FRAMEWORK OR PROCESS FOR CALFED ECOSYSTEM RESTORATION PROGRAM ECOLOGICAL INDICATORS DEVELOPMENT

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INTRODUCTION

Ecological indicators have an essential role in a science based strategy employing adaptive management to ecosystem restoration and protection (Figure 1; Hollings 1978; Noss 1990; NRC 1992; Cairns et al 1993). Indicators are used to describe and present science based information on ecological conditions, trends, and their significance (Bernard 1998). Ecological indicators are measurable surrogates for environmental end points (Noss 1990). Indicators are employed to translate program goals and objectives into a series of specific measurements that can be used to determine whether the goal and objectives have been met. Ecological indicators help define success: the ultimate achievement of the desired indicator levels shows that restoration or rehabilitation targets have been fulfilled, and incremental progress towards those levels over a predetermined time frame shows that the program is on track. Ecological indicators are appropriate measures of key ecological attributes or parameters; they represent components or processes of actual ecosystems.

The CALFED Bay-Delta Ecosystem Restoration Program (ERPP) will employ three general interrelated types of ecological indicators (Figure 2):

- indicators of ecological integrity or "health"
- scientific and management oriented indicators of ecosystem restoration and rehabilitation program/project performance and success
- more public oriented major indicators of ecosystem restoration and rehabilitation program/project performance and success ("leading ecological indicators").

The ecological integrity indicators provide the foundation for developing the program/project success indicators (Figure 2). Ecological indicators have several applications in the ERPP, including: evaluation of ecological integrity; pre-project evaluation of alternative restoration options; ongoing evaluation and measurement of the success and progress of the overall restoration program and its component actions (individual projects), which is essential to the adaptive management process; and, a convenient means of communicating program progress and success to the general public.

The ERPP Ecological Indicators Group has the lead role in developing indicators of ecological integrity. Since this indicator type is the basis for the other indicator types, and the process for developing all ecological indicator types is similar, the Indicators Group is also describing a general process or framework for developing ecological indicators (Figure 3).

PRECURSOR STEPS TO INDICATOR DEVELOPMENT

The first steps in designing an environmental management program are **initial identification of the major issues and problems, defining program goals and objectives, and setting the geographic boundary of the program** (NRC 1986). This initial process involves all interested parties--public, stakeholders, government, and scientific--so that all can express their views before major planning actions are taken (Council of Environmental Quality 1978). These first steps must have a strong scientific basis, but are ultimately policy decisions. These decisions provide the foundation for all program actions, including ecological indicator development. The ERPP Indicators Group utilizes the ERPP goals and geographic scope as the precursor framework for developing ecological indicators.

The CALFED Ecosystem Restoration Program goals are to:

- Achieve large, self-sustaining populations of at-risk native species dependent on the Delta and Suisun Bay, support similar recovery of at-risk native species in San Francisco Bay and the watershed above the estuary, and minimize the need for future endangered species listings by reversing downward population trends of non-listed native species.
- Rehabilitate the capacity of the Bay-Delta estuary and its watershed to support, with minimal ongoing human intervention, natural aquatic and associated terrestrial biotic communities, in ways that favor native members of those communities.
- Maintain and enhance populations of selected species for sustainable commercial and recreational harvest, consistent with goals 1 and 2.
- Protect or restore functional habitat types throughout the watershed for public values such as recreation, scientific research, and aesthetics.
- Prevent establishment of additional non-native species and reduce the negative biological and economic impacts of established non-native species.
- Improve and maintain water and sediment quality to eliminate, to the extent possible, toxic impacts on organisms in the system, including humans.

The primary geographic focus of the Ecosystem Restoration Program is San Pablo Bay, Suisun Bay and Marsh, and their watersheds; the Sacramento-San Joaquin Delta; and, the Sacramento River, the San Joaquin River, and their tributary watersheds below major dams and reservoirs (CALFED 1998). Secondarily, the ERPP addresses, at a programmatic level, upper watersheds above major dams and the northern California nearshore ocean specifically to cover potential ocean harvest management of anadromous fishes (CALFED 1998).

STEPS FOR DEVELOPING INDICATORS

Divide the program area into manageable units that reflect natural ecological organization.

Current ecological science organizes ecosystems hierarchically (O'Neill et al 1986; Noss 1990). Using previous work on the Bay/Delta/River watershed (Levy et al 1996; CALFED 1998), the Indicators Group adopted an ecological hierarchical approach for subdividing the program area and developing ecological indicators. This ecological hierarchy or typology has landscape, ecosystem, habitat, and species/ecological process levels. The ecosystems are San Francisco Bay estuary, Sacramento-San Joaquin Delta, lowland (alluvial) river-floodplain, and mountain (upland) river-riparian. Major habitat types in each ecosystem, and associated habitats, are identified (see attached Indicators Group Ecological Attributes document).

Describe the key ecological attributes for each level in the ecological hierarchy.

In a management context, perhaps the most practical means of summarizing the most relevant existing information on ecosystems is to develop, over an appropriate hierarchy of ecological scales, a list of key ecological attributes. Ecological attributes are characteristics of ecological structure and function, including biological communities/assemblages/species, ecological processes, and habitat types, that together define and distinguish ecosystems. Such lists of attributes serve as a convenient and necessary "check list" of environmental factors that might be addressed in an ecological restoration and/or rehabilitation program. Key ecological attributes for each level in the ecological topology or hierarchy should be listed and briefly described. These attributes should be organized into major (ecologically relevant) categories to facilitate comparison, assessment, and communication.

The Indicators Group derived five major or general categories for ecological attributes of the Bay-Delta watershed: hydrologic and hydrodynamic, geomorphic, natural habitat, native biological community, and energetics and nutrient dynamics. The Indicators Group has described the key ecosystem level attributes for the four major ecosystems in the program area (see Appendix A: Essential Ecosystem-Level Attributes of the San Francisco Bay-Delta Watershed. Note that Appendix A has not been completely updated to match the ecological attributes and indicators described for each ecosystem in the following section). This list of attributes is based on our understanding of (i.e., our hypotheses about) natural ecosystem structure and function. Attributes for each of the system's ecosystem-types were generated by assessing available information on (1) the historical state of these systems, (2) "pristine" remnant sites within this watershed, and (3) similar types of systems at other locations. They represent our best current evaluation of the condition of the ecosystem in its natural or pristine state, which may differ from a desired (or attainable) "target state" of a restoration or rehabilitation program. Additional expertise is needed to determine the key ecological attributes at lower levels (habitat and species/process). Appropriate work groups should be formed to develop attribute lists at the habitat and species/process levels. The Indicators Group can provide assistance and guidance to these work groups.

Delineate human stressors on the ecosystem.

An important planning step in any ecosystem restoration program is to accurately characterize anthropogenic factors that adversely affect natural ecological structure and function (i.e., human stressors or pressures) at all levels in the ecological hierarchy. Examples of human stressors include water management actions, land use and conversion practices, pollutant loading, introducing invasive non-native species, and overharvesting native species. Natural disturbance factors (e.g., meteorological events, natural fire regimes) would be defined under ecological attribute development because these are natural processes. Human stressors can, and often do, alter natural disturbance factors. The process of delineating human stressors was initiated by the Indicators Group but not completed, and needs further refinement.

Develop conceptual ecological models for each level in the ecological typology.

A useful tool in understanding and portraying fundamental characteristics of complex ecosystems is conceptual models. Ecological conceptual models describe key ecological attributes and their interrelationships; links among resources at risk; and, the effects of human activities (stressors) on these resources and attributes in ecosystems at risk (NRC 1990). Hypotheses on natural ecosystem structure and function and the effects of anthropogenic stressors are the underlying basis for these models. By depicting and focusing on cause-effect relationships regarding environmental changes, conceptual models help explain and justify ecological protection, restoration, and rehabilitation goals, objectives, and strategies; develop and refine specific, testable hypotheses to explain why particular effects should or should not occur; synthesize ideas and knowledge, including refining attributes and their interactions; identify supporting scientific information needs; and, develop indicators of ecosystem integrity which can be used to evaluate program actions (NRC 1986). The Indicators Group initiated conceptual model development; but this process was not completed and needs additional work.

Establish categories to organize indicators.

