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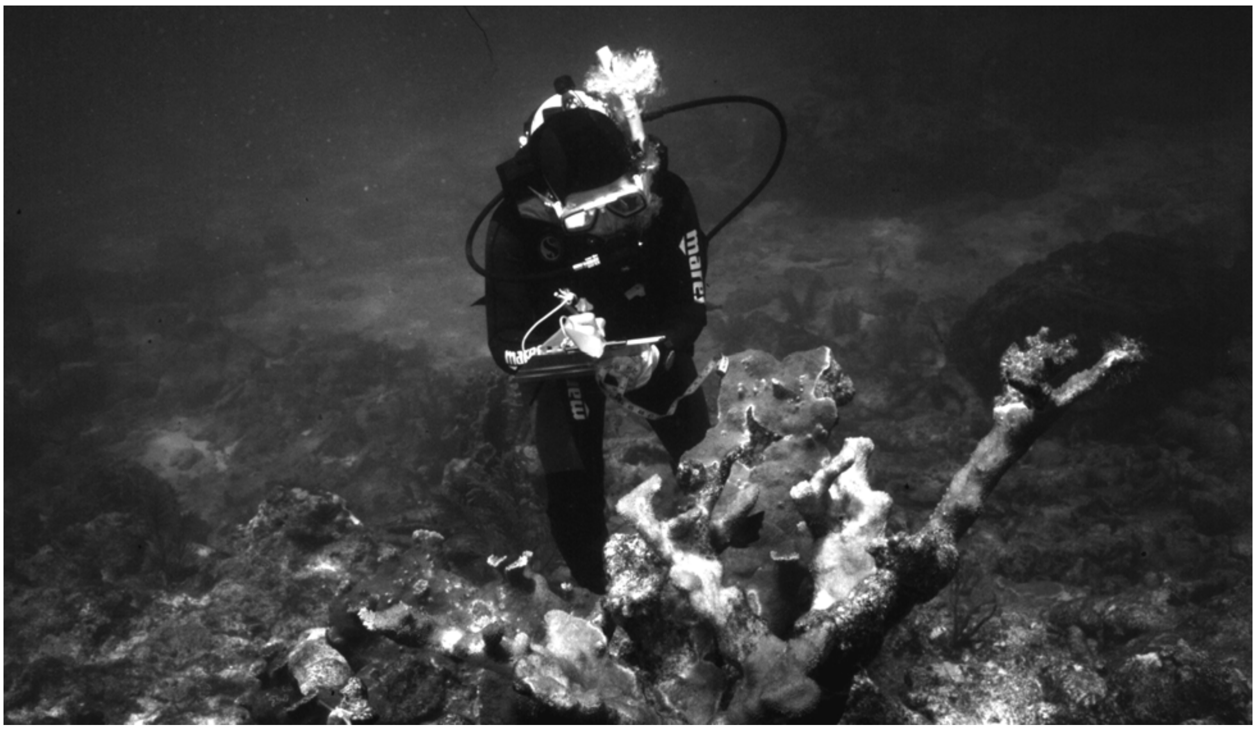
NOAA Fisheries Technical Guidance Manual for Success Criteria in Restoration Projects



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EXECUTIVE SUMMARY

The objective of the NOAA Fisheries Success Criteria Guidance is to provide technical assistance for sound scientific monitoring of restoration activities that maximize, to the greatest extent possible, benefits to Living Marine Resources (LMR) and their habitats. One of the missions of NOAA Fisheries is to restore degraded LMR habitat and conserve and protect restored and acceptable LMR habitat. In developing this guidance, NOAA Fisheries recognizes that individual restoration and monitoring projects must be judged in the context of their spatial and temporal environments as well as their relationship to other activities (i.e. potential impacts to habitat should be viewed from a watershed management perspective). This guidance document provides an opportunity to develop scientifically sound, appropriate success criteria in support of restoration activities.

Restoration is the process of reestablishing a self-sustaining habitat that, in time, can come to closely resemble a natural condition in terms of structure and function. LMR habitat must be enhanced and conserved, as well as restored. Conserving LMR and their habitats is central to the mission of NOAA Fisheries and is mandated through procedures such as in the Magnuson-Stevens Fishery Conservation Act, Clean Water Act, Endangered Species Act, and Fish and Wildlife Coordination Act (see Appendix F). Restoration is only one of many tools available to turn the tide of habitat loss and degradation.

Thirteen coastal and marine habitat types (Appendix A) are addressed in terms of success criteria and monitoring. Specific structural and functional characteristics of each habitat type are listed to provide guidance in selecting success criteria (Appendix B). Other information includes a list of experts by habitat type (Appendix C), references to appropriate monitoring and sampling methods (Appendix D), an annotated bibliography (Appendix E), summaries of major environmental acts that support monitoring (Appendix F), and cost estimates for monitoring, including labor, equipment and supplies (Appendix G).

SUCCESS CRITERIA AND MONITORING GUIDANCE
NOAA FISHERIES

I. INTRODUCTION

NOAA Fisheries is responsible for conserving and restoring Living Marine Resources (LMR) and their habitats. Living Marine Resources will be repeatedly referred to simply as LMR. These NOAA Fisheries trust resources include anadromous and marine fishes, marine mammals, and sea turtles. The NOAA Fisheries Success Criteria and Monitoring Guidance manual addresses coastal and marine habitat restoration project implementation. If one does not have quantifiable success criteria: (a) inappropriate and/or unmeasurable goals may be established; (b) a lack of appropriate measures to establish the need for mid-course corrections would exist; (c) there would be no basis for the establishment of contractual compliance; (d) successful achievement of objectives may not be quantifiable. The guidance presented in the following sections of this document addresses these concerns by providing minimal monitoring criteria to determine restoration success and/or progress from project, regional, and national perspectives as well as at program and policy levels.

The objective of the Guidance is to insure that restoration and subsequent monitoring operations are conducted in a manner that maximizes, to the greatest extent possible, benefits to LMR and their habitats. One of the missions of NOAA Fisheries is to restore degraded LMR habitat and conserve and protect restored and viable LMR habitat. While this guidance is intended to direct NOAA Fisheries development and implementation of restoration projects, it has many implications for judging mitigation under NOAA Fisheries' Habitat Protection mission as well. In developing this guidance, NOAA Fisheries recognizes that individual restoration and monitoring projects must be judged in the context of their spatial and temporal environments as well as their relationship to other activities, i.e. potential impacts to habitat should be viewed from a watershed management perspective. This guidance document provides an opportunity for developing scientifically sound and appropriate success criteria for specific projects.

Restoration is the process of reestablishing a self-sustaining habitat that, in time, can come to closely resemble a natural condition in terms of structure and function. Living Marine Resource habitat must be enhanced and conserved, as well as restored. Prevention of the loss of LMR and their habitat is central to the mission of NOAA Fisheries and is mandated through procedures such as those related to consultations for Essential Fish Habitat (EFH). Restoration is only one of many tools available to turn the tide of habitat loss and degradation.

Responsibility for protection, conservation, and restoration of coastal habitat is a shared trusteeship responsibility with the states, Tribal Nations, and other federal departments of the U.S. Through authority delegated by the Secretary of Commerce, NOAA Fisheries is responsible for the protection, conservation, and restoration of LMR and their coastal and marine habitats under several federal mandates. Legislative authority includes the Clean Water Act, Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA), Comprehensive Environmental Response, Compensation and Liability Act (CERCLA or Superfund), Magnuson-Stevens Fishery Conservation and Management Act, the National Environmental Policy Act

(NEPA), the National Marine Sanctuaries Act (NMSA), the Oil Pollution Act of 1990 (OPA), and other related laws, such as the Endangered Species Act. None of the recommendations presented in this document are intended to supersede these pieces of legislation, their supporting regulations or any other laws. Rather, the recommendations are offered to help restoration project managers further the policies and goals of this agency by standardizing methods of evaluating restored habitat structure and function (see Appendix F for summaries of these acts).

The authors would like to thank those listed in Appendix C for their extensive assistance in preparing this document. In addition, the authors would like to especially recognize Dr. Joy Zedler and her associates, Dr. Carolyn Currin, and Mr. Jim Bybee for their very thoughtful reviews. This manual was extensively coordinated and reviewed within NOAA and other federal agencies, state and local governments, restoration practitioners, and academics.

This Guidance is subject to comprehensive review and revision to be initiated and coordinated by the NOAA Restoration Center. The text of the Guidance, as well as additional information on the NOAA Restoration Center, may be found on the World Wide Web at http://www.nmfs.gov/habitat/restoration. Inquiries may also be sent to the NOAA Restoration Center, National Marine Fisheries Service (F/HC3), 1315 East-West Highway, Silver Spring, MD 20910.

II. SCOPE OF SUCCESS CRITERIA GUIDANCE

The types of restoration activities described in this Guidance encompass LMR coastal and marine habitats. The scope of restoration includes coastal, estuarine and anadromous fish habitats, including tidal rivers, freshwater rivers and streams, and their associated wetlands and riparian zones. Based on opinions of restoration experts, the coastal and marine environment are divided into 13 habitat types (see Appendix A) and presented in this guidance document. The geographic range of these habitats extends from the open ocean into adjacent uplands. All habitat types provide some form of refuge and/or food resource for LMR.

Fully functioning restored systems are resilient, self-sustainable, and produce a quantity and diversity of organisms of similar composition to natural or reference systems. Part of this full functionality includes structural components such as a certain minimum level of water quality; sediment that is not contaminated, appropriate grain sizes; hydrodynamics that allow for removal or dilution of wastes/pollutants and colonization or dispersal of new recruits; and an abundance and diversity of flora and fauna similar to natural systems. This Manual addresses both structural and functional attributes of the ecosystem in question. Measures to monitor the success of restoration projects should include evaluations of these attributes. Structural success criteria include characteristics of the habitat's water quality, sediment type, hydrodynamic properties, topography, morphology, flora and fauna. Functional success criteria include the desired nutrient cycling, oxygen production, persistence and resilience of the created or restored habitat, provision of habitat for food resources and/or refuge, biomass production, and linkages to adjacent ecological systems. Achieving success is not a pass/fail test; rather it is the measurement of gradual progress toward ecological recovery. Decision-making procedures on using success criteria and monitoring protocols are summarized in Figure 1.

These criteria should be based on known conditions of the target or reference ecosystem. They should be developed during restoration planning and design, and should be linked to specific project or regional objectives (Zedler 1995). Additional information sources on monitoring methods are referenced in Appendix D.

III. PROBLEMS ASSOCIATED WITH LACK OF SUCCESS CRITERIA

Restoration failures, i.e. not achieving project goals and objectives, may occur for several different reasons:

1. Restoration may not provide the ecological benefits that were intended in project planning. It is impossible to determine whether functional habitat benefits are realized unless success criteria and monitoring are identified and implemented.

2. Project objectives and success criteria are not clear. These projects lack accountable milestones to judge progress, and in the absence of assessment criteria, it is impossible to obtain early warnings that the restoration is not "on track". Restoration needs to be strategically monitored and measured against success criteria.

3. Restoration projects are carelessly implemented. A contractor may disregard engineering or biological specifications. The failure is not a fault of ecological science or engineering knowledge but of poor control and implementation. Success criteria are necessary to determine whether contractual compliance was achieved.

4. Design criteria are scrupulous but the project designer's knowledge is inadequate to produce a functional restoration design. Project managers must have several tools at their disposal to gauge how well a restoration site is functioning ecologically both before and after completion.

5. Project coordination is lacking. Multiple projects in the same watershed or ecosystem should be evaluated using a similar set of success criteria. Otherwise, a disjointed effort may produce a patchwork landscape of restoration sites with varying degrees of success (Galatowitsch et al. 1998). Sets of monitoring and success criteria are needed to standardize efforts by habitat type and/or region.

6. Funding limitations preclude extensive monitoring. In an era of budgetary constraints, project participants may prefer to implement as many restoration projects as possible with minimal regard for post-construction monitoring and evaluation. Using agreed-upon success criteria is the proper means of assuring the public that funds will provide measurable products. Furthermore, monitoring of established criteria is an excellent way to gain knowledge on ecological functions and possibly reduce the costs of subsequent restoration projects.

