Science Support for Restoration of the Salton Sea

Recommendations of the USGS Salton Sea Tiger Team to

The Salton Sea Science Subcommittee

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EXECUTIVE SUMMARY

On December 19, 1997, Interior Secretary Bruce Babbitt announced an emerging consensus for governmental response to the declining Salton Sea ecosystem, urging a unified approach to restore its values to agriculture, fish and wildlife, and human recreation and development. The consensus included creation of the Salton Sea Science Subcommittee (SSC) to provide scientific and technical expertise. The SSC requested that the U.S. Geological Survey (USGS), the science bureau of the Department of the Interior, form a team to identify long term science activities required for successful ecosystem restoration. This report summarizes findings and recommendations of a USGS team and is intended to help the SSC draft a long-term Strategic Science Plan to support restoration of the Sea.

Since a canal gate failed along the Colorado River at Yuma in 1905, creating the modern Salton Sea in a dry lake bed in the Sonoran Desert of southern California, the ecosystem that resulted has profoundly changed. Originally filled with fresh water, the lack of an outlet for agricultural drainage, coupled with high evaporation, has now concentrated salts to 25 percent above ocean levels. Nutrients from sewage and agriculture, some locally applied agricultural chemicals, and natural selenium from the Colorado River also accumulate in the Salton Basin. Without intervention, the result of current trends is likely to be loss of major components of the current ecosystem, including multiple fish and bird species. Massive die-offs of fish and birds occur, attributed to disease and degraded water quality. Fish consumption advisories have been issued by local health officials. Algae blooms, depletion of dissolved oxygen, offensive odors, and fluctuating water levels have reduced habitat quality and deterred recreation and shoreline development.

Restoration alternatives now being considered include various combinations of water exchange and diked impoundments. Regardless of which project alternative is implemented, science will be required to monitor the outcome. Without measuring the response of the ecosystem (which requires an understanding of how the ecosystem works) restoration is likely to fail. This report recommends principles and elements that should be incorporated into the Strategic Science Plan, including conceptual modelling, long-term ecosystem monitoring, focused investigations to fill information gaps, quantitative modeling, management of scientific data and information, and oversight of science activities to assure they are relevant to restoration activities.

Recommendations to the SSC

1. Implement a comprehensive, open scientific review process to refine the existing draft restoration goals and objectives from a scientific ecosystem perspective. Based on this review, agree upon performance measures as benchmarks against which to measure true success of restoration.

2. Develop and continue to refine reliable, flexible conceptual models encompassing ecosystem components and their functional relationships.
3. Develop a long-term ecosystem monitoring program to establish baselines, measure

restoration outcomes, and help refine future actions.

4. Beyond monitoring of baseline conditions, include investigations of episodic, extreme, and unpredictable events such as fish and wildlife die-offs, algae blooms, and unusual climatic events that have the potential to significantly affect the ecosystem or influence individual valued resources.

5. Identify and prioritize investigations relevant to restoration, based on conceptual models and identified information gaps.

6. Develop quantitative, integrative, predictive models based upon identified conceptual relationships.

7. Establish a data and information management program to make results of long-term monitoring and focused investigations available to resource managers, scientists, stakeholders, and the public.

8. Prior to disbanding of the SSC, establish an organizational structure and process to implement the long-term Strategic Science Plan.

INTRODUCTION

The Salton Sea has provided substantial benefits to humans, fish, and wildlife ever since its accidental creation in 1905 when a canal gate broke, diverting the Colorado River into an old lake bed. This was not the first time water had entered the basin—in the past, the Colorado River discharged periodically to the basin creating even larger natural lakes. In its modern form, the Salton Sea serves as a repository for irrigation water, supporting one of the most productive agricultural valleys in the world. Originally, the hundreds of square miles of fresh water—in a desert region that is lucky to receive three inches of rain a year—supported a variety of freshwater fishes introduced from the Colorado River. It attracted thousands upon thousands of waterfowl and shorebirds, funneled in migration by the geography of the North American continent and attracted by water in the desert. Humans too, were attracted by the oasis. During the 1960s and 1970s, communities sprang up along the shorelines to serve water skiers, anglers, and beach aficionados.

Much has changed since 1905. The initially large and deep Sea diminished as evaporation depleted the floodwaters. Twenty years later, it rose again, as irrigation return flows increased, and it grew ever saltier. Lacking an outlet, the Sea concentrates everything the water carries, including nutrients from farm fields and sewage, selenium from natural deposits far to the north in the Colorado River drainage, and locally applied agricultural chemicals. The nutrients have stimulated aquatic productivity to exceptional levels. Certain salt-tolerant, exotic organisms, such as pile worms and an African fish, the tilapia, have responded dramatically to this productivity. The presence of fish has attracted birds, such as the endangered California brown pelican, which is attempting to establish a nesting colony at the Sea.

ORIGINS OF THE SALTON SEA

The Salton Sea today occupies some 380 square miles of the Salton Basin, a geologically active rift valley in the Sonoran Desert of southern California. Over its geological history, the Salton Sea has at times been an extension of the Sea of Cortez to the south and at times a vast ephemeral lake created by the Colorado River. The lake likely existed several different times in the last 1200 years. As recently as 500 years ago the basin was occupied by Lake Cahuilla, a body of water much larger then the present day Sea, which was used by indigenous peoples for fishing. The Sea now is 227 feet below sea level with no outlet. Maximum depth is about 50 feet, reduced from an initial depth of about 80 feet. Local precipitation is not nearly sufficient to maintain the level of the Sea naturally, due to nearly six feet of annual evaporation in this extremely arid region. Agriculture rapidly developed in the Imperial and Coachella valleys early in the century utilizing irrigation water diverted from the Colorado River and groundwater. In 1924, the Sea was legally designated as a repository for agricultural drain water. Today agricultural production in the region exceeds one billion dollars annually, and irrigation return flows constitute the Sea's primary inflow. Other diverted Colorado River water enters the Sea via the New River as wastewater from Mexicali, Mexico. For the past two decades, inflows have roughly balanced evaporation, and lake level has been fairly stable.

The salinity of the Sea can increase only so far before many species are eliminated, and the ecosystem appears to be nearing some fundamental limits. Its waters are 25 percent saltier than the ocean and approaching tolerance limits of many organisms that

sustain the food web. Fish and wildlife are stressed by concentrated salt and contaminants, depletion of dissolved oxygen, extreme temperatures, and possibly from toxins produced during algal blooms. Major fish and bird die-offs have attracted public attention as indicators that the Salton Sea is deteriorating. Fish routinely die by the tens of thousands, suffocating or succumbing to parasites or pathogens, some of which are also human pathogens. Bird populations have been repeatedly afflicted by disease—150,000 eared grebes died in 1992 of an undiagnosed cause; botulism killed more than ten percent of all western white pelicans and threatened more than 1,400 endangered California brown pelicans in 1996; Newcastle disease decimated breeding attempts by double-crested cormorants in 1997 and 1998.

For humans, too—also a part of the ecosystem—the Salton Sea no longer holds its former appeal. Shoreline communities established in the 1960s largely have been abandoned as water levels rose, dead fish littered the shores, and odors emanated from the sea. Fish can still be caught in abundance, but consumption advisories, issued due to high selenium concentrations and the presence of human pathogens, have tempered sport fishing.

