6.0 Monitoring and Research

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Photo 6-1. Gull-billed Tern.

Sampling to Assess Bay Health.

This Chapter addresses monitoring and research needs identified in Chapters 4 and 5, and places them in a program framework. A San Diego Bay Monitoring and Research program is discussed under the following subheadings:

- *Concepts and Models;*
- *Long-term Monitoring for Bay Condition and Trend;*
- *Project Monitoring;*
- *Research to Support Management Needs; and*
- *Data Integration, Assessment, and Reporting.*

Implementation strategies are addressed in Chapter 7.

6.1 Concepts and Models for Monitoring and Research

6.1.1 Tenets for Design of a Monitoring and Research Program

The most effective and complete approach to understanding the Bay is to combine long-term monitoring with experimental research and development of conceptual models about how the ecosystem works with disturbance. This is the only way to determine the cause and effect of changes in the Bay ecosystem.

The following are important tenets to be considered in the design of a monitoring and research program for San Diego Bay:

- Bay managers' objectives for research and monitoring need to be constantly and iteratively refined to meet management needs and guide researchers.
- The broad purpose of monitoring and research is to help management attain improvement in the quantity and quality of scarce and valued habitats and communities without trying to "reach" the past.
- Questions need to be integrated across monitoring components. For example, attempts at correlating the monitoring of physical or chemical factors should be related to trends in habitat quality, species abundance, and distribution on a routine basis.
- The program should build upon existing programs and avoid duplication of effort.
- Standardized state-of-the-art sampling protocols, equipment, and analytical methods should be used.
- Monitoring and research need to take place at various scales appropriate to the management problem and the natural scale at which processes operate. Inter-Bay, whole-Bay, Bay region, habitat-specific, and project-specific scales are appropriate for different management questions. These scales can be partially evaluated by looking at selected species' life histories that span them, including those that migrate and disperse over great distances using multiple habitats, and those that have little dispersal capability.
- Use of target species can help provide a focus for management and provide the detail needed to highlight important problems for species that are dispersal limited, process limited, food resource limited, or habitat area limited.
- The approach should foster integration and accessibility of results to researchers, managers, and the public.
- There should be a vigilantly kept, clear link to agency management and policy issues; the Bay's resource managers (agencies, landowners, and tenants) should have the final say in the type of research and monitoring conducted. Input from scientists should be sought, however.
- Four Bay regions (as discussed in Section 2.2.3.4 "Hydrodynamic Regions of the Bay") should be adopted as a standard means to stratify sampling and report monitoring and research results.
- Researchers should be asked to make explicit the conceptual model being used in their research design about how the ecosystem is structured and functions. This is to employ three functions of models (Walters 1998): problem clarification and enhanced communication to help narrow the list of variables that must be considered, policy screening to narrow the list of actions that most likely will not do any good, and identification of gaps in key knowledge.

6.1.2 Key Management Questions

The monitoring and research program should focus on some key management questions. These are (see also Section 2.8.1 "What We Need to Know to Describe the State of the Bay Ecosystem"):

Are vulnerable or scarce habitats adequately protected?

1. What are the greatest threats to vulnerable or scarce habitats and species?
2. How can activities be modified to abate these threats?

Is the San Diego Bay ecosystem function adequately protected?

1. What is the condition of the Bay ecosystem, and what is the relative importance of factors that contribute to it working well?
    - Are habitats, singly and together, providing their full benefit to fish and wildlife populations, food chain pathways, elemental/nutrient cycling, and natural diversity?
    - How do human activities such as military support, commercial shipping, recreation, and fisheries affect the continued viability of specific aspects of ecosystem functionality?
    - What specific factors of ecosystem functionality are presently threatened by human activity? What is the relative importance of substrate, tidal flushing, freshwater or nutrient flows from stormwater, predation, competition, or other parameters in contributing to or moderating these threats?
    - What is the relative importance of climate cycles or natural episodic events in structuring the ecosystem and driving change?
2. To what ecosystem trends are human activities contributing? Are basic markers of environmental structure changing, such as temperature, salinity, dissolved oxygen concentration, nutrients, and water transparency?
    - What are the correlations between changes in environmental structure and populations?
    - Is energy flow (productivity and nutrient cycling) changing?
    - Is community structure changing (diversity, patterns of dominance, functional groups)?
3. To what extent are specific, observed changes in the elements described above due to human versus natural causes, or local versus regional causes?

Are vulnerable or scarce populations adequately protected?

1. What are the trends in the distribution, composition and abundance of phytoplankton, zooplankton, invertebrates, fish, bird, and mammal populations?
2. What are the causes of those trends? Are the causes of the trends things that may be affected by management, or are they beyond the control of local or regional managers (e.g. global warming)?

What human activities conflict with maintaining functions of the Bay ecosystem and how can they be minimized or compatibility achieved?

1. What fraction of the trends in Bay structure and function is due to human activity versus natural change?
2. How can necessary project mitigation be most effectively managed to benefit the Bay?

3. What are the predictable future changes in the Bay and its use that are most likely to alter its current state?
4. What is the best way to evaluate and avoid the negative cumulative effects of human activities?

6.2 Program Elements

It will require long-term monitoring, improved standardization and coordination of existing monitoring, a focused research program, and a program for providing this information to managers and the public to address these questions. These are shown in Figure 6-1.

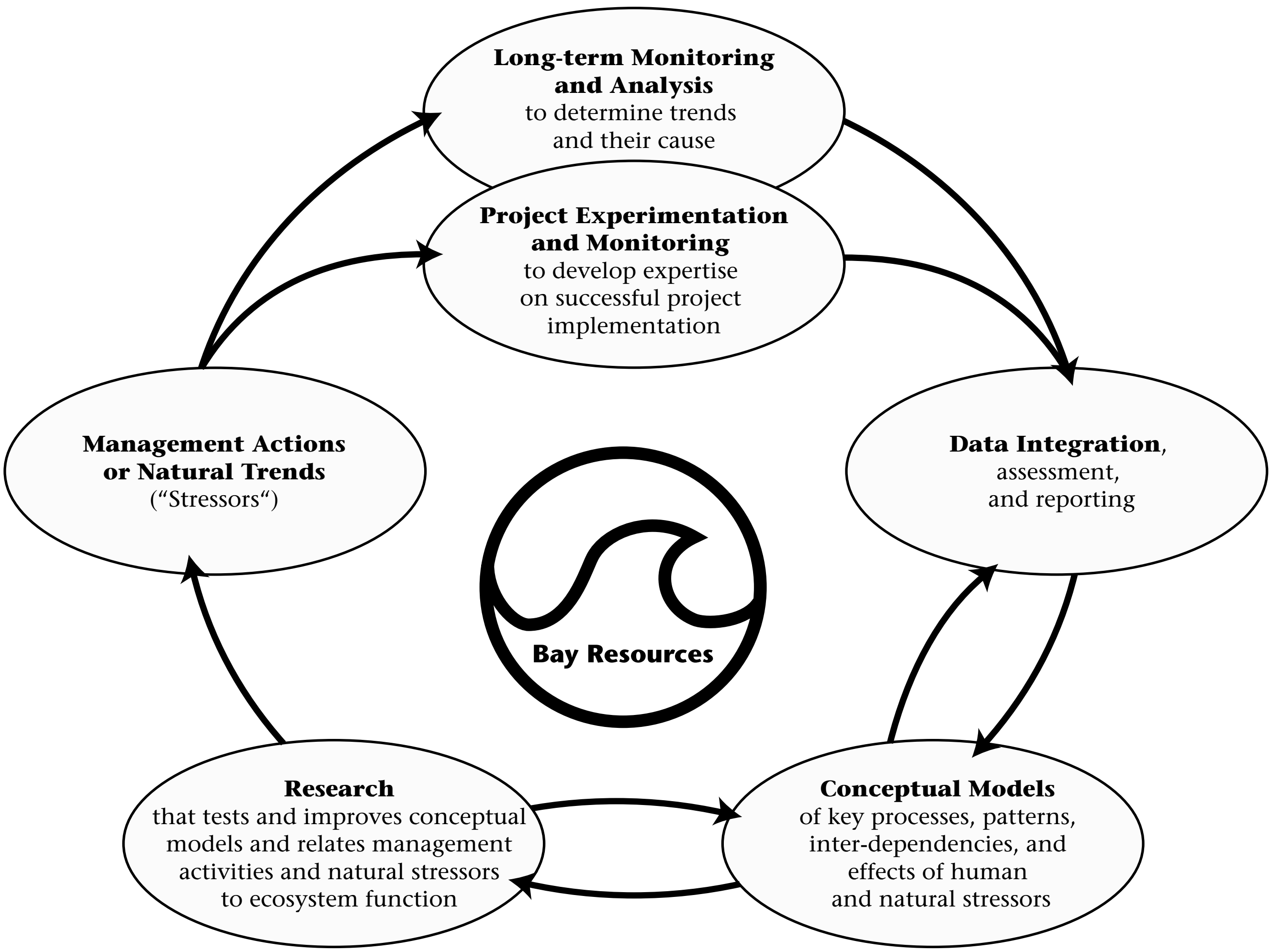


Figure 6-1. Monitoring and Research Program Elements to Support Management Decisions.

