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Special Section: Marine Sentinel Species

Southern Sea Otter as a Sentinel of Marine Ecosystem Health

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Abstract The southern sea otter (*Enhydra lutris nereis*) is listed as "threatened" under the Endangered Species Act (ESA) and is a "keystone species," strongly influencing the abundance and diversity of the other species within its kelp forest ecosystem. This is accomplished primarily by preying upon urchins that eat the kelp stipe and holdfast, which can reduce a kelp forest to an urchin barren. Sea otters are very susceptible to marine pollutants such as petroleum, which may be directly toxic and/or alter their fur's insulating properties. Sea otters are an excellent sentinel species. They eat approximately 25% of their body weight per day in shellfish and other invertebrates, and can concentrate and integrate chemical contaminants. In addition, they appear to be susceptible to a number of diseases and parasites that may have anthropogenic origins, and shellfish may serve as an intermediary for some of these infections. Many of the shellfish the otters eat are also harvested for human food. In their role as sentinels, sea otter health has implications for human health, economic sustainability of shellfisheries, as well as overall marine ecosystem health. The recent southern sea otter decline has been viewed with some alarm by conservationists and, indeed, recovery seems a long way off. High mortality rather than depressed recruitment appears to underlie the decline. A good deal of debate has centered on the role of infectious diseases and parasites, exposure to contaminants, nutrition and prey availability, net and pot fishery interactions, and other sources of mortality. Current research is being done related to major classes of mortality, various types of pollutants and some specific organisms causing southern sea otter mortality, and their implications for marine ecosystem health and sustainability.

Keywords ecosystem health - *Enhydra lutris nereis* - petroleum - pollutants - sea otter - sentinel species - toxoplasmosis

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INTRODUCTION

The southern sea otter (*Enhydra lutris nereis*) is listed as "threatened" under the Endangered Species Act. Once thought to be extinct, the remnant Big Sur populations of this subspecies grew steadily during the early half of the 20th century and expanded their range to both the north and south (Fig. 1). The recovery appeared to falter during the late 1970s, presumably due to bycatch in the gill net fishery (*Wendell et al., 1996*). But in the early 1980s, after government restrictions moved net fisheries away from most sea otter habitats, the recovery continued. Recovery faltered again in 1995 with an approximately 12% decline in the ensuing 4 years [Hatfield, unpublished report]. Data from Spring 2000 demonstrate an increase in the population; however, during the following spring, the count was back down. The overall trend of the sea otter population since 1995 has been a decline, and as of today there are 9% fewer otters than there were in 1995 (Fig. 2).