Restoring Ecosystem Values

On December 19, 1997, Interior Secretary Bruce Babbitt announced that a broad consensus had been achieved for a process to evaluate restoration actions for the Salton Sea. This process takes advantage of previous project planning by the Salton Sea Authority and U.S. Bureau of Reclamation, but also encompasses environmental factors not previously included. Several engineering projects are being considered for restoration of the Sea, but to date, none has been selected. An open environmental review process was initiated under the National Environmental Policy Act (NEPA) and the California Environmental Quality Act (CEQA) to review options for a restoration project and prepare a draft Environmental Impact Statement (EIS/EIR).

SALTON SEA RESTORATION:
PUMP-IN/PUMP-OUT OR DIKED IMPOUNDMENT?

Various projects to stabilize salinity and lake level at the Salton Sea have been proposed for decades. Two ideas that have frequently resurfaced are: 1) using pipelines to exchange waters: seawater or wastewater is pumped in, and saline waters are pumped out; and 2) creating a diked impoundment in or near the Sea to serve as an evaporation basin, to allow the non-diked portion to stabilize at a low salinity. The Salton Sea Authority and the U.S. Bureau of Reclamation have been screening these and other project alternatives, including a “no action” alternative. The no action alternative has greater significance than with many large ecosystems. Because the salinity increase is unrelenting, not taking action almost certainly will result in collapse of the current food web and elimination of most fish and some bird species, reducing the potential for recreation and development.

To support the NEPA/CEQA process, Secretary Babbitt created two government/stakeholder committees to guide and integrate scientific research related to restoration issues: a high-level Research Management Committee and a Science Subcommittee (SSC), consisting of scientists and technical representatives from

federal, state, and local organizations. The SSC is charged

with providing scientific information for the EIS, to be completed in 1999, and has funded a series of "reconnaissance" surveys to gather information quickly.

While an EIS will be developed in the near term, restoration of the Sea—regardless of the preferred project alternative—will be a long-term process. For restoration to succeed, reliable scientific information will be required over the long term. The SSC therefore asked the USGS to help develop a long-term Strategic Science Plan to be completed by the SSC before January 1, 2000. As the science arm of the Department of the Interior, the USGS has a key national role in addressing science needs associated with large ecosystems. In response to the SSC, a "Tiger Team" of USGS scientists, representing expertise in biology, geology, and water, was appointed to prepare a conceptual report guiding the development of the Strategic Science Plan. The team also included two non-USGS liaison members from the SSC to ensure continuity with SSC activities. This report is the result of the Team's 8-day deliberation: it provides the SSC, the Research Management Committee, and Secretary Babbitt with guidelines for how science can best support Salton Sea ecosystem restoration over the long term.

Five key restoration goals for the Salton Sea were established by the 105th Congress in H.R. 3267, and these goals were used as the framework for preparing our recommendations to the SSC. These 5 goals are:

1. Continue to use the Salton Sea as a reservoir for irrigation drainage
2. Reduce and stabilize the overall salinity of the Salton Sea
3. Stabilize the surface elevation of the Salton Sea
4. Reclaim, in the long term, healthy fish and wildlife resources and their habitats
5. Enhance the potential for recreational uses and economic development of the Salton Sea.

As part of the restoration planning process, draft objectives corresponding to the goals have been developed by the Bureau of Reclamation and Salton Sea Authority. The goals and objectives together provide a framework against which restoration success will be measured and should be subject to review by scientists and stakeholders. As part of this process, specific performance measures should be developed from the goals and objectives as predictions or desired outcomes of restoration activities to be monitored.

We recommend that the SSC implement a comprehensive, open scientific review process to refine the existing draft restoration goals and objectives from a scientific ecosystem perspective. Based on this review, the SSC and others should agree upon performance measures as benchmarks against which to measure true success of restoration.

COMPONENTS OF THE SCIENCE PROGRAM

A successful science program requires several components: conceptual modeling, long-term monitoring, study of extreme events, focused investigations, quantitative modeling, and data-management. These components are each essential, yet none can stand alone. A conceptual model guides both long-term monitoring and focused studies toward goals and objectives agreed upon by scientists and managers. The model also promotes collaboration among managers and scientists in working toward these goals. Monitoring is essential to evaluate the success of actions based on recommendations driven by scientific studies and to collect long-term data from which quantitative models can be validated. A characteristic of the ecosystem is its unusual and extreme events that may have dramatic effects on wildlife, whether they are extreme temperatures, influx to the Sea during unusual storms, or wind patterns that resuspend oxygen-depleting sediment. These extreme events require an unusual monitoring plan—one that anticipates unpredictable and short-term events. Conceptual models also guide the development of quantitative models by identifying processes and ecosystem functions thought to be important. Quantitative modeling generates hypotheses about these processes and ecosystem functions that focused investigations then explore. Focused investigations fill in key information gaps, support monitoring by identifying important measures that were not initially recognized, and also help in validating quantitative models. Ultimately, understanding of the ecosystem can be formalized in a quantitative model that helps to anticipate the outcome of restoration actions. A data management program that facilitates integration of data among monitoring, focused investigations, modeling, and management is an essential component of the science program. All successful studies require an awareness of each component of the science program and the ecosystem; that is, they must be integrative. Together, these components will contribute to a successful program.

ADAPTIVE MANAGEMENT

"Adaptive management" is frequently cited as an effective approach to management of natural sytems, however the term is widely misunderstood, and rarely is it actually undertaken. Adaptive management entails feedback between restoration practices and monitoring of responses in the ecosystem in order to measure the success of management actions and to fine tune future actions accordingly. In practice, this means that science is used to design the actions, and then monitoring results are provided to managers overseeing restoration so that adjustments can be made, if needed. This feedback works best if scientists are engaged in the design of restoration actions as experiments whose outcomes can be predicted and then measured. Modeling the ecosystem also will be most successful if approached from adaptive management principles, whereby models constructed by scientists are examined by restoration managers for applicability to the problems they face and cycled back to scientists for fine-tuning.

Conceptual Model of the Salton Sea Ecosystem

Ecosystems are composed of interacting physical, chemical, and biological elements that result in the organization and the flow of materials and energy. Ecosystems are also characterized as being open to the flux of organisms, materials, and energy across their boundaries. While this

definition is conceptually appealing, it has proven to be problematic to managers for several reasons. First, physical, chemical, and biological elements of ecosystems are often only partially understood. Second, knowledge of functions, such as energy flow, are typically lacking for most ecosystems. Third, ecosystem boundaries are necessarily somewhat arbitrary and are often at odds with political boundaries, creating jurisdictional fragmentation.

These limitations apply to the Salton Sea Ecosystem. Information on physical, chemical and biological elements is imbalanced or lacking, little is known about ecosystem functions, and its boundaries cross the international border with Mexico.

Meeting objectives for restoration of the Salton Sea Ecosystem will require managers and scientists to agree on a definition of the system and on an approach to solving its present problems. The Salton Sea Ecosystem is a complex system with many elements that defy simple explanation. Because of this complexity, it is helpful to begin by viewing the system in a simple form to which complexity may be added. The basic elements of the Salton Sea Ecosystem include the drainage basin, which when acted upon by climate, influence the physical and chemical properties of water and, in turn, the biota (Figure 1). This conceptual model emphasizes the interactions between the terrestrial and quasi-marine elements, as well as interactions between the biota and their environment. The value of this simple conceptual model is that it reinforces the interactions of major ecosystem elements.

