DRAFT REPORT OF TWO WORKSHOPS--

RESTORATION OF THE SAN FRANCISCO BAY-DELTA-RIVER ECOSYSTEM: CHOOSING INDICATORS OF ECOLOGICAL INTEGRITY

Prepared for the
CalFed Bay-Delta Program &
U.S. Environmental Protection Agency

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I. INTRODUCTION AND BACKGROUND

A. Policy Context

Provisions of the Bay-Delta "Accord"[1] and Central Valley Project Improvement Act (CVPIA), combined with requirements of the Endangered Species Act and the Clean Water Act, provide an unprecedented opportunity to design and carry out protection and restoration measures for the San Francisco Bay-Delta-River ecosystem. This complex ecosystem is defined here as the watersheds of the Sacramento and San Joaquin Rivers, their delta, and the San Francisco Bay. Within the context of each of these separate initiatives, new emphasis has been placed on the development of a comprehensive, whole-ecosystem plan for Bay-Delta-River restoration and management. This ecosystem-based approach is supported by a broad range of constituencies as the best means of not only protecting the environment, but also providing some certainty for water users regarding future environmental responsibilities.

In addition to the goal of effective whole-ecosystem management, each of these state and federal initiatives contains specific requirements for protecting or enhancing populations of particular species and the habitats that support them-- including suitable water quality and water flow regimes. Significantly, both the Accord and the CVPIA provide new tools for implementing these restoration measures, in the form of both river flow requirements and mechanisms to fund additional flows and habitat improvements.

A fundamental prerequisite for the success of all of these restoration and management efforts is to develop a solid scientific foundation to help define and assess the current "health" of the ecosystem, to help determine which types of restoration or management projects to undertake, and to provide the tools for evaluating the success of these projects. In addition, in order to achieve the stated objective of coordinated, whole-ecosystem planning and management, *an ecologically sound conceptual framework is*

[1] "Principles for Agreement on Bay-Delta Standards Between the State of California and the Federal Government," signed on December 15, 1994 by representatives of various stakeholder interest groups as well as California and federal government officials.

required to translate the "whole-system" theory into practice. In other words, the ecological integrity of the entire system (Bay-Delta-River) must be considered, in addition to considering the integrity of each of the component parts (such as Delta wetlands or particular anadromous fish species). The National Research Council (1992) has recommended this approach, stressing that restoration of an aquatic ecosystem requires coordinated and comprehensive management of all significant ecological elements, often on a watershed or other landscape scale.

The development of an explicit, logical and easily understandable conceptual framework has several benefits: it helps ensure that the restoration plan is comprehensive, reducing the likelihood of failing to consider significant ecosystem attributes or functions; it helps to efficiently integrate all of the components of the restoration plan into a coherent whole; it facilitates the determination of priorities among restoration actions; and it helps to explain the importance and function of each action to policymakers and the public.

B. The Role of Ecological Indicators

Providing the required scientific foundation within a coherent, ecologically-based framework is not a trivial exercise. Although ecological health and integrity are intuitively understandable concepts (see Box 1), capturing them with an *operational* definition -- one that tells you what to measure -- in a particular ecosystem can prove difficult. The challenge is compounded in a system as large, diverse, and modified as the Bay-Delta-River system. One approach is to use *ecological indicators*. Ecological indicators are defined as attributes of an ecosystem whose state (presence or absence, quantity, pattern, etc.) is used to measure the health or integrity of the ecosystem. Put more simply, ecological indicators provide an assay to measure ecosystem health, in the same way that a doctor takes the temperature of a patient to provide diagnostic information about his/her overall health. These indicators bridge the gap between "real world" science and intuitively desirable but less easily defined ecosystem properties such as "health", "integrity", "resilience", and "self-sustainability".

But how does one go about choosing the most useful indicators? Although many factors (scientific, economic, and sociopolitical) come into play, the fundamental requirement is that all of the important attributes of the ecosystem be represented. This is the role of the conceptual framework alluded to above. Two essential components of this framework should be a recognition of the importance of *both structural and functional attributes* of ecosystems and a recognition that these structural and functional attributes occur at a variety of scales (see, e.g., National Research Council, 1992; Noss 1990).

Structural attributes refer to the requisite pieces of the system and their relationship to one another. For example, spawning gravels must be available for anadromous fish and they must be connected to migration corridors. *Function* refers to the processes at work in the system. To continue our example, hydrological processes must keep the spawning gravels from becoming silt-laden.

Determining ecological indicators at many *scales* helps to ensure consideration of the whole as well as the parts. These scales include the whole landscape, a well-defined region or ecological zone, the habitat or community level, and the population or species level. Ecological indicators at the landscape scale can be thought of as the "leading ecological indicators" of the system, just as certain well-chosen leading economic indicators reflect the health of the economy. Attention to attributes of the system at a variety of scales ensures that large scale processes work in harmony with processes and structures at smaller scales.

Formulated in this way, a comprehensive suite of ecological indicators for the Bay-Delta-River system will be a useful tool to: define and assess the current health of the system; provide information that can be used to choose among specific management proposals; and determine whether the program is actually achieving its intended purpose (i.e., allow for adaptive management).

C. A Process for Developing Ecological Indicators

The Center for Sustainable Resource Development at the University of California, Berkeley (CSRD), the Environmental Defense Fund (EDF), and The Bay Institute of San Francisco (TBI) convened two workshops of local, national, and international experts in October, 1995 and January, 1996 to initiate the process of developing ecological indicators for the Bay-Delta-River system. Funding for the workshops was provided by the U.S. Environmental Protection Agency and by CalFed, the federal-state interagency group responsible for developing a long-term plan for managing the Bay-Delta estuary pursuant to the Bay-Delta Accord. The workshop agendas, minutes, background materials and lists of participants are attached as Appendices A and B.

The purpose of these workshops was two-fold: **to agree on a conceptual framework for indicator development,** and **to develop a provisional list of indicators.** The results of these efforts are presented in the body of this report. They provide the groundwork upon which further efforts to refine and develop additional indicators might build. Just as important, the framework provides an organizing tool for using ongoing monitoring and assessment programs in a coordinated fashion.

BOX 1: WHAT IS ECOSYSTEM HEALTH?

One of the challenges of protecting the integrity of the entire Bay-Delta-River ecosystem and the species that depend on it is simply determining what a healthy ecosystem is. *Ecosystem health* has been defined in a variety of ways. 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).

The following components of ecosystem health have been defined and used in the scientific literature:

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.
Vigor/scope for growth	Overall metabolism or energy flow
Balance	Existence of proper balance 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
NRC (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

Developing a more explicit definition of ecosystem health is part of the task of practitioners in the new fields of *ecosystem medicine*, *stress ecology*, and *clinical ecology*. These researchers have most often defined the concept of ecosystem health by what it is *not*. David Rapport and colleagues (e.g. 1984; 1989; Rapport, Regier and Hutchinson 1985; 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). 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).

This field of study is not limited to pure theory-- in the Great Lakes, some of the more heavily used, degraded subsystems exhibit this general distress syndrome. In case studies of these systems, likely ecological responses from each type of stress can be inferred from impact assessments, thus guiding rehabilitation efforts (Rapport, Regier, and Hutchinson 1985). 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).

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II. DEFINING ECOSYSTEM HEALTH USING A SUITE OF ECOLOGICAL INDICATORS

Several methods of developing a suite of indicators have been developed in various kinds of ecosystems. For the purposes of our workshops, we adopted a four step process suggested by Keddy et al. (1993) for putting the ideas of ecosystem health into practice and developing ecological indicators:

(1) define ecological integrity or health in an operational way;
(2) select appropriate indicators of health or integrity;
(3) identify target levels of selected indicators; and
(4) develop a monitoring system to provide feedback.

A. Step 1: Define Ecosystem Health 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. During the two workshops, it became apparent that there is some confusion-- in part semantic and in part substantive-- among the terms *goal*, *objective*, *ecosystem service*, and *indicator*. In order to clarify further discussion, we define these terms as follows: (1) *goals* describe the 'big picture' overview of what the restoration program is trying to achieve; (2) *objectives* are more precise descriptions of desired attributes, encompassing not only ecosystem services, but also ecosystem attributes that may be of intrinsic importance to the health of the system, such as maintenance of optimal biodiversity or an array of successional habitats; (3) *ecosystem services* are benefits that a healthy ecosystem provides, and often have been limited to those that are valued by people, such as water quality or flood control; and (4) numerical *ranges* for individual *indicators* (which in the past have often been termed 'goals') describe the on-the-ground measurements that need to be taken and numerical targets by which restoration needs, status, and success is assessed.

