Evaluating the Ecological Condition of the South Bay:

A Potential Assessment Approach

The City commissioned this report as a preliminary effort to explore the possibility of developing alternative assessment methodology and techniques that could be further developed and implemented as appropriate. The City's goal was to further the technical discussion on assessment opportunities and present alternatives to the regulatory community for consideration.

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Executive Summary

“Is the estuary healthy?” is one of the most common questions asked of estuarine researchers and environmental managers. People desire news about their environment, especially when they understand their activities may be creating adverse effects. Despite public calls for such an assessment, none presently exists due in part to the difficulty in defining the health of an estuarine ecosystem. An assessment of the health of the ecosystem would ideally also provide valuable feedback for public officials regarding the effectiveness of environmental policies and programs. The goal of this document is to present a method for preparing an assessment of the ecological condition or "health" of the South Bay.

The method proposed here assumes that an effective assessment must be: (1) relevant to existing legal and regulatory mandates, (2) prepared in plain language that is meaningful to the general public; (3) scientifically credible; and (4) based upon existing information to the maximum extent possible. Guided by these assumptions and a review of other programs and the scientific literature, the proposed method seeks to first identify the attributes of a healthy estuarine ecosystem based on the goals and objectives from public laws and our scientific understanding of the estuary. Some of these attributes include maintaining balanced indigenous wildlife, reversing measured population declines, increasing the amount of wetlands, maintaining water quality, and supporting commercial and sport fishing among others.

Using these attributes as guidance, a set of questions to be answered in an assessment of ecological condition is presented, phrased using plain language so that the importance of answering the questions is obvious to nonscientists. Examples of these questions include “Is it safe to eat fish and shellfish from the Bay?”, “Are key species successfully reproducing?” , or “Are Bay water or sediments toxic to animals or plants?”

Since we cannot measure all aspects of the ecosystem, we must select a set of indicators to measure to answer these questions. The report identifies a preliminary set of indicators for consideration, using selection criteria recently promulgated by the National Academy of Sciences. These indicators are presented to stimulate and focus debate; they will need to be carefully reviewed by stakeholders before a program to gather data and assess condition is implemented.

An initial survey of available data indicates there are many data sets available that could be useful for answering each of the assessment questions. This suggests that an initial assessment of condition could be conducted to a significant extent with existing data, rather than with new measurements, making the assessment more cost-effective.

The report also discusses several strategic considerations for the process of refining and implementing the assessment. The assessment protocol will need to be considered and supported by a majority of the stakeholders in the South Bay, including regulatory agencies. Upon favorable review, partnerships would need to be developed to guide and fund further refinement and peer-review of the indicators, and potential pilot monitoring. Since indicator

measurements are most useful when part of a long-term program, a long-term commitment to the measurements must be feasible.

There can be no doubt that an assessment of the ecological condition or "health" of the South Bay that tracks the status of the ecosystem could be a valuable tool for environmental decision-making. Citizens of the Bay Area and their elected officials want to know if environmental policies and programs are doing enough of the right things to protect the South Bay for future generations. The approach presented in this report has the potential, when fully developed, to fulfill this critical need.

Evaluating the Ecological Condition of the South Bay:

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Introduction

The most common questions asked of estuarine researchers and environmental managers by members of the public are, “How is our estuary doing?”, “Is it getting better or worse?”, and “Is the ecosystem healthy?” These questions originate not only out of concern for the estuary itself, but also from the understanding that human activities have altered the estuarine ecosystem in ways that may impair its ability to provide environmental goods and services we value. These goods and services include waste assimilation, food, navigation, wildlife habitat, and recreational and aesthetic opportunities. People desire news about their environment, especially when they understand their activities may be causing adverse effects.

Answering these questions effectively is a very difficult task. It requires the development of sensitive quantitative indicators of ecosystem health that can be measured in a cost-effective fashion, but no scientific or political consensus exists on what is “healthy” and how it is measured. The more one tries to tease apart the myriad attributes that could be measured to represent health, the more complex the assessment becomes, complicating the task of communicating the results in a meaningful and non-technical way to both policy makers and the public.

The goal of this document is to present a method for preparing an assessment to define the ecological condition or "health" of the South Bay. This assessment would compare existing conditions of the South Bay, derived from measurements of indicators, with desired conditions as described in legislation, regulations, regional management plans, and other public documents. The method proposed is based on four key assumptions about an effective and meaningful assessment: (1) it must focus upon characteristics people care about, using simple and straightforward language accessible to the general public, (2) it must be consistent with our scientific understanding of what is important to sustain ecosystem structure and function, (3) it must be based on measurements that are scientifically defensible, and (4) it must make maximum use of available data.

This method differs from existing assessment methods in that it draws on a much wider range of indicators measured over a long period of time. Most existing approaches to the assessment of ecological condition have focused upon chemical water quality as implemented through the Clean Water Act. This focus is due in part to the obvious chemical water quality problems that existed prior to implementation of technological controls on effluent discharges, and to the relative ease of implementing controls on point sources. However, chemical water quality is only one attribute contributing to ecological health, as the goal of the Clean Water Act is also to protect the physical and biological integrity of the nation's waters. This report will describe a broader set of indicators that could be used in making such an assessment.

The geographic boundaries for this assessment discussion will be the South Bay south of San Bruno Shoal. This recognizes the need to "start small" in the development of a program to assess the ecological conditions in San Francisco Bay. However, many potential indicators for the South Bay are influenced by factors outside of the geographic scope of the project, as the South Bay is an ecosystem nested in the larger ecosystem of San Francisco Bay and the coastal ocean. Changes in this larger ecosystem will influence measures of condition in the South Bay, and a scientifically credible assessment of condition may necessitate expanding the spatial scale of the project upon implementation.

The report will first present some background information on the issues confronting an assessment of ecological health or condition in an estuary. This will be followed by a review of assessment approaches currently underway in other large aquatic ecosystems in the United States (and, in one example, Australia). With that background, the report will present an approach for the assessment of health in the South Bay ecosystem in the form of a set of assessment questions, including the quantitative indicators that could be used to answer the questions. Available data sets that could be used to assess the status of the quantitative indicators will be identified, and an estimated budget for conducting the assessment will be presented.

Background

Answering the question "Is the estuary healthy?" is important for environmental decision-making. Citizens of the Bay Area have a right to a comprehensible assessment of whether we are doing enough of the right things to protect the estuary for future generations. Proposals have been made for the construction of runways, expansion of the ferry system, and returning salt ponds to wetlands, among other large-scale alterations. The future will certainly bring increased development pressure, expanding population, and climatic changes that will influence the estuary. An assessment of ecological health or integrity that tracks the cumulative impacts of our actions and the status of the ecosystem is essential feedback for sound public policy. It is thus no surprise that the need for such information is reflected in our major laws and public policy documents regarding management of the estuary (Table 1). CALFED, USEPA, SFEI, and the Bay Area Council have all called for an "environmental report card" for the estuary (T.F. Young, personal communication).

Despite public calls for such an assessment, there is presently no normative definition of the health of the estuarine ecosystem. Health is not an objective characteristic of the Estuary that can be measured, but a subjective assessment made by considering measurements of important attributes of the ecosystem. The status of these attributes will be determined by the structural and functional integrity of the ecosystem. Judging the health of the ecosystem requires interpreting data that will be variable in time and space, and identifying benchmarks or standards of health against which to compare our measurements.

Goals & Objectives for Ecosystem	Source [Reference]
Restore and maintain the chemical, physical, and biological integrity of the Nation's waters	Clean Water Act [1]
Provide maximum protection for existing and future beneficial uses of bay and estuarine waters	Porter Cologne Water Quality Act [2]
"Maintain the chemical, physical, and biological integrity of the Bay and Delta, including restoration and maintenance of water quality; a balanced indigenous population of shellfish, fish, and wildlife; and recreation activities in the Bay and Delta, and assure that the beneficial uses of the Bay and Delta are protected."	Comprehensive Conservation and Management Plan [3] p.47
Surface waters are safe for drinking, fishing, swimming, and support healthy ecosystems and other beneficial uses	State Water Resources Control Board Strategic Plan [4]
Restore healthy estuarine habitat conditions to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources	Comprehensive Conservation and Management Plan [3]
Protect and/or restore streams, reservoirs, wetlands and the Bay for the benefit of fish, wildlife and human uses	Santa Clara Basin Watershed Management Initiative [5]
Develop and implement a long-term comprehensive plan that will restore ecological health and improve water management for beneficial uses of the Bay-Delta System	CALFED 2001 Annual Report [6]
Healthy creek and bay ecosystems are protected, enhanced, or restored	Santa Clara Valley Water District Governance Policies [7]
Maintain thriving aquatic ecosystems and the resources those systems provide to society	San Francisco Bay Basin Plan [8]

Table 1: Laws and policy statements regarding the general goal of ecological "health" for San Francisco Bay.

The problem is somewhat simplified by inquiring not about the absolute state of the system compared to some benchmark of health, but instead inquiring about the relative condition of the ecosystem over time. Is the condition of the system improving, or is it deteriorating? This changes the question to be addressed from "Is the estuary healthy?" to "Are things getting better or worse?" This reformulation still requires agreement on (1) the important "things" (the valued attributes of the ecosystem), (2) the direction of change that is "better," and (3) how to integrate the measurement of “things” into an overall assessment of condition.

A variety of attributes of the ecosystem are presently monitored by federal, state, and local government agencies (e.g., California Department of Fish and Game, US Fish and Wildlife Service, Regional Water Quality Control Board, POTWs) and private organizations (e.g., SFEI, the Marine Science Institute or the Point Reyes Bird Observatory). These programs track characteristics such as water and sediment chemistry, abundance and distribution of fish and birds, and the primary production by phytoplankton that represents the base of the food web.

There is no program, however, with the task of integrating (politically and scientifically) these measurements into an assessment of condition. Moreover, there is no program with the task of identifying gaps – attributes that are intimately related to ecosystem condition but are not included in long-term monitoring programs.[1] Clearly, it would be very useful to identify a set of key attributes, measure indicators of these attributes, and then combine these measurements over time to assess condition. With reference to established benchmarks for each measurement, this method could be used to assess changes in condition over time ("are things getting better or worse?").

To create such a program it is necessary to (1) develop a satisfactory consensus regarding the attributes of the ecosystem that are valued by the public or identified by scientists as required for a representative assessment of ecological condition, (2) identify measurable indicators of these attributes that are both publicly meaningful and scientifically justified, (3) decide the direction of change for these indicators that is desired (or "healthy"), (4) establish benchmark values or "targets" for the indicators that can be used to quantify progress, and (5) determine how the indicators should be presented to both garner public interest and retain scientific credibility. Achieving these objectives will require that we work both from publicly adopted statements of environmental goals (both legislative and regulatory) and our scientific understanding of ecosystem process and composition.

Since our present scientific understanding of the estuary is incomplete, efforts to assess ecological condition are likely to be imprecise. Thus, deriving an assessment of ecological condition will be an iterative, long-term process in which assessment attempts are critiqued and improved upon. Maintaining a long-term program that allows for such a learning process requires political and institutional commitments that, while not unknown, are not the norm.

It is important to recognize that ecological condition is an integrated measure of the state of the ecosystem that is influenced by human activities and other driving forces including climate and weather. Measures of the state of the ecosystem do not produce information about cause and effect, and cannot by themselves specify potential management actions. In other words, determining whether things are getting better or worse doesn't determine why something is happening, or suggest what might be done to alter the trends. This means that measuring ecological condition must occur in conjunction with other monitoring and research that help us understand ecological processes and interactions that act to change the condition of the system.