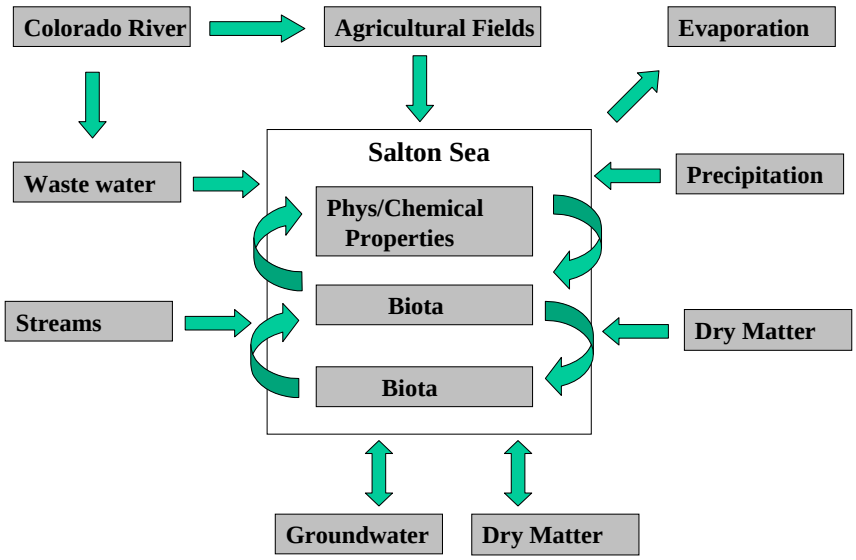

Figure 1. An example of a simple conceptual model of the Salton Sea Ecosystem.

We recommend that the SSC develop a conceptual model of the Salton Sea Ecosystem to 1) provide a common frame of reference for scientists and stakeholders; 2) guide long-term monitoring and focused investigations; 3) identify information gaps; and 4) unify and focus science activities. This model should be considered a working tool that is flexible rather than fixed, emphasizing processes and not detail.

Long-term Monitoring

Long-term monitoring of the ecosystem is critical to the success of restoration. Information derived from monitoring activities is provided to managers overseeing restoration actions so that engineering adjustments can be made if there is evidence that these actions are not having the desired effect. Monitoring, by definition, is the repeated measurement of a variable at established sites and fixed intervals using standardized methods. This standardization assures the scientific validity of the measures by accounting for natural variability inherent in the ecosystem. Every monitored variable will require a specific time interval between measures because of cost, the cycle of variation, and the precision needed for that variable.

Monitoring Principles and Elements

Ideally, for a project such as restoring the Salton Sea, monitoring information is desired for as many individual species, or parameters, as possible. However, with finite resources and with limitations of science, comprehensive monitoring is not practical. Strategies should be employed in the monitoring of the Salton Sea ecosystem that provide as much information as possible for the resources. Some of these strategies include:

Sound sampling design and statistical validity: The hallmark of a successful monitoring program is a sound sampling design that incorporates what is scientifically known about each variable, the degree of change we want to detect, desired sensitivity, and the available financial resources. Time of sampling, number and location of sampling stations and number of replicate samples should be determined after reconnaissance surveys are concluded and other existing data are taken into account. This information will provide a basis for determining the statistical probability to detect change. However, sample size will ultimately be a compromise between statistical power and cost.

Compilation of data from previous or ongoing efforts: The results generated from any earlier or ongoing efforts at the Salton Sea or comparable ecosystems will be invaluable in helping define sampling stations, sample sizes, and the value of some parameters in guiding the finer details of the monitoring program. Examples include ongoing reconaissance studies, routine data aquisition programs, focused programs, such as the San Joaquin Valley Drainage Program, the National Irrigation Water Quality Program, Binational Toxics Monitioring Program, and analogous study areas, such as the Great Salt Lake in Utah, the Aral Sea in central Asia, the

Dead Sea in the Middle East, and the Murray-Darling River Valley in Australia.

Baseline data: Collection of monitoring data should commence several years prior to implementing restoration actions so an adequate baseline exists against which future data can be compared.

Quality assurance/quality control: Data collected in the monitoring program must be quality controlled at all points in the process. Sampling, sample labeling, preservation, storage, transport, analysis, and data entry and compilation must all follow established and accepted guidelines. Any automated analysis must follow guidelines of calibration and standardization.

Keystone species: Often a key species holds a critical place in a food web where knowledge of its viability indicates the viability of related groups in the community.

Ecological indicators: Ecological relationships or even specific sensitivities often point to a target measure that is protective of a large group of organisms. For example, some species of birds are more sensitive to selenium toxicity, and long-lived, high-lipid, piscivorous fish usually accumulate the highest levels of organic contaminants. These types of species should be used as the most sensitive indicators.

Measures of relative abundance: Population monitoring can yield the relative abundance of a species or whether a population is increasing or decreasing, without determining the actual total population.

Extreme events: Biological populations are often less influenced by daily variation in the environment than extreme departures from normal conditions. Focusing on extreme events provides information that may explain changes in ecosystem components.

Based on Salton Sea Restoration goals, we have identified five components of the ecosystem that require dedicated investment of monitoring effort to assure the success of the restoration. These include:

1) Physical Processes
2) Water Quality and Contaminants
3) Biological Components
4) Extreme and Unpredictable Events
5) Socioeconomic Factors

These elements are elaborated upon in more detail in the following sections.

We recommend that the SSC develop a long-term ecosystem monitoring program to establish baselines, measure restoration outcomes, and refine future actions, by: 1) identifying key variables and analytes; 2) establishing appropriate spatio-temporal coverage; 3) assuring sufficient statistical power; 4) determining appropriate protocols for data comparability; 5) assuring adequate quality assurance and control; and 6) identifying the roles of involved agencies and organizations. Beyond monitoring of baseline conditions, include investigations of episodic, extreme, and unpredictable events such as fish and wildlife die-offs, algal blooms, and unusual climatic events that have the potential to significantly affect the ecosystem or influence individual valued resources.

Physical Processes

The physical environmental factors that are critical to monitor in the Sea and its immediate environment are water, salt, and sediment budgets. These factors must be monitored for a first-order understanding of the Salton Sea ecosystem; they set the stage for studies that integrate chemical and biological aspects of the ecosystem. Establishing these physical budgets will require measuring fluxes to and from the Sea, as well as taking measurements within the Sea. Some of the essential data are routinely collected and will require regular compilation and supplemental sampling, including water inflow volumes, water inflow salt load, rainfall, temperature, and evaporation rates. Data most needed are measurements of salinity in the Sea and transport of dust.

In addition to physical budgets, information on water movement in the Sea and external climatic variables are required. Water movement mixes inflowing water, nutrients, contaminants and suspended sediments. A program of measurements is needed to validate water circulation models. External physical factors in the ecosystem include wind, precipitation, temperature, and imported and exported dust. These factors and other air quality measures require monitoring in several locations, taking advantage of existing meteorological stations and established protocols where possible.

Water Quality and Contaminants

An important objective for monitoring is to acquire data that can be used to describe temporal changes and trends in water quality and contaminant levels. Selection of monitoring sites for water quality and contaminants should be guided by circulation models, results of reconnaissance studies, and restoration alternatives. Sites should include the dominant discharges to the Salton Sea and stations that represent a range of environments in the Salton Sea and wetlands. USGS gaging stations should be used where available to provide a link to historical water quality and discharge data.

The choice of water analytes to monitor should focus on those constituents most likely to impact the Sea's ecosystem and those having the potential for change following remediation. Analytes include basic field parameters, major ions, nutrients, and

selected minor elements, such as manganese and boron, selenium, current-use pesticides, and fecal coliforms. In the case of trace elements (including selenium) and hydrophobic organic compounds, particles suspended in the water column should be analyzed as they are a much more sensitive indicator of contaminant concentrations than is whole water.

