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Sea otters: factors that control distribution and abundance in Pacific Coast estuaries and a case study of Elkhorn Slough, California

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ABOUT THIS DOCUMENT

This document was written by Erin McCarthy, Elkhorn Slough National Estuarine Research Reserve. The following experts have generously reviewed and greatly improved this document.

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This document is part of a series of reports on key species that use estuarine habitats on the Pacific Coast. Coastal decision-makers are setting habitat and water quality goals for estuaries worldwide and exploring restoration projects to mitigate the major degradation estuarine ecosystems have undergone in the past century. These goals can be informed by an understanding of the needs of key species that use estuarine habitats. To inform on-going restoration planning as a part of ecosystem-based management at Elkhorn Slough, an estuary in central California, we have selected eight species / groups of organisms that are ecologically or economically important to estuaries on the Pacific coast of the United States. The first five sections of each review contain information that should be broadly relevant to coastal managers at Pacific coast estuaries. The final sections of each review focus on Elkhorn Slough.

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ABOUT THE ELKHORN SLOUGH TECHNICAL REPORT SERIES

The mission of the Elkhorn Slough Foundation and the Elkhorn Slough National Estuarine Research Reserve is conservation of estuarine ecosystems and watersheds, with particular emphasis on Elkhorn Slough, a small estuary in central California. Both organizations practice science-based management, and strongly support applied conservation research as a tool for improving coastal decision-making and management. The Elkhorn Slough Technical Report Series is a means for archiving and disseminating data sets, curricula, research findings or other information that would be useful to coastal managers, educators, and researchers, yet are unlikely to be published in the primary literature.

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A. Background

Sea otters play an important ecologic role in the coastal ecosystems they inhabit. They have a large impact on species richness, diversity and primary productivity, and they play an important role in human interactions with the environment both historically and presently. Members of the Mustelidae family, sea otters are the smallest of the marine mammals. They eat the equivalent of 20%-30% of their body weight per day, and feed on a wide variety of marine invertebrates including clams, mussels, urchins, snails, crabs and abalone, using a variety of foraging techniques including the use of tools. The maximum life span for sea otters is about 23 years, but most live 10-11 years. Females are reproductive at age 4 and males at age 5-6. In California, females generally give birth to one pup per year, predominantly in January-March, however pups can be born at any time of the year due to the females' capacity for delayed implantation with periods ranging from 4-12 months (Riedman and Estes, 1990).

There are 3 known subspecies of *Enhydra lutris*: *Enhydra lutris kenyoni* - northern sea otter, *Enhydra lutris lutris* - common or Asian sea otter and *Enhydra lutris nereis* - southern sea otter. The southern sea otter, or California sea otter, is the focus of this report (Figure 1). However, the range and abundance of the genus as a whole is described, and factors limiting population recovery refer to literature for both northern and southern subspecies.

The California sea otter predominantly occupies subtidal rocky habitats and kelp forests, soft-bottom habitats, or some combination of the two, within 1 km of shore. California sea otters were chosen as key species relevant to decision-making for estuarine ecosystem restoration for the following reasons: 1) human values, and 2) their ecological role.

Human values

Human values for sea otters have shifted from extractive to ecologic and intrinsic over the last century. Subsequent protective legislation has afforded the populations an opportunity to recover from near extinction caused by human hunting in the early 20th century. The success of the recovery of the California sea otter is yet to be determined.

Having once been valued by hunters for their dense fur, sea otters now play an important socioeconomic role in coastal environments by attracting the business of tourists and recreational natural resources users. According to a 2001 study, each sea otter per California county can bring between $170,100 to $589,100 in tourism revenues to that county each year (Aldrich 2001). Additional economic stimulus is created by jobs in the research and management sectors for the species. The contribution of sea otter populations bring to natural and social systems by enriching wildlife educational experiences and deepening human appreciation for nature, although difficult to ascertain, is likely invaluable.

Ecologic role

Sea otters play a major functional role in some nearshore communities where they have considerable influence on the distribution, abundance and demography of their benthic invertebrate prey (Estes and Palmisano 1974, Estes et al. 1978, Estes et al. 1982). Sea otters are considered keystone predators in rocky-bottom environments where some of the preferred prey species, such as sea urchin and abalone, are herbivores that regulate the growth of macrophytic algae and primary productivity (Power 1996, Jolly 1997). A drop in sea otter prey abundance can lead to a decrease in the cover of kelp forests and in the species richness of fishes in rocky-bottom habitats (Estes and Palmisano 1974, Estes et al. 1978).

Sea otters can also have large impacts on soft-sediment communities. Sea otter foraging has been shown to have substantial effects on abundance and size classes of preferred shallow-burrowing infauna, such as the Pismo clam (*Tivela stultorum*) and long-term predation may impact the density, biomass and size distribution of deep-burrowing infauna, such as the butter clam (*Saxidomus giganteus*) (Stephenson 1977, Kvitek et al. 1988, Kvitek and Oliver 1988, Jolly 1997). Research on otter foraging in soft-bottom communities in Alaska and the Kodiak Islands also links decreased prey abundance to long-term otter occupation (Kvitek and Oliver 1992). Otter predation on deep-burrowing prey could have secondary effects, such as potentially modifying the structure of the porewater system by digging in the seafloor, displacing or damaging small infauna, and the accumulation of discarded shells could change the quality of the substrate (Kvitek and Oliver 1988).

B. Trends in distribution and abundance

Enhydra lutris species

Before commercial hunting began in the mid-1700s, a combined total of 100,000-300,000 sea otters occurred along the 9,650 km of coastal waters spanning the rim of the North Pacific Ocean from Japan north to the Kuril Islands and Kamchatka, to the Commander Islands and the Aleutian Archipelago, south along Alaska and down the west coast of North America to Baja California, Mexico (Marine Mammal Commission 2003). The range of the species is limited by sea ice in the north and lack of kelp in the south.