With this background, the next section provides a summary of how those responsible for other large aquatic ecosystems are approaching the task of assessing condition. This will be followed by a description of an approach for conducting an assessment of the ecological condition of the South Bay.

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[1] The City of San Jose would like to see the Regional Monitoring Program lead the development of such a program, and has sponsored the present work to promote a region-wide discussion of this issue.

The Status of Ecological Assessments in Other Large Aquatic Ecosystems

Across the country, many communities are trying to establish programs to assess the condition or "health" of local ecosystems. In some places, indicators of condition are judged and "graded" to produce a public "report card" regarding ecological health or integrity. As part of designing a pilot assessment of ecological condition for the South Bay, multiple environmental assessment reports were reviewed (Table 2). The reports evaluating bay and estuarine ecosystems, and those assessing overall ecosystem health through the integration of scientific data sets, were analyzed in more detail (Table 3).

Within this selected list there is significant variation among the documents, driven often by differing environmental goals or the intended audience for a given report. Frequently, measurements of the status or the condition of the ecosystem are mixed with measurements of stressors and assessments of the success of management efforts. In general, the reports share the common objective of assessing the overall health and condition of a local ecosystem, most frequently by the analysis of monitoring data for selected indicators. The following discussion reviews some of the concepts of health, the indicators used to make the assessments, and the formats and methods of information dissemination.

Ecosystem Health, Goals, and Indicators

Most of the reports reviewed begin with the premise that issues of societal importance, such as public health, economics, water quality and living resources, should be included when determining the health or condition of aquatic ecosystems. Ecosystem goals can vary from loosely defined restoration objectives to the achievement of specific, government-mandated, environmental standards. In several regions a general goal is set that may be broad and poorly defined, but that serves as a basis for the establishment of more specific objectives (Table 4) [9-14].

In addition, some of the reports incorporate characteristics that may be “invisible” to the public, yet are important indicators of the structure and function of the ecosystem [15-18]. These characteristics provide information about the ability of the ecosystem to be self-sustaining and resilient to stress. They also potentially provide early warning of problems that have yet to be recognized by the general public.

The term ecosystem health often appears in goal statements, frequently with reference to the concept of sustainability. The program in Moreton Bay, Australia, uses the definition of Rapport *et al*. that a healthy ecosystem “maintains its biodiversity, is stable over time, and is resilient to change” [19, 20]. Similar to Rapport’s definition is the Chesapeake Bay Foundation’s definition of a “saved” bay as one that is “resilient enough to withstand the storms of nature and of human kind, and rich enough to nurture diverse cultures and contribute abundantly to the economy." The Chesapeake Bay Foundation also uses data inferred from the notes of Captain John Smith's explorations in 1600 to describe a healthy state of the ecosystem [9]. Definitions of health that refer to stability, such as that quoted above, have been criticized as inadequately reflecting our emerging understanding of the influence of decadal-scale climatic changes on ecosystem structure.

Chesapeake 2000 and the Bay: Where are we and where are we going? [21]
Chesapeake Bay Foundation: State of the Bay [9]
Chesapeake Bay Program: State of the Bay [10]
Delaware River Basin: Water Snapshot [22]
Ecosystem Health Monitoring Program: River Estuary Report Card 2001 and Moreton Bay Report Card 2001 [19]
Ebb & Flow: Galveston Bay Characterization Highlights [23]
Great Lakes Trends: Into the Millennium [24]
Heal the Bay: Beach Report Card [25]
Integrating the Nation's Environmental Monitoring and Research Networks and Programs: A Proposed Framework [16]
Inventory of Government Literature on Report Cards [26]; includes information on · Florida Benchmarks Report · The State of Boston Harbor · The State of Tampa Bay · State of the Great Lakes · Chesapeake Bay Program: State of the Bay · Northwest Forest Plan 1996 Accomplishment Report · Save our Everglades 1993 · U.S. Army Corps of Engineers: Linkage Between Environmental Outputs and Human Services · Restoration of the San Francisco Bay-Delta-River System: Choosing Indicators of Ecological Integrity · The Sustainable Seattle Indicators · Jacksonville: Quality Indicators for Progress · Accomplishments Report: Bureau of Land Management of Western Oregon · The Northwest forest Plan: A Report to the President and Congress · Integrating Environmental Monitoring and Research in the Mid-Atlantic Region · Chesapeake Bay Environmental Indicators: Measuring our Progress · Implementation Monitoring Program for Management of Habitat for the Late-Succession · Use of Performance Information in the Chesapeake Bay Program
LandWatch Monterey County [27]
Long Island Sound Report Card [28]
Measures of Success: Addressing Environmental Impairments in the Saginaw River and Saginaw Bay [29]
Monroe County Environmental Report Card [11]
Puget Sound's Health Report [30]
San Francisco Bay Estuary Project: Bay-Delta Environmental Report Card[12]
Silicon Valley: 1999 Environmental Index [31]
Southern California Environmental Report Card [32]
State of the Derwent: Year 2000 Report Card [33]
Sustainable Calgary: State of Our City [34]
The State of the Boston Harbor [35]
The State of the Great Lakes [14]
Wallis Lake Catchment Management Plan [36]

Table 2. Programs Assessing Environmental or Ecological Health. [Reference]

Chesapeake Bay Foundation: State of the Bay [9]
Chesapeake Bay Program: State of the Bay [10]
Ecosystem Health Monitoring Program: River Estuary Report Card 2001, Moreton Bay Report Card 2001[19]
Ebb & Flow: Galveston Bay Characterization Highlights [23]
Measures of Success: Addressing Environmental Impairments in the Saginaw River and Saginaw Bay [31]
Puget Sound's Health Report [30]
San Francisco Bay Estuary Project: Bay-Delta Environmental Report Card [12]
The State of the Great Lakes [14]
State of the Derwent: Year 2000 Report Card [33]
Wallis Lake Catchment Management Plan [36]

Table 3. Short List of Reports Pertinent to South San Francisco Bay. [Reference]

Report	Goal	Examples of Objectives
Chesapeake Bay Foundation: State of the Bay [9]	Remove the bay from the Environmental Protection Agency's list of impaired waters by the year 2010	Reduce nutrients that pollute the bay
Chesapeake Bay Program: State of the Bay Report [10]	To restore living resources including finfish, shellfish, underwater Bay grasses and other aquatic life and wildlife	Nutrient reduction, toxics reduction, air pollution reduction, landscape changes
Measures of Success: Addressing Environmental Impairments in the Saginaw River and Saginaw Bay [29]	Restore bay to its historic mesotrophic condition	Remove bay from list of Great Lakes Areas of Concern
The State of the Great Lakes Report 2001 [14]	To restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem	Assess the state of the Great Lakes ecosystem based on accepted indicators, strengthen decision-making and environmental management concerning the Great Lakes, inform local decision-makers of Great Lakes environmental issues, provide a forum for communication and networking amongst all the Great Lakes stakeholders
Wallis Lake Catchment Management Plan [36]	Manage the impacts of human activities on the catchment while maintaining the health of the catchment	Reduce soil erosion, restore wetlands, manage stock access to streams and stream banks, improve dairy effluent management systems, reduce stormwater inputs, reduce sulfuric acid leachate

Table 4. Examples of program goals and objectives from other large aquatic ecosystems.

The Southern California Environmental Report Card is an example of an assessment that focuses upon stressors. This report card is written by academic researchers in specialized fields whose goal it is to provide “the best scholarship possible in order to help inform local and regional policy decisions.” Instead of using monitoring data to assess ecosystem health, information is provided about the causes and effects of the most pressing environmental problems of the region. The overall goal is “to instigate informed communications from different sectors of the community as well as appropriate self-evaluation by the relevant agencies, the public and business communities” [32].

The indicators selected to evaluate ecosystem health often reflect local management goals. Indicators are generally chosen to represent valued attributes of an ecosystem, or to represent known or suspected stressors. Popular indicators of health or condition include water quality, safety of fish consumption, or the decline of native wildlife species. Indicators of stressors include measurements of nutrient loading (i.e., nitrogen and phosphorus concentrations), concentrations of pesticides in runoff, or measures of habitat modification. If an indicator is unfamiliar to the general public, an explanation of its relevance to ecosystem health and sustainability is commonly included [9-14]. Examples of indicators and their areas of concern are given in Table 5.

The most common area of concern in all reports is water quality. This is not surprising in the US, since the Clean Water Act has focused primarily on water quality for thirty years, thus promoting both public interest and widespread monitoring. This broad topic may include public health concerns such as chemical contamination of drinking water, or bacterial contamination of water used for recreation. Also included in water quality analyses are ecological concerns such as nutrient loading and water clarity (Table 6). For issues of immediate human health hazard some programs use short, quantitative reports to allow quick evaluation and decision-making [19, 25]. These types of concerns may call for frequent updating and may be published on a weekly basis. Continuous updating and quick reference of immediate hazards are facilitated by use of the Internet.

Another common indicator is the safety and availability of fish for consumption. These data are often evaluated through inter-annual comparisons [11, 13, 14, 19, 23, 24, 26, 33-35] Consumption safety is evaluated according to concentrations of chemical contaminants or the presence of pathogens (Table 7).

Indicators representing the survival and success of local wildlife are also used frequently in ecological assessments. Native wildlife populations commonly reported on include shore birds, native fish and large marine mammals, with some programs also reporting on indicators of available habitat for native species. Indicators related to erosion and degradation of wetlands and seagrass beds are the most common indicators of estuarine habitat [12, 19, 29]. The Wallis Catchment Program in New South Wales, Australia uses the survival of a single indicator, seagrass, to assess the overall health of the entire catchment[36].

Program	Area of Concern	Indicators
Chesapeake Bay Foundation [9]	Habitat	Wetlands, forested buffers underwater grasses, resource lands
	Pollution	Concentration of toxic chemicals, water clarity, phosphorus, nitrogen, dissolved oxygen
	Fisheries	Crabs, rockfish, oysters, shad
Galveston Bay Estuary Program [23]	Ecosystem and the Watershed	Open-bay water, open-bay bottom, oyster reef, seagrass meadow, marsh, intertidal flat
	Physical Form and Processes	Bay volume, shoreline change, freshwater inflow patterns, salinity regimes, surface runoff, circulation, sediment transport, sedimentation
	Water Quality	Temperature, pH, salinity, dissolved oxygen, nutrients, total phosphorus, nitrogen-ammonia, nitrate-nitrogen, chlorophyll-a, fecal coliform bacteria
State of the Great Lakes Committee [14]	Nearshore and Open waters	Walleye, *Hexagenia*, prey fish populations, spawning-phase sea lamprey abundance, native unionid mussels, lake trout, scud, deformities, eroded fins, lesions an tumors in nearshore fish, phytoplankton populations, toxic chemical deposition and water concentrations
	Coastal Wetlands	Amphibian diversity and abundance, contaminants in snapping turtle eggs, wetland-dependent bird diversity and abundance, coastal wetland area by type, effects of water level fluctuations
	Nearshore Terrestrial	Area, quality and protection of alvar communities, extent of hardened shoreline, contaminants affecting productivity of bald eagles, population monitoring and contaminants affecting the American otter,
	Land Use	Urban density, brownfields redevelopment, mass transportation, sustainable agricultural practices
	Human Health	*E. coli* and fecal coliform, chemical contaminants in edible fish tissue, drinking water quality, air quality
	Societal	Economic prosperity, water use
Puget Sound Water Quality Action Team [30]	Shellfish	Toxic contamination, pathogens
	Water for Recreation	Fecal coliform
	Invasive Species	*Spartina* sp.
	Contaminated Sediments	State sediment quality standards
	Toxic Contamination	Mussels, harbor seals, english sole
	Oil Spills	Oil spills
	Wildlife/Fish Habitat/Populations	Coho salmon, harbor seal, scoter, pacific herring
	Marine Water Quality	Fresh water temperature, nutrients
Chesapeake Bay Program [10]	What Lives in a Healthy Ecosystem?	Striped bass, shad, herring, blue crabs, oysters, bald eagles, ducks herons, egrets
	Stressors on the System: The Bay's Top Challenges	Nutrients, toxic chemicals/chemical contaminants, air pollution, landscape changes

Table 5. Ecosystem attributes and associated indicators from different programs.