6.2.1 Long-term Monitoring for the Bay's Ecological Condition and Trend

Current Management

There have been very few time series studies conducted that are specific to San Diego Bay. The following are examples:

1. NOAA's NS&T Program, *National Benthic Surveillance Program* (1984–present): physical, chemical, and biological parameters (diseases and bioaccumulation in fish); offshore in central and north Bay.
2. NOAA's NS&T Program, *Mussel Watch Project* (1986–present): bioaccumulation in mussels, plus other parameters; offshore in south Bay and intertidal and offshore in north Bay. There are too few sites, but there are trends over time.
3. SWRCB and CDFG, *State Mussel Watch Program* (1977–present): bioaccumulation in mussels (transplanted), plus other parameters; offshore throughout entire Bay and Bay approaches.
4. SCCWRP, *General Monitoring Activities*: sediment, stormwater, tissue, ecological assessment; Southern California Bight (1974–present), San Diego Bay, Chollas Creek (1986–88; as needed). Implementation of the Coordinated Monitoring Program of the Bay Panel for the year 1998.
5. A long-term study by Hoffman (see http://swr.ucsd.edu/hcd/cumcb.htm) was the only true time series for fishes in San Diego Bay prior to the work by Allen (1999). Hoffman's work is a long-term beach seine study of fishes, carried out in the north-central Bay. A single station at the base of the San Diego-Coronado bridge, on the Coronado side, was sampled quarterly beginning January 1988 through July 1999. Work at this site is being continued by Hoffman and Allen (1999). The Baywide study by Allen, sponsored jointly by the Navy and the Port, involves quarterly sampling of fish assemblages at representative locations in four regions of San Diego Bay: north, north-central, south-central, and south. At each of these four locations, five subhabitat types are sampled; they are from deep to shallow water: (1) channel, (2) nearshore, unvegetated, (3) nearshore, vegetated, (4) intertidal, unvegetated, and (5) intertidal vegetated (Allen 1999).
6. The Pacific Estuarine Research Laboratory has monitored vegetation, fish and invertebrates in the constructed and natural marshes of SMNWR since 1989 to help determine if constructed sites meet the mitigation criteria of the Biological Opinion for the site (US Fish and Wildlife Service 1988).

The major regional time-series monitoring programs do not contain data specific to San Diego Bay or any neighboring harbor. These include:

- Sport and commercial catch reported to CDFG, in which fishermen report the number and species caught (including lobster, sea urchin, and abalone), number of anglers fishing, area fished, and hours fished. However, no reporting is done specific to San Diego Bay. Bait fish and invertebrates are not included.
- MRFSS/NMFS periodically monitors surfperch, croackers, sand bass, and halibut by boat and dock checks of sport fishermen.
- The California Cooperative Oceanic Fisheries Investigation. This program which examines hydrology, primary production, zooplankton biomass, and larval fish distributions, originated in response to the collapse of the sardine fishery in 1947. It is unparalleled in its spatial extent, duration, and consis-

tency through time of its study of the ocean and fisheries biology. Sampling occurs in offshore and coastal waters.

- Data collection on sea surface temperature and other parameters from near the turn of the century at Scripps Pier, Scripps Institute of Oceanography.

Other regional or local programs that, to date, have lacked a long-term time series component are described below.

The SCCWRP has twice organized more than 40 public and private organizations for a regional water quality monitoring program in the Bight, once in 1994 and once in 1998. The 1998 effort included San Diego Bay as part of a comparative harbors investigation. The types of stations sampled in the Bay included fish collection using Larry Allen's stations and collection methods, fish collection, benthic invertebrate, sediment chemistry, and water quality sampling by the City of San Diego using the program's standard methods (25 ft [8 m] fish trawl net) at random stations, and a companion City of San Diego effort using Larry Allen's fish collection methods in confined or shallow waters at random stations, and the program's standard methods for other sampling.

A local effort called the Bird Atlas Program was recently initiated under the sponsorship of the San Diego Natural History Museum in cooperation with the San Diego Audubon Society. This program uses volunteers to survey breeding and wintering birds on a 3 mi x 3mi grid system covering all of San Diego County, including the Bay. The grid could be modified to meet the specific needs of the Bay Plan, if an agreement were reached with the sponsors. Surveys are winter (Dec., Jan., Feb.) and summer (breeding), which can extend Feb./Mar. through July, but is concentrated in April, May and June. There is no Fall monitoring i.e., August through November. Winter surveys of each block cover three years; breeding only one, if all criteria are met. Hours per volunteer are at least 25 in the winter plus 25 in the breeding season. This is a five-year project from 1997 through 2002. The result will be a book of maps, with interpretive text, portraying the distribution of each species of bird. Project proponents hope, among other things, to use the data gathered as a baseline against which regional programs such as the MSCP can be evaluated.

The San Diego Bay Interagency Water Quality Panel is in the process of completing its Comprehensive Management Plan and framework for a Coordinated Monitoring Program. While a coordinated funding mechanism is still being sought to achieve the Plan's long-term monitoring objectives, the initial monitoring effort will be conducted this year in San Diego Bay. Money from project sponsors normally used for project-specific mitigation was directed to the SCCWRP for in-Bay work in 1998. The Bay Panel Plan has both human health and ecological health objectives, emphasizing bacteriological monitoring of recreational waters and shellfish, chemical contamination of marine species harvested for food, habitat acreage, spatial distribution and variability of biological communities, and distribution of key physical and chemical parameters. Table 6-1 summarizes the contents of the recommended monitoring program.

Conservatively, at least $17 million is spent annually monitoring in the Bight (National Research Council 1990). Hundreds of thousands of dollars are spent on monitoring studies in San Diego Bay, most of which are project- or permit-related.

Evaluation of Current Management

- Habitat loss or degradation in San Diego Bay is severe in shallow and intertidal habitats, and is the most direct and obvious cause of ecological change. Today, there is at least some direct regulatory and management control through the permitting process and mitigation to help prevent further losses. However, effects on the food chain are less obvious but potentially as severe. These latter effects usually require long-term monitoring to detect.

Most of the Key Management Questions listed in Section 6.1.2 "Key Management Questions" cannot be answered without long-term monitoring data, with the exception of those directly tied to habitat loss. Habitat loss or degradation is one of the most direct and obvious anthropogenic impacts in San Diego Bay, and for this there is direct regulatory/management control through the permitting process and mitigation. Many species declines are believed to be directly tied to these losses, including the federally protected light-footed clapper rail, California least tern, and western snowy plover. However, for many questions, the influences of changing food chains and other aspects of environmental structure may be greater than direct habitat modification. The relative importance of the effects of habitat modification versus other influences upon key species in San Diego Bay is poorly documented.

Table 6-1. Priority Monitoring Parameters Agreed Upon by the San Diego Bay Interagency Water Quality Panel.

Community/ Substrate	Priority 1 Parameters (Essential)
Water Column	Dissolved oxygen, temperature, salinity, turbidity, and nutrients using automated sensors. Selected metals in stormwater.
Sediments	Grain size, total organic carbon, selected metals, pesticides, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons, and area (as a surrogate for habitat coverage) and contaminant exposure studies.
Fish and Edible Shellfish	Numbers, biomass, species composition (diversity), and concentrations of selected tissue contaminants, such as mercury, pesticides, polychlorinated biphenyls, and tributylin.
Eelgrass	Area and abundance.
Benthic Invertebrates	Numbers, distribution, community structure, contaminant exposure (toxicity), tissue contaminant assessments, exotic species, and spatial extent.
Birds	Numbers (by species), distribution, impacts from human activities, and tissue contaminant concentrations.
	Priority 2 Parameters (As Funding Source Identified)
Plants	Numbers, distribution, diversity, area of vegetative cover, and invasive and exotic species.
Mammals	Distribution and abundance, as they are observed during surveys for other organisms, such as fish and birds.
Benthic Algae	Numbers (also represented by biomass), distribution, community structure, and spacial extent.
Plankton	Chlorophyll as a surrogate for phytoplankton standing stocks.

- Managers concerned with ensuring the long-term health of the San Diego Bay ecosystem need to know what the long-term trends are in Bay populations and what is causing those trends. Populations fluctuate for a variety of reasons, and managers need to know what fraction of the variability is due to a particular project.

Managers concerned with ensuring the long-term health of the San Diego Bay ecosystem need to know what the long-term trends are in Bay populations and what is causing those trends. Some of these trends are largely driven by climatic change rather than any local human activity. Or, the change may be due to a natural but sporadic event like drought, storm surges or El Niño-La Niña cycles. Populations fluctuate for a variety of reasons, and managers need to know what fraction of the variability is due to a particular project.

Once trends are established, the key issues for targeting monitoring efforts are determining whether changes in populations are due to natural variability or human influences. If the trends are anthropogenic, are they caused by local influences that may be corrected by San Diego Bay management or large-scale influences that may be beyond the scope or only partly addressed by local management? Bay managers have direct control only over trends that are local and attributable to human activity. However, even if disturbance in the Bay is not the primary reason for a species' decline, for example, it still must be managed as a declining resource if disturbance is believed to be a contributing factor.