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In Keddy et al's (1993) formulation, the *goal* should be established first. The more specific *objectives* and *services* should also be defined as part of Step 1, but can be refined as necessary during the development of the *indicator* framework (Step 2). *Ranges for indicators* are developed during Step 3, and provide specific quantitative targets for restoration and management programs. The order of the steps is somewhat iterative; indicators can be developed for each particular *objective* or *service*, but *objectives* and *services* may also arise from considerations of ecological structure, function and services taken into account while developing indicators. For a further discussion of this issue, see Dr. Keddy's paper in Appendix A-1.

Goals

During the October workshop, a substantial proportion of the presentations and discussion focused on the definition of the *goal* that should guide the future management of the Bay-Delta-River system. Participants generally supported the goal statement offered by CalFed for ecosystem quality: "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." Participants of both workshops seemed to share a common goal of enhancing the self-sustaining qualities of the system, as opposed to moving in the direction of an increasingly highly managed one. Phil Williams dubbed this the *physis* approach (restoring physical processes that promote self-healing and maintenance), as opposed to reliance on continual intervention. Hans Bernhart and Lou Toth described similar approaches that proved successful for the Rhine River and the Kissimmee River, respectively. The Kissimmee River Restoration Program is detailed in Box 2 and in Dr. Toth's paper in Appendix A-1.

Combining these concepts, we refer here to the goal of Bay-Delta-River restoration and management as the **re-establishment of a healthy, functional system that supports a diversity of habitat types along with their resident communities of plants and animals, and is self-sustaining (requiring minimal intervention) and resilient to stresses.** It is important to note that this definition assumes that the system will continue to accommodate human use of natural resources, and that restoration to a healthy condition does not mean regenerating a pristine system.

Objectives / Services

The overall *goal* provides a paradigm for restoration of the Bay-Delta-River system. On-the-ground restoration efforts, however, require more specific program *objectives*. Both CalFed and the San Francisco Estuary Project's *Comprehensive Conservation and Management Plan* (CCMP) produced lists of ecosystem quality objectives to this end. In addition, participants in the workshop, "Goals for Restoring a Healthy Estuary", sponsored by the Natural Heritage Institute (NHI) and others, identified some key ecosystem services. A consolidated list of the goals that have been suggested by these various groups as operational definitions of ecosystem integrity is shown in Table 2 of Appendix A-2.

B. Step 2: Select Appropriate Indicators of Health or Integrity

Ecological indicators identify the most important elements of ecosystem structure and function necessary to achieve the goal and related objectives and services. In choosing ecological indicators, a framework is crucial to ensure that a comprehensive suite of indicators that includes all components of the ecosystem--including both structural and functional components at multiple scales of ecological organization -- is developed. Indicators that reflect attributes relating to the entire system should be developed, as well as indicators at smaller scales of ecological organization. The framework we used during the workshops is described more fully in Chapter III, below.

C. Step 3: Identify Thresholds and Target Levels of Selected Indicators

Once indicators are selected, a range of target values, from tolerable to desirable levels, should be developed for each. See Figure 1.

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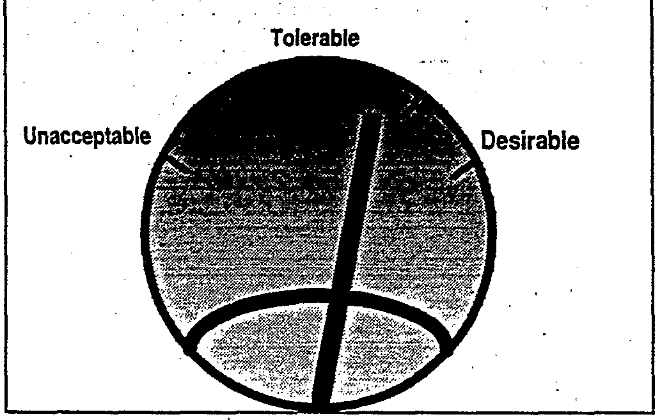
Because determining the target range of indicator values from first principles is often difficult, comparisons with reference systems are sometimes used. These references can be used to infer how a system with ecological integrity might look and/or function. One technique to establish reference conditions 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 (see Box 2). 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. 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 target levels for each indicator.

Figure 1: A numerical range should be set for each indicator selected, from unacceptable to desirable levels.



D. 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. Changes in the ecological indicators allow scientists and decision makers to determine whether the management and/or restoration program is having its intended effect. Monitoring also provides the foundation for *adaptive management*.

Because the behavior of biological systems is often difficult to predict, this flexibility is key in restoration projects. In general, pilot studies are also recommended, in order to define, evaluate, and calibrate the indicators prior to full-scale implementation of the program (Kremen 1992). The demonstration project carried out on the Kissimmee River in Florida provides an excellent model (see Box 2).

Ongoing uses of ecological indicators include short-term evaluation of success of a project and long-term monitoring. The Bay-Delta-River system is already monitored by a variety of ongoing programs that can serve these functions. We anticipate that step 4 of the process will be taken up by others, including the Interagency Ecological Program as part of their redesigned long-term monitoring efforts.

It is important to note that monitoring results can also be used for public outreach, by selecting 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.

BOX 2: RESTORATION OF THE KISSIMMEE RIVER

The historic Kissimmee River meandered for approximately 166 km within a floodplain that ranged from 1.5 to 3 km wide (Arrington 1995). Channelization of the river, started in 1962 and completed in 1971, resulted in the loss of approximately 14,000 ha of floodplain wetland habitats, as well as modification of the river into a series of impoundments which severely altered vegetation and animal communities by greatly simplifying what had been a complex, braided river-floodplain ecosystem. The 15-year restoration project planned for this system is expected to return approximately 70 km of contiguous river channel and 11,000 ha of wetland to a more natural condition (Cummins and Dahm 1995).

The Kissimmee River Restoration Project is a landmark case in restoration of large-scale systems. Recently, an entire issue of the journal *Restoration Ecology* was dedicated to this project. The steps taken by the researchers and policy-makers involved in this project to develop a restoration evaluation program draw some parallels to the steps taken with regard to the Bay-Delta-River system. Here, we describe the process of developing the Kissimmee River Restoration Project in terms of Keddy et al.'s (1993) four-step process for developing a suite of ecological indicators.

Step One: Goals and Objectives

The goals for the Kissimmee River ecosystem have evolved over time, but the basic tenets, including a holistic, landscape-scale approach to restoration and a belief in the need to re-establish the natural hydrologic regime, have remained essentially the same.

The impetus for restoring the system came with the Kissimmee Restoration Act of 1976, which included three primary goals: 1) use natural and free energies of the river system, 2) restore natural seasonal water level fluctuations, and 3) restore conditions favorable to increases in abundances of the native biota (Karr 1994).

The most oft-cited forum for developing environmental restoration goals and objectives for this system is the Kissimmee River Restoration Symposium, conducted by the South Florida Water Management District (SFWMD) in 1988. The symposium emphasized an ecosystem approach to restoration with a single goal: **to restore the ecological integrity of the Kissimmee River** (Toth 1993). Ecological integrity was defined as the capability to support and maintain biological communities with a species composition, diversity, and functional organization comparable to that of the natural habitat of the region (Karr 1994).

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Step Two: Indicators

First, a classification scheme (habitat typology) was developed for the Kissimmee River system, with five habitat types for the river channel, ten habitat types for the floodplain, and four habitat types for the channelized river. The organization of habitats into classes will be used to form the basis for a sampling program that measures key abiotic and biotic indicators.

At the symposium, it was proposed that the ecological integrity of systems like the Kissimmee River is determined by five classes of variables, which serve as indicators of ecological integrity:

1) **source of energy**: type, amount and size of allochthonous inputs, primary production, and the seasonality of available energy;
2) **water quality parameters**: temperature, turbidity, dissolved oxygen, nutrient inputs, organic and inorganic chemicals, heavy metals, and pH;
3) **habitat quality**: substrate, water depth, current velocity, availability of habitat for all life-history needs, and habitat diversity;
4) **hydrologic conditions**: water volume and temporal variability of discharge; and
5) **biotic interactions**: competition, predation, disease, and parasitism (Koebel 1995).

As a follow-up to the symposium, the SFWMD, in July 1991, commissioned a scientific advisory panel to provide recommendations for development of a comprehensive ecological evaluation program. The advisory panel suggested that the restoration evaluation program should be conducted from an ecosystem perspective, which requires evaluation of *biotic* and *abiotic* conditions within the Kissimmee River Basin (Dahm et al. 1995). The panel also recommended that the restoration evaluation program have the following features:

1) provide a thorough understanding of ecosystem structure and function;
2) show direct cause-effect relationships between restoration measures and ecological responses;
3) include quantifiable biological responses and statistical comparisons; and
4) document ecological changes that are of both social and scientific importance (Toth 1993).

