged, cut, or mowed early in the growing season, if soil moisture and salinity support growth. Noxious Eurasian weed spreading locally by adventitious shoots on rhizome-like shallow roots; root sprouts stimulated by pruning, light. Abundant seed are produced in early summer.

Raphanus sativa L. WILD RADISH. Occasional, terrestrial grassland ecotone, levee of diked marsh, and natural levees of tidal sloughs. In San Pablo Bay, *R. sativa* rapidly becomes dominant on freshly maintained (mud-capped) levees. European annual weed. Abundance in saline wetland soils is limited.

CARYOPHYLLACEAE

Carnation family

Spergularia salina J.S. Presl & C. Presl. (syn. *S. marina* (L.) Grisb. SAND-SPURREY. Occasional, drift-lines and disturbed patches in well-drained high tidal marsh. European annual native; not known to be invasive.

Spergularia maritima (All.) Chiov. (syn. *S. media* (L.) Grisb. SAND-SPURREY. Reported by B. Grewell. No verified Solano County collection localities are otherwise reported. European annual native; in Richardson Bay (Central San Francisco Bay, Marin County), locally dominant and invasive, forming monotypic stands in high mudflats.

Spergularia macrotheca var. *leucantha* is historically reported from alkali grasslands of Solano County, and *S. macrotheca* var. *macrotheca* estuarine collection localities range east in San Pablo Bay to Richmond (Point Pinole). It may potentially occur at Rush Ranch, and could be masked by presence of similar non-native *Spergularia* species.

CONVOLVULACEAE

Morning-glory Family

Calystegia sepium (L.) R. Br. ssp. ***limnophila*** (E. Greene) Brummitt. MARSH MORNING-GLORY. Occasional to common growing on tules along fringing marshes and banks of tidal sloughs. Native. Flowering summer-fall.

Convolvulus arvensis L. BINDWEED. Reported from tidal marsh localities by B. Grewell. Localities unknown.

Cressa truxillensis Kunth. ALKALI-WEED. Common in terrestrial ecotones of tidal marsh and grassland and alkali seasonal weltlands, and occasional in well-drained high tidal marsh plains. Flowering summer.

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CUSCUTACEAE

Dodder family

Cuscuta salina Engelm. var. ***major*** Yunker SALT MARSH DODDER. Widespread and abundant or locally dominant in well-drained tidal marsh plains, typically associated with *Sarcocornia* (in which it can cause significant thinning or large dieback patches). Emerging in spring, abundant by late summer; flowering summer.

FABACEAE

Pea or Legume Family

Lathyrus jepsonii Greene *var. jepsonii* JEPSON’S TULE PEA. Uncommon at Rush Ranch but occurring in locally abundant colonies. Established mostly at steep, well-drained banks of high tidal marsh bordering taller vegetation (including tules, and riparian scrub) over which it climbs. Most frequent along Hill Slough edges. Regionally rare. Flowering summer.

Lotus corniculatus L. BIRD'S-FOOT TREFOIL. Locally abundant in well-drained high marsh plains and terrestrial ecotones. European native, invasive in high brackish marsh and seasonal wetlands. Flowering spring-summer.

Lotus purshianus (Benth.)Clem. & E.G. Clem. var. ***purshianus*** SPANISH-CLOVER. Formerly observed in high tide lines near Rush Landing. Flowering summer.

Melilotus indica (L.) All. SOURCLOVER. Locally common in high brackish marsh and adjacent terrestrial grassland ecotones, southern Rush Ranch. Flowering summer.

Trifolium wormskioldii Lehm. COW CLOVER. Locally common in well-drained brackish marsh plains and fringing marsh. Flowering summer.

FRANKENIACEAE
Frankenia family

Frankenia salina (Molina) I.M. Johnston ALKALI-HEATH. Widespread and common in well-drained marsh plains, natural levees of tidal creeks and sloughs, and terrestrial ecotones; also in alkali grassland. Flowering spring-summer. Important nectar plant.

LAMIACEAE
Mint Family

Stachys albens A. Gray MARSH HEDGE-NETTLE. Uncommon, high brackish marsh. Recently (2010) confirmed at southern shore fringing marsh at Rush Landing. Flowering summer.

Lycopus asper E. Greene BUGLEWEED , WATER-HOREHOUND. Rare in fringing high marsh south of Rush Landing, with *Frankenia, Ambrosia, Distichlis*; possibly overlooked and occurring elsewhere. Previous collection localities in Solano and Suisun Marsh by W.L. Jepson (*14901*, Benicia) and A.A. Heller (Suisun Marsh near Suisun) are from the late 19th and earliest 20th c.

LYTHRACEAE
Loosestrife Family

Lythrum hyssopifolium L. HYSSOP-LEAF LOOSESTRIFE. Common, occasionally abundant, in high marsh turf pans and drift-lines, occasional in tidal marsh plains, including poorly drained depressions. European annual or short-lived perennial, invasive in seasonal pools.