As discussed above there are several types and uses for ecological indicators. Several "conceptual frameworks" have been developed for organizing and categorizing types and uses of environmental indicators (Bernard 1997). These frameworks help integrate the scientific, legal/regulatory, management, and philosophical approaches underlining environmental decision making. They also help to explain and present indicator information. The Indicators Group proposes four categories for environmental indicators. The categories are a synthesis of the pressure-state-response-effects and response-exposure/habitat-stressor frameworks described in Bernard (1997). The categories can be applied over various programmatic, ecological, temporal, and spatial scales.

The environmental indicator categories proposed by the ERPP Indicators Group are:

- Ecosystem state or condition indicators.
  These are indicators of the condition of ecological attributes, including biological communities/assemblages/species, ecological processes, and habitat types. Indicators of ecological integrity or health are in this category. Most of the indicators presented in the following sections are ecosystem state/condition indicators.

- Human stressor or pressure indicators.
  These are direct and indirect human stressors on natural ecosystems Examples include: water management actions/practices (e.g., number and timing of water diversions); land use

(agriculture, urban, forestry) conversion and practices (e.g., area of urban/suburban land use); pollutant/contaminant loads; and, invasive introduced species (e.g, measure of new introductions, measure of spatial extent).

- Ecological effects of (or responses to) human stressors indicators.
  These are indicators for key specific ecological effects due to human stressors. They could be a subset of the ecosystem state/condition indicators. However, they can be more specific and/or complex in that they focus on specific cause-effect relationships between attributes and stressors, on specific changes in attributes, and/or integrate attributes . Examples include: fish loss (percentage, number) via water diversions; loss and fragmentation of natural habitat due to land conversion; contaminant risk to organisms (waterfowl, sturgeon) feeding on benthic invertebrates (related to contaminant loading and exotic clam abundance and distribution); decline or loss in native species and/or change in biological community structure due to invasive exotics; native fish predation risk due to introduced fishes; and, deviation from natural fire regime due to land management practices. Indicators of the effects of human stressors on human health would be in this category; for example, risk of mercury contamination from eating gamefishes (mean/median mercury levels in gamefish tissue or percentage of gamefish with mercury levels above health advisory level).

- Management program actions indicators.
  These are also termed human or societal response indicators (Bernard 1997). They are indicators of management actions taken to achieve program goals. Examples include: habitat restoration project indicators (e.g., acres of habitat restored); pollutant load reduction indicators; indicators for invasive exotic prevention, control, and eradication; number of approved (by scientific expert review) and/or implemented restoration or recovery plans for listed and other at-risk species; and, regulatory program (e.g., mitigation) indicators.

Establish selection criteria for indicators.

The Indicators Group adopted the following selection criteria for developing indicators of ecological integrity (based on Noss 1990 and Kratz et al 1994):

- ecological relevance
- sensitivity to change
- measurability; ease and cost effectiveness to measure, collect, assay, and/or calculate
- baseline or historical data available
- appropriate temporal and geographic scales
- statistical relevance
- integrated and interrelated to other indicators, and broadly applicable to many stressors and sites
- relevant to management objectives and actions; compatibility with the decision making process.

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Determine the best short and long term ecological indicators at each level of the ecological hierarchy.

Ecological indicators should be developed to encompass a wide array of ecological attributes and temporal scales because multiple lines of evidence must be examined to evaluate ecological integrity and program/project success (Noss 1990). The need for short and longer term indicators (i.e. multiple temporal scales) is illustrated in the following example. When restoring tidal marsh or riparian habitat, certain physical and chemical conditions and processes must be attained before biological communities and processes become fully established. For biological communities there is further temporal succession: plant communities, followed by lower trophic level animals, and finally top carnivores. Thus, the need for ecological indicators to assess ecological structure and function at various successional states and temporal phases of a program/project. The need to apply indicators across temporal scales occurs at all levels of the ecological hierarchy. Tools for developing indicators include program goals and objectives, ecological attribute lists, stressor lists, conceptual models, scientific literature/information, expert opinion, and selection criteria. A well chosen group of indicators can reduce the number of attributes or parameters that need to be monitored.

Establish or determine quantified targets for ecological attributes and indicators.

Program and/or project goals and measurable objectives provide the basis for quantified targets (e.g., numerical ranges for ecological attributes). Targets must have a strong scientific basis. Establishing targets for an ecosystem restoration program, such as CALFED ERPP, is ultimately a policy decision. Determining targets for ecological attributes and indicators of ecological integrity is not a responsibility of the ERPP Indicators Group.

Provide scientific support and input for indicator development and application.

Independent scientific review must be utilized at all steps in the indicator development process. All products should undergo independent scientific review. The science program supporting the ecosystem restoration program (CMARP for CALFED ERPP) should assess the current state (i.e., quantified values) of ecological attributes and associated indicators; design and implement the scientific monitoring required for all indicators; and conduct needed focused empirical research related to determining and refining indicators and targets.

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Figure 1. An example of the role of ecological indicators in a science based strategy for ecosystem restoration (adapted from the South Florida Ecosystem Restoration Program).