Existing monitoring programs are insufficient because they are not long-term time series, or they do not include San Diego Bay as part of their sampling scheme. Bays do not necessarily function the same as waters offshore, so data collected elsewhere in the Bight may not apply. For example, conclusions about pollution from regional programs within the Bight may not apply to bays and harbors, which are more contaminated than the open coast (Mearns 1992).

Current environmental monitoring is not efficient in terms of cost, and it has not been used as well as it could to support management decisions, as has been thoroughly discussed elsewhere (National Research Council 1990).

Most of the Bay Panel's proposed Comprehensive Monitoring Program, shown in Table 6-1, is retained in the proposed monitoring program for that of this Plan. However, this Plan has a broader purpose, goal, and objectives than did the Bay Panel, which focused mostly on water quality issues. As a result, priority monitoring elements are somewhat different. As an example, long-term examination of phytoplankton and zooplankton would be considered a much higher priority under the objectives of this Plan than it was for the Bay Panel.

Summary of Specific Concerns

- While much information has been collected on the Bay's physical, chemical, and biological attributes over the years, little of it provides direction for better Bay management.
- Low-frequency variability (long-term change such as that associated with El Niño) often tends to be greater in magnitude than changes on seasonal and shorter time scales. A key and very difficult question for management and policy making is whether an observed change is due to natural or anthropogenic causes. These and many other management questions cannot be answered without long-term data sets that track conditions in the Bay and their cause. In general these long-term data sets are not available.
- Management questions also need to consider whether an anthropogenic cause is due to local, regional, or larger-scale processes. This means monitoring protocols should be related to those on a regional or larger scale to be most telling. Populations of some species should be tracked regionally to provide understanding of their local dynamics.
- Better definition of policy/management issues will allow more focused objectives for assessment and monitoring and more cost-effective strategies to reach the objective. In some cases, we do not yet have the baseline information or perhaps the insightful understanding necessary to define these issues and state specific objectives.

Proposed Management Strategy

Long-term monitoring is the core of the monitoring and research program proposed in this Plan. Time series data will support and serve as a powerful backdrop to all other aspects of monitoring, research, and conceptual modeling about ecosystem structure, function, and interdependencies that take place.

The aim is to strike the best balance between measuring a broad suite of environmental properties and species of interest, comparing new observations to the very limited data set from the past (to detect long-term trends), comparing trends in San

Diego to trends in other regions (to separate local from large-scale influences), and keeping the costs down to an absolute minimum (to ensure that the time-series data collection can be maintained). Priorities will be kept to the minimum program needed to detect long-term trends. Once such trends are detected, additional research may be needed to understand the causes and consequences of the trends.

- For the purposes of this Plan, we propose to monitor a set of "ecological indicators" (or markers) and certain target species to monitor trends and provide management cues (Table 6-2).

For the purposes of this Plan, we propose to monitor a set of "ecological indicators" (or markers) and certain target species to monitor trends and provide management cues (Table 6-2). Any environmental variable selected for monitoring and evaluation should be directly related back to effects on species, habitats, and communities. Indices that combine sets of data based upon species abundance or relative abundance as indicators of ecological health are not necessarily preferred over simple, long-term data on specific physical, chemical, or biological trends. While there are some species abundances and proportions strongly correlated with environmental perturbations, a very large data set is needed to calibrate such an index. It may be much more work to develop the index of some aspect of structure that would be accepted in the scientific community (if it were even possible) than it would be to take the samples needed to detect long-term change in the first place.

Many regional monitoring programs depend heavily on the use of indicators to assess ecological condition and trend, including that of Chesapeake Bay, San Francisco Bay, and many others both terrestrial and aquatic. Use of indicators as a management tool supports these advantages:

- Fosters continual reevaluation of efforts, refinement of objectives.
- Helps communicate a consistent public message.
- Supports program planning, strategic direction-setting.
- Supports targeting of resources.

Using target species as one of several types of ecological indicators can represent a practical means at the project and programmatic level to evaluate and monitor environmental and habitat quality. There has been ongoing debate in the scientific community about the reliability of using individual species as "ecological indicators" to interpret community- and ecosystem-level implications of disturbance (Patton 1987; Landres *et al.* 1988; Morrison *et al.* 1992; Marcot *et al.* 1994; Niemi *et al.* 1997). In fact, they should be used to infer effects only when direct measurement is not possible (Landres *et al.* 1988). However, target or indicator species have provided and likely will continue to represent one of the most tangible, measurable approaches to environmental inventory, monitoring, and assessment (Noss 1990). The criteria and assumptions used to select these species should be clearly defined prior to the selection process to ensure the best possible candidates are selected and to avoid over-interpreting results of monitoring and project evaluations (Landres *et al.* 1988).

- Target species are only one type of ecological indicator, and should not be used in isolation from other monitoring tactics that are equally important, such as those that are more directly habitat-based.

Target species can add an important level of detail to a time-series program that can allow the relating of physical and chemical data to a species' specific dispersal or other life history needs tied to its use of the Bay. The role of particular habitats or environmental factors may go undetected if at least some species are not examined at a fine, life-history scale. They are also meant to provide management a practical focus, under the assumption that managing for certain, carefully selected species of concern will take care of many others with overlapping habitat, food chain, or other ecological needs. However, target species are only one type of ecological indicator, and should not be used in isolation from other tactics that are equally important, such as those that are more directly habitat-based.

Table 6-2. Examples of the Proposed Use of Ecological Indicators to Learn about San Diego Bay's Condition and Trend

Plankton

Plankton remains a key component of a long-term monitoring plan because one of the most direct ways in which environmental change (natural or anthropogenic) influences ecosystems is through the food web. Many of the changes seen in fish, mammal, and bird populations in the offshore waters of California appear to be caused by trophic interactions. The ecosystem changes in ways that affect the growth rate and abundance of the phytoplankton plants at the base of the food chain (usually the nutrient input is changed). This, in turn, affects the abundance of the herbivorous zooplankton that feed upon the phytoplankton plants. The zooplankton are the food source for the birds, fish, and mammals, either as adults or their juvenile stages.

Temperature and Salinity

Temperature and salinity are strongly correlated with the success of many fish and invertebrate species. Allen (1999), in his five-year study on fishes of San Diego Bay, determined that almost 76% of the total variation in the individual station abundances of the 25 most abundant Bay species could be explained by these factors. In San Francisco Bay, the position in the estuary of the line of tidally averaged, near-bottom salinity equivalent to 2 psu (practical salinity units) is used as a management tool and is related to the physical response of that estuary to freshwater flows. The survival and abundance of a number of fish and invertebrate species are highly correlated with this line, either negatively or positively.

Shoreline Change

Monitoring the condition of the shoreline in terms of its natural or artificial state, habitat value, erosion, and even accumulation of marine debris can provide a publicly credible index of health in this transition interface between marine and upland habitats, and possibly highlight the need for improvement in this area.

Target Species

California halibut: California halibut, a commercially harvested species, is declining in numbers and a primary reason appears to be the loss of juvenile rearing habitat (Kramer 1990), such as San Diego Bay provides. Protecting the juvenile halibut (0.4–6 in/10–150 mm SL) at this stage, which lasts one to two years, is critical to the size and health of the entire population. Halibut use unvegetated and vegetated shallows, as well as intertidal habitats during this juvenile period, as shown by this brief description of their use of San Diego Bay resources.

After metamorphosis, young halibut migrate into protected bays or other coastal nursery areas (Kramer 1990). They can be found primarily in the shallows of bays and estuaries at less than 3-ft (1-m) depth (Kramer and Hunter 1987). Bay habitats are characterized by several biological, chemical, and physical factors that result in greater food supply and greater survival for juvenile California halibut. Water temperatures can be 5° C warmer than adjacent coastal waters. This increase in temperature may be the initial cue for settlement of recently metamorphosed halibut, or possibly even the cue for metamorphosis to begin (Kramer 1990). The warmer water temperatures are also important for increased growth and metabolism, given an adequate food supply (Haaker 1975; Innis 1980 in Drawbridge 1990). Drawbridge (1990) found that in warmer waters, there are fewer halibut with empty stomachs and stomachs are fuller than in halibut sampled in cooler coastal water. This apparently comes from greater feeding activity and digestion rate. Bay-reared halibut, therefore, have an advantage over coastal halibut in the same age class.

California halibut also prefer water with higher salinity. Horn and Allen (1981) found a greater abundance of halibut in more saline waters of bays. In a laboratory study, Baczkowski (1992) determined that small juveniles in particular are more susceptible to a decrease in salinity. The extra energy spent in osmoregulation results in weight loss and a decline of survivorship. In the early juvenile stage, halibut are coming into bay openings, where salinity is higher. They apparently can tolerate the natural salinity of shallow bay waters, as they are found there in great abundance.