These features serve as criteria with which to choose the most appropriate indicators to monitor.

Step 3: Target Levels

The target values for indicators of the Kissimmee River Restoration Program are based on research and modeling of the historic structure and function of the system. Extensive research was carried out to establish how the system functioned in its pre-channelization state.

The various proposed restoration alternatives were evaluated according to five hydrological

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criteria, based on the prechannelization hydrograph (Karr 1994).

Step 4: Monitoring & Adaptive Management:

Implementation of the large-scale restoration measures has not yet begun, but the Kissimmee River Restoration Project has already taken steps to monitor the system. The advisory panel suggested, as part of a five-phase restoration evaluation program, that baseline conditions be established to define the current state of the Kissimmee River ecosystem, such that comparisons could later be made with conditions resulting from restoration (Koebel 1995).

Additionally, the SFMWD conducted a demonstration project, intended to resolve remaining technical issues regarding the various alternatives and to evaluate the feasibility of restoring the system's biological resources (Toth 1993). 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. The SFWMD monitored the effect of hydrologic changes on floodplain vegetation, floodplain fish, secondary productivity, benthic invertebrates, and river channel habitat characteristics. Other agencies conducted alligator counts, bird surveys, fish population samples, water quality monitoring, and measurements of aquatic macroinvertebrate and periphyton responses (Berger 1992).

The demonstration project did not restore the Kissimmee River, but rather provided evidence indicating that restoration of ecological integrity of this river-floodplain ecosystem is possible (Toth 1993). This preliminary project provides an example of the utility of testing a restoration plan in a small area before applying it to the larger system. The demonstration project contributes to the aims of adaptive management; results and experiences of the demonstration project are already being used to guide planning, implementation, and monitoring efforts of the larger restoration project. Additionally, the validity of using historically based guidelines and criteria for developing a plan for restoring ecological integrity was verified by the demonstration project.

III. FRAMEWORK FOR DEVELOPING INDICATORS FOR THE BAY-DELTA-RIVER SYSTEM

The purpose of the two workshops on ecological indicators was to develop a suite of indicators of the entire Bay-Delta-River system. We chose to use a scientifically defensible, transparent framework to guide this work. One of the benefits of using a formal framework is that it helps in explaining the process used to choose indicators for the system so the importance and function of each action is clear to policymakers and the public. Use of a framework also provides an organizing tool to ensure that the suite of indicators is comprehensive.

The premise of the framework for developing ecological indicators for the Bay-Delta-River system is as follows: **the suite of indicators must represent structural and functional attributes of the system at a range of hierarchical scales: the entire landscape, the ecological zones present within that landscape, and two smaller scales (community/ecosystem and population/species) within the representative habitat types of each zone.**

Filling in the details of this framework requires several steps: developing a habitat classification scheme or *typology*, and then developing a set of indicators for each component of the typology (i.e., landscape, ecological zones and habitat types). Lastly, this framework involves screening the suite of indicators with several criteria for ecological indicators to choose the best ones.

A. Development of a Habitat Typology

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. Noss (1990) states that "no single level of organization (e.g., gene, population, community) is fundamental, and

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different levels of resolution are appropriate for monitoring and protecting biodiversity" (see Box 3). To cover all aspects of the system, therefore, a suite of indicators should cover several hierarchical levels of ecological organization, at multiple spatial and temporal scales. In order to do so, a system as large and complex as the Bay-Delta-River system must be divided into some sort of logical working units for analysis and management, without losing a sense of the whole.

Comments by October workshop participants made it clear that a typology (zone and habitat classification system) should be developed before proceeding with choosing indicators for the system. A habitat typology is defined here to mean a hierarchical classification system depicting various major levels of ecological organization of the entire ecosystem. This provides an organizing principle by which to define the components of the system at each scale of interest. EDF and TBI proposed a strawman typology and solicited feedback on it from workshop participants, both through a questionnaire sent out in December and through a plenary session at the outset of the January workshop. This typology characterized the Bay-Delta-River system at three basic scales: 1) *the entire landscape* (in order to consider the interactions between each of the different components of the system); 2) *ecological zones* (corresponding to major biomes at the landscape scale); and 3) *habitat-types* (ecologically distinct areas within each ecological zone) (Figure 2). Under this schema, the *suite* of indicators for the Bay-Delta-River system as a whole therefore would incorporate a *set* of indicators for the entire landscape as well as *sets* for each component ecological zone and habitat type.

Once the basic ecological zone divisions were agreed upon by workshop participants, breakout sessions met (grouped by ecological zone) to develop a list of habitat types for each ecological zone. The results are presented in Chapter IV, below. The next step involved developing indicators at the landscape scale, for each of the ecological zones, and for each habitat type within these ecological zones.

Typology Schematic

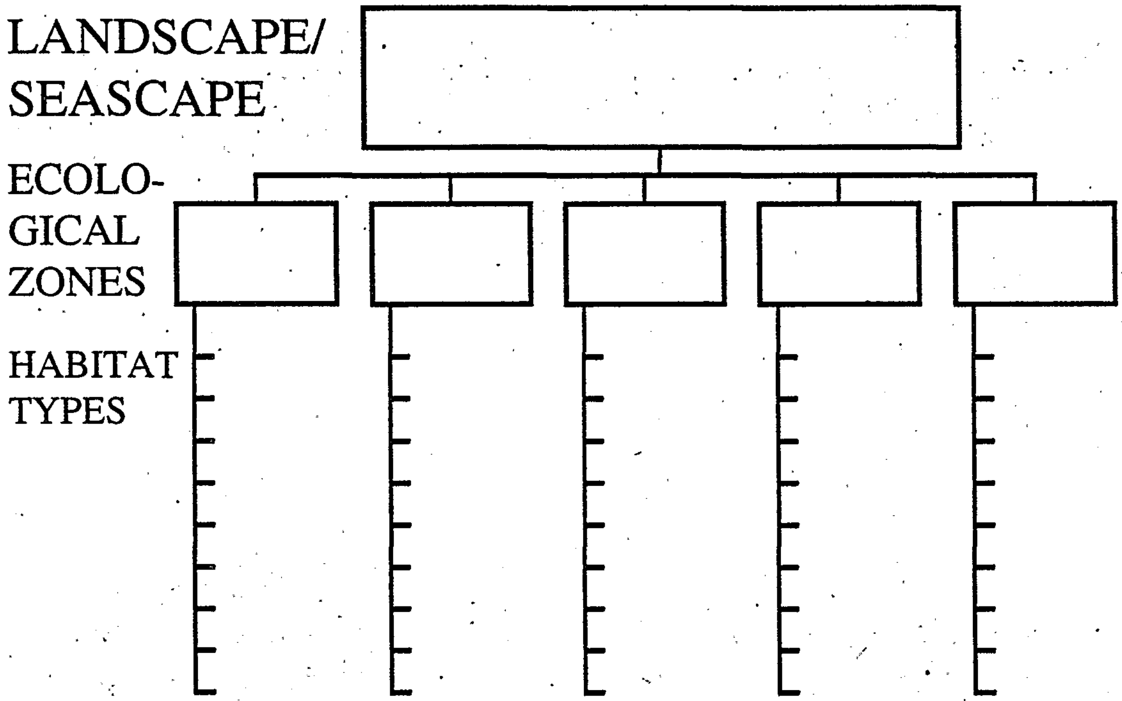

Figure 2: Schematic of the typology framework used for indicator development and organization. The first step is to establish a habitat typology by filling in the blanks, after which a set of indicators is developed for each box, addressing both structural and functional ecosystem attributes at several hierarchical scales of ecological organization. The *suite* of indicators incorporates a *set* of indicators for each component of this typology.

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B. Development of a Suite of Ecological Indicators

The fundamental requirement of a suite of ecological indicators is that all of the important attributes of the system be represented. Accordingly, indicators should include both *structural* and *functional* attributes of an ecosystem. By structural attributes, we refer to the physical characteristics of an ecosystem and the makeup of its biological communities. Functional attributes include the ecological and evolutionary processes at work in the ecosystem. At the landscape level, connectivity of habitat types and hydrologic regime are examples of structural and functional indicators, respectively. A structural indicator for a given habitat might be topography or age-structure of a population of interest, whereas nutrient cycling is an example of a functional indicator.

EDF and TBI offered a matrix for indicator development (Figure 3) which incorporates these levels of resolution, adapted from Noss' (1990) conceptual model of biodiversity at multiple levels of organization (see Figure 4). Our use of *structure* incorporates both the concepts of 'structure' and 'composition' as used by Noss. This matrix serves as a guiding principle and working tool for developing each set of indicators; it encourages development of a comprehensive, all-inclusive set of indicators for each ecological zone and habitat-type. Spaces are provided for both structural and functional indicators at the zone-level and, for each habitat type, structural and functional indicators at both the community and population levels. The matrix is useful not only in developing an initial set of indicators but also later, when refining this set, to identify gaps in knowledge of the health of the ecological zone or habitat type that the suite of indicators covers.