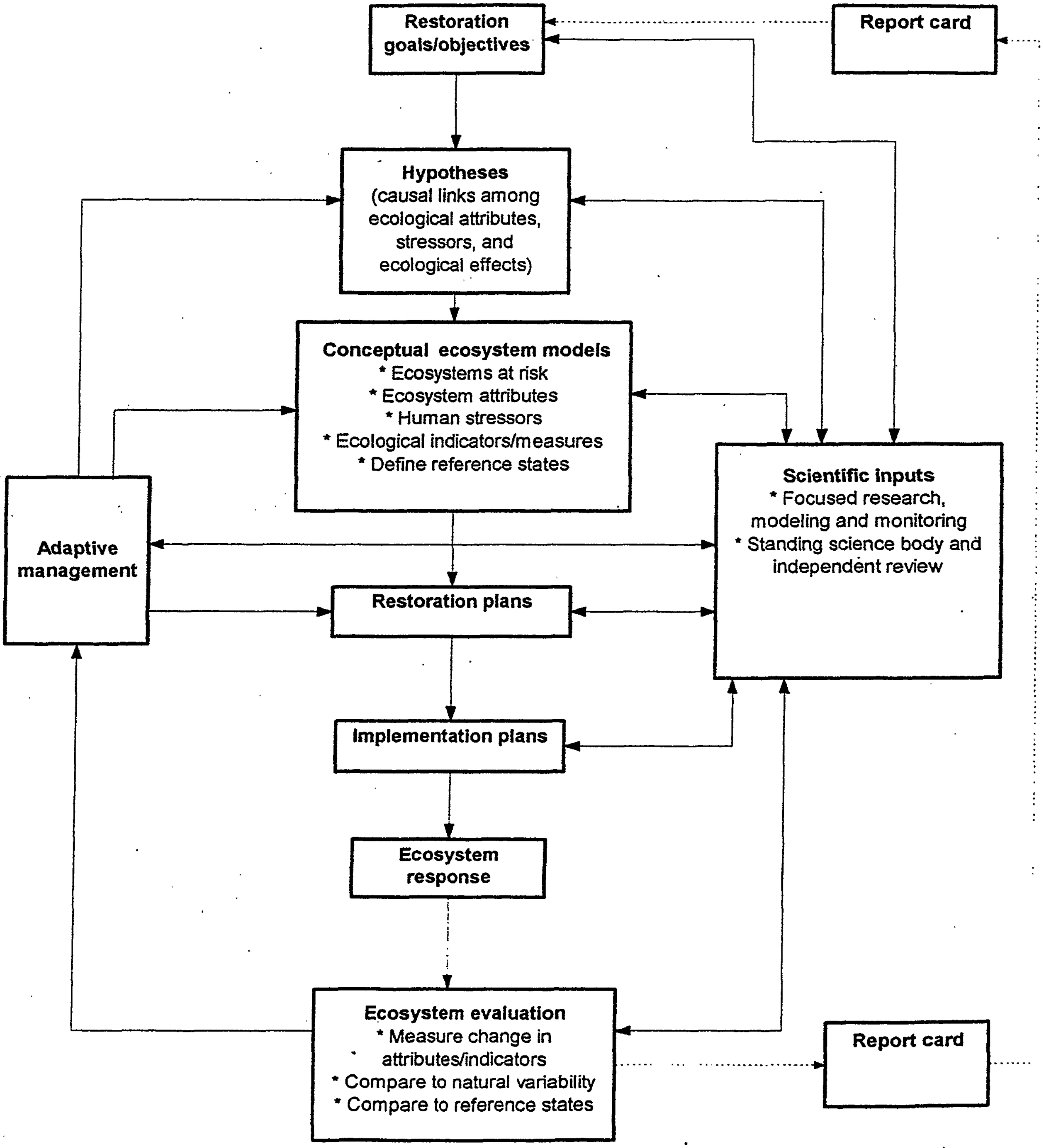


Figure 2. Types of Ecological Indicators

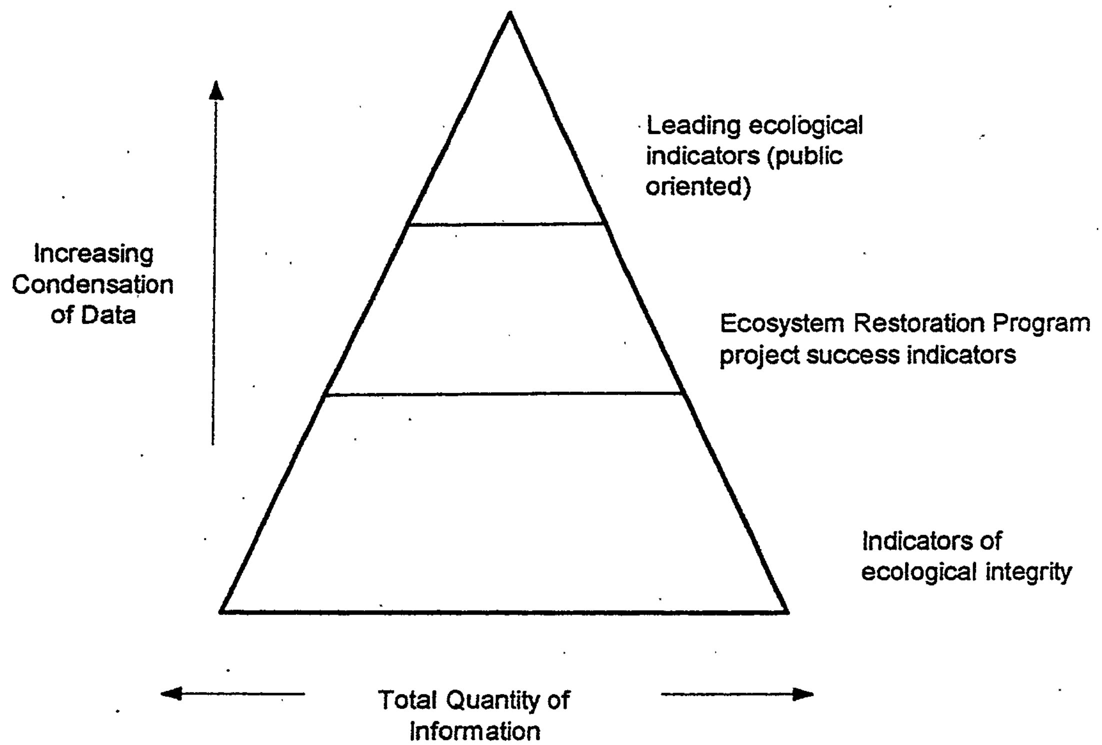
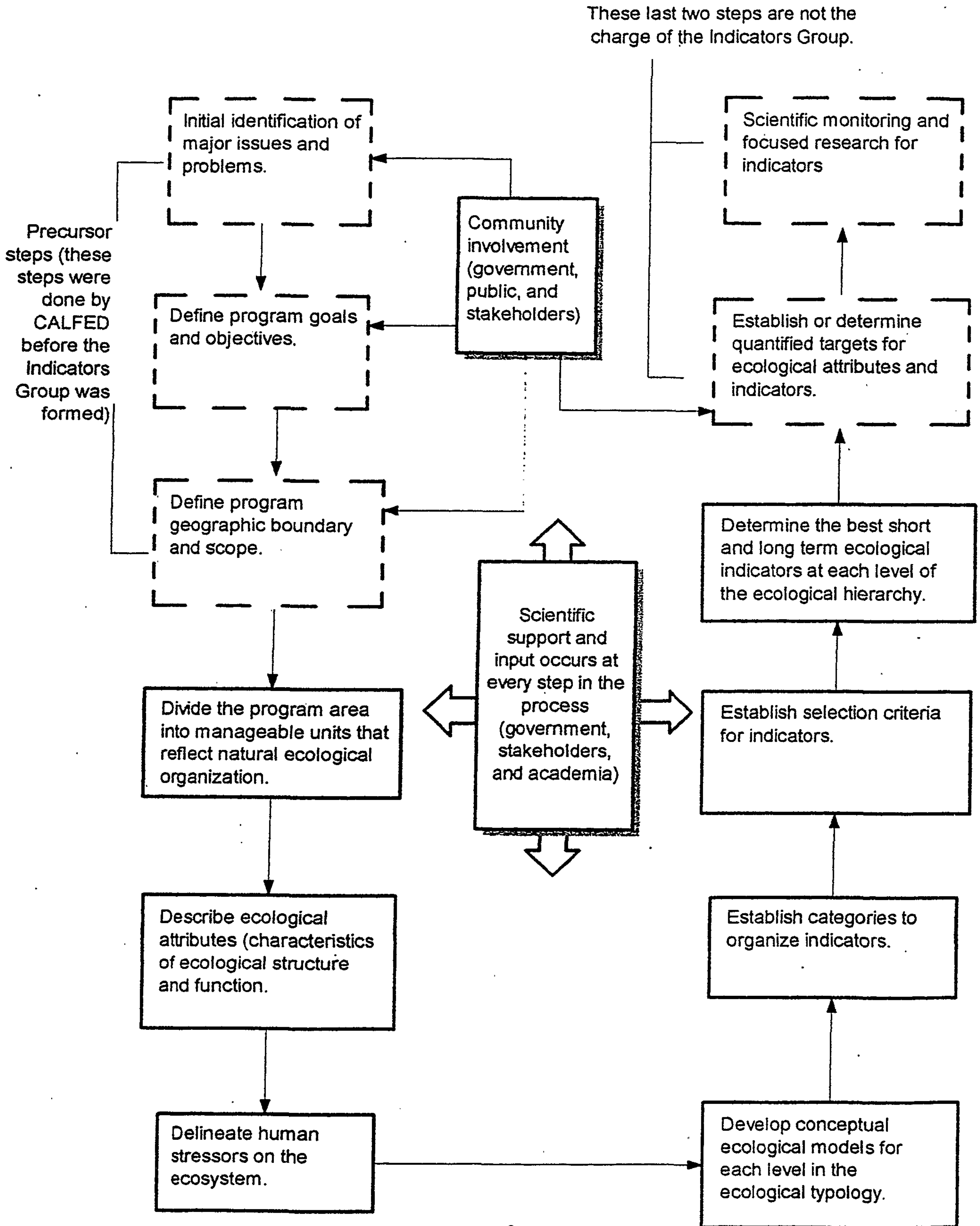


Figure 3. Process for Developing Indicators



PROPOSED ECOSYSTEM-LEVEL INDICATORS OF ECOLOGICAL INTEGRITY

Introduction

The indicators presented here were designed, in the aggregate, to serve as a composite measure of ecological integrity *at the ecosystem level* - defined as the fundamental ecological conditions capable of supporting the full range of native biodiversity and natural adaptive/evolutionary processes characteristic of ecosystems within this geographic region. Indicators can serve to reduce the number of variables that need to be monitored and if chosen carefully can provide an average of spatial and temporal environmental conditions. Because multiple lines of evidence must be evaluated to deem a project successful, a suite of indicators should be chosen to encompass a wide array of essential ecosystem attributes and multiple spatial and temporal scales (Noss 1990). Thus, the complete list provided below for each ecosystem serves as a guiding framework and baseline "checklist", to help ensure that the most essential ecosystem-level attributes have at least been considered, if not necessarily addressed, in project planning and/or evaluation. The indicators that will actually be employed (measured) in any particular project within the CALFED program will vary with project scope, objectives, and location, and may often consist of subsets of the more comprehensive lists, and/or may include additional specificity. The selection of appropriate indicators for any given project must be based on their compatibility with the decision making process, reliability in reflecting goals and objectives of proposed projects, and practicality in terms of quantitative measurement, evaluation and analysis.