Certain other biological factors of bay habitats make them particularly good rearing areas for juvenile halibut, including access to prey found abundantly in intertidal habitats. Allen (1988), Haaker (1975), and Drawbridge (1990) provided the following food habits summary for juvenile halibut in bays and estuaries. Halibut that are <0.8 in (20 mm) SL feed on harpacticoid and calanoid copepods (small, mostly planktonic crustaceans). Individuals between 0.8 and 2 in (20 and 50 mm) SL add gammarid amphipods and mysids to their diet. Small fish, primarily gobies, replace the small crustaceans in the diet of halibut >2 in (50 mm) in length. In a stomach analysis of bay juvenile halibut, Drawbridge (1990) found small crustaceans in 60% of analyzed stomachs and small fish in 80% of those stomachs. Crustacean species accounted for 90% of all prey species identified in these stomachs, while fish species accounted for only 8%. However, crustacean species contributed <10% of the total prey biomass and fish contributed 67% of that biomass.

California halibut prefer a sandy substrate at all life stages except juvenile (Drawbridge 1990). Adults are able to successfully bury themselves and blend in with the coarser grain sediments along the coast and in outer bay areas. It was demonstrated in lab tests that juveniles 0.5–1.1 in (12–29 mm) SL had difficulty in concealing themselves when presented with coarser grains and they significantly selected sediment with a grain size <2.5 in (63 mm) (Drawbridge 1990). It appears that the fine sediments of shallow bay waters improve the survival of very small halibut, compared to populations off the coast. Older juveniles (>2 in/50 mm) also benefit from their association with silty muddy intertidal habitats, as that is the habitat for important food items like gobies.

Water turbidity can also affect both the survival and feeding success for a flatfish like the California halibut. The fine sediments of shallow bay areas combined with freshwater runoff result in higher turbidity than is found at the mouth of the bay or in coastal waters, where the water column deepens and the substrate is coarser. Small juveniles (<2 in/50 mm) likely benefit from the higher turbidity as a means of avoiding predation (Drawbridge 1990). The primary predators of halibut in the bays are other halibut, staghorn sculpin, and shorebirds. Larger juveniles (>50 mm and <4.3 in [110 mm]) have a greater feeding success in shallow turbid waters. Gobies tend to concentrate at the bottom of the water column when turbidity is high. Turbid conditions bring prey closer and reduce the reaction time for halibut to ambush their prey (Drawbridge 1990). As juveniles grow and prey on increasingly larger fish, high turbidity may hinder their hunting efforts. It is probably at this time (>4.3 in/110mm) that they begin their migration to deeper bay and eventually coastal waters (Kramer 1990).

The abundance of small juveniles in bays suggests higher survivorship compared to coastal residents in this size class. The number of predators associated with California halibut are fewer in bays and there is greater chance of escaping predation in the turbid waters and fine sediments. Larger juveniles in bays probably experience greater growth rates than their coastal counterparts due to warmer waters, larger prey availability and size, energy efficient feeding techniques, turbidity, and substrate.

In summary, halibut dependency on juvenile rearing and feeding in unvegetated shallows and intertidal areas of bays and estuaries, make them potentially useful as an indicator of the health of these habitats.

- There are justifications to use migratory species as ecological indicators: 1) San Diego Bay may be part of a larger problem or it may not–this needs to be sorted out; 2) If Bay activities are in fact affecting habitats and populations of migratory species, it would be difficult to understand and address this without information from ongoing population and habitat monitoring; and 3) Some migratory species may be of such special interest economically, recreationally, culturally, scientifically, or from the regulatory side (listed, sensitive, etc.) to justify population and habitat trend monitoring.

The use of migratory target species can be problematic because it is difficult to separate effects on the species due to problems in San Diego Bay versus anywhere else on the migratory pathway. However, support of migratory fishes, invertebrates, birds, and mammals is one of San Diego Bay's primary functions, often involving different resource issues than those that can be addressed by monitoring populations and habitats of residents. It is best to select target species that are also being monitored along the entire migratory pathway to get the larger picture necessary for revealing causes and the extent of decline. There are justifications to use migratory species as ecological indicators: 1) San Diego Bay may be part of a larger problem or it may not--this needs to be sorted out; 2) If Bay activities are in fact affecting habitats and populations of migratory species, it would be difficult to understand and address this without information from ongoing population and habitat monitoring; and 3) Some migratory species may be of such special interest economically, recreationally, culturally, scientifically, or from the regulatory side (listed, sensitive, etc.) to justify population and habitat trend monitoring.

Objective: (1) Detect the extent and spatial scale of trends in critical ecosystem structural and functional attributes that contribute to the Bay's important role as a nursery for juvenile fish and invertebrates, as a major migratory stopover for shorebirds and waterfowl, as a breeding/nesting ground for wildlife, and for supporting endemic and rare species. (2) Determine the cause of detected trends, separating management effects from natural variability. (3) Use the trends to assess the relationship between physical and chemical factors and biological responses.

Long-term Monitoring for Bay Ecological Condition and Trend

I. Select ecological indicators for long-term monitoring that together meet the above objective.

A. The set of indicators should meet most of these criteria:

- It should be a marker of long-term trends in ecosystem structure or process.
- The sampling and analysis expected can be sustained in the long-term due to its cost-effectiveness.
- The indicators can serve as an early warning for ecosystem threats, such as exotics.
- The work has broad support and involvement by planners, managers, scientists, and the public.
- Information supports an annual report on the state of the Bay, produced in a manner useful to managers and the public, with synopses.

B. Periodically and iteratively refine objectives of long-term monitoring so that indicators can progressively define degradation of the Bay in a more quantitative sense (National Research Council 1990).

C. Consider the contents of Table 6-3 as a preliminary set of indicator monitoring parameters, which draw on the experience of other planning efforts around the country.

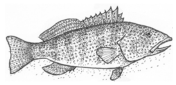
1. Refine this list of indicators with experience.

D. Phase the implementation of long-term monitoring based on a set of priority measures that are essential and should be accomplished at a minimum.

1. Define the types of analysis that will be conducted with these data.

Table 6-3. Priority Long-term Monitoring Parameters.

Community/Substrate	Parameters
Water Column	Dissolved oxygen, temperature, salinity, turbidity, and nutrients using automated sensors. Selected metals in stormwater.
Sediments	Grain size, total organic carbon, selected metals, pesticides, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and area (as a surrogate for habitat coverage) and contaminant exposure studies.
Productivity	Phytoplankton biomass, abundance, composition (native, exotic, toxic), algae in the marsh. Quarterly samples.
Habitats	■ Change in habitat proportions compared to historical. About every three years. ■ Eelgrass expansion/contraction of area by zone, internal density, condition, advancement of edge. Try remote methods (such as infrared photography?), and only monitor by diving if the remote method shows significant change in density or distribution. ■ Unvegetated shallow subtidal change in area. ■ Shoreline change (length of riprap or wall, biological value of armored areas, accretion/erosion). ■ Change in tidal elevation of marsh, mudflats and sand flats; growth and complexity of marshes and mudflats (marsh channel complexity, advancement of marsh edge). ■ Change in area of mudflats, sand flats and beaches by zone. ■ Upland transition (acreage protected, percent cover exotics; area functioning as high tide refugia; “bayscaping” natural habitat components in landscaped and shoreline areas, stream length with riparian structural complexity, natural flows or meanders). ■ Salt ponds (fledging success by nesting birds, use by shorebirds). ■ Condition of enhancement sites.
Landscape Function	■ Extent and distribution of patches of each natural habitat type. ■ Presence and distribution of species requiring multiple habitat types. ■ Buffers around sensitive areas.
Biological Species and Communities	■ Exotics: new invasions; abundance, spatial extent and distribution of selected exotic species. ■ Zooplankton: abundance and distribution, composition. Quarterly samples. ■ Algae: biomass, temporal and spatial distribution in relation to nutrients. ■ Vegetation: percent cover of dominant natives and exotics in marsh and upland transition vegetation. ■ Benthic invertebrates: numbers, large-scale distribution, community structure, seasonal dynamics, contaminant exposure (toxicity), tissue contaminant assessments, percent exotics, and spatial extent. ■ Fishes: larvae and juvenile abundance and distribution in shallow subtidal and intertidal areas for all species; top ten “Ecological Index” using Allen’s (1999) protocol. ■ Birds: annual midwinter shoreline survey using a standard protocol; abundance and distribution of shorebirds, water birds, marsh birds, breeding season monitoring in south Bay, and breeding upland transition birds. California least tern nesting (number of nests / young fledged per year). Western snowy plover nesting. Clapper rail nesting.
Processes	Determine an indicator that, for example, reflects a trend towards the natural pattern of variability in water residence time, salinity and temperature, or nutrient dynamics of the marsh and mudflats.
Upper Watershed Land Use	■ Percent of stream length not constricted by channelization. ■ Urban growth boundaries, cluster development, infill/community revitalization efforts, transit-oriented development (designed around light rail or bus systems), balanced communities (housing and jobs together). ■ Acres under Integrated Pest Management. ■ Nutrients via groundwater and surface water inputs. ■ Contaminant loading ■ Consumption of specific pesticides
Human Activity	■ Population growth. ■ Economic growth. ■ Number of permits issued for new construction. ■ Marine debris, trash on shorelines. ■ Volunteerism or public-private partnerships. ■ Bay attitudes survey. ■ Some measure of boating activity.