Report	Water Quality Measurement
Puget Sound Health Report [30]	Fecal coliform
Wallis Catchment Management Plan [36]	Fecal coliform, nitrogen, macrovertebrate populations
San Francisco Estuary Institute: The Pulse of the Estuary [70]	Trace organic and trace metal contaminants
Chesapeake Bay Foundation: State of the Bay [9]	Nutrient loads, dissolved oxygen, water clarity
State of the Boston Harbor [35]	Percent days failed swimming standards for fecal coliform
Ecosystem Monitoring Program [19]	Fecal coliform, nutrient loads, sediment loads
Heal the Bay [25]	total coliform, fecal coliform, enterococcus coliform, giardia/cryptosporidium
State of the Derwent: Year 2000 Report Card [33]	Nutrient loads, suspended solids, dissolved oxygen, inorganic nitrogen, fecal coliform

Table 6. Examples of water quality indicators.

Program	Tissue	Contaminant
Puget Sound Health Report [30]	Mussel	PCBs, PAHs, DDT, mercury, copper
Chesapeake Bay Program: State of the Bay [10]	Finfish Bivalve	Kepone mercury, chlordanes
State of Boston Harbor [35]	Fish, Shellfish	Pathogens, PCBs, metals
State of the Derwent: Year 2000 Report Card [33]	Fish	PCBs, metals, mercury
San Francisco Estuary Institute: The Pulse of the Estuary [70]	Fish	PCBs, PAHs, DDTs, pesticides, trace metals including mercury
Measures of Success: Saginaw Bay [29]	Fish	DDT, PCBs, chlordanes, dioxins, mercury

Table 7. Examples of contaminants in tissue for consumption.

Typically, programs attract the participation of a diverse array of stakeholders from federal and state agencies, local government, local industry, academia, citizens and environmental groups. The scientific or technical experts from these groups tend to be responsible for the selection and evaluation of indicators. Consideration of funding and monitoring feasibility normally requires that any list of indicators be limited, and the criteria used to select indicators are an important part of the public record [for example14].

There are also several examples of volunteer based programs in which citizens choose and monitor indicators [13, 22, 25, 28, 34]. For these programs, indicators are generally limited to those that are measured and evaluated easily. The information commonly collected includes water pH, salinity, turbidity, suspended solids and dissolved oxygen. There are also qualitative physical descriptions of ecosystem attributes included in some programs.

Report Formats and Distribution

Effective communication of information, particularly to non-experts about the multiple factors affecting an ecosystem, is a high priority for all programs. Some reports tend to stress illustration and education for the general public, while others include more in-depth analysis of technical interest to agency staff. Frequent publication (annual or biannual) allows interested parties to consider the issues without consulting outdated materials.

Frequently, short reports are geared to policy makers and the general public, representing summaries of larger detailed reports, with the larger reports easily accessible for those interested in a more complete evaluation of data. In some situations, a complete list of indicators may be developed for scientific monitoring, but only a short list of socially valuable indicators is reported in an environmental report card [13, 19, 23, 33]. Short reports may be included within the large report or they may exist separately with reference to the detailed report. This type of summary makes information and analysis available for multiple audiences while allowing easy access to detailed information for more specialized users.

Two examples of short reports used for public distribution are the Puget Sound Health Report and the Southern California Environmental Report Card [30, 32]. The *Puget Sound Health Report* is a 10 to 15-page newspaper insert that is distributed every two years in local newspapers. This report includes limited topics that are valuable and recognizable to citizens. These topics are illustrated by photographs and are evaluated using graphs of current status and historical trends. Other educational features directed at public audiences include an interactive games page to test readers on what they have read in the report and information on volunteering.

The Southern California Environmental Report Card is a 40 to 60-page annual report available both as a booklet and on the Internet. This report is a somewhat longer example of short formatting but provides good examples of the use of illustration to explain complex environmental issues. Photographs and simplified models of complex systems such as coastal currents, chemical fate and transport, and mechanisms of water treatment plants are seen throughout the report. It may be ordered directly from the UCLA Institute of the Environment or is accessed on the Internet with links to other programs and reports in the region. Internet access to such reports appears to be an effective method of distribution in terms of cost and accessibility.

Longer, comprehensive reports are commonly seen for larger ecosystems with long-standing monitoring programs [12, 14, 21, 23, 26, 29, 37]. These reports are usually the product of collaborative research programs stemming from long-term academic research and/or environmental concern by various levels of government. Typically, long reports are divided into broad areas of environmental concern and evaluate specific factors or indicators for each of these areas. This style of report is usually published with less frequency than shorter reports and contains much more detail on monitored environmental factors. These reports are often distributed internally to involved government and academic groups and made available as PDF files to download from websites. Though not highly technical, the length of these reports makes them less available to the public and more appropriate for use in legislation or scientific analysis by a wide range of experts. An ecosystem overview can be lost in the detail of some longer reports, although recent detailed reports are making overall ecosystem evaluation more of a priority [21, 26, 37]. Comprehensive reports normally include a summary of the overall condition of the ecosystem [9-14, 23, 25, 26, 29, 33]. In the State of the Great Lakes 2001 report, this summary is followed by a brief quantitative analysis for each of its environmental indicators on the following page [14].

Examples of shorter specialized reports published from comprehensive evaluations are *The Great Lakes Trends: Into the New Millennium* [24] and *Chesapeake 2000 and the Bay: Where are We and Where are We Going?* [7, 21] In these reports the status and trends are given for a summarized list of topics interesting to the general public such as water safety issues and wildlife populations. Such reports are often produced as web pages with links to glossaries and other available information including pertinent databases and government agency websites.

Recommended Approach for the South Bay

This section of the report presents a recommended approach for assessing the ecological condition of the South Bay. As was mentioned previously, the key assumptions underlying the approach are: (1) the importance of reporting on ecosystem attributes of public importance using simple and straightforward language accessible to the general public, (2) being consistent with our scientific understanding of what is important to sustain ecosystem structure and function, (3) basing these reports on measurements that are scientifically defensible, and (4) making maximum use of available data.

Given this general approach, the review of other programs and the scientific literature, it is recommended that an ecological assessment of the condition of South Bay be based on four guiding principles.

First, an assessment should be relevant to existing legal and regulatory mandates, and adopted goals and objectives in public planning documents. Clearly, for an assessment to be maintained over a long time frame where it can be expected to be the most useful, it must be relevant to existing public law and policy. This will allow public agencies to develop and support the assessment as part of carrying out their existing public mandates. In addition, some of these public mandates are the result of extensive negotiations and work among the various stakeholders in the region, and the assessment will be most useful if it can build from these agreements rather than being tangential to them.

The second guiding principle is to be meaningful to the general public. An assessment that relies upon technical concepts and scientific jargon will be opaque and uninteresting to the general public, and consequently will be less useful to decision-makers. The ultimate audience for the assessment must be the interested general public and their elected representatives.

The third guiding principle is that, while employing straightforward language and "common-sense" concepts, the assessment must retain scientific credibility or it will lose effectiveness. Scientific credibility is retained by (1) using scientific understanding, in addition to publicly adopted goals and objectives, to derive essential attributes representing ecosystem condition, and (2) making sure assessments are based on high quality data collected with defensible methods. Indicators derived from scientific understanding may not be immediately meaningful to the public (e.g., organic carbon cycling or sediment supply), yet their inclusion is important if the assessment is to represent the best thinking of ecological science. The challenge for using these indicators is to develop publicly-meaningful descriptions, which also provides an important opportunity for public education.

The final guiding principle is that the assessment must be based, to the maximum extent possible, on existing information. Given the myriad of demands on natural resource agencies and private foundations, it seems unlikely that a new program can be established to make the repeated measurements necessary to build a long-term picture of ecological condition. Instead, an assessment must make use of data from existing monitoring and research programs. The assessment's success will allow it to influence existing programs to modify their efforts to provide key additional data. It should be noted, however, that highlighting critical gaps in the existing information base is important in order to develop public support of monitoring [16, 18].

The other rationale for using existing data in the assessment is that historic measurements and maps can be used to hind-cast the ecological condition of the South Bay. Without such a retrospective analysis, a commitment to long-term measurement would be required before an assessment could be produced. Maintaining such a commitment is much easier with a sample product for decision-makers to consider.

With these guiding principles in mind, the next section details the specific steps in the approach. These are (1) identify essential ecosystem attributes implicit in goals and objectives from public laws and plans, (2) identify additional ecosystem attributes from ecological science, (3) develop a set of publicly meaningful assessment questions consistent with these attributes, and (4) identify indicators to be measured to answer the assessment questions. The final portion of this section describes how measurements can be interpreted and some strategic considerations for implementation of the assessment.

Identifying Essential Ecosystem Attributes

Essential ecosystem attributes that must be assessed to determine ecological condition can be drawn both from public laws and policies and ecological science. There are several laws and government programs/policies that focus upon improving the health or ecological condition of the estuary. The key laws are the Porter-Cologne Water Quality Act (California Water Code §13000 *et seq*.) and the federal Clean Water Act (33 US Code 26 §1251 *et seq.*). Key programs and policies include USEPA's Comprehensive Conservation and Management Plan (CCMP), the Regional Water Quality Control Plan ("Basin Plan") of the San Francisco Bay Regional Water Quality Control Board, the San Francisco Bay Wetlands Ecosystem Goals Project, the CALFED Bay-Delta program, and the Santa Clara Basin Watershed Management Initiative.[2] These laws and programs include goals for restoring and maintaining “biological integrity,” “thriving ecosystems,” and “ecological health” (Table 1), as do programs from other regions reviewed earlier (Table 4).

Implicit in these general goals, and in some of the more detailed objectives of these programs, are attributes of the ecosystem that would need to be assessed to determine if the overall goal of improved ecological health or condition is being achieved. These attributes can be grouped under the general headings of biota, habitat, human uses and pollution (Table 8). Attributes related to biota include maintaining balanced indigenous wildlife, protection of endangered species, and reversing measured population declines. Habitat attributes include increasing the amount of wetlands, including riparian habitats and tidal marshes, and protecting migratory corridors. Attributes related to pollution and human uses include chemical water quality, commercial and sport fishing (including shellfish harvest), navigation, and protection against toxic effects. Tracking indicators for these attributes would provide valuable feedback to decision-makers and the public regarding the ecological condition of the estuary.

Given the guiding principle to keep the assessment scientifically credible, we must also use our scientific knowledge of ecosystems in general and the San Francisco Estuary in particular to identify essential ecosystem attributes. As was mentioned previously, this is a subject that is receiving a significant amount of focus among scientists, including several recent attempts to identify a framework, or set of generic attributes, that should be considered when attempting to develop meaningful indicators of ecological condition. A brief description and comparison of these frameworks can be found in Appendix 2.