C. Criteria for Ecological Indicators

In developing and refining the suite of ecological indicators, criteria for what makes a valuable indicator should be kept in mind. Some criteria we classify as *essential*: indicators must be (1) ecologically relevant and (2) scientifically defensible. An ecologically relevant indicator is closely related to or reflective of key ecological

Figure 3: Matrix used by January workshop participants to guide indicator development

Indicator Development Matrix

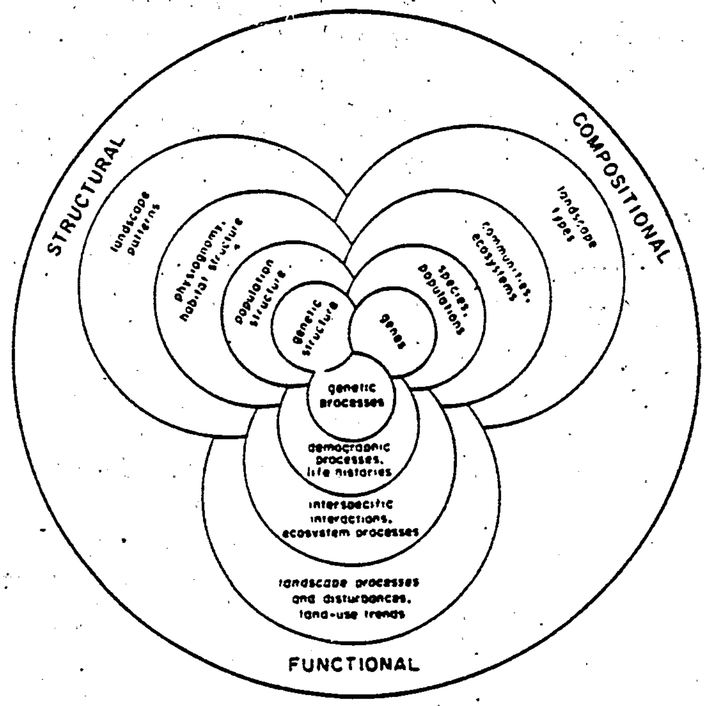
For each Ecological Zone:

	STRUCTURE	FUNCTION
	A e.g. acreage of each habitat type (measured from aerial photos)	**B** e.g. rate of transport of material through the system (measured by flow)

For each Habitat Type:

	STRUCTURE	FUNCTION
Community/ Ecosystem	**C** e.g. fractal dimension of river banks OR species diversity/richness	**D** e.g. water temperature OR trophic relationships within the community
Population/ Species	**E** e.g. age structure OR population genetic parameters (e.g. polymorphisms)	**F** e.g. fecundity OR frequency of lesions, tumors, or disease in aquatic organisms

Figure 4 (Taken from Noss (1990)): 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.



characteristics of a system or habitat. For example, phytoplankton density (or total chlorophyll) reflects primary production in the water column. Scientifically defensible indicators are quantitative, with sufficient accuracy and precision to allow for ready interpretation. The relationship of an indicator to the property it reflects should be unambiguous and demonstrable. In other words, the relationship between the indicator and the property should be verifiable experimentally. Exceptions to the *essential* criteria may be made if a certain indicator has significant public appeal, high economic significance, or is especially relevant to policy-makers for some other reason.

Other criteria are beneficial, but not crucial. These *desirable* qualities include: (1) ease of measurement, (2) sensitivity (quick response to stress/perturbation; ability to provide early warning of disturbance), (3) existence of a historical database, (4) benign to measure (monitoring of the indicator is not damaging to the environment), (5) general (applicable to different habitat types), (6) aids in distinguishing between natural processes and anthropogenic effects.

Additionally, certain *leading ecological indicators* that can be used to describe the health of the overall ecosystem to the public should be chosen. These are analogous to *leading economic indicators* or certain crucial medical assays, such as temperature or pulse. Ideally, these indicators would be ecologically relevant, scientifically defensible, economically significant, *and* have public appeal. However, this is not usually the case, so some trade-offs may be necessary.

BOX 3: TOP-DOWN VS. BOTTOM-UP

Focusing exclusively on indicators at one hierarchical level of ecological organization 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" serve useful 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 are more useful in some ways than indicators which inform that the system is already ailing. For example, using indicator species associated with soil productivity (e.g. mycorrhizal fungi) quickly detects problems with processes 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 inputs to the system may allow for early detection of an imminent problem, whereas monitoring of dissolved oxygen may signal changes only after it is too late for preventive measures.

Ultimately, when employing biota as indicators, a suite of indicators including 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). Thus, combining top-down and bottom-up approaches when developing indicators will produce the best suite of indicators.

IV. TYPOLOGY FOR THE BAY-DELTA-RIVER SYSTEM

As discussed in Chapter III, October workshop participants agreed that the eventual list of recommended indicators should be expanded beyond the population level, at which indicators are currently monitored, to include indicators at larger scales, such as the landscape, ecological zone, and habitat. A necessary preliminary step in the process is to develop a *habitat typology* (classification scheme) for the system, in order to clearly define the management units for which indicators should be selected.

In order to be of practical utility, such a typology must reflect ecological realities (i.e., have a sound ecological basis) as well as address the needs of resource managers to clearly recognize management units, and relate them to one another. Another desirable trait of a habitat typology is broad applicability to other systems of its type, in this case large river ecosystems. Thus, wherever practical, the subunits of the typology should be recognizable in other similar systems. This allows for cross-reference of information gathered from a number of ecosystems (and/or their subunits), eventually allowing for the elucidation of common and unique attributes of similar ecosystems. This is particularly valuable in the study of large complex ecosystems in which there exist many data gaps regarding the ecology of particular portions.

At the January workshop, participants were asked to consider and agree in plenary session upon the higher elements of the typology. This process was completed comparatively quickly, and with broad agreement. The system was first defined at the broadest (landscape/seascape) scale, and then subdivided into five *ecological zones* representing major biomes of which this system is comprised. The process resulted in the following scheme (see also Figure 5):

A. Level I: The Landscape/Seascape Level

The landscape/seascape encompasses the entire watersheds of the Sacramento and San Joaquin Rivers, their delta, San Francisco Bay, and the near shore ocean off the Golden Gate Bridge.

Typology Schematic

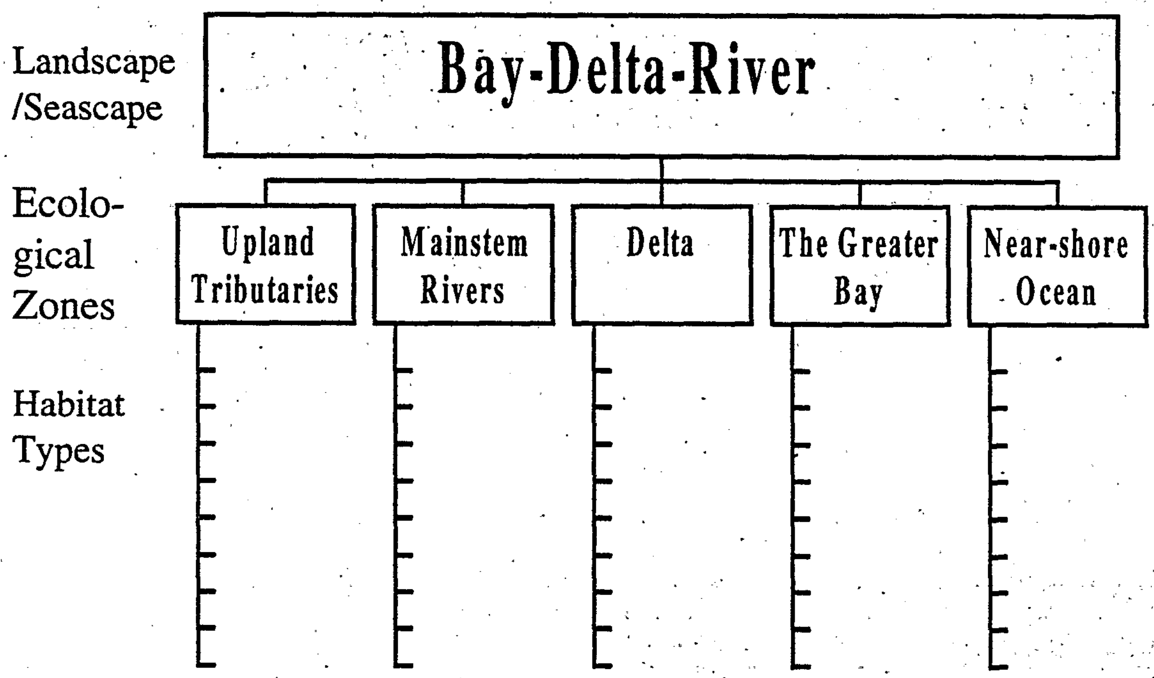


Figure 5: Schematic of the typology framework used for indicator development and organization, indicating the five ecological zones upon which workshop participants came to consensus. The habitat types are detailed in chapter IV. The *suite* of indicators for the Bay-Delta-River system will incorporate a *set* of indicators for each component of this typology.