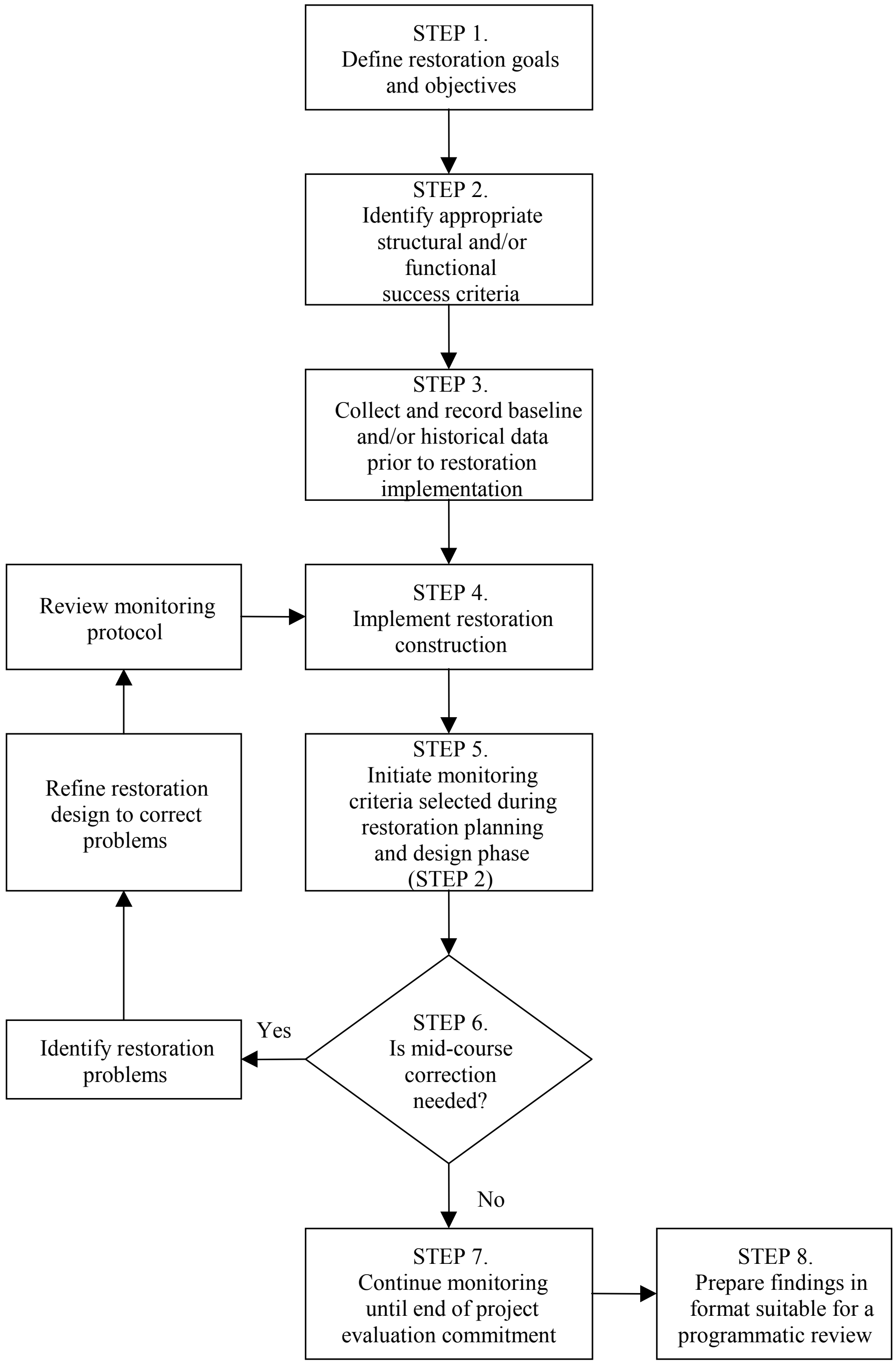
STEP 1.
Define restoration goals and objectives
STEP 2.
Identify appropriate structural and/or functional success criteria
STEP 3.
Collect and record baseline and/or historical data prior to restoration implementation
Review monitoring protocol
STEP 4.
Implement restoration construction
Refine restoration design to correct problems
STEP 5.
Initiate monitoring criteria selected during restoration planning and design phase (STEP 2)
Identify restoration problems
Yes
STEP 6.
Is mid-course correction needed?
No
STEP 7.
Continue monitoring until end of project evaluation commitment
STEP 8.
Prepare findings in format suitable for a programmatic review

Figure 1. Flowchart for success criteria and monitoring implementation.

7. Restoration as a science is still in the developmental stage. Applied ecological research is needed to determine the best methods of performing restoration and to further our understanding of landscape ecology.

IV. MONITORING IMPLEMENTATION

This section sets forth guidance for developing minimal monitoring criteria to determine restoration success and/or progress. The following boldface recommendations should not be regarded as static or inflexible. They may be revised as the science improves and areas of uncertainty are resolved. They are meant to be adaptable for regional or local use. A flowchart for success criteria priority and selection (Figure 2) is provided to aid in this process.

1. **Monitoring should last a minimum of three (3) to five (5) years following restoration activities.** Suggested monitoring time frames range anywhere between three to fifty years (D'Avanzo 1990; Zedler 1995; Bradshaw 1996; Mitsch & Wilson 1996; Simenstad & Thom 1996; Fonseca et al. 1998; USACE-WES 1999) depending on the objective of the restoration project. The restored system needs time to develop a natural range of ecological services. It is recommended that the system be monitored to a stable, successful end point.

2. **Monitoring should occur from high to low frequency as time progresses.** Immediately following the completion of restoration construction and a period of settling, monitoring should occur monthly or quarterly. This will gauge early progress of the restoration, and errors resulting from poor site preparation can be readily identified and corrected. Following the first year, the frequency may be scaled back depending on progress toward goals, success to date, and management objectives. Depending on project goals, some metrics may need to be measured with more frequency than others.

3. **NOAA Fisheries believes that at the very minimum, the following list of critical structural and functional characteristics for each of the 13 habitat types (a project could fall into one or more habitat types) must be considered in any restoration action undertaken to improve natural resources.**

- Riparian: Streamside canopy species, buffer zone, instream large woody debris (LWD), presence of boulders/rocks/cobbles/sand, water temperature, hydrogeomorphic degree of sinuosity and stream order, biomass production, identification of biological community structure, benthic invertebrate and finfish utilization (Hinton et al. 1995, *In-water restoration between Miller Sands and Pillar Rock Island, Columbia River*; Koski 1992, *Restoring stream habitats affected by logging activities*; Williams and Tuttle 1992, *The Columbia River: Fish habitat restoration following hydroelectric dam construction*; Gregory et al. 1991, *An ecosystem perspective of riparian zones*)

- Salt Marsh: Marsh surface elevation/slope, salinity, desirable vegetation species presence/absence, composition and percent cover, sediment grain size, fish and shellfish density/diversity, biomass production, flooding regime, organic matter content, identification of biological community structure, benthic invertebrate, finfish and bird

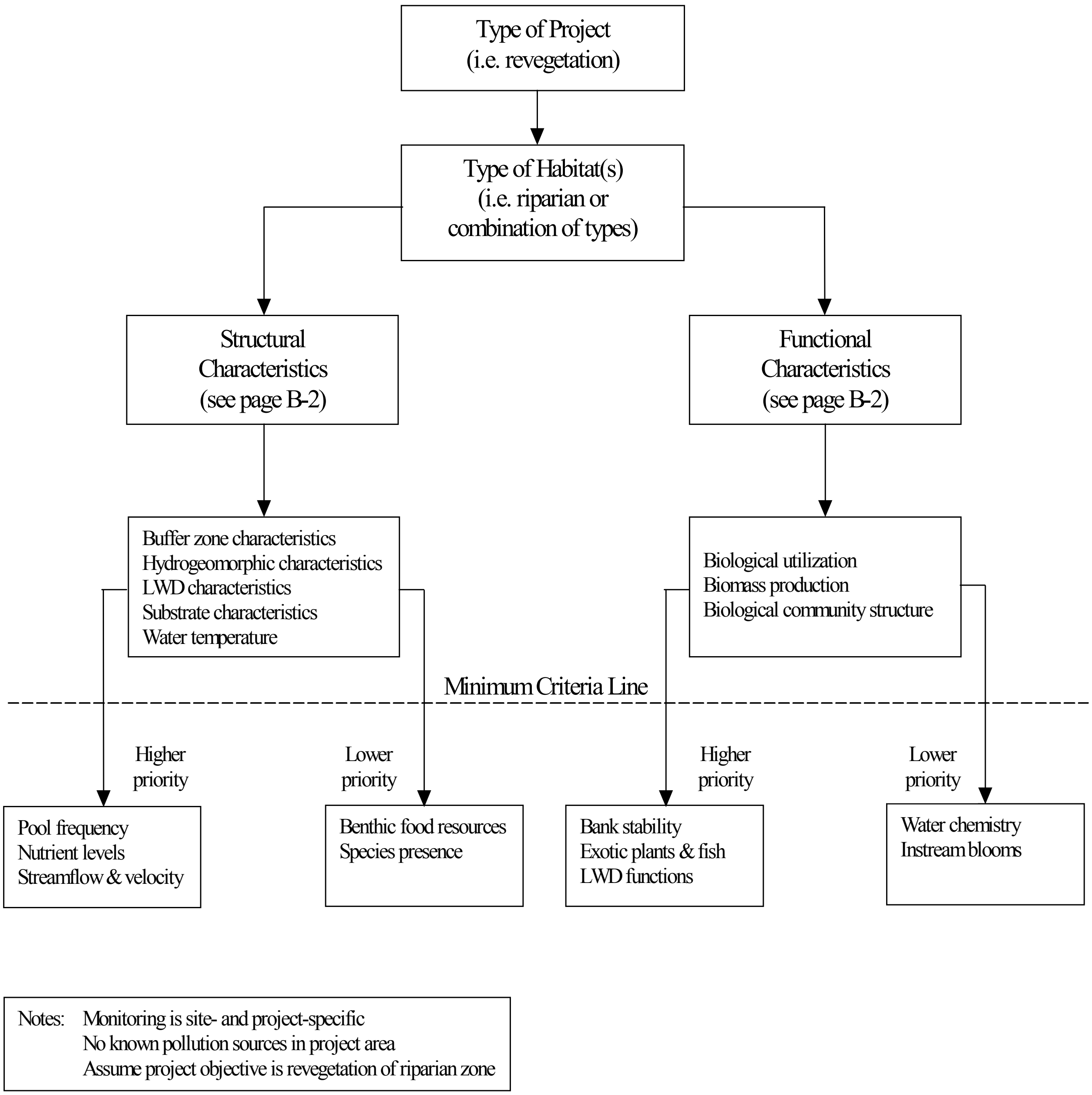

Figure 2. Flowchart for success criteria priority and selection.

utilization (Zedler 1992, *Restoring cordgrass marshes in southern California*; Zedler 1995, *Salt marsh restoration: lessons from California*; Zedler 1996, *Tidal Wetland Restoration: A Scientific Perspective and Southern California Focus*; Matthews and Minello 1994, *Technology and Success in Restoration, Creation, and Enhancement of Spartina alterniflora marshes in the United States; Copeland 1998, Salt Marsh Restoration: Coastal Habitat Enhancement; Roman et al. 1997, Accretion of a New England (U.S.A.) salt marsh in response to inlet migration, storms, and sea-level rise; Seneca and Broome 1992, Restoring tidal marshes in North Carolina and France)*

- Mangroves: Water salinity, temperature, hydrodynamics, floodwater retention, nutrient cycling, biomass production, identification of biological community structure, benthic invertebrate and finfish utilization (Cintron-Molero 1992, *Restoring mangrove systems*; Lugo et al. 1999, *Mangrove ecosystem analysis*)

- Rocky Shorelines: Hydrogeomorphologic characteristics as a result of energy dynamics, plant/animal zonation patterns, identification of biological community structure, benthic invertebrate and finfish utilization (Schlieper 1968, *Research Methods in Marine Biology*; Southwood 1966, *Ecological Methods*)

- Beaches: Natural organic input, topography and relief, identification of biological community structure, benthic invertebrate and finfish utilization (Salmon et al. 1982, *Dune Restoration and Revegetation Manual*; Stauble and Hoel 1986, *Physical and Biological Guidelines for Beach Restoration Projects*)

- Mud Flats: Salinity, slope and elevation/relief, flooding regime, development of creek/stream dendrisity, sediment grain size, sediment stability, identification of biological community structure, density/diversity of infauna and macrofauna, benthic invertebrate and finfish utilization (Short et al. in press, *Developing success criteria for multiple estuarine habitats*; Simenstad et al. 1991, *Estuarine Habitat Assessment Protocol*)

- Hard Bottom: Salinity, topographic complexity, source of attachment for sessile organisms, biomass production, identification of biological community structure, benthic invertebrate and finfish utilization (Simenstad et al. 1991, *Estuarine Habitat Assessment Protocol*; U.S. EPA 1992, *Monitoring Guidance for the National Estuary Program, Final*)

- Soft Bottom: Salinity, biomass production, sediment grain size, organic matter content, identification of biological community structure, benthic invertebrate and finfish utilization (Chesapeake Bay Program 1994, *Recommended Guidelines for Sampling and Analysis in the Chesapeake Bay Monitoring Program*, Simenstad et al. 1991, *Estuarine Habitat Assessment Protocol*; U.S. EPA 1992, *Monitoring Guidance for the National Estuary Program, Final*)Oyster Reef: Solid bottom 3-D substrate, sediment-free attachment surfaces for sessile organisms, identification of biological community structure, benthic invertebrate and finfish utilization (Clarke et al. 1999, *Dredged material as a substrate for fisheries habitat establishment in coastal waters*; Coen and Luckenbach in press, *Developing success criteria and goals for evaluating oyster reef restoration: ecological function or resource exploitation?*)

- Seagrass: Salinity, bottom coverage, biomass production, habitat stabilization and persistence, identification of biological community structure, benthic invertebrate and finfish utilization (Fonseca et al. 1998, *Guidelines for the Conservation and Restoration of Seagrasses in the United States and Adjacent Waters*; Short et al. in press, *Developing success criteria for restored eelgrass, salt marsh, and mud flat habitats*)

- Kelp: Suitable hard substrate, canopy with strong 3-D structure, biomass production, coverage, litter production, identification of biological community structure, benthic invertebrate, finfish, and mammal utilization (Schiel and Foster 1992, *Restoring kelp forests*; Simenstad et al. 1991, *Estuarine Habitat Assessment Protocol*)

- Coral Reef: Topographic complexity, stable 3-D hard substrate, breakwater for oceanic swells, cryptic habitat, accretion of hard substrate, biomass production, availability of shelter, shading, identification of biological community structure, benthic invertebrate and finfish utilization (Aronson and Swanson 1997, *Video Surveys of Coral Reefs: Uni- and Multivariate Applications*; Ginsburg et al. 1998, *Atlantic and Gulf Reef Assessment (AGRRA) Rapid Assessment Protocol*; Japp in press, *Coral Reef Restoration*)

- Water Column: Light penetration, turbidity, dissolved oxygen, salinity, temperature, biomass production (Albro et al. 1998, *Combined work/quality assurance plan for baseline water quality monitoring: 1998-2000*; APHA 1992, *Standard Methods for the Examination of Water and Wastewater, 18th ed.*; EPA 1993, *Volunteer Estuary Monitoring*: *A Methods Manual*)

More detailed structural and functional parameters and processes that are important to consider in characterizing any of these habitat types are provided in Appendix B. These should be considered in any monitoring plan depending on economic constraints and probably apply to pure scientific applications. Nonetheless, they suggest habitat functions to plan for in project design. If a critical criterion is not included in restoration or monitoring planning, a scientific justification for the exclusion of that criterion should be provided. Examples of literature that should be reviewed to determine methodologies, approaches, and/or statistical considerations are provided with examples here and in more depth in Appendices D and E.