An important feature of the scientific frameworks is the inclusion as key attributes ecosystem processes that create or sustain the biota, habitat, and human uses identified in the public goal statements. Examples of these processes include nutrient flow, carbon fixation and storage,

[2] Although programmatic goals and policies, in addition to laws and regulations, refer to ecosystem health, it is likely that laws and regulations will be the important drivers for the design and implementation of an assessment approach.

Goals & Objectives for Ecosystem from Laws, Policies, and Programs	**Assessment Question Number**	**Reference**
Biota		
A balanced indigenous population of shellfish, fish, and wildlife	1, 5	[3]
Protect the beneficial uses of RARE, SPWN, and WILD	1, 2, 4, 5	[3]; [8]
Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), with emphasis on natural production, and ensure the survival and recovery of listed and candidate threatened and endangered species	1, 2, 3, 4,5	[3]
Habitat		
Restore healthy estuarine habitat conditions to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources	1, 10, 11, 12, 13, 14	[3]
Expedite a significant increase in the quantity and quality of wetlands	10	[3]
No net loss of wetlands	10	[38]
Control smooth cordgrass	11	[38]
Protect, restore, increase and enhance all types of wetlands, riparian habitat and associated uplands throughout the San Francisco Bay region to benefit waterfowl and other fish and wildlife populations	1, 4, 10, 11	[39]
Increase tidal marsh from 9,000 to 25-30,000 acres; manage 10-15,000 acres of salt pond habitat for birds	10	[38]
Protect the beneficial uses of EST, MIGR	10, 11, 12, 13, 14	[3]; [8]
Pollution and Human Uses		
Protect the beneficial uses of COMM, IND, NAV, REC-1, REC-2, and SHELL	8, 9	[3]; [8]
Restoration and maintenance of water quality	6, 7, 13	[3] p.47
No toxic substances in toxic amounts	6, 7, 8	[8]
Protect against toxic effects, including bioaccumulation and toxic sediment accumulation	6, 7, 8	[3] p.133

Table 8: Valued attributes of a "healthy" South Bay derived from goals and objectives of public documents. Acronyms are beneficial uses of South Bay (see Appendix 1). Assessment question number refers to the questions in Table 9.

or geomorphic processes that shape landscapes and create specific habitats such as sediment transport. While these attributes may not be as readily understood by the general public, there is a strong scientific consensus that an assessment of ecological condition is incomplete without tracking indicators of key processes. Tracking processes provides a valuable indication of altered functions that can lead to future problems. Another feature of attributes that are part of scientific assessments is their focus on the biological composition of the ecosystem as a whole, with attributes such as community composition, genetic diversity, and trophic structure.

The scientific frameworks thus suggest some additional attributes that could be included in an assessment of condition. These include hydrology, water circulation, biogeochemical processes supporting biota habitats (nutrient or sediment supply, decomposition), and biological community composition (species diversity or richness, trophic structure).

Using these attributes as guides, a set of questions to be answered in an assessment of the ecological condition of the South Bay can be derived. To be consistent with the guiding principles, these questions should be phrased using nonscientific language, so that the importance of answering the question is obvious to nonscientists. Examples of these questions include "Is it safe to eat fish and shellfish from the Bay?" "Is the number of threatened or endangered species increasing or decreasing?" or "Are key species successfully reproducing?" The attributes derived from the scientific frameworks can also be translated into assessment questions. For hydrology and circulation, an assessment question could be "Are freshwater inflows sufficient to provide the water circulation required to maintain habitats and biota?" For biogeochemical processes, the assessment question could be "Is sediment supply adequate to maintain estuarine habitats?" For community composition, an assessment question would be "Is a diverse biological community present in the ecosystem?" (Table 9).

The assessment questions should also correspond to the goals and objectives for the ecosystem derived from law and policy and from scientific frameworks. Comparison of the assessment questions to existing goals and objectives demonstrates that each goal or objective does have at least one corresponding assessment question (Table 8, column 2). A similar comparison can be made between the list of assessment questions and the important ecosystem attributes identified by scientific frameworks. Again we find that there is a corresponding assessment question for each scientifically-derived attribute (Table 10).

While the assessment questions in Table 9 appear to be both scientifically credible and publicly meaningful, these are not the only questions that could be asked. Alternative judgements could be made regarding the extent to which the assessment questions address the attributes derived from public policies (Table 8) and scientific frameworks (Table 10). The current assessment questions represent an effort to build an assessment of condition. It is expected that alternative assessment questions will be put forward for consideration, and that over time the assessment questions will be refined. The questions posed in Table 9, however, provide a solid foundation from which to move forward.

Assessment Question	
No.	Biota
1	Are populations of key species stable, increasing, or decreasing?
2	Is the number of threatened or endangered species increasing or decreasing?
3	Are there adequate food resources to support key species?
4	Are key species successfully reproducing?
5	Is a diverse biological community present?
	Pollution & Human Uses
6	Is the Bay safe for contact recreation?
7	Are Bay water or sediments toxic to plants and animals?
8	Is it safe to eat fish and shellfish from the Bay?
9	Is commercial and sport catch of fish stable, increasing, or decreasing?
	Habitat
10	Is the amount of all wetland habitat types (including mudflats) stable, increasing, or decreasing?
11	What are long-term trends in salinity?
12	Are invasive plants destroying native wetlands?
13	Are freshwater inflows sufficient to maintain habitats and biota?
14	Is sediment supply adequate to maintain estuarine habitats?

Table 9: Questions to be answered in an assessment of the ecological condition of the South Bay.

Essential Ecological Attribute	**Assessment Question Number**
Landscape Structure and Composition	10
Biotic Condition	1, 2, 4, 5, 9
Ecological Processes	3, 4, 13
Physical and chemical characteristics	6, 7, 8, 14
Hydrology	10, 11, 13
Disturbance	12

Table 10: Correspondence of essential ecological attributes derived from scientific frameworks with assessment questions in Table 9. See Appendix 2 for more information on these scientific frameworks.

Potential Indicators of Ecological Condition in the South Bay

Measurements that answer the assessment questions must be based on reliable scientific methods. Since we cannot make measurements of all the biota, water and sediment in the South Bay, we must select indicators to represent the broader ecosystem. Such a selection process is challenging, as it requires judgments regarding what measurements provide the best information to answer the assessment questions. Indicators can be measurements of particular aspects of the environment, such as salinity or abundance of a particular species, or they can be multi-metric indices that combine several related measurements. The best known example of the latter is the Index of Biological Integrity that combines measurements of different taxa of aquatic insects into an indicator of stream health [40].

The following discussion initiates the process of indicator selection by identifying criteria for selection of indicators, and applying those criteria to a pilot list of indicators that could be used to assess the ecological condition of the South Bay. The National Research Council's (NRC) recent report *Ecological Indicators for the Nation* provides a useful set of criteria to consider when selecting indicators, including many criteria also identified by other researchers [40-44]. The NRC criteria include general importance, conceptual basis, reliability, temporal and spatial scales, statistical properties, data requirements, skills required for collection, cost/benefit and cost-effectiveness. These criteria are discussed below, and then applied to select a pilot set of indicators.

General Importance. The indicator must reflect something of importance that has public meaning or can be easily related to something that has public meaning. If the indicator does not track a characteristic of the ecosystem that is easily understood and of significance to many people, it will less likely to be observed and acted upon.

Conceptual Basis. There must be a clear scientific rationale for how the indicator relates to the assessment question, so that measurements can be interpreted in a manner consistent with our present scientific understanding. That understanding is often most usefully expressed in the form of a conceptual model that relates changes in the ecosystem to changes in the indicator, and provides guidance for how the indicator should be measured.

Reliability. Is there existing evidence that the proposed indicator has been successfully used in the past to indicate ecological condition in a meaningful way? Such an indicator will engender more public trust than a new untested indicator. Reliability of new indicators can be tested with a retrospective analysis. If a dataset for retrospective analysis is unavailable, then reliability can only be determined through experience.

Temporal and spatial scales. Selected indicators must be appropriate to the spatial scale of South Bay, so that a change in the condition of the South Bay will be reflected by the indicator. Similarly, the indicator should respond on a temporal scale that makes it useful, rather than lagging behind changes in the ecosystem. For example, the health of migratory species or animals that spend a significant amount of time foraging outside the South Bay will not necessarily reflect local conditions.

Statistical properties. The statistical properties of the indicator (accuracy, precision, sensitivity) should be adequate for the job. Given the normal variability in environmental measurements, an indicator will be more useful if it can separate a "signal" of a significant ecological change from the "noise" of normal variability.

Data requirements. Assessments of ecological condition will be based on examining trends in indicators over time, and the necessary length of the data set one may need to collect to observe trends should be considered. Some changes, such as those driven by climatic alterations, will take longer to observe, while changes driven by disturbance can be observed over a shorter timescale.

Necessary skills. To be useful, indicators must not be so unusual or difficult to measure that only a few specialists are capable of producing defensible data. This is important to ensuring that a long-term database can be developed and increases the possibility of involving citizens in monitoring, making the indicators more cost-effective.

Cost/benefit and cost effectiveness. In general, the costs to develop and implement a program to measure an indicator are easier to estimate than the benefits, which is the value of the information obtained. However, consideration of costs and benefits still must be part of indicator selection, especially when several alternative indicators for an assessment question are possible. It is quite likely that certain indicators can be measured for much lower cost than others.

With these criteria and the four guiding principles described earlier in mind, an initial set of indicators for assessing the ecological condition of the South Bay can be established (Table 11). These indicators are presented to stimulate and focus debate; they should be carefully reviewed by a wide variety of stakeholders before a program to gather data and assess condition is implemented.

These indicators are not all in the same stages of development, and deciding upon precisely what will be measured, where, and how will take some additional work in certain instances. Some are presently being measured by existing programs, and can be easily integrated into an assessment of condition. Some have established benchmarks that provide guidance for interpreting measured values, while others do not. The following discussion examines the set of indicators proposed for each assessment question, identifying strengths and weaknesses using the above criteria.

Assessment Questions		Potential Indicator
No.	Biota	
1	Are populations of key species stable, increasing, or decreasing?	Census data for key mammal, bird (nearshore & pelagic), fish (nearshore, pelagic, migratory)
2	Is the number of threatened or endangered species increasing or decreasing?	Number of listed species; abundance of listed species
3	Are there adequate food resources to support key species?	Timing and magnitude of phytoplankton bloom, zooplankton settled volume, clam biomass, bird weight at fledging
4	Are key species successfully reproducing?	Seal pup census, bird hatching success
5	Is a diverse biological community present?	
	Pollution & Human Uses	
6	Is the Bay safe for contact recreation?	Exceedences of water quality objectives; presence of noxious algae blooms; Prevalence of trash
7	Are Bay water or sediments toxic to plants and animals?	Frequency of toxicity in standard aquatic and sediment tests; exceedences of water quality objectives, dissolved oxygen concentrations
8	Is it safe to eat fish and shellfish from the Bay?	Existence and severity of health advisories for fish and shellfish
9	Is commercial and sport catch of fish stable, increasing, or decreasing?	CDF&G landings trends for herring, shrimp, and sport fish
	Habitat	
10	Is the amount of all wetland habitat types (including mudflats) stable, increasing, or decreasing?	Area from surveys at MLLW (satellites or other)
11	Are long-term trends in salinity stable, increasing or decreasing?	Monthly average salinity at surface and at depth
12	Are invasive plants spreading in wetlands?	Area or frequency of nuisance species
13	Are freshwater inflows sufficient to maintain habitats and biota?	Depth of stratification, frequency of freshets, position of X-2
14	Is sediment supply adequate to maintain estuarine habitats?	Sediment budget estimated from bathymetric surveys

Table 11: Potential indicators for developing answers to the assessment questions.

