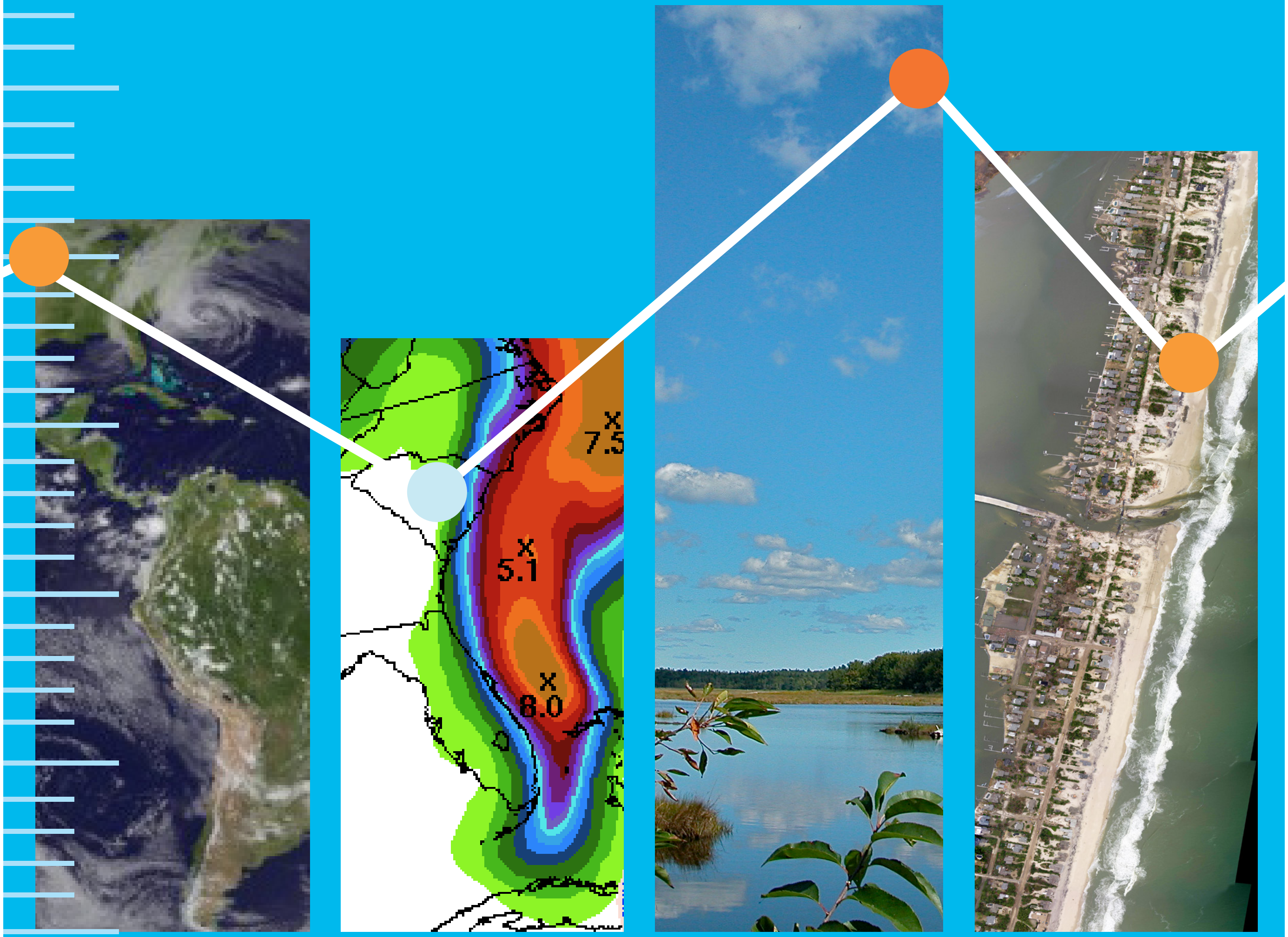
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

NATIONAL
ESTUARINE
RESEARCH
RESERVE
SYSTEM

CLIMATE SENSITIVITY OF THE NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM

July 2013



National Estuarine Research Reserve System

The National Estuarine Research Reserve System is a network of protected areas established for long-term research, education and stewardship. This partnership program between NOAA and the coastal states protects more than 1.3 million acres of estuarine land and water, which provides essential habitat for wildlife; offers educational opportunities for students, teachers and the public; and serves as living laboratories for scientists.

Authors

Background and Context for this Study

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The NERRS Social Sensitivity to Climate Change

Patrick Robinson, Katherine Curtis, Jing Gao, Ken Genskow, Jerrett Jones and Dan Veroff

Reserve Ecological Resiliency

Patrick Robinson, Katherine Curtis, Jing Gao, Ken Genskow, Jerrett Jones and Dan Veroff

NERRS Biophysical Sensitivity to Changes in Climate

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Summary of Findings and Conclusions

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Executive Summary

Healthy coasts provide many benefits to the people of the United States. These include critical economic and transportation links to the world through the nation's ports as well as abundant natural resources that provide food and recreational opportunities. Estuaries, where our rivers meet the seas, are an integral component of the array of diverse coastal habitats that make up the nation's coasts. Coastal habitats provide nursery habitat for fish and shellfish while buffering many of our coastal communities from the impacts of coastal storms and sea level rise. Yet, some estuaries may be much more vulnerable than others to the impacts of climate change. Scientists still do not fully understand which estuaries may be at greater risk or what the factors are which make some estuaries more susceptible to climate change than others. However, this kind of information is needed by coastal managers to make informed decisions.

This report examines some of the factors that make estuaries and the communities dependent on estuarine resources susceptible to climate change. The work is focused in the National Estuarine Research Reserve System (NERRS) a collection of 28 reserves located around the U.S. and Puerto Rico, which are managed as a partnership between the National Oceanic and Atmospheric Administration (NOAA) and the coastal states for long-term research, ecosystem monitoring, education, and coastal stewardship. The NERRS is uniquely positioned to assess climate change impacts in the nation's estuaries because the system is composed of a diverse set of managed coastal ecosystems encompassing different biogeographic regions and estuarine types that are exposed to various gradients of human- and climate-related stressors. Each reserve also makes important connections to the local communities and economies where it is located. Integrated research and training programs conducted by the reserves help communities address natural resource management issues, such as non-point source pollution, habitat restoration, invasive species and climate change. This is facilitated by the collaborative nature of the NERRS' federal-state partnership between NOAA and the state institutions that manage the program.

To our knowledge, this is the first national climate sensitivity analysis of U.S. estuaries. This study is also unique in that it examines both the biophysical and socio-demographic sensitivities of reserve sites to climate change. The study 1) analyzes and synthesizes available information and data that describe the physical, ecological and socio-demographic attributes of the reserves, 2) identifies the dominant stressors that impact reserves and examines reserve ecological resiliency, and 3) categorizes reserves based on their potential sensitivities to climate hazards/variables, ecological resiliency, projected changes in temperature, and projected sea level rise. Because the Reserve System forms a network of living laboratories that monitor estuarine conditions in a systematic and coordinated fashion, we had access to a relatively uniform set of rich biophysical data to draw upon for our analyses. However, climate change impacts not only natural resources but also the local communities dependent upon them. Therefore, this report also examines which socio-demographic factors can best be used to characterize the socio-economic sensitivity of the reserves and how these factors will potentially be impacted by climate change.

NERRS' Social Sensitivity to Climate Change

A growing body of knowledge shows that human-induced climate change is occurring and its societal impacts are projected to expand (Skinner 2012). It is also well understood that the environmental consequences of climate change will interact with existing social stresses within communities and influence the level of realized societal impact. This report analyzed socioeconomic, demographic, and infrastructure data to quantify the social sensitivity of reserves and all U.S. coastal communities to climate change at both reserve and coastal county levels. Therefore climate sensitivity, in the context of this report, is defined as whether and how a reserve or group of reserves will be affected by a change in climate conditions, measured over the particular environmental or social geography.

Key Findings

The reserve social sensitivity analysis revealed some large-scale spatial patterns in sensitivity around the nation, which characterized regional differences. Reserves on the East Coast of the U.S. were generally found to have lower social sensitivity to climate change than those in the Gulf of Mexico or on the West Coast. This does not mean that East Coast reserves are not susceptible to climate change impacts, only that the communities associated with East Coast reserves are better situated from a socio-economic perspective to respond to climate change impacts. The patterns in reserve social sensitivity around the country are related to differences in each reserve community's cultural barriers, dependence on natural resources, labor characteristics, and income levels. More specifically, reserves with higher socio-demographic sensitivity often exhibited one of more of the following characteristics:

- Greater employment within natural resource-dependent extractive industries
- Lower per capita income levels and median home values
- Higher percentage of Hispanic and/or American Indian residents
- Higher percentage of the population less than high school educated

The coastal county-level social sensitivity analysis included counties in which at least 15 percent of a county's total land area was located within the nation's coastal watershed or 15 percent of a county was within a coastal sub-basin. This analysis revealed spatial heterogeneity in social sensitivity; meaning that counties with low, moderate, and high sensitivity are commonly found located near each other. The following patterns emerged following a cluster analysis of the coastal county sensitivity data:

- The northern portions of the East and West coasts of the contiguous U.S., as well as the Great Lakes region, are primarily characterized by relatively low to moderate social sensitivity.
- The southern portion of the East Coast, as well as the Gulf Coast (with the exception of portions of Florida), has a mixture of low and high social sensitivities, diversely distributed.
- Portions of Florida, Texas, California, and Alaska have areas of very high social sensitivity; interestingly, those areas are also often next to low sensitivity areas.
- Alaska has a number of coastal areas with extremely high social sensitivity.

Overall, the results indicate that the scale of analysis for social sensitivity (e.g., reserve versus coastal county) is important, which is to be expected given the relative nature of the analysis and the differences in analytical units. While the data provide a basis for understanding large-scale trends at both the reserve and coastal county scales, it can also provide a richer understanding of the factors influencing sensitivity at a given location. Any further interpretation of the data should be done with consideration of the nature of the data used in the analysis, the relative nature of the index, and the scale of analysis.

Reserve Ecological Resilience

Reserve ecological resiliency was examined through an evaluation of reserve ecological stress and integrity. Ecological resiliency in this report is defined as a measure of the ability of an ecological system to return to its original state in a timely manner following an impact. Reserves that have higher ecological integrity and lower ecological stress are likely to be more resilient to the impacts of climate hazards.

Comprehensive direct measures of ecological stress and integrity are not currently available for the reserves, and the collection of novel data that would provide a direct measure of the variables was beyond the scope of this project. Given these constraints, expert input from reserve staff was used to develop an estimated measure of ecological stress and integrity.

The expert input process provided insights into staff perceptions of 1) the current level of ecological integrity at the reserves, 2) the overall ecological stress that reserves are experiencing, 3) the key ecological stressors impacting the reserves, 4) the relative contributions of key ecological stressors to overall ecological stress levels, and 5) causal factors related to the key ecological stressors. In addition, the responses were used to examine reserve resiliency.

Key Findings

Examining the underlying stressors leading to lowered resiliency can offer insights into management strategies that would reduce overall vulnerability to climate change. The key ecological stressors most frequently identified as impacting reserves included:

- Toxic contaminants
- Storm impacts (not including flooding)

- Invasive species
- Habitat fragmentation
- Sediment loading, and
- Coastal shoreline erosion

When percent contribution to overall ecological stress at reserves is also considered, the largest contributors, on average, to reserve ecological stress include the stressors already listed plus nutrient loading/eutrophication and habitat loss. This suggests that while nutrient loading/eutrophication and habitat loss may not be an issue at as many reserves as the other listed stressors, they are having a substantial relative impact at the reserves where they are occurring.

The most frequently identified causal factors contributing to key stressors included:

- Residential development
- Past land use
- Population growth
- Wastewater treatment, and
- Sea level rise

The identified causal factors underscore the considerable impact that anthropogenic activities are having on reserves.

It is expected that reserves with lower integrity ratings and higher stress would be less resilient and, therefore, have greater vulnerability to climate change. This suggests that sites with low ecological resiliency are at higher risk of climate change impacts when all other factors are considered equal. Our analysis indicates that the least ecologically resilient sites in the NERRS include:

- Tijuana River Reserve
- San Francisco Bay Reserve
- Waquoit Bay Reserve
- Elkhorn Slough Reserve
- Old Woman Creek Reserve
- Weeks Bay Reserve

And, the most ecologically resilient sites include:

- Guana Tolomato Matanzas Reserve
- Sapelo Island Reserve
- North Inlet-Winyah Bay Reserve

NERRS' Biophysical Sensitivity to Climate Variability

Coastal oceans, Great Lakes, and estuaries are complex and highly dynamic ecosystems shaped by coupled interactions among the physical, chemical, and biological processes associated with their terrestrial, freshwater, oceanic, and benthic components. These ecosystems are also highly productive, and therefore of great importance to society. Over time scales relevant to managers (i.e., the human life span) there are two overarching forces that are capable of perturbing the form, function, and ecosystem services provided by these systems: non-climatic human activities and climate variability and change. The combined effects of non-climatic and climatic stressors, interannual climate variability, and climate change can dramatically alter these environments causing eutrophication, modifying habitats, and changing basic environmental conditions, such as salinity, temperature, and alkalinity. Therefore, sensitivity of biophysical water conditions in the Reserve System represents a measure of dynamic responsiveness to climate change.

The connectedness between empirical water quality variables, such as temperature and specific conductivity, and the climate variables of precipitation and air temperature is examined in this report. An assessment of the responsiveness of springtime NERRS site-specific water quality variables to springtime atmospheric temperature and rainfall fluctuations across the NERRS was conducted. The main objective of this analysis is to evaluate the relative sensitivity of select water quality variables at each reserve to changes in climate variables. The secondary objective is to assess the most sensitive climate to water quality variable relationships across the NERRS, and to look for trends in sensitivity relative to reserve or water quality station characteristics, particularly land use and water drainage characteristics. Spring was chosen because, generally speaking, the annual growing season begins in spring due to increasing sunlight levels and warming temperatures. As such, variability in annual springtime rainfall and temperatures can result in dramatic changes in the biological structure and function of estuaries that influence biophysical processes and conditions throughout the rest of the year.

Key Findings

An NERRS Biophysical Sensitivity Index (BpSI) was developed to assess the relationship of climate and water quality at the reserve level. The result was an index that compared the reserves on a relative scale, ranging from Very High to Very Low biophysical sensitivity. The BpSI summarizes the annual spring atmospheric temperature and rainfall data at each reserve regressed against each water quality variable (water temperature, turbidity, water conductivity, pH, and dissolved oxygen) in order to characterize the strength of each reserve's climate-biophysical relationship.

- Reserves that were characterized as having Very High and High biophysical sensitivity relative to all the reserves in the NERRS were scattered around the country. Biophysically sensitive reserves included Tijuana River NERR (CA), Sapelo Island NERR (GA), ACE Basin NERR (SC), and Waquoit Bay NERR (MA).

- The Tijuana River Reserve (CA) had the highest average reserve BpSI (4.8) and its high biophysical sensitivity corresponds with its heavily developed, urbanized watershed where the water has been channelized.

- Sapelo Island (GA) and ACE Basin (SC) reserves have BpSI values in the Very High and High categories, respectively, and co-occur in the Southeast. Both reserves contain extensive salt marshes and are relatively undeveloped. Seven of the eight water quality monitoring stations in these two reserves are located in tidal creeks and their high biophysical sensitivity scores imply that the salt marsh tidal creek habitats in these two reserves are sensitive to climate-induced increases in temperature and precipitation.

- Waquoit Bay Reserve (MA) has a High BpSI value relative to all the other reserves due primarily to a strong climate-related linkage between air and water temperature. In contrast, Waquoit Bay Reserve's nearest neighbor, Narragansett Bay NERR (RI), had the second lowest BpSI value. This difference in biophysical sensitivity scores between these geographically close reserves indicates that local conditions are very important in determining climate-related biophysical sensitivity at these two reserves and possibly across the Reserve System.

- Eight of the nine reserves falling within the Moderate biophysical sensitivity group were located on the East Coast. Otherwise BpSI values did not show any distinct regional trends.

- The BpSI developed and used in this study separated reserves in an informative, relative scale, providing a useful foundation for exploring more detailed climate-biophysical relationships in the NERRS. The strongest individual relationships were found for the comparison of air temperature to water temperature and the comparison of precipitation to specific conductivity. The connection of climate variation to water temperature and saltiness is important, as these two water quality variables may have direct influences on estuarine natural resource populations.

- An important component of the variability seen in reserve sensitivity may be the result of the varying placement of the water quality monitoring stations in each reserve, which were originally established to assess targeted environmental gradients. It is recommended that the NERRS program evaluate different strategies for more targeted climate change monitoring at the reserve level.

Synthesis of NERRS Climate Sensitivity, Vulnerability and Exposure

The relative social and biophysical sensitivities and ecological resiliency of the reserves provide important insights into the potential climate change dynamics in the NERR system. The indicators developed for this report, as well as future projections of sea level rise and temperature, help provide a more robust examination of climate sensitivity and vulnerability of the NERRS. The approach also allows a comparison of spatial trends between the climate change indicators, contrasting and emphasizing potential climate change impacts at the reserve level and across the Reserve System.

The climate sensitivity and vulnerability indices we used in this report are as follows:

- Measurement of sensitivity for social conditions was achieved through analysis of societal characteristics and associated sensitivity scores within reserve-defined geographic boundaries and within contiguous coastal counties surrounding the reserve.

- The sensitivity of biophysical water conditions in the NERR system represents a measure of dynamic responsiveness to climate change and was measured by examining the connectedness between empirical water quality variables, such as temperature and specific conductivity, and the climate variables of precipitation and air temperature.

- The ecological resiliency analysis of the NERRS helped elucidate the possible impacts of potential climate stressors. This resiliency measure differed from other indices in this project in that it was based on the expert opinion of all available reserve staff and not directly on empirical data.

- Sea level rise information was based on the Coastal Vulnerability Index established by scientists at the United States Geological Survey (Hammar-Klose and Thieler, 2001). This assessment of coastal vulnerability to future sea level rise combines information about coastal geomorphology, shoreline erosion and accretion rates, coastal slope, rate of relative sea level rise, mean tidal range, and mean wave height. We assigned a score for each reserve based on the highest USGS score within the reserve boundaries.

- Air temperature rise is a main component of global climate change so we used an index of projected change in annual average atmospheric temperature by the 2050s. Data for this analysis are based on online, web-based projections from The Climate Wizard Tool (http://www.climatewizard.org/AboutUs.html).

Key Findings

The salient points that can be drawn from the synthesis of the five indices in this report predict that:

- All reserves will be impacted by climate change at some level, with all reserves having one or more indices rated as relatively High (or Very High).

- Social sensitivity is of particular concern along the West Coast and at isolated reserves in the Caribbean (Jobos Bay NERR, PR), Great Lakes (Lake Superior NERR, WI), and Gulf of Mexico (Mission-Aransas NERR, TX, and Apalachicola NERR, FL).

- Biophysical sensitivity is of highest relative concern at isolated reserves in the Southeast (ACE Basin NERR, SC, and Sapelo Island NERR, GA) and on the West Coast. The relevance of biophysical sensitivities at each reserve will also be determined by the natural resource management objectives of that reserve.

- Sea level rise will be a concern across all regions, with slightly less impact predicted for the Northeast than for other regions.

- Temperature change exposure will be a concern over most regions, with the largest effects in the Great Lakes, Northeast and Mid-Atlantic.

- The climate change indicators do not all co-vary. This means that reserves will have to consider different climate change stressors for their climate change vulnerability assessments and plan management strategies accordingly.

- Comparison of indicators reveals several reserves with notable climate change sensitivity. In relative terms, the Tijuana River NERR is the site that exhibits the highest risk to climate change impacts, when looking across all five indices. Waquoit Bay NERR is also at high risk.

- A better understanding of climate change vulnerability at the individual reserve level will require reserve-specific analyses.

Some salient points related to integrated approaches that were learned through this effort include:

- Defining an approach, strategy, or research effort as integrated at the onset helps to define expectations and roles, which leads to more coherent and collaborative integration.

- Integrated approaches need to include time for interdisciplinary learning. The language, methods, and concepts of disciplines are often different, and, as a result, integrated projects create learning opportunities and enhance perspective for all involved.

- Integration of data across disciplines can prove quite challenging; however, even when quantitative integration of data is not possible, qualitative integration can produce valuable results and important insights.

Recommendations

The work presented in this report is foundational. Like all research, it both improves understanding and highlights deficiencies. Important lessons were learned, which led to several recommendations for building upon this foundation:

- Combining climate change information across disciplines (e.g. social and biophysical) provided a much more holistic view than would have been offered by any one of these areas by itself. By design this project involved reserve staff whose expertise was critical in estimating the ecological resiliency of the reserves, helped focus attention on the management concerns of individual reserves and the implication of our climate change finding relative to those issues, and provided valuable input on the strengths and limitations of the water quality monitoring data. Future efforts to assess conditions across the NERRS should employ this multidisciplinary and collaborative analytical approach.

- This effort involved the compilation and processing of data in new ways and for purposes outside the original intent of the NERRS System-wide Monitoring Program (SWMP) sampling framework which was originally established to assess impacts from non-point source pollution and changing land use practices across the NERRS. The relationship of water quality variables to climate can be strengthened by the centralization and standardization of data related to SWMP stations (e.g. water depth, distance from shore, tidal amplitude and current velocity) as well as watershed characteristics (e.g. water volume, land-use dynamics, and average elevation).

- One unexpected limitation we encountered in analyzing the SWMP data was that we couldn't incorporate nutrient data into our analyses due to the variable coverage of that data set between reserves. We strongly recommend the continued, systematic collection of SWMP water quality data (both physical and nutrient), which will allow the inclusion of reserves and stations that had to be excluded from the biophysical sensitivity analysis and improve the characterization of those that were included. We think the Sentinel Site approach being adopted by the reserves is a good approach to strengthening the data set for assessing climate change impacts in the reserves.

- This synthesis has applicability to climate change planning and monitoring at both the NERR system and individual reserve levels. Opportunities to expand the analysis beyond the NERRS stations should be sought, since the process we employed for development of the social and biophysical indices, as well as the understanding of climate sensitivities in estuarine systems, could be applied to analyze other estuarine networks such as EPA's National Estuary Program.

- The focus of the research presented in this report was on long-term climate change impacts (e.g. over years). Profound impacts to reserve conditions also result from more short-term weather events, such as hurricanes and other severe storms. An analysis of extreme event sensitivity should be conducted to examine these types of impacts as well.

BACKGROUND AND CONTEXT FOR THIS STUDY

Background

The National Estuarine Research Reserve System (NERRS) consists of 28 reserves across the U.S. and Puerto Rico, which are managed as a partnership between NOAA and the coastal states for long-term research, ecosystem monitoring, education, and coastal stewardship (Figure 1-1). Reserves represent a diverse set of coastal ecosystems encompassing different biogeographic regions and estuarine types that are exposed to various gradients of anthropogenic and climate-related stressors. The NERRS was established in 1972 with the first reserve designated in 1974. Over 1.3 million acres of estuarine and coastal habitat is managed and protected by the Reserve System.

The severity of projected climate change impacts varies geographically around the U.S. (Karl et al. 2009), suggesting that some estuaries will be more vulnerable than others. Some estuaries will experience higher sea level rise impacts while other estuaries will experience wetter or dryer weather conditions that result from changing climatic conditions around the country. Unfortunately, there aren't many national data sets available to assess the impacts of climate change on estuaries. The vast majority of the information used to determine climate change patterns and impacts is focused on understanding temperature and weather patterns around the world and across the country using sophisticated global models to project impacts over hundreds of years. The Intergovernmental Panel on Climate Change (IPCC) has produced numerous reports over the past 20 years that document the physical scientific bases for climate change (IPCC 1990a, IPCC 2001a, IPCC 2007b). These reports also describe the potential impacts to human society (IPCC 1990b, IPCC 2001b, IPCC 2007c) and suggest possible mitigation strategies (IPCC 1990c, IPCC 2001c, IPCC 2007d). However, to date no comprehensive analysis has been conducted to systematically assess the climate sensitivity of U.S. estuaries.