Lythrum tribracteatum Salzm. ex Spring. [THREEBRACT LOOSESTRIFE]. Reported by B. Grewell from Rush Ranch tidal marsh. Localities unknown. Habitats presumably similar to *L. hyssopifolium.*

ONAGRACEAE
Evening-primrose Family

Epilobium ciliatum Raf. ssp. ***ciliatum*** WILLOW-HERB. Occasional in well-drained brackish marsh, natural levees of tidal creeks, terrestrial ecotones, and drift-lines.

OROBANCHACEAE Broomrape family
(including hemiparasitic genera of traditional Scrophulariaceae)

Chloropyron molle (A. Gray) A. Heller ssp. ***molle*** (syn. *Cordylanthus mollis* A. Gray ssp. *mollis* SOFT BIRD'S-BEAK. Rare hemiparasitic annual, occurring in various tidal sub-habitats within Suisun Marsh, including natural levees of tidal creek banks, well-drained high tidal marsh, edges of turf pans, and terrestrial ecotones, usually associated with relatively sparse cover of dominant vegetation, including *Sarcocornia* (host), *Distichlis*, *Cuscuta*, and other high tidal marsh annuals. At Rush Ranch, 2010 localities correspond with the vicinity of mapped locations of natural and seeded populations reported by B. Grewell (2005) near Spring Branch Creek. Annual populations may fail to emerge from seed banks but reappear at the same or proximate locations. Long-distance natural colonization events are infrequent.

Triphysaria versicolor Fisch. & C. . Mey. ssp. ***versicolor*** YELLOW FALSE OWL'S-CLOVER, BUTTER-AND-EGGS. Locally rare in turf pans of south Rush Ranch tidal marsh at the lower terrestrial ecotone, in association with *Lasthenia glabrata*, *Isolepis cernua*, *and Juncus bufonius*, as well as prostrate *Sarcocornia*. This is a ecologically distinctive and noteworthy occurrence, the only reported occurrence of *T. versicolor* in brackish tidal marsh; the species is typically found in the region within seasonal wetlands and alkali grasslands.

Castilleja ambigua (Hook. & Arn.) occurs in one high brackish marsh locality at Benicia (a succulent-leaf, late spring/summer-flowering form with large white and yellow corollas, and seed coats similar those of ssp. *humboldtiensis*), and at Point Pinole, Whittell Marsh (non-succulent, early spring-flowering form with purplish foliage and post-anthesis corollas) in association with a former population of *Chloropyron molle* ssp. *molle* and large populations of *Lasthenia glabrata*, both of which occur at Rush Ranch. Regionally rare tidal marsh ecotypes of this species may occur at Rush Ranch in corresponding habitats.

PLANTAGINACEAE Plantain Family

Plantago subnuda Pilger SEEP PLANTAIN. Occasional to locally common in brackish marsh plains and fringing marsh, and seeps in sandstone bluffs of Rush Landing within tidal range.

Plantago maritima L. (*P. maritima* var. *juncoides* (Lam.) A Gray SEASIDE PLANTAIN. Infrequent, reported by B. Grewell from Rush Ranch tidal marshes. No other collection localities are known from Suisun Marsh, but it was one of the earliest brackish marsh collections from the region by W.H. Brewer *997* (UC8020) at Martinez in 1862, where it was subsequently collected by J.B. Davy (*6670*) in 1900. The species is common in maritime salt marshes of west Marin County, and in Richardson Bay. Flowering summer.

P. coronopus, buck's-horn or rat-tail plantain, a non-native European halophyte that has become widespread and locally invasive in Marin County tidal marsh edges, has not yet been reported at Rush Ranch, but has been reported from railroad yard localities in Solano County as far back as the 1940s (JEPS6910, C.B. Heiser 1947), and maybe is expected at Rush Ranch and vicinity

P. elongata, Pursh, a diminutive annual of brackish flats and alkali vernal pools, has been historically collected at multiple locations near sea level in Suisun Marsh, may be expected in Rush Ranch tidal marshes. This species may be easily overlooked in turf pans.

POLYGONACEAE Buckwheat Family

Persicaria punctata (Elliott) Small *(*syn. *Polygonum punctatum* Elliott*)* DOTTED or WATER SMARTWEED. Occasional in brackish marsh plains and fringing marshes, drift-lines. (syn. *Polygonum punctatum* Elliott. Flowering summer to fall.

Polygonum aviculare L. ssp. ***depressum*** (Meisn.) Arcang. DOORYARD KNOTWEED. Occasional in brackish marsh plains and fringing marshes, drift-lines. European annual weed. Flowering spring to summer.