Ultimately, the effectiveness of the CALFED restoration program at the ecosystem level must be evaluated both in terms of actual biological parameters, as well as in terms of parameters that reflect environmental conditions believed to *promote* biological goals (i.e., abiological or "physical" indicators). This will require long-term measurements of biological variables across large spatial scales. While certain parameters (e.g., population trends, distribution, etc.,) of particular "*indicator species*" may be useful biological indicators for some applications, in general, such measures are inherently more temporally and spatially variable, and thus constitute less robust "indicators" of system integrity, than parameters that reflect characteristics of multi-species assemblages. Therefore community-level indicators, that measure attributes of multi-species assemblages, are preferable biological measures of ecological integrity at the ecosystem level.

The ecosystem-level indicators suggested here need additional refinement from experts in appropriate disciplines (The Indicators Group does not have the extensive expertise required). Several are essentially conceptual placeholders awaiting expert revision. This is especially true of the biological communities indicators which are very general. For example, avian ecologists need to be consulted to identify the best measures (e.g., abundance, reproductive success, species richness, species diversity, etc.) and select the best species and/or assemblages for the general avian indicator titled "Trends in the abundance, reproductive success, diversity, composition, and distribution of native resident and migratory birds".

PROPOSED ECOSYSTEM-LEVEL INDICATORS OF ECOLOGICAL INTEGRITY FOR THE UPLAND MOUNTAIN RIVER-FLOODPLAIN ECOSYSTEM

I. Ecosystem Typology

Upland river-riparian ecosystems are defined as rivers, streams, and associated riparian corridors that extend from headwaters elevations in the Coast Ranges, Cascade Range, and Sierra Nevada to the point near the floor of the Central Valley where they merge with alluvial river-floodplain ecosystems (in most cases near the 300 foot (91.4 m) elevation contour). The Sacramento River above Red Bluff is included in the upland river-riparian ecosystem. Most rivers and streams in this ecosystem correspond with the A2410 (fishless low-order tributaries) to A2430 (salmon-steelhead streams) series in the habitat classification system of Moyle and Ellison (1991) and Moyle (1996).

A. Riverine (mainstem and tributaries)

1. Water column.
    a. Pools.
    b. Riffles.
2. Bank.
    a. Littoral zone- region of bank between non-flood seasonal high and low water.
    b. Supra-littoral zone- inundated only during flood events.
3. Benthic substrates (channel bed)- bedrock dominated, submerged at all or most times.
4. Mid-channel formations- gravel bars and sand bars.

B. Floodplain

1. Riparian- willow/cottonwood/alder understory and coniferous canopy; occurs on lower terraces adjacent to channel; structural and microclimatic complexity contribute to increased humidity and availability of food resources for wildlife (Kondolf et al. 1996).

2. Mountain meadows- channels also pass through upland meadows, seasonally flooded grasslands, chaparral, etc.

C. Associated/interactive Habitats

1. Upslope forest (beyond riparian zone).
2. Oak woodlands (lower elevations).
3. Grasslands.

II. Proposed Indicators

A. Hydrologic Attributes/Indicators

Attributes:

1. Variable streamflows: Typical patterns of annual streamflows are broadly predictable, but specifics of magnitude, timing, duration, and frequency vary with patterns of storms and droughts and by drainage and are unpredictable. This unpredictability of streamflows maintains complex aquatic and riparian habitats.

Indicators:

a. Minimum base flows (cfs) at appropriate time scales (e.g., annually, seasonally) (Levy et al. 1996).
b. Seasonal shift in stream level: annual maximum to minimum range.
c. Measures of variability at appropriate time scales.

2. Floods: natural pattern: frequency, timing, magnitude, duration, and variability of overbank flows in the system.

Indicators:

a. Minimum surface area of floodplain inundated at least once every two years.
b. Flood duration (mean and variability).

3. Natural groundwater levels and exchange processes: sufficient to support riparian plant assemblages, in a corridor of natural width, particularly during drier periods.

Indicators:

a. Depth of water table.
b. Soil moisture levels, laterally from river banks.
c. Characteristic natural plant communities.
d. Width of riparian corridor.

B. Geomorphic Attributes/Indicators

Attributes:

1. Dynamic channel morphology: natural geomorphic processes that shape channels (e.g., erosion, scour, and deposition) vary temporally with climatic fluctuations, and spatially with topographic features. Natural dynamics and composition of coarse sediment are essential for maintaining microhabitat structural diversity. Over the long term, river reaches should export coarse sediment and gravels at rates equal to sediment and gravel input upstream.

Indicators:

a. Bedload movement.
b. Sediment particle size and distribution.
c. Natural ratio (by site) of pools to riffles.
d. Inter-annual comparison of fluvial geomorphic features (e.g., point bar size and distribution).

2. Balanced Sediment Budget:

Indicators:

a. Net change in depth per unit time of unconsolidated sediments.

C. Habitat Attributes/Indicators

Habitats representing the entire typology for this ecosystem-type must be sufficiently connected and available in large enough patches to support assemblage diversity and sustainable populations of native species.

Attributes:

1. Habitat mosaic and connectivity: These habitat characteristics are typically evaluated in terms of the diversity, distribution, and extent of primary habitat-types, and the ability of organisms to move adequately among habitats, and for energy/nutrient exchange to occur. For aquatic systems, connectivity implies adequate riverine cover and passage for anadromous fish, with little migration delay associated with natural and manmade barriers. Likewise, floodplains should have the essential spatial characteristics to function as migratory corridors for wildlife.

Indicators:

a. The extent and distribution of patches of all typology elements.
b. The presence and distribution of species requiring access to multiple habitats characteristic of this type of system (insects, amphibians, reptiles, birds, mammals).
c. Presence and distribution of native and migratory fish species.
d. Length of river channel obstructed by artificial barriers.
e. Length of riparian corridor unobstructed by artificial barriers.

2. Instream habitat complexity:

Indicators:

a. Pool to riffle ratio.
b. Abundance, distribution and recruitment rate of large woody debris (LWD).
c. Shaded riverine aquatic habitat.
d. Diversity of flow velocity.

3. <u>Water/sediment quality: Water and sediment quality parameters within natural ranges and specifically for toxic contaminants at levels that do not adversely impact native organisms or their habitats. These parameters include temperature, turbidity, and toxicity which must be within ranges suitable for native species assemblages.</u>

<u>Indicators</u>:

a. Toxicity (see CALFED Water Quality Program: Parameters of Concern).
   (1) Concentrations in water and sediment.
   (2) Tissue concentrations (body burdens) in selected species spanning multiple trophic levels (e.g. fish, birds, and benthic invertebrates).
   (3) Bioassays (especially sediment).
   (4) Biomarkers.
   (5) Bioindicators.
   (6) Contaminant loading.

b. Dissolved oxygen.

c. Turbidity-suspended solids.

d. Temperature.

e. Nutrients (forms of nitrogen, phosphorus and carbon).

D. Native Biological Community Attributes/Indicators

<u>Attributes</u>:

1. <u>Natural community structure: Naturalistic patterns of composition, diversity, dominance and distribution among native species.</u>

<u>Indicators</u>:

a. Trends in the diversity, composition and distribution of riparian insect assemblages by functional groups *(Rationale: Insects are ecologically diverse in terms of habitat and trophic requirements, and have short generation times: they generally respond much more rapidly than vertebrates to changes in environmental conditions. Insects may therefore represent the best single taxa in terms of <u>short-term</u> biological indicators of enhanced ecological opportunity).*

b. Trends in the diversity, composition and distribution of benthic invertebrate assemblages by functional groups *(Rationale: Benthic invertebrates are ecologically diverse in terms of habitat and trophic requirements, and have short generation times. They are therefore good short-term biological indicators of enhanced water quality and ecological opportunity in the aquatic environment, and generally respond much more rapidly than fishes to changes in environmental conditions; successful restoration should reestablish natural distribution patterns and result in higher proportions of native species and biomass).*

c. Trends in abundance, reproductive success, diversity, composition and distribution of native resident birds and migratory birds *(Rationale: Successful restoration should result in more natural distribution and movement patterns among more suitable habitats and a greater abundance of birds).*

d. Diversity and distribution and structural or successional complexity of native plant associations *(Rationale: successful restoration should re-establish natural plant associations dominated by native species).*

e. Distribution and diversity of native mammals *(Rationale: These wide-ranging species provide an indication of natural nutrient/energetic linkages among habitats and nearby ecosystems. Large native mammals are also known to play a major role in creating and maintaining habitat complexity in floodplain habitats).*

f. Distribution, diversity, and trophic structure of native fishes *(Rationale: successful restoration should permit the reestablishment of historic distribution patterns within restored areas, and support a more natural balance of different feeding types, in terms of proportionate abundance [biomass]).*

g. Invasive introduced (exotic) species *(Rationale: Although the CALFED Program does not intend to eradicate all exotic species and many exotics may be difficult to completely eradicate, a return to more "natural" environmental conditions should result in improved conditions for native species and overall ecosystem health).*
   (1) Measures of new invasions/introductions.
   (2) Abundance, spatial (geographic) extent, and distribution of selected invasive exotic species.
   (3) Number of selected exotic species eradicated or exhibiting no net increase in distribution.

h. Fish and wildlife health; incidence of diseases, tumors, fin damage, or other anomalies and deformities (Karr et al. 1986).