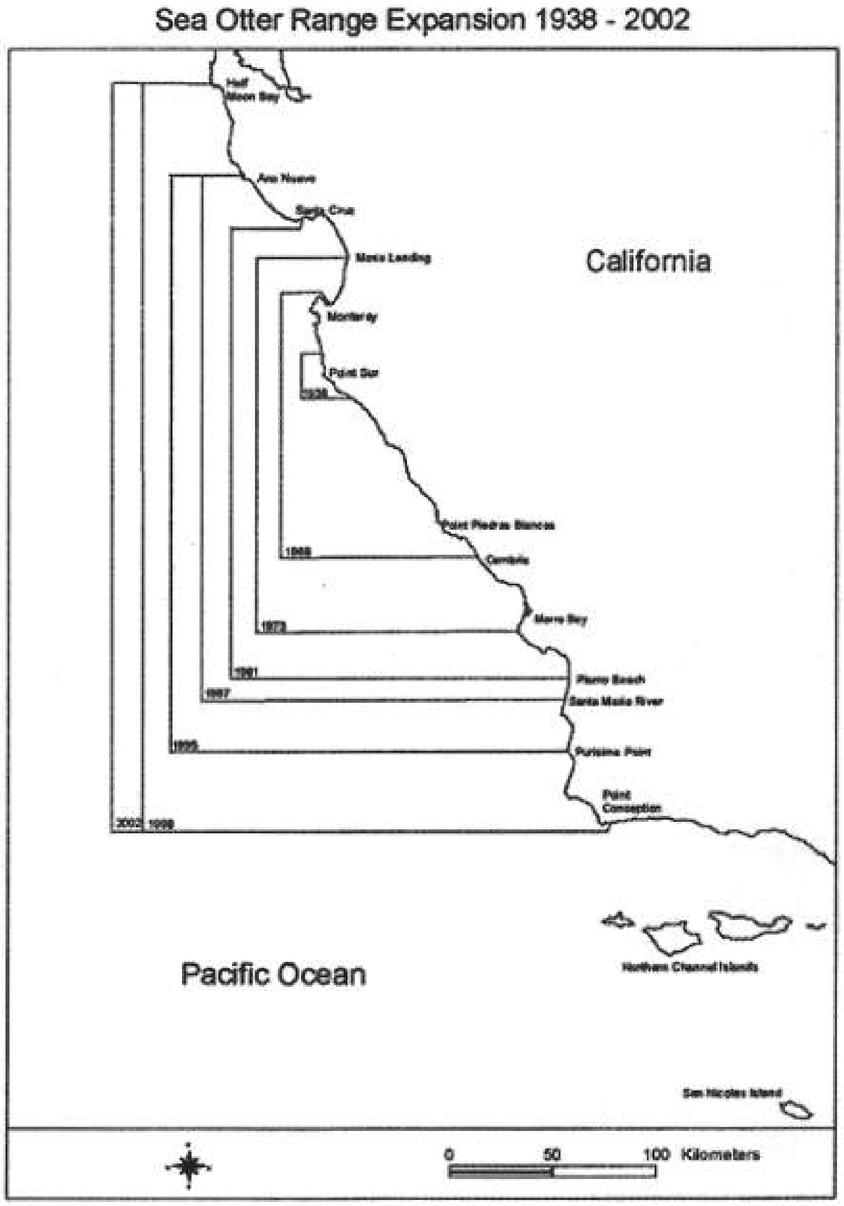

Figure 1 Sea otter range map with expanding ranges, 1938–2002.