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B. Level II: Ecological Zones

- **Upland Tributaries & Watersheds**-- Includes headwaters to juncture with mainstem rivers
- **Mainstem Rivers**-- The Sacramento and San Joaquin.
- **The Delta--** This zone includes the tidally influenced portions of the two mainstem rivers. The Delta is delineated in the west by Chipps Island, in the north by the confluence of the Sacramento and American rivers, and in the south by Vernalis.
- **Greater San Francisco Bay**-- Extends roughly from Chipps Island to the Golden Gate Bridge. This zone includes Suisun Bay, San Pablo Bay, the Central Bay, and the South Bay.
- **Near-shore Ocean--** A corridor extending 25 miles north and south of the Golden Gate Bridge, and seaward (west) to the continental shelf break.

C. Level III: Habitat Types

Within each of the ecological zones, a number of discrete habitat types exist. Participants were asked to divide themselves, according to expertise and interests, into five groups corresponding to the five zones delineated above, and to take the typology to its next level, that of primary and, where appropriate, secondary habitat types.

Within each zone, primary habitat types were to be considered ecologically distinct kinds of areas (in terms of structure and vital ecological processes), supporting distinctive and characteristic biological communities. Secondary habitat types were to be subdivisions of the primary habitats that were felt to be distinctive enough to warrant separate consideration within the context of this project. Thus "unconsolidated sediments" might be considered a "primary" benthic habitat type for the nearshore ocean, but distinctive and systematic differences in the community structure of benthic invertebrates might warrant a distinction between "mud" and "sand" as secondary habitat types within this scheme. Because the primary objective of the project was to develop a broad perspective of the system at the landscape scale, participants were urged to use the secondary habitat category cautiously and only when necessary, to keep the group from becoming involved in analyses that were too 'fine-grained' for the intended purposes of these workshops.

The results of the working groups for each zone are presented in their raw form, as reported and edited by the group leaders, in the minutes of the January workshop (Appendix B-4). Because the participants were of many different backgrounds and interpreted the basic guiding principles and directions in different ways, the final typologies derived by each group were reported in different, and in many cases incompatible, formats. In order to further the goal of a cohesive and integrated typology for the system with wide applicability to other large river systems, the technical staff of TBI and EDF modified the information provided by the breakout groups. Prior efforts to classify aquatic habitats in a variety of other ecosystems guided our efforts. The resulting typology is presented in Table 1[2]. The actual ecological indicators developed as the final step of the workshops (presented in Chapter V) will[3] be organized according to this scheme.

Table 1: Expanded Habitat Typology for the Bay-Delta-River system. Water column, benthic, edge, and other habitats are given for each ecological zone.

	UPLAND TRIBUTARIES	MAINSTEM RIVERS	DELTA	GREATER BAY	NEARSHORE OCEAN
Water Column Habitats	• Pools/riffles • Runs/glides	• Pools/riffles • Runs/glides	• Riverine • Embayments • Mixing zone (?) • Sloughs	• Shallow (<? m) • Deep (>? m) • Mixing zone	• Marine • Freshwater plume
Benthic Habitats	• Gravel • Sand	• Gravel • Sand	• Riverine • Embayments • Sloughs	• Unconsolidated • Consolidated • Dredged (?)	• Unconsolidated • Rocky reef • Kelp beds
Edge Habitats	• Riparian • Floodplain	• Riparian • Floodplain	• Tidal marsh • Non-tidal marsh • Riparian • Floodplain	• Marine marsh • Brackish marsh • Freshwater marsh • Small streams • Other vegetated • Other unvegetated	• Rocky intertidal • Beach • Wetlands
Other Habitats					• Offshore islands • Dunes

[2] This typology has also been sent to moderators for review, and their comments will be incorporated into the final report.
[3] after review

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V. INDICATORS OF HEALTH

At the January workshop, the discussion of landscape-level indicators was led by Charles Simenstad, of the University of Washington, in plenary. Indicators for each ecological zone and habitat type were developed in breakout group sessions.

The breakout groups used a variety of formats to develop different sets of indicators. Because each of the breakout groups worked independently, varying definitions of structure, function, indicator, objective, and service emerged. In order to resolve this "apples and oranges" problem, we have attempted to present here all of the information relayed by the groups in a common format. Indicators are categorized as structural or functional and the objective/service to which they relate are indicated. The work done by each group, in its original format, is reported in the draft workshop minutes (see Appendix B-4). [4]

Some groups followed the matrix for indicator development (Figure 3) more closely than others, so certain components of the framework are more complete for some groups. Not all groups developed indicators at both the ecological zone and habitat type levels. However, it is important to note that this is a first cut at the suite of indicators; we now need to go back and fill in the holes and, to the extent necessary, refine the list. We have intentionally printed the sections of the matrices left blank to show further work that should be done. Additionally, insufficient time was available at the workshop to conduct a systematic evaluation of the indicators to see if they meet the criteria for indicator development. Worksheets were provided for this purpose (see Appendix B-3) at the January workshop, and can be used in the future to further refine and help finalize the suite of indicators.

[4] The format of the indicators presented here still lacks consistency, in that the indicators proposed by some groups are not attributes that can be readily measured, but rather properties which would be valuable to assess in evaluating the health of the system. For example, primary productivity is listed by some groups as an indicator, when in fact chlorophyll *a* is the indicator which one would measure to assess primary productivity. The technical staff of TBI and EDF are currently working to resolve this problem, in conjunction with the group moderators. The final format in which the indicators are presented will distinguish among *property assessed*, *objectives/services* (as a rationale for why the property needs to be assessed), and *indicators* (actual measures of the property).

A. INDICATORS AT THE LANDSCAPE-LEVEL

Charles Simenstad, in the discussion he led at the January workshop, suggested that indicators at the landscape-level should be: applicable across habitats, ecosystems, and zones; directly or indirectly a measure of principal forcing processes; capable (scientifically, feasibly) of detecting change; scaled across levels of landscape organization; and referenced to baseline or target/expected levels (that encompass natural variability or noise in the system). This plenary discussion resulted in the indicators shown below.

LANDSCAPE		
	INDICATOR/PROPERTY ASSESSED	
OBJECTIVE/SERVICE	STRUCTURAL	FUNCTIONAL
• INCREASE FISH AND WILDLIFE • Movement (flow) of motile/migratory organisms (species of concern, prey) (S1, S2, F1) • Feeding opportunity (S3, S4, S5)	**S1**. Connectivity of habitats (corridors) (↑) **S2**. Barriers, bottlenecks (↓) **S3**. Natural channel density and complexity (↑) **S4**. Distance between "feeding stations" (habitats) (↓) **S5**. Average distance between nesting and foraging habitats for (resident) birds (↓)	**F1**. Natural water flow regime (↑)
• IMPROVE WATER QUALITY • Nutrient exchange (S6, F2)	**S6**. Marsh edge (↑)	**F2**. Variability in flooding duration and frequency (↑)
• RESTORE BIOLOGICAL INTEGRITY, RESILIENCE • Biodiversity (S7, S8, S9)	**S7**. Habitat heterogeneity (↑) **S8**. Habitat fragmentation (↓) **S9**. Composite metric	
• STABILIZE SHORELINES • Maintain & restore habitats' sediment supply (F3)		**F3**. Sediment flux and distribution (↑)
• FOOD WEB SUPPORT • Diverse sources, production, distribution or organic matter (F4, F5, F6, S10, S11, S12, S13)	**S10**. Proportional representation and area of all habitats (↑) **S11**. Sum ecological zone indicators across the landscape (% of elements) **S12**. Morphometry of the estuary (related to tidal prism)	**F4**. Total landscape productivity **F5**. Total number of temperature/physiochemical barriers to salmon migration (↓) **F6**. Sediment delivery to the estuary

***Note: ↑ indicates "increase", ↓ indicates "decrease"

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B. INDICATORS FOR EACH ECOLOGICAL ZONE & HABITAT-TYPE

MAINSTEM RIVERS & UPLAND TRIBUTARIES[5]

Group participants:

1. Pete Chadwick (moderator)
2. Matt Kondolf (moderator)
3. Sharon Gross
4. Judy Kelly
5. Bill Kier
6. Bruce McWilliams
7. Jud Monroe
8. Tim Ramirez

ECOLOGICAL ZONE: Alluvial Rivers

OBJECTIVE/SERVICE	INDICATOR/PROPERTY ASSESSED	
	STRUCTURAL	FUNCTIONAL
• Aquatic & riparian habitat (S3, S4, S5) • Migration habitat (provided by SRA[6]) (S4) • Connectivity between habitats (S9) • Fish habitat (S1, S2, F1, F2, F4, F7) • Sediment supply (F6)	**S1.** Abundance of anadromous fish **S2.** Survival rate of outmigrant anadromous fish **S3.** Channel length (including side channels); & ratio of current : historical (1) **S4.** Length of SRA[6] bank; length of rip-rap bank (1) **S5.** Channel migration rate (1) **S6.** Areal extent of classes of riparian vegetation (1) **S7.** Areal extent of open sand/gravel-floored channel (1) **S8.** Area (width) of potential meander belt migration (1) **S9.** Number of unscreened diversions **S10.** Area flooded by 2 year and 10 year floods (2)	**F1.** Number of outmigrants by race **F2.** Toxics-- bioindicators **F3.** Water temperature **F4.** Dissolved oxygen **F5.** Deviation from natural hydrograph -floods: post dam/pre-dam: Q_{maf} Q_2, Q_{10}, Q_{20} -baseflows: post/pre-dam: Q_{av}, August, Sept., ? -spring outflows: post/pre-dam: Q_{av}, May, June, July **F6.** Deviation from natural sediment budget **F7.** Groundwater regime

***Note: numbers in parentheses signify rating of the indicator (1= higher, 2= lower priority)

[5] Due to considerations at the workshop relating to the size of breakout groups, the ecological zones *Mainstem Rivers* and *Upland Tributaries* were merged for the purposes of the workshop and this report. Nevertheless, these two ecological zones should still be regarded as distinct.

[6] Shaded Riparian Area

DELTA

Group participants:

1. Bruce Herbold (moderator)
2. Eli Ateljevich
3. David Behar
4. Patrick Coulston
5. Phyllis Fox
6. David Fullerton
7. Chuck Hanson
8. Rick Soehren
9. Phil Williams
10. Leo Winternitz

ECOLOGICAL ZONE: Delta			
		INDICATOR/PROPERTY ASSESSED	
OBJECTIVE/SERVICE		STRUCTURAL	FUNCTIONAL
		S1. Populations of desirable species (↑) **S2**. Dispersal of estuarine species and landscape geographical distribution **S3**. Predictability of community structure (consistent rank abundance) **S4**. Index of native species abundance **S5**. Number of introduced fish and invertebrates per year **S6**. Total number of diversions **S7**. Ratio of screened/unscreened diversions **S8**. Percent of inflow diverted	**F1**. Desirable, sustainable harvest levels of non-toxic fish **F2**. Total sediment accumulation/ marsh accumulation **F3**. Primary and secondary productivity (↑) **F4**. Smolt survival through zone **F5**. Water toxicity (↓) **F6**. Flood risk (taking some more susceptible agricultural lands out of production decreases risk) (↓) **F7**. Number of exceedences of water quality standards per year **F8**. Non-consumptive recreation hours **F9**. Surveys of satisfaction

***Note: words in parentheses signify secondary or tertiary habitat types

HABITAT TYPE: Channels			
		INDICATOR/PROPERTY ASSESSED	
	OBJECTIVE/SERVICE	STRUCTURAL	FUNCTIONAL
Community/Ecosystem	• Aesthetics (S1, F2) • Food supply for organisms (S1, S2, F2) • Fish, bird (including nesting), mammal, invertebrate habitat (S1, S2, S5) • Biological filter/sediment trap/water quality (S1, S2, F2, F3) • Fish migration (S3) • Habitat access (S3, F3) • Minimization of predation effects (S3, F3) • Human health (F2) • Survival, fitness and condition (S4, F2) • Food web support (trophic dynamics) (F2)	**S1**. Miles of riprap or degraded bank replaced by habitats of higher wildlife value such as SRA[6] (edge) **S2**. Area or length of berm islands (edge) **S3**. Number of barriers to fish passage; fish migration (water) **S4**. Number of unscreened diversions or functional equivalent measure of fish entrainment (and) total diversions **S5**. Length of dead-end slough (tidal) (dead-end slough) **S6**. Number of branches (dead-end slough)	**F1**. Net positive flows during migration (water) **F2**. Reduction in applications of toxic materials (e.g. pesticides) (water) **F3**. Area of connected emergent vegetation (tidally influenced)
Population/Species		**S7**. Fish counts (also, % of sport fish of legal size that have reasonable toxin levels) (water)	

***Note: words in parentheses signify secondary or tertiary habitat types

HABITAT TYPE: Open Water			
		INDICATOR/PROPERTY ASSESSED	
	OBJECTIVE/SERVICE	STRUCTURAL	FUNCTIONAL
Community/Ecosystem		**S1.** Area and linear edge of emergent vegetation (or) diversity and stature of emergent vegetation	
Population/Species			

***Note: words in parentheses signify secondary or tertiary habitat types

HABITAT TYPE: Intertidal Marsh			
		INDICATOR/PROPERTY ASSESSED	
	OBJECTIVE/SERVICE	STRUCTURAL	FUNCTIONAL
Community/Ecosystem	• Biodiversity (increased quality of marshland) (S1)	**S1.** Quantity (area) of marshes with median marsh size above a certain threshold intertidal marsh **S2.** Area of evolved marshland (large marsh in which channels develop at a minimum rate) **S3.** Area of evolved marshland with buffer (at least certain distance from agricultural or urban areas)	
Population/Species			

***Note: words in parentheses signify secondary or tertiary habitat types

HABITAT TYPE: Non-tidal Marsh

	OBJECTIVE/SERVICE	INDICATOR/PROPERTY ASSESSED	
		STRUCTURAL	FUNCTIONAL
Community/Ecosystem		**S1**. Area of land less than one foot deep in December or March (agricultural land) **S2**. Area of natural vernal pools protected (vernal pools) **S3**. Length and width of riparian forest (riparian not adjacent to water)	**F1**. Amount of food (Kcal) produced which is available to waterfowl (may be separated by source into agricultural spoils and natural production) (agricultural land)
Population/Species			

***Note: words in parentheses signify secondary or tertiary habitat types

HABITAT TYPE: Floodplains

	OBJECTIVE/SERVICE	INDICATOR/PROPERTY ASSESSED	
		STRUCTURAL	FUNCTIONAL
Community/Ecosystem		**S1**. Length and width of riparian forest **S2**. Width of active meander belt	**F1**. Area of two/other-year frequency floodplain that interacts with river floodplain
Population/Species			

***Note: words in parentheses signify secondary or tertiary habitat types

GREATER SAN FRANCISCO BAY

Group participants:

1. Fred Nichols (moderator)
2. Roberta Borgonova
3. Randy Brown
4. Josh Collins
5. Susan Hatfield
6. Alex Horne
7. Lee Lehman
8. Charles (Si) Simenstad

ECOLOGICAL ZONE: Bay		
	INDICATOR/PROPERTY ASSESSED	
OBJECTIVE/SERVICE	STRUCTURAL	FUNCTIONAL
	S1. Salinity (1) **S2.** Connectivity (at several scales) (1) **S3.** Area (1) **S4.** Channel density (relative to sources of pollution, salinity zones, fish distribution, elevation) (1) **S5.** Complexity of elevational structure (topographic complexity) (2) **S6.** Vegetative patch structure (2) **S7.** Distribution of subordinate estuaries (3) **S8.** Number and/or biomass of newly introduced species (3)	**F1.** Freshwater flow variations (1) **F2.** Sediment supply (2) **F3.** Residence time of juvenile anadromous fish (2) **F4.** Distribution of pollutants (2) **F5.** Pollutant concentrations (2) **F6.** Net transport of organic matter at habitat interfaces (3 (b/c of complexity & expense)) **F7.** Amount of marsh-derived organic material in bay organisms (3) **F8.** (Some measure of support of resident fish & wildlife) (2)

***Note: numbers in parentheses signify rating of the indicator (1=higher, 3=lower priority)

HABITAT TYPE: Water Column (Shallow)