Biota

A publicly meaningful assessment of ecological condition must include information about biota in the ecosystem. Since there are many more species in the Estuary than can be measured cost-effectively, we must select a small group as indicators. There are two key challenges to using biota in an assessment of condition (1) identifying appropriate species to use as indicators and (2) interpreting data on species abundance that can be highly variable.

Selecting indicator species is a subject that has been considered in great detail by conservation biologists, especially in the context of protecting biodiversity [45, 46]. Concepts put forward include using species as indicators of (1) composition or condition of ecosystems ("indicator species" or "focal species"), (2) vital ecological functions ("keystone species," whose removal will alter the ecosystem significantly), (3) a larger group of species ("umbrella species," whose conservation will conserve a relatively large number of other species "under their umbrella"), and (4) public popularity and interest ("flagship species," popular species that tend to be high in the food web and can also serve as "umbrellas").

The assumption that a single species can indicate the condition of a complex system, or a large number of other (even related) species, can be called into question [44]. The practicality of this approach has led to its adoption by many government agencies, yet there is not much empirical evidence to support the concept, due in part to the difficulty of conducting experiments to test this assumption. Focusing upon a single indicator can result in making management decisions that benefit the indicator species (e.g., protecting or expanding its breeding habitat), but not necessarily other species in the ecosystem. Also, a particular sub-population of a species can have unique physiology (such as temperature tolerance) or behavior, making it less representative of the species as a whole.

Conservation biology has focused mostly upon terrestrial environments, and only recently has there been a focus upon marine ecosystems [47-50]. Marine and estuarine environments (especially the pelagic zone) pose special challenges as their structure is much less stable, both temporally and spatially, than terrestrial environments. Annual and decadal events, including regular storm systems, large storms, or climatic fluctuations such as "El Niño," can cause rapid changes in marine environments. Also, marine predators tend to be more generalist feeders, complicating the understanding of trophic dependencies.

Even when an indicator species is selected, data on its abundance and distribution (particularly fish and aquatic invertebrates) are highly variable in time and space. Abundance is influenced by reproductive success, predation rates, climate, habitat availability, and other factors. It is therefore not possible, without a significant amount of ancillary information, to draw conclusions about the cause of observed trends in abundance.

One recent scientific panel developing ecological indicators for the estuary [15] proposed to develop multi-metric indices to use as indicators of ecological or biological integrity instead of single species data. Their concept included five indices (fish, birds, vegetation, habitat specialists, decimated species) into which population data would be combined (in a method to be specified later) to produce an index more robust than single species abundance data

[17]. While such indices may be preferable to measurement of single species, they do not presently exist for the South Bay, and developing them would comprise an independent research project[3]. Use of such indices has many strengths, and the "Index of Biological Integrity" has been used to assess the impact of anthropogenic stressors in running waters and estuaries throughout the United States [40].

Despite the problems associated with using biota as indicators and interpreting data on abundance, there are still compelling reasons for incorporating them in an assessment of ecological condition. First, they satisfy the criterion of general importance and public reliability as well as any indicator. In addition, growth and reproduction of higher organisms is a clear indication of a functioning food web and environment that meets minimal habitat requirements. Many existing programs measure the biota of the estuary, especially its fish and birds, providing existing data for assessments.

The South Bay contains 57 resident species of fish [51] and over 500 species of phytoplankton (J. Cloern, USGS, personal communication). Thus, identifying the appropriate "key" species to answer the assessment questions (Table 9) requires applying the indicator selection criteria above using professional judgement. The Habitat Goals Project used several teams containing over 60 local scientists, and using eight criteria identified 131 key species [38]. The San Francisco Estuary Project developed a list of potential species (or groups) to include in a biological monitoring program including plankton, shrimp, fish bacteria, invertebrates, plants, and introduced species [3].

Since it is unlikely that a cost-effective survey of 131 species can produce statistically meaningful information, the list of key species must be smaller. The following discussion presents a provisional description of biota to be used as indicators, based on the criteria above and the need to answer the assessment questions in Table 9.

Are populations of key species stable, increasing, or decreasing? This indicator should include data on the abundance of higher trophic order species resident in the South Bay, selected to represent both nearshore and pelagic environments. Because of their visibility, such "flagship" species are of public importance; they are a valued attribute of the South Bay ecosystem. Their position in the food web provides an assessment of the ecological processes of carbon storage and transfer, and they integrate the impact a large number of anthropogenic and natural stressors. Their position in the food web also provides some "umbrella" characteristics as indicators for the ecosystem.

Due to the myriad factors influencing abundance cited above, the statistical properties of abundance data may make them difficult to interpret. This problem is lessened by long-term (decadal scale) datasets, where trends may become apparent despite interannual variability, including "regime shifts" characterized by large population changes over a short period. It is also inevitable that the few selected indicators will provide a biased view of the ecosystem, as no indicator is a perfect representation. Future research will help uncover factors that

[3] The Bay Institute is working presently on developing multi-metric biological indicators which include focal species instead of relying on focal species themselves as indicators of ecosystem health (A. Pawley, personal communication).

could be used to normalize abundance data among years, developing indices with less variation than the raw abundance data themselves.

Selecting indicator species from diverse taxa (e.g., mammals, birds, and fish) can maximize both the flagship and umbrella characteristics of the indicators. The best mammal indicator is likely the harbor seal (*Phoca vitulina richardsoni*), a piscivorous resident of the South Bay. Bird species could include pelagic-feeding piscivores such as the cormorant (*Phalacrocorax auritus*) or the Forster's Tern (*Sterna forsteri*), and nearshore feeders such as the Western snowy plover (*Charadrius alexandrinus nivosus*)or the black-necked stilt (*Himantopus mexicanus*). Proposing fish species as indicators is best accomplished after a detailed examination of DFG data [52]. To assess the beneficial use of South Bay as migratory habitat for fish, the returns of chinook salmon (*Oncorhynchus tshawytscha*) or steelhead (*Oncorhynchus mykiss*) to major streams in the South Bay (Alameda Creek, Guadalupe River, Coyote Creek, Stevens Creek, and San Francisquito Creek) could be assessed.

Is the number of threatened or endangered species increasing or decreasing? Endangered species in the South Bay tend to be indicators of the composition of the landscape, as they are often tied to particular habitats that have become rare or fragmented. A simple indicator is the number of species on the list of threatened and endangered plants and animals maintained by the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and DFG. While easy to collect, this is actually an indicator of our efficiency and commitment to listing species, rather than an indicator of the number of rare species in the South Bay.

An alternative is to select a few endangered species that reflect some of the most threatened habitats in the South Bay and monitor their abundance through time. Species to be included in such a program could be the California Clapper Rail (*Rallus longirostris obsoletus*), the Salt Marsh Harvest mouse (*Reithrodontomys raviventris raviventris*), the Western snowy plover or possibly the green sturgeon (*Acipenser medirostris)*. There are likely to be data available on the abundance of these species as public agencies are mandated to track their status and plan for their recovery.

Are there adequate food resources to support key species? Examining the food resources available to support key species provides an important indication of ecosystem function, although deciding which indicators are meaningful measures of this attribute can be problematic. One indicator is the timing and magnitude of the phytoplankton bloom as a measure of productivity at the base of the food web, where solar energy is converted to fixed carbon. Long term data sets for phytoplankton productivity are available [53], and the conceptual basis for linking productivity to ecosystem condition is solid.

Of course, key species do not consume phytoplankton, but rather organisms intermediate in the food web such as zooplankton, benthic invertebrates, and "forage" fish. Another possible indicator of available food resources is settled volume from zooplankton net tows, a simple measure of zooplankton abundance that has been used to track food for fish [54]. Measures of zooplankton are somewhat empirical based on net size, and not all species captured in the net would have the same value as "food" (R.T. Cooney, personal communication).

Zooplankton data from the South Bay are currently being examined by regional experts (W. Kimmerer, personal communication), who may be able to suggest a less uncertain indicator.

A measure of biomass of benthic invertebrates could be considered, but its statistical properties would make interpretation challenging. Alternatively, the number of taxa of benthic invertebrates could be considered. Long-term data on benthic fauna in the South Bay are available from studies conducted by the US Geological Survey, but scientists have largely been unable to explain observed variations (F.H. Nichols, personal communication).

Another indicator of food availability in the South Bay could be based on visits to nests of birds that forage in the region to measure growth rate, weight at fledging, or other characteristics of chicks. These measurements are relatively easy to make if the species selected has accessible nest sites (such as the snowy plover or cormorant). However, weight at fledging is influenced by other factors, and it has been suggested that in birds with long rearing times (e.g., penguins) weight at fledging is not well correlated with food supply [55]. Reduced food availability appeared to reduce the weight of murre chicks in Cook Inlet, Alaska, but kittiwake adults under these conditions tended to increase their foraging activity (losing weight themselves) while chick weights remain constant [56]. In another study, weight loss just before fledging was common in pigeon guillemots on South Farralon Island, although maximum chick weights were observed in years with higher food supply. This suggests that maximum weight prior to fledging might be a better indicator than weight at fledging [57].

Are key species successfully reproducing? Successful reproduction of key species is at the heart of maintaining a sustainable population, and is an indicator easily understood by the general public. Successful reproduction integrates many factors, including food and habitat availability, climate, predation refuge, and physiological health. To the extent that population measures focus on long-lived species, verifying reproduction is important to document the availability of young to recruit into the adult population.

Two indicators for reproduction of key species in the South Bay are pup counts at the harbor seal rookery in Mowry Slough and hatching success of resident birds such as black-necked stilts, snowy plovers, or cormorants. There are standard methods available for both of these measures, and data need only be collected during a small portion of the year. Colonial fish-eating birds have been used for many years as indicators in the Great Lakes region [58, 59]. These data could easily be collected in conjunction with the population census for harbor seals and fledging weight of bird chicks.

Reproductive conditions of invertebrates might also be used to assess the condition of the South Bay. Gamete production in the clam *Macoma balthica*, a resident of the South Bay, has been shown to be an indicator of reduction in pollution. The return of the ability of this resident invertebrate to reproduce, associated with a reduction in trace metal contamination, would be an easily understood indicator of improving ecological condition [60].

Is a diverse biological community present? While the health or abundance of flagship species is an easily understood concept in public discourse, the biological attributes derived from scientific assessments include a focus on biological composition of the ecosystem as a whole. Attributes such as species diversity, genetic diversity, and trophic structure are important aspects of the structure of the ecosystem that should be considered in an assessment of condition (see Appendix 2). Indicators of these attributes could include calculated indices of species diversity (either total or native), species or taxa richness, or number of species in particular taxonomic groups. Measures of trophic structure include food web complexity, presence/absence of apex predators or dominant herbivores, or the number of functional feeding groups or "guilds" [18].

While these attributes have a sound theoretical basis, reaching consensus regarding specific indicators may be difficult. More over, creating a publicly meaningful description of some of these measures might take some time. Deciding which species to include in these indicators is not straightforward, and if new surveys are required on a regular basis to make these indicators statistically robust they might not be cost-effective.

Pollution and Human Uses

Is the Bay safe for contact recreation? Human health impacts of water contact are among the most well understood pollution problems by the public given the severe impact of waterborne diseases throughout human history. There are established state and federal standards for assessing water quality in relation to bacterial contamination [Table 3 in 8], and these are used throughout the U.S. to identify potential health hazards. The existence of standard methods makes sampling straightforward, and exceedences of standards have been used to generate an assessment of condition of coastal ocean waters in Southern California [25].