4. **Historical data and reference sites should be used for comparison if readily available.** Historical information can provide insight into how the habitat functioned prior to degradation and provide a general "baseline" of ecological function. If undisturbed reference sites are available nearby, they may serve as a control for restoration progress to be gauged. Several reference sites should be used to establish a mean of metrics as a basis from which to judge "equivalency" of the restored habitat (Weinstein et al. 1997).
For example, the objective may be to establish a salt marsh with metrics that are 60-80% within the "bound of expectation" of several reference salt marshes nearby with similar elevations. Baseline monitoring should occur prior to restoration to determine seasonal and

interannual habitat flux.

5. **Experimental studies can be performed onsite in conjunction with restoration and monitoring.** Restoration science needs to be refined through carefully planned and executed experiments. Controlled, replicated field experiments can illustrate successes and failures in restoration methodologies and techniques. Both successes and failures need to be documented and published in order to further restoration science. In many instances, these experimental studies can and should be built into select restoration projects through dedicated funds from the project.

V. OPTIMUM MANAGEMENT

This section outlines an optimum example of monitoring and success criteria with a goal to maximize benefits to anadromous fish. This approach is intended only as an introduction for creating a very comprehensive assessment, management and monitoring program. Other examples can be found in the literature (Appendix E).

Phase I. Establish clearly defined project goals, objectives and criteria for successful restoration. Before construction commences, it is necessary to establish how success will be defined. With these clear objectives, restoration progress can be readily gauged and corrected if the system is not "on track".

Phase II. Prior to restoration construction, conduct comprehensive surveys and research to establish baseline or comparative environmental data. Use a combination of best available technologies and methods (based on funding and time frame), including field sampling and surveys, modeling, GIS technology and analyses of archival materials and historical databases, i.e. aerial photographs, maps, previous surveys. Characterize and identify species distribution and abundance; identify habitats critical to fisheries management objectives and NOAA Fisheries responsibilities under a variety of legislative mandates; determine the limiting environmental factors of the anadromous fish populations; calculate sediment budgets and hydraulic flow rates; predict possible changes in water quality, channel morphology. Identify several reference sites nearby that possess attributes similar to the proposed restoration site.

Phase III. Conduct restoration construction according to project design and specifications. Upon completing baseline monitoring and selecting success criteria, restoration construction can commence. Quality assurance/quality control monitoring should be implemented during construction to insure that proper design specifications are met.

Phase IV. Establish and implement a restoration monitoring program for a minimum of three (3) to five (5) years. This should continue Phase I objectives after completion of the project. It is important to acknowledge that there are significant gaps in our understanding of the methodology and effectiveness of restoration of coastal, marine and anadromous fish habitat. Overall, restoration as a science is relatively young and experimental and the processes and mechanisms are poorly understood. Little is known about the functional value, stability and resiliency of many so-called "restored" habitats. Standardized success criteria will improve cohesiveness between different agency approaches and different projects.

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APPENDIX A

HABITAT TYPES

NOTE: A restoration project may fall into a combination of habitat types. The following definitions attempt to characterize the habitats ecologically rather than from a regulatory standpoint.

1. Riparian – the interface between terrestrial and aquatic ecosystems that is occasionally flooded, comprised of the stream channel, floodplain and transitional upland fringe. It encompasses land inclusive of hydrophytes and/or with soil that is saturated for at least part of the growing season within the rooting depth of potential native vegetation. Riparian zones encompass sharp gradients of environmental factors, ecological processes and plant communities. Riparian habitats have high species diversity and density and high productivity due to periodic inflow of nutrients. Examples include bottomland hardwood and floodplain forests in the eastern and central U.S., bosque or streambank vegetation in the western U.S.

    - Federal Interagency Stream Restoration Working Group (1998)
    - Gregory et al. (1991)
    - Minshall et al. (1989)

2. Salt Marsh – coastal areas influenced by floods and ebbs of tides. The salinity of salt marshes ranges from near ocean water to freshwater further inland. They are generally dominated by the grass *Spartina* in the low intertidal zone and by the rush *Juncus* in the upper intertidal zone on the East Coast, and by *Spartina* in the low intertidal zone and *Salicornia* in the upper intertidal zone on the West Coast. The flora and fauna found in salt marshes have adapted to the stresses of salinity, periodic tidal inundation, and temperature fluxes.

    - Mitsch and Gosselink (1986)

3. Mangroves – dominant coastal habitat in subtropical and tropical regions (southern Florida and Puerto Rico). Dominant plant species are well adapted to saline wetland environment. Definite vegetation zonation patterns exist with generally little understory. Highly productive mangrove habitats are open to tidal flushing and inputs of nutrients from adjacent uplands.

    - Mitsch and Gosselink (1986)

4. Rocky Shorelines – are comprised of extensive littoral habitat on wave-exposed coasts. Rocky shores are characterized by sharp environmental gradients from low rocky intertidal to upper intertidal. They provide several functions including biomass export, wave energy attenuation, spawning and nursery habitat for fish, invertebrate habitat, and bird and mammal feeding grounds.

- Hawkins and Southward (1992)

5. Beaches – unconsolidated sandy sediment found adjacent to estuaries, sounds and open ocean, limited by low tide on the seaward margin and by storm wave action on the landward side. They provide essential habitat for beach-nesting birds, such as plovers and terns. Beaches also serve as barriers to dissipate wave energy and as a cycling area for nutrients and sandy sediments.

   - Davis (1982)
   - Fish and Wildlife Service (1999)

6. Mud Flats – unvegetated shallows characterized by fine-grained sediment, occurring at extreme low water tidal areas where exposure to the air is brief. They provide burrowing habitat for invertebrates and feeding grounds for birds and fish.

   - Mitsch and Gosselink (1986)

7. Hard Bottom (including reefs and banks) – sea floor composed of solid, consolidated substrate adjacent to rocky shorelines. They typically provide an attachment surface for sessile organisms as well as a rough 3-D surface to encourage water mixing and nutrient cycling.

   - Simenstad et al. (1991)
   - Tyer, D.F. (1979)

8. Soft Bottom (including worm mounds, sand dollar beds) – loose, unconsolidated substrate characterized by coarser grain sediment and located adjacent to beaches. Soft bottoms provide burrowing habitat suitable for invertebrates and flatfish.

   - Simenstad et al. (1991)

9. Oyster Reef – provide natural larval settlement habitat for oysters and the complicated three-dimensional meshwork necessary to support complex biological communities. Oysters are food items for juvenile blue crabs, mud crabs, and larval gobies and blennies. Many recreationally valuable fish species depend on oyster reefs as feeding grounds and nursery areas. Oysters improve water quality and clarity by filter feeding nutrients and sediment out of the water column.

   - Virginia Institute of Marine Science (1999)

10. Seagrass – marine flowering plants that grow in shallow, subtidal or intertidal unconsolidated sediment. Seagrass blades decrease water current speed and thereby act as a sink for water-column sediment and nutrients. The physical stability, reduced mixing and shelter of complex seagrass habitat provide for a highly productive environment. Seagrass beds function as nursery areas for many different fish species as well as blue crabs.

- Fonseca et al. (1998)

11. Kelp – shallow subtidal communities dominated by large brown algae such as *Macrocytis* spp. that form surface canopies. Kelp forests grow on hard bottom substrates. They are the most productive marine community in temperate waters due to habitat complexity and nutrient export.

    - Schiel and Foster (1992)

12. Coral Reef – wave resistant structures harboring plants and animals in shallow tropical seas and consisting of the remains of calcium carbonate secreting organisms. They are centers of high biodiversity and productivity, providing essential feeding, shelter, breeding and nursery habitat for a variety of reef fishes, algae, crustaceans and marine vertebrates. Healthy coral reefs both require and maintain water quality. They are among the most biodiverse habitats in the world.

    - Maragos (1992)

13. Water Column – body of water extending three-dimensionally from the atmospheric/water interface to, but not including, the benthic or bottom layer of substrate of the continental shelf and its associated high-energy coastline, as well as bays and estuaries. The water column is exposed to the atmosphere and is a dynamic environment subject to waves, currents, tidal and riverine influences. Water regimes are determined primarily by the ebb and flow of ocean tides in oceanic systems and freshwater inputs from tributaries in estuarine systems. Salinity of open ocean seawater is approximately 35 ppt, while estuarine systems become nearly freshwater near the headwaters. The quality of the water column affects all associated habitats.

    - Groves and Hunt (1980)
    - Dobson et al. (1995)

APPENDIX B

STRUCTURAL AND FUNCTIONAL CHARACTERISTICS

Structural and Functional Characteristics of:

Riparian
Salt Marsh
Mangroves
Rocky Shorelines
Beaches
Mud Flats
Hard Bottom
Soft Bottom
Oyster Reef
Seagrass
Kelp
Coral Reef
Water Column

STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF RIPARIAN HABITATS

An asterisk * denotes a characteristic that, at the minimum, should be considered in measuring restoration success.

Structural Characteristics

Buffer zone*
Hydrogeomorphic degree of sinuosity and stream order*
Instream large woody debris (LWD) per unit stream length*, positioning of instream large woody debris*
Presence of boulders/rocks/cobbles/sand*
Water temperature*
Appropriate benthic food resources
Inorganic nutrient levels
Limited exotic species
pH
Pool frequency (a function of channel width and depth)
Presence of anadromous species
Streamflow and velocity conditions
Rare exotics
Organic loads
Oxygen levels

Functional Characteristics

Benthic invertebrate and finfish utilization*
Biomass production*
Identification of biological community structure*
Appropriateness of boulder/cobble fields for similar provisions as noted under large woody debris
Appropriate chemical conditions conducive of spawning
Appropriate flow conditions to reduce instream blooms
Appropriate resident fish with limited exotics--function as reduced predation plus appropriate life support
Consideration of bank stability and undercutting
Large Woody Debris (LWD):

- Provision of riffle conditions
- Provision of spawning and nursery habitat
- Provision of erosion protection
- Provision of detrital trapping and therefore nutrient cycling
- Provision of oxygenation

Provision of appropriate oxygen content and cycle
Provision of appropriate thermal regime

STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF SALT MARSH HABITATS

An asterisk * denotes a characteristic that, at the minimum, should be considered in measuring restoration success.

Structural Characteristics

Desirable vegetation species presence/absence*, composition*, percent cover*, density/biomass/height, spreading rate and persistence
Fish and shellfish (in creeks and on marsh surface) density/diversity*
Flooding regime*
Marsh surface elevation/slope*
Organic matter content*
Salinity*
Sediment grain size*
Avifauna density/diversity
Creek dendrisity/stream order
Creek sinuosity
Dissolved inorganic nutrient concentration in sediment porewater
Exotic species
Infauna (both meio- and macro-fauna) density/diversity
pH, Eh
Porewater salinity
Sedimentation rates (both on marsh surface and in creeks)
Temporal/spatial change in ratio of open water:marsh

Functional Characteristics

Benthic invertebrate, finfish, and bird utilization*
Biomass production*
Identification of biological community structure*
Measurement of changes in nutrient cycling and fluxes
Primary production of macrophytes and algae
Provision of refuge and food to aquatic organisms
Resilience to perturbations, such as natural or human events
Stabilize sediments

STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF MANGROVES

An asterisk * denotes a characteristic that, at the minimum, should be considered in measuring restoration success.

Structural Characteristics

Hydrodynamics* (including mixing, trapping and outwelling)
Water salinity*
Temperature*
Canals (numbers, locations, configurations)
Density of mangroves species
Detritus
Erosion rates
Flushing and trapping
Frequency of tidal exposure

Freshwater content
Nutrients
Sediment characteristics (marl, peat, sand, some rock, shell, organic mix)
Sedimentation rates
Tidal amplitude (including flood tide)
Velocities

Functional Characteristics

Benthic invertebrate and finfish utilization*
Biomass production*
Floodwater retention*
Identification of biological community structure*
Nutrient cycling*
Detoxification of waste and purification of water
Food web support
Persistence and resilience (recover from anthropogenic disturbances and exotic species invasions)
Recreation, education, and research
Sediment retention
Species maintenance

STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF ROCKY SHORELINES

An asterisk * denotes a characteristic that, at the minimum, should be considered in measuring restoration success.

Structural Characteristics

Hydrogeomorphic characteristics as a result of energy dynamics*
Plant/animal zonation patterns* (reestablishment of normal zonation patterns should be the primary criteria for recovery or restoration success; because many of these systems are disturbance dominated known patterns of succession/zonation should be available)
Gradients decrease with increasing horizontal gradients of relief
High variability in populations due to disturbance and recruitment
Sharp gradients with high tidal amplitudes
Vertical gradient--slope function of both tidal height and energy

Functional Characteristics

Benthic invertebrate and finfish utilization*
Identification of biological community structure*
Characteristics a result of gradients/energy dynamics of site:

- Exposed shores--filter feeding dominated
- Moderately exposed/intermediate shores--moderate fluctuations in biomass
- Sheltered shores--algal/detritus based

Succession often halted or started by disturbance events:

- Sheltered shores--algal/detritus based
- Exposed shores--filter feeding dominated

STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF BEACHES

An asterisk * denotes a characteristic that, at the minimum, should be considered in measuring restoration success.

Structural Characteristics

Natural organic input*
Topography and relief*
Buffer zone between ocean and upland habitat
Sediment accretion and erosion cycling
Sediment grain size
Woody debris recycling

Functional Characteristics

Benthic invertebrate and finfish utilization*
Identification of biological community structure*
Habitat for shorebirds
Source of food for consumers

STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF MUD FLATS

An asterisk * denotes a characteristic that, at the minimum, should be considered in measuring restoration success.

Structural Characteristics

Density/diversity of infauna*, macrofauna*, fish, birds
Development of creek/stream dendrisity*
Flooding regime*
Salinity*
Sediment grain size*
Slope and elevation/relief*
Dissolved inorganic nutrient concentration in sediment porewater
Eh, sediment salinity
Energy regime
Organic matter content
Presence/absence of macroalgae

Functional Characteristics

Benthic invertebrate and finfish utilization*
Identification of biological community structure*
Sediment stability*
Biomass production
Bird foraging*
Change in infauna composition/density over time
Development and growth of oysters
Measurement of changes in nutrient cycling and fluxes

STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF HARD BOTTOM

An asterisk * denotes a characteristic that, at the minimum, should be considered in measuring restoration success.