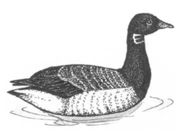


Spotted Sand Bass

II. Select target species based on the criteria (Table 6-4).

A. The following are criteria for selecting and using suitable target management species for the Bay using recommendations from the literature (Patton 1987; Landres *et al.* 1988; Morrison *et al.* 1992; Marcot *et al.* 1994; Niemi *et al.* 1997) as guidance and drawing on the experience of the San Francisco Bay monitoring program, among others. The target management species selected should meet most of these criteria and should be highlighted in project evaluations, long-term monitoring focus, and modeling and research priorities in implementing the Bay Plan.

- The species relies on the Bay to complete its life cycle.
- The species is sufficiently sensitive to Bay disturbances that it provides a marker of environmental degradation.
- The species is a keystone upon which the diversity of a large part of a community depends.
- The species is a habitat specialist that consistently uses one habitat type or condition, or a certain combination of habitats to complete its life cycle.
- Populations are of sufficient size or density to be reasonably detected and monitored.
- The species is a year-round resident or, if migratory, is known or strongly suspected of being primarily affected by local disturbances in the Bay.
- Populations are not normally sensitive to other environmental factors that would confound determination of cause-and-effect relationships (e.g. weather, predation, disease, competition).
- The species is in decline even if the cause is known to be non-Bay-specific.

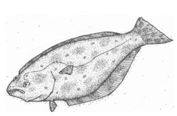


Black Brant

III. Coordinate sampling to maximize the ability to establish correlations among the monitoring elements.

A. Make effective use of existing regional monitoring data to shed light on the status and trend of conditions in San Diego Bay, and to separate natural from anthropogenic change.

1. Consider the Bay Panel Plan, California Cooperative Fisheries Investigation, SCCWRP, NOAA NS&T programs, and future studies of the type done by Fairey *et al.* (1996).
2. Expand MRFSS/NMFS periodic censuses (boat and dock checks, etc.); increase halibut and sand bass censuses.
3. Initiate Bay-specific catch reporting of species caught for bait (ghost shrimp, anchovy, and topsmelt) to CDFG.
4. Collate site-specific studies done by academics (Scripps Institute of Oceanography, SDSU, UCSD, etc.), consulting firms, etc.



California Halibut

Table 6-4. List of Candidate Target Species for Supporting Long-term Monitoring and for Project Planning.[1]

Scientific Name	Common Name	Reasons Selected	Habitat
Birds			
Limnodromus sp.	dowitchers	HI	mudflats
Aechmophorus clarkii transitionalis/ A. occidentalis var. *occidentalis*	Clark's grebe western grebe	CI, HI	open water, subtidal, salt marsh
Pelecanus occidentalis californicus	brown pelican	HI, SS, PS, MSCP	subtidal, salt marsh, artificial structures
Phalacrocorax auritus	double-crested cormorant	CI, HI, SS	deep/medium subtidal, salt works, artificial structures
Egretta thula thula	snowy egret	CI, PI	upland transition, salt marsh
Branta bernicla nigricans	**black brant**	**HI, D**	**eelgrass**
Anas acuta	northern pintail	CI, HI, EI, D	shallow subtidal, shallow subtidal aquatic vegetation, salt marsh, upland transition
Aythya affinis	**lesser scaup**	**CI, HI, D, M**	**open water, deep/medium subtidal, eelgrass**
Melanitta perspicillata	**surf scoter**	**CI, HI, D, M**	**open water, subtidal, intertidal rocky, intertidal sandy**
Oxyura jamaicensis rubida	ruddy duck	CI, HI, D	open water, deep/medium subtidal, shallow subtidal aquatic vegetation, intertidal mudflat, salt marsh
Circus cyaneus hudsonius	northern harrier	HI, SS	upland transition
Falco peregrinus anatum	peregrine falcon	CI, SS, PS, PI, MSCP	upland transition
Rallus longirostris levipes	**light-footed clapper rail**	**CI, HI, SS, PS, PI, MSCP**	**salt marsh**
Charadrius alexandrinus nivosus	**western snowy plover**	**CI, HI, SS, PS, SP, MSCP**	**intertidal sandy, intertidal mudflat, salt marsh, salt works, upland transition**
Ammodramus sandwichensis rostratus	large-billed sparrow	HI, SS	salt marsh
Ammodramus sandwichensis beldingi	**Belding's savannah sparrow**	**C1, H1, SS, DS, PI**	**salt marsh**
Pandion haliaetus carolinensis	osprey	HI, SS, PS, maybe CI	open water
Larus occidentalis wymani	western gull	CI, DS	deep water, medium subtidal, shallow subtidal, aquatic vegetation, intertidal rocky, sandy, mudflat, salt marsh, salt works, artificial structure, upland transition.
Sterna antillarum browni	California least tern	CI, HI, PS, PI, MSCP	subtidal, intertidal sandy, intertidal mudflat, salt marsh, salt works, artificial structures
Sterna elegans	elegant tern	HI, SS, D, MSCP	subtidal, intertidal sandy, intertidal mudflat, salt marsh, salt works
Sterna forsteri	Forster's tern	CI, HI, PI	shallow subtidal, intertidal sandy, intertidal mudflat, salt marsh, salt works
Arenaria interpres	ruddy turnstone	CI, HI	intertidal mudflats, breakwaters
Calidris canutus roselaari	red knot	CI, HI, SP	intertidal mudflat, salt marsh, salt works
Numenius americanus	long-billed curlew	CI, HI, SS, SP, MSCP	intertidal mudflat, salt marsh, salt works
Phalaropus lobatus	red-necked phalarope	CI, HI	salt works
Eremophila alpestris	coast horned lark	HI, SS	intertidal mudflat, salt marsh, upland transition
Fishes			
Urolophus halleri	round stingray	Top 10EI, CI, HI, RC, D	intertidal, nearshore, channel
Sardinops sagax caeruleus	pacific sardine	Top 10EI, HI, RC	nearshore, channel
Engraulis mordax	northern anchovy	Top 10EI, HI, RC, DS, PI	intertidal, nearshore, channel
Anchoa delicatissima	slough anchovy	Top 10EI, BESPP, NC, SC, S	intertidal, nearshore, channel
Anchoa compressa	deepbody anchovy	BESPP, HI	intertidal, nearshore, channel
Leuresthes tenuis	California grunion	HI	nearshore
Atherinops affinis	topsmelt	Top 10EI, CI, HI, RC, DS, PI	intertidal, nearshore, channel
Syngnathus griseolineatus	bay pipefish	CI	intertidal, nearshore, channel
Paralabrax maculatofasciatus	**spotted sand bass**	**Top 10EI, BESPP, RC**	**intertidal, nearshore, channel**
Paralabrax nebulifer	barred sand bass	Top 10EI, RC, HI	nearshore benthic, channel benthic

[1]Bolded items are considered highly likely candidates to be target species because of the number of criteria met. * = Exotic, CI = Community Indicator, DS = Dominant Species, HI = Habitat Indicator, SS = Sensitive Species, PS = Protected Species, EI = Economic Indicator, PI = Practical Indicator, SP = National Shorebird Conservation Priority, MSCP = Multiple Species Conservation Plan, D= Decline noted, but no official status, RC = Recreational and/or Commercial Species, BESPP = endemic to Bay, Top 10EI = Top 10 Ecological Indicator, M= Tied to Bay Management Issue.

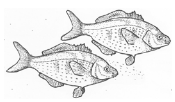
Table 6-4. List of Candidate Target Species for Supporting Long-term Monitoring and for Project Planning.[1]

