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Designing Restoration of the San Francisco Bay Delta-River Ecosystem-- A Framework for Developing Ecological Indicators and Thresholds

Discussion Paper for the Workshop "Restoration of the San Francisco Bay-Delta-River Ecosystem: Choosing Indicators of Ecological Integrity"

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A new model for defining the desired state of ecosystems impacted by human activities is emerging in response to some widely-acknowledged limitations of current ecosystem protection tools. In aquatic ecosystems, for example, the normal suite of water quality standards may not protect whole natural communities, in part because standards do not exist for some processes (such as primary productivity, competition, and nutrient transformation) that are critical to ecological services (such as harvestable fish production). Some elements of ecosystem structure, such as species richness, are also not accounted for in conventional standards. Others occur at larger spatial and temporal scales than are routinely monitored. These shortcomings are particularly problematic in ecosystems such as the San Francisco Bay-Delta-River ecosystem (comprised of the watersheds of the Sacramento and San Joaquin Rivers, their delta, and the San Francisco Bay) that are highly disturbed and intensively managed. Moreover, the fact that this ecosystem is composed of many interacting systems that occur over a large geographic scale further exacerbates the problem. As a result, new, more direct measures of the most important and desirable structural and functional attributes of the ecosystem may be necessary to ensure that these attributes are protected while human use of natural resources continues.

In this paper, we briefly review concepts for defining the desired state of ecosystems and for developing indicators of desired state in order to create a common vocabulary for the workshops jointly sponsored by the Environmental Protection Agency, UC Berkeley, The Bay Institute, and the Environmental Defense Fund. We then go on to propose a strawman: an organizing framework that can be used to define the elusive concept of ecological integrity and to develop ecological indicators and target levels defining desired state for the Bay-Delta-River ecosystem. The proposed framework is based on a four-step process suggested by Keddy et al. (1993). This framework incorporates a holistic approach to restoration, encompassing both structural and functional components of an ecosystem as well as various hierarchical levels of organization. The development of a clearly defined framework has several benefits: it provides a rational basis for developing a comprehensive suite of indicators; it reduces the likelihood of failing to consider important ecosystem attributes and indicators; it enhances the ability to set priorities among indicators, if necessary; and it helps to explain the importance and function of each indicator to the scientific community and policymakers. A coherent conceptual framework also will aid in the maintenance of the restoration program and of associated long-term monitoring programs.

ECOSYSTEM HEALTH

Practitioners in the new fields of *ecosystem medicine*, *stress ecology*, and *clinical ecology* are developing and attempting to use concepts such as *ecosystem health*, *ecological integrity* and *biological integrity*. *Ecosystem health* has been defined in a variety of ways (see Table 1 for examples). Karr (1993) defines ecosystem health as the condition in which a system realizes its inherent potential, maintains a stable condition, preserves its capacity for self-repair when perturbed, and needs minimal external support for management. *Biological integrity* refers to the "ability of an ecosystem to support and maintain a balanced, integrated, adaptive biological community having a species composition, diversity, and functional organization comparable to that of natural habitat in the region" (Karr and Dudley 1981). It is important to note that *biological integrity* distinguishes between human and naturally-caused changes whereas *ecosystem health* does not (Miller 1995). New institutions have formed to advance these concepts, such as the International Society for Ecosystem Health and the Society for Ecological Restoration.

The concept of ecosystem health has most often been defined, however, by what it is *not*. David Rapport and colleagues (e.g. 1989; Rapport, Regier and Hutchinson 1985; 1984; Rapport, Regier and Thorpe 1981; Rapport, Thorpe and Regier 1979) developed the concept of an *ecosystem distress syndrome*, marked by reductions in the stability and diversity of aquatic ecosystems, elimination of the longer-lived, larger species, and a tendency to favor short-lived opportunistic species (Rapport, Regier &

Hutchinson 1985). In the Great Lakes, some of the more heavily used, degraded subsystems exhibit the general distress syndrome. In case studies of these systems, likely ecological responses from each type of stress were inferred from impact assessments. A fairly comprehensive and detailed interdisciplinary set of conceptual frameworks was developed from this information, which can be used as a basis for rehabilitation of the Great Lakes ecosystem (Rapport, Regier, and Hutchinson 1985).

Additionally, Rapport et al. (1981) compare the stress response of an ecosystem (considered as an organism) to that of a mammalian system. The first response to stress is generally an alarm reaction (a characteristic change at the first exposure to stress), followed by resistance (when continued exposure leads to an adaptation), and, finally, exhaustion (irreversible damage following prolonged exposure). The five main groups of ecosystem stresses identified include: (1) harvesting of renewable resources; (2) pollutant discharges; (3) physical restructuring (including hydrologic modifications); (4) introduction of exotics; and (5) extreme natural events (Rapport, Regier & Hutchinson 1985).

ECOLOGICAL INDICATORS

Although ecological health and integrity have been defined conceptually in the literature, providing an *operational* definition-- with quantifiable measures --for the health or integrity of a particular ecosystem can prove difficult. One approach is the use of *ecological indicators* (alternatively known as metrics or state variables). Ecological indicators are components of a system whose characteristics (presence or absence, quantity, distribution) are used to represent those ecosystem attributes that are too difficult, inconvenient or expensive to measure (Landres et al. 1988). Indicators are intended to provide an assay to describe the health of an entire ecosystem, essentially 'taking nature's pulse'.

Keddy et al. (1993) suggest a four-step process for describing and predicting the states of ecosystems, using ecological indicators: (1) define health or integrity in an operational way; (2) select indicators of integrity; (3) identify target levels of the indicators that define desired states; and (4) develop a monitoring system to provide feedback that can be used to modify the indicators and their target levels as appropriate. In the following discussion, we propose a strawman framework for using these steps to develop ecological indicators for the San Francisco Bay-Delta-River ecosystem.

Step 1: Define health or integrity in an operational way

Step one constitutes the broad overview of an ecosystem management or restoration program, where the objectives for the program are set. Researchers ask: Are there intrinsic attributes that define health? If not, is there another way to describe a healthy ecosystem? In order to translate ecosystem health into goals for restoration, it is helpful to identify the most important elements of ecosystem structure and function necessary to support the desired state. Several policy-related and scientific groups have invested considerable time and energy into identifying a suite of goals that might be used as surrogates for ecosystem health descriptors for the Bay-Delta-River ecosystem. For example, both CALFED and the San Francisco Estuary Project Comprehensive Conservation and Management Plan (CCMP) have produced lists of ecosystem quality objectives that may also be used for this purpose. In addition, participants in a recent workshop, entitled "Goals for Restoring a Health Estuary", sponsored by the National Heritage Institute (NHI) and others, identified some key ecosystem service goals to use in an operational definition of ecosystem integrity. Many of the goals (or ecosystem functions and services) identified by these groups are comparable to one another; others appear to be more appropriate as indicators (step two) rather than definitions of the desired state of the ecosystem (step one). In Table 2 we have assembled a preliminary, consolidated list of the goals that have been suggested by these various groups as operational definitions of ecosystem integrity. The original documents are reprinted in Appendix I. **One of the objectives for this workshop is to determine whether the list in Table 2 is both appropriate and comprehensive.** It is particularly important to consider whether ecosystem "integrity" or "health" is captured by the suite of goals presented in the table.

In the longer term, insight into the adequacy of this suite of goals can be gained by analyzing a reference system, whose attributes can be used to infer how a system with integrity might look and/or function. One technique to establish reference conditions is to reconstruct how the system looked and functioned in the past, and compare it with how it functions now. This is similar to the approach used in the Florida Everglades, where a natural system model is being designed to serve as the template for restoration. Another method is to characterize comparable ecosystems in more pristine conditions, if they exist. Both types of reference systems can provide insight into developing and refining the objectives of the program.

Once refined, the list of program goals can provide a basis for choosing ecological indicators, using a methodology described below.

Step 2: Select indicators of health or integrity

Many factors (scientific, economic, and sociopolitical) come into play in choosing indicators for a particular ecosystem or program. The fundamental requirement, however, is that all of the important attributes of the system be represented. The National Research Council (1992) stresses that restoration of an aquatic ecosystem requires coordinated, comprehensive management of all significant ecological elements, often on a watershed or other landscape scale.[1]

To cover all aspects of the system, many authors (e.g. National Research Council 1992; Noss 1990) suggest that a suite of indicators should include both *structural* and *functional* attributes of an ecosystem. Topography and nutrient cycling are examples of structural and functional attributes, respectively. (See Table 3 for additional examples.) Additionally, Noss (1990) suggests that indicators for monitoring should include several hierarchical levels of ecological organization, at multiple spatial and temporal scales. He states that "no single level of organization (e.g., gene, population, community) is fundamental, and different levels of resolution are appropriate for monitoring and protecting biodiversity." Noss also maintains that "'Big picture' research on global phenomena is complemented by intensive studies of the life histories of organisms in local environments."

Focusing exclusively on indicators of one hierarchical level has several disadvantages. For example, it has been suggested that the success of species at top trophic levels indicates the health of lower trophic levels. Organisms at top trophic levels, usually vertebrates, have often been used as indicators. Indicators of the status of "charismatic megafauna" also serve other functions, such as helping to maintain political will for restoration. However, because of their relative longevity, the actual causes of perceived declines, once detected, are often difficult to unravel (Laudenslayer 1991). For this reason, Landres et al. (1988) conclude that using vertebrates alone to indicate habitat quality for other species is not a sound method, and recommend the use of other indicators as part of a comprehensive monitoring strategy.