National Estuarine Research Reserve System

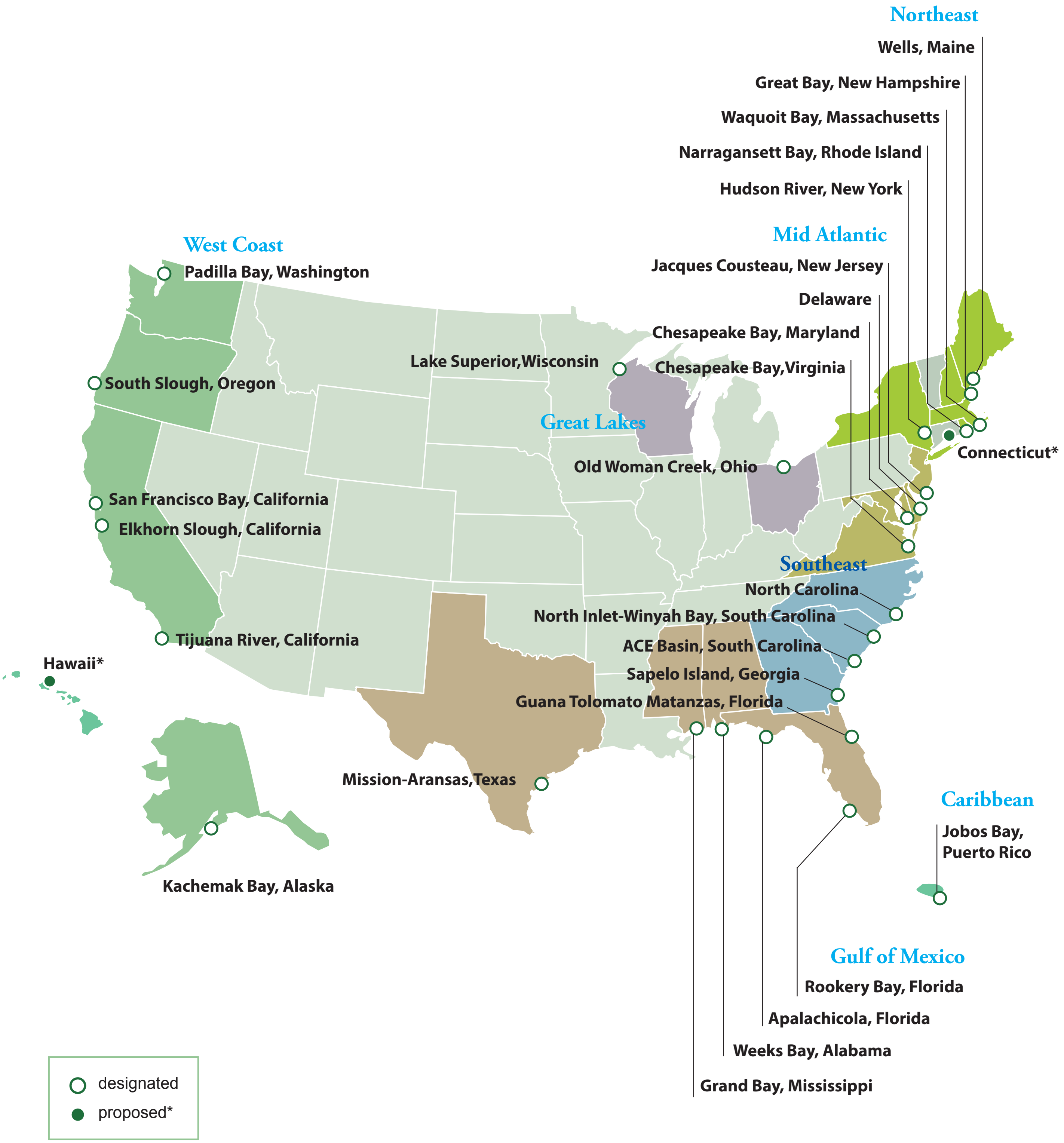

Figure 1-1. The National Estuarine Research Reserve System.

National Economic Role of Reserve Coastal Communities

Reserves protect ecosystems that support ocean-dependent industries (e.g., fisheries) and have a direct benefit to adjacent local economies (e.g., recreation, tourism). Reserve programs also provide important knowledge that can promote a sustainable ocean/Great Lakes-dependent economy. Since climate hazards will potentially impact both the reserves and the adjacent ocean/Great Lakes-dependent economies, it is important to understand the magnitude of the economic contribution the reserves and their surrounding communities contribute nationally. National Ocean Economics Program (NOEP, http://www.oceaneconomics.org/) data from 2009 estimates that ocean/Great Lakes-dependent industries contributed over $222 billion to our nation's economy and represented approximately 142,000 establishments with over 2,500,000 individuals employed. Ocean/Great Lakes-dependent industries also provided over $92 billion in wages.

Reserve-level analysis cannot provide a definitive measure of the reserve's contribution to the local ocean/Great Lakes-dependent economy, but it can help us understand the economic contributions of ocean/Great Lakes-dependent industries to the local economies at or near reserves. Reserves are a relevant part of this discussion because reserve stewardship, research, outreach, and education programs generate and share important knowledge that helps promote a sustainable ocean/Great Lakes-dependent economy. Additionally, by understanding those areas that are most dependent upon the ocean for economic goods and services, we can gain insights related to those reserves and associated coastal economies that might be most affected if climate hazards were to negatively impact ocean/Great Lakes-dependent industries.

Table 1-1 summarizes the economic impact of ocean/Great Lakes dependent industries associated with counties within or intersecting reserve boundaries. The economic data is summarized at the reserve level, meaning that the data for each reserve represents a summation of the data for the counties used in that reserve's analysis. The county summaries for each reserve can be found in Appendix A-1. The total 2009 economic impacts from ocean/Great Lakes economic sectors for the reserve counties analyzed include over 20,000 establishments, more than 370,000 employed individuals, over $21 billion in GDP, and over $10 billion in wages. The range for the analyzed economic variables across reserves is as follows:

Economic Impact Analysis

We used 2009 Economics: National Ocean Watch (ENOW) program county level data from the NOAA Coastal Services Center website (http://www.csc.noaa.gov/digitalcoast/data/enow) and data from National Ocean Economics Program (NOEP) for our analysis. The data is derived from U.S. Bureau of Labor Statistics and U.S. Bureau of Economic Analysis sources. The 2009 data represents the most recent information from ENOW and, to be consistent, 2009 data from NOEP was also used. Information related to six economic sectors that depend on the oceans and Great Lakes are included in the analysis. The economic sectors include: Living Resources, Marine Construction, Marine Transportation, Offshore Mineral Resources, Ship and Boat Building, and Tourism and Recreation. Summary data related to four economic indicators – establishments, employment, wages and gross domestic product (GDP) – were calculated for each reserve based upon its associated counties. Data for Puerto Rico was unavailable in the ENOW and NEOP data sets, so our economic analysis does not include the Jobos Bay Reserve.

- Ocean/Great Lakes Establishments as Percentage of Total County Establishments: 2.4% (Delaware) to 19.5% (Sapelo Island)
- Ocean/Great Lakes Employment as Percentage of Total County Employment: 3.0% (Delaware) to 19.7% (Narragansett Bay)
- Ocean/Great Lakes Wages as Percentage of Total County Wages: 1.2% (Delaware) to 36.8% (Grand Bay)
- Ocean/Great Lakes GDP as Percentage of Total County GDP: 0.7% (Delaware) to 25.9% (Kachemak Bay)

As can be seen from the above summary, there is wide variation across the NERR system regarding the percent contribution of ocean/Great Lakes-dependent industries to the local coastal economy. Despite this variation, it is clear that ocean/Great Lakes dependent industries are an important component of both the local and national coastal economies. As stated previously, ocean/Great Lakes-dependent industries contributed over $222 billion to our nation's economy in 2009. Based upon the summarized data, the counties representing the 28 reserves are responsible for approximately 9.6% of that total, which is substantial. This suggests that when examining the role that climate change will play on the NERRS, it is important to pay close attention to the potential for economic impacts. Furthermore, the programming conducted at reserves can contribute to a proactive and adaptive response to climate change that helps create a sustainable economic future for the associated coastal communities.

Table 1-1. Summary of economic impact of ocean/Great Lakes-dependent industries for counties within or intersecting reserve boundaries. The economic data for each reserve represents a summation of the data for the counties used in that reserve's analysis.

Table 1-1. Summary of economic impact of ocean/Great Lakes-dependent industries for counties within or intersecting reserve boundaries. The economic data for each reserve represents a summation of the data for the counties used in that reserve's analysis.

Reserve	Ocean/ Great Lakes Establishments	Percent of Total County Establishments	Ocean/ Great Lakes Employment	Percent of Total County Employment	Ocean/Great Lakes Wages	Percent of Total County Wages	Ocean/Great Lakes GDP	Percent of Total County GDP
Kachemak Bay, AK	362	19.3%	2,409	13.2%	$77,957,269	10.6%	$593,683,992	25.9%
Grand Bay, MS	328	13.2%	17,293	34.0%	$830,914,665	36.8%	$902,219,117	15.5%
Sapelo Island, GA a	46	19.5%	404	19.6%	$7,859,828	14.2%	$18,199,742	13.5%
Mission-Aransas, TX	1,113	10.6%	22,876	12.2%	$818,440,185	11.4%	$2,132,241,869	12.0%
Narragansett Bay, RI	462	13.9%	7,616	19.7%	$271,777,705	15.9%	$470,879,196	11.3%
Lake Superior, WI a	104	9.6%	1,871	12.4%	$57,506,392	11.7%	$124,214,715	10.9%
Waquoit Bay, MA	1,287	14.3%	14,240	16.1%	$327,404,451	9.5%	$645,783,616	9.2%
Apalachicola, FL	114	14.5%	1,003	14.7%	$19,312,735	9.2%	$46,252,950	8.8%
South Slough, OR	216	11.1%	2,636	12.3%	$57,937,146	8.9%	$118,633,944	7.1%
Chesapeake Bay, VA a	393	8.7%	8,237	13.6%	$151,517,694	7.6%	$311,904,115	6.5%
Old Woman Creek, OH	217	10.4%	5,200	14.8%	$74,870,851	6.4%	$165,549,137	6.2%
ACE Basin, SC	1,593	9.1%	32,492	12.0%	$662,990,920	6.6%	$1,458,386,895	5.9%
Guana Tolomato Matanzas, FL	518	6.6%	8,374	11.7%	$162,882,843	6.6%	$364,692,613	5.9%
Weeks Bay, AL	495	9.4%	7,305	12.4%	$119,931,561	6.6%	$244,153,300	5.8%
North Inlet-Winyah, SC	199	10.3%	3,147	13.7%	$50,006,065	6.7%	$102,862,037	5.6%
Rookery Bay, FL	616	5.2%	10,906	9.6%	$270,459,710	6.0%	$618,944,050	5.5%
Padilla Bay, WA	284	7.2%	3,836	8.4%	$101,969,761	6.0%	$224,723,698	5.4%
Wells, ME	568	9.1%	6,932	10.5%	$131,537,068	5.5%	$273,195,511	4.9%
Elkhorn Slough, CA	557	4.4%	12,523	7.6%	$326,369,530	4.9%	$742,263,551	4.6%
Chesapeake Bay, MD a	1,407	3.5%	35,038	5.2%	$1,604,837,301	5.0%	$3,159,299,714	4.2%
North Carolina	1,038	8.1%	16,180	10.7%	$258,926,455	4.8%	$520,537,316	3.6%
Tijuana River, CA	2,783	2.9%	73,635	5.9%	$2,425,363,797	3.9%	$4,951,318,615	3.3%
Great Bay, NH	1,223	6.2%	15,831	6.6%	$308,719,147	3.1%	$607,424,975	2.7%
San Francisco Bay, CA	892	4.1%	13,569	6.1%	$320,173,720	2.8%	$675,529,528	2.4%
Hudson River, NY	1,501	7.6%	15,380	6.3%	$291,706,797	2.6%	$561,669,150	2.2%
Jacques Cousteau, NJ	1,856	6.1%	23,295	4.9%	$496,957,732	2.4%	$902,984,606	1.9%
Delaware	513	2.4%	9,797	3.0%	$201,378,480	1.2%	$362,499,895	0.7%
Average for All Reserves	739	5.6%	13,287	7.6%	$372,489,636	4.8%	$760,715,995	4.0%
Total for All Reserves	**20,685**	-	**372,025**	-	**$10,429,7 09,808**	-	**$21,300,047,845**	-

[a] *Some data were not available due to privacy issues.*

NERRS' Unique Position

The NERRS is uniquely positioned to assess climate change impacts in the nation's estuaries. The Reserve System represents a diverse set of coastal ecosystems, and each reserve protects and manages the natural estuarine resources under its jurisdiction. Each reserve also makes important connections to the local communities and economies where it is located (Table 1-2). This is made possible by the collaborative nature of the federal–state partnership between the National Oceanic and Atmospheric Administration (NOAA) and state coastal agencies and universities involved in the program. Having managers and researchers locally situated at each of the reserve locations allows them to better understand the biophysical and socio-demographic conditions at each reserve and connect these to climate change impacts that are happening both locally and nationally. Additionally, the Reserve System forms a network of living laboratories around the country where long-term research and monitoring take place. However, climate change will impact not only natural resources, but also the local communities dependent upon the Nation's estuarine resources. Therefore, we also assess which socio-demographic factors can best be used to characterize the socio-economic sensitivity of the reserves and how these factors will potentially be impacted by climate change.

Table 1-2. Reserve regional affiliations and abbreviations that will be used throughout this report.

Region	Reserve Name	State	Abbreviation	Acreage	Year Established
Northeast	Wells	ME	WEL	2,250	1984
	Great Bay	NH	GRB	10,235	1989
	Narragansett Bay	RI	NAR	4,259	1980
	Waquoit Bay	MA	WAQ	2,780	1988
	Hudson River	NY	HUD	4,838	1982
Mid-Atlantic	Jacques Cousteau	NJ	JAC	114,873	1998
	Delaware	DE	DEL	4,930	1993
	Chesapeake Bay MD	MD	CBM	6,249	1985
	Chesapeake Bay VA	VA	CBV	3,072	1991
Southeast	North Carolina	NC	NOC	10,000	1985
	North Inlet-Winyah Bay	SC	NIW	18,916	1992
	ACE Basin	SC	ACE	99,308	1992
	Sapelo Island	GA	SAP	6,110	1976
	Guana Tolomato Matanzas	FL	GTM	73,352	1999
Caribbean	Jobos Bay	PR	JOB	2,883	1981
Gulf of Mexico	Rookery Bay	FL	RKB	110,000	1978
	Apalachicola Bay	FL	APA	246,000	1979
	Weeks Bay	AL	WKB	6,525	1986
	Grand Bay	MS	GNB	18,400	1999
	Mission-Aransas	TX	MIA	185,708	2006
West Coast	Tijuana River	CA	TIJ	2,531	1982
	Elkhorn Slough	CA	ELK	1,439	1979
	San Francisco Bay	CA	SFN	3,710	2003
	South Slough	OR	SOS	4,771	1974
	Padilla Bay	WA	PAD	11,460	1980
	Kachemak Bay	AK	KAB	366,100	1999
Great Lakes	Lake Superior	WI	LSP	16,697	2010
	Old Woman Creek	OH	OWC	573	1980

Conceptual Approach

The research reported here was undertaken to better understand climate change impacts in estuaries using a prototype, stepwise analysis approach. The first step in this process was to synthesize data and information about the socio-economic, physical, and ecological attributes of reserves with the NERRS. Using the best available data and information, physical, ecological and socio-demographic attributes that describe the ecological and socio-economic condition of reserves were identified in collaboration with reserve staff. This included a basic analysis of NERRS System-wide Monitoring Program (SWMP) data that are relevant and robust enough to be used to quantify climate stressors in the reserves. Initiated in 1995, the SWMP is an example of a national, reserve-wide program that measures water quality and weather parameters on a continuous basis using standardized protocols at all reserves around the country. This project draws upon the rich biophysical data collected by the SWMP program to assess how sensitive the SWMP monitoring data are at detecting climate change patterns in estuaries around the country.

Dominant climatic and non-climatic stressors that impact the reserves were also identified. Non-climatic stressors such as nutrient enrichment, sedimentation, and water diversions and climatic stressors such as sea level rise, precipitation frequency and intensity, and drought affect both ecological viability of habitat and services to the public. Identifying which of these stressors play an import factor in the NERRS provides additional contextual information for interpreting a reserve's sensitivity to climate stressors.

Social and biophysical attribute information from existing data sources were used to develop indicators of reserve-level sensitivity to climate change on a relative, system-wide basis. The measures of social and biophysical sensitivity were combined with measures of ecological resiliency and projected information on temperature change and sea level rise. The combined information was synthesized and provided the basis for an assessment of potential impacts to the Reserve System that may result from a changing climate.

THE NERRS' SOCIAL SENSITIVITY TO CLIMATE CHANGE

Introduction

A growing body of literature shows that human-induced climate change is occurring and its societal impacts are projected to expand. It is also well understood that the environmental consequences of climate change will interact with existing social stresses within communities and influence the level of realized societal impact (Karl et al. 2009; NOAA 2010).

Current climate change vulnerability assessments for coastal areas often take a singular, biophysical focus (e.g., NOAA 2010). However, to inform a more comprehensive understanding and assessment of vulnerability, our research includes an examination of the social sensitivity of the National Estuarine Research Reserve System (NERRS) and the U.S. coastal area in general. For the social sensitivity analysis, we have adapted the terminology from IPCC (2007a, d) and Glick et al. (2011): Social vulnerability to climate change is the degree to which a community is susceptible to, and unable to cope with, the adverse effects of climate change. It is a function of (1) the sensitivity of the community to climate change impacts, (2) its exposure to those changes, and (3) its adaptive capacity or resilience to the consequences.

Socioeconomic, demographic, and infrastructure data were analyzed to quantify the social sensitivity of reserves and all U.S. coastal counties to climate change. Coastal counties were included in the analysis to provide regional context to the social sensitivities identified at the reserve level.
A brief, annotated bibliography that summarizes some of the current literature related to social vulnerability and sensitivity can be found in Appendix 2.

Methods

Study Unit Definition and Database Construction

The NERRS represents an assemblage of unique geographies along oceanic and Great Lakes coastlines. The scale and composition of reserves range greatly from the 365,000-acre Kachemak Bay NERR in Alaska to the 573-acre Old Woman Creek NERR in Ohio. Some reserves represent one large contiguous area while others are composed of multiple, geographically separated components. In addition to the disparity in scale and geographic composition, each reserve's social context is defined by local conditions. For these reasons, finding a single, "one-size-fits-all" study unit for the social analyses was not considered appropriate. Meetings with all NERR sectors at the 2011 NERRS Annual Meeting confirmed that reserve staff also considered use of a single study unit across the system (e.g., counties, watersheds, reserve boundaries, etc.) problematic.

Because of these challenges and the local, place-based aspect of the NERRS, each reserve manager was asked to convene a staff meeting to discuss and define the appropriate reserve geography(ies) or unit(s) for the social sensitivity analyses; these units are referred to as "social geographies" for the purposes of this study. As guidance, the staff members were asked to define the geographic unit(s) that provides the most socially relevant context for the reserve. In other words, reserve staff defined the geography that best captures the social factors and communities most relevant to the reserve's programming and mission. Reserves were asked to reply with a description of the geographic unit(s), a map, and, if possible, geographic information system files for the boundary(ies).

Reserve staff defined more than one study unit for several reserves, resulting in the final data set including 44 study units. The sizes of the study units ranged from several census block groups (a single census block group covers an area containing from around 600 to 3000 people) to over ten counties. Six reserves used political boundaries (e.g., county, township, and/or municipality) for their definitions. For those reserves, and for all coastal counties[1], demographic and socio-economic data were compiled from the 2010 U.S. Census and the 2006-2010 American Community Survey (ACS) at the appropriate level. The remaining 22 reserves used watershed, other apolitical, or mixed boundaries for their study units. For those study units, 2010 U.S. Census and ACS data were collected for all block groups that had 50% or more of their area falling in the study unit as determined through GIS analysis. The census block group data were then aggregated for each unit.

Staff at the Tijuana River Reserve defined a study unit that included only modest land area in the United States with the remainder in Mexico. As delineated by reserve staff, 90% of the study unit land area is in Mexico. The portion in Mexico has almost all of its population concentrated in two cities, Tijuana and Tecate, and the remaining land area is very sparsely settled. Demographic and socio-economic data from the 2010 Census of Population and Housing of Mexico were collected for the Mexican portion of the Tijuana River NERR study unit. The most detailed data is available at the estado (state) or municipio (county equivalent) geographic levels. The variables and the geographic granularity of the data do not match the data from the 2010 U.S. Census and the 2006-2010 American Community Survey used for the other study units and reserves. However, the Mexican census does provide substantial data on basic demographic counts, socio-economic characteristics, and housing conditions. The most significant divergence from 2010 U.S. Census and American Community Survey data is that the Mexican census does not provide any data on income/poverty, tenure, or other financial characteristics of housing.

Coastal county-level analyses did not include Puerto Rico for two reasons: 1) uncertainty about the coastal county definition for Puerto Rico relative to the definition used in developing NOAA's List of Coastal Counties and 2) concerns that the relatively high proportion of Hispanic residents (in comparison to other U.S. coastal counties) may have the potential to confound statistical analyses.

Measuring Social Sensitivity to Climate Change

This study used a modified version of the Social Vulnerability Index (SoVI) to quantify social sensitivity to climate change (Cutter et al., 2003; University of South Carolina [USC], 2012). SoVI was initially developed

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[1] *As defined by NOAA's List of Coastal Counties for the Bureau of the Census, Statistical Abstract Series*

to capture social vulnerability to environmental hazards. It uses the aggregated individual characteristics of an area's population to assess the susceptibility of various communities to harm and their ability to respond. The social sensitivity captured by SoVI is applicable to any hazard imposed on the population and, therefore, is relevant to climate hazards. In addition to the conditions of a population, the characteristics of communities and the built environment contribute to place inequalities and the social sensitivity of places. Shepard et al. (2012) analyzed community vulnerability with an additional focus on the built environment, including measures of infrastructure.

Table 2-1. Variables used to quantify social sensitivity to climate change.

Name	Description	Reason	Social Sensitivity Concept	Increases (+) or Decreases (-) Social Sensitivity	Source(s)	Data Source
Asian	Percentage of the population who listed their race and ethnicity as non-Hispanic Asian	May be more vulnerable due to racial disparity-induced social, economic, and political marginalization	Race and ethnicity	+	Modified based on Cutter et al. (2003) and University of South Carolina [USC] (2012)	U.S. Census (2010)
African American	Percentage of the population who listed their race and ethnicity as non-Hispanic Black	May be more vulnerable due to racial disparity-induced social, economic, and political marginalization	Race and ethnicity	+	Modified based on Cutter et al. (2003) and USC (2012)	U.S. Census (2010)
Hispanic	Percentage of the population who listed their race or ethnicity as Hispanic or Latino	May be more vulnerable due to racial disparity-induced social, economic, and political marginalization	Race and ethnicity	+	Modified based on Cutter et al. (2003) and USC (2012)	U.S. Census (2010)
American Indian	Percentage of the population who listed their race and ethnicity as non-Hispanic American Indian	May be more vulnerable due to racial disparity-induced social, economic, and political marginalization	Race and ethnicity	+	Modified based on Cutter et al. (2003) and USC (2012)	U.S. Census (2010)
Age dependent population	Percentage of population 5 years of age or younger plus percentage of population 65 years of age or older	Dependents are usually socially and economically marginalized and may require additional assistance in emergency situations	Social dependence	+	Cutter et al. (2003), Shepard et al. (2012), and USC (2012)	U.S. Census (2010)
Public assistance	Percentage of households supported by public assistance	Vulnerable population that may require additional assistance related to a disaster	Social dependence	+	Shepard et al. (2012)	ACS (2006-2010)
Per capita income	Per capita income: total income divided by the size of the population	Wealthy communities have more assets that can be used to absorb and recover from hazards	Socioeconomic status	+	USC (2012)	ACS (2006-2010)

Name	Description	Reason	Social Sensitivity Concept	Increases (+) or Decreases (-) Social Sensitivity	Source(s)	Data Source
Less than high school educated	**Percentage of population over age 25 less than high school educated**	**Lower education level correlates with poverty and limited access to resources and infrastructure, thereby indicating higher potential need for assistance**	**Education**	+	**Shepard et al. (2012) and USC (2012)**	**ACS (2006-2010)**
Not working	Percentage of working-age population (age 16-64) who did not work in the past 12 months	May lower the community's preparedness and resilience thereby exacerbating potential losses	Employment	+	Modified based on Cutter et al. (2003) and USC (2012)	ACS (2006-2010)
Single parents	Percentage of households headed by a single parent	Single parents may be the sole provider of childcare and household income, thereby increasing potential vulnerability	Family structure	+	Modified based on Cutter et al. (2003), Shepard et al. (2012), and USC (2012)	U.S. Census (2010)
Female	Percentage of the population that are female	Women are more susceptible to sector-specific employment, lower wages, and family care responsibilities, thereby increasing potential vulnerability	Gender	+	Cutter et al. (2003) and USC (2012)	U.S. Census (2010)
Household occupant density	Number of persons per occupied household	Overcrowded living conditions may require additional infrastructure and assistance to react to both climate change impacts and disasters (e.g., flooding and sea level rise)	Social dependence	+	USC (2012)	U.S. Census (2010)
Housing density	Number of housing units per square mile	Captures the infrastructure at risk and reflects both permanent and seasonal residency	Residential infrastructure	+	Shepard et al. (2012)	U.S. Census (2010)
Renters	Percentage of occupied housing units designated as rental units	This measure reflects housing quality; renter occupied housing units are less likely to be insured and more likely to be compromised structures	Residential infrastructure	+	Shepard et al. (2012)	U.S. Census (2010)
Mobile homes	Percentage of households that live in mobile homes	This reflects housing quality; mobile homes can be more easily destroyed by hazards	Residential infrastructure	+	Cutter et al. (2003) and USC (2012)	ACS (2006-2010)

Name	Description	Reason	Social Sensitivity Concept	Increases (+) or Decreases (-) Social Sensitivity	Source(s)	Data Source
Recent movers	**Percentage of population residing in home less than 1 year**	**This population is more likely to be unfamiliar with the local environment and resources, thereby increasing potential vulnerability**	**Social dependence**	**+**	**Modified based on Shepard et al. (2012)**	**ACS(2006-2010)**
Median year home built	Median year home built	Newer housing units are usually less sensitive to damage from hazards	Residential infrastructure	-	Shepard et al. (2012)	ACS (2006-2010)
Median home value	Median value of owned homes	This is a proxy for assets and the quality of housing stock, which affect potential losses and recovery	Socioeconomic status	-	USC (2012)	ACS (2006-2010)
Extractive industries	Percentage of the civilian population (age 16+) employed in agriculture, forestry, fishing and hunting, and mining (i.e., extractive industries)	These industries are dependent on natural resources and may be severely impacted by climate change hazards	Employment	+	Cutter et al. (2003) and USC (2012)	ACS (2006-2010)
No vehicle	Percentage of households without a vehicle	Lack of a vehicle can limit mobility in a disaster scenario	Social dependence	+	Shepard et al. (2012) and USC (2012)	ACS (2006-2010)

Similar to the methodology for SoVI (Cutter et al., 2003), a principal component analysis (PCA) with varimax rotation was conducted for the 20 study variables to examine the underlying social factors that determine differences in social sensitivity to climate change for the analyzed geographies. Component selection was based upon examination of eigenvalues greater than 1 (Cutter et al., 2003; Kaiser, 1960). Resulting components were evaluated to determine what they broadly represent (e.g., wealth, housing characteristics, cultural barriers) and their overall influence on social sensitivity (i.e., whether they have a tendency to increase or decrease social sensitivity). Directional adjustments of components were made (i.e., positive, negative, or absolute) as necessary so that higher positive values were consistently interpreted as higher social sensitivity (Cutter et al., 2003). After all adjustments were made, an additive model was used to total the component scores and produce the composite social sensitivity to climate impacts index (SSCII). This analysis was conducted independently at both the reserve and coastal county levels. For reserves with more than one study unit, the SSCII scores for each unit were averaged to produce a single score for each reserve. The final SSCII scores for all reserve sites were divided into categories based upon standard deviation from the mean in order to identify the most and least sensitive geographies. SSCII is a relative measure and only compares reserves to other reserves included in the analysis.