DIFFERENCES BETWEEN THE SALTON SEA AND THE OCEAN

Although it is saline and contains several species of marine origin, the Salton Sea is a quasi-marine lake with a chemical composition that is very different from that of seawater. For example, nitrogen is much higher than in the oceans and it is present almost entirely in reduced rather than oxidized forms. Dissolved organic carbon concentration is nearly 50 times greater than in the ocean. Even the salt composition itself differs from that of the ocean—the Salton Sea is proportionately enriched in sulfate and calcium and depleted in sodium and chloride. Such differences affect the biological composition, biogeochemical processes, and toxicity of the Sea today and will continue to impact it under any restoration strategy

Biological Components

Plankton

Phytoplankton are primary producers and, as such, provide the basis for the Salton Sea food web. Elevated nutrient concentrations from anthropogenic sources in the Salton Basin have resulted in a productive phytoplankton community dominated by eutrophic indicators, such as cyanobacteria or blue-green algae. Phytoplankton should be monitored because of their importance to the Salton Sea food web and the potential role of toxic species in mortality of fish and perhaps birds. Monitoring of phytoplankton should include a seasonal evaluation of the composition and biomass with more frequent sampling when blooms occur; it should also provide information across gradients in salinity and dissolved oxygen and coordinate with physical/chemical monitoring.

PRIMARY PRODUCTIVITY AND DECOMPOSITION

The Salton Sea is highly eutrophic, by both freshwater and marine standards. Nitrogen and phosphorus from agricultural and municipal sources feed huge concentrations of planktonic algae, resulting in a rate of primary production some four times that of the most productive marine environments. The algae present include groups typically responsible for toxic “red tide” events in marine waters (e.g. *Gymnodinium* and *Gonyaulax*). The extremely high productivity creates a huge food base for zooplankters (rotifers, copepods and foraminiferans). The organic matter produced creates large amounts of detritus which supports benthic organisms such as the pile worm (*Neanthes succinea*). Decomposition of detritus reduces the dissolved oxygen concentration in both water and sediment to near zero over vast and variable areas of the Sea, contributing to frequent massive fish kills.

Zooplankton are consumed by most species of fish during their early life stages and by some species of birds. Like benthic invertebrates, the zooplankton transform energy from algae, bacteria, and detritus into animal tissue of high protein content. In addition to these general considerations, there are specific linkages between zooplankton and the feeding of some species of fish inhabiting the Salton Sea. Monitoring of the zooplankton should be considered to provide information on trends in species composition and biomass. As with phytoplankton, zooplankton

monitoring should provide information across gradients in salinity and dissolved oxygen and coordinate with physical/chemical monitoring.

Benthos

Benthic invertebrates are relatively short-lived and immobile and therefore reflect ambient conditions within a small area over temporal scales ranging from weeks to a year. Because many contaminants are concentrated by adsorption onto sediment particles, benthic invertebrates are the most likely to be exposed to high contaminant levels. They also are an important component of the food web, transforming fine particulate organic matter, consisting primarily of algae, bacteria and detritus, into animal tissue of high protein content that is important to fish and birds. These characteristics of their life history makes the benthic invertebrate community a valuable candidate for biological monitoring. We suggest the monitoring program include periodic sampling of benthic invertebrate community composition and biomass. Monitoring should be designed to provide information across gradients in salinity, sediment dissolved oxygen and sediment composition and coordinated with physical/chemical monitoring.

Fish

Several types of periodic assessments are necessary to track the presence/absence/condition, quality, and health of the ichthyofauna of the Salton Sea. These need to be done for the fish that make up the sportfishery, and the one state- and federally-listed endangered and endemic species, the desert pupfish. This latter species is tolerant of extremes of temperature, salinity and dissolved oxygen and would probably persist after most of the sportfish species are extirpated due to high salinity. Salinity in the Sea is now approaching -- or may be exceeding -- the upper salinity tolerance limit for the survival of the eggs and larvae of three of the four sportfish found in the Sea (orangemouth corvina, sargo and gulf croaker). The one sportfish species that may persist for some time in the Salton Sea is the Mozamibique tilapia, which is highly salt tolerant

FISH IN THE SALTON SEA

The only native species present prior to the creation of the modern Salton Sea is the diminutive desert pupfish, *Cyprinodon macularius*, now listed as an endangered species. The species is well-adapted to a desert environment and occupies the shallow margins of the Sea, including agricultural drains and other tributaries. Freshwater species colonized the Sea in 1905 and included the common carp, *Cyprinus carpio*, rainbow trout, *Oncorhynchus mykiss*, and several species native to the Colorado River (the bonytail chub, *Gila elegans*, and the humpback chub, *Gila cypha*). As the Seas's salinity increased, these fish dropped out of the community, and numerous introductions of marine species were attempted by fishery biologists. It was not until a series of fish stockings from the Sea of Cortez in the early 1950's that three marine species established breeding populations and created an excellent recreational fishery: the orangemouth corvina, *Cynoscion xanthulus*, the gulf croaker, *Bairdiella icistia*, and the sargo, *Anisotremus davidsoni*. By the mid-1970's another species of fish, the Mozambique tilapia, *Oreochromis mossambicus*, became a resident of the Sea. This fish, together with the previously mentioned species, provided not only one of the most productive sportfisheries in California but also contributed to the food base for numerous species of fish-eating birds. The fish populations of the Sea are subject to stress from several sources that include temperature extremes, high salinity, low oxygen concentrations, contaminants, and algal blooms. These factors are thought to be related to periodic massive fish kills, a high incidence of disease, and parasite infestations.

We recommend that a combination of gill net and creel (angler) surveys be conducted periodically to ascertain age and sex structure of the fish populations, growth, general body condition, health, contaminant levels, parasite infestations, diseases, food preferences, and overall quality of the sportfishery. The latter item can best be determined from catch per unit of effort and size composition of the fish in the angler's catch. In the case of the endangered desert pupfish, it is only important to monitor the presence/absence of the species through infrequent trapping surveys of the nearshore and shoreline pool areas. The use of gill nets and traps will also be effective in monitoring the establishment of any new fish species to the Salton Sea and in showing the presence/absence of some of the other currently known species, such as the sailfin molly, threadfin shad, and mosquitofish.