E. Community Energetics/Nutrient Cycling Attributes/Indicators

Attributes:
1. Natural patterns of nutrient loading:

Indicators:
a. Nutrients from salmon carcasses (anadromous streams).
b. Organic input from grazing animals.
c. Ratios of natural/anthropogenic sources of nutrients.

PROPOSED ECOSYSTEM-LEVEL INDICATORS OF ECOLOGICAL INTEGRITY FOR THE ALLUVIAL (LOWLAND) RIVER-FLOODPLAIN ECOSYSTEM

I. Ecosystem Typology

Lowland rivers, as defined herein, constitute those waterways and their floodplains that traverse the alluvial deposits of the Central Valley. The actual geomorphic "dividing line" between "upland" and "lowland" river-floodplain systems (as defined in this document) generally occurs at about the 300 ft. elevation contour. Lowland river-floodplain systems of the Central Valley are distributed across a vast area, covering thousands of square miles. This does not include the Redding Basin, which is considered part of the upland mountain river-floodplain ecosystem described in the previous section.

A. River (mainstem and tributaries)

1. Water column.
2. Bank.
   a. Littoral zone (region of bank between normal [non-flood] seasonal high and low water).
   b. Supra-littoral zone (inundated only during flood events).
3. Benthic substrates (channel bed)- submerged at all or most times.
4. Mid-channel islets.
   a. Frequently submerged sand/gravel bars (unvegetated).
   b. Vegetated (high-disturbance riparian) islets.

B. Floodplain

1. Riparian zone.
   a. High disturbance (willow/cottonwood dominated)- lower terraces adjacent to channel.
   b. Low disturbance (valley oak dominated)- higher terraces extending some distance outward from channel or cottonwood/willow zone.
2. Wetlands- includes low-lying areas of floodplain consisting of marshes and swamps connected to the mainstem by a system of winding channels and dead-end sloughs. This habitat encompasses so-called "backwater" channels, lakes and ponds formed alongside the mainstem river channels. Often, seasonally-flooded.
3. Other floodplain habitats- seasonally flooded grasslands, vernal pools, etc. These habitats transition to upland communities.

C. **Floodbasins (lower Sacramento Valley only):**

1. Wetlands- low-lying areas of basin, consisting mainly of tule marshes; typically, seasonally-flooded.
2. Other- less frequently inundated portions of basin consisting of grasslands, etc.

II. Proposed Indicators

A. Hydrologic Attributes/Indicators

Attributes:

1. Variable streamflows: Typical patterns of annual streamflows are broadly predictable, but specifics of magnitude, timing, duration, and frequency vary with patterns of storms and droughts and by drainage and are unpredictable. This unpredictability of streamflows maintains complex aquatic and riparian habitats.

Indicators:

a. Minimum base flows (cfs) at appropriate time scales.
b. Water level (depth).
c. Seasonal shift in stream level: annual maximum vs. minimum.
d. Measures of variability at appropriate time scales.
e. Geographic distribution of flows (inflows to mainstems by tributary).

2. Floods: natural pattern: Frequency, timing, magnitude, duration and variability of overbank flows in the system. Must be sufficient to sustain all riverine and floodplain habitat-types.

Indicators:

a. Minimum surface area of floodplain inundated at least once every two years, and at least once every ten years.
b. Mean annual frequency.
c. Flood duration (mean and variability).

3. Natural groundwater levels and exchange processes: Must be sufficient to cool deeper river levels, transport recycled nutrients from floodplain detrital chains to the river, and support riparian forest and marsh habitat, in a corridor of natural width, particularly during the drier periods.

Indicators:

a. Depth of water table.
b. Soil moisture levels, laterally from river banks.
c. Infiltration rates (surface to water table).

B. Geomorphic Attributes/Indicators

Attributes:

1. Natural topography: channel, bank and floodplain morphology within the natural range of variability characteristic of this system. Terrestrial species must have ready access to refuge from major floods. The elevation and topography of lands within the corridor will greatly affect habitat distribution and diversity.

Indicators:

a. Mean width of available (unconstrained by unnatural levees) meander corridor, as % of natural (for region).
b. Percent of river length not constrained by constructed levees.
c. Distribution and extent of floodplain habitats.
d. Distribution and extent of littoral zone.

2. Natural Patterns of River Meandering: An unrestricted meander corridor of sufficient width is necessary to support the full range of biological assemblages native to system habitat-types and subhabitats.

Indicators:

a. Percent of river miles exhibiting naturalistic meandering.

3. Natural sediment supply, delivery and movement processes: Must be sufficient to maintain natural dynamic processes and channel/substrate characteristics in meandering rivers. Natural movement of sediments is an essential geomorphic process in shaping an maintaining the structure and diversity of subhabitats of the system. Benthic substrate composition must approximate natural conditions.

Indicators:

a. Net change in depth/unit time of unconsolidated sediments.
b. Amount of coarse sediments delivered (expressed as proportion of pre-dam).
c. Lateral exchange: river to floodplain (amount and composition).
d. Inter-annual comparison of geomorphic features (sand bars, gravel bars, etc.).
e. Sediment particle size and distribution.
f. Natural ratio (by site) of pools/riffles.

C. Habitat Attributes/Indicators

Habitats representing the entire typology for this ecosystem-type (see above) must be sufficiently connected and available in large enough patches to fully support sustainable populations of all native species.

Attributes:

1. Habitat Mosaic and Connectivity: The diversity, distribution and extent of primary habitat-types, and the ability of organisms to move freely among habitats, and for energy/nutrient exchange to occur.

Indicators:

a. Extent and distribution of patches of all typology elements (see above).
b. Presence and distribution of species requiring access to multiple habitats characteristic of this type of system (insects, amphibians, reptiles, birds, mammals).
c. Presence and distribution of migratory fish species.
d. Number of unnatural barriers interfering with natural movements of native species.

2. Water quality: Water and sediment quality parameters within natural ranges and specifically for toxic contaminants at levels that do not adversely impact native organisms or their habitats. These parameters include temperature, turbidity, and toxicity which must be within ranges suitable for native species assemblages.

Indicators:

a. Toxicity (see CALFED Water Quality Program: Parameters of Concern).
    (1) Concentrations in water and sediment.
    (2) Tissue concentrations (body burdens) in selected species spanning multiple trophic levels (e.g. fish, birds, and benthic invertebrates).
    (3) Bioassays (especially sediment).
    (4) Biomarkers.
    (5) Bioindicators.
    (6) Contaminant loading.
b. Dissolved oxygen.
c. Turbidity/suspended solids.
d. Temperature.
e. Nutrients (forms of nitrogen, phosphorus and carbon).

D. Native Biological Community Attributes/Indicators

Attributes:

1. Natural community structure: Naturalistic patterns of composition, diversity, dominance and distribution among native species.