Scientific Name	Common Name	Reasons Selected	Habitat
Cymatogaster aggregata	**shiner surfperch**	**Top 10EI, HI, RC, DS, PI**	**intertidal, nearshore, channel**
Embiotoca jacksoni	black surfperch	HI	nonvegetated nearshore
Micrometrus minimus	dwarf surfperch	HI	intertidal, nearshore
Mugil cephalus	striped mullet	BESPP, HI	intertidal, nonvegetated nearshore, channel
Hypsoblennius gentilis	bay blenny	HI	intertidal, nearshore, channel
Heterostichus rostratus	giant kelpfish	Top 10EI, HI, VEGSPP	vegetated intertidal, nearshore
Clevelandia ios	arrow goby	BESPP, CI, HI, DS, PI	intertidal, nearshore
Hypsopsetta guttulata	diamond turbot	BESPP	unconsolidated sediment in intertidal, nearshore, channel
Paralichthys californicus	**California halibut**	**Top 10EI, HI, RC, DS, PI, EI**	**intertidal, nearshore, channel**
	fishes of artificial substrate	HI	artificial hard substrate
Reptiles			
Chelonia mydas agazzizii	green sea turtle	HI, SS	nearshore
Phrynosoma coronatum blainvillei	San Diego horned lizard	SS, MSCP	upland transition
Invertebrates			
Halichondria panicea	crumb of bread sponge	CI, HI	artificial hard substrate
Tetilla mutabilis	wandering sponge	CI, HI	unconsolidated sediment
Diadumene cf. *leucolena*	anemone	CI, HI	unconsolidated sediment, hard substrate
Pseudopolydora paucibranchiata	spionid	CI, HI, DS	tidal flat
**Neanthes acuminata*	neriid	CI, HI, DS	unconsolidated sediment
Leitoscoloplos elongatus	orbinid	CI, HI, DS	unconsolidated sediment
Capitella capitata	capitellid	CI, HI, DS	eelgrass, unconsolidated sediment, marsh channels
Megalomma pigmentum	sabellid	CI, HI, DS	unconsolidated sediment
Fabricia limnicola	sabellid	CI, HI, DS	eelgrass, unconsolidated sediment
Euphilomedes carcharodonta	ostracod	CI, HI	eelgrass
Parasterope barnsei	ostracod	CI, HI, DS	eelgrass, unconsolidated sediment
Acuminodeutopus heteruropus	aorid	CI, HI, DS	unconsolidated sediment
Plankton	Add planktonic indicators as they can be identified and prioritized.		
Caprella mendax	skeleton shrimp	CI, HI, DS	eelgrass, unconsolidated sediment
Euphilomedes carcharodonta	seed shrimp	CI, HI, DS	unconsolidated sediment
Crangon franiscorum	crangonid shrimp	HI, PI	eelgrass
Cancer antennarius	common rock crab	HI, PI	unconsolidated sediment, hard substrate
Hemigrapsus oregonesis	mudflat crab	CI, PI	eelgrass, unconsolidated sediment
Portunus xantusi	swimming crab	CI, PI	unconsolidated sediment
Callianassa californiensis	**ghost shrimp**	**CI, PI, RC**	**eelgrass, unconsolidated sediment**
Panoquina errans	wandering skipper	CI, PI, MSCP	salt marsh
Cerithidea californica	California horn shell	HI, DS, PI	unconsolidated sediment, vegetated salt marsh
****Musculista senhousia***	**Japanese mussel**	**CI, HI, DS**	**eelgrass, unconsolidated sediment**
**Tapes japonica (semidecussata)*	venerid clam	HI, DS, PI	unconsolidated sediment
Tagelus californianus	jackknife clam	CI, HI, DS	eelgrass, unconsolidated sediment
Macoma nasuta	bent-nosed clam	CI, HI	eelgrass, unconsolidated sediment
Crangon franiscorum	crangonid shrimp	HI, PI	eelgrass
Cancer antennarius	common rock crab	HI, PI	unconsolidated sediment, hard substrate
	mussels, barnacles	HI, PI	artificial hard substrate
Plants			
Spartina foliosa	cord grass	HI, D	salt marsh
Cordylanthus maritimus maritimus	salt marsh bird's beak	PS	salt marsh
Nemacaulis denudata var. *denudata*	coast woolly-heads	CI, SS	coastal dune
Lotus nuttallianus	Nuttall's lotus	CI, SS	coastal dune
Zostera marina	eelgrass	HI	eelgrass

[1]Bolded items are considered highly likely candidates to be target species because of the number of criteria met. * = Exotic, CI = Community Indicator, DS = Dominant Species, HI = Habitat Indicator, SS = Sensitive Species, PS = Protected Species, EI = Economic Indicator, PI = Practical Indicator, SP = National Shorebird Conservation Priority, MSCP = Multiple Species Conservation Plan, D= Decline noted, but no official status, RC = Recreational and/or Commercial Species, BESPP = endemic to Bay, Top 10EI = Top 10 Ecological Indicator, M= Tied to Bay Management Issue.

B. Develop and adopt a means to obtain and use this information in an integrated and coordinated manner that would avoid conflict and dilution of effort, as well as maximize the ability to conduct correlations among the monitoring elements.

1. The timing and locations of the meroplankton and ichthyoplankton sampling should be coordinated with those employed for the benthic invertebrate fauna and for Bay fishes. In that way, changes and long-term trends in the characteristics of these zooplankton groups can be related to those of the corresponding juvenile and adult populations. This approach will be important in helping to understand the important interrelationships between these pelagic, benthic, and demersal components of the Bay ecosystem.
2. Establish a set of permanent monitoring stations throughout the Bay for sediment and water column sampling, including at some storm drain outlets and river mouths, but also representative of the Bay as a whole. Some of these may be useful as control sites for sediment testing for dredging projects.



Shiner Surfperch

3. Consider identifying and sampling for functional ecological groups meaningful to management objectives, such as fish assemblages important for bird foraging, species associated with scarce habitats, young-of-the-year or subyearling stages for commercially sought-after species, or those providing a major prey base for an endangered species. The sampling could also be stratified by season, or an indicator season might be selected. Changes in species composition or relative abundance along the length of the Bay may also need to be determined, depending on management objectives.
4. Conduct certain standardized analyses. For instance, an environmental indicator variable such as salinity or temperature should be directly related back to effects on species, habitats, and communities.
5. The TOC had certain priorities for long-term monitoring that fill in a prominent information gap and build on past monitoring work:
   a. As an early priority, survey migratory birds Baywide. Establish uniform protocols.
   b. Survey for eelgrass every five years.
   c. Every three years, conduct fish surveys with beach seines only. Adopt protocols when complete and thoroughly evaluated.

Surf Scoter

IV. Use multiple public and private jurisdictions to implement the sampling, including a citizen monitoring program to help plug gaps in coverage.

V. Apply adaptive management principles to modify the content of a comprehensive monitoring program to be more supportive of the needs of managers.

VI. Establish a committee to make decisions on long-term monitoring. The purpose of the committee is to decide about long-term monitoring priorities, phasing or stepwise implementation of monitoring elements, quality assurance and quality control, and effective dissemination of monitoring results to a broad audience. This committee will not make management recommendations.

6.2.2 Project Monitoring

Current Management

Most monitoring is done in response to permit requirements for discharges or construction or maintenance projects. Discharge permits are administered by a number of agencies and there is no attempt to coordinate among them except for recent attempts by the SCCWRP (Bight 1984 and Bight 1998, of which the latter included San Diego Bay). This organization collected and integrated data from all municipal dischargers in the Bight during these years. This program is oriented to pollution rather than broader ecological questions.

Most other ecological monitoring in San Diego Bay is mandated by regulators for project proponents to accomplish and tends to be limited in its ability to provide management guidance. It is narrowly defined and completed within parameters of the permitting process and the project proponent's cost constraints. It tends to be poorly standardized, although eelgrass monitoring requirements have been established for some time and are an exception to this rule.

Evaluation of Current Management

The existing approach is piecemeal, nonstandardized, and generally not disseminated beyond the project proponent, the immediate agency in charge, and the consulting firm contracted to perform the monitoring. Project-oriented monitoring often provides little predictive insight because species abundance and diversity are inherently variable at many scales. Such monitoring typically does not allow for adequate experimentation or sampling to make it useful as a baseline for future or related studies. Furthermore, it does not provide any indication about whether the Bay as a whole is being affected by cumulative effects of the multitude of projects implemented within it.

Proposed Management Strategy—Monitoring Related to Projects

Objective: Improve the ability to build on existing and new project monitoring experience.
The outline below draws heavily on the San Francisco Baylands Goals Project (Goals Project 1999).

I. Obtain useful information from each restoration and enhancement project and use projects to test new ideas.

- **A.** Integrate the use of pilot projects for innovation in mitigation and restoration design and construction.
- **B.** Standardize methods and protocols to enable comparison among projects, as well as between short-term and long-term monitoring programs at a reasonable cost.

II. Provide quality control and assurance for monitoring data and their interpretation.

A. Assess existing monitoring efforts in San Diego Bay.

B. Establish a network of reference sites that can be used to monitor background variation in populations of target species of fish and wildlife and their habitats in relatively undisturbed areas.

III. Improve the effectiveness of monitoring related to permits so that it may provide insight on mitigation priorities and protocols beyond the scope of the project for which it is implemented.

A. Encourage public-private partnerships to research the design, implementation, and monitoring of mitigation projects.

B. Restoration projects should, where possible, involve the community, i.e. not on easily damaged sites.

C. Sponsor studies that support protocols and conditions for out-of-kind mitigation and mitigation banking.

D. Assess success of mitigation projects and use results to improve implementation.

IV. Make monitoring results readily available to agencies and the public.

A. Integrate project monitoring with regular reporting on the "State of San Diego Bay."

B. Report on the contributions of the project to the goal and objectives of this Plan.

C. An independent organization should manage the monitoring program, data archiving, and making data available to interested parties.

V. Supplement project-related monitoring with focused research on such topics as:

- the relative importance of habitat at a certain location compared to a neighboring area, to support evaluation of project placement/alternative sites.
- the strength of dependencies among habitats and organisms (productivity, physical material transport, tidal circulation, and biological linkages such as migration and feeding dependencies, etc.), in order to better define the area of influence of a project and cumulative effects.
- quantified area of influence, and
- quantified response time scale, and
- quantify changes in organism abundance and community structure.

VI. Evaluate project success based on priority goals and objectives of this Plan.

A. Consider success ranking based on the SCCWRP 1999:

- To what extent will the project restore functioning of natural processes (e.g. hydrology)?
- Will the project result in an increase in habitat acreage?
- Will the improvements be self-sustaining? What level of on-site management or maintenance will be required?
- To what extent is the site physically and ecologically connected to other natural upland transition habitats?
- To what extent is the site hydrologically and ecologically connected to marine habitats?
- To what extent will the project benefit marine and intertidal resources?
- What is the site's function and value from a regional perspective, including sensitive species habitat, use by migratory birds, fisheries support, and biodiversity?