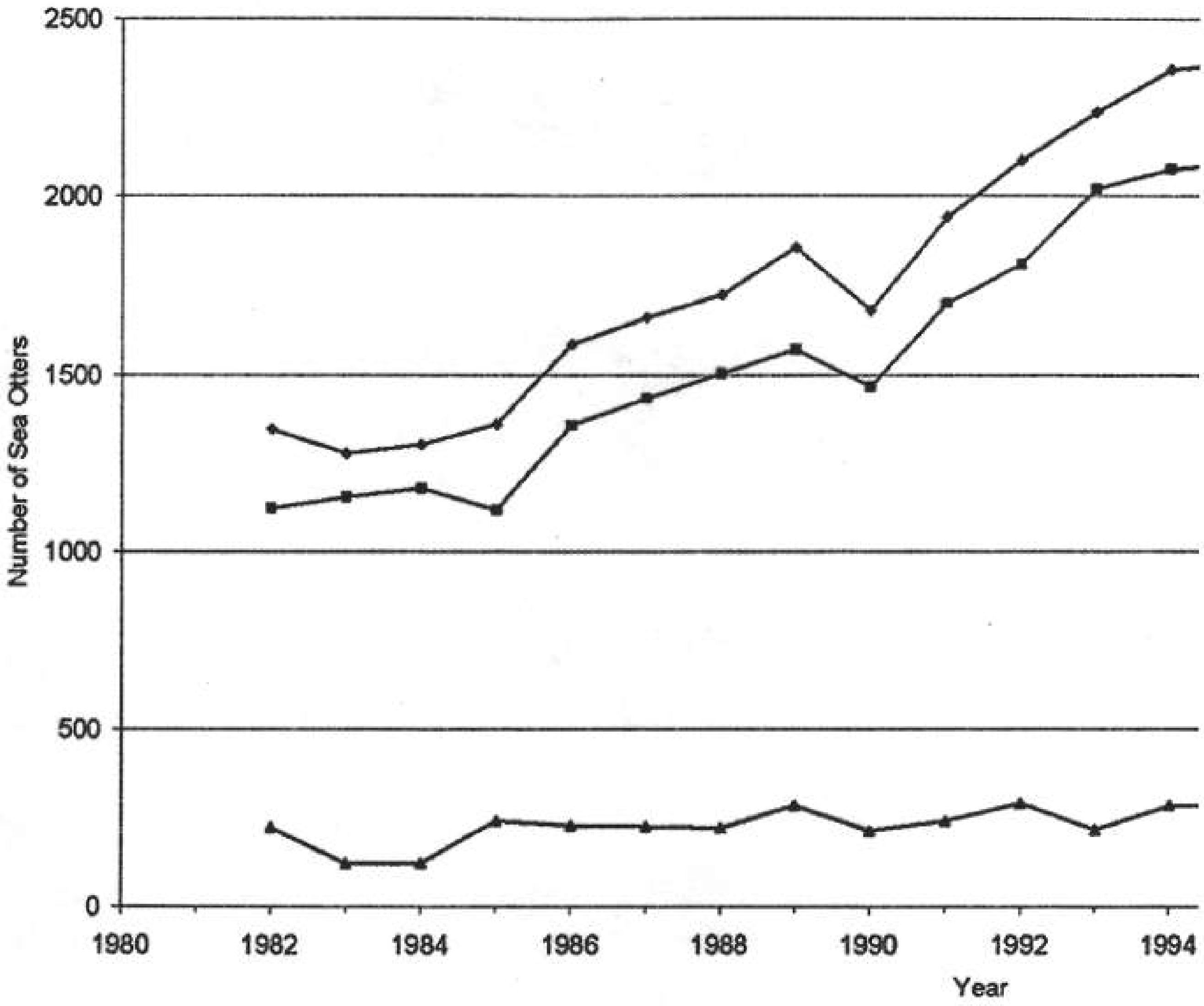

Figure 2 Chart of rangewide sea otter counts, 1975–2001.

The sea otter is a "keystone species," one that strongly influences the abundance and diversity of the other species within its kelp forest ecosystem, primarily by its effect on sea urchins that eat the kelp stipe and holdfast. An imbalance in the sea otter-to-urchin ratio can reduce a kelp forest to an urchin barren. In the presence of sea otters and a more abundant kelp canopy, many species of fin fish and other kelp-dependent species tend to be more numerous, and most shellfish tend to be fewer in number and smaller in size. Sea otters are also a very charismatic species; their antics and feeding and maternal behaviors are very attractive to people. Protection of sea otters may have the classic "umbrella species" effect, with a popular species providing protection and habitat for less noticeable, but nonetheless biologically important species. Many small businesses catering to various facets of the tourist industry profit from the presence of sea otters. Thus, the significant negative impacts of sea otters on some commercial and recreational shell fisheries may be partly offset by more general benefits to tourism.

The recent southern sea otter decline has been of concern to conservationists and, indeed, recovery is not likely in the foreseeable future. Higher adult mortality rather than depressed recruitment appears to be a component of the decline. A good deal of debate has centered on the role of infectious diseases and parasites, exposure to contaminants, nutrition and prey availability, net and pot fishery interactions, and other sources of mortality. Adult sea otter mortality, the contribution of emerging diseases, and population decline and/or failure of recovery are important conservation issues. Beneath these lay the issues of the general health of California's near shore marine ecosystems and the potential role of sea otters as sentinels of marine ecosystem health.

SEA OTTERS AS SENTINELS

The unique biology of sea otters potentially makes them an excellent sentinel species. They are relatively local, foraging in the near shore ecosystem, usually at depths less than 125 meters, unlike seals and small whales that range widely (*Riedman and Estes, 1990*). Although male otters may range over larger areas, females generally show significant site fidelity, typically ranging along 20 km or so of coastline. Thus, the pathogens and contaminants they accumulate are more representative of those present locally rather than regionally. Other cetaceans and pinnipeds range more widely and it is quite difficult to determine what the source or sources might be for their contaminants or pathogens.