Indicators:

a. Trends in the diversity, composition and distribution of riparian insect assemblages by functional groups *(Rationale: Insects are ecologically diverse in terms of habitat and trophic requirements, and have short generation times: they generally respond much more rapidly than vertebrates to changes in environmental conditions. Insects may therefore represent the best single taxa in terms of* <u>short-term</u> *biological indicators of enhanced ecological opportunity).*

b. Trends in the diversity, composition and distribution of benthic invertebrate assemblages by functional groups *(Rationale: Benthic invertebrates are ecologically diverse in terms of habitat and trophic requirements, and have short generation times. They are therefore good short-term biological indicators of enhanced water quality and ecological opportunity in the aquatic environment, and generally respond much more rapidly than fishes to changes in environmental conditions; successful restoration should reestablish natural distribution patterns and result in higher proportions of native species and biomass).*

c. Trends in abundance, reproductive success, diversity, composition and distribution of native resident birds and migratory birds *(Rationale: Successful restoration should result in more natural distribution and movement patterns among more suitable habitats and a greater abundance of birds).*

d. Trends in the diversity, composition and distribution of native plant associations *(Rationale: Successful restoration should re-establish natural plant associations dominated by native species).*

e. Trends in the distribution, composition and diversity of native mammals. *(Rationale: These wide-ranging species provide an indication of natural nutrient/energetic linkages among habitats and nearby ecosystems. Large native mammals are also known to play a major role in creating and maintaining habitat complexity in floodplain habitats)*

f. Trends in the composition, distribution, diversity and trophic structure of native fishes *(Rationale: successful restoration should permit the reestablishment of historic distribution patterns within restored areas, and support a more natural balance of different feeding types, in terms of proportionate abundance (biomass).*

g. Invasive introduced (exotic) species *(Rationale: Although the CALFED Program does not intend to eradicate all exotic species and many exotics may be difficult to completely eradicate, a return to more "natural" environmental conditions should result in improved conditions for native species and overall ecosystem health).*
   (1) Measures of new invasions/introductions.
   (2) Abundance, spatial (geographic) extent, and distribution of selected invasive exotic species.
   (3) Number of selected exotic species eradicated or exhibiting no net increase in distribution.

h. Fish and wildlife health; incidence of diseases, tumors, fin damage, or other anomalies and deformities (Karr et al. 1986).

E. Community Energetics/Nutrient Cycling Attributes/Indicators

Attributes:

1. Natural Nutrient/Energy Supply: A natural balance of types, sources and temporal variability of energy and nutrients entering, and available within, the system. Ratio of floodplain to river production.

Indicators:

a. Ratio of floodplain to river production.
b. Export of organic materials from floodplain to river channel.
c. Percent increase in dissolved nitrogen and phosphorus following overbank flows.
d. Concentrations of dissolved nitrogen and phosphorus in groundwater at selected sites.

PROPOSED ECOSYSTEM-LEVEL INDICATORS OF ECOLOGICAL INTEGRITY FOR THE DELTA ECOSYSTEM

I. Ecosystem Typology

The Delta is the easternmost (upstream) portion of the estuary, and today is clearly delimited by a legal boundary that includes areas that historically were intertidal, along with supra-tidal portions of the floodplains of the Sacramento and San Joaquin Rivers. Today's legal Delta extends between the upper extent of the tidewater (near the city of Sacramento on the Sacramento River and Mossdale on the San Joaquin River) and Chipps Island to the west, and encompasses the lower portions of the Sacramento and San Joaquin river-floodplain systems as well as those of some lesser tributaries (Mokelumne, Calaveras Rivers). The Sacramento and San Joaquin Rivers enter the Delta from the north and south respectively, where they join and together discharge their contents near the western margin of the Delta.

The historic delta (circa 1850) was a mosaic of three major habitat-types: intertidal wetlands, subtidal waterways, and elevated (supratidal) landforms (mainly levees) which typically supported riparian vegetation (Atwater and Belknap 1980). Around the historic Delta's intertidal perimeter, tidal wetlands merged gradually into non-tidal wetlands, and further upland into oak woodlands and grasslands dotted with vernal pools. These historic habitat types have been significantly altered in their extent and configuration; however, their restoration/rehabilitation could lead to significant benefits to the plant and animal communities that depend on these resources.

A. Tidally Influenced Area

1. Tidal Wetlands- complex mosaic of sub-habitats and successional states, including areas dominated by emergent vegetation, swamp-like areas, smaller tidal drainage channels, shallow lakes, ponds and pools, and mudflats *(=Tidal perennial aquatic habitat in ERPP).*

2. Waterways- includes two major types (riverine channels and distributary sloughs), each composed of three general sub-habitats: water column, benthic, and littoral zone *(includes Delta sloughs cited in ERPP)*
    - a. Riverine channels
        - (1) Water column.
        - (2) Benthic.
        - (3) Littoral zone- within-bank area alternately submerged and exposed by changing water levels.
    - b. Distributary Sloughs
        - (1) Water column.
        - (2) Benthic.

(3) Littoral zone- within-bank area alternately submerged and exposed by changing water levels.

3. Riparian/other elevated (supratidal) landforms surrounded by tidal areas *(includes Riparian habitat cited in ERPP and Mid-channel Islands and shoals)*- occupied by plant and animal assemblages generally typical of Central Valley river riparian zones; frequently topped by floods, resulting in a high-disturbance, successional habitat.

B. Non-tidal Floodplain

This area includes riverine channels and their associated floodplains which in turn are divided into riparian zones, wetlands, and other seasonally flooded habitats. Though this area is found within the legal boundary of the Delta, it's habitats are more similar to the Lowland (Alluvial) River-Floodplain System. Therefore for a complete description of this habitat and associated sub-habitats and indicators, see the Lowland (Alluvial) River-Floodplain section.

C. Associated/Interactive Habitats (Delta Uplands)

1. Native (mostly perennial) grasslands.
2. Oak woodlands.
3. Vernal pools.
4. Dune scrub.

II. Proposed Indicators

A number of key structural attributes and processes affect/determine the extent, quality, diversity, connectivity, and sustainability of habitats providing support for native species within the Delta Ecosystem. The following are system attributes (and their indicators) that we might be reasonably capable of manipulating in the Delta Ecosystem. These indicators are specifically applicable to the tidally influenced areas and aspects of the Delta floodplains. For portions of the system that occur in the non-tidal floodplain refer to the section on the Alluvial (Lowland) River-Floodplain Ecosystem.

A. Hydrologic/Hydrodynamic Attributes/Indicators

Attributes:

1. Positive seaward flow.

Indicators:

a. Delta outflow.

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2. <u>Water circulation patterns mimic natural patterns expected at various flows</u>.

<u>Indicators:</u>

a. Composite measures of water circulation: freshwater flow rates, water residence time, and direction of flow for key channels or areas in delta during high and low flow conditions.
b. Flows of tributaries mimic a pattern of unimpaired flows.

3. <u>Salinity gradient variable due to within year (seasonal) and between year differences in river discharge and local precipitation.</u>

<u>Indicators:</u>

a. Salinity patterns: measured at several locations, including areas in the western, central and eastern Delta (mean monthly salinity patterns).

B. Geomorphic Attributes/Indicators

Bathymetric and topographic features largely control water flow and availability, habitat types, and access to habitats for aquatic species.

<u>Attributes</u>:

1. <u>Extremely flat topography, with few places exceeding the historic level of wetland plain by more than ten feet.</u>

<u>Indicators:</u>

a. Difference in percent of area tidally inundated during MHHW versus MLLW.

2. <u>Dendritic pattern of distributary channels of varying dimensions</u> (*Rationale: The historic delta was composed of a variety of shallow water habitat types)*.

<u>Indicators:</u>

a. Total linear distance of channels per unit area.
b. Proportion of first, second and third order channels per unit area.

3. <u>Variable channel morphology</u>

<u>Indicators:</u>

a. Bank slope assessed directly or by comparing the degree to which plant associations mirror changes in bathymetry.

4. <u>Connectivity of riverine channels to wetlands and intermittently to some delta areas where natural levees are low enough to be regularly topped during flood events.</u>

5. Natural sediment production and acquisition resulting in net soil accretion at a rate comparable to the sea level rise rate, resulting in a system where the marsh plain remains just below the MHHW level. Inorganic sediment deposition occurs mainly during large flood discharges from the Sacramento River.

Indicators:

a. Marsh plain elevation relative to sea level (This measure incorporates accretion due to organic accumulation and soil erosion in addition to losses due to the effects of oxidation (subsidence)).

b. Change in area of Delta islands and islets (using tools like aerial photography, etc.)

C. Habitat Attributes/Indicators

Attributes:

1. Habitat Mosaic and Connectivity: The diversity, distribution and extent of primary habitat-types as defined in the typology, and the ability of organisms to move freely among habitats, and for energy/nutrient exchange to occur.

Indicators:

a. The spatial extent and distribution of patches of all habitat types (see above). At the ecosystem level, this macro-scale indicator refers to long term changes in the distribution of major habitat types.

b. The presence and distribution of species requiring access to multiple habitats characteristic of this type of system (includes selected members of any or all appropriate taxa including insects, amphibians, reptiles, birds, mammals).

c. Presence and distribution of resident and anadromous fish species *(Rationale: Some fish migrate within the Delta as well as across the entire landscape.)*

d. Number of unnatural barriers within the Delta interfering with natural movements of native species.