Sea otters were hunted to the brink of extinction for their remarkably dense pelage prior to passage of the International Fur Trade Treaty in 1911, which prohibited hunting under the terms of an international treaty for the protection of North Pacific fur seals and sea otters, signed by the U.S., Japan, Great Britain (for Canada), and Russia. At this time, only a few thousand survivors remained, scattered among small colonies in remote areas of Russia, Alaska, British Columbia, and central California (Marine Mammal Commission 2003). The U.S. federal government passed the Marine Mammal Protection Act in 1972, and sea otters were listed as threatened under the Endangered Species Act in 1977. The California population is also completely protected by state law.

With protective measures in place, sea otter populations have slowly increased and expanded, allowing researchers to gain appreciation for their important ecologic role. By the 1980s, remnant groups in Alaska had recolonized much of their historic range and grown in abundance to what may have approached historic levels. Several hundred sea otters were moved from Amchitka Island and Prince William Sound, Alaska, in the late 1960s and early 1970s to reestablish populations in southeastern Alaska and the outer coasts of Washington and Oregon. The Oregon translocation failed, but the Washington population has grown steadily after a slow start. A number of these sea otter populations have achieved sustained periods of increase at maximum growth rates and others have increased more slowly (Bodkin 1999, Estes et al. 2003).

Enhydra lutris nereis subspecies

A remnant population of no more than 50 sea otters was discovered along the central coast of California near Big Sur in 1938. By 1972, the population in California had grown to more than 1,000 individuals and had recolonized more than 370 km (200 miles) of the California coast (Marine Mammal Commission 2003). As of 2008, the population spanned about 375 km, from as far north as Half Moon Bay with occasional sightings north of San Francisco, and south to Santa Barbara and the Channel Islands (Marine Mammal Commission 2003). Currently the California sea otter is found in two estuaries- a substantial population in the Elkhorn Slough located in the center of Monterey Bay, and a small population in the Morro Bay estuary.

The California sea otter population, in contrast to the northern subspecies, did not increase at more than about 5% per year through most of the 20th century. This growth rate was unexpected given estimates that the state's coastal ecosystem could support as many as 16,000 otters (Marine Mammal Commission 2003). Counts indicate fairly steady growth with no clear trend, punctuated by two distinct periods of population decline. The first decline from approximately 1976 to 1984 was probably at least partially due to increased mortality from entanglement in set gill and trammel fishing nets (Marine Mammal Commission 2003, Estes et al. 2003, Kreuder et al. 2003). The second was a 12% decline that occurred from 1995 through 1999. The cause or causes of this latter decline remain uncertain, but research indicates that increased mortality rates, and not decreased reproductive rates, occurred during this period (Estes et al. 2003, Kreuder et al. 2003).

More recent counts of California sea otters, conducted semi-annually as a collaborative effort led by the U.S. Geological Survey (USGS), indicate no distinct trends. The most recent survey in spring 2008 totaled 2,760, down 8.8% from the record high spring 2007 count of 3,026, which was a 12.4% increase over the spring 2006 count (Figure 2) (Hatfield and Tinker, USGS-WERC census results 2008). Counts of sea otter abundance are subject to a significant degree of interannual variation associated with differences in counting conditions, otter distribution and other factors. Accordingly, the 3-year running average is the metric recommended for use by the U.S. Fish and Wildlife Service's Southern Sea Otter Recovery Plan (Hatfield and Tinker 2008). The 3-year running average for 2006-2008 was almost unchanged from the previous average at 2,826 (Figure 2).

Recent counts indicate substantial differences in dynamics observed across the California sea otter range. Averaged over 5 years from 2003-2008, the rate of change has been generally positive at the northern and southern peripheries of the range, but close to zero (or slightly negative) in the central portions. The areas in the center of the range showing little or no growth also tend to be the regions with the highest density of sea otters (Hatfield and Tinker 2008).

Role of estuaries for these species

Before exploitation, sea otters likely occupied many estuaries in California which were abandoned during their decline (Feinholz 1998). As the California population continues to recover, they will likely expand to occupy more estuaries (Anderson and Kvitek 1987). Information about otters currently inhabiting California estuaries is limited to research conducted in the Elkhorn Slough (and in the Moss Landing harbor at the mouth of the Slough) where the population reached a maxima of over 100 animals in 2008 (Maldini et al. in prep.), and observations and anecdotal information about a population in Morro Bay, where roughly 6-12 occur (M. Harris, pers. comm. 2009, B. Hatfield, pers. comm. 2009).

Estuaries provide otters with resting areas protected from stormy weather and predators, foraging grounds or close proximity to foraging grounds, areas for important social interactions and reproduction and nursery habitat. Resting and grooming occur in rafts (groups of individuals floating on their backs) or individually, and in both estuaries occupied in California, the otters tend to cluster in areas with anchoring material such as eel grass or macroalgae, or shallow waters sheltered from major winds and currents. Elkhorn Slough has been used for reproduction and pup rearing since 1999, and pups are also occasionally observed in Morro Bay (M. Harris, pers. comm. 2009, B. Hatfield, pers. comm. 2009).

Factors limiting population recovery

Factors that limit the abundance and distribution of California sea otters both overall and in estuaries, are described below. Additional limiting factors more specific to estuaries are described in Sections C and D.

<u>Low genetic diversity:</u> Because the California sea otter population was reduced to a mere 50 individuals or so by the 20th century, the recovering population has procreated from a reduced gene pool. The impacts of low genetic diversity and its association with factors limiting population growth are unclear and not discussed here, but it should be noted that genetics may play an important role in the recovery of the population.

<u>Increased mortality rates</u>: Failure of the California sea otter to attain expected recovery rates since 1995 appears to be due to increased mortality in all age classes. Reproductive rates have been comparable to those of more rapidly growing subspecies populations (Estes et al. 2003, Kreuder et al. 2003). Based on a study during February 1998- July 2001, Kreuder et al. (2003) identified four primary causes of death: acanthocephalan parasite infection, encephalitis by *Toxoplasma gondii*, shark attack, and cardiac disease. Contaminants were not addressed. Pathogens and contaminants are discussed below.