Monitoring at lower levels of organization within the ecosystem provides clues to the processes affecting the behavior of the whole (Rapport 1984) and may provide an early warning of ecological stress, because with this approach the ecological preconditions for a healthy ecosystem, such as primary productivity, are being monitored. Indicators of early steps in the process leading to stress may be more useful than an indicator which informs that the system is already ailing. For example, using indicator species associated with soil productivity (e.g. mycorrhizal fungi) quickly detects those effects that may be fundamental to the functioning of the system. Mycorrhizal fungi are important components in the diets of small mammals, which in turn are important diet components of carnivorous species (Laudenslayer 1991). In the case of eutrophication, monitoring nutrient flux may allow for early detection of an imminent problem, whereas monitoring of dissolved oxygen may signal changes only after it is too late for preventative measures. Additionally, when employing biota as indicators, a suite of indicators including

[1] This kind of ecosystem-level management has gained popularity lately, and has been adopted by the National Park and US Forest Service.

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multiple species and assemblages is more likely to provide improved detection capability over a broader range as well as protection to a larger segment of the ecosystem than single indicators(Kremen 1992; Karr 1993). One example of an indicator suite is Karr's Index of Biotic Integrity (IBI), which provides a quantifiable index of a number of ecological indicators for the assessment of the quality of water resources (Karr 1992). The IBI adopts the hierarchical approach discussed above, integrating 12 ecological characteristics, or metrics, of stream fish assemblages, classified into three major groups: species richness and composition, trophic composition, and fish abundance and condition (Karr 1987). Index scores range from 1-5, depending on how observed site conditions compare to those for a pristine reference site. Karr initially developed the IBI for use with fish communities, but the ecological foundation can be used to develop analogous indexes that apply to other taxa (Karr 1991). Miller et al. (1988) review the application of the IBI to various locations in the United States and conclude that the IBI holds promise for direct biological monitoring because of its strong ecological foundation and flexibility.

A second objective for this workshop is to provide the foundation for developing ecological indicators for the Bay-Delta-River ecosystem in a pragmatic, methodical way. These ecological indicators should assess the attainment of the goals identified in step one. In order to provide a framework that clearly outlines the logic behind the selection of specific indicators, and to ensure that the indicator suite adequately covers structural and functional ecosystem attributes as well as various hierarchical levels of organization, we suggest using Noss' (1990) conceptual model of biodiversity at multiple levels of organization (Figure 1). Figure 2 adapts Noss' figure into a proposed matrix for identifying ecological indicators at each level of organization for a particular operational definition of ecosystem integrity. A matrix would eventually be filled out for each operational attribute or goal, based on those listed in Table 2 or any others workshop participants may propose. We have attempted to fill in a matrix for the goal of "Increasing and Improving Aquatic Habitats" (Figure 3) for the purpose of illustrating what is meant by the three categories and four scale levels in the matrix; no attempt was made to ensure that the sample indicators were the most appropriate or scientifically defensible indicators possible. The utility of the proposed framework is primarily to ensure that the suite of ecological indicators adequately addresses the range of ecosystem structure and function at a variety of hierarchical levels.[2]

[2] Missing from the strawman framework as outlined so far is an explicit treatment of specific stressors. In order to assure that the suite of ecological indicators is sensitive to and provides early warning of disruption due to stressors, we suggest that the following "check" be undertaken as part of step 2. First, a list of likely stressors for the Bay-Delta-River ecosystem should be developed. The list would probably encompass the five general stressor categories identified by Rapport, Regier and Hutchinson (1985), listed above. Second, the likely responses from each category of stressor could be explored, considering both the ecosystem attributes defined in step one and the matrices already developed in step two. Finally, the likely responses could be compared to the existing list of ecological indicators, to determine whether the

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In filling out these matrices, some considerations about indicators must be kept in mind. Ideally, indicators should be (1) sufficiently sensitive to provide an early warning of change; (2) distributed over a broad geographical area, or otherwise widely applicable; (3) capable of providing a continuous assessment over a wide range of stress; (4) relatively independent of sample size; (5) easy and cost-effective to measure, collect, assay, and/or calculate; (6) able to differentiate between natural cycles or trends and those induced by anthropogenic stress (Noss 1990); (7) ecologically meaningful (closely related to maintenance of essential processes and functions) (Keddy et al. 1993); (8) relevant to societal concerns (Angermeier and Karr 1994); and (9) environmentally benign to measure (Barbour, Stribling & Karr 1995). Kimmerer (1995) also suggests some key features to ensure the scientific defensibility of an ecosystem health indicator: (1) Primary indicators (those monotonically related to an ecosystem property) are preferred over derived ones (those assumed to be related to some primary indicator that itself may not be measurable or interpretable); (2) easily interpretable indicators take precedent over those which require value judgments; (3) measurable indicators are preferred to conceptual ones; (4) quantitative indicators are preferred to qualitative ones; and (5) existence of a long historical data record is desirable. Many indicators have been suggested in a variety of forums (see, for example, Appendices II & III).

Step 3: Identify target levels of indicators that define integrity or lack thereof

Once indicators are selected, a range of target values, from tolerable to desirable levels, should be developed for each. Because determining the target range of indicator values from first principles is difficult, comparisons with reference systems are often used. As discussed above, the reference system can be either a similar, but more "pristine" system or a historical reconstruction of the system when it was in the desired state. In disturbed ecosystems such as the Bay-Delta-River system, it is clearly unreasonable to strive for the restoration of pristine conditions. However, an historical reconstruction can provide insights into what target levels could be, through a comparison of increasingly less disturbed states. In addition, such an approach has the advantage of being holistic. A consideration only of present-day structure and function may result in a limited and fragmentary vision and strategy for restoration. An extended discussion of methodologies for defining target levels is planned for a future workshop. In general, pilot studies also are recommended, in order to define, evaluate, and calibrate the metrics prior to full-scale implementation of the program (Kremen 1992).

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indicators, combined with the routine monitoring programs already underway, will provide adequate early warning of a significant stress response.

Step 4: Develop a monitoring system to provide feedback

A monitoring system is crucial to the successful use of ecological indicators as a management tool. Monitoring provides a way to assess the utility of indicators and their target levels, developed in steps two and three, and then modify them if necessary. Similarly, the monitoring and assessment program allows for *adaptive management*: changes in the ecological indicators allow decision makers to determine whether the management and/or restoration program is having its intended effect. Additionally, monitoring results can be utilized as a tool for public outreach, using appropriate indicators for different audiences. For example, simplistic indicators of ecosystem health, such as the Chesapeake Bay white sneaker visibility test (a proxy for water clarity) may not be scientifically defensible, but can help inform the public and educate them about restoration efforts in their region. Post-management uses of ecological indicators include short-term evaluation of success of a project and long-term monitoring.

INSIGHTS FROM OTHER PROGRAMS

Indicators have long been employed by environmental toxicologists. However, only recently has the concept of ecological indicators been suggested for assessing the overall health of ecosystems, when contaminants are not the sole issue. Past attempts to employ ecological indicators and ecosystem-level management provide valuable lessons for applying the general approach outlined above to the Bay-Delta-River ecosystem. We describe a few examples to illustrate some lessons for the successful application of ecological indicators. One characteristic shared by all of them is an effective monitoring program.

"Soft engineering" techniques were used to restore the Blanco River in southwestern Colorado, channelized by the U.S. Army Corps of Engineers (COE) in the 1970's in a flood-control effort. Results of the channelization included channel instability, stream-bank failure, and erosion, among other problems. A landowner initiated the restoration project with the goal of "stabilizing the river in a well-carved but natural-looking permanent channel that would enable it to handle floods" (step 1 of the methodology proposed in this paper). Hydrologist D.L. Rosgen used as his reference site a similar, stable section of the river about a mile downstream from the project site. Project indicators[3] were measured at the project site and on a similar area to verify that the reconstructed reach would be able to accommodate the demands placed on it (steps 2 & 3). In the course of three years, the river's width when full was reduced from a 400-ft-wide braided channel to a single 65-ft channel with the desired characteristics: stable, deep, and slow-moving (high pool-to-riffle ratio) (Berger 1992a).

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[3] Indicators used include river width, depth, velocity, discharge, slope, energy slope, roughness, sediment load, sediment size, sinuosity, width-to-depth ratio, dominant particle size of bed and bank materials, entrenchment of channel, confinement of channel, landform confinement of channel, landform features, soil erodibility, and stability.

The demonstration restoration project for the Kissimmee Riverine-Floodplain System provides an example of the utility of testing a restoration plan in a small area before applying it to the larger system. The goal of the demonstration project was to show that wetland vegetation and other wildlife would readily recolonize the reflooded areas, and riverine ecosystems would respond favorably to resumption of natural flow regimes (step 1). The project successfully demonstrated that restoration of riverine-floodplain values and functions is possible, and this success has garnered much-needed support for the restoration of the larger Kissimmee system. An inter-agency monitoring program played a crucial role in demonstrating this success (step 4).[4]

Some particularly successful components of the Kissimmee project include: (1) setting explicit goals (i.e. restoration of ecological integrity) in advance; (2) not establishing criteria in terms of numbers of fish or waterfowl to be restored, which avoided battles among different user groups; (3) a more extensive scientific peer-review process than most restoration projects have; (4) use of hydrologic models to establish probable outcomes for some of the nonbiological aspects of alternative restoration plans, which reduced uncertainty about these outcomes; (5) monitoring designed from an ecosystem perspective; and (6) a major public education effort on the part of scientists and engineers to acquaint people with the complexities of ecological restoration (Berger 1992b).