A modified approach was developed to analyze social sensitivity for the Tijuana River Reserve Mexican portion of the study unit due to differences in available data for Mexico. Because of the disparity in data, the social sensitivity of the Mexican portion of the Tijuana River NERR was evaluated as a unique case in this research. The U.S. portion of the reserve study unit, however, was included in the SSCII analysis. For the Mexican portion, we compiled and analyzed data from the 2010 Census of Population and Housing of Mexico for the municipios of Tijuana and Tecate that were similar to U.S. Census data categories used in the SSCII. Selected variables were categorized according to the components generated in the U.S.-based analysis. Values on the selected variables were reported for three geographies that approximately correspond with the geographies analyzed in the U.S.-based reserves. Moving from crudest to finest scale, the geographies include the Tecate and Tijuana municipios, Tecate and Tijuana cities, and sub-municipio areas contained by the portion of the reserve. These data were to provide a picture of the potential social sensitivity to climate change for the Mexican portion of the Tijuana River reserve study unit.

Categorizing Social Sensitivity Characteristics

The SSCII value provides an indication of the relative social sensitivity of a place; however, two similarly high or low scores may be caused by different underlying drivers. To further examine the local drivers of social sensitivity to climate change, a hierarchical cluster analysis (HCA) was conducted for the reserve data set and for the coastal county data set. All 44 of the reserve study units were included in the HCA, meaning that there were multiple units analyzed for some reserves. We decided to use all of the reserve study units to enable a more detailed analysis of potential clustering within and among reserve geographies. In the analysis, reserve study units or coastal counties are treated as cases to be grouped based on their social sensitivity characteristics. The characterizing variables are the underlying components identified by the PCA analysis; they are more appropriate to use than the original variables because PCA reduces redundant information and correlation among variables. Ward's method was used for clustering, with squared Euclidean distance used to measure similarities between cases (Sharma, 1996).

The number of clusters used in a cluster analysis is a relatively subjective choice. The dendrogram of each data set was examined to identify a natural cut-off point on the relative scale of similarity, so that the resulting number of clusters was neither too large nor too small. An overly large number of clusters can blur the overall pattern by including too much detail, and an overly small number of clusters can filter out too much variation. We chose cut-off points that provided six clusters at both the reserve and county levels for our analysis. For each cluster, the means of the PCA-identified components for the clustered geographies were calculated and used to understand the demographic and/or socio-economic characteristics of the cluster's sensitivity. Components were considered a driver for a cluster when the mean for that component was greater than one.

Results and Discussion

Social Sensitivity to Climate Impacts for Reserves and Coastal Areas

Maps of the study unit(s) for each reserve can be found in Appendix 3, while original data for all of the study variables for each reserve can be found in Appendix 4. There were six principal components that described the reserves based upon their relative level of social sensitivity (Table 2-2) and seven principal components that described the coastal counties' relative level of social sensitivity (Table 2-3). Variable loadings for a principal component can range from 0 to 1. For this analysis, variables with a loading greater than 0.5 on a given principal component were considered a dominant variable for that component. The PCA identified some similar social dimensions at the reserve and county levels, but there were also some differences. Likewise, their ranking in terms of explained variability also reveals some similarities and differences.

Wealth and cultural barriers and natural resource dependence are identified in both the reserve-level and county-level PCAs and are ranked similarly. Variables related to labor and length of residency can also be found in both analyses but with slightly different rankings. Interestingly, housing characteristics and tenancy explained the most variation for reserves while housing characteristics was ranked much lower and explained less variability for coastal counties. For reserves, the variable related to percentage of the population that is female loaded onto the same component as not working, Hispanic, less than high school educated, extractive industries, and per capita income, while for coastal counties it loaded onto its own component. Public assistance loaded with housing-related variables and vehicle ownership for reserves, while in coastal counties it loaded with other variables related to socially dependent groups.

A summary of the data for the Mexican portion of the Tijuana River Reserve is shown in Table 2-4. As mentioned earlier, data disparities require that the Mexican portion of the Tijuana River NERR study unit be evaluated as a unique case in this research.

Table 2-2. Reserve social sensitivity components

Component	Name	Cardinality[a]	Percent Variation Explained	Dominant Variables	Component Loading
1	Housing characteristics and tenancy	+	20.0	Median year home built No vehicle Public assistance Renters Single parents Housing density	-0.898 0.882 0.747 0.729 0.596 0.589
2	Labor characteristics and status	+	19.8	Not working Hispanic Lacking high school education Female Extractive industries Per capita income	0.852 0.850 0.836 -0.646 0.622 -0.519
3	Wealth	-	14.4	Median home value Mobile homes Housing density Per capita income	0.886 -0.633 0.613 0.580
4	Household composition	+	12.6	Household occupant density Age dependent population Asian	0.813 -0.740 0.681
5	Cultural barriers & natural resource dependence	-	9.1	American Indian African American Extractive industries	0.858 0.598 -0.526
6	Recent movers	+	7.4	Recent movers	0.866

[a] Cardinality refers to whether the component has a net positive or negative effect on the SSCII.

Table 2-3. Coastal county social sensitivity components

Component	Name	Cardinality[a]	Percent Variation Explained	Dominant Variables	Component Loading
1	Labor market barriers and employment	+	15.5	African American Not working Lacking high school education Mobile homes Per capita income	0.777 0.776 0.711 0.708 -0.531
2	Socially dependent groups	+	13.9	American Indian Public assistance No vehicle Single parent	0.882 0.847 0.783 0.516
3	Wealth	-	13.6	Median home value Per capita income Asian Housing density	0.843 0.708 0.677 0.637
4	New residents and renters	+	10.8	Recent movers Age dependent population Renters	0.843 -0.679 0.621
5	Cultural barriers and natural resource dependence	+	9.9	Hispanic Household occupant density Extractive industry Lacking high school education	0.899 0.616 0.536 0.548
6	Housing characteristics	+	8.9	Median year home built Household occupant density	-0.805 -0.521
7	Female	+	7.4	Female	0.802

[a] Cardinality refers to whether the component has a net positive or negative effect on the SSCII.

Table 2-4. Tijuana River Reserve social sensitivity components

Component	Name	Variables	Municipios	Rate/Percent Cities	Sub-municipio Area †
1	Housing characteristics and tenancy	No vehicle Public assistance Housing density (per sq mi)	63.4 44.9 384	64.3 43.2 4,572	63.6 44.2 2,101
2	Labor characteristics and status	Not working (population age 12 and over who are unemployed) Lacking high school education Female	5.3 39.0 49.6	5.3 40.3 49.8	5.3 39.5 49.7
3	Wealth	Housing units with a dirt floor Housing units without electric lights Housing units without running water Housing density (per sq mi)	2.9 0.6 3.1 384	2.9 0.5 2.1 4,572	3.0 0.5 2.6 2,101
4	Household composition	Household occupant density Age dependency Population under age 15 Population age 65+	3.65 29.2 3.9	3.66 28.1 4.3	3.64 28.8 4.0
5	Cultural barriers and natural resource dependence	No equivalent	-	-	-
6	Recent movers	Recent movers (population age 5 and older who lived in a different "entidad federative" (state) in 2005)	6.1	5.5	5.8

† Sub-municipio area contained by the Mexico portion of the reserve social geography.

Table 2-5 provides the component scores and SSCII values by reserve. All scores in this table are relative, meaning they show the relative high or low of an analytical unit (i.e., reserve site or coastal county) on a social dimension in comparison to the other analytical units. More simply, the scores can be interpreted as distances to the mean of all the analytical units on a social dimension, where a positive value of an analytical unit means it is higher than the average level of all analytical units on that social dimension and a negative value means it is lower. The magnitude of the score shows how far away from the average level an analytical unit is, relative to its sign, on the social dimension.

Figures 2-1 and 2-2 show the relative SSCII ratings at the reserve and coastal county levels. A map of the SSCII rating results for a separate analysis of each of the reserve study units can be found in Appendix 5. When interpreting the results of the SSCII analyses, it is important to keep in mind that a reserve analysis evaluates reserve social sensitivity relative to other reserves, and a coastal county analysis evaluates coastal county social sensitivity relative to other coastal counties. Because the analyses are relative, the resulting reserve and coastal county SSCII scales are not directly comparable. Regional patterns in social sensitivity and associated sensitivity drivers at the reserve and coastal county scales, however, can offer insights into the spatial distribution of sensitivity and associated drivers at the different scales.

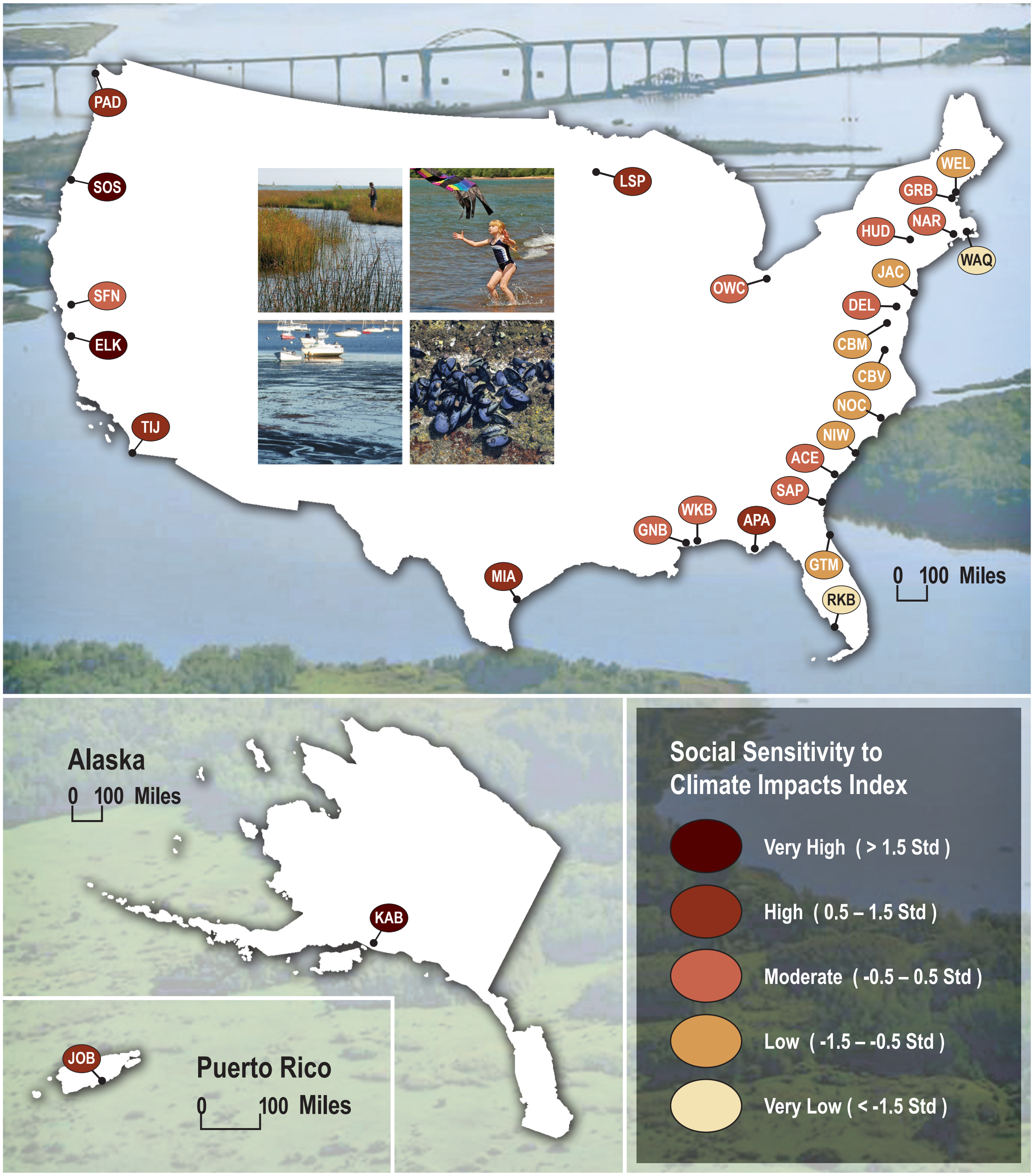
Figures 2-3 and 2-4 show the results of the cluster analysis at both the reserve and county levels.

Table 2-5. Component scores and SSCII values by reserve

Reserves	Region	Housing characteristics and tenancy score	Labor characteristics and status score	Wealth score	Household composition score	Cultural barriers and natural resource dependence score	Recent movers score	SSCII[a]
Kachemak Bay	West Coast	0.28	-0.49	0.24	-0.25	4.00	0.92	4.69
Elkhorn Slough	West Coast	-0.43	2.30	-1.20	2.56	1.50	-0.66	4.08
South Slough	West Coast	0.27	-0.09	0.42	-0.63	2.28	1.75	4.00
Tijuana River	West Coast	0.67	1.36	-1.16	2.42	-0.33	0.37	3.33
Jobos Bay	Caribbean	0.88	4.05	0.81	-0.86	-0.25	-1.70	2.93
Lake Superior	Great Lakes	0.94	-0.59	0.88	-0.55	2.28	-0.63	2.35
Mission-Aransas	Gulf of Mexico	-0.51	1.96	0.63	-0.54	0.28	0.23	2.04
Apalachicola	Gulf of Mexico	-0.84	1.80	1.23	-1.28	0.12	0.95	1.99
Padilla Bay	West Coast	-0.34	-0.35	0.00	0.41	1.54	0.43	1.68
ACE Basin	Southeast	-0.65	-0.24	1.78	0.13	-1.02	1.55	1.55
Hudson River	Northeast	2.32	-0.23	-0.42	0.00	-0.63	0.05	1.09
Grand Bay	Gulf of Mexico	-0.61	0.18	1.39	0.41	-0.28	0.00	1.09
San Francisco	West Coast	-0.19	0.08	-1.82	1.45	-0.12	1.37	0.77
Sapelo Island	Southeast	-0.40	-0.37	1.32	0.45	-1.14	0.77	0.63
Old Woman Creek	Great Lakes	1.05	-0.67	0.87	-0.04	-0.41	-0.64	0.17
Narragansett Bay	Northeast	1.12	-0.44	-0.18	0.24	-0.02	-0.62	0.10
Weeks Bay	Gulf of Mexico	-0.98	-0.13	0.61	-0.25	-0.06	0.64	-0.17
Delaware	Mid-Atlantic	-0.12	-0.52	0.57	0.52	-0.55	-0.10	-0.21
Great Bay	Northeast	-0.03	-0.76	0.26	0.28	0.42	-0.52	-0.35
North Inlet-Winyah	Southeast	-0.61	-0.13	1.09	-0.38	-0.92	0.37	-0.58
Chesapeake Bay MD	Mid-Atlantic	-0.33	-0.76	0.41	1.00	-0.71	-0.39	-0.77
Chesapeake Bay VA	Mid-Atlantic	-0.66	-0.31	0.74	0.44	-0.14	-0.96	-0.89
Wells	Northeast	0.16	-0.77	0.20	-0.07	0.43	-0.84	-0.91
Jacques Cousteau	Mid-Atlantic	-0.26	-0.12	-0.02	0.05	-0.15	-1.19	-1.70
Guana Tolomato Matanzas	Gulf of Mexico	-0.76	-0.26	-0.46	-0.45	-0.34	0.52	-1.73
North Carolina	Southeast	-0.36	-0.66	-0.20	-0.52	0.08	-0.19	-1.85
Waquoit Bay	Northeast	0.00	-0.67	-0.48	-0.61	0.32	-1.33	-2.76
Rookery Bay	Gulf of Mexico	-0.76	0.78	-1.43	-1.32	-0.52	0.25	-3.00

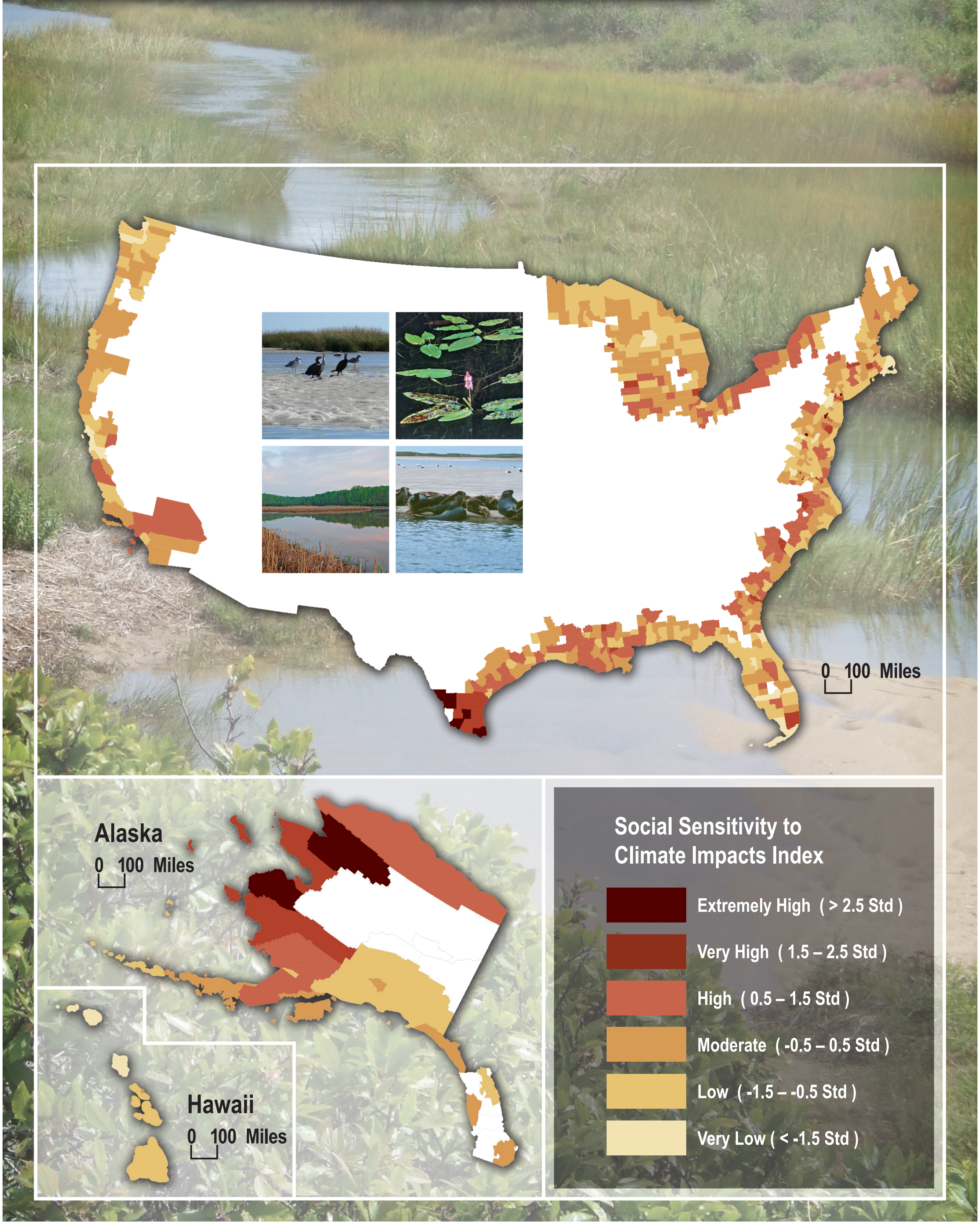
[a] *Summation differences are due to rounding.*

Figure 2-1. Social sensitivity to climate impacts for Reserves. *(See Table 1-2 for reserve abbreviations.)*



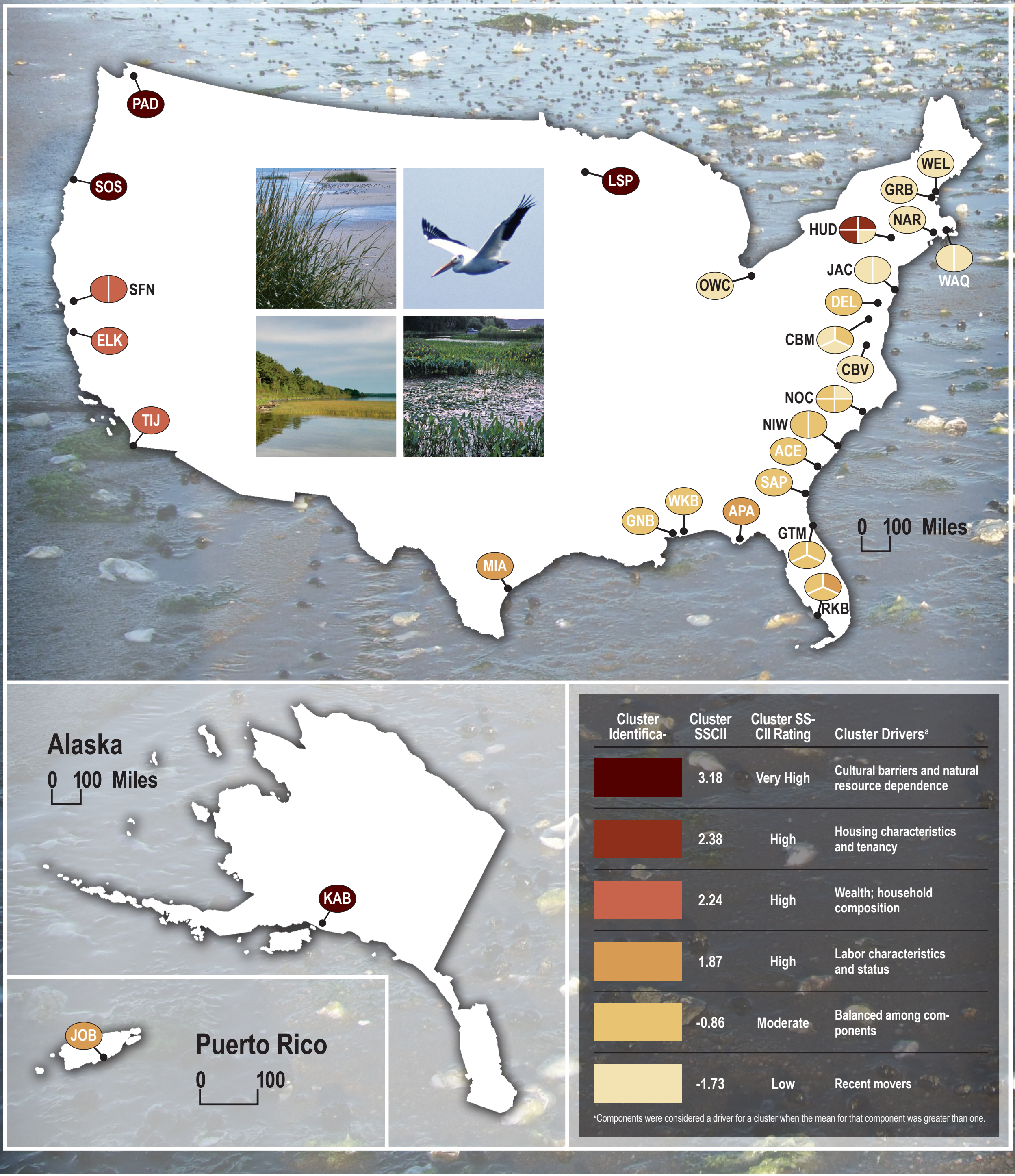
Background photo: LSNERR; small photos clockwise from upper left: Jeffrey J. Strobel, Frank Koshere, Jeffrey J. Strobel (two photos)

Figure 2-2. Social sensitivity to climate impacts index for coastal counties.



Background photo: Jeffrey J. Strobel; small photos clockwise from upper left: Jeffrey J. Strobel (3 photos), Mike Anderson

Figure 2-3. Cluster analysis for Reserve study unit social sensitivity to climate impact.
(See Table 1-2 for reserve abbreviations.)