2. Water/sediment quality: Characteristics such as temperature, turbidity, and toxicity that affect habitat type and function and the ability of organisms to utilize habitat. Water temperature, dissolved oxygen levels, turbidity and toxicity must be within ranges suitable for native species assemblages.

Indicators:

a. Toxicity of water and sediments (see CALFED Water Quality Program: Parameters of Concern).

   (1) Concentrations in water and sediments.

   (2) Tissue concentrations (body burdens) in selected species spanning multiple trophic levels (e.g. fish, birds, and benthic invertebrates).

   (3) Bioassays.

(4) Biomarkers.
(5) Bioindicators.
(6) Contaminant loading.

b. Dissolved oxygen.
c. Turbidity.
d. Temperature.
e. Nutrients (forms of nitrogen, phosphorus and carbon).
f. Salinity/TDS.

D. Native Biological Community Attributes/Indicators

Attributes:

1. Natural community structure: Naturalistic patterns of composition, diversity, dominance and distribution among native species.

Indicators:

a. Trends in abundance, diversity, composition and distribution of benthic invertebrate assemblages by functional groups *(Rationale: Benthic invertebrates are ecologically diverse in terms of habitat and trophic requirements, and have short generation times. They are therefore good short-term biological indicators of enhanced water quality and ecological opportunity in the aquatic environment, and generally respond much more rapidly than fishes to changes in environmental conditions. Successful restoration should reestablish natural distribution patterns and result in higher proportions of native species and biomass).*

b. Trends in abundance, reproductive success, diversity, composition and distribution of native resident birds and migratory birds *(Rationale: Successful restoration should result in more natural distribution and movement patterns among more suitable habitats and a greater abundance of birds).*

c. Trends in abundance, diversity, composition and distribution of native plant associations *(Rationale: successful restoration should re-establish natural plant associations dominated by native species).*

d. Trends in abundance, composition and distribution of native mammals *(Rationale: These wide-ranging species provide an indication of natural nutrient/energetic linkages among habitats and nearby ecosystems. Native mammals are also known to play a major role in creating and maintaining habitat complexity in some floodplain habitats).*

e. Trends in abundance, composition and distribution of native resident and anadromous fishes. Resident species such as the delta smelt may be particularly suitable for assessing trends within the Delta ecosystem *(Rationale: Successful restoration should permit the reestablishment of historic distribution patterns within restored areas, and support a more natural balance of different feeding types, in terms of proportionate abundance (biomass)).*

f. Cohort replacement and survival rates of selected life stages of certain species of fish *(Rationale: Successful restoration should increase survival rates).*

g. Invasive introduced (exotic) species *(Rationale: Although the CALFED Program does not intend to eradicate all exotic species and many exotics may be difficult to completely eradicate, a return to more "natural" environmental conditions should result in improved conditions for native species and overall ecosystem health).*
   (1) Measures of new invasions/introductions.
   (2) Abundance, spatial (geographic) extent, and distribution of selected invasive exotic species.
   (3) Number of selected exotic species eradicated or exhibiting no net increase in distribution.

h. Trends in abundance, composition and distribution of phytoplankton and zooplankton (seasonal and annual comparisons).

i. Trends in abundance, diversity, composition and distribution of threatened and endangered species, and species of concern (see those species listed as part of the CALFED Conservation Strategy).

j. Fish and wildlife health; incidence of diseases, tumors, fin damage, or other anomalies and deformities (Karr et al. 1986).

E. Community Energetics/Nutrient Cycling Attributes/Indicators

Attributes:

1. Natural levels of plankton productivity sufficient to support higher trophic levels in plankton-based food chain.

Indicators:

a. Primary productivity rates.
b. Abundance of zooplankton (secondary production preferable but not easily measured in riverine-delta systems).

2. Levels of benthic production necessary to support self sustaining native fish and bird populations dependent on native invertebrates.

Indicators:

a. Secondary production of zoobenthos.

3. Net transport/export of detrital organic matter (carbon and other nutrients) from marshes to mudflat, benthic, and pelagic (open water) habitats.

Indicators:

a. Flux of detrital organic matter (carbon, nitrogen and phosphorus) between marshes and other aquatic habitats.
b. Spatial extent of wetlands habitat.

4. Variable sources of nutrient loading to the Bay.

Indicators:

a. Nutrient loading (total organic carbon, total nitrogen and total phosphorus).

PROPOSED ECOSYSTEM-LEVEL INDICATORS OF ECOLOGICAL INTEGRITY FOR THE GREATER SAN FRANCISCO BAY ECOSYSTEM

I. Ecosystem Typology

Greater San Francisco Bay, as defined here, is that part of the estuary between Chipps Island and the Golden Gate. It includes four major embayments: Suisun Bay and Marsh, San Pablo Bay, and central and south San Francisco Bay.

A. Pelagic (Water Column)

1. Shallow water (≤ 2 - 3 m).
2. Deep water (> 3 meters).

B. Benthic (Subtidal)

1. Unvegetated soft (unconsolidated) bottom.
2. Vegetated (seagrass, macroalage) soft bottom.
3. Hard bottom (central bay).

C. Mudflat (Intertidal)

D. Marsh (Wetland) [after Josselyn 1983]

1. Tidal salt marsh- Spartina foliosa (low marsh zone) and Salicornia (high zone) dominated.
2. Tidal brackish marsh- Scirpus (low and middle zones), Typha (middle zone), and Juncus (high zone) dominated.
3. Tidal freshwater marsh (≤ 0.5 ppt)

(Note: Diked or managed marsh, common in bay today, is not a natural habitat type)

E. Rocky Intertidal

F. Tidally Influenced Tributary Streams

G. Associated/Interactive Habitats: adjacent terrestrial habitats; bay watersheds

II. Proposed Indicators

A. Hydrologic/Hydrodynamic Attributes/Indicators

Attributes:

1. Freshwater inflow (seasonal and interannual): timing, quantity, and distribution.

Indicators:

a. X2 location: distance from Golden Gate where salinity is 2 ppt, incorporates seasonality.
b. Salinity measured at appropriate fixed locations throughout bay generating bay-wide salinity profile; incorporate temporal (seasonal and interannual) variability.

2. Spatial and temporal (seasonal and interannual) salinity patterns.

Indicators:

a. Salinity measured at appropriate fixed locations throughout bay generating bay-wide salinity profile; incorporate temporal (seasonal and interannual) variability.
b. X2 location: distance from Golden Gate where salinity is 2 ppt, incorporates seasonality.

3. Hydrodynamics: Water circulation, movement, and mixing patterns.

Indicators:

a. Water movement and vertical mixing measured at appropriate locations throughout the bay generating a bay-wide circulation (hydrodynamics) pattern; includes temporal (seasonal) variability.

B. Geomorphic Attributes/Indicators

Attributes:

1. Sediment supply: Net sediment accretion rate comparable to sea level rise rate. Sufficient sediment supply and to maintain natural deposition and erosion processes in tidal marsh and mudflat habitats.

Indicators:

a. Net sediment accretion rate measured at appropriate subtidal and intertidal sites throughout bay. Compare to sea level rise rate.
b. Elevation at appropriate fixed sites in marshes and mudflats (intertidal habitats) throughout bay. Compare to sea level.

C. Habitat Attributes/Indicators

Attributes:

1. Habitat mosaic and connectivity: The diversity, distribution and extent of primary habitat types; sufficient biological and physical connectivity for organisms to move freely among habitats and for ecosystem process functions.

Indicators:

- a. The spatial extent and distribution of patches of all natural habitat types (see typology above).
- b. Presence and distribution of resident and anadromous fish species.
- c. Presence and distribution of resident and migratory bird species.
- d. Number/amount of unnatural barriers interfering with natural movements of native species, water flow (hydrodynamics), sediment transport and supply, and organic and inorganic nutrient transport (e.g., miles of diked marsh-open water interface [shoreline]).

2. Water/sediment quality: Water quality parameters within natural ranges; and specifically for toxic contaminants at levels that do not adversely impact native organisms.

Indicators:

- a. Toxicity (see CALFED Water Quality Program: Parameters of Concern):
  - (1) Concentrations in water and sediment.
  - (2) Tissue concentrations (body burdens) in selected species spanning multiple trophic levels (e.g. fish, birds, and benthic invertebrates).
  - (3) Bioassays (especially sediment).
  - (4) Biomarkers.
  - (5) Bioindicators.
  - (6) Contaminant loading to bay ecosystem.
- b. Nutrients (forms of nitrogen, phosphorus and carbon).
- c. Dissolved oxygen.
- d. Salinity/TDS.
- e. Turbidity.