B. Identify a predisturbance reference condition to help evaluate success.

C. Where possible, restore processes instead of structural habitat features, in order that the work be self-sustaining. Emphasis should be on process-based ecosystem restoration, such as those processes that naturally sustain marshes, channels, mudflats, etc.

6.2.3 Research to Support Management Needs

In contrast to monitoring, research is problem-solving and hypothesis-testing, and focuses on mechanisms. It requires articulation of an explicit conceptual model to evaluate its relevance to the concerns of Bay managers.

Current Management

Current research programs are sponsored by individual organizations with a specific interest relative to their use of the Bay and which are usually related to compliance with environmental laws. This Plan summarizes much of the past and current research in Chapter 2.

Evaluation of Current Management

Research on the Bay suffers from the same problems already identified in Section 6.2.1 "Long-term Monitoring for the Bay's Ecological Condition and Trend" and Section 6.2.2 "Project Monitoring." It is conducted piecemeal and project by project. Much of it falls in the "gray literature" and is poorly disseminated to interested parties. Much is not peer-reviewed.

Proposed Management Strategy

A systematic program is needed, designed to fill gaps in data and technology as these are prioritized by managers, rather than the past project-by-project, opportunistic approach.

Table 6-5 is a list of priority research interests identified by the TOC during the production of this Plan.

Table 6-5. Research (or Pre-research) Interests Identified by TOC (April 21, 1999).

Research Topic
Artificial Habitats
What can be done to make man-made structures and altered habitats in the urbanized areas of the Bay more habitable by diverse, native species without compromising the effectiveness of the structures?
Contaminants
What are the effects of toxic constituents in Bay sediments on benthic infauna?
What is the pollutant input from urbanized watersheds (e.g. Chollas Creek)? What are the effects on fish and invertebrate communities?
How do the industrial Bay users (shipbuilding) affect biological communities? What is the pollutant input?
How can sediment remediation be accomplished?
How can important habitats be protected from sources of contaminants?
What is the relationship of contaminated sediments and water to fish tissue levels in migratory species?
What part does pollution play in habitat loss or degradation?
How can causes of pollutants from nonpoint sources be determined, and their effects?
Cumulative Effects
How is armoring the shoreline with riprap and continually covering open water areas with structures (i.e. wharves, docks) changing biological, fish, and invertebrate communities? What are the cumulative effects?
Disturbance
What are the anthropogenic disturbances on animal populations in the Bay (population pressure, boats, recreation)? How should an adequate survey of Bay surface users be conducted?
How can design criteria to adequately buffer preserve impacts at urban interface be determined, i.e. render adjacent impacts compatible with proper natural system functioning to guarantee long-term productivity of target species and habitats (noise, light, pollution, water quality, exotic/invasive species)?
Ecological Dependencies
What physical and chemical conditions affect Bay phytoplankton and zooplankton?
What is the contribution of Bay ichthyoplankton to juvenile and adult diversity, biomass, and productivity in the Bay / nearshore ocean?
What is the ecological and productivity value of the benthic algae masses (*Gracilaria* sp.) in the Bay? How are they formed, what allows them to remain and what would cause them to be disrupted?
What is the relationship between fish biomass/productivity in north/central Bay in summer, and south/central in January? What physical (and biological) components best explain this?
How should utilization of tidal flat (both mud and sand) by marine resources and linkages with adjacent subtidal and upper intertidal habitats be assessed?
Ecosystem Processes
Can we identify markers of ecosystem function: what are the organisms, rates, and communities?
Enhancement Planning
How can planned or potential development areas vs. future enhancement needs be identified in advance and made compatible?
Exotics
Is natural population succession of created habitats affected by exotic species? How should populations be tracked? What habitats or systems are most susceptible to invasion by exotics and what species are most likely to invade San Diego Bay and cause significant damage to the ecosystem?
Habitats
What is the ecological function and value of unvegetated, shallow habitat?

Table 6-5. Research (or Pre-research) Interests Identified by TOC (April 21, 1999). (Continued)

Research Topic
What is the ecological function and value of intertidal habitat for shorebirds and marine fish? What tidal elevations seem to be most highly utilized? What species are dependent upon these areas? What species of benthic invertebrates are present, and what are the numbers of organisms by tidal elevations?
How should trends in habitat extent be identified, and habitat maps updated?
What is the extent of eelgrass?
What portion of existing habitat is degraded due to direct impacts and indirect impacts such as fragmentation, sediments, disturbance, edge impacts? How do different habitats interact and how does habitat fragmentation affect ecosystem function?
What has been the effect of the loss of needed interrelating rivers, marshes, subtidal, and mudflats, to habitat value?
What threats may result in additional habitat losses?
How can shoreline erosion be determined/addressed, and sand replenishment be accomplished?
What wetland habitat and upland transition loss is due to development?
Mitigation/Restoration
What are the important habitat areas to be protected by way of mitigation sales? What is the benefit of using a mitigation bank?
What are new or revised mitigation strategies that will improve and replace diminished habitats?
What research can be done to aid the success of tidal mudflat and wetland restoration projects? How should success be evaluated?
Is tidal wetland restoration in San Diego Bay successful?
What are the relationships between shoreline topography and elevation along the Bay and tidal wetland plant communities?
Monitoring
How can we make specific pre- and postproject implementation surveys useful for comparison data (including relating system functionality to wildlife use) in an ecological restoration-related monitoring program?
What should be the effectiveness measures (criteria) for intertidal flat and marsh mitigation programs?
How can baseline monitoring be accomplished in the long term?
Populations
How does the power plant operation (or nonoperation) affect the green sea turtle population and ecology? What research should be done into the ecology of the green sea turtle population?
Is there a shorebird population decline? What are the causes?
What improvements to south Bay forage fish production/populations can be made?
Shorebird survey for the entire San Diego Bay shoreline (what are the species, numbers, and distribution patterns?).
Update the waterbird survey of San Diego Bay (a second survey).
How should an adequate comprehensive survey of birds be accomplished (i.e. shorebirds separate from rafting birds, and full access to all Bay locations for observers)?
Where are California least tern populations and nesting locations in South America?
How can gaps in the clapper rail breeding survey/census be filled?
Regional Growth
How should regional population growth issues be addressed?
How can continued development pressures be anticipated and planned for?

Research to Support Management Needs

Objective: Support management decisions by conducting research on the mechanisms and processes that provide value to the Bay as an ecosystem.

I. Prioritize research using the following criteria:

- Ongoing work must address a specific, acknowledged management need. Research is directly linked to management objectives that are identified and ranked by managers.
- The protocols, methods, and results of research must be presented in a form useful to managers.
- Research is linked with, continues, or augments accepted past and current monitoring programs.
- Work must be done in the context of a disturbed ecosystem, requiring that projects focus on impact dynamics rather than on traditional ecology alone. However, the work could compare disturbed and undisturbed functions.
- Research must be done at a scale applicable to management.
- The work must provide insight into the strength and dependencies of one habitat or community upon another, and structure and function of the ecosystem. The work supports technically sound decisions about the relative quantities (habitat balance) desirable for San Diego Bay.
- Research addresses highly ranked items on a Priority Problem List, which is agreed upon by consensus of the TOC, Science Panel, and stakeholders. If there is disagreement, then managers carry the day. The list is reconsidered every year, based on adaptive management principles. The criteria for making the list are (1) prevention of new problems or threats to the Bay's ecosystem; (2) helps resolve conflict with Bay uses; (3) reduces an ecosystem-wide impact or provides an ecosystem-wide benefit; (4) improves conditions of the most impaired habitats or species in the Bay; or (5) relatively cost-effective for achieving the goal and objectives.

■ Monitoring for the socio-economic health of the Bay is discussed in Chapter 5 "Compatible Use Strategies."

II. Establish a committee of scientists, managers, landowners, and users, and the involved public to prioritize research needs. The purpose of the Research Committee will be to set research priorities in relation to management concerns, decide what management concerns make the Priority Problem List and rank issues on the list, ensure the quality of research conducted and tie-in to management, and communicate research results effectively to a broad audience.

A. The committee should develop, maintain and update conceptual models of how species groups use the Bay in order to: improve communication about how the ecosystem works, help identify research and monitoring priorities, and provide a framework within which to identify and test key processes.

III. The broad purpose of a research program will be to:

- Increase understanding of physical/chemical processes in the Bay that support fish and wildlife use and that relate to management actions.
- Help relate information from long-term and project monitoring into conceptual models about Bay functions on multiple scales from individual species life history to the Bay as a whole.

- Test cause-and-effect relationships identified in conceptual models.
- Reduce scientific uncertainty with respect to management decisions.

A. Conduct baseline, whole-Bay characterization studies. Fill critical information gaps needed to understand the functional relationships among habitats and communities well enough to provide guidance for impact assessment and enhancement priorities.