Structural Characteristics

Salinity*
Topographic complexity*
Circulation through substrate structure
Minimize scouring
Solid bottom substrate

Functional Characteristics

Benthic invertebrate and finfish utilization*
Biomass production*
Flora and fauna production rates*
Source of attachment for sessile organisms*
Areal coverage of sessile invertebrates
Flora and fauna biomass
Flow deflection (roughness)
Identification of biological community structure
Turbulent boundary layer to encourage mixing

STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF SOFT BOTTOM

An asterisk * denotes a characteristic that, at the minimum, should be considered in measuring restoration success.

Structural Characteristics

Density/diversity of infauna*
Organic matter content*
Salinity*
Sediment grain size*
Sediment accretion and erosion
Slope and elevation relief
Woody debris content

Functional Characteristics

Benthic invertebrate and finfish utilization*
Biomass production*
Identification of biological community structure*
Flow deflection (roughness)
Nutrient cycling

STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF OYSTER REEF

An asterisk * denotes a characteristic that, at the minimum, should be considered in measuring restoration success.

Structural Characteristics

Solid bottom 3-D substrate*
Breakwater for oceanic swells
Hydrodynamic complexity

Functional Characteristics

Benthic invertebrate and finfish utilization*
Identification of biological community structure*
Sediment-free attachment surfaces for sessile organisms*
Filtration of sediment from water column
Improved water clarity and visibility
Nutrient recycling
Source of food for consumers

STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF SEAGRASS

An asterisk * denotes a characteristic that, at the minimum, should be considered in measuring restoration success.

Structural Characteristics

Bottom coverage*
Salinity*
Canopy surface area
Canopy biomass
Belowground biomass with variable architecture
Shoot density
Blade length (canopy height)
Associated epiphytes and macroalgae
Fining sediments
Elevated sediment organic content
Elevated concentrations of selected sediment nutrients
Variable landscape pattern
Reduced, in-canopy water motion

Functional Characteristics (relative to unvegetated areas)

Benthic invertebrate and finfish utilization*
Biomass production*
Habitat stabilization and persistence*
Identification of biological community structure*
Canopy structure & structural complexity (canopy volume)
Dampens wave and current energy
Detrital and organic carbon production
Elevated animal densities

Elevated food sources and modified feeding pathways
High epibenthic and benthic production
High primary production and growth
Modified nutrient cycling
Nutrient and contaminant filtration
O_2 production
Sedimentation
Shelter

STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF KELP HABITATS

An asterisk * denotes a characteristic that, at the minimum, should be considered in measuring restoration success.

Structural Characteristics

Canopy with strong 3-D structure*
Coverage*
Suitable hard substrate*
Appropriate epiphytic complex
Appropriate water depth/light attenuation conditions
Appropriate water motion conditions
Presence of appropriate fish community
Presence of food support complex

Functional Characteristics

Benthic invertebrate, finfish and mammal utilization*
Biomass production*
Identification of biological community structure*
Litter production*
Appropriate light attenuation conditions for plant growth
Development of composition and diversity to resemble natural habitats
Hard substrates (artificial or normal) for holdfast attachment
Provision of energy dampening
Surfaces for epiphytic growth and herbivore feeding

STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF CORAL REEF

An asterisk * denotes a characteristic that, at the minimum, should be considered in measuring restoration success.

Structural Characteristics

Accretion of hard substrate ($CaCO_3$)*
Breakwater for oceanic swells*
Cryptic habitat*
Stable 3-D hard substrate*
Topographic complexity*
Hydrodynamic complexity

Rubble and sediment production and consolidation

Functional Characteristics

Benthic invertebrate and finfish utilization*
Biomass production*
Favorable recruitment sites for reef fish and invertebrates*
Identification of biological community structure*
Shading*
Shelter from predation*
Attachment surfaces for sessile organisms
Food source for consumers
Recycling of nutrients
Source of gametes and larvae

STRUCTURAL AND FUNCTIONAL CHARACTERISTICS OF WATER COLUMN

An asterisk * denotes a characteristic that, at the minimum, should be considered in measuring restoration success.

Structural Characteristics

Dissolved oxygen concentration/percent saturation*
Light penetration (Secchi disk visibility)*
Salinity*
Temperature*
Turbidity*
Chlorophyll concentration
Current magnitude and timing
Diversity/density of aquatic organisms
Fecal coliform
N:P:Si ratios
Planktonic taxonomic composition
P/R ratios
Sediment type and pollutant load
Suspended sediments
Vertical zonation of fauna
Wave energy

Functional Characteristics

Biomass production*
Medium for nutrient exchange between organisms and environment
Predator/prey interaction
Presence/absence of exotic species vs. native species (indication of resiliency of the system)

APPENDIX C

LIST OF CONTACTS BY HABITAT TYPE

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APPENDIX D

TECHNICAL SAMPLING METHODS

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APPENDIX E

ANNOTATED BIBLIOGRAPHY

This appendix was published as NOAA Technical Memorandum NMFS-F/SPO-42, May 2000 and has been since updated.

1. Barrett, N.E. and W.A. Niering. 1993. Tidal marsh restoration: trends in vegetation change using a geographical information system (GIS). *Restoration Ecology* 1(1):18-28.

A study measuring restoration success by extent of geographical similarity between restored vegetation and pre-diked vegetation was carried out in a formerly diked and ditched Connecticut coastal salt marsh. Restoration is a continuous process with salt marsh vegetation communities in constant flux. In addition to vegetation pattern and distribution as structural criteria, ecosystem functioning, such as biomass and nutrient exchange, need to be evaluated as well. Using GIS to compare vegetation coverages between the pre-impounded, impounded, and restored states, tidal reintroduction was found to be a semi-effective restoration tool. Pre-impoundment marsh was dominated by stunted *Spartina alterniflora*. During the impoundment period, marsh vegetation switched to dominance by *Typha*. Following restoration, the wetland became a mosaic of different plant communities with much of the marsh reverting to *S. alterniflora*. The restored marsh was only 28 percent similar to pre-disturbance conditions in terms of vegetation species and coverage. Returning the marsh to pre-disturbance conditions is unlikely but should be viewed as the pinnacle of success against which other projects can be measured. The restored site has reverted to a viable, coastal salt marsh that is reconnected with the estuarine environment.

2. Bradshaw, A.D. 1996. Underlying principles of restoration. *Canadian Journal of Fisheries and Aquatic Sciences* 53(Suppl. 1):3-9.

Restoration should incorporate ecosystem structure and function into habitat development. Restoring a system to its original state may be unrealistic and expensive; thus other options exist, including rehabilitation and replacement. Natural restorative processes should be used whenever possible. These restoration processes are progressive, and success criteria are sometimes difficult to define. If progressive natural processes are to be used for restoration, what level should be achieved and what is considered the predisturbance state? Establishing an appropriate time frame for post-restoration monitoring and evaluation is also difficult. Less than three years is not enough time for aquatic or terrestrial ecosystem development following restoration. One invaluable tool for monitoring is a check list of potential limiting factors or problems in degraded ecosystems that require restoration, i.e. nutrient deficiency. Since restoration must be based on a sound understanding of ecosystem function, it is imperative that experimental studies be conducted in conjunction with restoration. This allows different treatments to be applied to the ecosystem and results to be compared against controls or non-treatments. It is equally important to restoration science that accounts of restoration failures and successes be published.

3. Burchett, M.D., A. Pulkownik., C. Grant, and G. Macfarlane. 1998. Rehabilitation of saline wetlands, Olympics 2000 site, Sydney (Australia) – I: management strategies based on ecological needs assessment. *Marine Pollution Bulletin* 37(8-12):515-525.

The Homebush Bay area, Sydney, site of the Olympic Games 2000, has been largely occupied for nearly a century by an abattoir, brickworks, armaments depot, and waste dumps. However, it contains remnants of original ecosystems, including two estuarine wetlands. The Olympic Coordination Authority (OCA) was set up to manage the redevelopment of the site and is committed to the restoration of these ecosystems. The ecological approaches and rehabilitation measures used for one of the wetlands are detailed. Apart from a history of disturbance, it has been cut off from tidal flushing for ten years. However, these wetlands are the largest remaining in the Sydney estuary and are significant for a number of reasons including biodiversity and waterbird conservation. The ecological parameters of the site, the results of a "before-restoration-impact" study, and the iterative links between science and management in the introduction of the rehabilitation measures, are presented. Criteria for success are discussed, along with biomonitoring strategies to test success.

4. Cintron-Molero, G. 1992. Restoring mangrove systems. In Restoring the Nation's Marine Environment, ed. Thayer, G.W. College Park, MD: Maryland Sea Grant College, Publication UM-SG-TS-92-06. 716 pp.

Mangrove restoration or creation historically has occurred as compensation for lost habitats or desire to create new mangrove habitats. Site selection and preparation are essential for successful mangrove restoration. Plantings should be made using the dominant species found in nearby locations with similar tidal heights and flooding regimes. Three basic factors can lead to mangrove restoration failure: 1) failure to recognize factors limiting establishment (need for shelter from wave and wind action, tides and currents); 2) lack of provision for proper hydrologic regime; and 3) failure to provide follow-up, including replacement for mortality and lack of consideration of mangrove stand maintenance. Furthermore, ten broad types of problems or factors that control mangrove establishment and development are addressed. Viable restoration design and strategy are addressed, as well as steps to ensure restoration success.

Criteria used to determine long-term success are highly subjective. No detailed quantitative assessments of structural or functional attributes are available. Eight criteria are cited as quantifiable in terms of measuring stand development through time: 1) species composition; 2) stem density; 3) basal area; 4) vegetation height; 5) percentage canopy cover; 6) leaf area index; 7) mean diameter of the stand; and 8) above-ground biomass. The suggested minimum monitoring duration is 15 to 30 years, in order to allow the system to reach maximum persistent biomass.

5. Coen, L.D., D.M. Knott, E.L. Wenner, N.H. Hadley, A.M. Ringwood, and M.Y. Bobo. 1999.
Intertidal oyster reef studies in South Carolina: design, sampling and experimental focus for evaluating habitat value and function. In *Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches, Proceedings from the Symposium*, eds. M.W. Luckenbach, R. Mann and J.A. Wesson. Williamsburg, VA, Apr. 1995. Virginia Institute of Marine Science, College of William and Mary: VIMS Press.

In South Carolina, *Crassostrea virginica* can be considered a keystone species by forming extensive biogenic reefs, often generating the only three-dimensional structural relief, both as living organisms and dead shell on unvegetated soft-bottoms. Whether these intertidal habitats are functionally analogous to submerged aquatic vegetation (SAV) or marsh, especially where SAV nursery habitats are absent (i.e. South Carolina), is an important question. A past focus of oyster research has been directed toward enhancing oyster harvests; however, our understanding of the role of intact reefs on ecosystem function is limited. Additionally, many states where oysters are commercially harvested, minimally require cultch (shell) replanting; however, no rigorous experimental data presently exist for optimizing shell placement or evaluating the effectiveness of this practice for reef restoration efforts.

Our long-term studies of the oyster ecosystem are designed to: (1) evaluate the utilization of reefs by transient and resident species; (2) examine the tempo and mode of intertidal oyster reef recruitment and succession using rigorous statistical designs; (3) aid in the development of habitat quality criteria; (4) formulate strategies for habitat management of these living resources; and (5) utilize the information to develop restoration and mitigation methodologies. Two study sites were selected, one at a relatively pristine oyster flat, the other at a developed (impacted) area near a marine/condominium complex. Three replicate intertidal experimental reefs per site (each ~ 24 m^2) have been constructed of 156 subunits. We now have established sampling protocols and developed and conducted efficiency tests for sampling transient and resident faunas associated with experimental and adjacent natural reef substrates. Over the next four to six years, we will be following reef development, collecting continuous environmental data and comparing contaminant levels and oyster disease status, along with other life history parameters on both natural and adjacent experimental reefs. By initiating and following the reef development over an extended period, we will be able to explore and model potential changes in reef habitat status and function with reef succession.

6. D'Avanzo, C. 1990. Long-term evaluation of wetland creation projects. In Wetland Creation and Restoration: The Status of the Science, eds. Kusler, J.A. and M.E. Kentula. Washington, DC: Island Press.

Assessment of created wetlands was performed using six criteria for success. These include: 1) comparison of vegetation growth characteristics between created and reference wetlands after two or more growing seasons; 2) habitat requirements of plants colonizing the created site; 3) success of planted species; 4) comparison of animal species composition and biomass between created and reference wetlands; 5) chemical analyses of soils between created and reference wetlands; and 6) evidence of hydrogeologic changes over time.

Many created wetland projects have failed because of improper hydrology, erosion, herbivory, or upland plant invasion. Some projects have never been evaluated or monitored to determine success. One to two years of monitoring is too short; 10-20 years of monitoring is more desirable. Monitoring vegetation characteristics may be useful but does not indicate ecosystem function.

7. Dobson, J.E., E.A. Bright, R.L. Ferguson, D.W. Field, L.L. Wood, K.D. Haddad, H. Iredale III, J.R. Jensen, V.V. Klemas, R.J. Orth, and J.P. Thomas. 1995 Apr. NOAA Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation. NOAA Technical Report NMFS 123. 92 pp.

The Coastal Change Analysis Program (C-CAP) is developing a nationally standardized database on land-cover and habitat change in the coastal United States. C-CAP is part of the Estuarine Habitat Program of NOAA's Coastal Ocean Program. C-CAP inventories benthic habitats, wetland habitats, and adjacent uplands to learn more about the linkages between coastal and upland habitats, as well as impacts on living marine resources. Through remote sensing technology, C-CAP monitors changes in these habitats on a one- to five-year cycle. Satellite imagery, aerial photography, and field data are meshed in a geographic information system (GIS) for spatial analysis. Ongoing C-CAP research will continue to develop remote sensing techniques to measure biomass, productivity, and functional status of wetlands and other coastal habitats. Land-cover maps will be produced on both local and regional scales for distribution.

8. Fonseca, M.S. 1992. Restoring seagrass systems in the United States. In Restoring the Nation's Marine Environment, ed. Thayer, G.W. College Park, MD: Maryland Sea Grant College, Publication UM-SG-TS-92-06. 716 pp.