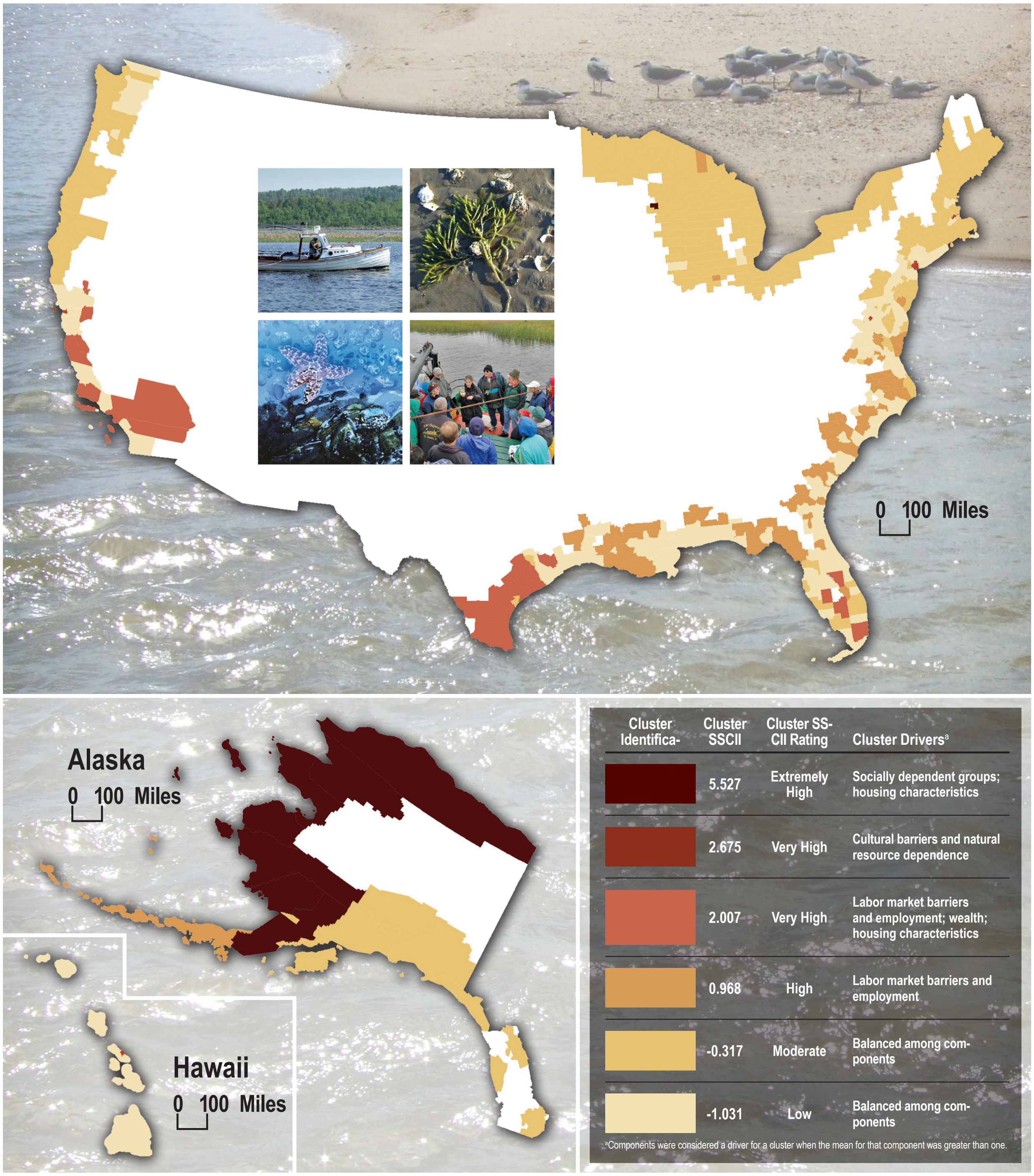


Cluster Identifica-	Cluster SSCII	Cluster SS-CII Rating	Cluster Drivers[a]
🟫	3.18	Very High	Cultural barriers and natural resource dependence
🟥	2.38	High	Housing characteristics and tenancy
🟥	2.24	High	Wealth; household composition
🟧	1.87	High	Labor characteristics and status
🟨	-0.86	Moderate	Balanced among components
⬜	-1.73	Low	Recent movers

[a]Components were considered a driver for a cluster when the mean for that component was greater than one.

Background photo: Jeffrey J. Strobel; small photos clockwise from upper left: Jeffrey J. Strobel (three photos), Amy Elliot

Figure 2-4. Cluster analysis for coastal county social sensitivity to climate impacts



Cluster Identifica-	Cluster SSCII	Cluster SSCII Rating	Cluster Drivers[a]
🟫	5.527	Extremely High	Socially dependent groups; housing characteristics
🟥	2.675	Very High	Cultural barriers and natural resource dependence
🟥	2.007	Very High	Labor market barriers and employment; wealth; housing characteristics
🟧	0.968	High	Labor market barriers and employment
🟨	-0.317	Moderate	Balanced among components
🟨	-1.031	Low	Balanced among components

[a]Components were considered a driver for a cluster when the mean for that component was greater than one.

Background photo: Jeffrey J. Strobel; small photos clockwise from upper left: LSNERR, Jeffrey J. Strobel, LSNERR, Jeffrey J. Strobel

Figure 2-1 shows that the reserves with the lowest social sensitivity indices are primarily located along the eastern coast of the U.S., while the three reserves with the highest index ratings are all located on the western coast of the U.S. The cluster analysis results also reveal regional clustering patterns for reserves based upon the social sensitivity variables (Figure 2-3). In fact, these regional drivers of clustering among social geographies often displayed regional patterns that were even stronger than those suggested by the summary of reserve-level sensitivity scores. The East Coast reserve social geographies principally cluster into two groups that are characterized as having low to moderate social sensitivity. The low social sensitivity cluster was most influenced by the recent movers component while the moderate social sensitivity cluster had a relatively balanced influence from all six principal components. The one exception along the East Coast was the Hudson River Reserve. Three of the four social geographies for the Hudson River Reserve grouped into a high social sensitivity cluster that was driven by the housing characteristics and tenancy component. The reasons for this will be explored in greater detail in the regional breakdowns in the following sections. Two additional high sensitivity clusters and a very high sensitivity cluster were also identified. The very high sensitivity cluster was driven by the cultural barriers and natural resource dependence component and included the Padilla Bay, South Slough, Kachemak Bay, and Lake Superior reserves.

Overall, the coastal county analysis reveals a more spatially heterogeneous distribution of low and high sensitivity indices (Figure 2-2). One exception is the pocket of "extremely high" and "very high" social sensitivity indices in portions of Texas and Alaska, although there are no reserves located in the counties that received these ratings. The cluster analysis revealed that the low sensitivity counties are clustering based upon a balanced influence from all seven principal components (Figure 2-4). The coastal counties with the highest sensitivity are clusters 1, 2, and 3, which, respectively, are primarily driven by socially dependent groups and housing characteristics; cultural barriers and natural resource dependence; and labor market barriers and employment, wealth (which had a negative influence on social sensitivity for this cluster), and housing characteristics.

Regional Comparisons

The following sections provide an analysis and discussion of the results of the social sensitivity analyses on an NERRS regional basis. It is important to keep in mind, however, that reserve-level analyses are only specific to the study units designated by the reserves (see Appendix 3 for maps of the study units) and should not be considered representative of areas outside of those units.

Northeast Region

Reserves in the NERR Northeast region are characterized by one reserve with very low relative social sensitivity (Waquoit Bay), one reserve with low social sensitivity (Wells), and three reserves with moderate social sensitivity (Great Bay, Narragansett Bay, and Hudson River; Figure 2-1). An examination of the distribution of component scores by reserve (Table 2-5) provides insights into the driving forces behind these observed trends. For example, Narragansett Bay and Hudson River Reserve are the reserves in this region with the highest SSCII values. As can be seen in Table 2-5, these reserves both scored highest on the housing characteristics and tenancy component for this region. A look at the underlying data (Appendix B-3) reveals that the study units for these two reserves have some of the oldest homes in the entire Reserve System, and older structures tend to be more sensitive to hazards. On the other end of the spectrum, Waquoit and Wells Bay had the lowest SSCII values for the region and had the lowest scores for the recent movers component. This suggests that the social geographies defined for both reserves have longer-term residents, relatively speaking, which lowers their social sensitivity to potential climate hazards.

The majority of the reserve social geographies in this region cluster together into a group characterized as having low social sensitivity that is primarily influenced by the recent movers component (Figure 2-3). This indicates that, on a regional basis, the reserves in the northeast have longer-term residents and less sensitivity associated with new residents being unfamiliar with their surrounding environment and resources. The one exception was the Hudson River Reserve. Three of the four social geographies for the Hudson River Reserve grouped into their own high social sensitivity cluster that was driven by the housing characteristics and tenancy component. A closer look at the data in Appendix 4 reveals that these social geographies had the following characteristics that increased their sensitivity relative to other reserve social geographies:

- Relatively old homes and older structures, which tend to be more sensitive to hazards.
- A relatively high percentage of individuals without a vehicle, which can limit mobility and the ability to respond to hazards.
- A relatively high percentage of the population receiving public assistance, suggesting an elevated vulnerability among the populace.
- Relatively high housing unit densities, which puts more infrastructure at risk.
- A relatively high percentage of rental units, which are less likely to be insured and more likely to be compromised by hazards.

The low-sensitivity reserve social geographies from this region also cluster with social geographies from three of the four reserves in the Mid-Atlantic region (Jacques Cousteau, Chesapeake Bay MD, and Chesapeake Bay VA), one social geography from the Southeast region (North Carolina), and with the Old Woman Creek Reserve in the Great Lakes region.

The Northeast region reserves are surrounded mostly by coastal counties with social sensitivity levels that are relatively similar to the reserves' sensitivity levels (Figure 2-2). The moderate sensitivity reserves are surrounded primarily by coastal counties with low to moderate sensitivity, and the very low sensitivity Waquoit Reserve is surrounded mostly by counties with ratings of very low and low sensitivities. The Hudson River NERR is surrounded by counties with a diverse mix of sensitivities ranging from low to extremely high. Coastal counties surrounding the reserves primarily cluster into a moderate sensitivity cluster with a balanced influence from all social sensitivity principal components (Figure 2-4).

Mid-Atlantic Region

The Mid-Atlantic reserves have low (Jacques Cousteau, Chesapeake Bay VA, and Chesapeake Bay MD) to moderate (Delaware) social sensitivity (Figure 2-1). Overall, the reserves demonstrated a relatively balanced influence from the principal component variables; however, the Jacques Cousteau Reserve did have a relatively large negative score associated with the recent movers component, which decreased the social sensitivity for the reserve.

Most of the reserve social geographies in this region cluster into a low sensitivity cluster that is primarily influenced by the recent movers component (Figure 2-3). The Delaware Reserve social geography and one of the Chesapeake Bay MD social geographies cluster into a moderate sensitivity cluster that has a relatively balanced contribution from all social sensitivity components. Reserve social geographies in the low social sensitivity cluster also group with reserve social geographies from the Northeast, Southeast, and Great Lakes regions. The reserve social geographies in the moderate social sensitivity cluster also group with reserve social geographies in the Southeast and Gulf of Mexico regions.

Coastal counties in this region have social sensitivities ranging from very low to extremely high, with no clearly discernible patterns (Figure 2-2). The counties primarily group into three clusters: a low sensitivity cluster, a moderate sensitivity cluster, and a high sensitivity cluster (Figure 2-4). The fact that the clusters range from low to high sensitivity is not surprising given the wide range in individual coastal county sensitivities.

Southeast Region

The reserves in this region had low (North Carolina, North Inlet-Winyah Bay, and Guana-Tolomato-Matanzas) to moderate social sensitivity (ACE Basin and Sapelo Island; Figure 2-1). ACE Basin and Sapelo Island had the strongest influence coming from the wealth score due to relatively low per capita incomes and median home values.

All but one of the reserve social geographies in this region clustered into a moderate sensitivity grouping that had a balanced influence from all of the principal components (Figure 2-3). The social geographies in this grouping also clustered with social geographies in the Mid-Atlantic and Gulf of Mexico regions. A single social geography from the North Carolina Reserve grouped with the low sensitivity cluster already discussed in the preceding sections.

In this area, coastal counties with ocean shoreline tended to have low to moderate social sensitivity while counties without shoreline tended to have high to very high social sensitivity (Figure 2-2). It's important to note that the social sensitivity index does not incorporate sea level rise exposure directly into the index. Sea level rise will be treated separately later in this report. The coastal counties in this region primarily grouped into a low sensitivity cluster or a high sensitivity cluster (Figure 2-4). The low sensitivity cluster had a balanced influence from all principal components while the high sensitivity cluster was driven by the labor market and employment barriers component. Counties with ocean shoreline were more frequently included in the low sensitivity cluster. The findings indicate that those counties that are not bordering the ocean have a higher sensitivity rating due to fewer individuals working, which may lower community preparedness and resilience. In addition, these same counties tended to have fewer high school-educated individuals. Lower education levels can create a higher need for assistance due to an associated increased incidence of poverty and limited access to resources.

Gulf of Mexico Region

The Gulf of Mexico region had the highest variability in reserve social sensitivities with the following SSCII ranges present (Figure 2-1):

- High – Mission-Aransas and Apalachicola
- Moderate – Grand Bay and Weeks Bay
- Very Low – Rookery Bay

Reserve social sensitivity did generally tend to increase from east to west in this region. Labor characteristics and status provided the greatest contribution to increased social sensitivity for the Mission-Aransas and

Apalachicola Reserves. A review of the data in Appendix 4 reveals that the study units for both reserves had the following characteristics on a relative basis:

- High unemployment
- High percentage of the population less than high school educated
- High employment in natural resource-dependent extractive industries
- Low per capita income

Social geographies from Rookery Bay (i.e., two of the three social geographies for this reserve), Weeks Bay, and Grand Bay were in a moderate sensitivity cluster that had a balanced principal component influence (Figure 2-3). Reserve social geographies from the Southeast and Mid-Atlantic regions also grouped with this cluster. The Mission-Aransas and Apalachicola social geographies grouped with one of the Rookery Bay social geographies in a high sensitivity cluster that was driven by the labor characteristics and status component. The only reserve outside of this region that was also in this cluster was Jobos Bay from the Caribbean region.

As with the reserves, the general spatial trend in sensitivity for coastal counties in this region increased from east to west. Coastal counties clustered into four groupings in this region that represented clusters of low, moderate, high, and very high sensitivity. Interestingly, several coastal counties in Texas and Florida grouped together into a very high sensitivity cluster despite the overall general east-west trend in increasing sensitivity. This high sensitivity cluster was driven by the cultural barriers and natural resource dependence component, meaning that those counties had the combined influence of a relatively high percentage of the population that is Hispanic (which can create vulnerability related to racial disparity-induced social, economic, and political marginalization), employed in natural resource-dependent extractive industries, less than high school educated, and living in a household with a high number of occupants.

West Coast Region

Reserves in this region had moderate (San Francisco Bay), high (Tijuana River[2] and Padilla Bay), or very high (South Slough, Elkhorn Slough, and Kachemak Bay) social sensitivity values (Figure 2-1). When looking across the entire NERRS, reserves from the West Coast region had the four highest SSCII values (Table 2-5). Reasons for this relatively high sensitivity are listed below for reserves with high or very high sensitivity values.

Kachemak Bay

- High percentage of the population that is American Indian
- High employment in natural resource-dependent extractive industries
- High percentage of population that has been in their home for less than one year
- High percentage of the population receiving public assistance

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[2] This part of the analysis only includes the U.S. portion of the Tijuana River NERR study unit, which represents only 10% of the total study unit. Ninety percent of the study unit is located in Mexico. The social sensitivity of the Mexican portion is evaluated using a separate analysis.

Padilla Bay

- High percentage of the population that is American Indian

South Slough

- High percentage of the population that is American Indian
- High employment in natural resource-dependent extractive industries
- High percentage of the population receiving public assistance
- Low per capita income
- High percentage of the population living in mobile homes
- High percentage of population that has been in their home for less than one year

Elkhorn Slough

- High percentage of the population that is Hispanic
- Low per capita income
- High percentage of the population less than high school educated
- High percentage of households run by a single parent
- High number of persons per occupied household
- High percentage of rental units
- High employment in natural resource-dependent extractive industries

Tijuana River

- High percentage of the population that is Hispanic
- High percentage of the population that is Asian
- High percentage of the population receiving public assistance
- Low per capita income
- High unemployment
- High percentage of the population less than high school educated
- High percentage of households run by a single parent
- High number of persons per occupied household
- High percentage of rental units

An analysis of the Tijuana River Reserve Mexican portion of the study unit relative to comparable socio-demographic variables for the other reserves (Appendix 4) reveals patterns that suggest that the

Mexican portion of the study unit has an extremely high social sensitivity level. A comparison of values for some of the variables is shown below to demonstrate the types of differences that support this conclusion.

Percentage of population with no vehicle
Average for Mexican portion of Tijuana Reserve – 63.8%
Average for U.S. reserves – 7.3%

Percentage of population receiving public assistance
Average for Mexican portion of Tijuana Reserve – 44.1%
Average for U.S. reserves – 2.5%

Percentage of population less than high school educated
Average for Mexican portion of Tijuana Reserve – 39.6%
Average for U.S. reserves – 14.6%

The reserve social geographies in this region cluster in the following manner (Figure 2-3):

- San Francisco Bay, Elkhorn Slough, and Tijuana River: High sensitivity cluster primarily driven by wealth (characterized in this instance by lack of wealth) and household composition components; there were no reserve social geographies from any other region included in this cluster.

- Padilla Bay, South Slough, and Kachemak Bay: Very high sensitivity cluster primarily driven by the cultural barriers and natural resource dependence component; the Lake Superior Reserve from the Great Lakes region is also in this cluster.

Clusters of social geographies in this region did not closely follow reserve-level sensitivity patterns, suggesting that patterns in the principal component scores and relative influence of principal components varied for reserves despite similarities in overall sensitivity ratings. As an example, Elkhorn Slough and Tijuana Reserve had different reserve-level sensitivity ratings but similar drivers of sensitivity (e.g., high percentage of the population that is Hispanic), so they clustered together.

Coastal counties in this region (with the exception of Alaska) ranged from lower sensitivities in the north to higher sensitivities in the south. In this region, reserve-level sensitivity was sometimes higher than might be expected when looking at coastal county sensitivities, especially in the northern portions of the West Coast. The potential for variation in sensitivity levels observed at local levels versus countywide levels could be responsible for this finding.

The coastal counties in Alaska represented some of the highest sensitivity levels, with several counties along the shoreline rated as having high, very high, or extremely high sensitivity. These Alaskan coastal counties were so unique that they formed their own cluster with extremely high sensitivity that was driven by the socially dependent groups and housing characteristics components. The counties with extremely high sensitivity were characterized by a relatively high percentage of the population being American Indian (and potentially vulnerable due to racial disparities and marginalization), receiving public assistance, lacking a vehicle, living in a household headed by a single parent, and living in a household with a high number of occupants. Other counties in this region grouped into five other clusters with low, moderate, high, or very high sensitivity. The northern contiguous U.S. West Coast counties grouped with low to moderate sensitivity clusters, while the southern contiguous U.S. West Coast counties grouped with either low or very high sensitivity clusters. This region was the only region with all six coastal county clusters represented, although the inclusion of Alaska in this region was a driving force for the observed diversity.

Great Lakes Region

This region only includes two reserves, the Lake Superior and the Old Woman Creek reserves. The Lake Superior Reserve had high social sensitivity and the Old Woman Creek Reserve had moderate social sensitivity. The Lake Superior Reserve's high social sensitivity was influenced by a relatively high percentage of the population being American Indian, a high percentage of households receiving public assistance, and low median home value. Old Woman Creek had relatively old homes and low median home values.

The Lake Superior Reserve social geography clustered with social geographies of several West Coast reserves in a very high sensitivity cluster primarily driven by the cultural barriers and natural resource dependence component. This clustering is primarily a reflection of the relatively high percentage of American Indians present in the social geographies for all of the reserves in this grouping. The Old Woman Creek social geography clustered with social geographies from East Coast reserves in the Northeast and Mid-Atlantic regions in a low sensitivity cluster primarily influenced by the recent movers principal component.

Social sensitivities of coastal counties in this region tended to increase from "low to moderate sensitivity" to "moderate to high sensitivity" in an easterly direction. Despite this gradient, most coastal counties in this region grouped into the same moderate sensitivity cluster represented by a balanced influence from all principal components.

Caribbean

The only reserve in the Caribbean region is Jobos Bay in Puerto Rico. The Jobos Bay Reserve had a high social sensitivity due to the following relative characteristics:

- High percentage of the population that is Hispanic (99.38%)
- High percentage of the population receiving public assistance
- Low per capita income
- High percentage of the population less than high school educated
- High unemployment
- High percentage of households run by a single parent
- High employment in natural resource-dependent extractive industries
- High percentage of individuals without a vehicle
- Low median home value

The Jobos Bay Reserve social geography clustered with reserve social geographies in the Gulf of Mexico region. This cluster had high social sensitivity and was primarily driven by the labor characteristics and status principal component.

As stated earlier, coastal county analyses were not conducted for Puerto Rico because of uncertainty about how Puerto Rico defines coastal counties, and concerns related to the relatively high proportion of Hispanic residents, given the necessary comparison to other U.S. coastal counties. These factors would potentially confound statistical analyses.

Conclusions

The reserve social sensitivity analysis revealed some spatial patterns in sensitivity within the national system, which characterized regional-level differences. Reserves on the eastern coast of the U.S. were generally found to have lower sensitivity indices than those in the Gulf of Mexico or on the West Coast. The analysis indicated that these patterns are the result of influence from socio-demographic and built environment variables related to cultural barriers and natural resource dependence, labor characteristics, and income levels. More specifically, reserves with higher sensitivity often exhibited one or more of the following characteristics within their study unit area(s):

- Greater employment within natural resource-dependent extractive industries
- Lower per capita income levels and median home values
- Higher percentage of Hispanic and/or American Indian residents
- Higher percentage of the population less than high school educated

The coastal county SSCII values reveal spatial heterogeneity in social sensitivity at the individual coastal county level; meaning that counties with low, moderate, and high sensitivity can commonly be found located near each other. When looking at the cluster analysis of the coastal counties, however, patterns based upon the principal components become clearer. Some of those patterns include the following:

- The northern portions of the East and West coasts of the contiguous U.S., as well as the Great Lakes region, are primarily characterized by relatively low to moderate social sensitivity.
- The southern portion of the East Coast, as well as the Gulf Coast (with the exception of portions of Florida), has a mixture of low and high social sensitivities diversely distributed.
- Portions of Florida, Texas, California, and Alaska have areas of very high social sensitivity; interestingly those areas are also often next to low sensitivity areas.
- Alaska has a number of coastal areas with extremely high sensitivity.

Overall, the results indicate that the scale of analysis for social sensitivity (e.g., reserve versus coastal county) is important, which is to be expected given the relative nature of the index and the differences in analytical units. While the data provides a basis for understanding large-scale trends at both the reserve and coastal county scales, it can also provide a richer understanding of the factors influencing sensitivity at a given location. Any further interpretation of the data should be done with consideration of the nature of the data used in the analysis, the relative nature of the index, and the scale of analysis. In addition, Schmidtlein et al. (2008) discuss the importance of expert judgment in interpretation of social sensitivity indicator results. Expert input is an important part of examining whether the results are reasonable and consistent with local knowledge of the study areas and for determining the potential implications of the results. Next steps from this research should include working with reserve staff to review and examine the results of this assessment and to determine potential system-wide and reserve-level strategies for reducing social sensitivity to climate change.

Reserve Ecological Resiliency

Introduction

Resiliency is one aspect of understanding vulnerability, along with sensitivity and exposure. For this study, ecological resiliency refers to the ability of a reserve ecosystem to recover from a disturbance or impact, such as a climate hazard, without substantial loss of ecological structure or function. Reserve ecological resiliency was examined through an evaluation of reserve ecological stress and integrity. Reserves that have higher ecological integrity and lower ecological stress are likely to be more resilient to the impacts of climate hazards (Glick et al. 2011). Importantly, the information in this chapter refers only to ecological resiliency and does not consider, evaluate, or discuss social resiliency.

Comprehensive direct measures of ecological stress and integrity are not currently available for the reserves, and the collection of novel data that would provide a direct measure of the variables was beyond the scope of this project. Given these constraints, expert input was used to develop an estimated measure of ecological stress and integrity. The following definitions were used for the project:

Ecological Integrity: The ability to support and maintain key functional processes and intact abiotic and biotic components.

Ecological Stressor: Any factor that causes an adverse impact to ecological integrity.
Overall Ecological Stress: An estimate of the cumulative impact of all the ecological stressors impacting a reserve.

The expert input process provided insights into staff perceptions of 1) the current level of ecological integrity at the reserves, 2) the overall ecological stress that reserves are experiencing, 3) the key ecological stressors impacting the reserves, 4) the relative contributions of key ecological stressors to overall ecological stress levels, and 5) causal factors related to the key ecological stressors. In addition, the responses were used to examine reserve resiliency.

Methods

A web survey was designed using Qualtrics© to help facilitate the collection of information from each reserve related to ecological stress and integrity. Lists of key stressors and causal factors included in the survey were based upon a review of the management plans for all 28 reserves. Before finalization, the web survey was piloted among members of the project Steering Committee. Pilot studies are often used to test the efficacy and suitability of a proposed instrument (Dillman, Smyth, & Christian, 2009). After completing the pilot survey, respondents were asked to answer the following questions:

1) Are the introduction and instructions easy to understand and clearly written? If not, how could they be improved?
2) Are any items ambiguous or difficult to answer? If yes, please suggest changes.
3) Were the instructions and process for multi-component reserves clear and understandable?
4) Do you have any other suggestions for improving the survey?