1. Give priority to baseline studies that will be taken up in the long-term monitoring program, except when the results of the study are expected to suffice for an extended time (such as sediment characterization).
2. Establish baseline data sets for community abundance and distribution, emphasizing lower trophic levels or physical factors that have predictive value for organisms.
   a. Sediment characterization (grain size, toxics)
   b. Temperature and salinity
   c. Phytoplankton
   d. Zooplankton
   e. Algae
   f. Benthic invertebrates
   g. Larval fishes
   h. Shorebirds
   i. Water birds
3. Use correlation among the relevant variables as a guide for more focused studies.

B. Conduct focused studies on the effects of natural and anthropogenic disturbance that test conceptual models.

1. Conduct studies to better characterize the fish species assemblages associated with different artificial or man-made habitats in San Diego Bay.
2. Waterfowl as a guild might be monitored for susceptibility to boat traffic.
3. Research the scope and impact of nonindigenous invasions of San Diego Bay.

C. Conduct studies on ecosystem function and process. Improve understanding of the essential elements of habitat and environmental quality necessary to support the potential productivity, abundance, and diversity of biological resources in San Diego Bay.

1. For example, investigate subyearling use by fish and crustaceans in mid- and upper-intertidal areas.
2. Conduct studies on the feeding dependencies of declining bird species.
3. Research structural surrogates of ecological function that are easier to monitor than functions themselves (such as the height of cordgrass and its suitability for clapper rail use).
4. Develop a method to determine reference conditions for the four different Bay regions.

D. Conduct pilot projects that expand restoration science or technical understanding. Examples are:

1. Optimal design, configuration, and management of shoreline armoring to maximize its habitat value.
2. Optimal design, configuration, and management of salt ponds to support shorebirds, waterfowl, and marsh birds in the absence of commercial salt production.
3. Effective and affordable methods for controlling nonnative invasive plants.

IV. Facilitate cooperation among involved organizations, including integrated and collaborative actions, and collaboration of relevant scientific and engineering disciplines.

6.3 Data Integration, Access, and Reporting

Success of the approaches undertaken in this Plan to management, research, and monitoring depend upon public confidence. There is a broad public perception that the Bay is environmentally degraded. To ensure accurate public understanding and well-placed concern and support for the Bay's resources, consistent and accurate communication from Bay managers and researchers about extraordinarily complex natural ecosystem processes is needed. Such effective reporting of monitoring and research results, as well as progress in Plan implementation, will help keep the Plan strong, relevant, and responsive.

Current Management

Historical and current information on the Bay's natural resources is scattered throughout regional libraries as well as agency, installation, and consultant offices. In many cases, few copies are in circulation of reports funded by the Navy or the Port. Newspaper articles appear sporadically and tend to be tied to a specific event.

Evaluation of Current Management

Existing data on the Bay are not in a form that gets used by Bay managers. Complex problems such as those described as key management questions are interdisciplinary and require interfacing across disciplines and agencies.

There should be better synthesis and analysis of the monitoring data presented to public agencies and better communication of that analysis to the public (National Research Council 1990), so that it will be used effectively as a basis to target resources.

Proposed Management Strategy—Data Integration, Access, and Reporting

***Objective:* Ensure the most effective integration, analysis, and dissemination of monitoring and research on San Diego Bay, and communication of this information to all concerned, so resources are targeted effectively for Bay ecosystem health.**

I. Set up a central clearinghouse for data, reports, and publications on the Bay's natural resources that is accessible to a broad range of users, both technical and nontechnical.

- ***A.*** The criteria for selection of an institution for managing a data clearinghouse should include longevity, objectivity, ability to work with the public, and cost benefit.
- ***B.*** Develop and adopt a means to catalog and access this information that would avoid conflict and dilution of effort.
  - *1.* Establish or use an existing website for San Diego Bay natural resource information that is designed to be useful to the general public, agency, and academic users.
  - *2.* Establish a standardized format for submitting data or reports to the clearinghouse.

II. Organize events to promote data sharing, technology transfer, and communication for a broad range of involved parties.

- ***A.*** Develop a newsletter to report on progress in implementing this Plan and other Bay activities.
- ***B.*** Produce a biannual report on the results of long-term monitoring and other research in a format accessible to the involved public (see Figure 6-2). The report should focus on the "State of San Diego Bay."
- ***C.*** Promote biennial workshops or conferences on ongoing research and monitoring, and management planning for the Bay.
- ***D.*** Develop shared field programs that will promote cross-disciplinary working relationships.
- ***E.*** Target reporting and communication in conjunction with neighboring "estuarine" systems: Tijuana Estuary, Mission Bay, Los Penasquitos, etc.
- ***F.*** Integrate data with other bays and estuaries on the west coast including information on shorebirds from Point Reyes Bird Observatory and San Francisco Bay Bird Observatory.
- ***G.*** Ensure outreach to and participation by cities.

III. Seek standardization of the approach to communicate research and monitoring results so that the format is accessible to a broad audience, through the two separate committees established to manage the research and the long-term monitoring programs.

- ***A.*** "Bundle" sets of indicators for reporting to management and the public so that the monitoring results are more comprehensible.

IV. Enhance data compatibility and standardization of study methods so that data may be more effectively integrated.

A. Ensure that GIS data are collected and delivered in a standard format so that layers are compatible among studies, such as in the federal government's Tri-Services format

B. Integrate San Diego Bay GIS with related GIS databases (e.g. there is a large one for the Tijuana Estuary Watershed and for inland southern California).

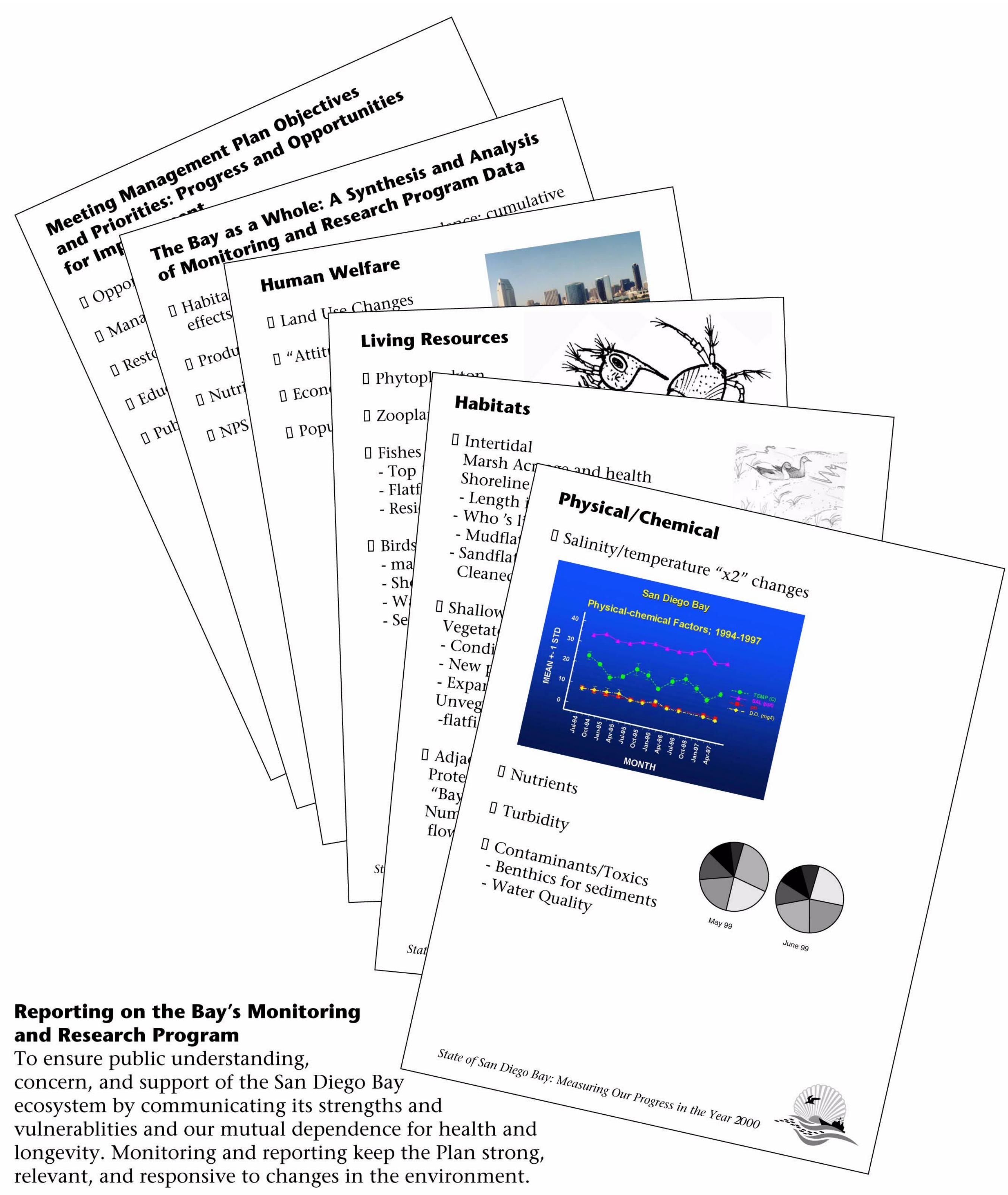


Figure 6-2. Sample State of San Diego Bay Annual Report.