The goal in the creation of Sweetwater Marsh National Wildlife Refuge was to create nesting habitat for the light-footed clapper rail (*Rallus longirostris levipes*), and foraging habitat for the California least tern (*Sterna antillarum browni*) (step 1). Restoration of some 128 ha of wetlands and some uplands along the east side of San Diego Bay began in 1984 with the excavation of approximately 4.9 ha of disturbed upper intertidal marsh, including areas previously used as an urban dump. The managers used soil nitrogen concentrations as well as a "functional equivalency index" to compare constructed and natural wetland functioning (step 2). For each of 11 marsh attributes,[5] mean values for the constructed marsh were expressed as percentages of the mean value for a reference wetland (step 3). A monitoring program to assess plant cover and faunal use was implemented from the outset of the project. The results indicated less than 60% equivalency when the marsh was 4-5 years of age (step 4). The

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[4] The South Florida Water Management District (SFWMD) monitored the effect of hydrologic changes on floodplain vegetation, floodplain fish, secondary productivity, benthic invertebrates, and river channel habitat characteristics. Other agencies, including the Florida Game and Fresh Water Fish Commission and the Florida Department of Environmental Regulation, conducted alligator counts, bird surveys, fish population samples, water quality monitoring, and measurements of aquatic macroinvertebrate and periphyton responses.

[5] Attributes include organic matter content, sediment inorganic nitrogen, sediment nitrogen total Kjeldahl nitrogen (TKN), pore-water inorganic nitrogen, nitrogen fixation (surface cm.), nitrogen fixation (rhizosphere), biomass of vascular plants, foliar nitrogen concentration, height of vascular plants, epibenthic invertebrate numbers, and epibenthic invertebrate species lists.

project's exceptionally high criteria for judging success serves as a model for future restoration efforts (National Research Council 1992). Whether or not this restoration project was a success in terms of created habitat for birds, the use of a reference condition by which to evaluate the project can be considered successful.

Ecological indicators can also be used to provide insight into the state of non-managed systems. For example, the United States Environmental Protection Agency (USEPA) initiated a nationwide environmental monitoring and assessment program (EMAP), with the goal of "establishing baseline conditions against which future changes can be documented with confidence" (Breckenridge et al. 1995). In the context of this project, the operational definition of ecological integrity is based upon societal values (step 1). The program classifies its indicators into four types (response, exposure, habitat, and stressor) to evaluate habitat productivity, biological integrity, and aesthetics: the focal points of the program (Hunsaker, Carpenter and Messer 1990). *Response indicators* quantify the overall biological conditions of ecosystems by measuring either organisms, populations, communities, or ecosystem processes. *Exposure indicators* measure ecosystem exposure to toxics, nutrients, heat, acidity, and ionizing or electromagnetic radiation. *Habitat indicators* represent conditions on a local or landscape scale that are necessary to support a population or community (e.g. availability of snags, vegetation cover, vertical layers of vegetation). *Stressor indicators* reflect activities or occurrences that cause changes in exposure or habitat conditions and include pollutant, management, and natural process indicators (e.g. number of wastewater discharges, proximity to urban areas, and introduction of exotic species) (Hunsaker, Carpenter and Messer 1990) (step 2).

Another important element of successful restoration projects has been careful scientific and political consensus-building, such as the process employed for deciding upon the X_2 salinity standard for the Bay-Delta-River ecosystem. Participants in a series of workshops sponsored by the San Francisco Estuary Project agreed upon a scalar index consisting of the position of a particular near-bottom isohaline as a "policy" variable that could be used to set standards for managing freshwater inflow (step 1 & 2). Participants then agreed upon the 2% near-bottom isohaline (denoted as X_2) in particular for further exploration (Jassby et al. 1995) (step 3). Some of the workshop participants later tested the choice of X_2 and found that it has a clear and pervasive relationship with estuarine biological properties, demonstrates integration of effects over space and time, has unambiguous relationships with many habitat variables (including salinity distribution and net outflow from the Delta), is quantifiable by automated or synoptic monitoring, is important to ecological structure and function, responds to stressors and management strategies, can be measured by a standard method, has low measurement error, has a historical data base, and can be considered cost-effective (Jassby et al. 1995) (step 4). These are all attributes considered critical or desirable for habitat indicators by the USEPA's EMAP program (Messer 1990). They also meet many of the criteria described in the section on step two of this paper.

CURRENT OPPORTUNITIES

Provisions of the Bay-Delta Accord and the Central Valley Project Improvement Act (CVPIA), combined with requirements of the Endangered Species Act (ESA) and the Clean Water Act (CWA), provide an unprecedented opportunity to carry out protection and restoration measures for the Bay-Delta-River ecosystem. CALFED, a state-federal program launched in the wake of the Bay-Delta water accord of last December, is currently in the process of exploring restoration plans for the Bay-Delta-River ecosystem, with the target of formulating preliminary alternative packages by early next year. Additionally, a variety of private sector interests are attempting to achieve consensus on key issues related to California's water resources. The variety of ecosystem types involved and the complexity of the issues will prove challenging obstacles to restoration. If a holistic ecosystem approach to the Bay-Delta-River restoration program is to be embraced, now is the time to advance it and build consensus for it. Ecological indicators and targets may prove to be useful tools to facilitate ecological restoration and continued human use.

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Table 1: Some proposed descriptors of ecosystem health.

Ecosystem health descriptor	Definition
Costanza (1992):	
• Homeostasis	Maintenance of a steady state in living organisms by the use of feedback control processes
• Absence of disease	Lack of stress, or perturbation with particular negative effects on the system
• Diversity/Complexity	Evenness and richness of species.
• Stability/resilience	How fast the variables return towards their equilibrium following a perturbation. Not defined for unstable systems
• Vigor/scope for growth	Overall metabolism or energy flow
• Balance	Proper balance exists between system components
Westman (1978):	
• Resilience	Degree, manner, and pace of restoration of initial structure and function in an ecosystem after disturbance
• Inertia	Ability of a system to resist displacement in structure or function when subjected to a disturbing force
• Elasticity	Time involved in restoration
• Amplitude	Degree of brittleness of the system; threshold beyond which ecosystem repair to the initial state no longer occurs
• Hysteresis	Degree to which the pattern of recovery is not simply a reversal of the pattern of initial alteration
• Malleability	The ease with which the system can become permanently altered; compare the new stable state to the former one
National Research Council (1992):	
• Persistence	The ability of the ecosystem to undergo natural successional processes or persist in a climax sere, all without active human management
• Verisimilitude	A broad, summative, characteristic of the restored ecosystem reflecting the overall similarity of the restored ecosystem to the standard of comparison, be it prior conditions of the ecosystem or of a reference system

Table 2: Some proposed operational definitions of ecosystem integrity and sources from which they were derived.* The operational definitions of ecosystem integrity in the first column can be used to fill in the blank at the top of the matrix in Figure 2.

OVERALL GOAL:	Source:
• Improve, increase, restore and protect aquatic and terrestrial habitats and improve ecological functions in the Bay-Delta-River ecosystem to support sustainable, diverse, balanced and healthy populations of plant and animal species, focusing on indigenous species	-Improve and increase aquatic and terrestrial habitats and improve ecological functions in the Bay/Delta to support sustainable populations of diverse and valuable plants and animal species (CALFED) - Restore and protect a diverse, balanced and healthy population of fish, invertebrates, wildlife, plants and their habitats, focusing on indigenous species (CCMP)
OPERATIONAL DEFINITION OF ECOSYSTEM INTEGRITY:	Source:
Habitat	
• Improve and increase <u>aquatic</u> habitats (including riverine, delta, estuarine, and bay)	- Improve and increase aquatic habitats so that they can support the sustainable production and survival of native and other desirable estuarine and anadromous fish in the estuary (CALFED)
• Improve and increase <u>terrestrial</u> habitats (including wetland, riparian, upland and ???)	- Improve and increase important wetland habitats so that they can support the sustainable production and survival of wildlife species (CALFED)
Biota	
• Stem and reverse the decline in the health, abundance, and species richness of <u>aquatic</u> biota (native and desirable non-indigenous) with an emphasis on natural production (for riverine, delta, estuarine, and bay systems)	- Stem & reverse the decline in the health and abundance of estuarine biota (native and desirable non-indigenous) with an emphasis on natural production (CCMP) - Stem & reverse the decline of estuarine plants and animals and the habitats on which they depend (CCMP) - Increase population health and population size of Delta species to levels that assure sustained survival (CALFED) - Restoration goals for anadromous fish are equal to, or at least twice the mean estimated natural production for the baseline period of 1967-1991 (DPlan)
• Stem and reverse the decline in the health, abundance, and species richness of <u>terrestrial</u> biota (native and desirable non-indigenous) with an emphasis on natural production (for wetland, riparian, upland, and ??? systems)	- Restore populations of indigenous species to levels not likely to result in extinction (NHI-WS)

Table 2 (continued)

• Ensure the survival and recovery of listed and candidate <u>aquatic</u> endangered and threatened species, as well as other species in decline	- Ensure the survival & recovery of listed and candidate (aquatic) species, as well as other species in decline (CCMP) - Establish self-sustaining populations of the species of concern that will persist indefinitely (NF)
• Ensure the survival and recovery of listed and candidate <u>terrestrial</u> endangered and threatened species, as well as other species in decline	- Ensure the survival & recovery of listed and candidate (terrestrial) endangered and threatened species, as well as special status species (CCMP)
Ecosystem Services & Functions	
• Provide commercial and sport-fishing opportunities	- Provide anglers with a reasonable chance of catching sport fish (NHI-WS) - Increase naturally-produced populations of anadromous fish (NHI-WS) - Chinook salmon, green sturgeon and splittail - recovery goals include having large enough populations so that a limited harvest can once again be sustained (NF)
• Preserve and restore the capacity of the system to provide essential ecosystem services, including (1) flood control, (2) water quality enhancement, (3) erosion control, (4) recreation, and (5) aesthetic enjoyment	- Preserve and restore wetlands to provide habitat for wildlife, improve water quality and protect against flooding (CCMP) - Restore and enhance the ecological productivity and habitat values of wetlands (CCMP) - Enhance aesthetic values (NHI-WS)

* Sources are cited as follows: "San Francisco Estuary Project Comprehensive Conservation and Management Plan", 1992 (CCMP); "Draft: CALFED Bay/Delta Program- Ecoystem Quality Objectives Statements" (CALFED); "Recovery Plan for the Sacramento-San Joaquin Delta Native Fishes: Technical/Agency Draft", 12/94 (NF); "Working Paper on Restoration Needs: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California" (DPlan); Draft Report on the National Heritage Institute Definitional Workshop, "Goals for Restoring a Healthy Estuary" (NHI-WS).