Potential Climate Change Impacts on Estuaries

So why is climate change such a threat to estuaries? Rapid sea level rise can drown salt marshes (Kirwan et al., 2010) while increasing temperatures threaten the survival of critical estuarine habitats such as eelgrass beds.

Eelgrass (Zostera marina L.) is an important estuarine plant that provides nursery habitat for many fish (Orth and Heck, 1980). Research by investigators at the Chesapeake Bay Virginia NERR indicates that eelgrass beds are in decline due to numerous factors, including excess nutrient and sediment input (Jarvis and Moore, 2010) and higher water temperatures (Moore and Jarvis,. 2008).
In the Chesapeake Bay Virginia NERR, eelgrass beds suffered significant die-offs in 2005 and 2010 (Moore et al., 2012). These die-offs are linked to increasing water temperatures. This is because in the Chesapeake Bay eelgrass lives near the southern limit of its temperature range (30oC) and a temperature increase of just 1-2o C can be sufficient to cause significant eelgrass mortality.

Even under the best-case scenarios for temperature increases (1-3o C) due to climate change (IPCC 2007a), estuaries like the Chesapeake Bay could see significant declines in eelgrass habitat, the results of which will have untold ecological ripple effects on the estuary.

Changes to the survey were made based upon respondent feedback obtained through the pilot survey. For example, a number of changes related to response options and the data collection process were made based upon respondent feedback.

To administer the survey we asked each reserve manager to meet with their staff to collectively discuss and fill out the final survey (see Appendix 6 for a copy of the final web surveys for both single component reserves and multi-component reserves). At the meetings, reserve staff used best professional judgment to estimate the ecological integrity for the reserve using a scale from 1 (very low) to 10 (very high). Similarly, overall ecological stress was estimated using a scale of 1 (no ecological stress) to 10 (very high ecological stress). Staff also identified and estimated the relative importance of key ecological stressors and identified causal factors responsible for those stressors.

The reserves were asked to submit their responses using the web survey once staff had agreed upon their final responses. Multi-component reserves (i.e., reserves that have two or more discrete geographic areas designated for the reserve) were allowed to consider their components collectively or independently, depending upon whether staff perceived that the ecological integrity and/or stressors varied substantially across components. Likewise, and based upon reserve-initiated requests, some single-component reserves filled out separate surveys for different areas of their reserves based upon perceived substantial differences in ecological integrity and/or stress within different areas of the reserve.

To categorize an ecological resiliency variable, the scores for overall ecological stress for each reserve were reverse coded. Next, the mean of the ecological integrity and reverse coded ecological stressor rating was calculated. For reserves that provided a single survey response, the calculated mean was used as an estimate of "Relative Ecological Resiliency." For reserves with more than one survey response (e.g., some multi-component reserves), the overall mean for all survey responses was used to derive a single score per reserve.

After the Relative Ecological Resiliency scores were calculated for each reserve, the reserves were grouped into five categories based upon percentiles.

Results

The average ecological integrity and overall ecological stressor ratings for each reserve are shown in Table 3-1. The ratings and full survey responses for all reserves and components can be found in Appendix 7.

Table 3-1. Reserve ecological integrity and overall ecological stress ratings

Reserve	Ecological Integrity Ratinga	Overall Ecological Stress Ratingb
ACE Basin	8.0	4.0
Apalachicola	8.4	4.4
Chesapeake Bay MDc	7.0	5.0
Chesapeake Bay VAc	7.3	7.6
Delawarec	6.5	5.8
Elkhorn Slough	4.0	7.0
Grand Bay	6.6	6.4
Great Bay	6.0	5.5
Guana Tolomato Matanzasc	8.1	1.9
Hudson Riverc	6.3	7.3
Jacques Cousteauc	6.5	4.5
Jobos Bayc	7.0	5.5
Kachemak Bay	8.0	6.0
Lake Superior	5.6	6.5
Mission-Aransas	8.5	6.0
Narragansett Bay	9.0	6.0
North Carolinac	6.5	5.1
North Inlet - Winyah Bayc	8.0	3.0
Old Woman Creek	5.5	9.2
Padilla Bay	7.0	3.0
Rookery Bay	7.9	8.3
San Francisco Bayc	6.0	7.5
Sapelo Island	8.5	3.1
South Slough	7.5	4.0
Tijuana River	6.6	8.1
Waquoit Bay	5.0	7.0
Weeks Bay	4.0	8.0
Wells	7.0	5.0

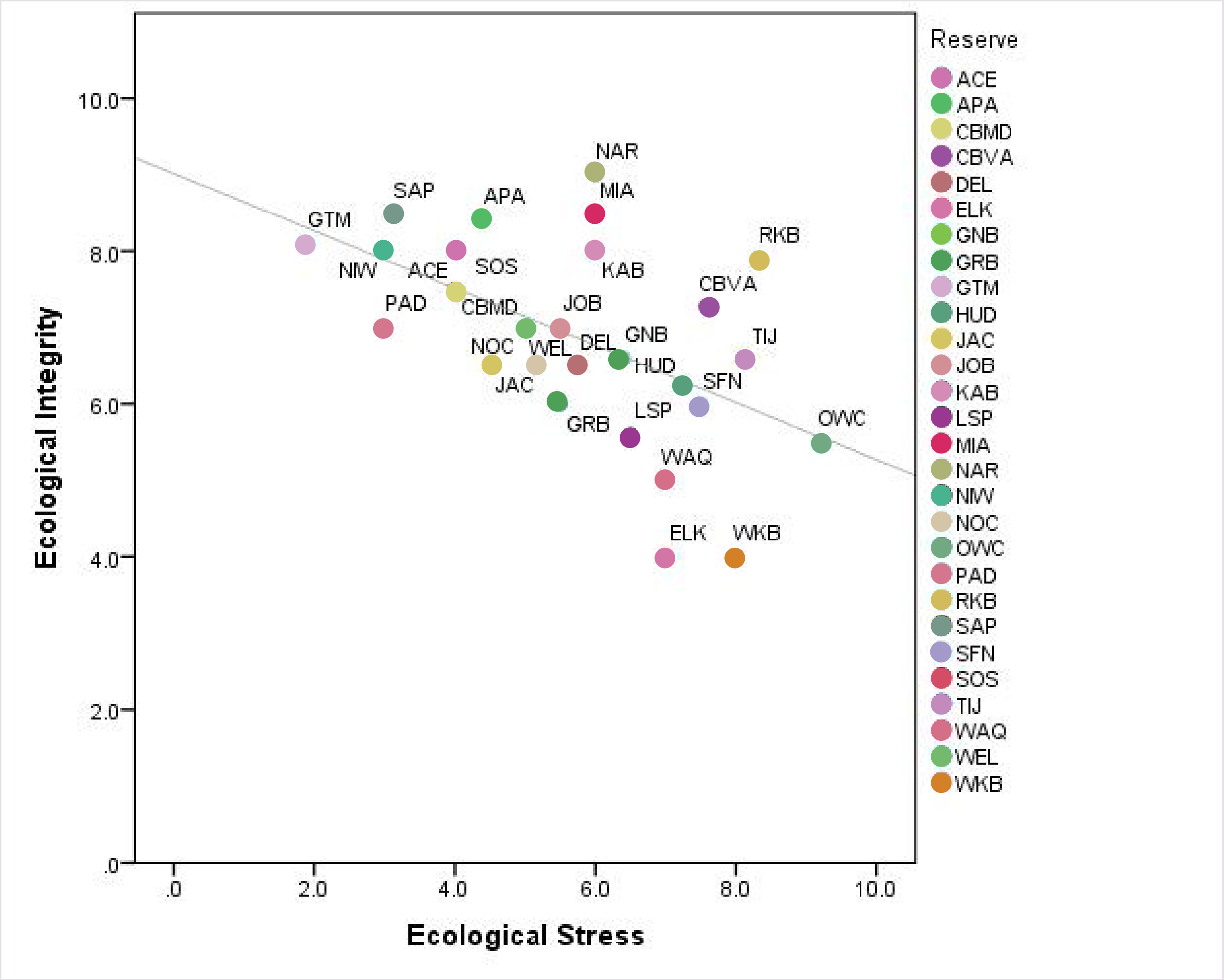
[a] Ecological integrity for the reserve was rated using a scale from 1 (very low) to 10 (very high).

[b] Overall ecological stress was estimated using a scale of 1 (no ecological stress) to 10 (very high ecological stress).

[c] Ratings are based upon the mean of scores provided for multiple reserve components or areas.

A scatter plot of reserve ecological integrity versus overall ecological stress is shown in Figure 3-1. The reserves rated by staff as having high ecological integrity were more likely to be rated as having low overall ecological stress. In fact, a linear regression analysis found the relationship between ecological integrity and overall ecological stress to be strongly significant ($p=0.004$; the regression line is shown on Figure 3-1), meaning that NERR staff perceived and reported the inverse relationship between integrity and stress in a manner that demonstrated a significant, definable relationship between the variables.

Figure 3-1. Scatter plot of reserve ecological integrity versus ecological stress. See Table 1-2 for reserve name abbreviations.



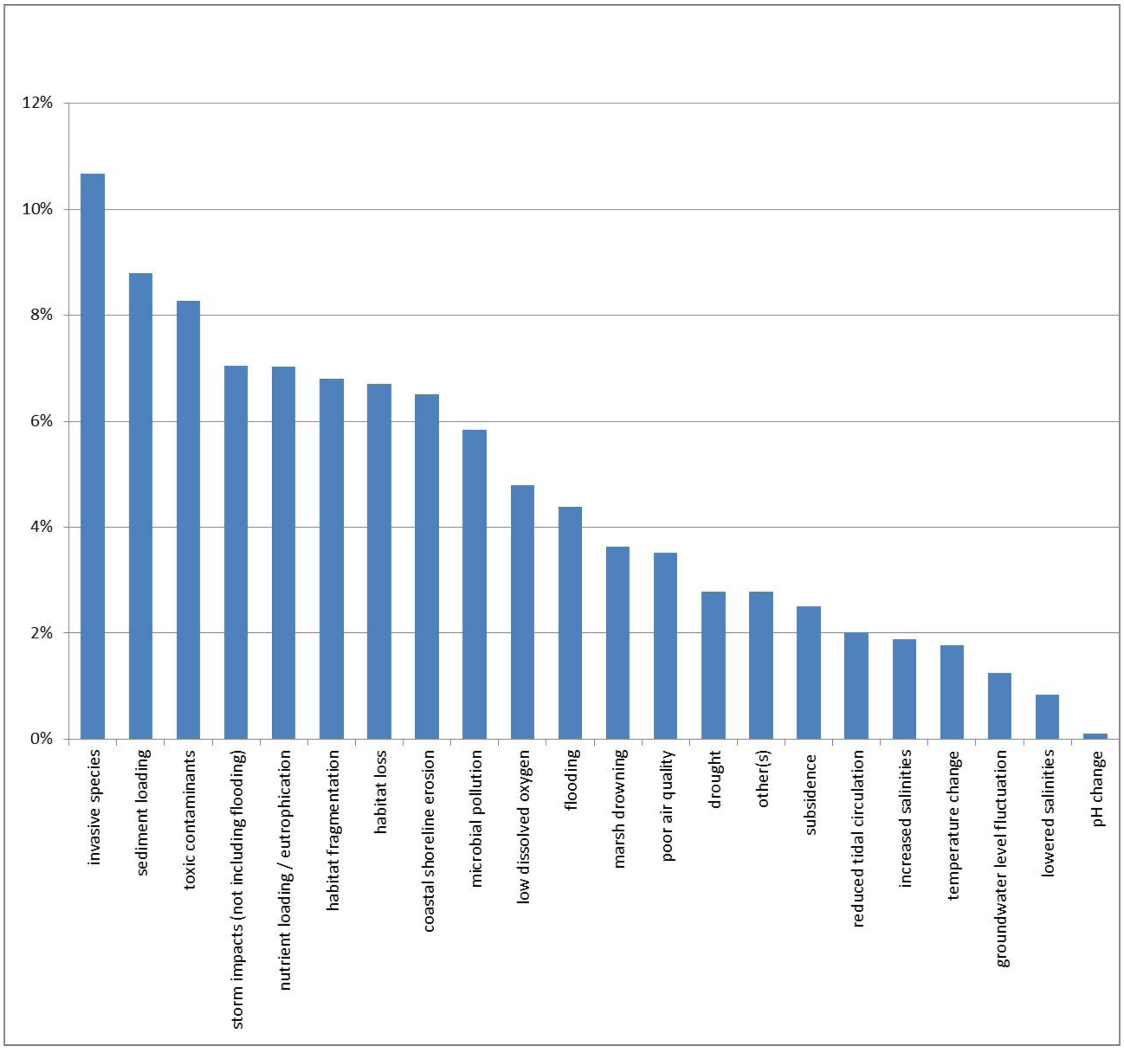
The number of times each individual ecological stressor was chosen as a key stressor for a reserve or reserve component is shown in Table 3-2. The percent contribution of each key stressor to overall ecological stress across reserves is shown in Figure 3-2.

Table 3-2. Response frequency for key ecological stressors.

Key Ecological Stressor	Number of Times Selected[a]
Toxic contaminants	30
Storm impacts (not including flooding)	30
Invasive species	29
Habitat fragmentation	29
Sediment loading	26
Coastal shoreline erosion	26
Microbial pollution (e.g., Escherichia coli)	24
Nutrient loading / eutrophication	21
Low dissolved oxygen	21
Poor air quality	20
Flooding	19
Habitat loss	16
Marsh drowning	16
Drought	14
Subsidence	13
Groundwater level fluctuation	13
Increased salinities	10
Temperature change	10
Reduced tidal circulation	9
Lowered salinities	8
pH change	3

[a] *n=45 for all survey responses related to individual reserves or reserve components.*

Figure 3-2. Percent contribution of key ecological stressors to overall ecological stress across reserves, as identified by reserve personnel.



The number of times that each causal factor for the key stressors was selected across all reserves is shown in Table 3-3.

Table 3-3. Response frequency for causal factors.

Causal Factors	Number of Times Selected
Residential development	33
Past land use	31
Population growth	29
Wastewater treatment	27
Sea level rise	25
Shoreline modification (e.g., hardening, diking)	22
Hydrologic alteration	22
Commercial and industrial development	21
Recreation	20
Agriculture	19
Roads	19
Wetland filling	17
Residential fertilizer use	16
Dredging & dredge spoil	16
Fire regime alteration	14
Residential pesticide use	13
Recreational harvest	11
Marine debris	11
Upstream water withdrawals	11
Commercial harvest	10
Waste management	7
Socio-economic factors (e.g., poverty)	7
Logging	5
Loss of drinking water supplies	4
Upstream water releases	4
Aquaculture	2

[a]n=45 for all survey responses related to individual reserves and reserve components.

Table 3-4 shows the percentiles and categories for the Relative Ecological Resiliency scores, and Table 3-5 shows the breakdown by category for the Reserve Relatively Ecological Resiliency scores. Figure 3-3 shows the distribution of resiliency categories across the system, while Appendix 8 lists the scores for each unique response unit (e.g., all reserves and components) for the study based upon percentile distributions.

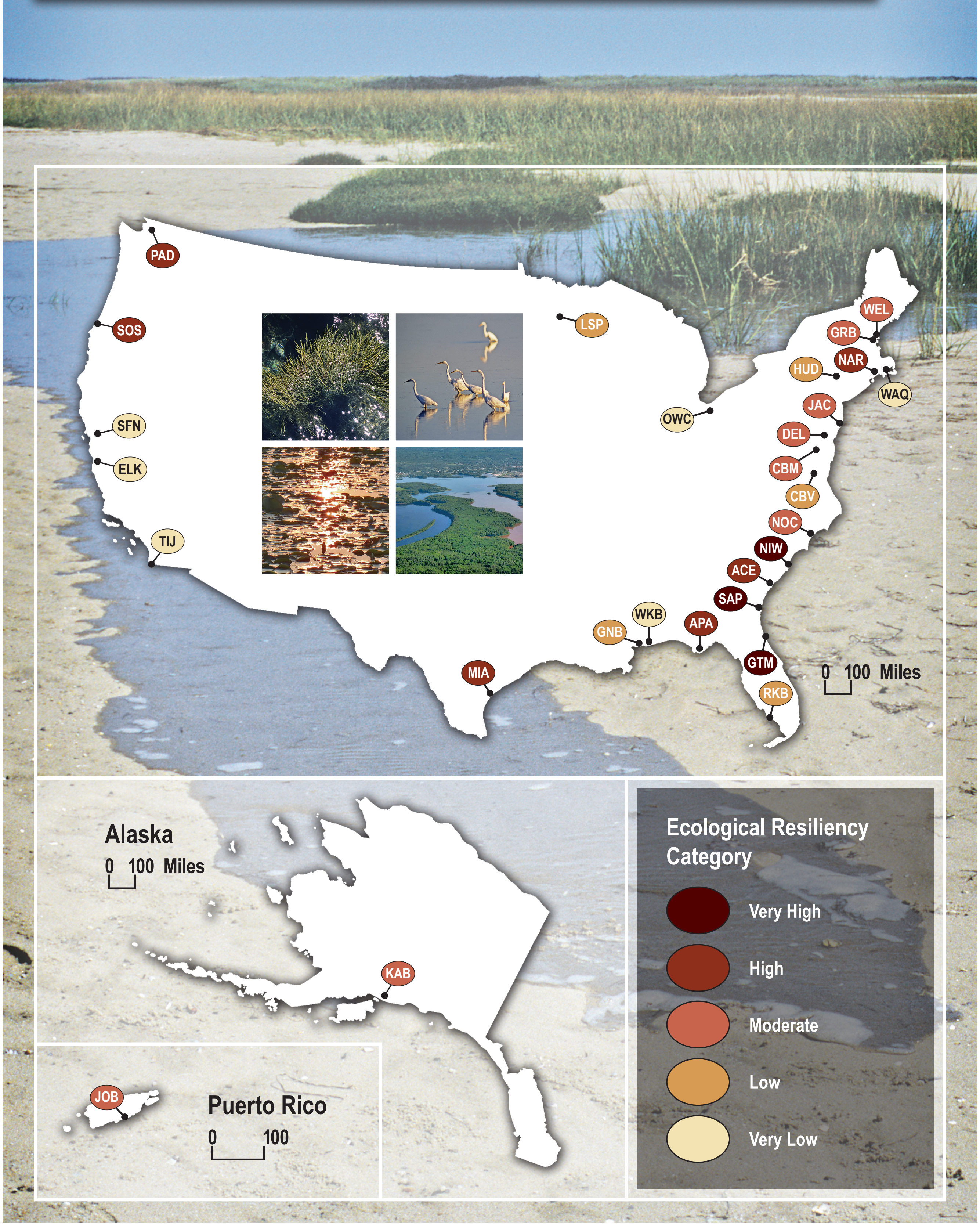
Table 3-4. Percentiles and categories for Relative Ecological Resiliency scores.

Percentile	Scores Included	Category
81-100	>7.5-10	Very High (5)
61-80	>6.5-7.5	High (4)
41-60	>5.7-6.5	Medium (3)
21-40	>4.8-5.7	Low (2)
0-20	0-4.8	Very Low (1)

Table 3-5. Relative Ecological Resiliency scores by category for the reserves.

Reserve	Relative Ecological Resiliency Score	Category
Guana Tolomato Matanzas	8.6	Very high (5)
Sapelo Island	8.2	
North Inlet-Winyah Bay	8.0	
Padilla Bay	7.5	High (4)
Apalachicola	7.5	
ACE Basin	7.5	
South Slough	7.3	
Narragansett Bay	7.0	
Mission-Aransas	6.8	
Wells	6.5	Medium (3)
Kachemak Bay	6.5	
Jacques Cousteau	6.5	
Chesapeake Bay MD	6.5	
Jobos Bay	6.3	
North Carolina	6.2	
Delaware	5.9	
Great Bay	5.8	
Grand Bay	5.6	Low (2)
Chesapeake Bay VA	5.4	
Rookery Bay	5.3	
Lake Superior	5.1	
Hudson River	5.0	
Tijuana River	4.8	Very low (1)
San Francisco Bay	4.8	
Waquoit Bay	4.5	
Elkhorn Slough	4.0	
Old Woman Creek	3.7	
Weeks Bay	3.5	

Figure 3-3. Relative ecological resiliency categories for Reserves. (See Table 1-2 for reserve abbreviations.)



Background photo: Jeffrey J. Strobel; small photos clockwise from upper left: Jeffrey J. Strobel (two photos), LSNERR, Jeffrey J. Strobel

Summary and Conclusions

Given the absence of comprehensive direct measures of ecological stress for the Reserve System, expert input was used to develop an estimate of reserve ecological stress and integrity. Those estimates were then used to calculate a relative ecological resiliency score for each reserve. Reserves that are more ecologically resilient should have greater capacity to adapt to, or recover from, a climate hazard without substantial loss of ecological structure or function.

Reserve ecological integrity ratings were based on a scale from 1 (very low) to 10 (very high). The ratings provided for the reserves ranged from 4.0 (Elkhorn Slough and Weeks Bay) to 9.0 (Narragansett Bay). The overall ecological stress ratings were based on a scale from 1 (no ecological stress) to 10 (very high ecological stress), and the reserve ratings ranged from 1.9 (Guana Tolomato Matanzas) to 9.2 (Old Woman Creek). Reserve staff responses reflected a perceived inverse relationship between integrity and stress, which is to be expected. There were no clear regional trends in ratings for either integrity or stress. Reserve ecological resiliency scores ranged from 8.6 (very high, Guana Tolomato Matanzas) to 3.5 (very low, Weeks Bay). With regard to climate change sensitivity, it is expected that reserves with lower integrity ratings and higher stress would be less resilient and, therefore, have greater vulnerability to climate change. This suggests that sites with low resiliency are at higher risk of climate change impacts when all other factors are considered equal. For the Reserve System, the least resilient sites include the following:

- Tijuana River
- San Francisco Bay
- Waquoit Bay
- Elkhorn Slough
- Old Woman Creek
- Weeks Bay

The most resilient sites include the following:

- Guana Tolomato Matanzas
- Sapelo Island
- North Inlet-Winyah Bay

Reserve resiliency should be considered when interpreting the results of the social and biophysical climate change sensitivity analyses done for the Reserve System. For example, if two reserves have equal biophysical and social sensitivity, we would expect the reserve with lower resiliency to have greater potential to be impacted by climate change. Furthermore, examining the underlying stressors leading to reduced resiliency can offer insights into management strategies that would reduce overall vulnerability to climate change.

The key ecological stressors most frequently identified as impacting reserves included toxic contaminants, storm impacts (not including flooding), invasive species, habitat fragmentation, sediment loading, and coastal shoreline erosion. When percent contribution to overall ecological stress at reserves is also considered, the largest contributors, on average, to reserve ecological stress include the stressors already listed plus nutrient loading/eutrophication and habitat loss. This suggests that while nutrient loading/eutrophication and habitat loss may not be an issue at as many reserves as the other listed stressors, they are having a substantial relative impact at the reserves where they are occurring. The most frequently identified causal factors contributing to key stressors included residential development, past land use, population growth, wastewater treatment, and sea level rise. The identified causal factors underscore the considerable impact that anthropogenic activities are having on reserves. Reserves can use the information regarding stressors and causal factors to develop and implement management strategies aimed at reducing ecological stress, increasing ecological resiliency, and lowering vulnerability to climate change.

NERRS BIOPHYSICAL SENSITIVITY TO CHANGES IN CLIMATE

Introduction

Coastal-oceans, Great Lakes, and estuaries are complex and highly dynamic ecosystems shaped by coupled interactions among the physical, chemical, and biological processes associated with their terrestrial, freshwater, oceanic, and benthic components. These ecosystems are also highly productive and therefore of great importance to society. Over time scales relevant to managers (i.e., the human life span) there are two overarching forces that are capable of perturbing the form, function, and ecosystem services provided by these systems: human activities and climate. The combined effects of human activities and climate (weather events, interannual variability, and change) can dramatically alter aquatic environments causing eutrophication, modifying habitats, and changing basic environmental conditions such as salinity, temperature, and alkalinity (Harley et al, 2006, Scavia et al. 2002).

Several recent weather/climate events have highlighted the impacts that climatic forces might have on estuarine systems. Hurricane Isabel, for example, was just one in a series of hurricanes in the last two decades that have impacted the water quality, phytoplankton populations, erosion dynamics, and natural resources of estuaries along the Mid-Atlantic coast (Sellner, 2005). More recently, Hurricane Sandy has caused far-reaching ecological impacts on the coastal ecosystems of New Jersey and New York.

While climate models cannot yet be relied upon to provide accurate and detailed projections of future conditions at local scales, managers, politicians, and the general public is seeking practical information about climate change effects that can inform their decision making processes (see Pyke et al., 2008, as an example). An appropriate place to begin, therefore, is in attempting to better characterize how coastal and estuarine conditions change with interannual variability in atmospheric temperature and precipitation. With this information, managers can determine how and why conditions in their systems may vary under one or more climate-change scenarios.

A study of the effects of climate variability and change for the NERRS also offers a unique platform for examining potential links between climate variables and the biophysical characteristics of estuarine waters across the nation.