	OBJECTIVE/SERVICE	INDICATOR/PROPERTY ASSESSED: STRUCTURAL	INDICATOR/PROPERTY ASSESSED: FUNCTIONAL
Community/Ecosystem	• Food web support (S1, S2, S4, S5, F1, F2) • Commercial & recreational fishery (F3) • Fish & wildlife habitat (S3)	**S1.** Water column stratification (1) **S2.** Density and diversity of larval fish (1) **S3.** Diving bird abundance and diversity (+ some success metric) (1) **S4.** Diatom : flagellate ratio (3) **S5.** Biomass of planktivorous fish (3)	**F1.** Chlorophyll *a* (as a measure of primary production) (1) **F2.** Turbidity (as a measure of primary production) (1) **F3.** Catch per unit effort (2)
Population/Species	• Food web support (F4) • Fish & wildlife habitat (S6)	**S6.** Harbor seal abundance (3)	**F4.** Juvenile herring growth rate (3)

***Note: numbers in parentheses signify rating of the indicator (1=higher, 3=lower priority)

HABITAT TYPE: Water Column (Deep)

	OBJECTIVE/SERVICE	INDICATOR/PROPERTY ASSESSED: STRUCTURAL	INDICATOR/PROPERTY ASSESSED: FUNCTIONAL
Community/Ecosystem	• Food web support (S1, S2) • Fish & macroinvertebrate habitat (F1)	**S1.** Benthic shrimp & mysid biomass/density (1) **S2.** Mollusc biomass/density (1)	**F1.** Change in pollutant levels in sediments (2)
Population/Species			

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HABITAT TYPE: Mixing Zone			
		INDICATOR/PROPERTY ASSESSED	
	OBJECTIVE/SERVICE	STRUCTURAL	FUNCTIONAL
Community/Ecosystem			**F1**. X_2 (1) **F2**. Exceedence of X_2
Population/Species			

***Note: numbers in parentheses signify rating of the indicator (1=higher, 3=lower priority)

HABITAT TYPE: "Unvegetated" Intertidal Shallows (Mudflats)			
		INDICATOR/PROPERTY ASSESSED	
	OBJECTIVE/SERVICE	STRUCTURAL	FUNCTIONAL
Community/Ecosystem	• Fish & wildlife species support (S2, S3) • Source of organic matter (F2) • Sediment supply (F3) • Shellfish harvest (F1)	**S1**. Area (1) **S2**. Prey abundance & distribution (3) **S3**. Wildlife sign (incl. bird feces, bat-ray divets)- rate/time (3)	**F1**. Fishery success rate (1) **F2**. Chlorophyll *a* on sediments (3) **F3**. Deviation from expected elevation (3) [structural]
Population/Species			

***Note: numbers in parentheses signify rating of the indicator (1=higher, 3=lower priority)

HABITAT TYPE: "Unvegetated" Subtidal Shallows

	OBJECTIVE/SERVICE	INDICATOR/PROPERTY ASSESSED	
		STRUCTURAL	FUNCTIONAL
Community/Ecosystem	• Food web support (S1, S2) • Fish & macroinvertebrate habitat (F1)	**S1.** Benthic shrimp & mysid biomass/density (1) **S2.** Mollusc biomass/density (1)	**F1.** Change in pollutant levels in sediments (2)
Population/Species			

***Note: numbers in parentheses signify rating of the indicator (1=higher, 3=lower priority)

HABITAT TYPE: Vegetated Shallows (Submerged Aquatic Vegetation (SAV) & Macroalgae)

	OBJECTIVE/SERVICE	INDICATOR/PROPERTY ASSESSED	
		STRUCTURAL	FUNCTIONAL
Community/Ecosystem	• Fish & wildlife habitat & food-web support (S2, S4, S5)	**S1.** Area (1) **S2.** Macroalgae and SAV coverage (2) **S3.** Epiphyte load (3)	
Population/Species		**S4.** Herring spawn (egg density) (1) **S5.** Seagrass shoot density (2)	

***Note: numbers in parentheses signify rating of the indicator (1=higher, 3=lower priority)

HABITAT TYPE: Managed Marshes

	OBJECTIVE/SERVICE	INDICATOR/PROPERTY ASSESSED	
		STRUCTURAL	FUNCTIONAL
Community/Ecosystem	• Supply of resident wildlife habitat (S1, S2, S3, S4, F1)	**S1.** Acreage (1) **S2.** Habitat complexity (1) **S3.** Proximity to & amount of neighboring sanctuaries and natural habitats (1) **S4.** Diversity of plant species (2)	**F1.** Water quality/supply (3)
Population/Species			

***Note: numbers in parentheses signify rating of the indicator (1=higher, 3=lower priority)

HABITAT TYPE: Hard Substrate

	OBJECTIVE/SERVICE	INDICATOR/PROPERTY ASSESSED	
		STRUCTURAL	FUNCTIONAL
Community/Ecosystem	• Supply of fish & wildlife habitat (S1, S2)	**S1.** Amount of natural hard substrate (1) **S2.** Proximity to "holding areas" (e.g. for herring) (2)	
Population/Species	• Supply of fish & wildlife habitat (S3)	**S3.** Herring spawn (density of eggs) (1)	

***Note: numbers in parentheses signify rating of the indicator (1=higher, 3=lower priority)

HABITAT TYPE: Salt Marshes/Brackish Marshes/Freshwater Marshes			
		INDICATOR/PROPERTY ASSESSED	
	OBJECTIVE/SERVICE	STRUCTURAL	FUNCTIONAL
Community/Ecosystem	• Water quality/fish foraging (S3, S4, F2) • Wildlife habitat (S3, S5, S6, S7) • Protection of shoreline from erosion (S3, S8, F1) • Supply of organic matter (dissolved or particulate) (S3, F4, F5) • Nutrient cycling (S3, F3) • Support of migratory species (S1, S3)	**S1**. Ratio of non-vegetated : vegetated marsh (1) **S2**. Acreage (1) **S3**. Channel density (relative to sources of pollution, salinity zones, fish distribution, elevation) (1) **S4**. Proportion of *Spartina alterniflora* in the marsh community (2) **S5**. Habitat metrics for each ecologically important species (e.g. marsh plant shoot height/density) (2) **S6**. Complexity of elevational structure (topographic complexity) (2) **S7**. Diversity of plant species (2) **S8**. Width of marsh relative to wave energy (fetch and boat wakes) (3)	**F1**. Change in position of marsh edge (towards shoreline (-); away from shoreline (+)) (1) **F2**. Pollutant concentrations (2) **F3**. Sedimentation rate (2) **F4**. Net transport of organic matter at habitat interfaces **F5**. Amount of marsh-derived organic material in bay organisms
Population/Species	• Wildlife habitat (F4)		**F6**. Change in population of ecologically important species (1)

***Note: numbers in parentheses signify rating of the indicator (1=higher, 3=lower priority)

HABITAT TYPE: Small Tributary Streams

	OBJECTIVE/SERVICE	INDICATOR/PROPERTY ASSESSED	
		STRUCTURAL	FUNCTIONAL
Community/Ecosystem	• Supply of fish habitat (S1, S2, S3)	**S1**. Number of "barriers" to fish passage (1) **S2**. Area of brackish water habitat at stream mouths (1) **S3**. Number of young, outmigrating anadromous salmonids (2)	
Population/Species			

***Note: numbers in parentheses signify rating of the indicator (1=higher, 3=lower priority)

NEAR-SHORE OCEAN

Group participants:
1. Bill Alevizon (moderator)
2. Rod Fujita (moderator)
3. Bill Kier
4. Ann Nothoff

ECOLOGICAL ZONE: Near-Shore Ocean		
	INDICATOR/PROPERTY ASSESSED	
OBJECTIVE/SERVICE	STRUCTURAL	FUNCTIONAL
• Structural integrity of shoreline and benthic habitats (S2) • Water Quality (S2, F1, F2, F3) • Sustainable harvest levels (F4)	**S1.** Proportion and total area of sandy beaches, rocky intertidal, estuaries/wetlands, benthic **S2.** Abundance and diversity of marine organisms (Farallons, Bolinas Lagoon, etc.)	**F1.** Toxic substances (loads in seabird eggs, levels in fish and mussel tissue) **F2.** Plume-related (vert. salinity profiles)-- 25 mile radius **F3.** Nutrients/production/ trophic support **F4.** Catch/unit effort for commercial and sport fisheries

***Note: It was recommended that substantially more work would need to be done to identify suitable indicators for this ecological zone

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VI. USING INDICATORS TO RESTORE ECOSYSTEM HEALTH

A. Where do we go from here?

The indicators derived at the January workshop provide a solid starting point for full development of a suite of indicators for the Bay-Delta-River system. The next stage of the process will involve refining this suite of indicators. Using the framework, typology, and preliminary suite of indicators developed through this project, each component of the typology can be addressed and refined in turn. A separate group of experts for each of the different components of the typology, capitalizing on the expertise in existing programs, might be the most appropriate forum for indicator refinement.