The use of a single bacterial standard for determining public health risk has been criticized [61, 62], although a recent survey of the scientific literature suggests that the rate of certain symptoms or symptom groups is significantly related to bacterial indicator counts [63]. A criticism is that indicator bacteria measured in standard tests cannot distinguish between fecal contamination of human and animal origin [64, 65]. In addition, viruses and protozoa that also pose a human gastrointestinal health risk are not detected by bacterial indicators, nor are microbes that cause respiratory infections. Measurements of bacterial indicators in small water bodies can also be highly variable, and there is a significant amount of variability in the standard test methodology. The established standards are of greatest use in detecting gross episodes of contamination, such as sewage overflows and runoff from major rainfall events.

Consequently, it is clear that the conceptual basis for the present indicator is imperfect, and the improvement of contact recreation indicators, especially for non-swimming recreational activities, is an area of active research [66]. However, there is an extensive amount of available data for this indicator collected using standardized methods. It is measured frequently by existing programs because of existing legal standards.

Are Bay water or sediments toxic to plants and animals? The toxic impact of pollutants on aquatic life is an issue of considerable public importance and a major driver for existing water quality law and regulation. Toxic impacts, from factors such as dissolved oxygen sags, have been used reliably to indicate water quality historically, and there are many established techniques for assessing water chemistry and toxicity. Laboratory studies have been used to derive water quality objectives (chemical concentrations), and these objectives are used for legally defining the condition of ambient waters as "impaired."

Available indicators to address this assessment question typically include measurements of water chemistry (including dissolved oxygen and toxic chemicals for which there are water quality objectives). Laboratory tests of aquatic toxicity are also used to assess the impact of complex mixtures of contaminants in ambient waters. Chemical and toxicological measures are routinely made in sediments, although interpreting these data has been more challenging (there are no current sediment quality objectives in existence). The RMP routinely measures chemical concentrations and toxicity in water and sediment, making these data readily available for use in assessing condition.

The conceptual basis for using these tools is not without uncertainty. For example, water quality objectives and sediment quality guidelines based on laboratory studies are not always predictive of impacts in a given environment. These problems can be addressed, however, as when recent experiments demonstrated that phytoplankton in the South Bay were not harmed when exposed in ambient water to copper concentrations above the federal water quality objective [67]. Species used in EPA-approved standard laboratory toxicity tests are not necessarily resident in the South Bay, and resident species could be more or less sensitive to contaminants. Although chemical and toxicological measurements require specialized skills and equipment, there are many organizations capable of accurately following established protocols. The USEPA has standardized many methods, and the RMP maintains a strong program of quality control that promotes data quality in the region.

Is it safe to eat fish and shellfish from the Bay? The cleanliness of fish and shellfish in the Bay is an indicator of pollution that is easily understood by the public, and is directly linked to the human health and safety for those who harvest fish and shellfish from the estuary. Oyster culture was a historic beneficial use of the estuary, which is presently impaired due to pollution. Assessing the safety of consuming contaminated fish and shellfish is a complex task involving modeling contamination and consumption patterns, medical information, and assumptions regarding tolerable risks. In California this is the job of the Office of Environmental Health Hazard Assessment (OEHHA). Based upon the concentrations of PCBs, mercury, DDT, dieldrin, chlordane, and dioxins in fish from San Francisco Bay [68], OEHHA issued a health advisory [69] recommending that anglers consume no more than two meals of fish from San Francisco Bay per month. Nursing women, women who are or may become pregnant, and children under six years of age are advised to consume no more than one meal of fish per month.

Fish contamination is a reliable indicator for the public, and one that has already been assessed using standardized methods by existing programs. The existence of health advisories, and the degree of the restriction, could therefore be used as an indicator of condition. According to a recent consumption survey in the Bay Area, the five most popular fishes eaten by anglers (in decreasing order of popularity) were striped bass, halibut, jacksmelt, sturgeon, and white croaker [70]. These five species are all currently being monitored for contaminants by the Regional Monitoring Program for Trace Substances in the San Francisco Estuary (RMP) on a triennial basis, with the next sampling effort planned for 2003. Resulting data will be submitted to OEEHA for analysis.

Is commercial and sport catch of fish stable, increasing, or decreasing? Commercial and sport fishing are traditional human uses of productive aquatic ecosystems, and are identified as beneficial uses of the South Bay (Appendix 1). In general, the productivity of the ecosystem as measured by the amount of fish or shellfish available for human harvest is an easily understood measure of condition. A more productive ecosystem, as evidenced by sustainable catches of fish over the long-term, can be considered a publicly reliable indicator of ecological condition. DFG has a significant amount of long-term data on fish catch.

The conceptual basis for using commercial fish catch statistics from DFG can be challenged, however, as the abundance of commercial species (such as herring or salmon) can be greatly influenced by hemispheric-scale climatic fluctuations. A better measure of commercial catch for the South Bay might be the small shrimp fishery that is sometimes present, or sport fish statistics collected for this region.

Habitat

Is the amount of all wetland habitat types (including mudflats) stable, increasing, or decreasing? The protection and restoration of wetland habitats in the Bay Area is an environmental objective with widespread consensus support (Tables 1, 8), due mainly to the well-documented loss of wetlands and the endangered status of species that rely on these habitats. Areal extent of wetlands is an easily-understood concept, making this measure a compelling indicator. Digital analysis of aerial and satellite imagery in geographic information systems provides the ability to track the extent of various wetland habitats in the South Bay, and a strong baseline data set is already in existence [38].

Wetlands can be classified in many different ways. Two recent assessments of the Bay Area used different schemes [38, 71], and these in turn were different from the National Wetlands Inventory of the US Fish and Wildlife Service. Use of a consistent definition will be necessary to obtain the most statistically robust long-term trends. Data can be expensive to obtain and analyze, and existing data regarding the state of attempted restoration projects (including their success) are not easily obtained (A. Pawley, Bay Institute, personal communication). Moreover, it is possible to restore wetland coverage without necessarily restoring all functions of a natural wetland ecosystem. A multi-agency effort to coordinate monitoring of wetlands in the Bay Area is being developed as part of the newly-formed multi-agency Bay Area Wetland Restoration Executive Council. Useful data regarding the extent of wetlands in the South Bay will likely be available from this program in the future.

Are long-term trends in salinity stable, increasing or decreasing ? In an estuary, salinity can be considered an important descriptor of habitat. Salinity variations promote primary production in the Spring through stratification of the water column, and are indicative of differences among freshwater, brackish water, and saltwater habitat. Plant and animal communities in the South Bay have evolved within daily and seasonal cycles of salinity changes, and tracking these cycles provides an indication of habitat condition in the estuary. There are extensive existing data on salinity, and more data are relatively easy to collect using inexpensive standard methods.

While certain salinity regimes are necessary for particular species or habitat types (such as salt marsh), characterizing salinity on the appropriate temporal and spatial scale is essential to track condition. Daily, weekly, or monthly sampling will provide a different type of data set for analysis, as will samples at the surface as compared to samples at depth. Salinity information will be most useful when trends in long-term data collections allow for conclusions to be drawn regarding changes in the average conditions of the South Bay. Long-term data sets will also provide a perspective for interpreting short-term changes (such as drought periods). If a relationship can be established between salinities in the South Bay and the position of X-2 (2 ppt isohaline) in the northern reach, then X-2 might also be an indicator for salinity of value to the South Bay.

Are invasive plants spreading in wetlands? San Francisco Bay is an amalgam of native and introduced species, both in the estuary [72, 73] and in tidal marshes [74]. While some of these species might be present in only small numbers that do not greatly influence other biota, some introduced species can spread very quickly and develop large populations that can significantly impact valued ecosystem attributes.

Among the latter are several species of invasive plants including Atlantic and English cordgrass (*Spartina alterniflora* and *S. anglica*), pepper weed (*Ledidium latifolium*), and yellow star thistle (*Centaurea solstitialis*). *S. Alterniflora* (also known as smooth cordgrass) has the capability to alter mudflats and tidal channels into dense marsh that cannot be used by many species [38]. The existing consensus regarding the problem these species present, and the fact that a quantitative measure of their distribution can be documented from ground surveys, suggest that the areal extent of invasive plants could be a reliable indicator of habitat condition of the South Bay. There is significant interest in attempting to control these species, and a long-term measure of their areal extent could also provide a meaningful assessment of change in condition over time.

There is also extensive documentation of the introduction of aquatic animals in the Bay, and some of these (e.g., the Asian clam *Potamocorbula amurensis*) can become very widespread. The correlation between the introduction of the clam and the decline in zooplankton stocks in the Northern reach of the estuary suggests that aquatic species can also have broad-scale impacts on the ecosystem [75], although *P. amurensis* does not appear to have had such an impact on the pelagic food web in the South Bay (J. Thompson, 2001 State of the Estuary conference). The high variation in the abundance and distribution of these aquatic species (even from surveys lasting decades) makes it difficult to document trends reliably (F.H. Nichols, personal communication). Since means to control or eliminate these animals are particularly challenging, there will be little or no influence of eradication programs to track as will be the case for invasive plants.

An assessment of exotic species established over time [73] could be used as a long-term indicator of condition. Such data appear to be available on the scale of the entire Bay. Data for the entire Bay, however, are not necessarily representative of the South Bay, where the environment will be conducive to a different set of introduced species than the Bay as a whole.

Are freshwater inflows sufficient to maintain habitats and biota? Freshwater inflow is clearly a factor of critical ecological importance, and has a major influence on salinity [76], on the spring time stratification so critical for phytoplankton production [77], on the distribution and maintenance of various marsh habitats, and on fish populations [78]. Freshwater inflow significantly reduces the residence time of water in the South Bay, providing increased flushing of dissolved contaminants (and reduced bioaccumulation of silver in particular) [72].

The precise mechanisms by which freshwater inflows are related to various indicators is a vastly complex subject studied by many scientists in the region for decades (e.g., the Interagency Ecological Program), and it is not possible to summarize that information here for purposes of identifying indicators. Defining “sufficient” fresh water inflows for use as an indicator may not be feasible. Concepts that could be investigated as indicators of sufficient flows include depth and/or duration of stratification, frequency of freshets, relative coverage of freshwater, brackish water, and saltwater marsh, or indices of circulation across the San Bruno Shoal or other locations.

Is sediment supply adequate to maintain estuarine habitats? While the processes of sediment input and loss is unlikely to be high on the minds of members of the public when considering the ecological condition of the estuary, on the scale of decades these processes play a critical role in forming the estuarine habitats that sustain the ecosystem. Marshes, mudflats, and tidal channels are maintained over time by a dynamic equilibrium between sediment supply and loss, and the processes that redistribute sediment through the system.

Our present understanding suggests that sediment supply to the estuary will decline over coming decades due to a combination of factors, and could produce significant changes in the estuary [38, 79]. These changes include erosion of mudflats and marshes, slower accretion of sediment, and reduced suspended sediment concentrations in the water column. Given that primary productivity by phytoplankton is generally light-limited in San Francisco Bay, a change in sediment supply could result in increased primary production and attendant problems of eutrophication.

The importance of sediment supply suggests that an indicator to track this process would be valuable in considering the ecological condition of the Bay. One potential indicator is the overall change in sediment mass in the estuary, which can be estimated from bathymetric surveys corrected for sea level rise [80]. Such an indicator will not provide information on more local process of erosion and accretion, and would likely need to be combined with measures of these processes at index sites in the estuary.