Table 3: Possible structural and functional ecological assessment criteria, over a range of ecological levels of organization. Taken from *National Research Council (1992)* unless otherwise noted.

STRUCTURE	FUNCTION
Water quality (dissolved O_2, dissolved salts, dissolved toxics and other contaminants, floating or suspended matter, pH, odor, opacity, temperature profiles)	**Decomposition rate** (Landres 1992)
Soil condition (soil chemistry; erodibility; permeability; organic content; soil stability; physical composition, including particle sizes and microfauna)	**Surface and ground water storage, recharge, and supply**
Geological condition (surface and subsurface rock and other strata, including aquifers)	**Floodwater and sediment retention**
Hydrology (quantity of discharge on annual, seasonal, and episodic basis; timing of discharge; surface flow processes, including velocities, turbulence, shear stress, bank/stream storage, and exchange processes; ground water flow and exchange processes; retention times; particle size distribution and quantities of bed load and suspended sediment; and sediment flux (aggradational or degradational tendencies) (Rosgen 1988))	**Transport of organisms, nutrients, and sediments**
Topography (surface contours; the relief (elevations and gradients) and configuration of site surface features; and project size and location in the watershed, including position relative to similar or interdependent ecosystems)	**Humidification of atmosphere** (by transpiration and evaporation)
Morphology (shape and form of the ecosystem, including subsurface features)	**Oxygen production**
Flora and fauna (species richness, guild structure, functional dominance (Landres 1992), density, diversity, growth rates, longevity, species integrity (presence of full complement of indigenous species found on the site prior to disturbance), productivity, stability, reproductive vigor, size- and age-class distribution, impacts on endangered species, incidence of disease, genetic defects, genetic dilution (by nonnative germ plasm), elevated body burdens of toxic substances, and evidence of biotic stress)	**Nutrient cycling** (loss of, turnover, horizontal transport, vertical cycling (Landres 1992))
Carrying capacity, food web support, and nutrient availability as determined for specific indicator species	**Biomass production, food web support, and species maintenance** (primary productivity, production : respiration and production : biomass ratios (Landres 1992)) **Provision of shelter for ecosystem users** (e.g. from sun, wind, rain, or noise) **Detoxification of waste and purification of water** **Reduction of erosion and mass wastage** **Energy flow**

Figure 1: Compositional, structural, and functional biodiversity, shown as interconnected spheres, each encompassing multiple levels of organization. This conceptual framework may facilitate selection of indicators that represent the many aspects of biodiversity that warrant attention in environmental monitoring and assessment programs (Taken from Noss 1990).

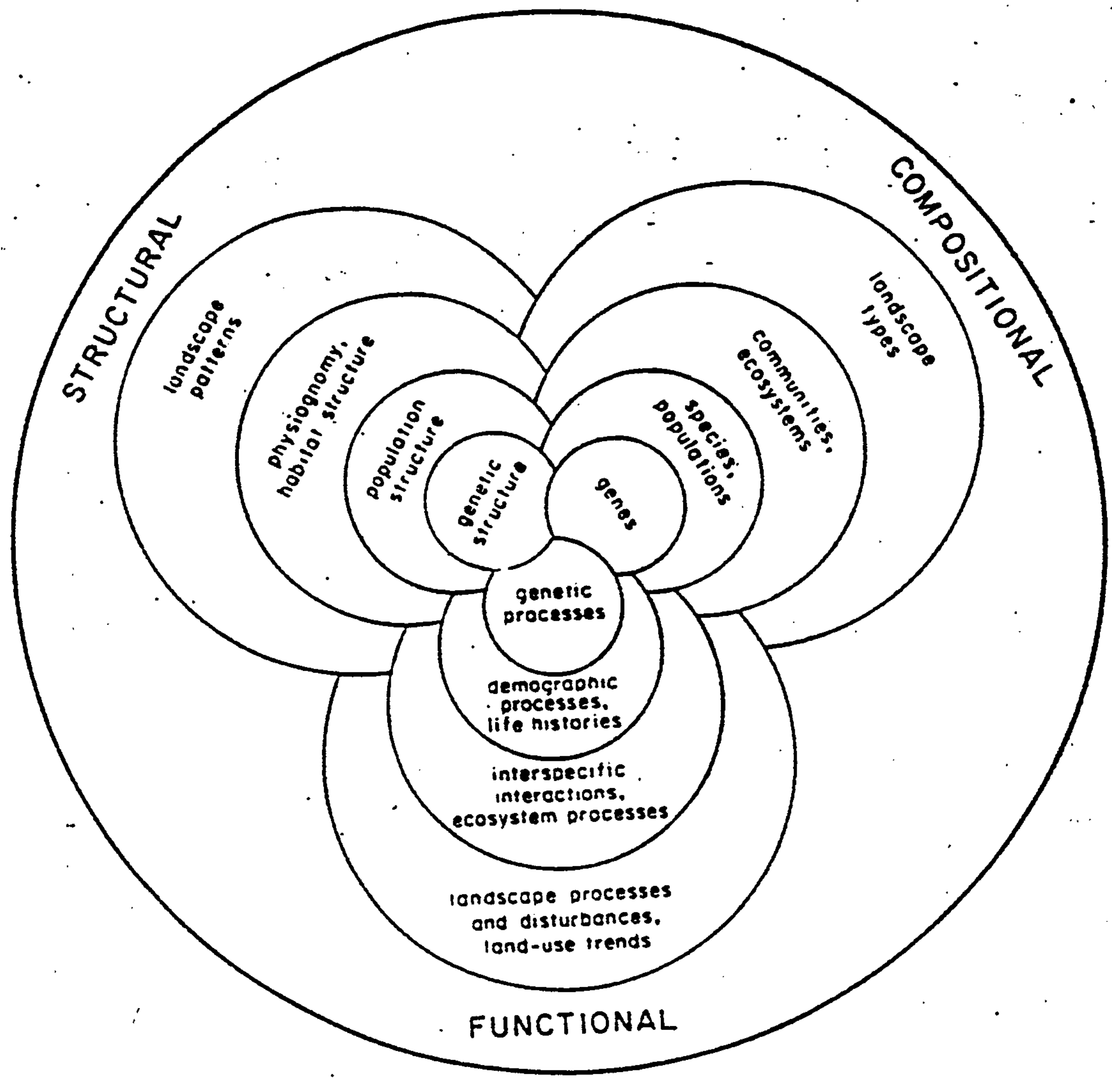

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Figure 2: Proposed matrix for identifying ecological indicators at each level of organization for a particular operational definition of ecosystem integrity.

OPERATIONAL DEFINITION OF ECOSYSTEM INTEGRITY: ______________________

STRUCTURAL ELEMENTS	STRUCTURAL PATTERNS	FUNCTIONAL ATTRIBUTES
Landscape types	Landscape patterns	Landscape processes and disturbances, land-use trends
Communities, ecosystems	Physiognomy, habitat structure	Interspecific interactions, ecosystem processes
Species, populations	Population structure	Demographic processes, life histories
Genes	Genetic structure	Genetic processes

Adapted from Noss (1990)

Figure 3. Strawman matrix with examples of possible indicators

OPERATIONAL DEFINITION OF ECOSYSTEM INTEGRITY: Improve and Increase Aquatic Habitats

STRUCTURAL ELEMENTS	STRUCTURAL PATTERNS	FUNCTIONAL ATTRIBUTES
Landscape types	**Landscape patterns**	**Landscape processes and disturbances, land-use trends**
Rivers (various order streams, floodplains) Delta (including sloughs) Estuary (including X-2) Bay (including Suisun, San Pablo, Central, South)	Connectivity between protected and restored habitats The right habitats in the right places Degree of stream sinuosity	Survival rates of all life cycle phases of desired species Degree of resemblance between actual hydrograph and natural hydrograph
***Communities, ecosystems**	***Habitat patterns**	***Interspecific interactions, ecosystem processes**
Extent of shaded riparian zones Extent of shallow riverine habitat Extent of river edge habitat Type and amount of large woody debris	Pool-to-riffle ratio Relative amounts of habitat types Minimum habitat size	Bank stability, nutrient and sediment retention Nutrient loading, transformation Production of forage for desired species Primary productivity by desired species Toxic compound concentrations
***Species, populations**	***Population structure**	***Demographic processes, life histories**
Appropriate spawning sites Appropriate water quality conditions Desirable forage for target organisms Indicator species (e.g., benthic invertebrates, water hyacinth, native fish species, salmon) Fish condition	Age structure Spawning sites located where water is clear, cold, and flowing at appropriate speed	Competition Population resilience Spawner-to-recruit ratio Water quality parameters (e.g., temperature, dissolved oxygen, toxic compounds)
***Genetic, Biochemical, Physiological Elements**	***Genetic structure**	***Genetic processes**
Mixed-function oxidase activity	Pattern of gene distribution within and among populations	Water quality parameters (e.g., temperature, dissolved oxygen, toxic compounds)

Adapted from Noss (1990)

*Examples of indicators at hierarchical levels below the landscape level are for riverine systems only. A similar suite of indicators should be developed for each landscape type. The completed matrix should include indicators of both physical and biological components of habitat, and of stresses as well.

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Appendix I.