SPECIES WITH SPECIAL STATUS

The following list contains the special status species found within the Salton Sea ecosystem. These include Federal Endangered (FE), Federal Threatened (FT), State Endangered (SE), State Threatened (ST), and State Species of Special Concern (SC). It includes 12 Federal and California State Threatened and Endangered species (1 fish, 11 birds) as well as 34 State Species of Special Concern (all birds). The list does not include extremely rare species with only a few records of occurence at the Sea. Whereas there are 12 threatened and endangered species found in the Salton Sea ecosystem, use of the Sea ecosystem is probably critical to only one: Yuma clapper rail.[1]

SPECIES	FE	SE	FT	ST	SC
Desert Pupfish[2] (*Cyprinodon macularius*)	X	X			
Brown Pelican[2] (*Pelecanus occidentalis*)	X	X			
American White Pelican[2] (*Pelecanus erythrorhynchos*)					X
Double-crested Cormorant[2] (*Phalacrocorax auritus*)					X
American Bittern[3] (*Botaurus lentiginosus*)					X
Western Least Bittern[2] (*Ixobrychus exilis hesperis*)					X
White-faced Ibis[2] (*Plegadis chihi*)					X
Wood Stork (*Mycteria americana*)					X
Fulvous Whistling-Duck[2] (*Dendrocygna autumnalis*)					X
Osprey[3] (*Pandion haliaetus*)					X
Bald Eagle (*Haliaetus leucocephalus*)		X	X		
Northern Harrier (*Circus cyaneus*)					X
Sharp-shinned Hawk (*Accipiter striatus*)					X
Cooper's Hawk (*Accipiter cooperi*)					X
Swainson's Hawk (*Buteo swainsoni*)				X	
Ferruginous Hawk (*Buteo regalis*)					X
Merlin (*Falco columbarius*)					X
Peregrine Falcon (*Falco peregrinus*)	X	X			
Prairie Falcon (*Falco mexicanus*)					X
Black Rail[2] (*Laterallus jamaicensis*)				X	
Yuma Clapper Rail[2] (*Rallus longirostris yumanensis*)	X			X	
Greater Sandhill Crane (*Grus canadensis tabida*)				X	
Western Snowy Plover (inland)[2] (*Charadrius alexandrinus nivosus*)					X
Mountain Plover (*Charadrius montanus*)					X
Long-billed Curlew (*Numenius americana*)					X
Laughing Gull[2] (*Larus atricila*)					X

California Gull[2] (*Larus californicus*)				X
Gull-billed Tern[2] (*Sterna nilotica vanrossemi*)				X
Black Tern (*Clidonias niger*)				X
Black Skimmer[2] (*Rynchops niger*)				X
Burrowing Owl[2] (*Athene cunnicularia*)				X
Long-eard Owl (*Asio otus*)				X
Short-eared Owl (*Asio flammeus*)				X
Vaux's Swift (*Chaetura vauxi*)				X
Gila Woodpecker[2] (*Melanerpes uropygialis*)		X		
Southwestern Willow Flycatcher (*Empidonax trailli extimus*)	X	X		
Vermillion Flycatcher (*Pyrocephalus rubinus*)				X
Loggerhead Shrike[2] (*Lanius ludovicianus*)				X
Least Bell's Vireo (*Vireo belli pusillus*)	X	X		
Bank Swallow (*Riparia riparia*)			X	
Crssal Thrasher[2] (*Toxostoma crissale*)				X
Le Conte's Thrasher[2] (*Toxostoma lecontei*)				X
Yellow Warbler (*Dendroica petechia*)				X
Saltmarsh Common Yellowthroat[2] (*Geothylpis trichas sinuosa*)				X
Yellow-breasted Chat[2] (*Icteria virens*)				X
Large-billed Savannah Sparrow (*Ammodromus sandwichensis rostarus*)				X

Footnotes:

1 - Data on occurence at the Sea compiled from M. A. Patten. 1998. Checklist of the birds of the Salton Sea, appendix to (Point Reyes Bird Observatory) A synthesis of avian concerns at the Salton Sea. Draft report to the Salton Sea Science Subcommittee.

2 - Successful breeding occurs within Salton Sea ecosystem.

3 - Breeding suspected.

Birds

An important goal of the Salton Sea Restoration Project is to restore the habitat for resident and migratory birds. In recent years, diseases have killed hundreds of thousands of birds (particularly eared grebes, white pelicans, and ruddy ducks) at the Sea. To determine the success of restoration efforts, the condition and health of bird populations must be monitored regularly. Because large-scale die-off events are a recent troubling phenomenon, bird deaths must also be monitored. For the entire Salton Sea ecosystem, including terrestrial habitats, there are five primary monitoring objectives. Trends in populations of threatened, endangered, and other special status species should be tracked by continuing focused surveys on all populations of special status birds and on brood success where applicable. Surveys of populations of other species using the Sea should be conducted in each season. Efforts should also be directed at annual monitoring of the nesting activity and brood success of birds at all known colonial waterbird rookeries in the Salton Sea watershed, recording mortality levels of key species, and measuring contaminant levels in eggs and feathers of target species.

BIRDS AT THE SALTON SEA

Because of its geographic location and the loss of over 95% of historical wetlands in California, the Sea has exceptionally high values for birds as a migratory stopover, wintering area, and breeding habitat.

More than 400 bird species are recorded for the Salton Sea, of which about 100 species have established breeding populations. Fourteen species of colonial nesting waterbirds breed at the Sea in recent times, including the endangered California brown pelican, white pelican, double-crested cormorant and a diversity of herons, ibises, gulls, and terns. The Salton Sea is the only inland breeding location for black skimmers in the U.S., and several colonial nesting waterbirds are listed as Species of Special Concern by California. The Sea is utilized as a migratory stopover by up to 90 percent of the North American population of eared grebes. The southward narrowing of the North American continent, and the rarity of water in the region generally, funnel a high proportion of Pacific Flyway waterfowl and shorebird species to the Salton Sea. Nearly 80,000 ducks, geese and swans of 36 species either stop in migration or winter at or near the Sea. Likewise, the location has international significance for shorebirds, where more than 90,000 birds representing 44 species have been recorded using the Sea in a single month. Various species are listed as endangered, threatened, or of concern by the State of California or Federally (e.g. Yuma clapper rail and brown pelican). The high aquatic productivity (plankton, invertebrates, and fish) and surrounding agricultural fields create food sources that are heavily used by some bird species. Conversely, bird die-offs from disease have occured with increasing severity.

Wetland Vegetation

Freshwater wetland habitats adjacent to the Salton Sea are limited in size but provide critical habitat for many species of birds and breeding areas or refugia for some fish species. Because vegetation in these wetlands can remain static relative to other biological aspects of the Salton Sea, and the vegetative components are distinctly different at all times of the year from surrounding uplands, monitoring can be directed towards utilization of existing remote sensing technologies. Initial evaluations of wetlands should focus on establishing areal extent of existing wetlands using satellite imagery supported with ground-truthing, delineation of vegetative species composition, and evaluations of contaminant burdens/partitioning among sediments, flora, and fauna. Monitoring changes in acreage or general health of the vegetation can then also be accomplished with remote sensing. Changes in vegetative species composition can be tracked with surveys along permanent transects. Other monitoring efforts already recommended for the Salton Sea will provide data concerning water quality of tributaries flowing through these wetlands.

Extreme and Unpredictable Events

Many of the problems at the Salton Sea have been exemplified by massive fish and bird kills, extreme events that are neither spatially nor temporally predictable. Other unpredictable events that could potentially influence components of the Salton Sea ecosystem include unusual climatic events (e.g. high winds and rainstorms), algal blooms, and spills of hazardous materials, such as pesticides. Information related to these events could easily be missed in a routine monitoring program. Therefore, a special effort is required to detect these events and respond immediately to document their occurrence, their cause and/or impact on fish, birds and other resources, and the environmental conditions associated with their occurrence. This will require multi-agency participation and commitment.

Currently, fish and bird kills are discovered incidentally while conducting other activities at the

Sea or when observed and reported by the public. Methods should be devised for more routine surveillance of animal mortality, using transects or other methods, and reporting by the public should be encouraged and facilitated. Also, a procedure for rapid notification of animal health experts and protocols for submitting diagnostic specimens should be established. In the case of large kills and unusual cases, field investigations should be conducted to gather epidemiologic data, such as carcass numbers, species, and distribution, environmental conditions in the vicinity of a kill, and other pertinent information that may help establish functional linkages.