Sea otters eat approximately 25% of their body weight per day in shellfish and other benthic invertebrates (*Riedman and Estes, 1990*). These invertebrates and shellfish can concentrate and integrate a variety of chemical and biological contaminants. In addition, sea otters appear to be susceptible to a number of infectious pathogens and parasites that may have anthropogenic origins, and shellfish may serve as an intermediary for some of these infections. Many of the shellfish otters eat are also harvested for human food, some of the pathogens that we are finding in shellfish, which also cause disease and death of sea otters, are potentially serious or opportunistic human pathogens. Shellfish are only valuable to both commercial and recreational fisheries if they are fit for consumption. Thus, in its role as a sentinel, the sea otter health may have implications for human health, economic sustainability of shell fisheries, and overall health of the near shore marine ecosystem.

MARINE ECOSYSTEM HEALTH

Marine ecosystem health is a relatively new and poorly defined concept. It is generally agreed, however, that healthy ecosystems (marine or terrestrial) are those that do not have obvious environmental degradation, frequent pollution events, or serious anthropogenic effects due to over harvest; do not have a high frequency of new or emerging diseases/intoxications with negative implications for human and wildlife health; have stable, or at least not declining, species abundance and diversity; and do not have frequent dieoffs or similar stochastic events, particularly those involving "indicator" or "keystone" species (*Rapport, 1989*).

THE PERSISTENT ORGANIC POLLUTANTS CHLOROPHENOTHANE (DDT) AND POLYCHLORINATED BIPHENOLS (PCB's)

Previous work suggests that contaminants such as DDT, PCBs, PLEASE DEFINE DDT AND PCB AT FIRST USE IN TEXT. and tributyl tin (an organometallic compound, with impressive biocidal activity, which has been used extensively in marine paint formulations to prevent the accumulation of barnacles and slime on boat hulls) may predispose southern sea otters to dying from infectious diseases (*Kannan et al., 1998*; *Nakata et al., 1998*), although these initial studies were quite limited in sample size and have serious spatial, temporal, and age biases. Currently, we are expanding on this work and investigating the potential relationships between contaminant burdens and cause of death in a much larger group of animals.

It has also been observed that higher mortality rates appear to follow years of higher than normal runoff and subsequent release of a variety of contaminants into the near shore environment [Parades and Worchester, unpublished data]. Mercury and organochlorine pesticides in sea otter food items and the potential for synergistic and/or endocrine disruptor effects are of concern Jessup D, unpublished data]. *Kannan et al. (2003)* PLEASE CONFIRM IF KANNEN ET AL. IS THE BEGINNING OF A NEW SENTENCE, OR CLARIFY AS NEEDED have shown that sea otters concentrate organic pollutants from their prey 60 to 240 times in their tissues and appear to be capable of metabolizing PCBs with lower numbers of halogen substitutions. We are now examining the potential connections between contaminant exposure, immune function, and health of live free-ranging southern sea otters in several study areas across the length of their range.

California receives over 200 million gallons of crude oil a day and the threat of a major oil spill continues to loom over the sea otter. Incidental drowning of sea otters in nets and, potentially, in fish traps have been a cause for renewed concern and have resulted in observer programs and mandated changes in fishing regulations.

Several newly recognized diseases and intoxications have been identified. These include harmful algal blooms that cause amnesic shellfish poisoning and neurotoxic shellfish poisoning. These may be relatively new phenomena or simply increasing in frequency and/or severity. Coccidioidomycosis (San Joaquin Valley Fever), a soil-borne fungal disease, is affecting sea otters, and cases are clustered in the southern end of their range (San Luis Obispo County) near the Santa Maria River mouth. Soil disturbance due to agriculture and development may be the ultimate source of these fungi (*Jessup, 2003*). Recent investigations suggest sea otter infections with pathogenic protozoa *Toxoplasma gondii* and *Sarcocystis neurona* (*Miller et al., 2001a,b*) may be related to terrestrial runoff or human/domestic animal pollution. Several bacterial septicemias (*E. coli*, *Clostridium perfringens*, *Salmonella*, *Listeria*, *Eyrsipelas*, *Bortdetella*, *Archanobacter*) that have been implicated in sea otter deaths could have originally come from terrestrial habitats.