Once the suite of indicators is refined, ranges of target values can be set for each indicator (Step 3). These thresholds will be the real tool for on-the-ground management and monitoring (Step 4). Long-term monitoring and baseline information upon which threshold values are set will be based on research organized around the indicators and other specific hypotheses. Previous work by existing monitoring programs will be useful in providing historical databases.

B. How the indicators can be used

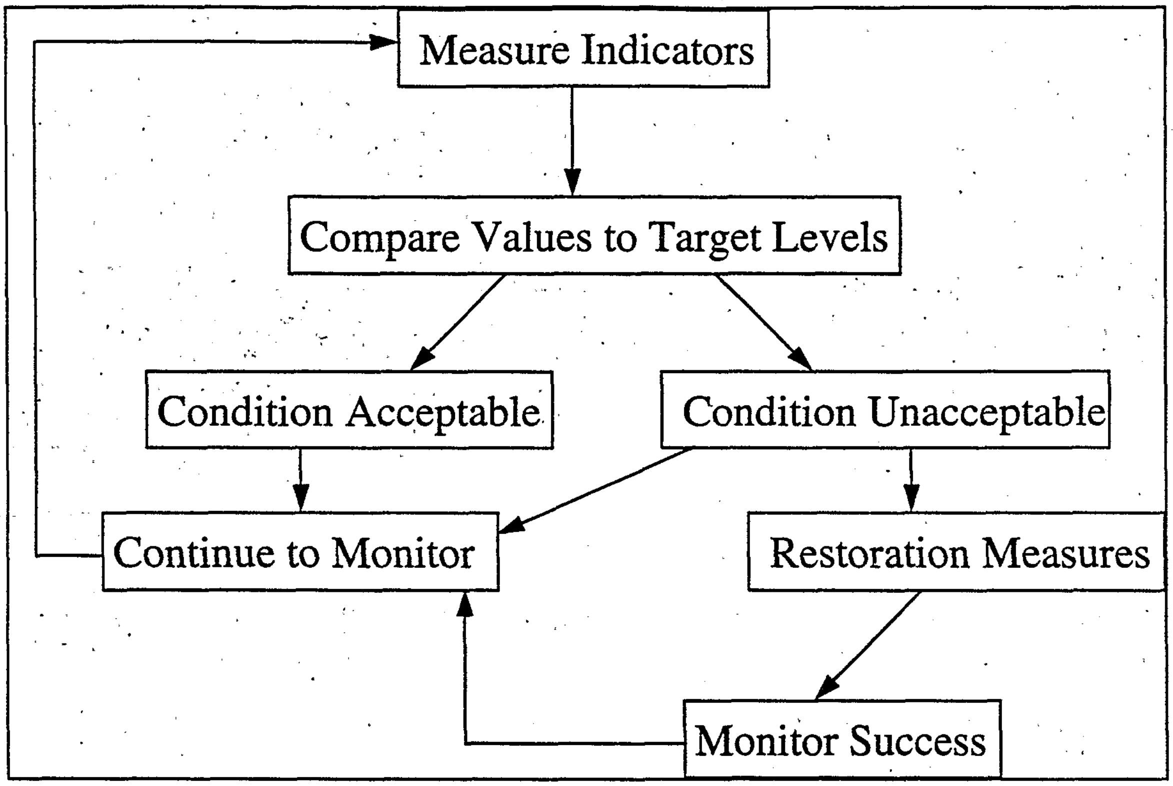
Monitoring and Evaluation of Restoration Efforts

Any restoration measures taken in the Bay-Delta-River system will require extensive monitoring. Indicators can be used to focus the monitoring effort on the most relevant and useful parameters, and to evaluate the attainment of restoration goals and objectives. Because few precedents exist for restoration in large-scale systems, careful evaluation of the results will be invaluable both for this and other systems.

Adaptive Management

The threshold values for the indicators will provide the basis for an adaptive management program, by which management actions, indicators and thresholds are evaluated and adjusted as necessary (see Figure 6).

Figure 6: The Process of Adaptive Management



Public Accountability

Monitoring of indicators will be critical in relating Bay-Delta-River information to the public. Public interest and enthusiasm for large-scale projects depend on effective communication between scientists, policy makers, government agents, the media, and the public. Conversely, responsible management depends on accountability to the public. One effective mode of communication might be to develop a list of the ***leading ecological indicators*** for the system, which could be published regularly by the media. Examples of these kinds of indicators might include area of wetlands restored or salmon abundance. Five such leading indicators could be developed by a small steering group of policy makers and scientists, then subjected to external peer review.

Establishment of an Ecological Health Board

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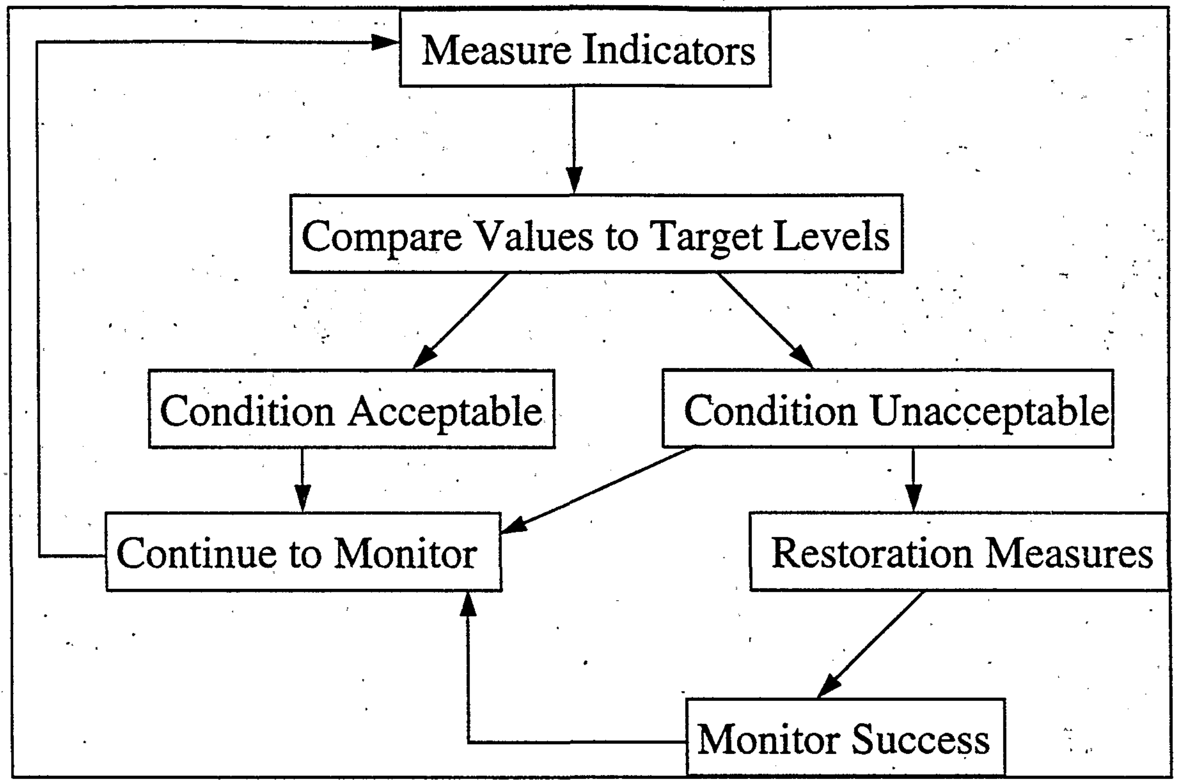

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Establishment of an Ecological Health Board

One suggestion brought up at the workshops was the establishment of an **Ecological Health Board,** which would use the information generated by monitoring efforts to indicate where restoration efforts are working, where we need better ecosystem health, and what other parameters or regions need to be monitored. The board would need to be vested with substantial authority to maintain or modify management measures in accordance with lessons learned from the indicators and related research.

Influencing Policy

In terms of the current Bay-Delta-River events, the two immediate applications of the indicators are to help evaluate the CalFed alternatives and the Anadromous Fish Restoration Plan (AFRP). The indicators can be used in ongoing evaluations of the AFRP and other plans, as well as in future versions of the CalFed alternatives and in the NEPA/CEQA process with which CalFed will be involved later this year. In his closing remarks at the January workshop, Dick Daniel, CalFed Assistant Director for Habitat Restoration, said that the results of the workshop will influence the CalFed planning process in validating and refining actions and components of the alternatives, helping to set priorities, guiding the necessary near and longer term research, and helping to develop a vision for restoration of the landscape and for the ecological zones. The ultimate purpose of the indicators, according to Daniel, will be to eventually measure the successes of the program.