Beginning in 1995, the National Estuarine Research Reserves System (NERRS) established a System-wide Monitoring Program (SWMP) that includes both abiotic (water quality, weather, nutrients) and biotic (vegetation, benthos) parameters. The NERRS also operates a Central Data Management Office (CDMO), which compiles monitoring data, performs quality assurance analyses, and ensures the proper preservation and distribution of the data. This data set provides the opportunity to characterize the responsiveness of water quality characteristics (water temperature, dissolved oxygen, specific conductivity, pH, and turbidity) to long-term changes in air temperature and precipitation, two of the most important driving variables expected to vary through time as a result of projected climate changes.

In this study, we assessed the responsiveness of springtime NERRS site-specific water quality variables to springtime atmospheric temperature and precipitation fluctuations across the NERRS. The main objective of this analysis was to evaluate the relative sensitivity of selected SWMP variables at each reserve to changes in climate variables. The secondary objectives were to assess the most sensitive climate-SWMP relationships across the NERRS and to look for trends in sensitivity relative to reserve or station characteristics, particularly land and hydrogeomorphological characteristics.

This investigation focused on relationships between climate and water quality variables throughout the spring season. Because intra-annual variability would mask changes across multiple years, our analysis focused on one season. Spring was chosen because, generally speaking, spring is when increasing insolation levels and warming temperatures combine to initiate the beginning of the annual growing season. As such, variability in annual springtime precipitation and temperatures can result in dramatic changes in ecosystem dynamics that influence biophysical processes and conditions throughout the rest of the year. For example, interannual fluctuations in spring precipitation have been shown to strongly influence the timing, extent, and location of low oxygen 'dead zones' in many of the nation's estuarine ecosystems, which, in turn, can result in degraded habitat conditions, alterations in the food web, and declines in value of the ecosystem services (e.g., recreation, fishery harvests, tourism) derived from these otherwise highly productive systems (Hagy et al., 2004; Murowski, 1993; Winder and Schindler, 2004).

For ease of presentation and discussion in this chapter, abbreviations for SWMP station names are presented in Appendix 9.

Methods

A survey was developed and conducted electronically (http://www.surveymonkey.com) to gather data about the reserves and the active SWMP stations within each reserve, with the intention of using this information to help discover trends in the biophysical sensitivity scores. Personnel from each reserve completed the survey, providing information about the active SWMP stations and the reserve as a whole. Specifically, the survey asked each reserve to provide information regarding the following questions/statements:

1. Does information on general physical reserve characteristics (e.g. flushing time, surface area, volume, bottom type) exist?
2. For each SWMP station located within your reserve please provide a response that best characterizes the type of system (tidal creek, tidal river, non-tidal river, river mouth, open estuary, estuary, other) being monitored.
3. For each SWMP station located within your reserve please provide a response that best characterizes the dominant land use (forest, agriculture, urban, residential, other).

Water quality data (SWMP data) was obtained from the NERRS CDMO. This data was presented in very large data files each containing millions of data lines for each of six regions of the U.S. (e.g., Gulf Coast). Embedded within each file were quality control/quality assurance codes designated by the CDMO staff, which were used to select or cull data for this analysis. Nutrient data had to be excluded from our analysis due to a lack of sufficient data for many reserves over the time period of our analysis. Salinity data were excluded as salinity is calculated based on, and is therefore redundant with, specific conductivity. Thus, the biophysical parameters included in this study were water temperature, specific conductivity, pH, dissolved oxygen, and water clarity (i.e. turbidity).

Precipitation and air temperature data was gathered from NOAA's National Climactic Data Center (NCDC). This climate data set, called the Time Biased Corrected Divisional Temperature-Precipitation-Drought Index, represents a very useful tool for examining climate changes over time, as the record extends from the late 1800's to the present day. Each state is separated into between one and ten

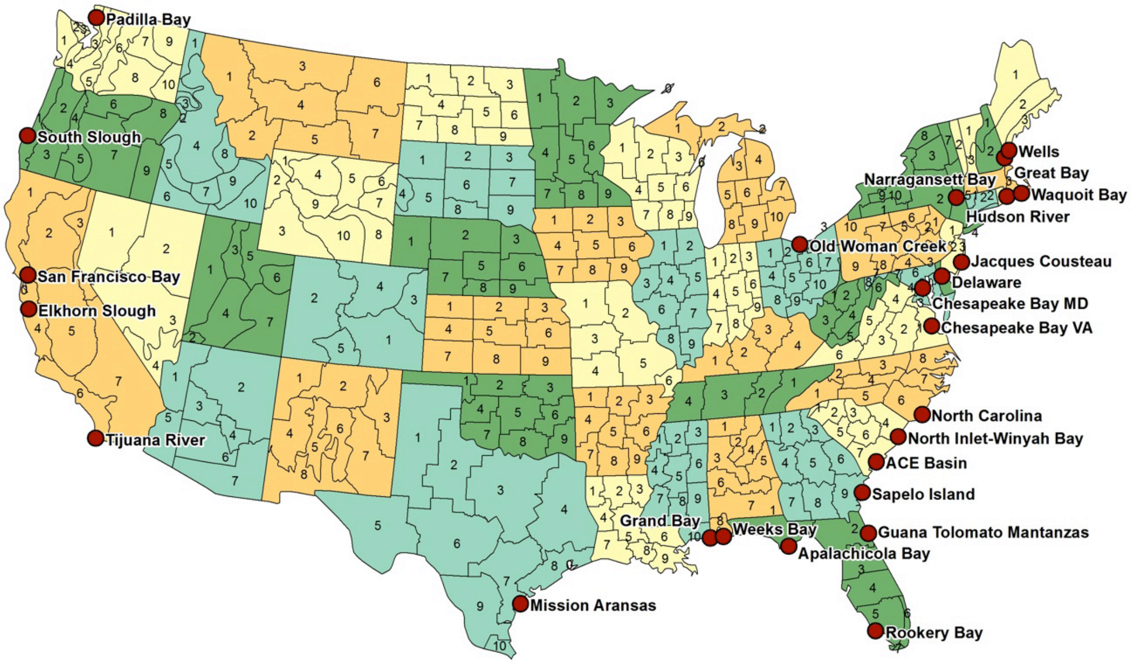


Figure 4-1. Location of the National Estuarine Research Reserves in relation to the NCDC Climate divisions for the contiguous U.S.

divisions based on the size of the state (Figure 4-1). This NCDC data is reported by division as monthly means for temperature and monthly totals for precipitation. Climate divisions and NERRS reserves were matched spatially using geospatial information system software (ESRI), by performing a spatial join. Despite the advantages of using data that has been processed and corrected uniformly over all climate divisions, this particular NCDC data set only includes data for the contiguous United States, thus excluding the Kachemak Bay (Alaska) and Jobos Bay (Puerto Rico) reserves from this analysis.

In order to match the temporal scale of the NCDC data, we calculated monthly means for all of the available biophysical data. We then calculated springtime means for each biophysical and climate variable. For most reserves, data from the astronomical spring (March-May) were included in the analyses. However, reserves in northern latitudes experience a delayed spring, and therefore, data from April through June were used for these reserves. We classified the eight reserves north of 40°N latitude as 'northern' reserves. This decision was supported by the lack of biophysical data before April of each year for several stations in northern latitudes.

Biophysical sensitivity scores were calculated by testing the statistical relationship between the climate (air temperature and precipitation) and response variables (water quality variables). Annual spring atmospheric temperature and precipitation data were regressed against each biophysical variable in order to quantitatively characterize the strength (coefficient of determination; R2) and slope of each climate-biophysical relationship (Figure 4-2).

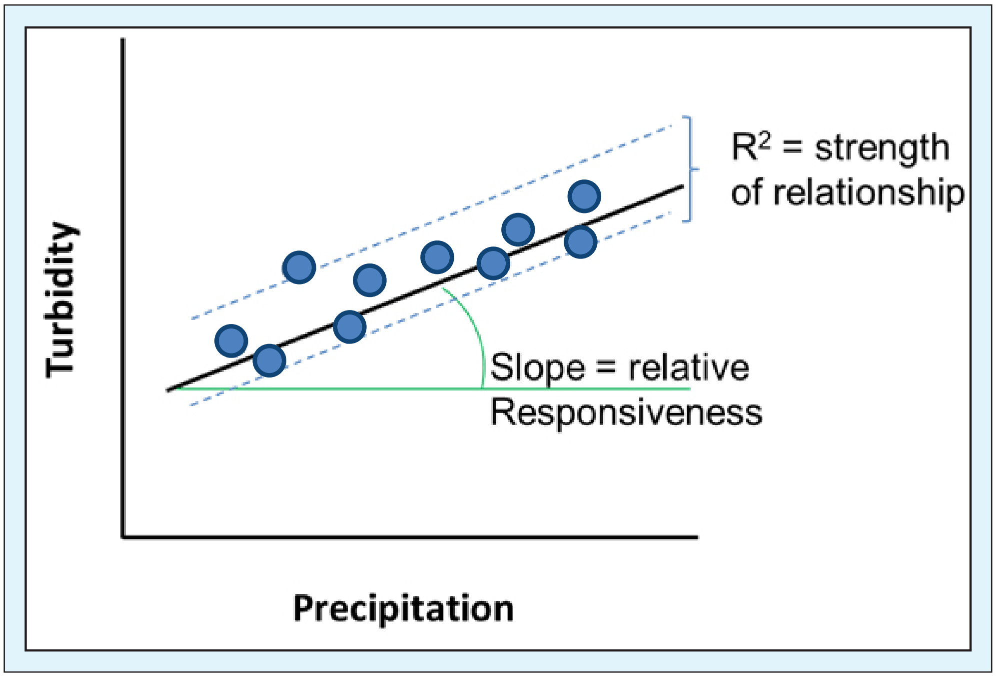


Figure 4-2. Approach used for the sensitivity scoring methods.

Annual spring means were only calculated if there were at least two months of data for any given station.

Because slope values depend on the units of the variables involved in the regression, slope values were scaled to allow for their comparison among the various climate-biophysical variable analyses. Because R2 values range from 0-1, regression slopes were scaled similarly. Therefore, values for both the scaled slope and R2 ranged from 0 to 1, giving the strength and responsiveness of climate-water quality relationships equal weighting in our sensitivity index. The slope and R2 were multiplied to provide a sensitivity value for the comparison of each climate variable and biophysical parameter at each station.

Preliminary comparisons revealed a significant, negative relationship between the average biophysical sensitivity values and the number of years of data available for each station (corr. coefficient=-0.51, P <0.001) (Appendix 10). To eliminate this bias, we sought to identify the minimum number of years that were required before this relationship was no longer significant. Our analysis demonstrated that this bias was removed when stations with records for less than 7 years were removed from the data set .

The NERRS Biophysical Sensitivity Index (BpSI) was then calculated by averaging squared station sensitivity values for each reserve. The individual climate-water quality sensitivity values were squared in order to emphasize the strongest climate-water quality relationships, as the variability among the entire assemblage of values was found to be relatively low. These station sensitivity values were then averaged for each reserve. Finally, in order to place the BpSI values on a similar scale as the social sensitivity and ecological resiliency values, these averages were multiplied by 100 to yield the final NERRS Biophysical Sensitivity Index.

To summarize the calculation of sensitivity and BpSI values, we first performed a regression analysis on each combination of climate and water quality variables. We normalized the slopes of the regression lines, within each variable combination, to range from zero to one. We then multiplied the normalized slopes against their corresponding regression coefficient. These products represent the SWMP station and climate-water quality specific sensitivity values. To calculate the BpSI values, we then squared the sensitivity values, averaged them by reserve, and multiplied these reserve-specific values by 100.

One of the primary objectives of the overall sensitivity project was to synthesize indicators for both social and biophysical sensitivity. In order to ease interpretation of sensitivity in this synthesis product, we chose to categorize the relative sensitivity of reserves to a common grading scheme. For biophysical sensitivity we choose to categorize the relative sensitivity of each reserve to changes in air temperature and precipitation into 5 groups ranging from ‘very low’ to ‘very high’. Because the BpSI values are relative only within the current results, we divided the range of BpSI values into five equal parts.

Results

Reserve Sensitivities

Reserve-level climate sensitivity index (BpSI) values ranged from 4.81 for Tijuana River to 0.39 for Grand Bay (Table 4-1). The distribution of BpSI values was slightly skewed but did not differ statistically from the normal distribution (Figure 4-3; Shapiro-Wilk test, P=0.23). The majority of BpSI values fall within the two groups labeled Low and Moderate. The categories of Low, High, and Very High each contain two reserves (Table 4-1).

Table 4-1. BpSI values and relative sensitivity categories.

Reserve	CSI	Sensitivity
Tijuana River	4.81	Very high
Sapelo Island	4.30	Very high
ACE Basin	3.67	High
Waquoit Bay	3.62	High
North Carolina	2.97	Moderate
Rookery Bay	2.78	Moderate
Hudson River	2.70	Moderate
Delaware	2.58	Moderate
Jacques Cousteau	2.35	Moderate
Wells	2.27	Moderate
Great Bay	2.18	Moderate
Chesapeake Bay VA	2.04	Moderate
South Slough	2.02	Moderate
North Inlet-Winyah Bay	2.01	Moderate
Old Woman Creek	1.95	Low
Guana Tolomato Mantanzas	1.94	Low
Elkhorn Slough	1.90	Low
Weeks Bay	1.84	Low
Chesapeake Bay MD	1.71	Low
Apalachicola Bay	1.53	Low
Padilla Bay	1.45	Low
Narragansett Bay	0.79	Very low
Grand Bay	0.39	Very low

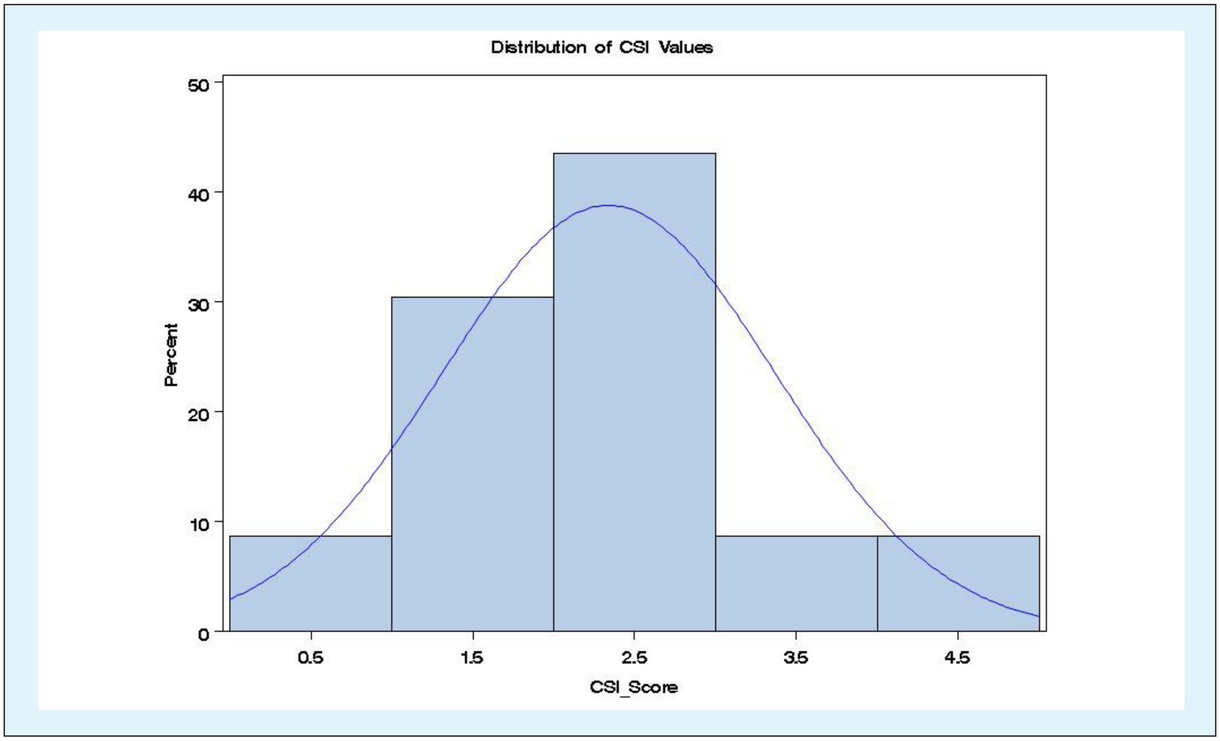


Figure 4-3. Distribution of Biophysical Sensitivity Index values for the 23 reserves included in the analysis. The blue line indicates the shape of the normal distribution based on the mean and standard deviation of the BpSI values.

In general, BpSI values did not show regional trends. Biophysical sensitivity is of highest relative concern at isolated reserves in the Southeast and on the West Coast. Only the Moderate BpSI scores display a visually discernible spatial pattern, where eight of the nine sites falling within this group were located on the East Coast (Figure 4-4). Sapelo Island and ACE Basin have BpSI values in the Very High and High categories, respectively, and co-occur in the Southeast. In contrast, Waquoit Bay has a High BpSI value relative to all the other reserves, but is very close geographically to Narragansett Bay, which had the second to lowest BpSI value.

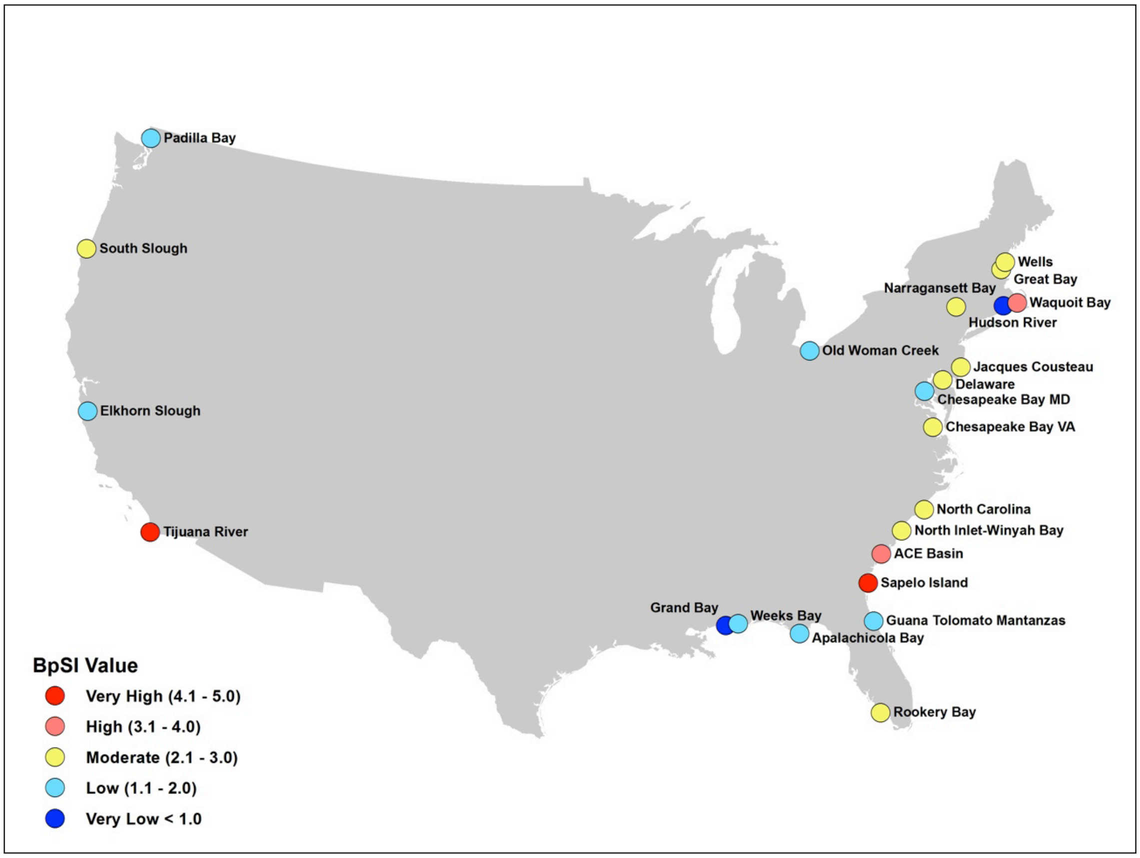


Figure 4-4. Map of reserve-level BpSI values.

Individual Climate-Biophysical Sensitivity Scores

In the process of deriving the BpSI, sensitivity scores for each climate-biophysical relationship (e.g. air temperature and water temperature) were calculated for 91 stations, across 23 reserves. These scores ranged from 0 to 0.86, with an average of 0.08 and a standard deviation of 0.13.

Averaging the individual scores for each biophysical relationship across all SWMP stations revealed that the relationships of air temperature to water temperature, and precipitation to specific conductivity were far stronger than all others (Figure 4-5) and accounted for most of the high sensitivity scores. Examination of the maximum sensitivity values at each reserve highlights the strong relationship between air and water temperatures (Figure 4-6a) for most reserves and the trend toward strong relationships for precipitation and specific conductivity for at least some of the SWMP stations in the Southeast and along the West Coast (Figure

4-6b). The connections of air temperature with water temperature and precipitation with specific conductivity were important to note, as water temperature and salinity may act to directly influence the size and range of estuarine populations. It should be stressed however, that the distribution of station scores for each climate-biophysical relationship were highly skewed, with at least one relatively high sensitivity score for each climate-biophysical relationship. Therefore, while the relationships of air temperature to water temperature and precipitation to specific conductivity were far stronger than the other eight combinations, for each of the other relationships at least one station featured a strong score (Figure 4-5).

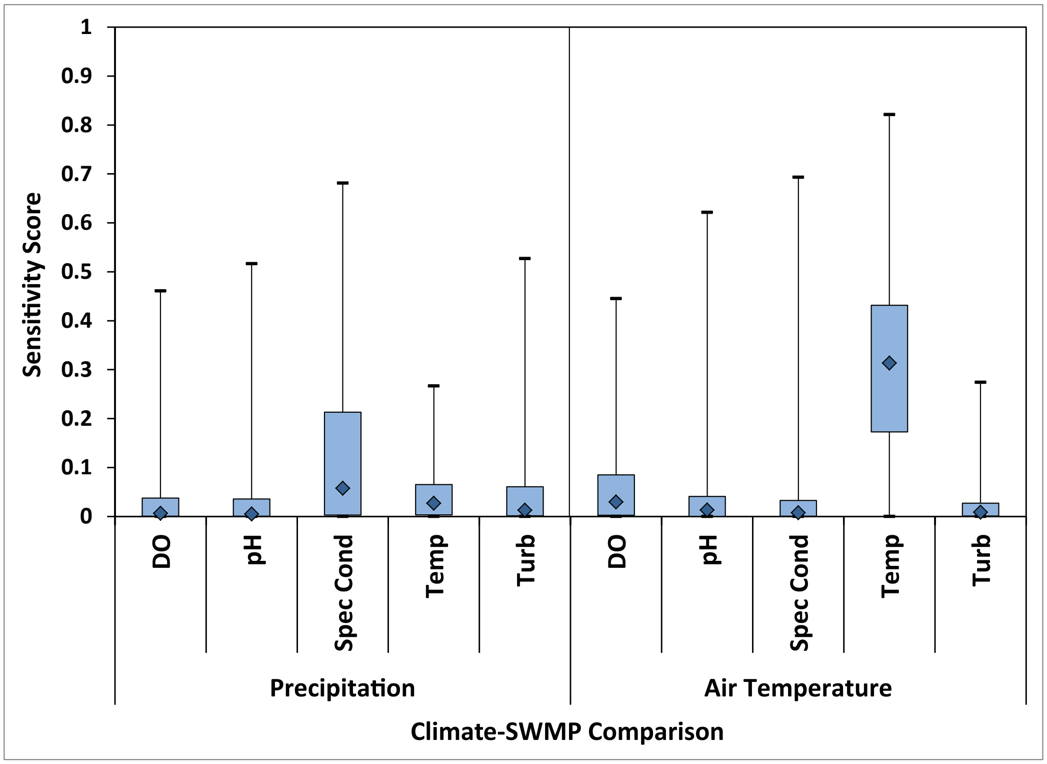


Figure 4-5. Box-and-whisker plots of sensitivity scores for climate and biophysical variable comparisons for all stations combined. Boxes span the 25 to 75% quartiles of the data, with the whiskers showing the extreme values. Diamonds represent median values. Biophysical variables included are dissolved oxygen (DO), specific conductivity (Spec Cond), water temperature (Temp), and turbidity (Turb).