Annotated Bibliography on Existing Ecosystem Goals From Bay/Delta Policy Processes

1) **CCMP:** (original attached)

2) **DRAFT: CALFED BAY/DELTA PROGRAM** - Ecosystem Quality Objectives Statements (original attached)

3) **Delta Protection Act of 1992** (original attached)

4) NHI Workshop Goals (original attached)

5) **"Recovery Plan for the Sacramento-San Joaquin Delta Native Fishes", Technical /agency Draft 12/94**

> "The objective of the recovery plan is to establish self-sustaining populations of the species of concern that will persist indefinitely. For Chinook salmon, green sturgeon and splittail include having large enough populations so that a limited harvest can once again be sustained." Recovery criteria, when possible, is based on two independant measures: population abundance and geographic distribution using a historical base period that includes natural variation. The historical base period used was generally 1967-1980s. The time period over which abundance and distribution criteria must be met was set a five generations, but for some species there is an additional requirement of meeting the criteria through a minimum number of years of stressful environmental conditions. Species addressed include: delta smelt, longfin smelt, Sacramento splittail, green sturgeon, spring-run, late fall-run, San Joaquin fall-run chinook salmon and Sacramento perch.

6) **"Working Paper on Restoration Needs: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California", May 1995**

The restoration goals for four races of chinook salmon, steelhead, striped bass, American shad, and white and green sturgeon are presented. The goal for anadromous fish is equal to at least <u>twice</u> the natural production of adults for the baseline period of <u>1967-1991</u> (as specified in the Central Valley Project Improvement Act.) These goals will serve as a platform upon which a reasonable anadromous fish restoration plan will be developed.

Executive Summary

The Estuary

A Significant Natural Resource

San Francisco Bay and the Delta combine to form the West Coast's largest estuary. The Estuary conveys the waters of the Sacramento and San Joaquin Rivers to the Pacific Ocean. It encompasses roughly 1,600 square miles, drains over 40 percent of the state (60,000 square miles), and contains about five million acre-feet of water at mean tide.

The Estuary watershed provides drinking water to twenty million Californians and irrigates 4.5 million acres of farmland. The Estuary also hosts a rich diversity of aquatic life. Each year, two-thirds of the state's salmon pass through the Bay and Delta, as do nearly half of the waterfowl and shorebirds migrating along the Pacific Flyway. In addition, Estuary waters enable the nation's fourth-largest metropolitan region to pursue many activities, including shipping, fishing, recreation, and commerce.

The San Francisco Estuary Project

A Cooperative Approach to Environmentally Sound Management

Growing public concern for the health of the Bay and Delta led the U.S. Environmental Protection Agency (U.S. EPA) to establish the San Francisco Estuary Project (SFEP or Project) in 1987. The Project, part of the U.S. EPA's National Estuary Program, is a five-year cooperative effort to promote more effective management of the San Francisco Bay-Delta Estuary and to restore and maintain the Estuary's water quality and natural resources. The Project is jointly sponsored by the U.S. EPA and the State of California. It is financed by federal appropriations under the Clean Water Act and matching funds from the state and local entities.

Managing a resource as important and complex as the Estuary is a challenging task. The compelling need for environmental protection must be weighed against competing uses of Estuary waters and resources. To address this challenge, the Project brought together over one hundred representatives from the private and public sectors, including government, industry, business, and environmental interests, as well as elected officials from all twelve Bay-Delta counties. After five years, the Project's cooperative public-private partnership has reached its goal of developing a Comprehensive Conservation and Management Plan (CCMP) for the Estuary.

The Plan

A Blueprint for Estuary Conservation and Restoration

The CCMP presents a blueprint to restore and maintain the chemical, physical, and biological integrity of the Bay and Delta. It seeks to achieve high standards of water quality; to maintain an appropriate indigenous population of fish, shellfish, and wildlife; to support recreational activities; and to protect the beneficial uses of the Estuary.

For the purposes of the CCMP, restoration implies improving the health of the Estuary. Rather than attempting to completely restore the Estuary to its historical state, the CCMP strives to maintain, protect, and enhance the ecological integrity of the Estuary within the given urban context. The CCMP attempts to regain as much of the altered or destroyed wetlands as possible, to establish the highest restoration or target goals, to ensure continuance of beneficial uses, and to generally provide a sustainable ecosystem.

To develop the CCMP, the Project's Management Conference identified five critical program areas of environmental concern: 1) decline of biological resources; 2) pollutants; 3) freshwater diversions and altered flow regime; 4) dredging and waterway modification; and 5) intensified land use. Subcommittees then produced status and trends reports that summarized the current state of the Estuary's resources. Next, the subcommittees prepared recommendations that became the basis for a CCMP Action Plan. The Management Committee reviewed a working draft of the Plan in November, 1991. The Management Committee then met frequently during the first seven months of 1992. Through facilitated, consensus-building discussions, the Management Committee developed a Draft CCMP, which was released for public comment in August of 1992. Finally, the Management Committee incorporated public comments on the Draft CCMP and finalized the CCMP. The Management Committee unanimously adopted the final CCMP at its March 31, 1993, meeting.

The CCMP sets forth this vision for the Estuary:

"We, the people of California and the San Francisco Bay-Delta region, believe the San Francisco Bay-Delta Estuary is an international treasure and that our ongoing stewardship is critical to its preservation, restoration, and enhancement. Acknowledging the importance of the Estuary to our environmental and economic well-being, we pledge to achieve and maintain an ecologically diverse and productive natural estuarine system."

The mission statements that guided the development of the CCMP are to:

- Restore and protect a diverse, balanced, and healthy population of fish, invertebrates, wildlife, plants, and their habitats, focusing on indigenous species.
- Assure that the beneficial uses of the Bay and Delta are protected.
- Improve water quality, where possible, by eliminating and preventing pollution at its source, while minimizing the discharge of pollutants from point and nonpoint sources and remediating existing pollution.
- Manage dredging and waterway modifications to minimize adverse environmental impacts.
- Effectively manage and coordinate land and water use to achieve the goals of the Estuary Project.
- Increase public knowledge about the Estuary ecosystem and public involvement in the restoration and protection of the health of the Estuary.
- Increase our scientific understanding of the Estuary and use that knowledge to better manage the Estuary.
- Develop and expand non-regulatory programs, such as public-private partnerships and market incentives, in conjunction with regulatory programs, to achieve the goals of the Project.
- Preserve and restore wetlands to provide habitat for wildlife, improve water quality, and protect against flooding.
- Assure an adequate freshwater flow as one of the essential components to restore and maintain a clean, healthy, and diverse Estuary.

Adoption of the Plan

Governor and Administrator Approval

After the Management Committee approved the CCMP, it was sent to the Project's Sponsoring Agency Committee (SAC) for review. The SAC forwarded the Plan to the Governor of California and the Administrator of the U.S. Environmental Protection Agency. Governor Wilson concurred on the CCMP on November 17, 1993. Administrator Browner approved the CCMP on December 9, 1993. Formal implementation of the Plan may now commence.

CCMP Program Areas

In the sections that follow this Executive Summary, you will find program areas on Aquatic Resources, Wildlife, Wetlands Management, Water Use, Pollution Prevention and Reduction, Dredging and Waterway Modification, Land Use, Public Involvement and Education, and Research and Monitoring. Each program area includes the following elements:

- A problem statement;
- Discussion of the existing management structure;
- Program area goals;

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- A recommended approach to the problem; and
- The stated objectives and actions.

For purposes of this Executive Summary, the discussion of the existing management structure has been eliminated, and the list of actions abbreviated. Therefore, not all recommended actions for a particular program area will appear in this Summary.

Aquatic Resources

The Problem

Native flora and fauna in Estuary waters have declined precipitously in recent years. This is largely the result of human activities that modify waterways, impair water quality, alter freshwater flows, and introduce non-native species. For example, water development projects reduce Delta outflows and contribute to an increase in salinity levels in the lower reaches of the Estuary. The projects thereby eliminate low-salinity habitat necessary for certain estuarine-dependent species. Water diversion facilities can also trap and displace migrating fish.

As a result of these habitat modifications, the number of Chinook salmon returning to spawn in the Estuary's tributaries has declined by 70 percent from historical levels. Populations of striped bass, Delta smelt, longfin smelt, Sacramento split-tail, and California bay shrimp—all of which depend on the Estuary for reproduction and survival—are also in decline.

During the past century, at least one hundred species of non-native aquatic invertebrates have been introduced into the Estuary. This has also taken its toll on native species. For example, the Asian clam, *Potamocorbula amurensis*, has reached populations of up to 30,000 clams per square meter in some places. The clam is rapidly replacing native bottom-dwelling organisms and interfering with the aquatic food supply.

Recommended Approach:

The Aquatic Resources section of the CCMP Action Plan seeks to build on cooperative efforts already underway among government agencies, non-governmental organizations, academic institutions, and water consumers to improve the management of aquatic resources in the Estuary. This section recommends development of a comprehensive plan to manage estuarine aquatic resources, development of species-specific management plans to control or eliminate undesirable non-indigenous species, and adoption of standards for salinity and flow that will increase the probability of successful reproduction and survival of important living resources.

Goals

- Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), with an emphasis on natural production.
- Restore healthy estuarine habitat conditions to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources.
- Ensure the survival and recovery of listed and candidate threatened and endangered species, as well as other species in decline.
- Optimally manage the fish and wildlife resources of the Estuary to achieve the purpose of these goals.

Actions

Actions to achieve water quality, flows, and management goals include such measures as:

- Designing, installing, and effectively operating fish screens or other protective devices at diversions associated with fish mortality;
- Protecting and restoring shaded riverine aquatic habitats;
- Identifying alternative water quality and flow standards, water management measures, operational changes, habitat improvements, and facilities to improve protection of estuarine resources;
- Adopting and implementing measures to control discharges of ship ballast water within the Estuary or adjacent waters;
- Prohibiting the intentional introduction of exotic species into the Estuary and its watershed;
- Providing necessary instream flows and temperatures in tributaries to the Delta to benefit anadromous fish;
- Identifying and protecting remnant stream habitats containing indigenous and endemic fishes by establishing Aquatic Diversity Management Areas;
- Implementing the Upper Sacramento River Management Plan; and
- Developing and implementing a San Joaquin River management plan.