D. Native Biological Community Attributes/Indicators

Attributes:

1. Natural community structure: Naturalistic patterns of composition, diversity, dominance and distribution among native species.

Indicators:

a. Trends in abundance, diversity, composition, and distribution of native phytoplankton and zooplankton assemblages.

b. Trends in abundance, diversity, composition, and distribution of native plant associations *(Rationale: successful restoration should re-establish natural plant associations dominated by native species).*

c. Trends in abundance, diversity, composition, and distribution of native benthic invertebrate assemblages *(Rationale: Benthic invertebrates are ecologically diverse in terms of habitat and trophic requirements, and have short generation times. They are therefore good short-term biological indicators of enhanced water quality and ecological opportunity in the aquatic environment, and generally respond much more rapidly than fishes to changes in environmental conditions. Successful restoration should reestablish natural distribution patterns and result in higher proportions of native species and biomass).*

d. Trends in abundance, diversity, composition, and distribution of native resident and anadromous fishes *(Rationale: Successful restoration should permit the reestablishment of historic distribution patterns within restored areas, and support a more natural balance of different feeding types, in terms of proportionate abundance (biomass)).*

e. Trends in abundance, reproductive success, diversity, composition and distribution of native resident birds and migratory birds *(Rationale: Successful restoration should result in more natural distribution and movement patterns among more suitable habitats and a greater abundance of birds).*

f. Population trends (abundance, distribution) of selected listed species (threatened, endangered, and species of special concern included in CALFED Conservation Strategy).

g. Invasive introduced (exotic) species *(Rationale: Although the CALFED Program does not intend to eradicate all exotic species and many exotics may be difficult to completely eradicate, a return to more "natural" environmental conditions should result in improved conditions for native species and overall ecosystem health).*
   (1) Measures of new invasions/introductions.
   (2) Abundance, spatial (geographic) extent, and distribution of selected invasive exotic species.
   (3) Number of selected exotic species eradicated or exhibiting no net increase in distribution.

h. Fish and wildlife health; incidence of diseases, tumors, fin damage, or other anomalies and deformities (Karr et al. 1986).

E. Community Energetics/Nutrient Cycling Attributes/Indicators

Attributes:

1. Natural levels of plankton productivity sufficient to support higher trophic levels in plankton-based food chain.

Indicators:

a. Phytoplankton productivity.
b. Zooplankton productivity.

2. Levels of benthic invertebrate production sufficient to support self-sustaining native fish and bird populations dependent on benthic invertebrates.

Indicators:

a. Benthic invertebrate productivity.

3. Net transport/export of detrital organic matter (carbon and other nutrients) from marshes to mudflat, benthic, and pelagic (open water) habitats.

Indicators:

a. Flux of detrital organic matter (carbon, nitrogen and phosphorus) between marshes and other aquatic habitats.

PROPOSED LANDSCAPE LEVEL INDICATORS OF ECOLOGICAL INTEGRITY

Landscape level indicators of ecological integrity suggested by the ERP Indicators Group are listed by major landscape level attribute. Under each attribute is a potential indicator or group of potential indicators which could and probably should be used in combination or aggregate. It is important to put these **attributes/indicators** in a landscape context. They represent or measure characteristics across the landscape (system wide); although many of these attribute/indicators are also measured, in some form, at ecosystem and habitat levels. Landscape is defined here as a heterogeneous land area composed of clusters of interacting ecosystems (Forman and Godron 1986). These potential indicators need review and additional refinement by experts in appropriate disciplines. The Indicators Group does not have the extensive expertise needed to provide a broad array of detailed indicators.

A. Landscape Hydrologic Attributes/Indicators

Attribute:

1. Freshwater flow patterns (magnitude, timing, and distribution) through the system.

Indicators (these probably should be used in combination):

a. Ratio of system runoff to water flowing through the system at various locations. Could be used for magnitude and timing (seasonality). May want to subdivide by major watershed (Sacramento, San Joaquin), adding distribution component.
b. Flows of tributaries mimic a pattern of unimpaired flows.
c. Estuarine (Delta and Bay) salinity patterns (perhaps X2 location and/or mean annual salinity at series of fixed points). Could also incorporate seasonality (timing).

(Unfortunately there is no natural system hydrologic model to serve as comparison.)

B. Landscape Habitat Pattern (Mosaic and Connectivity) Attributes/Indicators

Attribute:

1. Landscape-level habitat patterns or mosaic (e.g., spatial extent, configuration, habitat diversity, etc). Mosaic is defined as the pattern and composition of habitat types and patches within the landscape (Forman 1996).

Indicators (These would be also measured at the ecosystem level. The landscape level indicator could be an index or measure summing the ecosystem levels. This would provide a landscape analysis (using GIS) of changes in habitat diversity and spatial extent and shifts in habitat configuration):

a. Landscape level indices or measure of diversity (number of selected habitat types) and spatial extent (proportional representation) of selected habitats. This index would be compared to reference baseline (e.g., year or condition).
b. Landscape level indices or measures of habitat configurations; if practical. Configuration is defined as "the location and juxtaposition of the landscape elements" (Forman and Godron 1986). Configuration could be described and quantified by the following metrics: alignment, contiguity, nearest neighbor, and fractal dimension as a measure of shape complexity (Science Subgroup 1997). Again, this indicator would be compared to a reference baseline.
c. Number of selected habitat-types NOT represented by at least two areas of sufficient size and with sufficient ecological function (i.e., processes) to support self-sustaining populations of all remaining characteristic native species.

2. <u>Biological and physical (ecological process) connectivity at landscape level.</u>

<u>Indicators:</u>

a. Net change in the number of anthropogenic instream barriers (e.g., physical, temperature, hydrodynamic related) to migratory aquatic species (i.e., anadromous fishes) movement across the landscape.
b. Net change in the number of anthropogenic barriers to water flow, sediment transport and supply, and organic and inorganic nutrient transport across the landscape. Specific barrier types to be included need to be defined.
c. Indices or measures of connectivity for organisms and ecological processes, and/or proximity, among patches of same habitat type (for major habitat types, e.g., riparian); and/or nodes/clusters of multi-habitat complexes.

C. Landscape Water/Sediment Quality Attributes/Indicators

<u>Attributes:</u>

1. <u>Water and sediment quality parameters within natural ranges; and specifically for toxic contaminants at levels that do not adversely impact native organisms.</u>

<u>Indicators:</u>

a. General Water Quality Indicator: Number of times water quality standards are violated per year at selected sites across the landscape.

b. Toxic Contaminants Indicators

(1) Load reduction for selected contaminants (e.g., selenium, mercury, pesticides). That is, amount, and change, of toxic contaminants entering the system from within system anthropogenic sources. A composite, weighted index?

(2) Landscape level index of contamination based on a scoring matrix for contaminant concentrations in sediment and biological groups. This could be done for individual contaminants; and could be done for the major contaminants in the system. This has been done for selenium in San Joaquin watershed (Lemley reference).

D. Landscape Biological Attributes/Indicators

Attributes:

1. Trends in spatial distribution of species.

Indicators:

a. Number of selected species exhibiting range extensions. Index of percent of range extension for selected species.

2. Anadromous/ Migratory Fishes: Broad distribution of self-sustaining populations of anadromous fishes.

Indicators:

a. Distribution, movement, and/or population trends. Selected species and/or cumulative index.

3. Migratory Birds: System-wide distribution patterns and diversity of self-sustaining populations of migratory (and nonmigratory system-wide?) bird species.

Indicators:

a. Population trends (e.g., abundance, reproductive success), distribution, movement. Selected species and/or cumulative index.

4. Listed and Other At-Risk Species (to be defined by CALFED Conservation Strategy).

Indicators:

a. Number of "listed" species and other at-risk species; to be compared to reference baseline (e.g., year). The following are subsets of the above that could also serve as indicators:

(1) number of delisted species
(2) number of new (including candidate species) listings
(3) number of extirpated species

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b. Index of population trends (% increase/decrease; upward/downward) of select listed species (e.g., those with good abundance data, identified by Conservation Strategy).

5. Introduced Invasive (Exotic) Species

Indicators:

a. Measures of new invasions/introductions.
b. Spatial extent/distribution of selected exotic species (e.g., species with good database) possibly composite, weighted index.
c. Number of exotic species eradicated or no net increase in spatial extent or distribution.

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