- Pathogen pollution/disease: Encephalitis due to parasitic protozoan infection is among the most significant mortality factors (Miller et al. 2002, Estes et al. 2003, Kreuder et al. 2003). Overall, encephalitis of all types caused death in 28% (n=105), and was a contributing cause in another 18%, of carcasses examined by Kreuder et al. (2003). Encephalitis was most frequently caused by *Toxoplasma gondii* and *Sarcosystis neurona*. *T. gondii* infection was also associated with cardiac disease, another leading cause of death. Expanding populations of hosts for the pathogens (domestic cats and opossums), and decreased natural filtration of watershed runoff through coastal estuaries may be causing increased otter exposure (Kreuder et al. 2003).

Infection by *T. gondii* is also spatially clustered among otters on the California coast. Kreuder et al. (2003) show a significant spatial cluster of *T. gondii* encephalitis cases at the southern end of Estero Bay, just south of Morro Bay (Kreuder et al. 2003). Miller et al. (2002) examined serum samples from both living and deceased otters from 1997-2001 and results also show a cluster of *T. gondii* seropositivity in southern Estero Bay and a second cluster of *T. gondii* seropositivity within a 27 km region centered on Elkhorn Slough (Miller et al. 2002). The results of this study link likelihood of seropositivity to *T. gondii* with proximity to land-based surface runoff (Miller et al. 2002).

Peritonitis caused by acanthocephalan worm parasites is another primary cause of death, and was the leading cause in 17%, and contributing cause in another 10%, of carcasses examined by Kreuder et al. (2003). There was a spatial cluster in the occurrence of otters with fatal acanthocephalan infections from the southern end of Monterey Bay. Sand crabs (*Emerita analoga*) and possibly spiny mole crabs (*Blepharipoda occidentalis*) serve as intermediate hosts for these parasites, and these crabs are found in predominantly sandy habitat (Hennessy 1977).

- Contaminants: Contaminants impair reproduction and compromise immune function, possibly making otters more susceptible to pathogens. Studies conducted on California sea otters throughout their range identify organochlorines (e.g., DDTs and PCBs), polycyclic aromatic hydrocarbons (PAHs, e.g., naphthalene), metals and tributyltin as potentially important contaminants (Nakata et al. 1998, Kannan et al. 2008).

  Tissue samples reveal that DDTs rank highest of organochlorines throughout their range except in samples from Monterey Harbor, where PCBs were much higher than in other regions (Nakata et al. 1998). DDTs were most concentrated near areas of higher agricultural and urban drainage and were associated with otters that died of infectious disease (Nakata et al. 1998). Among PAHs, di- and tri-cyclic aromatic hydrocarbons, namely napthaline, fluorene, phenanthrene/anthracene, and acenaphthylene were the predominant compounds found in liver tissue. Overall, PAH profiles in sea otter tissues suggest petroleum sources (Kannan et al. 2008). No studies were identified that evaluated the cause effect linkage of contaminants and the slow growth of the California sea otter population as compared with the northern populations.

C. Factors affecting estuarine density

Some of the factors limiting the abundance and expansion of the entire California sea otter population also limit their abundance and expansion in estuaries, for example population demise by human hunting, limited genetic diversity and mortality. Below is a review of additional estuarine factors that may have implications for sea otter densities.

Prey abundance

Abundance of multiple prey species and proximity to rich foraging grounds are directly related to sea otter densities in estuaries. Densities may be limited by the number of otters that prey stocks can support, and may fluctuate with prey abundance. Common prey in soft sediment habitats throughout the *Enhydra* species range can be divided into three groups listed in order of general vulnerability to predation: epifauna, shallow-burrowing infauna and deep-burrowing infauna. Epifaunal prey include crabs, shrimp, snails and mussels, shallow-burrowing infauna primarily include several species of clam, and deep-burrowers include long-siphoned clams and echiuroid and polychaete worms (Kvitek and Oliver 1986). In Morro Bay, California, Dungeness crabs are likely a dominant prey item despite an apparently substantial clam stock (M. Harris, pers. comm.). In Elkhorn Slough, prey items include moon snails (*Polinices lewisii*), mussels (*Mytilus edulis*) and crabs (*Cancer productus* and *Cancer gracilis*), all epifauna, and California butter clams (*Saxidomus nuttallii*), gaper clams (*Tresus nuttallii*) and fat innkeeper worms (*Urechis caupo*), all deep-burrowing infauna. Important prey species may vary according to individualization of foraging habits.

Depth of unconsolidated sediments

Unlike rocky subtidal communities where sea otters feed optimally on epifuanal prey, California sea otters that forage on deep-burrowing infauna in soft-sediment communities appear to be site-selective, choosing areas where preferred bivalve prey have shallower burrow depths, maximizing caloric return per excavation effort (Kvitek et al. 1988, Jolly 1997). Because burrow depth is limited by sediment density, sediment stratigraphy can influence prey accessibility and sea otter density.

Pathogens and contaminants

Estuarine systems frequently receive high inputs of pollutants from coastal urban activity and agriculture, and pathogens and contaminants are typically far higher in estuaries than open coastal areas. Therefore, mortality associated with pathogens and contaminants can be more prevalent in estuarine systems.

D. Factors affecting estuarine distribution

Most of the factors that affect sea otter distributions in estuaries probably have a combined effect with factors affecting their distributions and densities more broadly. A few factors affecting their distribution are described below.

Distribution of prey (water quality)

Sea otters occur in areas where prey is available, and therefore their distribution within estuaries may reflect habitat requirements for prey species. In Elkhorn Slough, sea otter abundance declines roughly with large clam and crab abundance (Ritter et al. 2008). Otters are rarely present in areas with less oceanic influence, because important prey species such as California butter and gaper clams are not abundant in these areas. Although otters do occasionally occur in areas with muted tides, these areas may be less accessible.

Population structure

Distribution of sea otters in estuaries may be associated with their social behavior, which may depend on age and sex. New territories are colonized by migration of young males, and females tend to recruit into established female areas. Presence of territorial or reproductive males may limit the recruitment of additional males to a particular area, and may influence rafting and foraging locations for other males.