Seagrass restoration has been carried out as a defensive or remedial action in conjunction with natural resource damages, rather than for the purpose of improving ecological resilience and functioning. In order to protect seagrass habitat, better project goals need to be established from the outset. Goals may include developing persistent cover, generating equivalent acreage, increasing acreage, replacing the same seagrass species as was injured or removed, and restoring faunal production. Monitoring for cover and persistence should last for three years. Site selection remains a major problem in ensuring seagrass restoration success. Eight research needs are stressed to improve seagrass restoration science: 1) a definition of functional restoration; 2) a compilation of population growth and coverage rates; 3) the resource role of mixed species plantings; 4) the impact of substituting pioneer for climax species on faunal composition and abundance; 5) culture techniques for propagule development; 6) transplant-optimization techniques such as the use of fertilizer; 7) the importance of maintaining genetic diversity; and 8) the implementation of a consistent policy on seagrass restoration and management among resource agencies. Permit compliance needs to be strictly enforced through intra- and interagency coordination; a monitoring system that tracks permits and evaluates them for both compliance and performance needs to be developed.

9. Fonseca, M.S., W.J. Kenworthy, and G.W. Thayer. 1998. Chapter 4: Monitoring and Evaluating Success. In *Guidelines for the Conservation and Restoration of Seagrasses in the United States and Adjacent Waters*. NOAA Coastal Ocean Program Decision Analysis Series No. 12. NOAA Coastal Ocean Office, Silver Spring, MD. 222 pp.

Several criteria have been used for evaluating seagrass planting success. However, the simple measures of coverage and persistence are the most cost-effective and efficient. Many habitat functions seem to relate directly to these two structural criteria. Seagrass monitoring should provide for mid-course correction and improved planning of future restoration projects. Structural criteria include planting survival, areal coverage, and number of shoots. Seagrasses should be monitored at least quarterly after the first year and every six months for at least the following four years (total of five years). If replanting is necessary because of shoot failure, the monitoring clock is reset to zero and should continue for five years. In terms of achieving success, a nearby reference site may be used for comparison. An alternative strategy is to compare the monitored site with currently published structural values to gauge restoration performance. Cost estimates per hectare of seagrass restoration are discussed.

10. Galatowitsch, S.M., A.G. van der Valk, and R.A. Budelsky. 1998. Decision-making for prairie wetland restorations. *Great Plains Research* 8(Spring 1998):137-155.

Restoration of prairie pothole wetlands needs to occur on two levels: landscape and site. Reestablishment of wetland complexes and their functions should be the primary goal of prairie pothole restoration. A comprehensive assessment framework on a landscape level is presented. Historic data or reference complexes are also necessary to evaluate success of prairie wetland restoration. Previous assessment frameworks have focused on evaluation of easily observed structural attributes, such as vegetation or topography. The connection between structural attributes and wetland function is still uncertain. A more recent assessment tool is the hydrogeomorphic (HGM) technique that stresses the importance of hydrology in determining wetland function. Certain wetland functions are linked to a certain HGM subclass that has similar hydrogeomorphic properties. Long-term data collection at reference sites is crucial for gauging pre-restoration conditions and evaluating restoration progress. Most wetland functions are difficult and inefficient to measure directly; therefore, useful and reliable indicators of wetland function need to be developed for prairie pothole ecosystems. For example, soil organic matter is easily measurable and is presumed to be indicative of many wetland functions, including denitrification, phosphorus retention, and success of re-establishing plant species.

11. Grayson, J.E., M.G. Chapman, and A.J. Underwood. 1999. The assessment of restoration of habitat in urban wetlands. *Landscape and Urban Planning* 43:227-236.

Wetlands in urban areas are often restored in an attempt to reduce the loss of such habitats. Unfortunately, the success, or otherwise, of restoration programs has rarely been systematically evaluated. Through not knowing whether restoration programs are successful or not, valuable human and economic resources potentially continue to be wasted, wetland habitats remain degraded and restoration methods are not assessed and refined for future projects. Several factors have contributed to poor assessment of restoration of urban wetlands. First, the goals of restoration have often been unrealistic because they failed to consider that wetlands in urban areas are subjected to ongoing and often large-scale anthropogenic disturbances. Second, goals of restoration often have not been clearly defined during planning and, consequently, predictive hypotheses were not formulated to evaluate restoration success. Third, even when restoration success has been assessed, this has not always been adequate because of inappropriate sampling design. Such problems can be overcome by treating habitat restoration as experiments and using the knowledge gained from each project to improve restoration in the future. This will ensure that the remaining semi-natural habitats in urban areas can be more effectively managed.

12. Harris, R.R. 1999. Defining reference conditions for restoration of riparian plant communities: examples from California, USA. *Environmental Management* 24(1):55-63.

Currently, there is an emphasis on restoration of riparian vegetation in the western United States. Deciding on what and where to restore requires an understanding of relationships between riparian plant communities and their environments along with establishment of targets, or reference conditions, for restoration. Several methods, including off-site data and historical analysis have been used for establishing restoration reference conditions. The author proposes criteria for interpreting reference community composition and structure from the results of multivariate cluster analysis. Criteria proposed for establishing a reference community include: (1) abundance of one community relative to others; (2) community complexity, i.e. species richness and structure; (3) presence/absence of exotics; and (4) floristic and structural similarity to reference communities elsewhere in the region. The approach is illustrated with data from streams in the California Sierra Nevada, Central Valley, and southern coastal region to derive descriptions of reference communities for stream reaches and floodplain landforms. Cluster analysis results can be used to quantify the areas of both degraded and reference communities within a floodplain, thereby facilitating restoration cost estimation.

13. Houghton, J.P. and R.H. Gilmour. Ecological functions of a saltmarsh/mudflat complex created using clean dredged material, Jetty Island, Washington. In *Wetland and Riparian Restoration: Taking a Broader View, Proceedings of a Conference*, eds. K.B. Macdonald and F. Weinmann. Society for Ecological Restoration International Conference, Seattle, WA, 14-16 Sep. 1995. 284 pp. EPA 910-R-97-007.

The Port of Everett and the U.S. Army Corps of Engineers created a sand berm on Jetty Island, Washington, in 1989-1990. The purpose of the berm was to slow erosion losses on the west side of the island, create additional dune grass habitat, create a protected embayment that would be colonized by marine invertebrates, and demonstrate a beneficial use of clean dredged material. Increased productivity and invertebrate colonization would provide favorable habitat for juvenile salmonids, other fish, waterfowl, and shorebirds. Progress towards meeting these objectives was monitored over five years. Physical monitoring of the site included coastal geomorphology and topography; success was defined as a target rate of erosion. Biological monitoring included epibenthic zooplankton productivity, salmonid habitat evaluation, fish use of the project area, and vegetation percent cover. The project has met the preset criteria in terms of usage by juvenile salmonids and their prey items. Other fish such as juvenile surf smelt have colonized the area due to the high productivity. Percent cover of vegetation in the planted embayment did not differ significantly from that of the reference marsh. Shorebirds seem to benefit the most from creation of the berm and have been observed in greater numbers than elsewhere on the island.

14. Kaly, U.L. and G.P. Jones. 1998. Mangrove restoration: a potential tool for coastal management in tropical developing countries. *Ambio* 27(8):656-661.

Kaly and Thomas discuss a framework for determining whether mangrove restoration has been "successful". Past restoration projects have focused on planting trees and have neglected the reestablishment of complex, long-term ecosystem functioning. The authors discuss a three-step framework. The first step establishes requirements for a "natural" functioning ecosystem and identifies success criteria by which to measure the outcome of restoration. Criteria should be quantifiable and include factors such as slope and height of the substratum, distribution of freshwater inputs, and species composition. Historical data regarding previous mangrove ecosystem structure may be available, but nearby pristine reference mangrove stands likely will have to be used for comparison. Success should be measured by the degree that functional replacement of mangrove ecosystem has been achieved. This is in contrast to previous practice that establishment of vegetative cover over a percentage of the restoration site for a period of approximately two to three years.

15. Kondolf, G.M. 1995. Five elements for effective evaluation of stream restoration. *Restoration Ecology* 3(2):133-136.

Current restoration practices ignore the importance of post-project evaluation and monitoring. This may be due in part to lack of funding and equating monitoring with research, as opposed to applied activities such as restoration construction. Those restoration projects that have been evaluated were failures or proved ineffective. Five elements are cited as crucial for effective evaluation of project success. These are: (1) clear objectives to design an effective project and evaluation plan; (2) baseline data collected as long before the project begins as possible, in order to provide a reference point for quantitative evaluation of success; the choice of variables should follow logically from the project objectives; (3) good study design in order to acquire quantifiable data and results and measure the same variables over the same period of time at other reference sites; (4) commitment to the long term, to allow the system to recover and undergo a natural range of variability; floodplain river systems should be monitored for at least a decade, as well as after major disturbance events; and (5) willingness to acknowledge failure, since each project may be viewed as an experiment from which valuable lessons can be learned for future projects; failures are equally as valuable as successes in refining restoration science.

16. Lenihan, H.S. 1999. Physical-biological coupling on oyster reefs: how habitat structure influences individual performance. *Ecological Monographs* 69(3):251-275.

A large-scale experimental study was conducted to test different aspects of restored reef design on oyster performance. Reef height was the independent variable tested to determine oyster performance and recruitment. Four reef heights were constructed at 3-m water depth in a North Carolina estuary: tall (2 m), short (1 m), dredged (0.6 m), and low (0.1 m). To determine whether oyster performance varied with water depth and hydrographic conditions, tall and short reefs were also constructed at 6-m water depth. The study elicited several physico-chemical and oyster performance variables that may be used as success criteria for oyster reef restoration projects. Flow speed, sedimentation, temperature, salinity, dissolved oxygen, and oyster performance were measured as a function of reef height, position on reef, and water depth over a ten month period. The results indicated that reef height controls habitat quality and quantity indirectly through its effect on flow and rates of sedimentation.

Physical conditions on the experimental reefs had a significant impact on oyster performance. After ten months, oyster recruitment and growth were greatest on the crests of tall and short reefs, where flow speed and quality of suspended food material were highest, and sedimentation was lowest. Growth was greatest overall at the crests of tall reefs located at 6-m depth where flow speed was high, and exposure to hypoxic/anoxic conditions and salinity variation were lowest.

17. Levin, L.A., D. Talley, T. Talley, A. Larson, A. Jones, G. Thayer, C. Currin and C. Lund. 1997. Restoration of *Spartina* marsh function: an infaunal perspective. In *Wetland and Riparian Restoration: Taking a Broader View, Proceedings of a Conference*, eds. K.B. Macdonald and F. Weinmann. Society for Ecological Restoration International Conference, Seattle, WA, 14-16 Sep. 1995. 284 pp. EPA 910-R-97-007.

The roles of sediment-dwelling fauna (infauna) in salt marsh function were examined at two sites in North Carolina and California. Despite their ability to cycle organic matter, serve as food for fish, birds and other predators, and link primary producers with higher order consumers in the food web, infauna are not routinely monitored in wetlands restoration. The study investigated factors that influence recovery of restored systems, rates of recovery, and possible causes of compositional differences between created and natural marshes.

Experimental organic matter treatments were applied at the North Carolina site. Macrofaunal densities and species richness were reduced in the created marshes compared to the natural reference marsh, especially at higher elevations. Species composition between created and natural marshes was significantly different, with oligochaetes dominating natural marsh and tube-dwelling, surface-deposit feeders dominating the created marsh. At the California site, planktotrophic organisms were dominant in the created marsh and rarely found in the natural marsh. Densities and species richness in the created marsh were actually higher than in the natural marsh in California. It was concluded that organic treatments should be used if they enhance *Spartina* growth despite an initial retardation of macrofaunal colonization. Although similarities in faunal densities and species richness may readily occur between created and natural marshes (as in California), it is necessary to examine species composition as well. Recovery of salt marsh seems to be site- and taxon-specific, with no guarantees that time alone will yield functional equivalence.

18. McCormick, P.V. and J. Cairns. 1994. Algae as indicators of environmental change. *Journal of Applied Phycology* 6:509-526.

The authors list 16 criteria for ecosystem indicator selection and discuss how algae fit many of these criteria. Despite their ecological importance at the base of the aquatic foodweb, algae are not as widely used as assemblages of benthic invertebrates or fish. This results from the lack of standard monitoring protocols. Measuring structural characteristics of algal condition may be more efficient than monitoring functional characteristics. The authors cite the use of diatoms (*Bacillariophyceae*) in algal assemblage monitoring. They also stress the importance of monitoring several taxonomic groups, rather than algae, fish, or invertebrates alone to gauge overall ecosystem integrity.

19. Minello, T.J. and J.W. Webb, Jr. 1997. Use of natural and created *Spartina alterniflora* salt marshes by fishery species and other aquatic fauna in Galveston Bay, Texas, USA. *Marine Ecology Progress Series* 151: 165-179.

Nekton and infauna densities were compared among five natural and ten created salt marshes in Galveston Bay, Texas, to determine whether these marshes were functionally equivalent. The marshes ranged in age from three to 15 years old. Densities of the most abundant decapod were not significantly different; however, the size of these decapods in created marshes was significantly smaller than in natural marshes. Densities of another decapod and three commercially important crustaceans were significantly lower in created marshes than in natural marshes. Although species richness of nekton were equivalent in created and natural marshes, fish densities in vegetated areas were significantly lower in created marshes than in natural marshes. Sediment macro-organic matter and density and species richness of macroinfauna were significantly lower in created marshes than natural marshes. The conclusion was that marsh elevation and tidal flooding were key characteristics affecting nekton use of salt marshes, more important than marsh age.

20. Minello, T.J. and R.J. Zimmerman. 1992. Utilization of natural and transplanted Texas salt marshes by fish and decapod crustaceans. *Marine Ecology Progress Series* 90:273-285.