Wildlife

The Problem

Many of the Estuary's wildlife species are in long-term decline, succumbing to urban growth, pollution, water development, disease, predation, loss of habitat, and other factors. In particular, development over the past 140 years has drastically reduced and fragmented the Estuary's native wildlife habitats, forcing wildlife to concentrate in small, isolated areas. Primarily as a result of habitat loss, at least seven insect species, one reptile species, three bird species, and five mammal species have become extinct in the Estuary region.

The environmental changes associated with human activities and regional population growth continue to have an enormous impact on the Estuary's wildlife. Total waterfowl numbers in the Estuary dropped from a record high of 1.3 million in 1977 to a low of 109,000 in 1982. Populations of dabbling ducks and geese are at all-time lows. Meanwhile, growing numbers of red fox (a non-native species) continue to prey on many shorebird populations, including the endangered California clapper rail. Unlike the fox, however, many small native mammals and carnivores can now find little food and habitat in the Estuary's fast-developing counties.

As a result of these declines, federal and state governments have designated over 130 species of fish, insects, amphibians, reptiles, birds, mammals, and plants in the Estuary as deserving of special protection or monitoring.

Recommended Approach:

Many of the problems associated with the decline in abundance and diversity of the Estuary's wildlife are interrelated. This section of the CCMP Action Plan can only be effective when coupled with other actions identified throughout the CCMP. Recommended actions in other sections, such as increasing and protecting critical habitat, increasing biodiversity, decreasing harmful pollutants, and managing freshwater flows through the Estuary, will collectively help restore populations of Bay-Delta wildlife.

Goals

- Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
- Ensure the survival and recovery of listed and candidate threatened and endangered species, as well as special status species.
- Optimally manage and monitor the wildlife resources of the Estuary.

Actions

Actions designed to achieve wildlife protection goals include:

- Preserving, creating, restoring, and managing large and contiguous expanses of tidal salt marsh and necessary adjacent uplands;
- Completing the expansion of the San Francisco Bay National Wildlife Refuge and its satellite refuges;
- Restoring tidal marshes in San Francisco Bay;
- Identifying and converting/restoring non-wetland areas to wetland- or riparian-oriented wildlife habitat;
- Enhancing the biodiversity within all publicly owned or managed wetlands and other wildlife habitats as appropriate;
- Completing and implementing a wildlife habitat restoration and management plan for the Estuary;
- Implementing predator control programs;
- Updating and, where necessary, preparing recovery plans for all listed wildlife species; and
- Monitoring the status of all candidate species and listing them if warranted.

Wetlands

The Problem

In 1850, the Estuary's tidal marshes covered 545,371 acres. By 1985, they had dwindled to approximately 45,000 acres, due largely to urban and agricultural development. These losses have reduced the Estuary's capacity to support sustainable populations of fish and wildlife and to provide the other benefits associated with wetlands. Of the thirty-two wildlife species whose populations are currently declining, twenty-three are associated primarily with wetlands. Although wetlands degradation and conversion have slowed substantially since the 1970s, wetland losses continue. Unless substantial efforts are made to avoid future losses and increase wetland acreage and values, the health of the Estuary will continue to deteriorate.

Recommended Approach:

The Wetlands Management Program seeks to improve wetlands regulation and management for all ecological wetlands, consistent with the general welfare of the state and with respect to private property rights, by identifying ways for state, federal, and local agencies to work together more effectively. This section intends to expand efforts to acquire, enhance, restore, and create wetlands, as well as improve existing regulatory mechanisms.

The actions recommended here establish clear, non-duplicative goals and policies for wetlands protection and restoration and encourage private initiatives to protect wetlands. This section also recommends that the state government develop a comprehensive wetlands protection program that recognizes the Bay-Delta Estuary as a resource of statewide significance and relies on local wetlands protection programs.

Goals

- Protect and manage existing wetlands.
- Restore and enhance the ecological productivity and habitat values of wetlands.
- Expedite a significant increase in the quantity and quality of wetlands.
- Educate the public about the values of wetlands resources.

Actions

Actions within the Wetlands Management area include:

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Ecosystem Quality Objective Statements

Improve and increase aquatic and terrestrial habitats and improve ecological functions in the Bay-Delta to support sustainable populations of diverse and valuable plant and animal species.

Improve and Increase Aquatic Habitats so that they can support the sustainable production and survival of native and other desirable estuarine and anadromous fish in the estuary.

1. **Increase Amount of High Quality Shallow Riverine Habitat** to allow sustainable fish spawning and early rearing.

   a) **Increase Amount of Quality Riverine Edge Habitat** to allow spawning and rearing by a sustainable population of native fish species.

   b) **Increase Amount of Quality Shallow Shoal Habitat** within the main channels of the Delta and upper Bay to allow shallow foraging by a sustainable population of juvenile estuarine fish.

2. **Increase Amount of High Quality Shaded Riverine Habitat** to allow the growth and survival of sustainable populations of estuarine resident and anadromous fish in the estuary.

   a) **Increase Amount of Quality Riparian Woodland Habitat** to allow production of terrestrial food sufficient to support sustainable populations of resident and anadromous fish.

   b) **Increase Amount of Large, Woody Debris** along Delta levees to allow juvenile and adult feeding and refuge for sustainable populations of fish.

   c) Increase Amount of Shaded Riverine Habitat to provide for localized temperature reduction.

3. **Increase Amount of Quality Tidal Slough Habitat** containing emergent and submerged vegetation to support the fish-production capacity of the Delta.

   a) **Increase Amount of Dead-End Slough Habitat** to allow spawning and rearing of sustainable populations of some resident species.

   ~~b) **Increase Amount of Open-Ended Slough Habitat** to allow spawning and rearing of sustainable populations of some resident species.~~

   b) **Reduce Water Hyacinth** populations in tidal slough habitats to improve habitat quality for sustainable populations of Delta fish.

   c) **Increase Amount of High Quality Tidal Slough Habitat** to allow increased ~~energetic exchange between aquatic and terrestrial ecosystems.~~ primary biological production.

4. **Increase Amount of High Quality Estuary Entrapment/Null Zone Habitat** to support sustainable

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fish populations in the Delta.

a) Reduce Saltwater Intrusion into Suisun Bay to increase the nursery area for sustainable populations of plants and animals.

b) Expand the geographic extent of Low Salinity Habitat in Suisun Bay.

c) Increase the occurrence of Brackish Water Habitat in San Pablo Bay during the winter and spring to support sustainable populations of Bay species.

5. Provide Sufficient Transport Flows at the proper times to move larval and juvenile fish from spawning habitats to nursery habitats in the Delta and Bay.

a) Increase the Transport of Young Fish from the Delta to Suisun Bay nursery areas to support sustainable populations of important estuarine species.

b) Increase the Transport of Young Fish Through the Delta to the ocean to support sustainable populations of estuarine and anadromous fish species.

c) Reduce the Transport of Young Fish from North to South across the Delta and the entrainment of fish in the Delta to increase the survival and abundance of estuarine and anadromous species.

d) Reduce the Blockage of and Alterations to Transport Flows by local structures.

6. Reestablish Appropriate upstream and downstream movement of anadromous and estuarine fish.

a) Enhance Upstream Migration of Adult Salmonids through the Delta.

b) Increase Successful Outmigration of Juvenile Fish through the Delta.

c) Enhance Upstream Migration of Adult Estuarine Fish into the Delta and River Spawning Areas.

7. Improve the Productivity of the Aquatic Habitat Food Web ~~Chain~~ to support sustainable populations of desirable fish (and other) species.

a) Reduce Entrainment of biological productivity throughout the aquatic food web ~~chain~~.

b) Reduce Concentrations of Toxicants in the water column and in sediments.

c) Reduce the Effects of Introduced Species on ecosystem productivity and in competing with desirable species for habitat.

d) Increase the Residence Time of Water in Delta Channels to increase plankton productivity and reduce undesirable algal-mat growth in the Delta.

e) Increase the Input of Nutrients from wetland and riparian habitats to aquatic habitats.

f) **Reduce Salinity Levels** in Delta aquatic habitats.

g) **Increase Flows of Freshwater** into the Delta Estuary.

h) Increase Amount and Quality Shallow Water Habitats in the Estuary.

8. **Reduce Concentrations of Toxic Constituents and Their Bioaccumulation** to eliminate their adverse effects on populations of fish and wildlife species.

a) **Reduce the Concentrations of Pesticide Residues** in Delta water and sediments.

b) **Reduce the Concentrations of Hydrocarbons, Heavy Metals, and other Pollutants** in Delta water and sediments.

B. **Improve and Increase Important Wetland Habitats** so that they can support the sustainable production and survival of wildlife species.

1. **Increase the Amount of High Quality Brackish Tidal Marsh Habitat** to better support sustainable populations of native wildlife species in the Delta.

a) Modify salinity levels in Brackish Tidal Marshes to **Improve their Vegetation Composition.**

b) **Increase the Areal Extent** of Brackish Tidal Marsh Habitats.

c) Restore Appropriate Salinity Levels in brackish tidal marshes to enhance forage productivity and habitat suitability for some native species.

c) **Improve the Connectivity** Between Brackish Tidal Marsh Habitats and Their Supporting Habitats such as aquatic habitats and riparian woodlands and adjacent uplands.