E. Predicted changes in estuary-wide abundance in response to estuarine restoration projects

Changes to water quality

Impacts to prey species: Restoration projects that change water quality such that it is less habitable for benthic epifauna and infauna species would likely change otter abundance and/or distribution. Otters would either change feeding locations (possibly leading to changes in locations used for other activities) or would stay put but turn to alternate prey items, which may be less energetically efficient. Conversely, restoration projects resulting in water quality that favors growth of populations and of individual sizes of preferred prey could contribute to increased otter abundance and distribution.

Pathogen pollution/contaminants: Restoration projects that lead to increased natural filtration of pathogens and contaminants in estuaries and others areas of high urban and agricultural runoff, especially near areas that are (or could potentially be) occupied by otters, may be particularly important to increasing growth rates via decreased mortality and increased reproductive success.

Changes to habitat extent

Sea otter habitat can be limited by any combination of a number of factors, including prey habitat extent, physical features and disturbance.

Prey habitat extent: Habitat extent for prey species influences sea otter abundance. In soft-bottomed estuaries this is likely limited by the extent of subtidal areas with strong oceanic influence with appropriate substrate for prey species. Otters that feed in Elkhorn Slough likely require areas that can host clam beds with larger individuals that can be relatively easily excavated.

Expanding habitat extent for otter prey species by restoring tidal activity to restricted areas could lead to increased otter distribution (and possibly abundance) in an estuary, and could increase sea otter habitat extent by making formerly inaccessible areas accessible to otters.

Disturbance: Accessible tidal creeks that are highly sheltered from disturbance, both from humans and other sea otters, are used for pupping and pup rearing and a decrease in extent of these habitats could lead to decreased reproductive success and a less diverse population structure in the estuary.

F. Elkhorn Slough trends

The Elkhorn Slough is a shallow, muddy bottom embayment in Moss Landing, California, located at the center of Monterey Bay. It shares a mouth with the Moss Landing Harbor (Figure 5). The sea otter population was extirpated from this area by the early 1900s. In the 1980s, a small group returned to this historic habitat. A population of over 100 was present in 2008.

The sea otter population in this area is now thought to consist of two subgroups: one mainly inhabiting the Moss Landing Harbor at the mouth of Elkhorn Slough, and the other predominantly occupying areas within the Slough itself (K. Mayer, pers. comm., ongoing study at Monterey Bay Aquarium). These two subgroups are referred to in combination unless otherwise specified. The areas used by the population function as resting, foraging, socializing and pupping habitat, and likely play an important role in the recovery of the California sea otter population.

Trends in abundance

Historic sea otter presence in the Elkhorn Slough coincided with the period of Native American habitation of the area, who utilized sea otter pelts for clothing. Archaeological evidence at several sites around the watershed as well as on the coast indicates harvesting of the species by native peoples since at least 600 B.C.-1000 A.D (Jones 2002). Otters were likely extirpated from the area by human hunting after European expansion during the late 1800s and early 1900s.

Seasonal reoccurrence of the otters in the Elkhorn Slough area was documented in the early 1980s, prior to their establishment of a consistent presence in the 1990s. Otters observed during 1984-1986 showed a seasonal pattern of increase during the spring followed by a decline in summer and winter (Kvitek and Oliver 1986, Anderson and Kvitek 1987, Kvitek et al. 1988). From March of 1984 through March of 1985, otter counts peaked in May at 23, decreased throughout the summer months to just a few during the fall, and increased again in February (Kvitek and Oliver 1986). Speculation at the time was that males used the area as a spring communal area and departed during the breeding season (Kvitek et al. 1988).

Abundance increased through 2000, with a sharp influx of sea otters into the estuary occurring between November 1994 and January 1995. The mean number of otters in 1995 was 25, or six times that in 1994 (Feinholz including data from Elkhorn Slough Safari 1998). The increase in abundance may be related to its coincidence with a series of strong storms that hit the California coast which may have, combined with other factors, induced juvenile males normally living in exposed coastal areas to move into the Elkhorn Slough area (Feinholz 1998). The general upward trend in abundance continued until 2000, with maximum mean monthly counts of 52 otters occurring during 1998 (Figure 3) (Kieckhefer et al. 2007).

From 2001 to 2004 the trend shifted. In 2001, the mean otter count decreased dramatically to 29, with a sharp decline beginning in July and continuing to drop through December to a mean of only 6 otters (Figure 3) (Kieckhefer et al. 2007). Mean counts continued to remain low through 2004. However, the declining numbers of otters in the Elkhorn Slough area from 2001 to 2004 coincides with an increase in the Monterey Bay counts, and therefore may represent a shift in distribution rather than a drop in overall abundance (Hoffman 2003, Kieckhefer et al. 2007).

In 2005, otter abundance began to again increase and the trend has continued through 2008. Mean monthly counts in 2005 were 30, and in 2006 were 68 (Kieckhefer et al. 2007). The number of sea otters in the Moss Landing Harbor raft has continued to increase through 2008 (Maldini unpublished data). The fall USGS count for the Moss Landing/Elkhorn Slough area in 2007 was 117 plus 4 pups (USGS-WERC fall survey results 2007). The highest numbers of otters in the area are registered at night with estimates up to 150 (Maldini unpublished data).

Trends in distribution

From the mid-1980s to the mid-1990s the areas predominantly used for rafting and foraging shifted up-slough (Figures 4 and 5). Between 1984-1986 otters transitioned from spending most of their time rafting and feeding in the Moss Landing Harbor area and just east of the Highway 1 bridge near the PGandE outflow at that time. Foraging otters were rarely observed beyond Seal Bend (Kvitek et al. 1986, Anderson and Kvitek 1987). By the mid-1990s, the rafting areas had shifted to the north Moss Landing Harbor and further up the Slough to Seal Bend (Feinholz 1998). Raft locations were generally 30 to 50 meters offshore, and at Seal Bend rafting occurred over a patch of eel grass which can be used for anchoring, in an area relatively protected from heavy tidal flow and boat traffic (Feinholz 1998).