Functional habitat utilization of three natural and three transplanted *Spartina alterniflora* marshes in Texas were compared. The created marshes were established on dredged material and were two to five years old. Use of replicate sampling over one year allowed scientists to test the null hypothesis that transplanted marshes on the Texas coast were equivalent to natural marshes. Mean values for stem density and aboveground biomass of *S. alterniflora* were higher in the transplanted marshes than in the natural marshes. Macro-organic matter (MOM) and densities of polychaetes, amphipods, and decapods were lower for transplanted marshes than natural marshes. However, densities of fish were similar between transplanted and natural marshes. These small fish may rely on salt marsh vegetation for cover from predators rather than for enhanced food resources. Comparison of prey abundance between transplanted and natural marshes requires an understanding of the trophic pathways and access to the marsh surface. If tidal flushing of small prey items and detrital matter into open water is the primary mechanism, then natant macrofauna on the marsh surface may not be indicative of relative marsh value for these organisms. Conversely, larger predators may actively move onto the marsh surface to feed, and the densities of decapods and fishes and their prey should reflect habitat value for the marsh.

21. Minns, C.K., J.R.M. Kelso, and R.G. Randall. 1996. Detecting the response of fish to habitat alterations in freshwater ecosystems. *Canadian Journal of Fisheries and Aquatic Sciences* 53(Suppl.1):403-414.

In order to detect fish responses to habitat alterations, e.g. restoration, four components need to be considered: expectations, measures, variability, and scale. Habitat alterations might be expected to cause four types of fish community and ecosystem response: (1) change in total fish biomass and production; (2) change in fish assemblage composition; (3) change in distribution of fish assemblage in time and space; and (4) change in non-fish biotic elements of ecosystem. The presence/absence matrix of these four elements leads to 16 total response patterns, with one being the null hypothesis where no responses occur due to habitat alterations.

Four approaches to dealing with problems of detecting biotic responses to habitat alterations include experimentation, science, ecosystem management, and coordination. Restoration activities should be considered experiments from which lessons can be learned. Scientific hypotheses and predictions need to be made before restoration commences. Ecosystem management is more holistic and ecosystem-oriented, and interdisciplinary cooperation is more important than ever.

22. Mitsch, W.J. and R.F. Wilson. 1996. Improving the success of wetland creation and restoration with know-how, time, and self-design. *Ecological Applications* 6(1):77-83.

Successful wetland creation and restoration projects have three essential requirements: understanding wetland function, giving the system time, and appreciating the notion of self-design. Studies on successful establishment of a biologically viable and sustainable wetland ecosystem revealed a spotty track record. Historically, vegetation cover has been the easiest and most widely implemented monitoring variable. However, it is a poor indicator of wetland function, and usually improper water levels and hydroperiod are more responsible for restoration failure.

The majority of failures in wetland creation can be attributed to lack of general knowledge of wetland science principles, such as the importance of proper hydroperiod. Wetland managers usually expect created or restored ecosystems to develop in a short time span, approximately five years or less. This time horizon is arbitrary and probably too short. A time line of 15-20 years is suggested, and coastal wetlands will require even more, i.e. > 50 years. There is a lack of appreciation for self-design in wetland creation. In other words, wetland managers are more likely to establish "designer" wetlands with planted species as opposed to wetlands that are naturally colonized over time. Wetland scientists need to make the correlation between structural (vegetation density, diversity, productivity) and functional (wildlife use, nutrient cycling, organic sediment accretion) characteristics.

Other tools are provided to reduce the uncertainty of wetland creation and to predict a time frame for success. Larger, ecosystem scale experimentation is recommended over smaller systems to ascertain the true functionality of the landscape. Predictive modeling using tools such as stochastic inputs, adaptive model structure, higher-order modeling languages, and spatially dynamic models can help reduce mitigation uncertainty as well. These tools have not been readily applied yet can effectively expand the time horizon of the project.

23. Moy, L.D. and L.A. Levin. 1991. Are *Spartina* marshes a replaceable resource?: A functional approach to evaluation of marsh creation efforts. *Estuaries* 14(1):1-16.

A study was conducted to compare functional ecological equivalence of a man-made *Spartina* salt marsh (between ages one to three years) with two adjacent natural marshes. Sediment properties, infaunal community composition, and *Fundulus heteroclitus* marsh utilization were the quantifiable criteria measured. Sediment organic content of the planted marsh was much lower than the natural marshes. Infaunal type differences were mirrored in *Fundulus* diets. *Fundulus* abundance in the planted marsh was significantly lower than in the natural marshes, indicating that fewer fish were being supported by the habitat. Furthermore, the planted *Spartina* stem densities were much lower than the natural marshes, affording inadequate protection or spawning habitat for the fundulids. The conclusion was that the planted marsh was not functionally equivalent to the natural marshes after three years. Mitigation success could be improved by increasing tidal flushing to allow marine organisms more access to the salt marsh, as well as adding *Spartina* wrack to increase sediment organic-matter content and porosity. Salt marshes, in general, should not be treated as replaceable resources in the short-term, and it is virtually impossible to replicate functionality of a lost salt marsh on another site.

24. National Research Council (U.S.) Committee on the Role of Technology in Marine Habitat Protection and Enhancement, Marine Board, Commission of Engineering and Technical Systems. 1994. Improving project performance. In Restoring and Protecting Marine Habitat: The Role of Engineering and Technology. Washington, D.C.: National Academy Press. 193 pp.

Performance criteria that are quantitative and measurable need to be established prior to restoration implementation so that all involved parties' expectations are clear. The key to project success is the flexibility of design and implementation. Projects can fail due to several reasons ranging from lack of understanding of ecosystem processes to poor implementation. Each of these reasons leads to failure of one or more ecosystem characteristics, such as proper hydrology, soil/substrate, etc. In order to track project performance, monitoring schemes need to be established. The time period during which performance will be monitored is essential; zero to five years is considered short-term, and beyond five years is considered long-term. Pre-project monitoring and baseline data collected seasonally for a full year is needed for comparison to restored sites. Post-project monitoring should occur at least monthly in the first year following construction completion. After the first year, the sampling schedule can be relaxed to monthly or seasonally. As time progresses, lower frequency monitoring can be phased in to cut down on project costs. In terms of monitoring criteria, all vegetated sites need evaluation in terms of survival rates, percent cover, reproduction, and other indicators of growth. Monitoring of deepwater habitats and seagrass beds also requires tracking of current and wave movements, sediment transport, colonization and habitat use by organisms, topographic changes, and water quality.

25. Northern Coast Range Adaptive Management Area Guide. Chapter 6 – Monitoring. 19 Feb. 1998. http://sequoia.fsl.orst.edu:80/ncama/guidch6.htm (4 Aug. 1999)

The Monitoring and Evaluation Plan in the Northwest Forest Plan establishes a general framework for evaluation criteria. Existing guidance on ecosystem monitoring is broad and not detailed; specific measures still need to be researched and developed at the site-specific level. Five general categories of monitoring are cited: late-successional forest, species of concern, riparian species and habitat, human communities, and adaptive management. Each of these categories features a central issue with related questions posed. A list of monitoring variables is provided in association with each category. For example, late-successional forest issues include the lack of existing habitat to support associated species. Variables to be monitored include patch size, successional status, and understory composition.

26. Patience, N. and V.V. Klemas. 1993. Wetland functional health assessment using remote sensing and other techniques: literature search. NOAA Technical Memorandum NMFS-SEFSC-319, 114 pp.

Wetland functional health determination techniques are reviewed and analyzed in conjunction with remote sensing techniques. These techniques are relevant to NOAA's CoastWatch Change Analysis Program (C-CAP) as well as other evaluation methods, such as EPA's Environmental Monitoring and Assessment Program (EMAP). Remote sensing technology is rapidly advancing, allowing for finer scale mapping in the future. Wetland biomass evaluation is possible with the use of remote sensing, thereby reducing the need for conventional methods. Some indicators of wetland health such as extent and type, habitat structural, and vegetation component of wetland productivity can be surveyed by remote sensing alone. Other indicators still require the use of more conventional techniques.

27. Richardson, J.S. and M.C. Healey. 1996. A healthy Fraser River? How will we know when we achieve this state? *Journal of Aquatic Ecosystem Health* 5:107-115.

The large Fraser River network in British Columbia, Canada is presented as an example of the difficulty of monitoring a large ecosystem. For large-scale watersheds and environments, no single index of ecosystem health exists for simple assessment. Therefore, we are limited to methods that compare current ecosystem conditions against some nearby reference site or existing historical data.

The first method involves building a predictive model using multivariate characterization of "pristine" sites by environmental measures and structure of benthic assemblages. A second method is to use historical reconstruction to model ecosystem functioning in the past. Estimation of natural variation in species abundance and composition will assist in focusing in on ecosystem variation due to anthropogenic stresses. The major constraint is the inability to directly link environmental stressors to ecosystem changes. Reference sites are difficult if not impossible to ascertain for large-scale ecosystems. Caution must be exercised when extrapolating patterns of benthic assemblages from smaller ecosystems to larger watersheds. Despite these concerns, the diagnosis of ecosystem health is evolving and will be primarily based on expert opinion rather than experimental tests of cause and effect.

28. Richter, K.O. Criteria for the restoration and creation of wetland habitats of lentic-breeding amphibians of the Pacific Northwest. In *Wetland and Riparian Restoration: Taking a Broader View, Proceedings of a Conference*, eds. K.B. Macdonald and F. Weinmann. Society for Ecological Restoration International Conference, Seattle, WA, 14-16 Sep. 1995. 284 pp. EPA 910-R-97-007.

In order to achieve self-sustaining populations of breeding lentic amphibians in the Pacific Northwest, several watershed features and wetland characteristics need to be included in the design of wetland restoration and creation sites. Attributes considered include breeding, feeding and refuge habitat, as well as migration corridors and dispersal habitat. The criteria provided are based on landscape ecology and conservation biology literature, as well as the author's personal studies in the Puget Sound Basin. Quantified measures of habitat are suggested as design criteria for successful restoration. These measures include area, lengths, widths, and quality of refuge and movement habitats; wetland attributes such as current velocity, minimum water depths, water level fluctuations, open water and vegetation requirements for breeding. On a landscape scale, connectivity, wetland size, and buffers are discussed to enhance successful amphibian migration and spawning.

29. Rogers, C.S. Common (or is it uncommon?) sense about coral reef monitoring. In *A Coral Reef Symposium on Practical, Reliable, Low-Cost Monitoring Methods for Assessing the Biota and Habitat Conditions of Coral Reefs*, eds. Crosby, M.P., G.R. Gibson and K.W. Potts. Annapolis, MD, 26-27 Jan. 1995. 80 pp. EPA 904/R-95/016.

In order to design effective coral monitoring protocols, one must consider several factors including management objectives, who will perform monitoring, what methods will be used, sampling duration, frequency and intensity, and data analysis and accessibility. The objectives behind coral reef monitoring will determine what success criteria should be selected and what type of data gathered. Long-term assessment of coral reef health is central to any monitoring scheme. Repeated sampling at permanent sites over the long term is vital. Monitoring methods need to be dynamic and flexible enough to address future concerns.

Specific methods to measure coral reef structure (percent cover, species diversity, relative abundance) include quadrats, photo-quadrats, and chain transects; these monitoring methods are summarized and compared as well. Photography is essential in supplementing coral reef monitoring. Changes in reef structure may be correlated to physical and chemical measurements of the surrounding waters. A coral reef monitoring program will most likely involve a variety of methods and long-term monitoring at random sampling sites. Monthly observations are suggested for individual coral colonies, whereas quadrat and transect data should be collected every six months. These frequencies strike a balance between undersampling and destructive activity. Quality assurance/quality control is important for data quality. Standardization of sampling data on a nationwide or global level is recommended, although this goal is not realistically viable.

30. Schweitzer, C.J. What is restoring bottomland hardwood forests? A study from the lower

Mississippi alluvial valley. In *Transactions of the 63rd North American Wildlife and Natural Resources conference*. Orlando, FL, 20-25 Mar. 1998. Washington, D.C.: Wildlife Management Institute.

Restoration of bottomland hardwood forests focuses on vegetation with no mention of restoring hydrologic, edaphic, or faunal components. A survey of 47 Wetland Reserve Program tracts was conducted in 1996, four years after planting, to evaluate reforestation success; soil and hydroperiod were not considered. Since vegetation has been the easiest and most common method of vegetation, the objective focused on attaining a goal of 125 trees per acre after three years. Admittedly, functions such as population dynamics, nutrient cycling, and hydrological cycling are difficult to monitor. Other problems with current reforestation practices include lack of long-term monitoring plots, failure to establish measurable goals, failure to initially restore hydroperiod to ensure planting success, and disregard for soil and faunal monitoring.

31. Simenstad, C.A. and R.M. Thom. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. *Ecological Applications* 6(1):38-56.

The ability to predict long-term trends in wetland restoration success was tested using seven years of monitoring data in the Gog-Le-Hi-Te wetland in Puget Sound, Washington. Sixteen ecosystem functional attributes were analyzed to gauge restoration progress and/or success. These measures included habitat and sediment structure, primary production, benthic and epibenthic invertebrates, fish, and birds. Experiments to assess function directly were also executed, such as monitoring juvenile salmon residence time, foraging, and growth. The results of seven years of monitoring indicated few predictable trends of system development and ecological function. Several ecological functions indicate that Gog-Le-Hi-Te is still in early stages of development, such as static or slow change in sediment organic content and infauna taxa richness and density. Natural variability in reference wetlands must be studied in order to select proper criteria for functional equivalency. Longer time frames for monitoring are needed to determine whether a restored wetland can withstand natural perturbations and variability. Furthermore, current monitoring mainly focuses on structural attributes rather than functional processes. These more costly measures of function are necessary to evaluate ecosystem functioning at both local and landscape scales, as well as identify “endpoints” of estuarine wetland development.

32. Streever, B. 1999. Performance standards for wetland creation and restoration under Section 404. *National Wetlands Newsletter* 21(3):10-13.

In 1998, the U.S. Army Corps of Engineers (Corps) reviewed over 300 section 404 permits to determine whether trends existed for wetland mitigation standards. Many of these 300 permits that required compensatory wetland did not include performance standards or success criteria. Nine examples of performance standards are excerpted from the permit review process; all of them considered vegetation community development to some extent. The 300 permits revealed the lack of a universally accepted set of success criteria for section 404 mitigation. The permit review did identify seven general approaches to how the Corps develops performance standards, i.e. use of indices to compress large amounts of information. Development of a universal set of criteria is complex since different wetlands provide difference functions and require slightly different restoration approaches.