2. **Increase the Amount of High Quality Freshwater Marsh Habitat** to better support sustainable populations of native wildlife species in the Delta.

a) **Restore Appropriate Salinity Levels** in freshwater marsh habitat in the Delta to enhance forage productivity and habitat suitability for some native species.

b) **Increase the Areal Extent** of freshwater marsh habitats.

c) **Improve the** Juxtaposition Connectivity of freshwater marsh habitats to provide corridors for population movement and genetic exchange for dependent species.

d) **Reduce the Vulnerability** of existing freshwater marshes to levee failure.

3. **Increase the Amount of High Quality Riparian Woodland Habitat** in the Delta to better support sustainable populations of native wildlife populations.

a) **Increase Amounts of Riparian Habitat Structure** for nesting near foraging areas for some native bird species.

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b) **Reduce the Fragmentation** of riparian woodland habitat patches to provide corridors for population movement and genetic exchange for dependent species.

c) **Increase the Areal Extent** of riparian woodland habitats.

d) **Improve the Connectivity Between Riparian Woodlands and Their Supporting Habitats** such as aquatic habitats and brackish marsh habitats.

4. **Increase the Amount of Breeding Waterfowl Habitat** to better support sustainable populations of dabbling ducks.

a) **Increase the Amount of High Quality Brood Habitat** near nesting habitat for dabbling ducks.

b) **Increase the Amount of High Quality Nesting Habitat** near brood habitat for dabbling ducks.

5. **Increase the Amount of Wintering ~~Waterfowl~~ Wildlife Habitat** for foraging and resting to better support sustainable populations of wintering waterfowl.

a) Increase supplies of suitable forage such as **Waste Grain** on agricultural lands.

b) Increasethe amount of **Resting Areas** near foraging areas for wintering ~~waterfowl~~ wildlife.

c) Increase the amount of high quality **Foraging Areas** (e.g. freshwater marsh and brackish water marsh) for wintering ~~waterfowl~~ wildlife.

d) **Reduce the Vulnerability** of some existing Wintering ~~Waterfowl~~ Wildlife Habitats to levee failures.

6. **Increase the Amount of ~~Wintering~~ Managed Permanent Pasture Habitat** for ~~Greater Sandhill Cranes~~ to better support wintering crane populations. ~~sustainable populations.~~

a) Increase the amount of **Foraging Habitat** in proximity to roosting habitat.

b) Increase the amount of **Roosting Habitat** in proximity to foraging habitat.

~~7. Improve the Connectivity Among Wetland Habitats to provide corridors for population movement and genetic exchange.~~

7. **Increase Flood Plains and Associated Riparian Habitat** to improve diversity and sizes of fish and wildlife populations.

a) Increase suitable flood plains to improve the availability of **Temporary Flooded Spawning Habitat** for fish.

b) Improve narrow restricted channels to **Reduce the Risk of Catastrophic Losses** of wildlife habitat from levee failure.

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C. **Increase population health and population size of Delta species to levels that assure sustained survival.**

1. Contribute to the recovery of threatened, endangered or species of special concern.

2. Increase populations of economically important species.

3. Increase populations of prey or food species.

DELTA PROTECTION ACT OF 1992

This act, incorporated into the Public Resources Code (Section 21080.22 and Division 19.5), establishes the Delta Protection Commission and specifies its duties and powers. The Commission is to develop a comprehensive long-term resources management plan for the Delta by July 1, 1994, and is to be abolished on January l, 1997. The Delta primary zone, the area to which the resource management plan will apply, is shown on the map titled Delta Primary and Secondary Zones.

SECTION 1. Section 21080.22 is added to the Public Resources Code, to read:

21080.22. (a) This division does not apply to activities and approvals by a local government necessary for the preparation of general plan amendments pursuant to Section 29763, except that the approval of general plan amendments by the Delta Protection Commission is subject to the requirements of this division.

(b) For purposes of Section 21080.5, a general plan amendment is a plan required by the regulatory program of the Delta Protection Commission.

SEC. 2. Division 19.5 (commencing with Section 29700) is added to the Public Resources Code, to read:

DIVISION 19.5. DELTA PROTECTION ACT OF 1992

CHAPTER 1. FINDINGS AND DECLARATIONS

29700. This division shall be known, and may be cited, as the Johnston-Baker-Andal-Boatwright Delta Protection Act of 1992.

29701. The Legislature finds and declares that the Sacramento-San Joaquin Delta is a natural resource of statewide, national, and international significance, containing irreplaceable resources, and it is the policy of the state to recognize, preserve, and protect those resources of the delta for the use and enjoyment of current and future generations.

29702. The Legislature further finds and declares that the basic goals of the state for the delta are the following:

(a) Protect, maintain, and, where possible, enhance and restore the overall quality of the delta environment, including, but not limited to, agriculture, wildlife habitat, and recreational activities.

(b) Assure orderly, balanced conservation and development of delta land resources.

(c) Improve flood protection by structural and nonstructural means to ensure an increased level of public health and safety.

29703. The Legislature further finds and declares as follows:

(a) The delta is an agricultural region of great value to the state and nation and the retention and continued cultivation and production of fertile peatlands and prime soils are of significant value.

(b) The agricultural land of the delta, while adding greatly to the economy of the state, also provides a significant value as open space and habitat for water fowl using the Pacific Flyway, as well as other wildlife, and the continued dedication and retention of that delta land in agricultural production contributes to the preservation and enhancement of open space and habitat values.

(c) Agricultural lands located within the primary zone should be protected from the intrusion of nonagricultural uses.

29704. The Legislature further finds and declares that the leveed islands and tracts of the delta and portions of its uplands are floodprone areas of critical statewide significance due to the public safety risks and the costs of public emergency responses to floods, and that improvement and ongoing maintenance of the levee system is a matter of continuing urgency to protect farmlands, population centers, the state's water quality, and significant natural resource and habitat areas of the delta. The Legislature further finds that improvements and continuing maintenance of the levee system will not resolve all flood risks and that the delta is inherently a floodprone area wherein the most appropriate land uses are agriculture, wildlife habitat, and, where specifically provided, recreational activities, and that most of the existing levee systems are degraded and in need of restoration, improvement, and continuing management.

29705. The Legislature further finds and declares that the delta's wildlife and wildlife habitats, including waterways, vegetated unleveed channel islands, wetlands, and riparian forests and vegetation corridors, are highly valuable, providing critical wintering habitat for waterfowl and other migratory birds using the Pacific Flyway, as well as certain plant species, various rare and endangered wildlife species of birds, mammals, and fish, and numerous amphibians, reptiles, and invertebrates, that these wildlife species and their habitat are valuable, unique, and irreplaceable resources of critical statewide significance, and that it is the policy of the state to preserve and protect these resources and their diversity for the enjoyment of current and future generations.

29706. The Legislature further finds and declares that the resource values of the delta have deteriorated, and that further deterioration threatens the maintenance and sustainability of the delta's ecology, fish and wildlife populations, recreational opportunities, and economic productivity.

29707. The Legislature further finds and declares that there is no process by which state and national interests and values can be protected and enhanced for the delta, and that, to protect the regional, state, and national interests for the long-term agricultural productivity, economic vitality, and ecological health of the delta resources, it is necessary to provide and implement delta land use planning and management by local governments.

29708. The Legislature further finds and declares that the cities, towns, and settlements within the delta are of significant historical, cultural, and economic value and that their continued protection is important to the economic and cultural vitality of the region.

29709. The Legislature further finds and declares as follows:

(a) Regulation of land use and related activities that threaten the integrity of the delta's resources can best be advanced through comprehensive regional land use planning implemented through reliance on local government in its local land use planning procedures and enforcement.

(b) In order to protect regional, state, and national interests in the long-term agricultural productivity, economic vitality, and ecological health of delta resources, it is important that there be a coordination and integration of activities by the various agencies whose land use activities and decisions cumulatively impact the delta.

29710. The Legislature further finds and declares that agricultural, recreational, and other uses of the delta can best be protected by implementing projects that protect wildlife habitat before conflicts arise.

29711. The Legislature further finds and declares that the inland ports of Sacramento and Stockton constitute economic and water dependent resources of statewide significance, fulfill essential functions in the maritime industry, and have long been dedicated to transportation, agricultural, commercial, industrial, manufacturing, and navigation uses consistent with federal, state, and local regulations, and that those uses should be maintained and enhanced.

29712. The Legislature further finds and declares as follows:

(a) The delta's waterways and marinas offer recreational opportunities of statewide and local significance and are a source of economic benefit to the region, and, due to increased demand and usage, there are public safety problems associated with that usage requiring increased coordination by all levels of government.

(b) Recreational boating within the delta is of statewide and local significance and is a source of economic benefit to the region, and to the extent of any conflict or inconsistency between this division and any provisions of the Harbors and Navigation Code, regarding regulating the operation or use of boating in the delta, the provisions of the Harbors and Navigation Code shall prevail.

29713. The Legislature further finds and declares that the voluntary acquisition of wildlife and agricultural conservation easements in the delta promotes and enhances the traditional delta values of agriculture, habitat, and recreation.

29714. The Legislature further finds and declares that, in enacting this division, it is not the intent of the Legislature to authorize any governmental agency acting pursuant to this division to exercise their power in a manner which will take or damage private property for public use, without the payment of just compensation therefor. This section is not intended to increase or decrease the rights of any owner of property under the California Constitution or the United States Constitution.

29715. To the extent of any conflict or inconsistency between this division and any provision of the Water Code, the provisions of the Water Code shall prevail.

29716. Nothing in this division authorizes the commission to exercise any jurisdiction over matters within the jurisdiction of, or to carry out its powers and duties in conflict with the powers and duties of, any other state agency.

CHAPTER 2. DEFINITIONS

29720. Unless the context otherwise requires, the definitions set forth in this chapter govern the construction of this division.

29720.5. "Aggrieved person" has the same meaning as defined in Section 29117.

29721. "Commission" means the Delta Protection Commission created by Section 29735.