Similar field investigations should be conducted when algal blooms are discovered or reported. Standard protocols should be developed to collect samples for species identification and composition of the bloom and for evaluating its potential toxicity. Local environmental conditions in the vicinity of the bloom should be measured, and mortality of fish or other animals should be documented. Unusual climatic events, such as excessive rainfall, should be monitored for their effects on physical and chemical parameters of the environment.

SIGNIFICANT BIRD MORTALITY EVENTS AT THE SALTON SEA

YEAR	SPECIES	EST. MORTALITY	CAUSE
1992	Eared grebes, ruddy ducks	150,000	Undetermined etiology, avian cholera
1994	Eared grebes, ruddy ducks	2,500	Undetermined etiology, avian cholera
1995	Eared grebes, ruddy ducks	2,000	Undetermined etiology
1996	Pelicans, herons, etc.	15,000	Type C avian botulism
1997	Double crested cormorants	1,700	Newcastle disease
	Pelicans, herons, etc.	2,300	Type C avian botulism
1998	Double crested cormorants	6,021	Newcastle disease
	Waterfowl	8,066	Avian cholera
	Eared grebes	3,492	Undetermined etiology, avian cholera

Socio-economic factors

In addition to monitoring biological and physical attributes of the ecosystem, human uses that are directly and indirectly related to the Salton Sea are addressed by restoration goals and require monitoring. Consumptive and non-consumptive uses provide measures of an ecosystem's benefit to humans. Recording visitor usage of parks, refuges, and other managed facilities should be formalized and the data disseminated in a standard format. Hunter harvest of gamebirds and ducks and creel surveys are needed to establish levels of these recreation activities and provide demographic information about birds and fish. Related information useful for recording recreational activities are boat usage (including personal watercraft) and recreation activities, such as camping, hiking, swimming, picnicking and birding.

Land-use patterns in the nearby watershed are needed to understand potential impacts on the ecosystem. Examples are agricultural chemical usage, crop types, abundances and distribution, and other land uses such as industrial activities, feed lots, golf courses, residences, campgrounds,

and off-highway vehicle disturbance. Many of these patterns of land use can be monitored efficiently using remote-sensing methods. These land uses can strongly influence contaminants introduced to the Sea, visual clarity, odors, and airborne disease.

Focused Investigations

Fundamental information gaps exist for the Salton Sea, some of which cannot be addressed by monitoring alone. Determining ecosystem cause-effect relationships, for example, will require tests of hypotheses generated by the conceptual and quantitative models. This information is critical to determine the functional linkages between ecosystem components and to verify the models as reliable for managers. Other information gaps will require one-time surveys in order to determine monitoring needs--for example, whether the level of surfactants in the Sea from domestic wastewater requires inclusion in the long-term monitoring program. One-time surveys are in essence a continuation of the "reconnaissance" studies developed for the NEPA/CEQA planning process.

Focused investigations, whether directed research or surveys, should be aimed at priority needs to guide management during restoration and should be undertaken by consensus ranking of information needs by scientists and managers. Efforts to identify information needs have already begun. In 1997, The U.S. Fish and Wildlife Service held a research needs assessment workshop, entitled *Saving the Salton Sea*, in which major knowledge gaps about the Salton Sea ecosystem were identified. Although not a comprehensive list, the following are examples of information needs that should be considered for focused investigations.

We recommend that the SSC identify and prioritize investigations relevant to restoration, based on conceptual models and recognized information gaps, in order to: 1) complete descriptions of baseline conditions with one-time surveys; 2) improve understanding of ecosystem functions and cause-effect relationships; and 3) verify and improve conceptual and quantitative models.

Physical Processes

Many knowledge gaps exist in baseline information on the physical environment and the interaction of the biotic and abiotic components of the Salton Sea ecosystem. Three general areas of research are needed to close these knowledge gaps, including improvement of modeling capabilities for the Sea, study of sediments in and near the Sea, and study of interactions between sediment and water.

Modeling is needed to predict the outcomes of restoration activities and understand the interaction between biotic and abiotic realms. The circulation model for the Sea should be extended to include the capability to model sediment transport. In addition, developing hydrologic, water-quality, and salt models for the Sea will improve predictive efforts.

The value of monitoring studies and the ability to predict underwater habitat and the results of sediment exposure during water-level decline depend on establishing comprehensive data that describe the lateral and vertical heterogeneity of Sea-bed sediments. A coordinated program of geophysical profiling and coring, coupled with a study of adjacent on-land sediment, would provide this information. Core sediments can be studied to evaluate historical changes in contaminant and nutrient load in past (buried) sediment layers. Related measurements include particle size characterization of the suspended sediment in Sea inflows, which provides information on adsorption of chemical compounds.

Interactions between water and sediment are poorly understood. The degree to which calcium salts precipitate from Sea water and accumulate in the sediment needs to be evaluated, along with nutrient flux between water column and sediment, and determining the conditions of hydrogen sulfide production that may contribute to fish kills. Attention will need to be focused on whether special techniques are needed for laboratory water analysis to avoid matrix effects associated with high salinity.

Biological Components

Even though fish and wildlife die-offs have been conceptually linked with physical, chemical, and biological stresses within the Salton Sea, there has been no systematic, integrated research program on the biology of the Salton Sea. Focused investigations should be developed to initiate

an understanding of the limnology of the Salton Sea and the relationship to fish and avian population biology. While not all-inclusive, we offer the following examples as the types of studies necessary for this understanding.

Limnological studies should examine algal and aquatic invertebrate populations while measuring physical and chemical parameters to better understand how these factors might interact with macrobiota. This information could aid in the elucidation of how major mortality events are triggered. Studies evaluating how major groups of birds utilize the Sea and surrounding environs should examine habitat availability, habitat use and movements, foraging strategies, food habits and indices of body condition, as well as behaviors and reproductive success. Additionally, studies should be conducted to evaluate the relative importance of the Sea to avian populations to better understand its relationship to remaining wetlands of western North America.

Freshwater and estuarine areas may be important for the survival of the orangemouth corvina, gulf croaker and the sargo, especially as salinity in the main body of the Sea becomes too great for the eggs and larvae to survive. Therefore, spawning grounds and nursery areas for these species should be determined. Trophic level studies of the sargo and the tilapia in the Salton Sea food web are necessary for understanding the relationships of these species to the other fish, invertebrates, and plankton. Little is known about the seasonal or daily use and movement of sportfish within the Sea and whether certain habitats are important for particular species to carry out their life functions. Since the orangemouth corvina, the gulf croaker, and the sargo are all capable of producing sounds underwater, it is possible that these species can be differentiated from one another by the types of sounds they emit and their movements tracked through the use of hydro-acoustic equipment. Fish are now recognized as having important influences on nutrient dynamics in lakes. Because of their trophic status and abundance, the bioenergetics of tilapia and their influence on nutrient cycling in the Salton Sea should be investigated. Finally, data collected by the California Department of Fish and Game in 1981-83 from several thousand fish should be analyzed and published. This would provide useful information on life history characteristics (age, growth, condition, size-and-age-at-sexual maturity and spawning seasons) for all four sportfish currently in the Sea and would give a basis for comparison with current reconnaissance work and any future work to assess the status of the sportfish populations.