33. Trexler, J.C. 1995. Restoration of the Kissimmee River: a conceptual model of past and present fish communities and its consequences for evaluating restoration success. *Restoration Ecology* 3(3):195-210.

Restoration of fish communities in the Kissimmee River requires selection of carefully defined criteria for assessing success. Two conceptual models were designed to predict the outcome of restoration of fish based on pre-channelization and current conditions. Both models compartmentalize the river into two broad habitat classifications. Three key ecosystem function criteria were cited as being critical to successful restoration of Kissimmee River fish communities. These elements include (1) availability of floodplain habitats to river fishes during summer highwater months; (2) seasonal draining of wetland marshes for export of detritus, invertebrates, and fish; and (3) continuous flow of water throughout the watershed to increase seasonal oxygen minima.

In order to assess the three ecosystem functions detailed, five types of information should be collected when assessing restoration in terms of fish monitoring. The five criteria include (1) export of organic matter, invertebrates, and fish from marshes to river-channel habitats during water recession, as well as low-water refuges for small fish, juveniles, and larvae on the floodplain; (2) movement of spawning adults onto marshes during highwater periods; (3) patterns of spatial variation in abundance by species; (4) systemwide oxygen levels and current velocities, with velocities recommended between 10 and 50 cms^{-1}; and (5) food-web analysis for all abundant fish taxa, conducted before and after restoration, including monitoring of response of indicator species to restoration progress. Criteria (1) and (2) measure key elements of ecosystem function and are considered critical to evaluating restoration success.

34. U.S. Army Corps of Engineers. 1996 Sep. *Planning and evaluating restoration of aquatic habitats from an ecological perspective*, eds. Yozzo, D., J. Titre and J. Sexton, Alexandria, VA: The Institute for Water Resources. 426 pp. IWR Report 96-EL-4.

The U.S. Army Corps of Engineers (Corps) addresses issues of ecological restoration planning and evaluation. The restoration planning process is detailed in several steps, including the selection of restoration objectives and monitoring criteria. Six ecosystem types are addressed: open coastline and near coastal waters, subtidal estuaries, estuarine and coastal wetlands, freshwater wetlands, streams and rivers, lakes and reservoirs. Each section provides information on the ecosystem such as key ecological processes, nutrient sources and distribution, functional values. Although specific quantifiable success criteria are not provided, key structural and functional characteristics are cited for each habitat. Monitoring plans should measure certain variables depending on the restoration objectives and goals. Brief case studies are provided for each habitat type as insight into how the Corps is conducting restoration and post-project evaluation.

35. U.S. Army Engineer Waterways Experiment Station. 1999. Case Study: Application of the HGM *Western Kentucky Low-Gradient Riverine Guidebook* to monitoring of wetland development, *WRP Technical Notes Collection* (TN WRP WG-EV-2.3). U.S. Army

Engineer Research and Development Center, Vicksburg, MS. http://www.wes.army.mil/el/wrp (9 Aug. 1999).

The hydrogeomorphic (HGM) approach for assessing wetland functions is a potential method of monitoring wetland restoration progress. Although the HGM method is designed to assess impacts of proposed projects on wetland functions, it can also be used to monitor wetland development following mitigation or restoration activities. This case study illustrates the potential uses of the HGM approach in the 15-year development of low-gradient riverine wetlands in western Kentucky. Ten variables associated with wetland vegetation development and functional capacity were measured. These included biomass, plant species composition, tree density, floodplain roughness, snag density, and woody debris and log biomass. Four wetland functions were selected that depended heavily on biotic variables measured at the sites: nutrient cycling, organic carbon export, maintenance of characteristic plant community, and wildlife habitat.

There was considerable variability in the field measures for each variable, although certain measures exhibited distinct trends over time. Average O-horizon biomass, site roughness, and similarity in species composition between assessed and reference wetlands all increased over time. Herbaceous ground cover generally declined as average density and basal area of trees increased. All four wetland functions increased in capacity over time, except for the oldest stand of trees. It was determined that performance standards for success should change with site age, rather than comparing restoration to a mature reference site. Unfortunately, Section 404 permit requirements for monitoring usually last for up to five years following mitigation. Development of certain structural characteristics can be engineered within a short time frame. Functional or biological characteristics may require many years to reach optimal levels; for instance, field measures of biological variables in the case study were well below reference standards even after 15 years.

36. Weinstein, M.P., J.H. Balletto, J.M. Teal, and D.F. Ludwig. 1997. Success criteria and adaptive management for a large-scale wetland restoration project. *Wetlands Ecology and Management* 4(2):111-127.

Two kinds of degraded salt marsh were restored in Delaware Bay, New Jersey, in order to mitigate losses of finfish populations from a local power plant. Two basic questions were asked to determine whether the project would be successful: how long would marsh restoration take, and what is the endpoint of restoration? In order to evaluate the success of these restoration efforts, three categories of performance criteria were developed: (1) percent coverage of the marsh by vegetation; (2) reduction in *Phragmites australis* coverage; and (3) percent open water. Three reference marshes were used to establish the “bound of expectation” in terms of measurable endpoints for restoration. Features including geomorphology and vegetation that represent the expected range of variability were monitored in the reference marshes, and these same variables were measured in the restoration sites.

In order to incorporate benefits to finfish in marshes, four structural and functional measures were identified: (1) geomorphology and hydrology; (2) low marsh; (3) hydroperiod; and (4) plant coverage and diversity. Three reasonable restoration endpoints were suggested, including open water coverage, *Phragmites* coverage, and desirable vegetation coverage. To ensure benefits for finfish, a composite evaluation system that merges marsh restoration and optimizes fisheries production was presented. A Habitat Value (HV) scoring method was used to ensure equal weight for each habitat component. For example, either a "lawnscape" of *Spartina* spp. with poor drainage features or an unvegetated, well-drained mud flat would yield an undesirable habitat.

An adaptive management process that can implement corrective actions is also presented. Three hydrology thresholds and two vegetation thresholds were established to gauge when corrective measures would be necessary. Other biological responses were also suggested, such as local herbicide application and planting *Spartina* species.

37. Wilcox, D.A. and T.H. Whillans. 1999. Techniques for restoration of disturbed coastal wetlands of the Great Lakes. *Wetlands* 19(4):835-857.

Wetland restoration in large lake systems is a relatively new practice. This article compiled tested methods and developed additional potential methods to provide an overview of approaches for restoration. Rather than providing specific details of methods, the overview of restoration approaches focuses on four general fields of science: hydrology, sedimentology, chemistry, and biology. Some of these methods were used in three major wetland restoration projects and are illustrative of practical applications in the Great Lakes. Successful wetland restoration is usually determined by a set of measures that describe how closely the restored site resembles the structure of an undisturbed reference site. Such success criteria are usually selected through the regulatory process rather than by following ecological principles. Short-term regulatory measures of success are not indicative of long-term success as most wetland restoration projects need considerable time to develop proper ecological functioning. Measures of wetland structure and function are more meaningful targets for restoration efforts. Five measures are suggested: 1) sustainability, 2) productivity, 3) nutrient retention, 4) invasibility, and 5) biotic interactions.

38. Williams, G.D. and J.B. Zedler. 1999. Fish assemblage composition in constructed and natural tidal marshes of San Diego Bay: relative influence of channel morphology and restoration history. *Estuaries* 22(3A):702-716.

This study evaluated the use by fish of restored tidal wetlands and identified links between fish species composition and habitat characteristics. The study compared the attributes of natural and constructed channel habitats in Sweetwater Marsh National Wildlife Refuge, San Diego Bay, California, by using fish monitoring data to explore the relationships between channel environmental characteristics and fish species composition. Fishes were sampled annually for eight years (1989-1996) at eight sampling sites, four in constructed marshes and four in natural marshes, using beach seines and blocking nets. The authors also measured channel habitat characteristics, including channel hydrology (stream order), width and maximum depth, bank slope, water quality (dissolved oxygen, temperature, salinity), and sediment composition. Fish colonization was rapid in constructed channels, and there was no obvious relationship between channel age and species richness or density. Total richness and total density did not differ significantly between constructed and natural channels, although California killifish (*Fundulus* *parvipinnis*) were found in significantly higher densities in constructed channels. Multivariate analyses showed fish assemblage composition was related to channel habitat characteristics, suggesting a channel's physical properties were more important in determining fish use than its restoration status. This relationship highlights the importance of designing restoration projects with natural hydrologic features and choosing proper assessment criteria in order to avoid misleading interpretations of constructed channel success. The authors recommend that future projects be designed to mimic natural marsh hydrogeomorphology and diversity more closely, the assessment process utilize better estimates of fish habitat function (i.e. individual and community-based species trends, residence time, feeding, growth) and reference site choice, and experimental research be further incorporated into the restoration process.

39. Winfield, T.P., J. Florsheim, and P. Williams. Creating tidal marshes on dredged materials: design features and biological implications. In *Wetland and Riparian Restoration: Taking a Broader View, Proceedings of a Conference*, eds. Macdonald, K.B. and F. Weinmann. Society for Ecological Restoration International Conference, Seattle, WA, 14-16 Sep. 1995. 284 pp. EPA 910-R-97-007.

A set of general design criteria is needed to ensure structural and functional equivalency of created tidal marshes on dredged materials with natural tidal marshes. A study was performed on four tidal marshes in San Francisco Bay to investigate the biological and physical attributes of created tidal marshes and natural tidal marshes. Furthermore, the study identified important design features for consideration in future salt marsh creation projects on dredged material, to increase chances of success. Determination of success has been questionable due to lack of well-defined objectives and inadequate monitoring. Significant differences in vegetation percent cover between created and natural tidal marshes were found, and these were attributed to poor development of a tidal slough channel network at the constructed marshes. The initial elevation of dredged materials on the created tidal marsh is essential to development of slough channel density and morphology.

40. Zedler, J.B. Restoring cordgrass marshes in southern California. 1992. In Restoring the Nation's Marine Environment, ed. Thayer, G.W. College Park, MD: Maryland Sea Grant College, Publication UM-SG-TS-92-06. 716 pp.

Efforts to restore southern California cordgrass (*Spartina foliosa*) marshes have focused on revegetation, but full ecosystem functioning has yet to be documented. In an example in San Diego Bay, created marshes had not reached functional equivalency with natural reference marshes within five years. Other examples illustrate a less than 60 percent functional equivalency with an adjacent reference wetland. Research is needed to understand what causes functional inequivalency, and new methods are underway to improve restoration projects. Long-term studies of coastal restoration sites and development of new ecotechnological methods are needed to improve and accelerate wetland functional equivalency.

41. Zedler, J.B. 1995. Salt marsh restoration: lessons from California. In Rehabilitating Damaged Ecosystems, 2nd edition, ed. Cairns, J. Jr. Boca Raton, FL: CRC Press, Inc. 425 pp.

Mitigation of wetlands has become a justification for "quality replaces quantity". This has been propagated by the lack of documentation of restoration failures. In order to evaluate success, goals and objectives need to be specifically stated prior to any restoration activities. Several goals are presented as examples, including the need for regional coordination, maintaining native species communities that are uncommon in the region, maintaining the "natural variety" of communities rather than simply increasing "diversity", etc. Other goals for hydrological planning are discussed as well, such as the need to maintain natural variations in hydrologic conditions to manage native salt marsh communities.

Experimentation is the only way to refine the science of salt marsh restoration. Knowledge of both failures and successes through controlled, replicated field experiments, performed in conjunction with restoration will be extremely valuable. There are two reasons for assessing restoration success. The first is the need for resource agencies to keep track of how much regional wetland is being restored. The second is to determine whether mitigation has met contractual requirements. Two general criteria of success are whether the restoration project has met the preset objectives and what the restoration provided in comparison to the region's needs. Assessment must be performed over the long-term, from at least one to five years up to beyond 20 years. Detailed and frequent sampling is required to detect changes due to restoration as opposed to natural variation. Results of monitoring and restoration need to be published and peer-reviewed such that refinements can be made.

42. Zedler, J.B. 1996. *Tidal Wetland Restoration: A Scientific Perspective and Southern California Focus*. California Sea Grant College System, University of California, La Jolla, California. 129 pp. Report No. T-038.

Structural attributes are measured during monitoring as surrogates for functional processes. This is mainly due to the fact that basic ecosystem functioning is still being discovered, and monitoring structural criteria is cheaper than extensive functional assessments. Each monitoring program should have performance criteria that are tailored to that site. With respect to Southern California tidal salt marshes, frequency of monitoring is as follows: water quality is biweekly or monthly; vegetation in September; salinity of marsh soil in April and September; fishes and invertebrates on a quarterly basis; and special interest species during reproductive periods.

Three indicators of ecosystem functioning were selected as simple criteria. These included ability to support biodiversity, canopy architecture, and other indicators. Monitoring should be designed to track populations of sensitive and endangered species in order to support biodiversity. Canopy architecture needs to be monitoring such that the vegetation can support endangered birds. Other indicators such as water quality can be used to assess potential for support of fishes and invertebrates. Once these indicators have been selected, they must be reviewed and accepted by scientific peers. Agencies that manage endangered species must then test the cause-effect relationship between the indicator and the ecosystem function it represents.

APPENDIX F

SUMMARIES OF MAJOR ACTS THAT SUPPORT MONITORING

The following summaries of the major Acts mentioned in this Success Criteria Guidance, with the exception of the Rivers and Harbors Act of 1899 and Magnuson-Stevens Fishery Conservation and Management Act, were obtained from Buck (1995)[1].

Anadromous Fish Conservation Act

The Anadromous Fish Conservation Act (16 *U.S.C.* 757a-757g; Pub. L. 89-304, as amended) authorizes the Secretary of Commerce, along with the Secretary of Interior, or both, to enter into cooperative agreements to protect anadromous and Great Lakes fishery resources. To conserve, develop, and enhance anadromous fisheries, the fisheries which the United States has agreed to conserve through international agreements, and the fisheries of the Great Lakes and Lake Champlain, the Secretary may enter into agreements with States and other non-Federal interests. An agreement must specify: (1) the actions to be taken; (2) the benefits expected; (3) the estimated costs; (4) the cost distribution between the involved parties; (5) the term of the agreement; (6) the terms and conditions for disposal of property acquired by the Secretary; and (7) any other pertinent terms and conditions.