29722. "Delta" means the Sacramento-San Joaquin Delta, as defined in Section 12220 of the Water Code, for all provisions of this division, other than Chapter 3 (commencing with Section 29735). For the purposes of Chapter 3 (commencing with Section 29735), "delta" means the area of the delta minus the area contained in Alameda County.

29723. (a) "Development" means on, in, over, or under land or water, the placement or erection of any solid material or structure; discharge of any dredged material or of any gaseous, liquid, solid, or thermal waste; grading, removing, dredging, mining, or extraction of any materials; change in the density or intensity of use of land, including, but not limited to, subdivisions pursuant to the Subdivision Map Act (Division 2 (commencing with Section 66410) of Title 7 of the Government Code), and any other division of land including lot splits, except where the land division is brought about in connection with the purchase of the land by a public agency for public recreational or fish and wildlife uses or preservation; construction, reconstruction, demolition, or alteration of the size of any structure, including any facility of any private, public, or municipal utility; and the removal or harvesting of major vegetation other than for agricultural purposes.

(b) "Development" does not include any of the following:

(1) All farming and ranching activities, as specified in subdivision (e) of Section 3482.5 of the Civil Code.

(2) The maintenance, including the reconstruction of damaged parts, of structures, such as marinas, dikes, dams, levees, riprap (consistent with Chapter 1.5 (commencing with Section 12306) of Part 4.8 of Division 6 of the Water Code), breakwater, causeways, bridges, ferries, bridge abutments, docks, berths, and boat sheds. "Maintenance" includes, for this purpose, the rehabilitation and reconstruction of levees to meet applicable standards of the United States Army Corps of Engineers or the Department of Water Resources.

(3) The construction, repair, or maintenance of farm dwellings, buildings, stock ponds, irrigation or drainage ditches, water wells, or siphons, including those structures and uses permitted under the California Land Conservation Act of 1965 (Chapter 7 (commencing with Section 51200) of Part 1 of Division 1 of Title 5 of the Government Code).

(4) The construction or maintenance of farm roads, or temporary roads for moving farm equipment.

(5) The dredging or discharging of dredged materials, including maintenance dredging or removal, as engaged in by any marina, port, or reclamation district, in conjunction with the normal scope of their customary operations, consistent with existing federal, state, and local laws.

(6) The replacement or repair of pilings in marinas, ports, and diversion facilities.

(7) Projects within port districts, including, but not limited to, projects for the movement, grading, and removal of bulk materials for the purpose of activities related to maritime commerce and navigation.

(8) The planning, approval, construction, operation, maintenance, reconstruction, alteration, or removal by a state agency

Ecosystem Service Goals Adopted by the NHI Workshop: "Goals for Restoring a Healty Estuary"

Goals unanimously endorsed:

- Restore populations of indigenous species to levels not likely to result in extinction
- Maintain populations of fish and waterfowl that can be eaten safely
- Provide anglers with a reasonable chance of catching sport fish
- Increase naturally-produced populations of anadromous fish
- Maintain a sediment contamination at least below levels seen in 1950
- Prevent conditions that result in water column anoxia or nuisance algal blooms
- Restrict additional introductions of exotic species
- Enhance aesthetic values
- Sustain natural evolution of baylands

Goals not unanimously endorsed:

- Establish a viable commercial fishery in San Francisco Bay that provides fish or shellfish for consumption
- Decrease turbidity of the water and increase seagrass habitat

Goals not addressed to the point of agreement or disagreement:

- Provide a greater "sense of place" for Californians with respect to the Bay-Delta
- Maintain sustaining to increasing populations of ecologically important species

Appendix II.

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APPENDIX II: Indicators proposed by Kimmerer (1995):

Abundance
Abundance of a species qualifying as threatened or endangered
Abundance or indices of environmentally sensitive species
Abundance or indices of recreationally important fish
Existence of a viable commercial fishery
Abundance or indices of ecologically important species
Long-term declines in abundance of species
Percentage of native species with stable populations

Species composition
Diversity or species richness (open water)
Diversity or species richness (marsh)
Community trophic structure
Rate of extinction
Frequency of introductions
Resistance to invasion
Degree of genetic diversity within populations
Frequency of hybridization
Presence of undesirable species
Noxious algal blooms
Abundance of opportunistic species

Population Characteristics
Population age structure
Gross morphology
Population resilience

Energy Flow
Primary production (open water)
Fish or invertebrate biomass (mass)
Fish or invertebrate production (mass/time)
Growth rates
Production : respiration ratio

Water Quality
Abundance of debris
Oxygen percent saturation in water or sediment
Water clarity
Size distribution of organic matter
Frequency or intensity of nutrient loading

Toxicity and Disease
Frequency of lesions, tumors, or disease in aquatic organisms
Suitability of fish for consumption
Concentrations of pollutants in reference to thresholds
Frequency or intensity of toxicant discharge
Results of toxicity bioassays indicative of pollutant effects

Physical Habitat
Quantity of certain kinds of habitat
Quality of marsh or open-water habitat
Instream/riparian cover
Habitat fragmentation or linkage
Habitat heterogeneity
Channel sinuosity
Fractal dimension of banks
Physical stability of substrate and banks

Flow Variables
X_2
Net delta outflow
Variability of freshwater flow
Percent freshwater flow diverted
Diversion flow or frequency

Other Characteristics
Natural beauty
Resilience

Appendix III.

APPENDIX III: FOOD FOR THOUGHT ON DEFINING AND CATEGORIZING INDICATORS (from Draft Bay Area Regional Wetlands Monitoring Plan). Note that the terminology used here is different than in the proposed framework of this paper. "Candidate Indicators" here correlate with this paper's "operational definitions of ecosystem integrity", and "Component Measures" with "ecological indicators".

2.3.1 Performance Indicators, Stressor Indicators, and Component Measures

Performance Indicators are the most direct measures of progress toward the regional wetlands habitat goals, the conditions relative to the wetlands assessment issues of the CCMP, or the performance of wetlands restoration projects.

Stressor Indicators represent the most likely causes of failure of a wetlands restoration project, or failure to achieve the regional wetlands habitat goals. Stressor Indicators are monitored to assess changes in the level of risk of failing to achieve the Reference Condition for each Performance Indicator. While data about the Performance Indicators provide a basis to assess project progress or success, the Stressor Indicators provide a basis to identify remedial actions to enhance project performance for any or all project goals.

Component Measures are the quantified data of the indicators. The data for an indicator consist of measurements for parameters that are collectively termed an indicator. For example, the hydrology indicator may be represented by data for a number of Component Measures, including hydroperiod, wetted area, water depth, tidal regime, and tidal prism (see Section 2.5.4 below).

CANDIDATE PERFORMANCE OR STRESSOR INDICATORS

Candidate Indicators	Example Functions	Component Measures
Wetland Integrity *	wetland self-maintenance	tidal prism conservation wetland acreage
Shoreline Change *	wetland self-maintenance	total shoreline length horizontal accretion horizontal erosion
Channel Morphology	wetland self-maintenance aquatic resources support avian resources support sediment entrapment pollutant filtration	cross-sectional profile hydraulic geometry meander geometry longitudinal profile channel density network order
Wetland Hydrology	wetland self-maintenance aquatic resources support avian resources support plant resources support pollutant filtration	hydroperiod tidal regime wetted area water depth tidal prism
Tidal Elevation	avian resources support plant resources support sediment entrapment	vertical accretion tidal regime subsidence
Patchiness	plant resources support diversity conservation	patch temporal variability shoreline development patch classification patch size frequency percent total cover patch diversity
Sediment Profile	plant resources support sediment entrapment pollutant filtration	hydraulic conductivity bioturbation depth sediment texture depth of detritus redox potential bulk density chemistry
Water Profile	aquatic resources support sediment entrapment pollutant filtration nutrient cycling	suspended sediment temperature chemistry plankton
Target Population Status	endangered species support diversity conservation	distribution and abundance individual morphometry tissue chemistry habitat metrics habitat quality

APPENDIX III (continued):

CANDIDATE PERFORMANCE OR STRESSOR INDICATORS

Candidate Indicators	Example Functions**	Component Measures
Plant Community Structure		species distribution and abundance percent exotic species primary production plant architecture species richness percent cover standing crop
Invertebrate Community Structure		species distribution and abundance percent exotic species secondary production species richness biomass
Fish Community Structure		species distribution and abundance percent exotic species secondary production size class distribution species richness biomass
Small Mammal Community Structure		species distribution and abundance percent exotic species species richness biomass sign
Avian Community Structure		species distribution and abundance percent breeding species percent migrants species richness guild structure sign
Human Operations		land management practices personnel turnover land use intensity land use history funding

* These indicators only pertain to regional assessments of wetlands condition and would not be used to assess project performance.

** These indicators relate to support functions for living resources.

CCMP ASSESSMENT ISSUES AND CANDIDATE INDICATORS

Scale	Assessment Issue	Performance Indicator	Stressor Indicator
Ecosystem	wetlands area	geomorphic integrity shoreline change patchiness	wetland hydrology human operations
	pollution	population status sediment profile water profile	channel morphology wetland hydrology *human operations* shoreline change
	stewardship	geomorphic integrity community structure channel morphology wetland hydrology shoreline change sediment profile water profile patchiness	human operations
	tidal prism	channel morphology wetland hydrology sediment profile tidal elevation water profile	community structure channel morphology wetland hydrology human operations tidal elevation water profile
Community	food web support	community structure population status	geomorphic integrity channel morphology wetland hydrology human operations sediment profile tidal elevation water profile patchiness
Population	exotic species	community structure population status	geomorphic integrity channel morphology wetland hydrology human operations shoreline change sediment profile tidal elevation water profile patchiness
	endangered species	community structure population status	geomorphic integrity community structure wetland hydrology human operations sediment profile water profile