Numerous hypotheses have been developed to explain the apparent increase in mortalities caused by thorny headed worms (Acanthocephala of the genus *Profilicolis* and *Corynosoma*) in the 1990s. These include emergence or host shifts of the more pathogenic species and changes in foraging habitat or prey species selection by sea otters. The *Profilicolis* spp. of thorny headed worms appears to be much more poorly host adapted than the *Corynosoma* spp. and, thus, they are more pathogenic. The sand crab hosts of *Profilicolis* vary in abundance and in consumption by sea otters depending on weather cycles and possibly alternative prey availability (*Mayer et al., 2003*). In recent years, the percentage of sea otters dying from thorny headed worm infestations has declined and, suffice it to say, the complexity, importance, and connection to anthropogenic activity of these infestations are poorly understood. From both ecological and regulatory perspectives, if anthropogenic activities including traditional chemical or pathogen pollution from point sources, non-point sources, or other ecological changes are definitely shown to cause significant morbidity and mortality of sea otters at the population level, regulatory and management actions must be considered.

Abundance of many of California's fish and shellfish stocks are depressed or fluctuate widely. Regulatory agencies have recently reduced or eliminated the harvest of a number of once plentiful species. Several preferred sea otter prey species, including red, black, green, pink, and white abalone (*Haliotis rufescens, H. cracherodii, H. fulgens, H. corrugata, H. sorenseni*), are in serious decline or on the brink of extinction, due at least in part to introduction of pathogens and parasites. Emaciation is a relatively common finding in sea otters, although it is unclear whether it is primary or secondary to disease. If sea otter numbers decline further, the structure of some kelp forests may be altered via reduction in their "keystone species" role, with resulting further reduction in the abundance and diversity of species dependent on the kelp canopy.

Notable, and still unexplained, focal sea otter mortality events occurred in 1995 and 1998, and, between 1995 and 2001, the southern sea otter counts declined by 9%, apparently due in part to increased adult mortality. This decline preceded and has spanned both the El Niño and La Niña oceanic cycles. When one compares the above cited findings, facts, and events with the criteria for ecosystem health, it seems reasonable to conclude that the marine ecosystems supporting sea otters, as well as the otters themselves, are showing signs of ill health.

CAUSES OF MORTALITY

Current evidence suggests that no one single activity or organism is responsible for the decline of sea otters. It is not "a shot to the heart" that is killing them, but rather "the death of a thousand cuts." Several lines of evidence suggest that there are many obvious and subtler connections to human activities. In a recent study, approximately 40% of mortalities of fresh necropsied otters were attributed to infectious diseases and parasites (*Thomas and Cole, 1996*). Protozoal encephalitis, caused by *Toxoplasma gondii* and *Sarcocystis neurona*, may prove to be an emerging disease of marine mammals. The most recent reviews suggest that mortality due to these two organisms may be occurring at levels sufficient to be the cause of the current population decline (*Kreuder et al., 2003*; *Jessup, 2003*). The first recognized cases in free-living marine mammals in California were reported in both harbor seals (*Phoca vitulina*) and sea otters in the early 1990s (*Thomas and Cole, 1996*; *Lapointe et al., 1998*). The only common definitive host for *T. gondii* is the domestic cat. The opossum (*Didelphis virginiana*), an introduced species in California, is the definitive host for *S. neurona*. Thus, sea otters and harbor seals may act as sentinels for potentially pathogenic protozoa in the near shore ecosystems of central California whose presence may be related to introduced and invasive terrestrial species associated with disturbed habitats.