Using Indicators to Assess Condition

Once measurements of indicators are available, how are these data used to assess the condition (and ultimately the "health") of South Bay? This is a complex question to which there is no single answer. Depending on the indicator and the nature of the trends in the data, various scientists or other stakeholders could derive different interpretations. Even with the input of impartial peer reviewers, it is quite possible that different interpretations could be considered reasonable.

This section will briefly review how data from indicators could be evaluated by examining two situations. The first situation is where there is a clear quantitative benchmark, such as a legally enforceable water quality objective, by which to evaluate indicator measurements. The second situation, which will be more frequently encountered with the indicators described above, is when quantitative benchmarks do not exist.

A quantitative benchmark, or target value, for an indicator essentially defines the "healthy" condition for the ecosystem. Such is the situation for most of the indicators of water quality where standards exist against which we can compare measurements. This allows for publicly-accessible, quantitative assessments such as the percent of samples that exceed standards [81] or are toxic in laboratory bioassays [82]. Appendix 3 provides a brief description of quantitative assessments of condition from different programs, all of which are based on measures of water quality. This appendix describes the method used in Southern California to calculate letter grades for water quality based upon exceedences of bacteriological standards [25].

Comparison of a long-term trend to a quantitative benchmark can also be easily depicted graphically. For example, a long-term trend in dissolved oxygen concentration in the South Bay, if measurement began prior to sewage treatment plant construction, would show concentrations below the 5 mg/L water quality objective rising to above the standard (i.e., improving health and condition) after construction. Long-term measurements of the areal extent of wetland habitats can also be gathered and compared in a very straightforward fashion to the goal of increasing the areal extent of tidal marsh in the South Bay from 9,000 to 25-30,000 acres [38].

When quantitative benchmarks are not readily available from regulatory standards, they must be devised or the data must be analyzed in a qualitative fashion. Benchmarks can be calculated by using historic ranges for certain measurements or by identifying reference conditions against which to compare existing measurements of an indicator. An example of the latter strategy is the calculation of "Effects Ranges" for use with measurements of sediment chemistry. These indicators were calculated from measurements of biological response that were correlated with measurements of sediment chemistry from a large number of sites around the country. From this large database sediment chemistry concentrations were estimated above which effects are probable (effects range median or ERM) and below which effects are unlikely (effects range low or ERL) [83]. Despite criticism of these guidelines as not predictive in many cases [84], they are often used to provide a meaningful interpretation to measurements of sediment chemistry [81, 82, 85] as there are few alternatives.

In some instances, establishing benchmarks may be difficult. For example, there is relatively poor historic data on harbor seal populations in the South Bay, nor do we have a reference location that can provide a meaningful comparison. In this instance, examining future trends will be essential to interpreting condition. For example, a stable or increasing harbor seal population indicates better ecological condition than a declining population, which suggests the adverse impact of anthropogenic or natural stressors. Another example of indicator data without clear benchmarks is long-term trends for contaminant concentrations in bivalves, where statistically significant declines are evident in the South Bay over the last 20-30 years for silver in both transplanted mussels [86] and resident clams [60]. As silver is a known toxicant in estuaries [87], its declining concentration can be considered an indication of improving condition, particularly when correlated with other measures such as improved reproductive health in clams [60].

Continued research should improve our ability to interpret trends in the future. By correlating long-term trends in indicators with various other data sets, it is possible to generate hypotheses regarding causative linkages that can be tested by research. Thus, instead of waiting until research identifies how best to measure indicators, it can be argued that we should begin measuring indicators in order to learn how to refine them.

In the end, certain indicators will be more amenable than others for use in a quantitative "grading" scheme for a report card. Publicly-meaningful information can be derived, however, even if there are not clear benchmark values against which to compare indicator measurements. Any method of quantification leading to a "grade" must be clearly documented so that stakeholders can understand how the measurements of an indicator were used. As public debate and scientific research clarify the meaningful interpretations of indicators, it will be possible to re-evaluate past "grades" using alternative schemes developed in the future.

Strategic Considerations for Implementation

From the preceding discussion of indicators and their interpretation, it is clear that the suggested framework presented for the assessment of ecological condition in the South Bay needs further refinement and evaluation before commitment to its long-term implementation. This section describes strategic considerations for establishing a process for refining and implementing the assessment.

The assessment protocol will need to be considered and supported by a majority of the stakeholders in the South Bay, including regulatory agencies. This will require identifying an existing group or establishing a new one that can serve as a Steering Committee for the assessment. Since journalists will communicate assessment results to the public, a journalist should serve on the committee to comment on both the content and format of the product.

With approval of a conceptual protocol, the assessment should be drafted by a select group of local scientists for two reasons. First, a critical step in conducting the assessment will be refining the indicators to improve and clarify their conceptual basis. Which characteristic of bird chicks provides the best insight into food availability, and which species should be assessed and precisely when should the measurements be taken? What is the quality of historic data? Can these data be trusted for use in an assessment of ecological condition? These are questions best answered by scientists, and their authority and knowledge will be vital for the creation of a cogent and meaningful assessment. Second, public review will be best made on a completed draft that details the scientific interpretations of the indicators. Only with these interpretations available will it be possible to evaluate the effectiveness of the report.

Since indicator measurements are most useful when part of a long-term program, a long-term commitment to the measurements must be feasible. Given the short-term nature of public funding decisions, this is a challenging goal. However, there are local examples of existing programs that have successfully made long-term ecological measurements, including several conducted the U.S. Geological Survey, DFG, the RMP, and the Interagency Ecological Program. Understanding the methods they used will be valuable in designing a successful long-term strategy for assessing condition. In particular, consideration should also be given to data quality control and archiving [88]. The integrity of long-term time series is essential to allow analyses to elucidate condition and establish benchmarks.

Finally, any program to assess condition will need to practice "adaptive" management, in which interim results are considered and used to refine the components and direction to better achieve programmatic objectives. In a long-term program, it is likely that programmatic objectives will evolve in response to changing conditions. For example, climatic changes over coming decades could alter species composition and landscape form in the South Bay, resulting in a need to re-examine some indicators through adaptive management.

Available Data for Evaluation of Indicators

One of the key assumptions in the development of the proposed approach for assessing condition of the South Bay is the use of available data to the maximum extent possible. An initial survey was conducted to identify data sets that would be useful for addressing the assessment questions. The results of this preliminary survey uncovered data sets that could be useful for each of the assessment questions (Table 12). Of course, until the data are obtained and considered in more detail, it is not possible to know if they will actually be appropriate for an analysis of ecological condition, and the discussion above has identified problems with interpreting some types of data included in Table 12. This list of data sets is unlikely to be comprehensive given the large number of agencies and organizations that collect data in the South Bay. In addition, not all the inquires made as part of preparing the report have been answered, and it is expected that additional data sets will be identified once all correspondents have been contacted. It is encouraging to see that there is so much relevant available data, however, given the importance of trying to construct retrospective analyses of condition in a pilot assessment.

Areas of Concern	Question Number	Data Set	Custodian
Biota	1, 5	Fish Data	Marine Sciences Institute, IEP Program
	3	Zooplankton	SF State University (Kimmerer)
	1, 5	Black-necked stilts	Point Reyes Bird Observatory
	1, 5	American Avocets	Point Reyes Bird Observatory
	1, 4, 5?	Song birds of the South Bay	San Francisco Bay Bird Observatory
	1, 4?	Water Birds of the South Bay	San Francisco Bay Bird Observatory
	1, 5	Bird Count	SC Valley Christmas Bird Count
	1, 5	Mid-winter Duck Counts	DFG
	4, 5	Harbor Seal Census in South Bay	DFG
	1	1980-1995 Fish, Shrimp, and Crab Sampling in the San Francisco Estuary	DFG
	3	Benthic macrofauna of a South Bay, mudflat, 1974 to 1983 microform	USGS
	2	Endangered Species Report	U.S. Department of Fish and Wildlife**
	2	Important data sets for Salt Marsh Harvest Mouse	San Francisco Bay Estuary Project
	1	Status and Trends on Wildlife in the San Francisco Estuary	San Francisco Bay Estuary Project
Pollution & Human Uses	9	Annual state of the fisheries report	DFG
	6	Beach Watch	USEPA-Office of Water
	9	California's Living Marine Resources and Utilization	University of California-Agricultural and Natural Resources
	7	Dissolved oxygen data	USGS
	8	Fish Consumption Advisory	Office of Environmental Health Hazards Assessment
	8	RMP Bivalve Tissue Data	San Francisco Estuary Institute
	6,7	RMP Water Data	San Francisco Estuary Institute
	7	RMP Sediment Data	San Francisco Estuary Institute
	8	RMP Fish Data	San Francisco Estuary Institute
	6	Bay Area Waste Diversion Rates	CA Integrated Waste Management Board
Habitat	10	Wetlands & Riparian Habitat Acquired & Restored in the SF Bay Delta Estuary	San Francisco Estuary Project
	10	National Wetlands Inventory	U.S. Fish and Wildlife Service
	10	Index of watershed indicators	USEPA
	11, 14	Water Quality of San Francisco Bay	U.S. Geological Survey
	11, 14	RMP Water Data	San Francisco Estuary Institute
	13	Delta outflow	Interagency Ecological Program
	12	European Green Crabs	Marine Sciences Institute
	12	Chinese Mitten Crab	Marine Sciences Institute
	12	Biological Invasions	San Francisco Estuary Institute

Table 12: Preliminary list of available data sets for use in answering assessment questions. Question number refers to numbered questions in Table 9.

Possible Next Steps

Clearly, there is still much work to be done to develop methods to assess the ecological condition of the South Bay. This section will conclude the report by describing steps that could be taken to refine the assessment methodology. These steps begin with an evaluation by stakeholders, including the regulatory community, as to the worthiness of this approach to assess ecosystem condition. Upon favorable review, partnerships would need to be developed to guide and fund further refinement and peer-review of the indicators and potential pilot monitoring.

Developing partnerships. The City of San Jose commissioned this report as a preliminary effort to explore the possibility of developing alternative assessment methodology and techniques that could be further developed and implemented as appropriate. Given the large number of stakeholders interested in such an assessment, however, some type of regional partnership would appear to be the only feasible approach to take to discuss, and on favorable review, prepare, an assessment.

While the assessment approach described in this report is based on recent publications from authoritative sources such as the Science Advisory Board of USEPA and the National Academy of Sciences, and has been reviewed by several leading local scientists, review by a broad array of stakeholders is an essential first step to establishing a partnership. For the approach described in this report to be useful, it must be considered valuable by a large segment of the community. Are the assessment questions compelling? Would answers to these questions provide the knowledge we need to address policy questions related to management of the Estuary? Are there other assessment methods that would be more useful to the community? The answers to these questions can only be obtained through review of the report by a broad and diverse audience.

Several characteristics of an assessment of condition help define who must be included in the review of the report. First, this project would require the participation of those public resource agencies with a mandate that includes the South Bay ecosystem. These include state agencies (Regional Water Quality Control Board, Department of Fish and Game), federal agencies (U.S. Geological Survey, U.S. Environmental Protection Agency [San Francisco Estuary Project]), and local government (city and county agencies, water and flood control districts). Second, the diversity of indicators requires expert advice from a broad array of scientists, representing the disciplines of ecology, toxicology, chemistry, biology, and physics. Finally, due to the judgment that will need to be exercised to establish indicators and interpret the measurements, the project will require the collaboration of many stakeholders from government, environmental and other public interest groups, and the regulated community.