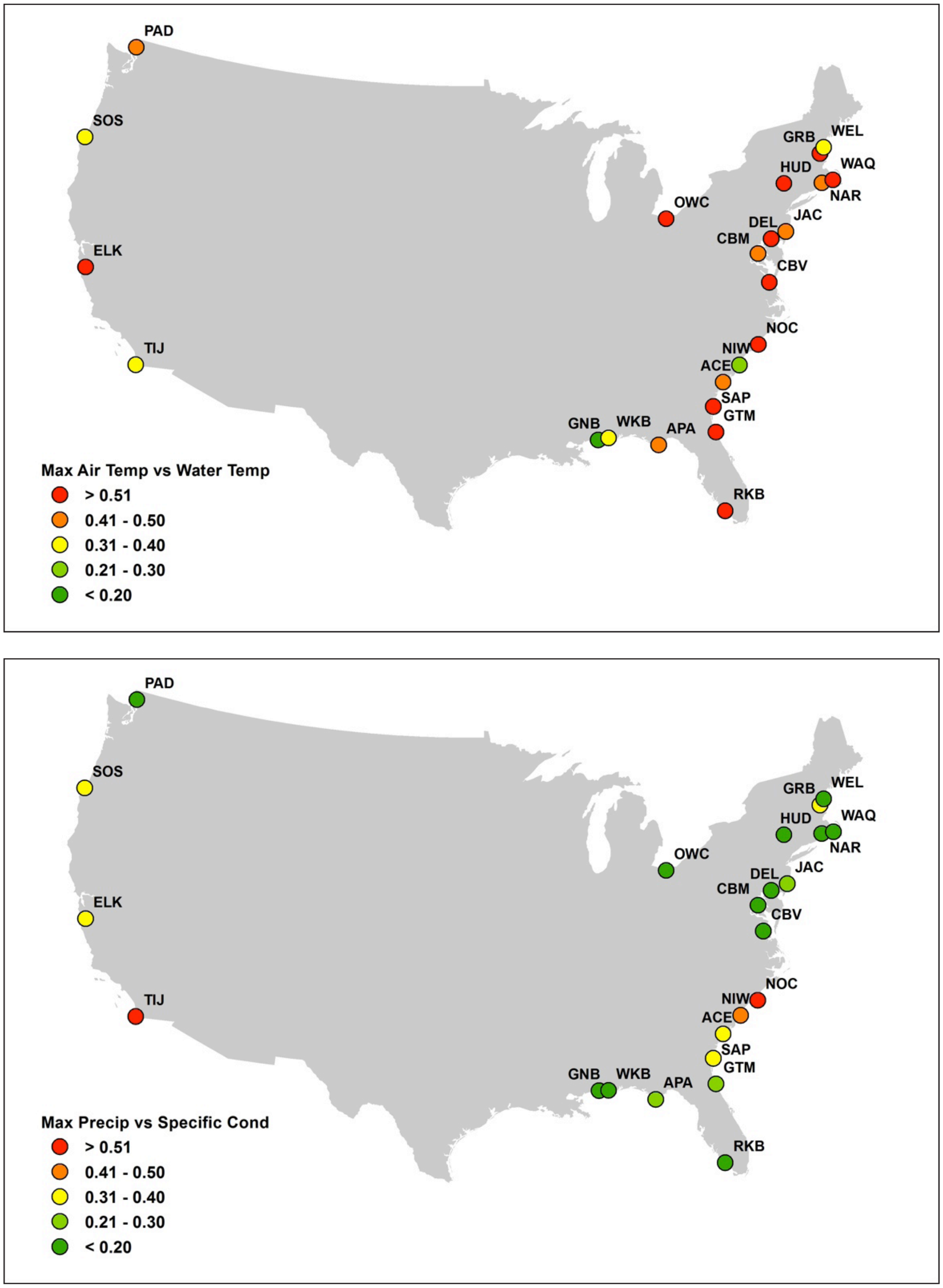


Figure 4-6. Maximum sensitivity value by reserve for (A) air temperature compared with water temperature and (B) precipitation and specific conductivity.

An examination of the climate-biophysical sensitivity scores for each reserve provides some insight into the types of biophysical parameters that are most sensitive to climate changes for that reserve. For example, the Tijuana River Reserve had the highest BpSI, due primarily to high scores for the relationship between air temperature and water temperature and for the relationship of precipitation and specific conductivity (Figure 4-7a). One Tijuana SWMP station in particular (tl;

Tidal Linkage) had very high sensitivity for several climate-biophysical relationships relative to all other SWMP stations. In contrast, the only biophysical variable with relatively high sensitivity to climate change at the Waquoit Bay Reserve was water temperature as it related to air temperature (Figure 4-7b), and the sensitivity score for this relationship was similar for all four stations in the reserve. Charts of climate-biophysical sensitivity scores for each of the 23 reserves included in the analysis are provided in Appendix 11.

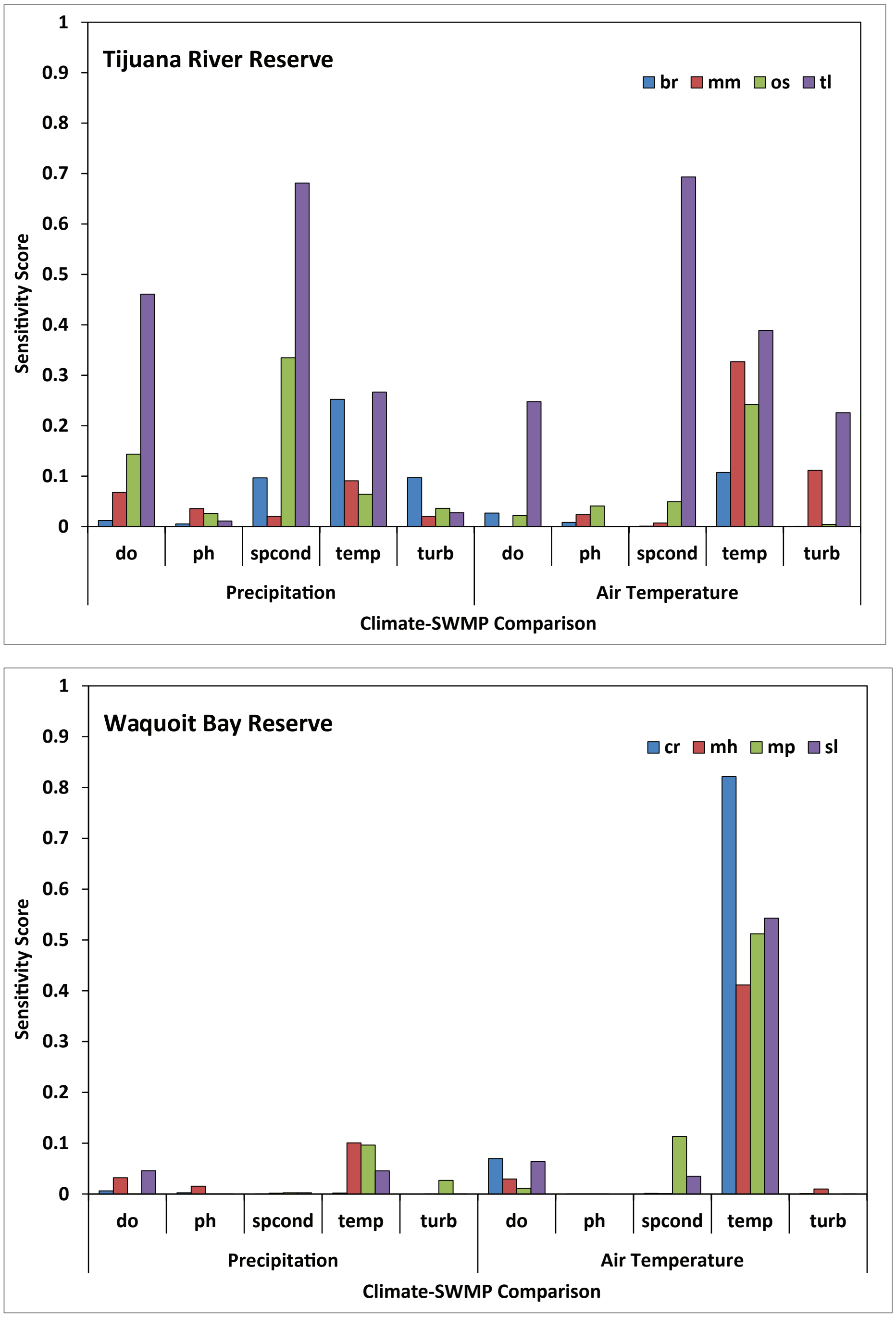


Figure 4-7. Sensitivity scores for each biophysical-climate relationship for the Tijuana River (panel A) and Waquoit Bay (panel B) reserves. Bar colors are representative of different stations within each reserve. Biophysical variables included are dissolved oxygen (do), pH, specific conductivity (spcond), water temperature (temp), and turbidity (turb).

Sensitivity Trends

Comparative analyses of sensitivity values across the NERRS were also conducted. Hydrogeomorphology and dominant land use variables for each SWMP station were obtained through the reserve-level survey (Figure 4-8 and 4-9, Appendix 12). Other variables examined were station depth (as approximated by datasonde depth), average salinity and average water temperature, which were gathered from the SWMP data. An analysis of variance comparing SWMP station sensitivity scores between land use and hydrogeomorphology categories and correlation analysis of sensitivity values with the other continuous variables (e.g. average water temperature) revealed no notable significant relationships or any general patterns nationally.

We also performed a cluster analysis of SWMP stations based on sensitivity values for all ten combinations of climate and water quality variables (hierarchical clustering with Wards method). These clusters were not significantly correlated with any of the explanatory variables we examined, including region, latitude, land use, hydrogeomorphology, station depth, average water temperature, or average specific conductance.

The lack of relationships between stations based on sensitivity values is not surprising given the uniqueness of most SWMP stations and the challenge in quantifying place-based influences at each one. While a more in-depth analysis, based on the compilation of additional, detailed SWMP station information is needed, there were a few qualitative points worth noting.

One notable finding was that the highest average reserve BpSI value occurred for the Tijuana Reserve, which features a watershed that has been heavily developed and the water largely channelized. Tijuana was the only reserve in our survey in which all four active SWMP stations were classified as having urban surroundings.

In contrast, Sapelo Island and ACE Basin reserves, which have the second and third highest BpSI values respectively, are both located on the southeast coast, contain extensive salt marshes, and are relatively undeveloped. These two reserves have high climate-biophysical sensitivity scores for the relationship of air temperature and water temperature, and ACE Basin shows a notable relationship between precipitation and turbidity.

The Narragansett Bay and Grand Bay reserves had the lowest BpSI values. These two reserves are geographically distant from one another and seemingly have little in common. For example, the Narragansett Reserve is saltier and far less turbid than the Grand Bay Reserve. It is not clear, given the current data set, what might explain the relative lack of sensitivity to precipitation and air temperature seen in the water quality characteristics of these two reserves.

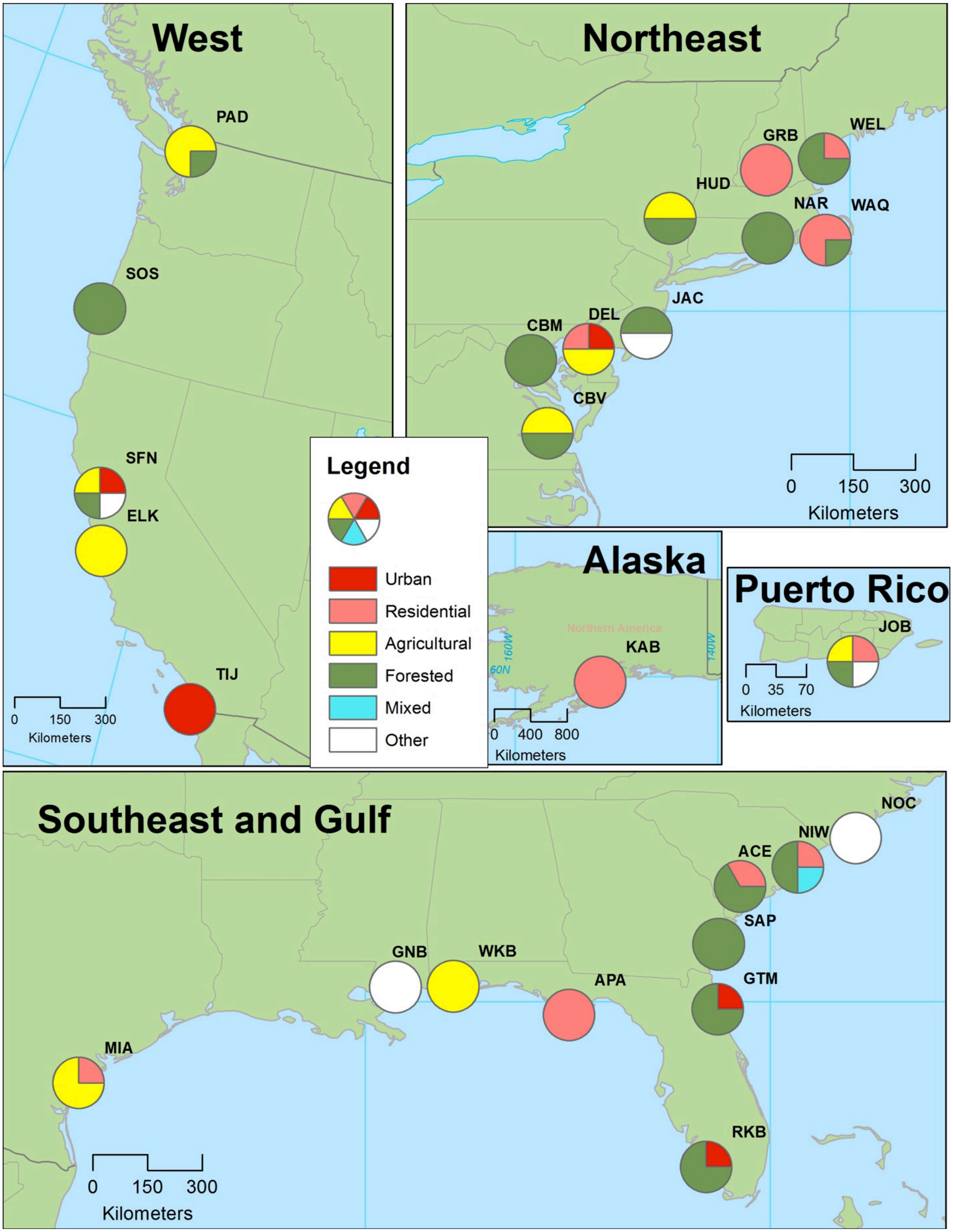


Figure 4-8. Land use by reserve according to reserve staff survey responses. See Table 1-2 for reserve name abbreviations.

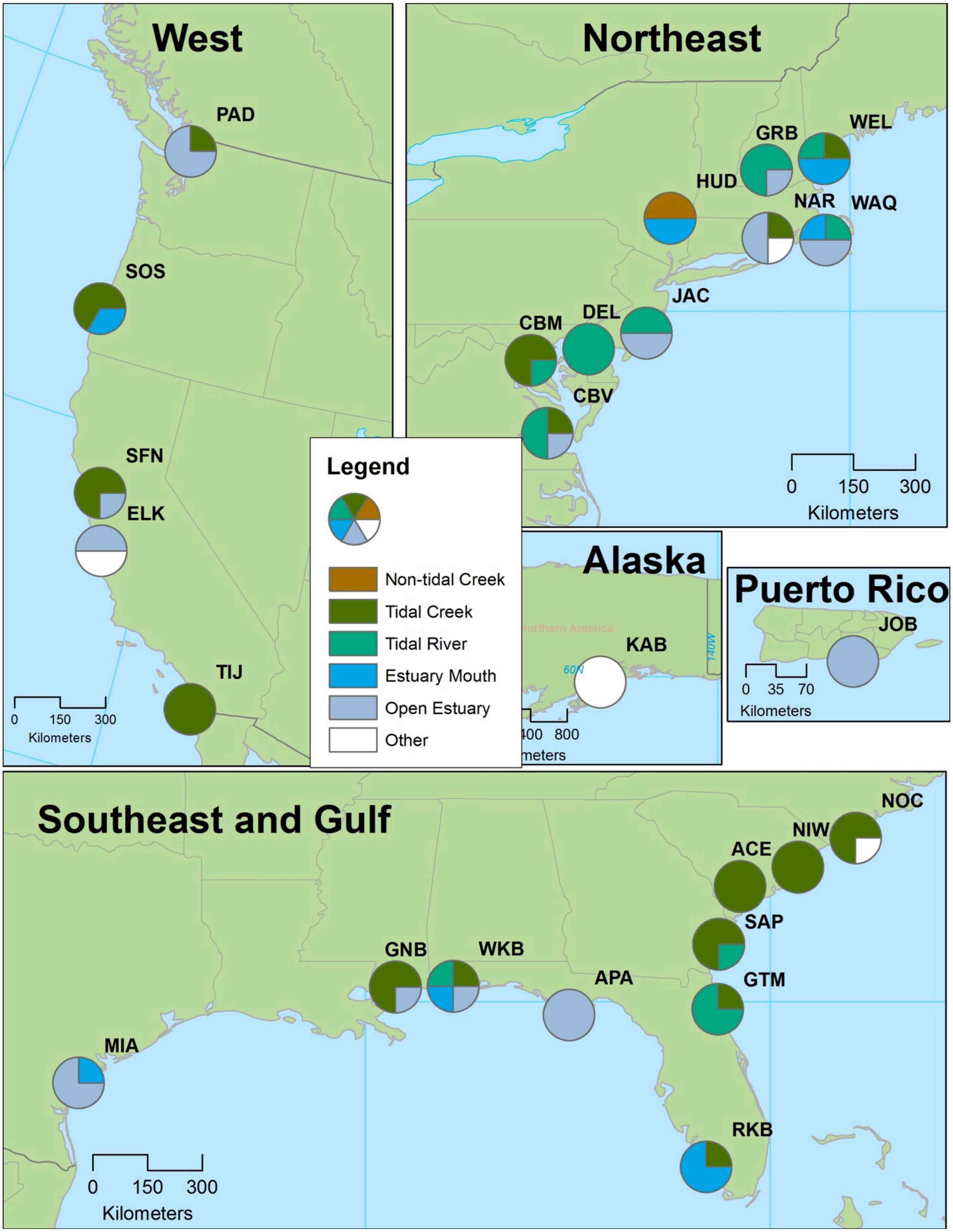


Figure 4-9. Hydro-geomorphology classification of SWMP stations by reserve. See Table 1-2 for reserve name abbreviations.

Discussion and Recommendations

The Biophysical Sensitivity Index we developed separated reserves according to an informative, relative scale, which will provide a useful foundation for exploring more detailed climate-biophysical relationships in the NERRS. Biophysical sensitivity to climate change, as described by this analysis, was relatively strong at Tijuana and Waquoit and future analyses might begin by focusing on these reserves. A large number of reserves in the Moderate sensitivity category are located along the East Coast. Reserves in this category may have significant relationships for only one or two biophysical-climate comparisons, which could guide mitigation strategies at those reserves.

A few qualitative relationships between BpSI values and land use have been noted for several reserves with relatively high BpSI values. Efforts to uncover connections between reserve sensitivities and both environmental and climatic variables have been attempted and will continue, but would benefit from additional SWMP station-specific data that would allow further in-depth analyses at individual reserve and SWMP station levels. We recommend that a more extensive database of metadata regarding reserve and SWMP station characteristics be compiled and maintained. This compilation of information, which should engage personnel at the individual NERRs, might help uncover linkages between station climate-biophysical scores and characteristics of the stations.

Overall, relationships between climate variability and water quality conditions at the NERRS varied greatly within many reserves. Much of this variability may result from the fact that SWMP station locations, which initially were selected based on a number of targeted environmental gradients and not with the goal of addressing changes in climate on biophysical conditions in the reserves. A recommendation formed through this analysis would be for the Estuarine Research Division to evaluate strategies for more targeted climate change monitoring on an NERRS level.

There are several important ecological reasons, as discussed previously, to focus on spring for this analysis. It is likely that our results would have been somewhat different for some reserves if we had focused on another season. For example, large-scale weather events such as hurricanes might have an impact on average conditions in some years, depending on things like the size and duration of the event and the size of the watershed. These effects could influence the relationship between climate variables and water quality in a nonlinear and weather event-specific way.

The treatment of multi-component reserves was complicated by the fact that most have only one or two SWMP stations per component. Because components may differ significantly in such factors as land use, hydrogeomorphology, watershed size, and water physico-chemistry (e.g. components of the Chesapeake Bay Maryland Reserve), the ideal approach would be to treat them as separate analysis units for biophysical climate sensitivity. This would require changing the current sampling design.

This analysis is one that should be revisited as new data becomes available. The presence of a longer time scale of data in coming years should allow the inclusion of more stations and more variables (e.g. nutrients). There were some notable relationships detected between nutrient concentrations and climate variables in our preliminary analysis, which ultimately had to be excluded from the final analysis in order to include the greatest number of reserves as possible. Further data collection and some within-reserve analysis should highlight some of the climate dynamics lost at the NERRS level. Reserves lacking climate division data, or those outside the contiguous U.S., may be incorporated by collecting and processing climate data from a representative number of meteorological sampling stations.

SYNTHESIS OF CLIMATE CHANGE INDICES

Integration of Indicators across the NERRS

In order to provide a broad sense of potential climate change vulnerabilities and impacts for the reserves, we chose to synthesize information from multiple climate change indicators. Several of these indicators were developed by our team and outlined in the previous chapters, while other indicators have been developed elsewhere and are incorporated in this synthesis chapter. Our original intent was to combine indicators quantitatively in order to provide a general climate change impact score for each reserve. However, the indicators we used are based on very distinct data sets, assumptions and calculations about climate change and proved difficult to combine mathematically. Therefore, we decided to simply compile these values for qualitative comparison. A benefit of this approach is that it highlights differences in spatial trends between the climate change indicators, contrasting and emphasizing potential climate change impacts at the reserve level and across the Reserve System.

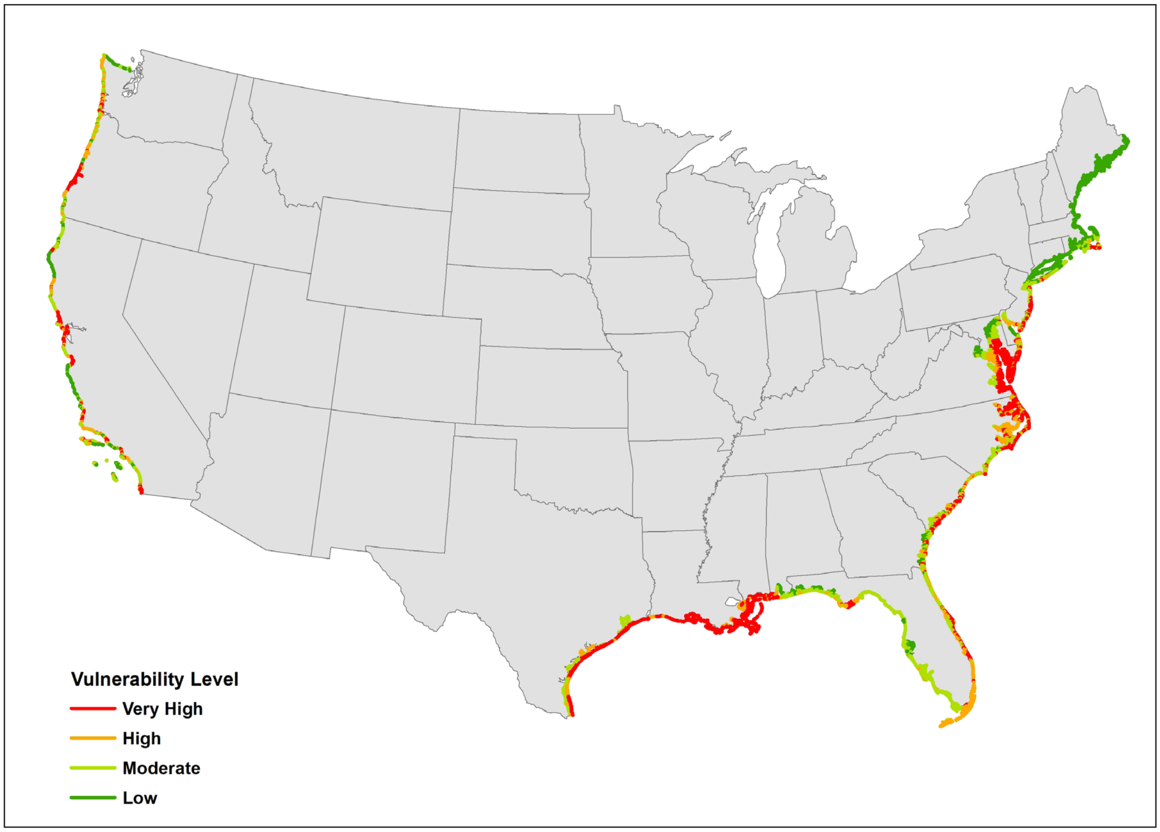
Before examining the compiled indicator values, it is important to consider what the assembled climate change indicators represent and how they differ. Climate sensitivity, in the context of this report, is defined as whether and how a reserve or group of reserves will be affected by a change in climate conditions, measured over the particular environmental or social geography (Glick et al. 2011). Measurement of social sensitivity was achieved through analysis of societal characteristics and associated sensitivity scores within reserve-defined geographic boundaries and within contiguous coastal counties surrounding the reserves. Sensitivity of biophysical water conditions in the NERR system represents a measure of dynamic responsiveness to climate change. Biophysical sensitivity was measured by examining the connectedness between empirical water quality variables, such as temperature and specific conductivity, and the climate variables of precipitation and air temperature.

The ecological resiliency analysis of the NERRS helps further elucidate the possible impacts of potential climate stressors. Resiliency is a measure of the ability of an ecological system to return to its original state in a timely manner following an impact (IPCC, 2007c). The resiliency index in this study differed from the other indices in this project in that it did not depend on empirical data, but on the expert opinion of all available staff at each reserve.

While calculating the relative social and biophysical sensitivities, as well as the ecological resiliency of the reserves, provides important insights into potential climate change impacts in the NERR System, projections of climate change exposure are included to provide a more robust examination of climate sensitivity and vulnerability. Extensive work outside of this project has resulted in well-supported projections of sea level rise and atmospheric temperature increases (IPCC, 2007a, b), and the vulnerability of coastal areas to these changes (IPCC, 2007c). We chose to incorporate these two indices in order to present a broader view of potential climate change impacts.