Pathogens/Disease

Major knowledge gaps exist as to the cause of many of the disease problems in fish and wildlife in the Salton Sea, their magnitude and effect on fish and wildlife resources, the environmental factors contributing to these diseases, and the role of ecosystem degradation in the recent increase in magnitude and diversity of disease problems. Specific examples of knowledge gaps that will require focused investigations include the link between fish mortality and avian botulism outbreaks, the cause of frequent, massive mortality in eared grebes, the role of algal toxins in contributing to fish and bird mortality, and the interactions between salinity, contaminants, and disease in fish and birds. In addition, baseline reconaissance studies are needed to analyze environmental conditions in relation to patterns of fish and wildlife mortality and changes in pathogenic microbial populations. Sentinel animals could be used to evaluate

site-specific factors, such as localized microbial flora, biotoxins, and contaminants, that may contribute to the occurrence of disease. The potential impact (and end result) of any proposed restoration efforts should also be evaluated through surveys of selected microbial and algal species in mesocosm studies (for diking projects) and in the Sea of Cortez (for pump in/pump out solutions).

A FISH/BIRD LINK FOR BOTULISM?

The 1996 type C botulism outbreak that afflicted over 15,000 pelicans and other fish-eating birds at the Salton Sea was unusual for a number of reasons. Evidence suggested that sick and dying tilapia (*Oreochromis mossambica*) were the most probable source of toxin for birds, although fish and fish-eating birds had not previously been associated with type C botulism. Also, this event was the largest die-off ever documented in pelicans in the U.S. and appears to be unique to the Salton Sea. The mechanism by which fish acquired toxin is unclear. Some evidence suggests that fish were ingesting toxin and contracting the disease and the intoxicated fish were then consumed by birds. Laboratory experiments have recently confirmed that tilapia are susceptible to the toxin. Another possibility is that fish were sick from other bacterial diseases (such as vibriosis), and conditions in their intestinal tracts provided a suitable environment for the production of botulinum toxin. Local environmental stressors, such as high temperatures, high salinity, and parasitic infections (*Amyloodinium ocellatum*) may have been important contributing factors.

Contaminants

Sediment that accumulates on the floor of the Sea is derived from terrestrial runoff, atmospheric deposition, and biological production within the Sea. Selenium and nutrients are among the chemical contaminants that are incorporated at elevated levels within the bottom sediment. Their spatial distribution, possible remobilization into overlying water, and bioavailability to benthic and planktonic organisms depend strongly on redox status within the sediment and water column and perhaps on additional physicochemical properties of the sediment. Restoration of the Sea has the potential for altering these factors, especially redox, in unpredictable ways, thereby changing the level of exposure to these contaminants. Focused studies should be conducted on contaminants in sediment, water, and biota to quantify processes of exchange across the sediment/water interface and determine if, and under what conditions, contaminants within the sediment become available for reintroduction into the food chain.

SELENIUM SEQUESTRATION IN SEDIMENT

Selenium is imported into the Salton Basin with Colorado River water and is concentrated in water by evaporation when the water is applied to agricultural fields. Selenium concentrations in the Salton Sea (1 ppb) are less than those in the Colorado River (2 ppb). However, sediment Se levels in Salton Sea are higher than in Colorado River sediments. Tissue selenium levels of Salton Sea biota are also elevated to levels which could impact biota. The low dissolved selenium concentrations in Salton Sea water and paucity of information demonstrating biotic impact may be attributable to 1) sequestration of selenium in sediments, and 2) selenium removal, primarily by the production of volatile selenium compounds by bacteria and/or fungi.

DDT or its metabolites persist in biota from the Salton Sea basin, and the presence of pesticides in current use has also been documented in drains, rivers, and nearshore margins of the Sea. It is unknown if levels present today pose an environmental hazard,

and, if so, how changes in management practices, such as reduction in tailwater runoff, would affect exposure. While many historical studies have measured concentrations in either tissue, water, or sediment, they have not included concurrent observations of toxic effects in resident biota. Focused research should be conducted to measure all relevant environmental concentrations and link these analyses to concurrent visual and physiological indicators of animal health.

Visual evidence of environmental degradation in the Salton Sea Basin that is often cited by the public is the presence of foam on the surface of the New River as it crosses the international boundary. The source of this foam is believed to be discharge of detergents, but it is unknown if the surfactants apparently present in the New River are readily degraded or if they continue to accumulate in the Salton Sea in a manner analagous to the soluble salts. If they do accumulate, does this have environmental implications or is most of the elevated dissolved organic carbon in the Salton Sea simply the result of production within the Sea itself? Focused research is needed to characterize physicochemical properties of dissolved organic carbon in the Salton Sea and its tributaries and to determine its role in biological processes.

ORGANIC CONTAMINANTS

Several studies of pesticides and other organic contaminants within the Salton Sea Basin have been conducted by the USGS and others since the early 1970's. They lead to the following conclusions:

1. Organochlorines that are no longer used in the U.S., such as DDT and its metabolites, continue to be supplied to drains, rivers, and the Sea by runoff from surrounding soils.
2. Pesticides in current use are present in drains and rivers and in the immediate delta areas where they discharge to the Sea. They are not present in subsurface drainwater and interior parts of the Sea. The pesticides are transported by tailwater runoff and, to a lesser extent, aerial drift.
3. The temporal distribution of currently used pesticides in drains and rivers tracks their pattern of agricultural use with maximum aqueous concentration of several commonly used insecticides occurring in late winter and early fall.
4. Concurrent measurements of pesticides and bioassays in the Alamo River confirm a strong correlation between concentration of carbamate and organophosphate insecticides and toxic response.
5. Transport of organic and trace element contaminants typically found in urban settings occurs where the New River crosses the international boundary. However, the concentrations of these contaminants decrease to very low levels by the time the river reaches the Salton Sea.

Quantitative Modeling

Quantitative modeling is necessary for both complete understanding of the complex interacting biotic and abiotic systems of the Salton Sea ecosystem and to predict outcomes of restoration actions. Quantitative models test our understanding of the ecosystem, enabling scientists and managers to predict the ecosystem response to changes in various inputs, such as lowered Sea elevations level and altered populations levels. In addition, quantitative models help to identify gaps in data and incomplete understanding of functional relationships, which in turn lead to refocused monitoring and new focused investigations.

Quantitative models must be flexible and dynamic. Flexibility is needed to model nested systems from detailed subsystems to complete predictive system models. The models must be

able to incorporate and integrate large amounts of diverse information generated during montoring and focused research. The models also must not be static; they must be continually refined as data accumulate and understanding of functional links improve. Refining and validating models is essential.

Quantitative modeling provides essential links among the many parts of the science program and provides checks and balances on the most important studies needed. As important, modeling provides predictive feedback to managers challenged with restoring the ecosystem.