Pursuant to the agreements authorized under the Act, the Secretary may: (1) conduct investigations, engineering and biological surveys, and research; (2) carry out stream clearance activities; (3) undertake actions to facilitate the fishery resources and their free migration; (4) use fish hatcheries to accomplish the purposes of this Act; (5) study and make recommendations regarding the development and management of streams and other bodies of water consistent with the intent of the Act; (6) acquire lands or interests therein; (7) accept donations to be used for acquiring or managing lands or interests therein; and (8) administer such lands or interest therein in a manner consistent with the intent of this Act. Following the collection of these data, the Secretary makes recommendations pertaining to the elimination or reduction of polluting substances detrimental to fish and wildlife in interstate or navigable waterways. Joint NOAA Fisheries-FWS hold regulations applicable to this program are published in 50 *C.F.R.* Part 401.

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[1] Buck, E.H. 1995. Summaries of major laws implemented by the National Marine Fisheries Service. CRS Report for Congress. Congressional Research Service, Library of Congress, March 24, 1995.

Clean Water Act

The Clean Water Act (CWA; 33 *U.S.C.* 1251-1387; Act of June 30, 1948, as amended) is a very broad statute with the goal of maintaining and restoring waters of the United States. The CWA authorizes water quality and pollution research and monitoring, provides grants for sewage treatment facilities, sets pollution discharge and water quality standards, addresses oil and hazardous substances liability, and establishes permit programs for water quality, point source pollutant discharges, ocean pollution discharges, and dredging or filling of wetlands. The intent of the CWA Section 404 program and its 404(b)(1) "Guidelines" is to prevent destruction of aquatic ecosystems including wetlands, unless the action will not individually or cumulatively adversely affect the ecosystem. NOAA Fisheries provides direct consultations to the Environmental Protection Agency and the U.S. Army Corps of Engineers as to the impacts to living marine resources of proposed activities and to methods for avoiding such impacts.

Endangered Species Act

The Endangered Species Act (ESA; 16 *U.S.C.* 1531-1543; Pub. L. 93-205, as amended) was enacted in 1973 to provide for the conservation of species that are in danger of extinction throughout all or a significant portion of their range. "Species" is defined by the Act to mean either a species, a subspecies, or, for vertebrates (i.e., fish, reptiles, mammals) only, a distinct population.

Anyone may petition to have a species considered for listing as endangered or threatened, the action which qualifies it for increased protective measures[2]. NOAA Fisheries regulations concerning ESA listing procedures are published at 50 *C.F.R.* Parts 217-227, with joint NOAA Fisheries-FWS regulations appearing at 50 *C.F.R.* Parts 402 and 424-453. Generally, the U.S. FWS coordinates ESA activities for terrestrial and freshwater species, while NOAA Fisheries is responsible for marine species and Pacific salmon. Within 90 days of a listing petition's filing, an agency decision is made on whether to reject the petition, or accept it for a further intensive status review of the species. If a status review is conducted, it is initiated with a public solicitation of information and data relevant to the species of concern. A species must be listed if it is threatened or endangered because of any of the following five factors: (1) present or threatened destruction, modification, or curtailment of its habitat or range; (2) overutilization for commercial, recreational, scientific, or educational purposes; (3) disease or predation; (4) inadequacy of existing regulatory mechanisms; and (5) other natural or manmade factors affecting its continued existence.

Additional important considerations for an ESA listing decision, especially concerning anadromous fish, include defining population segments that qualify as species, determining the abundance threshold for threatened and endangered status, and determining the causes of decline. NOAA Fisheries will consider listing individual Pacific salmon populations only if they are evolutionarily significant units (ESUs), defined as "substantially reproductively isolated" and

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2 However, either NOAA Fisheries or the FWS may initiate a status review for a species without a petition for listing.

"an important component in the evolutionary legacy of the species" (56 *Federal Register* 58612, Nov. 20, 1991).

Economic considerations are not legally relevant to the listing decision; this decision is to be made solely on the basis of the best biological data available. Except for extensions due to consideration of other proposals, a one-year time limit is placed on making the decision to propose listing. If the agency proposes listing, public comments are again solicited on the proposed listing, and a final decision is made within one year after the issuance of the proposal.

Concurrent with the listing decision, critical habitat believed necessary for the continued survival of species is designated. For this decision, economic impacts must be considered. If information is insufficient to designate critical habitat at the time of listing, or if designation of critical habitat would not be "prudent," the Government may take an additional year to identify it[3].

Once a species is listed, recovery plans are prepared which identify mitigation measures to be initiated to improve the species' status. In addition, the ESA Section 7 consultation process requires all Federal agencies to use their authorities to conduct conservation programs (mitigation measures) and to consult with NOAA Fisheries (or the FWS) concerning the potential effects of their actions on any species under the Act's jurisdiction.

Fish and Wildlife Coordination Act

The Fish and Wildlife Coordination Act (16 *U.S.C.* 661-666c; Act of March 10, 1934, as amended) requires that wildlife, including fish, receive equal consideration and be coordinated with other aspects of water resource development. This is accomplished by requiring consultation with the FWS and NOAA Fisheries whenever any body of water is proposed to be modified in any way and a Federal permit or license is required. This consultation determines the possible harm to fish and wildlife resources, and the measures that are needed to both prevent the damage to and loss of these resources, and to develop and improve the resources, in connection with water resource development. NOAA Fisheries submits comments and recommendations to Federal licensing and permitting agencies and to Federal agencies conducting construction projects on the potential harm to living marine resources caused by the proposed water development project, and submits recommendations to prevent harm.

Magnuson-Stevens Fishery Conservation and Management Act

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA; 16 U.C.S. 1801 et seq.) provides authority to the Secretary, through NOAA Fisheries, to conserve, manage, and monitor fisheries in the exclusive economic zone (EEZ). Fishery Management Plans must include a provision to describe and identify the Essential Fish Habitat (EFH), including adverse impacts, identify adverse impacts from fishing activities, minimize to the extent practicable adverse impacts from fishing, identify non-fishing sources of adverse impacts, and identify

[3] If there is substantial disagreement regarding the sufficiency or accuracy of available data, this one-year period may be extended an additional six months.

actions to encourage the conservation and enhancement of EFH. Federal agencies are required to consult with NOAA Fisheries on all actions that may adversely affect EFH. NOAA Fisheries is required to provide EFH conservation recommendations for any Federal or state activity that may adversely effect EFH. The action agency must respond in writing stating how it will avoid or mitigate adverse impacts on EFH, or explain why it will not follow NOAA Fisheries' recommendations. Councils may comment on Federal or state actions which may affect the habitat of fishery resources and must comment if there may be substantial adverse effects to anadromous fish habitat.

National Environmental Policy Act

The National Environmental Policy Act (NEPA; 42 *U.S.C.* 4321-4347; Pub. L. 91-190, as amended) requires Federal agencies to analyze the potential effects of a proposed Federal action which would significantly affect historical, cultural, or natural aspects of the environment. It specifically requires agencies to use a systematic, interdisciplinary approach in planning and decision-making, to insure that presently unquantified environmental values may be given appropriate consideration, and to provide detailed statements on the environmental impacts of proposed actions including: (1) any adverse impacts; (2) alternatives to the proposed action; and (3) the relationship between short-term uses and long-term productivity. The agencies use the results of this analysis in decision-making. Alternatives analysis allows other options to be considered. NOAA Fisheries plays a significant role in the implementation of NEPA through its consultative functions relating to conservation of marine resource habitats.

Rivers and Harbors Act of 1899

The Rivers and Harbors Act of 1899, Section 10 (33 *U.S.C.* 403) requires that all obstructions to the navigable capacity of navigable waters of the United States must be authorized by Congress. The Secretary of the Army must authorize any construction outside established harbor lines or where no harbor lines exist. The Secretary of the Army must also authorize any alterations within the limits of any breakwater or channel of any navigable water of the United States.

APPENDIX G

COST ESTIMATES FOR MONITORING

(These examples of planning estimate costs will vary by region and demand. These are presented to aid in the development of monitoring plans. Personnel cost estimates include salary, benefits, equipment, and supplies. This generic list is designed as an aid in the development of rough planning estimates for costs of monitoring, based on personnel, labor, and equipment. These can be updated by cost inflation factor.)

Item No.	Supplies/Services	Unit Price	(per hour unless otherwise noted)
1	Marine Ecologist	100	
2	Junior Marine Ecologist	40	
3	Aquatic Ecologist	70	
4	Junior Aquatic Ecologist	30	
5	Marine Benthic Ecologist	60	
6	Junior Marine Benthic Ecologist	30	
7	Senior Wetland Ecologist	100	
8	Wetland Ecologist	50	
9	Ornithologist	50	
10	Senior Invertebrate Zoologist	60	
11	Invertebrate Zoologist	50	
12	Junior Invertebrate Zoologist	20	
13	Senior Toxologist	80	
14	Senior Sedimentologist	80	
15	Senior Physical Oceanographer	110	
16	Senior Chemical Oceanographer	110	
17	Senior Biochemist	110	
18	Senior Botanist	70	
19	Botanist	50	
20	Junior Botanist	30	
21	Senior Limnologist	80	
22	Limnologist	50	
23	Senior Ichthyologist	50	
24	Ichthyologist	40	
25	Junior Ichthyologist	30	
26	Senior Mammalogist	70	
27	Mammalogist	30	
28	Junior Mammalogist	30	
29	Senior Wildlife/Biologist (Management)	80	
30	Wildlife/Biologist (Management)	30	
31	Junior Wildlife/Biologist (Management)	30	
32	Senior Fishery Biologist (Freshwater & Marine)	60	
33	Fishery Biologist (Freshwater & Marine)	50	
34	Junior Fishery Biologist (Freshwater & Marine)	30	
35	Beach Dune Ecologist	90	
36	Senior Chemist	110	
37	Landscape Architect	70	
38	Senior Geographer	110	
39	Senior Geographer/Land Use Planner	50	

40	Geographer/Land Use Planner	50
41	Junior Geographer/Land Use Planner	30
42	Senior Planktonist (Fresh & Salt Water)	50
43	Planktonist (Fresh & Salt Water)	30
44	Junior Planktonist (Fresh & Salt Water)	10
45	Senior Hydrologist	70
46	Senior Diving (SCUBA) Biologist	40
47	Diving (SCUBA) Biologist	30
48	Boat Operator	50
49	Junior Boat Operator	30
50	Senior Chemical Technician	80
51	Chemical Technician	60
52	Junior Chemical Technician	50
53	Senior Biological Technician	30
54	Biological Technician	30
55	Junior Biological Technician	20

Item No.	**Supplies/Services**		**per unit**
56	Direct Reading Current Meter	420	Day
57	Direct Recording Current Meter	500	Month
58	REMOTS Camera	570	Day
59	Image Analysis System	160	Hour
60	Range/Azimuth Position System	2070	Month
61	Fish Trawler with gear (300 ft.)	1380	Day
62	Van used to haul equipment and boat trailer	50	Day
		0.38	Mile
63	Sub-bottom profiler	540	Day (+ 500.00 Mobil.)
64	Chart Digitizing System	210	Day
65	Large Research Vessel (70-100 ft.)	2630	Day
66	Sampling Barge with heavy duty winch	410	Day
67	Gill Nets-variable mesh (50 meters long)	50	Day
68	Rocking Chair Dredge (clam)	30	Day
69	Oyster Dredge	20	Day
70	Benthic Sample Box Core Grab (0.25 m, 0.5 mm sieve)	1660	Sample Offshore
		830	Sample Inshore
71	Benthic Sample Van Veen Grab (0.04 m, 0.5 mm sieve)	380	Sample
72	Benthic Sample Smith-McIntyre Grab (0.1 m, 0.5 mm sieve)	690	Sample
73	Fish Sample Gill Net Variable Mesh 50 m Scientific (6 hours deployed)	200	Sample
74	Fish Sample Otter Trawl (two 15 minute or one 30 minute tows)	620	Day
75	Box Core Grab (0.25 m)	30	Day
76	Van Veen Grab (0.04 m)	6	Day
77	Smith-McIntyre Grab (0.1 m)	70	Day
78	Biological Sieves (0.5 mm and 2 mm sieves 75 cm diameter)	6	Day
79	Current Meter (General Oceanic Type) (with analysis)	2200	Month
80	Electro Shocker Equipment	60	Day Backpack
		260	Day Boat
81	Video Camera	60	Day
82	IBM PC Computer	220	Day

83	Portable Turbidimeter	10	Day
84	Hach Portable Spectrophotometer & Water Quality Reagents	10	Day
85	D.O. Meter/Salinometer/Refractometer	40	Day
86	All terrain vehicle for equipment & personnel	50	Day
87	Wide Canoe (minimum 12 ft.)	30	Day
88	Electric outboard engine for canoe & rubber raft	10	Day
89	Rubber Raft (4 man) with Gas-Outboard 25 Horse	60	Day
90	Eight Man Inflatable (e.g. Zodiac) with all necessary operational equipment (i.e. 25 horse motor) and trailer	90	Day
91	Otter Trawl (24 ft. minimum)	30	Day
92	Planktonic Nets (1 meter diameter)	20	Day
93	Microwave Positioning System	250	Day
94	Computerized Navigation System	210	Day
95	Digital Fathometer System w/CTD	420	Day
96	Research Vessel equipped with a radio, depth finder, position indicator, diver ladder (capacity to 200 ft. trawls, grabs) and all marinebiological, chemical, physical sampling gear and necessary equip. to undertake any study (including jars, buckets)	410	Day
97	Mobilization and Demobilization for above Item 96	6	Mile
98	Work Boat, Minimum 22 ft.	340	Day
99	Mobilization and Demobilization for above Item 98	1	Mile
100	Work Boat, Minimum 16 ft.	100	Day
101	Mobilization and Demobilization for above Item 100	1	Mile
102	Side-Scan Sonar, magnetometer, sub-bottom profiler	1350	Day (+ 840.00 Mobil.)
103	Equipment for core sampling and ground water monitoring	710	Day
104	Per diem travel costs	110	Day
105	Geographic Information System (GIS)	580	Day