Overall, from 1994-2006, the otters' main pupping and rafting areas shifted down-slough from Parsons Channel and Seal Bend to Seal Bend and the region near the north Moss Landing Harbor jetty (Figure 4) (Kieckhefer et al. 2007). Additionally, activity expanded upstream into the Parsons Channel, an area of subtidal mudflats and tidal creeks, where the first pup was observed in 1999, followed by 2-3 additional pups in 2000. A new pupping area was later established at Seal Bend where an estimated 10-12 new pups were born during 2005-2006. Currently (as of 2009), a subgroup composed of females and territorial males occupies areas of the lower Slough including small side channels near Seal Bend and in Parsons Slough, and male-dominated rafting activity is concentrated in the north Moss Landing Harbor (K. Mayer, pers. comm.) (Figure 5).

Overall distribution throughout the Elkhorn Slough watershed can also be described in terms of tidal exchange. Otters are concentrated in the lower and middle portion of the Slough in areas with full tidal exchange. A small number of individuals are occasionally observed in sites with muted tidal exchange (such as Bennett Slough and Whistlestop Lagoon), and otters are absent from sites that are fully tidally restricted (such as Porter Marsh and Moro Cojo).

Population structure

The Elkhorn Slough population had been predominantly young males since their recolonization of the estuary in the 1980s. With the influx of otters between 1994 and 1995, the male to female ratio changed from 4:1 to 11:1, respectively. Twenty-four percent of the sexed animals were identified as old in 1994, and 10% in 1995, implying that the increase in abundance in the Slough was attributed to influx of juvenile males (Feinholz 1998).

More recent information suggests that the population is diversifying. The transition to a more diverse population structure may be indicated by recent preliminary data showing a higher percentage of older individuals in the raft compared to 1995 (which may be the same otters that have aged) (Maldini/Okeanis, unpublished data), by territorial behavior and related shifts in raft locations, and by increases in pupping.

Further, the two subgroups that now compose the population appear to have different population structures. An ongoing study by researchers at the Monterey Bay Aquarium (2005-present) indicates that the subgroup of otters primarily occupying the Moss Landing Harbor at the mouth of Elkhorn Slough is comprised predominantly of males, ranging in age from juvenile to adult, including reproductive males, with occasional and temporary presence of a few females. The subgroup occupying the Slough itself tends to consist of juvenile, sub-adult, and adult females (some with pups) and a smaller number of territorial males (K. Mayer, pers. comm.). Research also indicates differences in habitat use patterns for the two groups (see below).

Foraging habits

Kvitek and Anderson (1987) and Kvitek et al. (1998) studied otter foraging ecology shortly after otters arrived in Elkhorn Slough in 1984 when there were less than 25 otters present for any period of time. They identified deep-burrowing California butter and gaper clams as primary prey species, and found no effect on abundance and distribution of the clams after 3 years of predation. Otters appeared to be site selective for prey, choosing patches of clams with shallower burrow depths influenced by sediment stratigraphy (a thin sandy layer on top of a clay-like layer). Otters also selected butter clams in greater proportion to their density.

Jolly (1997) conducted research on sea otter foraging ecology in Elkhorn Slough during 1994-1995 and found that otters selected prey based on energetic profitability, with profitability depending on size of individuals and ease of attainment. Most profitable prey items (accounting for excavation time and average size of individuals consumed) were 1) California butter clams 2) *Cancer* crabs 3) gaper clams 4) fat innkeeper worms and 5) other bivalves. Four species comprised most of the diet: California butter and gaper clams together comprised 41% of the diet, fat innkeeper worms comprised 19% and *Cancer* crabs 9%.

Jolly (1997) also compared data from bivalve surveys at a foraging site in the lower Slough from 1986 (Kvitek and Oliver 1987) and 1996 (Jolly 1997). She found significant reductions in size of individuals and a 60% reduction in biomass for both prey species, with reductions attributed to over a decade of predation by sea otters. Bivalve density, however, did not decrease as might be expected, in fact gaper clam density increased for unknown reasons (see discussion in Jolly 1997). Jolly (1997) speculated that prey populations may not sustain long-term otter predation.

A later study by Kieckhefer et al. (2007) shows changes in the composition of otters' diets over time. There was a gradual decrease in the number of California butter clams consumed by otters from 1998-2006. The number of innkeeper worms in the diet increased significantly in 2000-2001, the number of gaper clams increased significantly in 2002-2004 and the number of crabs increased from 2002 through 2005 with a slight decrease in 2006.

Recent research (Maldini et al. in prep., K. Mayer, pers. comm.) indicates that the subgroups within the population have different foraging patterns. The bulk of the population, mainly males that occupy the Moss Landing Harbor, tend to feed in Monterey Bay, near the jetties at the harbor channel, or in the lower Slough. The females that predominantly occupy areas in the Slough tend to feed in the lower portion of the main Slough channel, with a relatively small number traveling to feed in the Moss Landing Harbor area or offshore (Figure 5). Research is currently being conducted by staff of Okeanis to determine the implications of different foraging locations for different groups of the population.

Speculations about trends

<u>Changes in abundance</u>: The variable trend of sea otter abundance in the Elkhorn Slough area may be indicative of periodic use of this area for foraging, with sea otters heavily impacting multiple prey populations before switching to alternate prey and feeding locations (Jolly 1997). Speculations about the apparent shift in distribution from the Elkhorn Slough area to Monterey Bay during 2001-2004 are related to prey abundance: the increased otter population may have depleted choice individuals of preferred prey species (such as larger and relatively easily excavated California butter clams) in the Slough, and then shifted to foraging for alternative species offshore; or the population of Dungeness crabs in the Bay may have been abundant during this time period and otters may have temporarily abandoned the Slough to feed on a preferred prey item (Maldini, pers. comm.). Also, in 2003 there was an unusually high mortality rate which may have been associated high domoic acid levels offshore and a shift in sea otters foraging primarily on offshore crab (primarily Dungeness) rather than clam species in the Slough (Jessup et al. 2004, Kieckhefer et al. 2007). Further, California butter clams were observed less frequently in otter diets for several years leading up to this period, and other (likely less desirable) prey species, such as fat inn-keeper worms, were eaten more frequently (Kieckhefer et al. 2007). Additional concurrent data about clam populations are needed to form more concrete speculations about predator-prey relationships and their affect on otter populations in Elkhorn Slough.