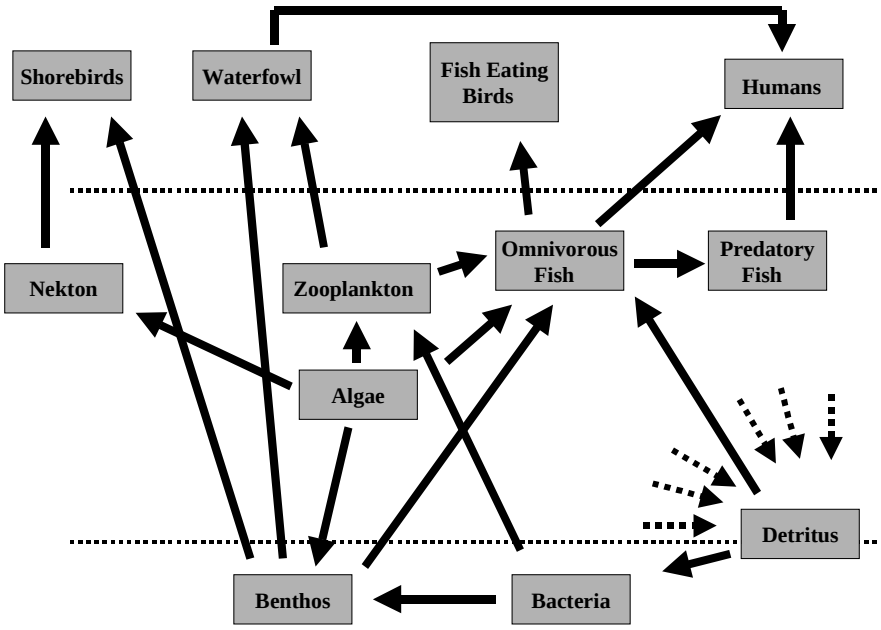

Figure 2. A simple example of the Salton Sea food web. Fnctional relationships among components of the conceptual food web model should be quantified to link rates of matter, nutrient and energy flow. Other examples of information that should be modeled include hydrology, sediment transport, the fate of nutrients and contaminants, epizootiologic patterns, bioenergetics of abundant fish species, and the population dynamics of abundant organisms.

We recommend to the SSC that integrative, quantitative models, based upon identified conceptual relationships, should be developed for predicting ecosystem response to specific restoration actions.

Data and Information Management

All technical information collected as part of the Science Program must be organized, stored, and made accessible through a common data management system. This system will assure that data meet quality control objectives, are made available to resource managers, scientists, stakeholders, and the public in a timely manner, and are in a format that enables synthesis by project scientists.
In order to develop a data management system, it will be necessary to:

Establish a data management team: A data management team should be established through a competitive process. This team would be responsible for establishing protocols for data reporting, archiving, and communicating, and assuring data meet quality assurance guidelines, such as Federal Geospatial Data Committee requirements. The team would coordinate support to scientists and statisticians in all aspects of data management and analysis.

Design a data management system: The data management team should develop a data and information infrastructure that: 1) classifies data into components of the conceptual models, 2) allows for remote data entry by program scientists, 3) provides offline and online serving tools for decision support and the analysis of data, 4) develops tools and methods (e.g. web sites) to make information widely available in synoptic form (e.g. maps, figures, summaries, indicators, visualizations), and 5) establishes a plan for maintaining and archiving data, reports, and synopses.

Develop a data approval process: The data management team should develop a process that discerns between preliminary and finalized data so that only finalized, QA/QC approved data is released to the public or used in quantitative models.

It is critical that the data management team work closely with and not independent from scientists conducting the monitoring, investigations, and model development. Scientists, working with the help of data managers, need to be ultimately responsible for interpretation of correlations among ecological indicators and physical processes. These interpretations will help to evaluate status and trends in the Salton Sea ecosystem, causes and consequences of change in ecosystem components, and relationships between status and trends and restoration efforts, if any. These analyses will also help in predicting future rates of change, assessing uncertainties, and guiding future investigations to reduce those uncertainties.

We recommend the development of a comprehansive data management system for the organization, storage, approval and dissemination of data generated by the Science Program. The Science Subcommitee should establish, through competition, a Data Management Team to develop and information infrastructure that: 1) classifies data into components of the conceptual models, 2) allows for remote data entry by program scientists, 2) allows for remote data entry by program scientists, 3) provides offline and online serving tools for decision support and the analysis of data, 4) develops tools and methods (e.g. web sites) to make information widely available in synoptic form (e.g. maps, figures, summaries, indicators, visualizations), and 5) establishes a plan for maintaining and archiving data, reports, and synopses.

IMPLEMENTATION

Ultimately, the success of Salton Sea restoration depends on collaboration to produce cost-efficient, relevant, accurate, and precise information to guide management. By monitoring suites of indicators, defining performance measures and management outcomes, and describing the overall state of the ecosystem for decision support, science is indispensable in providing feedback for a continued incremental rehabilitation of the ecosystem. Science will have a maximum impact for decision support if feedback linkages are structurally built into the program organization.

In order for feedback to be effective, we recommend creation of a permanent committee or council, that for purposes of this report, will be termed a *Science Council*. Creating this council and agreeing on an organizational structure and process for long-term science support should be achieved before disbanding the SSC, so that continuity between restoration planning and implementation phases is maintained.

The Science Council would advise Salton Sea resource and project managers (within whatever organizational structure evolves) on all aspects of monitoring and focused research during restoration. This would include three principal kinds of activities: 1) assuring a continous information feedback process linking science and resource mangement; 2) managing science activities such as defining needed projects and overseeing reviews; and 3) providing oversight of data and information management activities. In funded counterpart progams nationwide (e.g. CALFED, National Estuary Programs), such an organizational structure is supported by a permanent staff.

NEEDS FULFILLED BY A SCIENCE COUNCIL

Creating a council to establish linkage among scientists and managers fulfills at least five critical needs for successful ecosystem restoration:

1. It closes the feedback loop with managers by providing a flow of critical information to shape project and ecosystem management activities.
2. It informs managers about how restoration actions can be designed to make them experimental in a scientific sense (that is, capable of yielding useful information).
3. It enables science activities to be internally coordinated (research with monitoring; scientists with data managers, etc.).
4. It provides for independent scientific review of project, monitoring, and research programs.
5. It provides all parties with a documented, step-wise rationale for ecosystem management decisions.

Because the science activities will actually be completed by a variety of agencies and organizations, an important role of the Science Advisory Council will be to integrate these activities. Some projects would be defined and funded by the program itself to fulfill specific needs outlined in the Strategic Science Plan through the funding of Requests for Proposals while other activities will consist of independent activities undertaken by various bureaus, that could be leveraged and coordinated to help fulfill restoration needs, utilizing the forum provided by the Science Advisory Council.

Membership of the Science Council should include government, university, and stakeholder scientists and technical professionals with expertise across the disciplines encompassed by Salton Sea restoration. Specific suggested responsiblilities of the Council include:

- Oversee implementation of the Strategic Science Plan after initial NEPA/CEQA activities are completed.

- Coordinate the formation and functioning of technical working sub-groups in such areas as conceptual modeling, monitoring comparability, quality assurance and quality control, information management, predictive and quantitative modeling, and information synthesis and reporting.

- Create and manage an ongoing science-information-needs process to identify and rank research and monitoring needs in an ecosystem context.

- Establish and manage a sustained proposal and peer-review process to assure that funds spent on science support conform to program needs and use state-of-the-art science, that studies are cost-effective, and that qualified investigators are not excluded from the proposal process.

- Sponsor periodic meetings of scientists, managers, policy leaders, stakeholders, and the public to report on science and monitoring findings as they relate to implementation.

- Oversee periodic independent scientific review of implementation, monitoring, and research activities.

Prior to disbanding of the SSC, an organization (here termed the Science Advisory Council) should be established to oversee implementation of the long-term Strategic Scince Plan and thereby: 1) link restoration science and management; 2) coordinate various science activities; 3) rank information needs and recommend award of project funds to fulfill thoses needs; 4) oversee project and program peer reviews; and 5) foster informal and formal exchange of information and ideas among scientists and stakeholders.

LIST OF ACRONYMS

CEQA	California Environmental Quality Act
EIR	Environmental Impact Report as defined by CEQA
EIS	Environmental Impact Statement as defined by NEPA
NEPA	National Environmental Policy Act of 1969
SSC	Science Subcommittee
USGS	United States Geological Survey