Polygonum marinense T. Mert. & Raven MARIN KNOTWEED. Uncommon in turf pans below and within terrestrial ecotones, south Rush Ranch in 2010, and possibly in the same habitats as *P. aviculare*. The identity of this putative rare native annual species, formerly believed to be endemic to western Marin salt marsh edges, is questionable. It has undergone rapid range expansion from isolated locations in west Marin salt marshes in the 1960s (where it was presumed to be endemic) to widespread occurrences in brackish marshes of the northern San Francisco Estuary, east at least to Martinez and Rush Ranch in recent years. Its pattern and rate of spread has been more like an invasive species than a narrow endemic. It may be synonym of *P. robertii* Lois., or related non-native species, according to the treatment in the 1993 Jepson Manual (Hickman *et al*. 1993). It is distinguished by glossy dark achenes up to 4 mm long. Flowering late spring to early summer.

Rumex crispus L. CURLY DOCK. Occasional, well-drained brackish high marsh, natural levees of tidal creeks, drift-lines. European perennial forb, invasive in non-tidal fresh-brackish seasonal wetlands, but seldom invasive in tidal marshes. Flowering spring to early summer.

Rumex occidentalis S. Watson WESTERN DOCK. Common but not abundant above banks of tidal creeks and fringing marshes. Distinguished from non-native *Rumex* species in wetlands by lack of inflated valves around achenes when in fruit, and by large rosy immature fruits. Flowering late spring or early summer.

PHYRMACEAE Lopseed family
(includes former traditional Scrophulariaceae genera)

Mimulus guttatus DC. MONKEY-FLOWER. Occasional in brackish high marsh near banks of tidal creeks or fringing marshes, and around and drift-lines, particularly near freshwater discharges of seeps or upland runoff. Brackish marsh ecotypes are not known west of Suisun Marsh. Flowering summer, sporadically to fall.

PLUMBAGINACEAE Leadwort family

Limonium californicum (Boiss.) A. Heller CALIFORNIA SEA-LAVENDER. Infrequent but locally common in well-drained high marsh plains and creek banks.

PRIMULACEAE Primrose family

Anagallis arvensis L. SCARLET PIMPERNEL. Occasional in disturbed drift-lines and terrestrial ecotones. European annual weed. Flowering spring, soon withering.

Glaux maritima L. SEASIDE MILKWORT. Widespread, patchy, locally common in well-drained brackish marsh plains and fringing marshes. Flowering summer. Native to Pacific and Atlantic North American coasts, and Europe. Ant-pollinated in European populations.

ROSACEAE Rose Family

Argentina egedii (Wormsk.) Rydb. PACIFIC SILVERWEED. Widespread, common, and locally abundant (often in association with Juncus arcticus ssp. balticus) in both well-drained and poorly-drained tidal marsh, forming clonal (stoloniferous) colonies. (Syn. *Potentilla anserina* L. ssp. *pacifica* (Howell) Rousi).

Rubus armeniacus Focke (syn. **R. discolor** Weihe & Nees.). HIMALAYAN BLACKBERRY. Locallly abundant to dominant on levees of the diked marsh west of Rush Ranch headquarters, and rooted in riparian scrub of bluff scarps bordering Hill Slough, spreading over tidal marsh edges. Noxious invasive Eurasian weed.

SALICACEAE Willow Family

Salix lasiolepis Benth. ARROYO WILLOW. Uncommon, riparian scrub ecotones of tidal marsh bordering Hill Slough.

SOLANACEAE Nightshade family

Solanum physalifolium Rusby var. ***nitidibaccatum*** (Bitter) Edmonds *(S. villosum (*L.) Mill.*, S. saccharoides* Sendtn. misapplied*).* Reported by B. Grewell in tidal marshes of Rush Ranch. Localities unknown.

FLORISTIC ANALYSIS

Families	**number of species**
[Monocots]	
Cyperaceae	10
Juncaceae	3
Juncaginaceae	2
Liliaceae	1
Poaceae	14
Potamogetonaceae	2
Typhaceae	3
[7]	[35]
[Dicots]	
Aizoaceae	1
Amaranthaceae /Chenopod.)	5
Apiaceae	9
Asteraceae	28
Boraginaceae	1
Caryophyllaceae	2
Convolvulaceae	3
Cuscutaceae	1
Fabaceae	5
Frankeniaceae	1
Lamiaceae	2
Lythraceae	2
Onagraceae	1
Plantaginaceae	2
Polygonaceae	5
Phyrmaceae	1
Plumbaginaceae	1
Primulaceae	2
Rosaceae	2
Salicaceae	1
Solanaceae	1

	[21]	[76]
TOTAL	**28**	**111**

Non-native species 40 (40/111 =36%)

Endangered species: 2 (*Cirsium hydrophilum* ssp. *hydrophilum*, *Chloropyron molle* ssp. *molle*)

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