<u>Changes in distribution</u>: Although the activity and population structure around Seal Bend has changed over time, it has likely been a hub of otter activity due to the large patch of eel grass unique to this site that serves as anchoring material. The large raft of mostly young males that once occupied the site has probably shifted to the north Moss Landing Harbor because the area around Seal Bend is now occupied by reproductive females and therefore by territorial males. The few otters that occasionally travel further up-slough have likely also been chased out of the Seal Bend area (R. Scoles, pers. comm.).

Factors affecting abundance and distribution at Elkhorn Slough

<u>Artificial harbor mouth</u>

The construction of the Moss Landing Harbor in 1946 and the subsequent opening of an artificial mouth to the Elkhorn Slough has played an important role in the occupation of this area by otters and likely has important and mixed implications for the California sea otter population. The artificial mouth altered the condition of the Slough by creating a permanent, much wider and deeper opening that resulted in increased oceanic influence in portions of the Slough open to tidal flow. This creates a hospitable environment for otter prey species and provides access to foraging grounds and sheltered areas. However increased tidal velocities are causing scouring of soft sediments in the lower Slough, a main foraging area (sediments are swept into the Bay during ebb tides). These soft sediments are necessary for deep burrowing prey and for their accessibility to otters. Further, the influx of otters to the Elkhorn Slough may negatively impact the population if it leads to increased mortality rates from exposure to pathogens and toxins.

Tidal regimes

The otters in Elkhorn Slough are mainly limited to areas of full tidal exchange in the lower portion of the Slough. This is probably related to prey abundance, accessibility and social behaviors. They do occasionally occupy areas in the upper Slough and areas with muted tidal flow. Distribution within the Slough also fluctuates with tides, with individuals tending to rest in smaller back channels during daytime high tides and forage in the main channel during daytime low tides (K. Mayer, pers. comm.).

Water quality

Water quality can have implications for otters in Elkhorn Slough by directly affecting mortality rates and reproductive success and can indirectly affect otters through impacts to prey species. Water quality concerns for direct impacts to otters in this area include agricultural and industrial contaminants and pathogens. Currently, the rafting location in the north harbor is directly in the receiving area for agricultural runoff from the Gabilan/Tembladero watershed and concentrations of DDTs in tissue samples examined by Nakata et al. (1998) are concentrated at Moss Landing. In addition to pesticides from runoff, activities in the harbor may be a source of additional contaminants such as tributylins. Contaminant exposure is associated with infectious disease (Nakata et al. 1998), which may be of particular importance in this area.

Disease, especially by pathogen infection, is a primary cause of mortality for Cailfornia sea otters, and although the population in Elkhorn Slough has increased, it is possible that local pathogen concentrations will negatively impact abundance and distribution of the local population or of the population overall. The likelihood of seropositivity to *T. gondii* is directly linked to proximity to land-based surface runoff, and this is particularly evident in a 27km region centered on Elkhorn Slough where 79% (15/19) of otters sampled were seropositive for *T. gondii* (Miller et al. 2002). Otters sampled within 10 km of Elkhorn Slough were 1.5 times more likely to be seropositive than all otters examined by Miller et al. (2002) combined. Likely magnifying this threat in Elkhorn Slough is low levels of natural filtration of poor quality runoff.

High concentrations of nutrients and pesticides may negatively impact bivalve populations in the Slough, which could lead to otters abandoning the area, traveling greater distances to forage, or foraging on less energetically profitable individuals or species. Consumption of polluted prey could also negatively impact the population.

Prey populations

The relationship between prey stocks and otter abundance and distribution is not fully understood, but there is speculation that shifts in distribution in the Slough reflect changes in populations of prey species (Kieckhefer et al. 2007). If densities of preferred prey decline substantially, the otters could shift to predominantly occupying the Monterey Bay either long-term or temporarily, returning to the Slough after stocks are replenished. The otters may also continue to use the same resting areas but travel further to forage. The observations that most of the otters that occupy the harbor mouth (and some of the otters that occupy the lower Slough) travel to the Monterey Bay to feed on a daily basis may be a sign of decimated prey stocks in the Slough or it may reflect a preference for prey items in the Bay.

Immigration and emigration

Sea otter abundance is also influenced by immigration and emigration on several time scales. The male-dominated subgroup in the Moss Landing Harbor fluctuates diurnally with otters entering the area to rest during the nighttime and exiting the area to forage in the daytime (Maldini et al. in prep.). Also, tagged sub-adult and adult males that may not have established territories sometimes depart for days to weeks and move extensively throughout the range, then return Moss Landing for days to weeks (K. Mayer pers. comm.). Abundance also fluctuates seasonally, with increases in the winter time probably resulting from increased storm activity along the coast (Maldini et al. in prep).

Human activity

Human activity and associated disturbance may have a significant effect on distribution and habitat use patterns in Elkhorn Slough, though it is does not appear that levels of disturbance are significant enough to affect sea otter abundance (K. Mayer, pers. comm.). Mother/pup pairs would tend to be most sensitive to human disturbance, and most affected by energetic costs of avoidance behavior. Access to side channels that are removed from human activities could be an important way for females with pups to minimize energy costs related to disturbance (K. Mayer, pers. comm.).

G. Predictions for Elkhorn Slough under different management alternatives

Overview

Four large-scale management alternatives for Elkhorn Slough were developed with the goal of decreasing rapid rates of subtidal channel scour and salt marsh conversion to mudflat habitat that have been documented over the past decades (Williams et al. 2008, Largay and McCarthy 2009). Changes to physical processes and water quality in response to these management alternatives vs. a “no action” alternative have been modeled and summarized (Williams et al. 2008, Largay and McCarthy 2009). In order to determine which management alternative best optimizes estuarine ecosystem health, the coastal decision-makers involved in this process of wetland restoration planning require at minimum some basic information about how species that play major ecological or economic roles are likely to respond to the different management alternatives. In the absence of detailed demographic data and rigorous quantitative modeling, it is impossible to obtain robust quantitative predictions about response of these key species. Instead, the goal of the preceding review of factors affecting density and distribution of the species across their range and the evaluation of trends at Elkhorn Slough is to provide sufficient information to support qualitative predictions based on professional judgment of experts. These predictions represent informed guesses and involve a high degree of uncertainty. Nevertheless, for these species the consensus of an expert panel constitutes the best information available for decision-making.