Data from detailed necropsies of freshly dead southern sea otters are currently being analyzed for geographical, temporal, and demographic patterns, as well as possible risk factors for certain categories of mortality. Interestingly, this has revealed that otters bitten by white sharks (*Carcharodon carcharias*) commonly have preexisting disease that may have impaired their ability to avoid predation (*Kreuder et al., 2003*). This information suggests that an even higher percentage of sea otters may actually be dying of infectious causes, and that general classifications used to assign cause of death from the 1960s through the 1990s may need reexamination. Finally, prominent ecologists and sea otter biologists are beginning to hypothesize that diseases may help explain why southern sea otter populations have never grown at rates similar to sea otter populations in Washington, British Columbia, or Alaska, even in the presence of unexploited habitats.

EMERGING DISEASES

Miller and colleagues (2002a) validated a new serological test for protozoal encephalitis in sea otters and harbor seals. An Immunofluorescent Antibody Test (IFAT) was developed to confirm infection by the protozoal parasite *Toxoplasma gondii*, one of the two main causes of protozoal encephalitis in California sea otters. It has been used to screen serum from otters from California, Washington, and Alaska, and significant differences in exposure are present. Risk factor analysis for protozoal infection and seropositivity in sea otters shows locational effects (risk of exposure is increased nine times for animals in Morro Bay) and that fresh water inputs are associated with an approximately three times higher risk of exposure (*Miller et al. 2002b*). The limitation of the study did not allow conclusions about sewer outfalls. This type of work is continuing and, when completed, it may allow researchers to use sea otters across their North Pacific range as sentinels for diseases of importance.

Molecular techniques are being used to compare isolates of *T. gondii* from sea otters to those from humans and other animals. This work should help confirm the sources or pathogens discovered in the marine environment, but to date isolates appear to be similar to those from humans and cats. Studies on the ability of marine bivalves to remove pathogenic protozoa, such as *T. gondii*, from polluted water are also in progress and to date have shown that blue mussels (*Mytilus* spp.) can concentrate viable oocysts. Additional studies of other potential bacterial and protozoal pathogens in Pacific marine and estuarine environments have been conducted. In studies on the Atlantic coast of the United State, mussels, clams, and oysters have been shown to concentrate protozoal pathogens in their tissues (*Graczyk et al., 1998*, *1999a,1999b*). If this also occurs in California, shellfish may be a source of infection for sea otters, and potentially humans. We are working on a means to use both free-living sea otters and planted clean shellfish together as sentinels of protozoal and bacterial pollution in marine ecosystems.

Two other disease syndromes, some of the bacterial septicemias and coccidioidomycosis (San Joaquin Valley Fever) caused by *Coccidioides immitis*, may have terrestrial origins and may also have human health implications. A short-term study has been undertaken to evaluate sea otters for certain types of intestinal protozoa and bacteria known to cause illness and mortality in humans and domestic animals. Sick humans and terrestrial animals may shed these infectious agents in their feces, and these feces could possibly end up in the near shore marine environment through sewage leaks and/or surface runoff. Where these contamination incidents occur, the sea otter could serve as a sentinel species for "spill" detection, as it lives and feeds in the near shore marine environment and feeds almost exclusively on filter-feeding marine invertebrates, which are known to concentrate bacteria and protozoa. The goal for the first phase of this study is to examine fresh fecal samples from wild otters for presence of infectious agents, including *Salmonella* spp., *Campylobacter* spp., *Clostridium perfringens* type A, *E. coli* type 0157, *Pleisomonas shigelloides*, *Vibrio* spp., *Cryptosporidium* spp., and *Giardia* spp. Most of these potential pathogens have been detected in sea otters to date [Miller M, unpublished data]. Molecular techniques to directly compare bacterial and protozoal isolates obtained from sea otters with similar strains obtained from humans and domestic animals are also underway.

Long-term studies to evaluate tissue burdens of over 150 environmental pollutants in the southern sea otter have been initiated. The goal of this research is to screen banked tissues from freshly dead sea otters for environmental pollutants, and to evaluate the resulting data for relationships between high tissue levels of pollutants and certain categories of mortality, such as infectious disease. The tissue contaminant loads of sea otters will be compared to burdens of these same contaminants in blue mussels that are regularly monitored as part of California Department of Fish and Game's "Mussel Watch" program. Again, combining data from marine invertebrates and one of their predators may yield a more complete picture of the extent and potential effects of contaminants in the near shore marine ecosystem of California.