Sea level rise information is included in our analysis by incorporating the Coastal Vulnerability Index (CVI), which was established by scientists at the United States Geological Survey (USGS) (Hammar-Klose and Thieler, 2001) (Fig. 5-1). This assessment of coastal vulnerability to future sea level rise combines information about coastal geomorphology, shoreline erosion and accretion rates, coastal slope, rate of relative sea level rise, mean tidal range, and mean wave height. The resulting USGS CVI values were calculated for the coastal regions of the contiguous United States. We assigned a score for each reserve based on the highest USGS score within the reserve boundaries. In order to match the geographic scale of the social, biophysical and ecological indices, multicomponent reserves (reserves incorporating more than one geographic location) such as the Chesapeake Bay Maryland NERR were also assigned a single CVI score.

Figure 5-1. Coastal Vulnerability Index (CVI) (Hammer-Klose and Thieler, 2001; http://pubs.usgs.gov/dds/dds68/)



Air temperature rise represents a main component of global climate change, so using data obtained from the online, web-based program called The Climate Wizard Tool (http://www.climatewizard.org/AboutUs.html) (Girvertz et. al., 2009) we projected the change in annual average atmospheric temperature by the 2050s for each reserve. Base climate projections for the online tool were downscaled by Maurer et al. (2007). Table 5-1 shows the temperature change data obtained from Climate Wizard. For the analysis, we choose to use an air circulation model which predicted temperature changes in the middle of all available models (Ensemble Average) and a moderate green-house gas emissions scenario (medium A1B) based on the Intergovernmental Panel on Climate Change Special Report (Girvetz et. al., 2009).

Table 5-1. Estimate of reserve temperature change exposure[a].

Reserve	Projected Change in Annual Average Temperature by the 2050s (oF)
Lake Superior, WI	5.4
Old Woman Creek, OH	5.1
Great Bay, NH	4.8
Wells, ME	4.8
Hudson River, NY	4.7
Narragansett Bay, RI	4.5
Jacques Cousteau, NJ	4.5
Delaware	4.4
Waquoit Bay, MA	4.4
Chesapeake Bay, MD	4.3
Chesapeake Bay, VA	4.1
Mission-Aransas, TX	4.1
Grand Bay, MS	4.0
Tijuana River, CA	4.0
Weeks Bay, AL	4.0
ACE Basin, SC	3.8
Sapelo Island, GA	3.8
North Carolina	3.8
Apalachicola, FL	3.7
Elkhorn Slough, CA	3.7
San Francisco Bay, CA	3.7
Padilla Bay, WA	3.7
North Inlet-Winyah, SC	3.6
Guana Tolomato Matanzas, FL	3.6
South Slough, OR	3.3
Rookery Bay, FL	3.2
Kachemak Bay, AK	2.3
Jobos Bay, Puerto Rico	1.6

[a]Data obtained from Climate Wizard ((http://www.climatewizard.org/AboutUs.html)

Comparison of Indicators across the NERRS

Relative scores for all five indices of potential climate change impacts are presented by reserve in Table 5-2. From the perspective of the NERR system, social sensitivity, temperature exposure, and sea level

Table 5-2 . Indicators of climate sensitivity, resiliency and exposure for each reserve.

□ ░ ▒ ▓ █ --- No Data

The darker the shading the higher the level of climate sensitivity or exposure and the lower the ecological resiliency.

Region	Reserves	Social Sensitivity to Climate Impacts	Biophysical Sensitivity to Climate Impacts	Ecological Resiliency	Temperature Change Exposure	Sea Level Rise Exposure
Caribbean	Jobos Bay (PR)	▓	---	▒	□	---
Great Lakes	Lake Superior (WI)	▓	---	▓	█	---
	Old Woman Creek (OH)	▒	░	█	█	---
Gulf of Mexico	Apalachicola (FL)	▓	░	░	▒	█
	Grand Bay (MS)	▒	□	▓	▓	█
	Mission Aransas (TX)	▓	---	░	▓	█
	Rookery Bay (FL)	□	▒	▓	▒	▓
	Weeks Bay (AL)	▒	░	█	▓	□
Mid-Atlantic	Chesapeake Bay (MD)	░	░	▒	▓	█
	Chesapeake Bay (VA)	░	░	▓	▓	█
	Delaware (DE)	▒	▒	▒	▓	░
	Jacques Cousteau (NJ)	░	▒	▒	▓	█
Northeast	Great Bay (NH)	▒	▒	▒	▓	□
	Hudson River (NY)	▒	▒	▓	▓	---
	Narragansett Bay (RI)	▒	□	□	▓	□
	Waquoit Bay (MA)	□	▓	█	▓	▓
	Wells (ME)	░	▒	▒	▓	□
Southeast	ACE Basin (SC)	▒	▓	□	▒	█
	Guana Tolomato Metanzas (FL)	░	░	□	▒	▓
	North Carolina (NC)	░	▒	▒	▒	█
	North Inlet-Winyah Bay (SC)	░	░	□	▒	▓
	Sapelo Island (GA)	▒	█	□	▒	▓
West Coast	Elkhorn Slough (CA)	█	░	█	▒	█
	Kachemak Bay (AK)	█	---	▒	░	---
	Padilla Bay (WA)	▓	░	░	▒	---
	San Francisco Bay (CA)	▒	---	█	▒	█
	South Slough (OR)	█	░	░	░	█
	Tijuana River (CA)	▓	█	█	▓	█

rise showed some notable regional trends. With respect to social sensitivity, reserves on the West Coast tended to have higher relative sensitivity to climate change than reserves in other regions. Social sensitivity index values were also relatively high for Mission-Aransas and Apalachicola in the Gulf of Mexico, Jobos Bay in the Caribbean and Lake Superior in the Great Lakes.

Reserves in the Gulf of Mexico, Mid-Atlantic, Northeast, and Great Lakes are at greater risk from exposure to increased air temperatures than those in the Southeast or West Coast. Both reserves in the Great Lakes, Old Woman Creek and Lake Superior, were classified as being at very high risk of exposure to increased air temperature changes, while all reserves in the Northeast and Mid-Atlantic regions were classified as having high exposure risk to air temperature changes.

Reserves in the Gulf of Mexico, parts of the Mid-Atlantic, Southeast, California and Oregon are at greatest risk of sea level rise exposure.

Within the NERRS, relative biophysical sensitivity was classified as very high or high at only four out of 25 reserves, with these four reserves scattered across the Northeast, Southeast, and West Coast. Likewise, reserve ecological resiliency was highly variable within most regions, although reserves in the Southeast tended to have relatively higher resiliency than other regions.

The Tijuana River and Waquoit Bay reserves had the most notable climate change rankings. Tijuana River was the only reserve where all five indices indicated a relatively high likelihood of potential climate change impacts. This reserve is part of a watershed that includes U.S. and Mexican land, high-density housing, and four water reservoirs. Therefore, management of this reserve for potential climate change impacts will require international cooperation and could prove challenging. Similar to Tijuana River, Waquoit Bay was classified as having relatively high biophysical sensitivity, temperature change exposure, and sea level rise exposure, while also having very low ecological resiliency. In contrast, the social sensitivity for Waquoit Bay was classified as very low.

There were many other reserves with relatively high index values for a subset of the indicators. For example, Grand Bay and Chesapeake Bay Virginia reserves appear to have high exposure to changes in atmospheric temperatures and sea level rise and lower ecological resiliency. Even though these two reserves are currently assessed as having relatively low social and biophysical sensitivity compared to the other reserves, they should be viewed as reserves that will likely be impacted by several important climate change stressors, especially if pressures from anthropogenic sources continue to increase.

Not surprisingly, synthesis of these five indicators of potential climate change impact show that the indicators do not co-vary across the NERRS. The relative importance of this information to a particular reserve and the management implications of climate change will depend on additional local analyses and the overall management goals at that reserve. A Planning Guide for State Coastal Managers (NOAA, 2010) provides a good context for how this report’s results can be used:

> “a climate change adaptation plan identifies and assesses the impacts that are likely to affect the planning area, develops goals and actions to best minimize these impacts, and establishes a process to implement those actions.”

The calculation of social and biophysical sensitivities and of ecological resilience will help the NERRS identify and assess likely impacts, and plan accordingly. For example, several reserves on the West Coast have, relatively speaking, very high social sensitivity to climate stressors due to cultural barriers, natural resource-dependent jobs, and wealth and household composition factors, but relatively low sensitivity and vulnerability for the indices related to biophysical sensitivity and temperature change exposure. Climate change planning for these areas may need to include expanded efforts related to societal factors such as local economies and infrastructure. Conversely, Waquoit Bay was classified as being sensitive or vulnerable to all indices except for social sensitivity. As a result, managing for climate change at this reserve may emphasize potential physical changes to the reserve (e.g. effects of rising sea level and biological impacts of changing water quality characteristics).

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The impacts of climate change are projected to have significant impacts on both terrestrial and aquatic environments globally (IPCC 1990a, IPCC 2001a, IPCC 2007b). Several characteristics of estuaries, such as high biological productivity and intense human use, increase the importance of climate change to estuarine systems over many other environments. To our knowledge, this represents the first national climate sensitivity analysis of U.S. estuaries. Thus, this report provides useful and timely information regarding the sensitivities of estuarine systems in the United States to changes in climate. In addition, this research was defined at the onset as an integrated social and biophysical analysis. While the need for integrated, interdisciplinary efforts is well documented, such efforts are still the exception rather than the norm. The research outlined in this report offers important lessons related to integrated approaches, and those lessons complement and add to the empirical findings of the research.

To summarize, some of the salient points that can be drawn from the synthesis of the five indices in this report (Table 5-2) predict that:

1. All reserves will be impacted by climate change at some level, with all reserves having one or more indices rated as high (or very high).

2. Social sensitivity is of particular concern along the West Coast and at isolated reserves in the Caribbean, Great Lakes, and Gulf of Mexico.

3. Biophysical sensitivity is of highest relative concern at isolated reserves in the Southeast and

on the West Coast. The relevance of biophysical sensitivities at each reserve will also be determined by the natural resource management objectives of that reserve.

4. Sea level rise will be a concern across all regions, with slightly less impact predicted for the Northeast than for other regions.

5. Temperature change exposure will be a concern over most regions, with the largest effects in the Great Lakes, Northeast and Mid-Atlantic

6. The climate change indicators do not all co-vary. This means that reserves will have to consider different climate change stressors in their climate change vulnerability assessments and plan management strategies accordingly.

7. Comparison of indicators reveals several reserves with notable climate change sensitivity. In relative terms, the Tijuana River Reserve has the highest risk for climate change impacts when looking across all five indices. Waquoit Bay Reserve is also at high risk.

8. A better understanding of climate change vulnerability at the individual reserve level will require reserve-specific analyses.

Some salient points related to integrated approaches that were learned through this effort include the following:

1. Defining an approach, strategy, or research effort as integrated at the onset helps define expectations and roles, which leads to more coherent and collaborative integration.

2. Integrated approaches need to include time for interdisciplinary learning. The language, methods, and concepts of disciplines are often different and, as a result, integrated projects create learning opportunities and enhance perspectives for all involved.

3. Integration of data across disciplines can prove quite challenging; however, even when quantitative integration of data is not possible, qualitative integration can produce valuable results and important insights.

Recommendations

This work is foundational. Like all research, it both improves understanding and highlights deficiencies. Important lessons were learned, which led to several recommendations for building upon this foundation.

Combining climate change information across disciplines (e.g. social and biophysical) provided a much more holistic view than would have been offered by any one of these areas by itself. A major strength of this study is the collaborative nature of the research. From the outset the project was designed to involve reserve staff, whose expertise was critical in estimating the ecological resiliency of the reserves. This helped focus attention on the management concerns of individual reserves and the implication of our climate change findings relative to those issues, and provided valuable input on the strengths and limitations of the SWMP data. A project steering committee, composed of reserve staff and various federal agencies working in the climate change arena, also provided a forum for the project team to assess the utility of the various analytical approaches for the project. This helped guide the project's cross-disciplinary analytical strategy by providing feedback on which approaches being considered by the project team might prove most useful to the NERRS. Future efforts to assess conditions across the NERRS would benefit from this multidisciplinary and collaborative analytical approach.

This effort involved the compilation and processing of data in new ways and for purposes outside the original intent of the SWMP sampling framework, which was originally designed to assess impacts from non-point source pollution and changing land use practices across the NERRS. One unexpected limitation we encountered was that we couldn't incorporate nutrient data into our analyses due to the variable collection of the data among reserves. We strongly recommend the continued, systematic collection of SWMP water quality data (both physical and nutrient), which will allow the inclusion of reserves and stations that had to be excluded from the biophysical sensitivity analysis and improve the characterization of those that were included. The relationship of water quality variables to climate can be strengthened by the centralization and standardization of data collected by SWMP stations (e.g. water depth, distance from shore, tidal amplitude and current velocity) as well as watershed characteristics (e.g. water volume, land-use dynamics, and average elevation). We think the new Sentinel Site approach (NERRS, 2012), which expands environmental measurements at the reserves with the goal of assessing local impacts of climate change, is a good approach to strengthening the available data set for assessing climate change impacts in the reserves. Monitoring of these sites over a long time period will be critical for making climate change observations.

This synthesis has applicability to climate change planning and monitoring at for both the NERR System and individual reserves. Opportunities to expand the analysis beyond the NERRS should be sought, since the process we employed for development of the social and biophysical indices, as well as the understanding of climate sensitivities in estuarine systems, could be applied to analyze other estuarine networks such as EPA's National Estuary Program.

The focus of the research presented in this report was on long-term climate change impacts (e.g. over years). Profound impacts to reserve conditions also result from more short-term weather events, such as hurricanes and other severe storms. While the social sensitivity analysis does provide some insights into potential social impacts from extreme events, a more purposeful and thorough analysis of extreme event sensitivity should be conducted to examine these types of impacts in more detail.

References

Cutter, S. L. (2003). Social vulnerability to environmental hazards. Social Science Quarterly, 84, 242–261.

Dillman, D. A., Smyth, J. D., & Christian, L. M. (2009). Internet, mail, and mixed-mode surveys: The tailored design method (3rd ed.). Hoboken, NJ: John Wiley & Sons, Inc.

Girvetz E. H., Zganjar, C., Raber, G. T., Maurer, E. P., Kareiva, P., & Lawler, J. J. (2009). Applied climate-change analysis: The Climate Wizard Tool [Online]. Available: PLoS ONE 4(12): e8320. doi:10.1371/journal.pone.0008320

Glick, P., Stein, B. A., & Edelson, N. A. (Eds.). (2011). Scanning the conservation horizon: A guide to climate change vulnerability assessment. Washington, D.C.: National Wildlife Federation.

Hagy, J. D., Boynton, W. R., Keefe, C. W., & Wood, K. V. (2004). Hypoxia in Chesapeake Bay, 1950–2001: long-term change in relation to nutrient loading and river flow. Estuaries, 27, 634-658.

Hammar-Klose, E.S., & Thieler, E.R. (2001) Coastal vulnerability to sea level rise: A preliminary database for the U.S. Atlantic, Pacific and Gulf of Mexico Coasts [Online]. U.S. Geological Survey Digital Data Series – 68. Available: http://pubs.usgs.gov/dds/dds68/.

Harley, C. D., Hughes, A. R., Hultgren, K. M., Miner, B. G., Sorte, C. J. B., Thornber, C. S., Rodriguez, L. F., Tomanek, L., & Williams, S. L. (2006). The impacts of climate change in coastal marine systems. Ecology Letters 9 (2), 228-241.

Intergovernmental Panel on Climate Change [IPCC]. (1990a). Climate change: The IPCC scientific assessment. Houghton, J. T., Jenkins, G. J., & Ephraums, J. J. (Eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Intergovernmental Panel on Climate Change [IPCC]. (1990b). Climate change: The IPCC impacts assessment. McG Tegart, W. J., Sheldon, G. W., & Griffiths, D. C. (Eds.). Canberra, Australia: Australian Government Publishing Service.

Intergovernmental Panel on Climate Change [IPCC]. (1990c). Climate change: The IPCC response strategies, report prepared for intergovernmental panel on climate change by working group III.. World Meterological Organization/United Nations Environment Program, Intergovernmental Panel on Climate Change. Covelo, CA: Island Press.

Intergovernmental Panel on Climate Change [IPCC]. (2001a). Climate change 2001: The scientific basis. Contribution of working group I to the third assessment report of the Intergovernmental Panel on Climate Change. Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K., & Johnson, C. A. (Eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Intergovernmental Panel on Climate Change [IPCC]. (2001b). Climate change 2001: Impacts, adaptation, and vulnerability. McCarth, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J. & White, K. S. (Eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Intergovernmental Panel on Climate Change [IPCC]. (2001c). Climate change 2001: Mitigation. World Meterological Organization/United Nations Environment Program, Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Intergovernmental Panel on Climate Change [IPCC]. (2007). Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor M., & Miller, H. L. (Eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Intergovernmental Panel on Climate Change [IPCC]. (2007a). Climate change 2007: Synthesis report. Contribution of working groups I, II, and III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Pachauri, R. K., & Reisinger, A. (Eds.). Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Intergovernmental Panel on Climate Change [IPCC]. (2007b). Climate change 2007: The physical science basis. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M.,. Averyt, K.B, Tignor, M., & Miller, H.L. (Eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Intergovernmental Panel on Climate Change [IPCC]. (2007c). Climate change 2007: Mitigation. Contribution of working group III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Metz, B., Davidson, O. R., Bosch, P. R., Dave, R., & Meyer, L. A. (Eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Intergovernmental Panel on Climate Change [IPCC]. (2007d). Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Parry, M. L., Canziani, O. F., Palutikof, J. P, van der Linden, P. J., & Hanson, C. E. (Eds.). Cambridge, United Kingdom: Cambridge University Press.

Jarvis, J. C., & Moore, K. (2010). The role of seedlings and seed back viability in the recovery of Chesapeake Bay, USA, Zostera marina populations following a large-scale decline. Hydrobiolobia 649, 55-68.

Kaiser, H. F. (1960). The application of electronic computers to factor analysis. Educational and Psychological Measurement, 20, 141-151.

Karl, T. R., Melillo, J. M., & Peterson, T. C. (Eds.). (2009). Global climate change impacts in the United States. A state of knowledge report from the U.S. Global Change Research Program. Cambridge University Press [Online]. Available: http:// www.globalchange.gov/publications/reports/scientific-assessments/us-impacts

Kirwan, M. L., Guntenspergen, G. R., D'Alpaos, A., Morris, J. T., Mudd, S. M. & Temmerman, S. (2010). Limits on the adaptability of coastal marshes to rising sea level. Geophysical Research Letters 37, L23401.

Maurer, E. P., Brekke, L., Pruitt, T., & Duffy, P. B. (2007). Fine-resolution climate projections enhance regional climate change impact studies. Eos Trans. AGU, 88 (47), 504.

Moore, K. A., & Jarvis, J. C. (2008). Environmental factors affecting recent summertime eelgrass diebacks in the lower Chesapeake Bay: Implications for long-term persistence. J. Coast. Res. 55, 135-147.

Moore, K. A., Shields, E. C., Parrish, D. B., & Orth, R. J. (2012). Eelgrass survival in two contrasting systems: role of turbidity and summer water temperatures. Mar. Ecol. Prog. Ser. 448, 247-258.

Murowski, S. (1993). Climate change and marine fish distributions: Forecasting from historical analogy. Transactions of the American fisheries Society, 122 (5), 647-658.

Orth, R.J., & Heck, K.L., Jr. (1980). Structural components of eelgrass (Zostera marina) meadows in the lower Chesapeake Bay – Fishes. Estuaries 3, 278-288.

National Estuarine Research Reserve System (NERRS). (2012). The NERRS sentinel sites program guidance for climate change impacts. Washington, DC: NOAA Estuarine Reserves Division.

National Oceanic and Atmospheric Administration [NOAA]. (2010). Adapting to Climate Change: A Planning Guide for State Coastal Managers [Online]. Available: http://coastalmanagement.noaa.gov/climate/adaptation.html

Norton, S. B., Rodier, D. J., van der Schalie, W. H., Wood, W. P., Slimak, M. W., & Gentile, J. H. (1992). A framework for ecological risk assessment at the EPA. Environmental Toxicology and Chemistry, 11, 1663–1672.

Pyke, C., Najjar, R., Adams, M. B., Breitburg, D., Hershner, C., Kemp, M., Howarth, R., Mullholland, M., Paolisso, M., Secor, D., Sellner, K., Wardrop, D., & Wood, R. (2008). Climate change and the Chesapeake Bay: State-of-the-science review and recommendations [Online]. Edgewater, MD: Chesapeake Bay Program STAC. Available: http://www.chesapeake.org/pubs/climatechangefinaldraft.pdf.

Scavia, D., Field, J. C., Boesch, D. F., Buddemeier, R. W., Burkett, V., Cayan, D. R., Fogarty, M., Harwell, M. A., Howarth, R. W., Mason, C., Reed, D. J., Royer, T. C., Sallenger, A. H., & Titus, J. G. (2002) Climate Change Impacts on U.S. Coastal and Marine Ecosystems. Estuaries, 25 (2), 149-164.

Schimdtlein, M. C., Deutsch, R. C., Piegorsch, W. W., Cutter, S. L. (2008). A sensitivity analysis of the social vulnerability index. Risk Analysis, 28 (4), 1099-1114.

Sellner, K. G. (Ed.) (2005) Hurricane Isabel in perspective (CRC Publication 05-160). Edgewater, MD: Chesapeake Research Consortium.

Sharma, S. (1996). Applied multivariate techniques. New York: John Wiley & Sons.

Shepard, C., Agostini, V., Gilmer, B., Allen, T., Stone, J., Brooks, W., & Beck, M. (2012). Assessing future risk: quantifying the effects of sea level rise on storm surge risk for the southern shores of Long Island, New York. Natural Hazards, 60 (2), 727-745.

Skinner, L. (2012). A long view on climate sensitivity. Science, 337, 917-919.

University of South Carolina. (2012). Social Vulnerability Index for the United States – 205-2009 [Online]. Available: http://webra.cas.sc.edu/hvri/products/sovi2009.aspx

Winder, M., & Schindler, D. E. (2004. Climate change uncouples trophic interactions in an aquatic ecosystem. Ecology, 85 (8), 2100–2106.

Key Terms

Attribute is an inherent or ascribed reserve socio-economic or biophysical quality or characteristic.

Disaster: Severe alterations in the normal functioning of a community or a society resulting from the interaction of hazardous physical events and vulnerable social conditions that leads to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery (IPCC, 2007c).

Climate: Climate in a narrow sense is usually defined as the average weather or, more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. The classical period of time is 30 years as defined by the World Meteorological Organization (IPCC, 2007d).

Climate Change: Climate change refers to any change in climate over time due to natural variability or human activity (IPCC, 2007d).

Climate Stressor is any physical, chemical, or biological entity primarily associated with a changing climate that causes an adverse impact on reserve socio-economic or biophysical attributes (NOAA, 2010).

Climate Sensitivity, in the context of this report, is defined as whether and how a reserve or group of reserves will be affected by a change in climate conditions, measured over the particular environmental or social geography.

Ecological Integrity is and estuaries' ability to support and maintain key functional processes and intact abiotic and biotic components.
Ecological Resiliency is the ability of a reserve ecosystem to recover from a disturbance or impact, such as a climate hazard, without substantial loss of ecological structure or function
Ecological Stressor is any factor that causes an adverse impact to ecological integrity.
Exposure is the nature and degree to which a system is exposed to significant climatic variations (IPCC, 2001b).

Non-climate Stressor is any physical, chemical, or biological entity not primarily associated with a changing climate that causes an adverse impact on reserve socio-economic or biophysical attributes (Norton et al., 1992).

Overall Ecological Stress is an estimate of the cumulative impact of all the ecological stressors impacting a reserve.
Reserve is a generic term used to refer to the designated locations or activities (e.g. reserve research) within the National Estuarine Research Reserve System.

Resilience is the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner through ensuring the preservation, restoration, or improvement of its essential basic structures and functions (IPCC, 2007c).

Risk is the combination of the probability of an event and its consequences (IPCC, 2001b).

Sensitivity is a measure of whether and how a reserve or group of reserves is likely to be affected by both climate and non-climate stressors (Glick et al., 2011).

Sentinel Sites, in the context of this report, are reserve monitoring locations that have the operational capacity for intensive study and sustained observations to detect and understand changes in the ecosystems they represent, like sea level rise and coastal inundation (NERRS, 2012).

Social vulnerability or sensitivity to climate change is the degree to which society or a defined social unit is susceptible to and unable to cope with the adverse effects of climate change.

Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. There are three components to vulnerability as the term is used in this report: sensitivity, resilience, and exposure.

ACRONYMS AND ABBREVIATIONS

ACS:	American Community Survey
BpSI:	Biophysical Sensitivity Index
CDMO:	Centralized Data Management Office
CVI:	Coastal Vulnerability Index
ENOW:	Economics: National Ocean Watch program
GDP:	Gross Domestic Product
GIS:	Geographic Information System
HCA:	Hierarchical Cluster Analysis
IPCC:	Intergovernmental Panel on Climate Change
NCDC:	National Climatic Data Center
NERR:	National Estuarine Research Reserve
NERRS:	National Estuarine Research Reserve System
NOAA:	National Oceanic and Atmospheric Administration
NOEP:	National Ocean Economics Program
PCA:	Principal Component Analysis
SoVI:	Social Vulnerability Index
SSCII:	Social Sensitivity to Climate Impacts Index
SWMP:	System-Wide Monitoring Program
USC:	University of South Carolina
USGS:	United States Geological Survey

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