One issue that will need to be addressed in creating the partnership is the geographic area to be addressed by an assessment of ecological condition. While the City of San Jose has particular interest in the South Bay, it may be that assembling an effective partnership will require expanding the coverage of the assessment to the entire Bay. At this spatial scale, the assessment may have more relevance to several potential partners, and attract more interest and support.

Refining and peer reviewing indicators. The prospective indicators identified in earlier sections of this report are certainly not definitive selections, but rather are provided to stimulate and focus debate among local scientists and managers. Changes to the assessment questions and the conceptual model, may suggest changes to the indicators that should be reviewed carefully by experts before development of a program that uses them to assess the ecological condition of the estuary.

The process of refining indicators could be conducted by a set of work groups with specific expertise. There may be existing work groups, such as the RMP Exposure and Effects Pilot Study or the Bay Institute's Expert Panel on Indicators, that could be used for this purpose. To keep the project focused on preparing indicators that are understandable by the public and useable by the regulatory community, the work groups will need to be interdisciplinary in nature and include scientists, regulators, and the regulated community. A likely task for the work groups will be to methodically apply the NRC criteria to potential indicators to establish a clear record-of-decision for recommended indicators.

Funding. The goal of this report is to present an approach for conducting an assessment of the ecological condition of the estuary. If accepted as appropriate by stakeholders, funding will be required to complete program planning. These planning funds could be used to support the establishment of the Steering Committee, and a formal review and refinement of the indicators. It may be useful to make explicit the conceptual model that is inherent in the assessment questions. This model, after review by the Steering Committee and others, could be used in the process of refining indicators.

Until more information is available on the set of indicators to be used, it is not feasible to produce a meaningful cost estimate for an assessment program. It seems unlikely that an ongoing program to assess ecological condition will be conducted independent of existing monitoring programs. Instead, a program to assess ecological condition will likely depend on existing programs to compile data on particular indicators, and then these data will be integrated and published as an assessment of condition.

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Appendix 1: Beneficial Uses of the South Bay

The Regional Water Quality Control Board is responsible under State Law with protecting and enhancing the beneficial uses of the waters of San Francisco Bay and its watershed. The existing and potential beneficial uses, as outlined in the "Basin Plan" or Water Quality Control Plan for the Bay, are presented in the Table below.

Beneficial Use	Basin Plan Abbreviation	South Bay Basin (north of Dumbarton Bridge and South of Bay Bridge)	Santa Clara Basin (south of Dumbarton Bridge)
Ocean, commercial, and sport fishing	COMM	E	E
Estuarine Habitat	EST	E	E
Industrial Service Supply	IND	E	E
Fish Migration	MIGR	E	E
Navigation	NAV	E	E
Endangered Species	RARE	E	E
Water Contact Recreation	REC-1	E	E
Non-Contact Water Recreation	REC-2	E	E
Shellfish Harvesting	SHELL	E	P
Fish Spawning and early lifestage development	SPWN		
Wildlife Habitat	WLD	E	E

Table A1-1: Beneficial Uses of South Bay in the Water Quality Control Plan for the San Francisco Bay Region. E = existing use, P = potential use

Appendix 2: Scientific Frameworks for Assessing Ecological Integrity and Health

The need to report on the health or integrity of ecosystems is clearly recognized in the scientific community. Scientists are attempting to take our present understanding of ecosystems and use this to identify a framework, or set of generic attributes, that should be considered when attempting to develop meaningful indicators of ecological health or integrity.

As part of preparing testing the scientific credibility of the assessment questions (Table 8), three of the main scientific assessment frameworks were reviewed. These include the National Research Council's recent report *Ecological Indicators for the Nation* [88], a report by the Ecological Processes and Effects Committee of the Science Advisory Board (SAB) of the USEPA(to be released in the Spring of 2002; T.F. Young, personal communication), and a report prepared by a blue-ribbon scientific panel convened by Environmental Defense (ED/UC) and the University of California [15]. The latter group focused on San Francisco Bay-Delta watershed, and worked closely with the CALFED Ecological Indicators Working Group. Both the SAB and the ED/UC group followed an framework put forth recently by Harwell *et al.* [43].

Table A2-1 summarizes the ecosystem attributes that have been identified from these more scientific approaches. We can see that the attributes implicit in the policy goal statements (Tables 5 and 8) are reflected in the scientifically-derived set of attributes,. The scientific frameworks focus upon the concepts of ecosystem processes and functions as an essential attributes. The lexicon among the different studies can vary (e.g., the SAB separates water quality as attribute, while the ED/UC group includes water quality as an aspect of habitat quality).

Due to the various shortcomings of focusing upon the abundance of particular species (often vertebrates) as a key attribute [44], when so many factors can influence abundance, the ED/UCB and SAB groups rely upon the concept of focal species [89] to tie assessments of biota more closely to ecosystem processes. This approach considers the ecological factors limiting species (area, resources, certain processes), and the most limited species in each group is the focal species. If the focal species are protected, then other species with less demanding requirements should also be protected.

In addition, the known stressors in the ecosystem and the scale of the assessment can influence description of important attributes. The NRC is considering an assessment of all the nation's ecosystem (aquatic and terrestrial), and focuses it's consideration of water quality on the widespread issue of nitrogen and phosphorus loading. Attributes that track known stressors in the ecosystem provide essential knowledge to link management actions with ecological condition.

EPA SAB	National Research Council	ED/UC
Landscape Structure and Composition	**Extent and Status of Ecosystems**	**Habitat Quality**
Spatial extent, landscape pattern, landscape diversity	Land cover, land use	Habitat type, proportions, and connectivity; water quality
Biotic Condition	**Ecological Capital: Biotic Raw Materials**	**Native Biota**
Community presence/absence; species/taxa diversity; species composition; trophic diversity	Total species diversity	Focal species of fish, birds, vegetation
Genetic diversity, population patterns and dynamics, habitat for focal species	Native species diversity	Habitat specialists
Physiological status of organisms; symptoms or signs of disease		Decimated species
Ecological Processes	**Ecological Functioning**	**Energy/Nutrient Flow**
Energy flow	Productivity, NPP, carbon storage	Primary production, bioavailable carbon
Material flow	Nutrient use efficiency; nutrient balance	
Genetic information flows	Lake trophic status; stream oxygen	
Physical/chemical characteristics	**Ecological Capital: Abiotic Raw Materials**	
Macro/micro nutrients	Nutrient runoff	
Trace organic & inorganic chemicals	Soil organic matter	
Dissolved oxygen, pH, particle size of sediments		
Hydrology and Geomorphology		**Hydrology**
Surface/groundwater flow		Circulation
River morphology, habitat complexity, floodplain extent		**Geomorphology**
Sediment transport		Growth/complexity of marshes
Natural Disturbance Regimes		**Disturbance**
Frequency, extent, intensity, duration		Exotic species introductions

Table A2-1: Essential ecosystem attributes derived from scientific assessments for use in assessing ecosystem integrity. EPA Science Advisory Board (EPA SAB) framework from [18], National Research Council from [88], Environmental Defense/UC Berkeley (ED/UC) from [15, 17].

Appendix 3: Examples of Ecosystem "Report Cards"

This appendix discusses several examples for quantitative assessments of ecosystem indicators. The examples are taken from existing assessments of water quality, and ecosystem health. The styles of quantitative assessments reviewed include letter grades (A-F), percentages of set standards and pre-established narrative terminology.

Letter grades are often used to analyze water quality data where benchmark standards have been established by local government and deviations can be quantified systematically. A schematic for the Heal the Bay Report Card grading system is given in Figure 1[Heal the Bay, 2001 #497]. These letter grades are assigned using health risk threshold levels based on standards set by Assembly Bill 411 and the findings from a local epidemiologic study [90]. Grades are based on a 28-day rolling average with the data from most recent week of monitoring more strongly weighted (1.5x) to reflect current conditions. For each threshold a standard deviation is used to quantify the magnitude of exceedance. Increasing point values for each indicator are assigned for each increasing standard deviation. The points from the week are then subtotaled and combined with the subtotals from the three previous weeks. Total points subtracted from a clean score of 100 generate an overall score which is interpreted into a letter grade.

A similar system is used by the Ecosystem Health Monitoring Program in Moreton Bay, Australia [Ecosystem Health Monitoring Program, 2001 #511]. In the year 2000 report cards, demerit points were assigned to given indicators according to deviations to local and national guidelines when available. The higher the value of the demerit points, the lower the report card grading. Higher values of demerit points were assigned for indicators considered more sensitive or crucial to ecosystem health. In the first attempt at a report card evaluation, an expert panel was still necessary to qualify graded evaluations. In the past two years, the program has strived to develop more effective indicators and to refine the grading system to be used without the qualification of a panel of experts. This in part is being done by establishing reference values for all indicators within management objectives.

The scientists from the Chesapeake Bay Foundation also use a points system to evaluate the ecological health of Chesapeake Bay but do not assign letter grades to indicator status [Chesapeake Bay Foundation, 2001 #484]. This group uses scientific opinion rather than set standards to assign point values. For each indicator the points are subtracted from a maximum of 100 representing the status of the indicator in a pristine state of the bay. Points are averaged for each indicator in three main categories; habitat, pollution, and fisheries to give an overall assessment of the bay. A final score is given for the entire bay and reported as a percentage of a pristine 100%.

Scientific evaluation by pre-established terms is another method of quantitative assessment that is employed by the State of the Great Lakes Committee to evaluate indicator status [Environment Canada and USEPA, 2001 #494]. There are no points assigned in this system. Instead panels of experts are responsible for indicator evaluation and assignment of one of the given terms. Pre-established terms include the following: poor, mixed/deteriorating, mixed, mixed/improving and good. These terms are used like letter grades to rate the status of chosen indicators. A summarized report card using graphs of these terms is given at the beginning of each of four comprehensive indicators reports that follow with a scientific justification for each grade assigned.

Exceedance Thresholds

Group	1 T - 1 s.d.[1]	2 T + 1 s.d.	3 >T + 1 s.d.	4 Very High Risk
Total Coliform	6,711-9,999	**10,000**[2]-14,900	>14,900	*
Fecal Coliform[3]	268-399	**400**-596	>596	*
Enterococcus	70-103	**104**-155	>155	*
Total to Fecal Ratio (when: Total >= 1,000)	10.1-13	7.1-**10**	2.1-7	<2.1

Group	1 T - 1 s.d.	2 T + 1 s.d.	3 >T + 1 s.d.	4 Very High Risk
Threshold Points	6	18	24	*
Total to Fecal Ratio (when: Total >= 1,000)	7	21	35	42

Points	**Letter Grade**
100	A+
90-99	A
80-89	B
70-79	C
60-69	D
0-59	F

Figure 1. The Heal the Bay grading system. The first table designates group numbers for magnitude and frequency of exceedence of set threshold values in terms of standard deviations. (It should be noted that total to fecal ratio values are used only when total coliform levels meet or exceed 1000 cfu/100ml). The second table designates points for each group; as the magnitude of bacteria densities increases, the amount of points subtracted increases. These points are added to obtain a subtotal for that week, and then are combined with the previous 3 week's subtotal. The final total is then subtracted from 100. The final table is then used to assign a letter grade. The higher the grade, the lower risk of illness from water contact. (1) s.d. - standard deviation (2) Bold red numbers are the state's standards for a single sample, (3) Orange County measures for *Escherichia coli* (*E.coli*). Although not one of the monitoring criterea within AB411, *E.coli* is considered, in this case, to represent 80% of Fecal Coliforms. Heal the Bay is using the County's *E.coli* number and multiplying it by 1.25 to determine a Fecal Coliform number. Heal the Bay will not use this number to determine a total/fecal ratio.