An additional major mortality factor, infestation with acanthocephalans and subsequent peritonitis, may be due to parasite pathogenicity or abundance shifts, shifts in sea otter diet, and/or habitat shifts due to changes in abundance of preferred prey species. Sea otter population pressures, pollution, reduced ecosystem carrying capacity, or nutrient cycles may also be driving these changes.

LONG-TERM MONITORING

In another collaborative effort between federal and state agencies and several universities, and as part of larger ecological studies, we are capturing and sampling apparently healthy southern sea otters at three locations within their California range. Study sites are at the southern end of the range where otter populations are growing and expanding their range; in the center of the range where otter populations appear stable, mortality seems low, and human activity is minimal; and near the northern end of their range where otter morbidity and mortality seem higher, and they are in waters heavily used by several medium-sized coastal communities. Animals are sampled for general health, contaminants, presence of and exposure to a variety of pathogenic organisms, immune function, genetics, and health indicators. It is anticipated that these studies will be of value in comparing sentinel species health problems in specific habitat types.

Mortality is cumulative, and when adult mortality from all causes in a slow reproducing species like sea otters exceeds recruitment rate, the population will decline. When some or many of those mortalities are caused directly or indirectly by human activities, only changes in attitudes and actions, management policies, regulations, and enforcement are likely to reverse the negative trend. We have tended to think only of direct take (shooting, net entanglement, and boat strike) as human-caused mortalities. Human-induced changes in marine environments may, however, be increasing the flow of pathogens into the system or increasing the susceptibility of sea otters to seemingly natural causes of death. Some important diseases of sea otters may originate from point sources of pollution and from runoff. If this is true, these mortalities are also related to human activity and must be addressed if sea otter losses and the trends in marine ecosystem health they may portend are to be dealt with effectively.

Based on the definitions given above of ecosystem health (indicator species dieoffs, frequent pollution events, emerging diseases, declining species abundance and diversity), the southern sea otter decline may be a result of, and thereby a sentinel for, generally declining marine ecosystem health. Metallic and organohalene contaminants have been identified at concerning levels in southern sea otter tissues and sea otter food items from at least one location [Jessup D. unpublished data]. In 1998 and 1999 toxic algal blooms (*Pseudonitzschia australis*) were implicated in the death of several sea otters (and at least 70 sea lions) by domoic acid poisoning (*Scholin et al., 2000*). Toxic algal blooms causing marine mammal and/or bird mortalities have previously been relatively rare in the Pacific Ocean. In several cases, we know that diagnosis of these emerging or newly recognized diseases along the Pacific coast has been made possible by new diagnostic technologies, increased monitoring and interest in marine animal mortality, and by maximizing collaboration between agencies and institutions.

CONCLUSIONS

Marine mammals, that are obligate inhabitants of near shore ecosystems, may serve as sentinels for the health of their ecosystem. Oil spills, sewage spills, and depletion of fisheries are anthropogenic and usually result in short-to-medium duration changes that are amenable to changes in management. Chronic pollution, the introduction of novel pathogens, or changes in the prevalence of some diseases and parasites may also be the result of as yet unrecognized human impacts; but once these processes have begun, there are relatively few effective management tools to address them. Large-scale variation in prey species abundance and ocean nutrient cycles, whether natural, due to global warming, or due to other etiologies, may cause perturbations of longer duration, and may not be, and perhaps cannot be, the focus of management programs. The bottom line is that human-caused changes in marine ecosystem function and health come from a variety of sources that must first be identified, and then mitigated, if possible.

Mortality events involving different species at various trophic levels have been used as a measure of the health of the Gulf of Mexico and Atlantic Ocean (Epstein *et al.*, 1998). The catastrophic collapse of marine ecosystem health in Chesapeake Bay, Peconic Bay and along the Florida coast should serve as a warning to California. As programs for monitoring causes of marine animal deaths continue, we should try to move towards a fuller understanding of the implications for marine ecosystem health and toward management practices that could preserve and improve the health of the oceans.

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