Biological predictions based on habitat extent

Our assessment of the management alternatives has multiple components. First, we predict how population sizes will respond to alternatives based only on extent of habitat of the appropriate tidal elevation. This assessment was based on the predictions of habitat extent at Year 0, 10, and 50 under the five alternatives (as summarized in Largay and McCarthy 2009 and shown in Table 1). Note that all alternatives involve major loss of salt marsh and concurrent gain of other habitat types at year 50; this is due to an assumption of 50 cm of sea level rise, which largely overshadows effects of the alternatives. A significant change in habitat area was defined as an increase or decrease of 20% or greater over year 0, No Action (Alternative 1) acreages. Likewise, a significant change in population size of the species was defined as an increase or decrease of 20% or greater over the average population size of the past decade (1999-2008). For the habitat and species predictions, the geographic boundaries are all the fully tidal estuarine habitats of Elkhorn Slough excluding the Parsons complex (predictions do not include tidally restricted areas). For this first component, we made a very simplified assumption that population size is a linear function of area of habitat of appropriate tidal elevation. Thus for example a significant increase in habitat extent translates directly into a significant increase in population size.

Because sea otters mainly rest, interact, pup and forage in intertidal and subtidal areas, we used “total mud” area (intertidal mudflat plus shallow and deep subtidal, part E of Table 1) to make these predictions. The predictions based on habitat extent alone are indicated with “H” and shown in blue in Figure 6. Sea otter abundance and distribution in Elkhorn Slough are affected by prey abundance and distribution as well as other factors (see Sections C and D above and External Factors section below). Their main prey species, gaper and butter clams and fat innkeeper worms, occupy the same habitat types so there probably is a limited positive correlation between population size and extent of habitat of the appropriate tidal elevation, but the correlation may not be very strong due to the influence of additional “external” factors including social behavior, population structure and extent to which an area is sheltered. Therefore using habitat-based estimates is probably a reasonable starting point for predicting response to management alternatives, but these estimates should only be considered in combination with additional factors, both related and unrelated to the management options.

Factors other than habitat extent that may be altered by management alternatives

Clearly the assumption of a strictly linear correlation between population size and extent of habitat of appropriate tidal elevation is overly simplistic and unlikely to accurately describe population response to the alternatives. Habitat quality or environmental conditions other than habitat extent are also important drivers of estuary-wide population size. Unfortunately, we lacked quantitative predictions for most parameters relevant to habitat quality for these species. In order to address this short-coming, we attempted to identify key aspects of each management alternative that might affect habitat quality or critical environmental conditions. Consideration of these aspects led to characterization of “best case” and “worst case” scenarios for each alternative, indicated by arrows in Figure 6. These arrows represent qualitative assessments; the exact length or location of the arrow has no quantitative significance. Each arrow is marked with a letter; abbreviations are described below. The description of the range of possible outcomes may be as important for decision-makers as the rough predictions of changes to population sizes based on habitat extent. Moreover, we indicate what sort of measures might be taken to avoid or mitigate the worst case scenario. This information will provide important guidance on future design or refinement of management alternatives. Identification of important parameters other than habitat extent which may be altered by the management alternatives may also lead to future physical modeling and predictions of these parameters, funding permitting, which would enable more robust biological predictions to be made in future iterations of this process, as management alternatives are refined. Here we review the factors invoked in the development of worst and best case scenarios for each of the alternatives.

Sea otter distribution is limited to areas with strong marine influence, and areas with sandy sediments where prey species are abundant. Their distribution is therefore concentrated in the lower Elkhorn Slough, where eelgrass patches also occur, and in the adjacent harbor. Their distribution also extends into accessible tidal creeks further up-slough, such as in the Parsons Slough Complex. Predictions are not available for how the alternatives will alter gradients of tidal energy or sediment size distribution. However it seems plausible that under Alternative 1 and Alternative 4 (which is fairly similar for the lower estuary) the proportion of the estuary which has strong tidal flushing and sandy sediments is likely to increase in years 10 and 50 as a result of continued increase in tidal prism. This may lead to increases in estuary-wide abundance of prey species. (These scenarios are marked with "+m" for "increased extent of marine-influenced, sandy habitats" in Figure 6.) Conversely, it is likely that under Alternatives 2-3 the proportion of the estuary which has strong tidal flushing and sandy sediments will decrease, in all years, due to decrease in tidal prism. This may lead to decreases in estuary-wide abundance of preferred prey species (such scenarios are marked with "-m" for "decreased extent of marine-influenced, sandy habitats" in Figure 6).

Otters in Elkhorn Slough tend to select foraging sites with deep unconsolidated sediments, which are required for burrowing prey species. Observations over the past decades suggest that there has been extensive loss of these fine sediments from the subtidal zone near the mouth of the estuary as a result of tidal scour – the depth of unconsolidated sediments has been decreased to near zero for some areas of the lower main channel. No predictions are available for depth of unconsolidated sediments under the management alternatives, but it seems likely that tidal scour will continue to export fine sediments from the channel, thus making some areas that currently have deep enough unconsolidated sediments for burrowing unavailable in the future.

The potential for a decrease in prey populations due to loss of burrowing habitat under Alternative 1 (and similar Alternative 4) could lead to temporarily or permanently decreased otter abundance or to continued occupation of the Slough and harbor area but with increased traveling to the Monterey Bay to forage. This latter possibility is perhaps more likely, since prey abundance is not the only factor contributing to otter abundance in the Slough (see External Factors below) and this foraging pattern has already been observed for a substantial portion of the otters in this area (see Section F). (These scenarios are marked with "-d" for decreased depth of unconsolidated sediments in Figure 6.) Conversely, Alternatives 2-3 should allow for more fine sediments to accumulate in the main channel, restoring areas that are now scoured to appropriate habitat for burrowing prey species. This could indirectly lead to increases in otter abundance, or could simply lead to increased foraging activity in the Slough relative to the Bay. (These scenarios are marked with "+d" in Figure 6.)

Increased stratification and eutrophic conditions (hypoxia or algal cover) potentially created under Alternatives 2-3 might also indirectly impact the otter population due to negative impacts to populations of prey species. Water quality predictions (by K. Johnson, summarized by Largay and McCarthy 2009) did not suggest that hypoxia would be common under any alternative. However, the modeling assumed good mixing in the water column. The possibility for stratification to occur under Alternatives 2-3 could lead to decreased abundance of subtidal populations of prey species (gaper and butter clams or fat innkeeper worms in the deep portion of the lower main channel) due to prolonged hypoxia. Additionally, macroalgal mats might also accumulate under stratified conditions, which are associated with reduced abundance of prey species (see invertebrate predictions). Impacts to the otter population are similar to those described for loss of unconsolidated sediments. (These scenarios are marked with "+e" for increased eutrophication in Figure 6.)

The impacts possibly associated with water quality impairment under Alternatives 2-3 could be significant to the population of California sea otters both locally and/or statewide. Pathogens are a primary cause of mortality for the species, and Elkhorn Slough appears to be a "hot spot" for otter exposure. Because little is currently known about the source and transport of pathogens in the Slough, the potential effects of these alternatives are unclear. For example, if pathogens are entering the system high up in the watershed, Alternatives 2-3 could lead to higher pathogen concentrations due to decreased flushing in the upper slough. If the main source is the Tembladero and the Old Salinas River channel, then Alternatives 2-3 (mouth re-route and a sill, respectively) could lead to decreased pathogen concentrations. The effects of water quality are not indicated in Figure 6 due to the uncertainty associated with them.

It is possible that fewer sea otters would occupy the Slough as a result of Alternatives 2-3 due to navigational challenges. Alternative 2 (the mouth re-route) has a complete dam between the harbor area, which is most heavily populated by otters currently, and the Slough. However, it is plausible that the otters shift to utilizing the new inlet for access to the Slough. (This scenario is marked with "+b" for barrier to movement of mammals and fish in Figure 6, but there is a high degree of uncertainty associated with it). Alternatives 3a and 3b (low and high sill) might entail navigational challenges for passage over high velocity areas between the harbor area and the Slough. As sea otters regularly navigate turbulent water, this is probably less of concern under Alternative 3a, the low sill, but may be an important issue with a high sill configuration. (This scenario is marked with "+b" for barrier to movement of mammals and fish in Figure 6.)

Biological predictions

Each alternative is evaluated below. The assessment for each includes a) predictions based on extent of habitat of appropriate tidal elevation alone, summarized by the "H" and blue font in Figure 6, b) consideration of other factors (habitat quality, environmental conditions) related to the management alternatives that might alter these predictions, leading to "best" and "worst" case scenarios shown by arrows in Figure 6, and c) suggestions for how worst case scenarios could be avoided or mitigated.

Alternative 1 – No action

Based on habitat extent changes alone, we predict no change in abundance at Year 10 because acreage of total mudflat habitat does not change significantly. At Year 50, we predict significant increases in population size because total mudflat habitat extent increases significantly.

In the best case scenario, the estuary-wide population might increase sooner or more than expected (arrows marked with "+m" in Figure 6), because extent of habitat with strong tidal influence and sandy sediments, which is hospitable for prey species, might expand from the mouth and lower Slough area up the estuarine gradient. Further, increased tidal scour may continue to promote accessibility to more parts of the Slough.

As a worst case scenario, the population might decrease sooner or more than expected because tidal scour could reduce the availability of soft sediment habitat for burrowing prey, leading to decreases in the species distributed near the mouth, a main foraging location (arrows marked with "-d" in Figure 6).

For the female and territorial male-dominated subgroup that primarily feeds in the lower Slough, decreased prey abundance in this area could lead to re-distribution of foraging activity farther up-slough, in areas with increased marine influence. Subsequently, prey abundance and distribution would become more limiting (a function of sea otter foraging in addition to loss of suitable sediment for burrowing bivalves), and abundance of female sea otters in Elkhorn Slough would be expected to reach carrying capacity or begin to decrease due to increase in emigration and/or elevated rates of mortality (K. Mayer, pers. comm.). Pupping could also be negatively effecting by scouring of protected side-channels and population expansion up-slough.

<u>Alternative 2 – Re-route of estuary mouth to create new inlet and decrease tidal prism</u>

Based on habitat extent changes alone, we predict that the population will not undergo any significant changes in size in any of the three periods, because total mudflat habitat (intertidal + subtidal) is not predicted to change significantly (relative to year 0, Alternative 1).

In the best case scenario, the sea otter population may increase if decreased tidal velocities allow soft sediments to accumulate in areas that have previously been scoured, leading to greater abundance of burrowing prey species (arrows marked with "+d in Figure 6).

This alternative creates a barrier separating the primary rafting area in the harbor from the Slough and creates a new inlet, which could lead to several different scenarios. Otters inhabiting the harbor area could continue to inhabit the area or could relocate to utilize the new inlet. Worst case scenarios may result from negative impacts to abundance and distribution resulting from the barrier preventing access to foraging habitat in the lower Slough and preventing the recruitment of young males from the Slough to the harbor subgroup (K. Mayer, pers. comm.). Abundance may drop temporarily if otters relocated from the harbor to the new inlet, or they may not inhabit the new inlet (arrows marked with "+b" in Figure 6). Additionally, a worst case scenario might result from decreases in population size and distribution due to decreased habitat with strong marine influence (arrow marked with "-m" in Figure 6). Further, potential impacts to water quality, such as stratification leading to hypoxia, decreased export of algal mats and increased pathogen concentrations, could negatively impact both prey species and sea otters (shown with arrows marked "+e" in Figure 6). Design refinements of this alternative that would permit navigability, and prevent water column stratification and algal mat accumulation by permitting tidal flushing, would help mitigate these impacts.

Alternative 3a – Low sill under Highway 1 bridge to slightly decrease tidal prism

Based on habitat extent changes alone, we predict no significant change in the otter population at Year 0 or Year 10, as there are no significant changes in total mudflat area (intertidal + subtidal) relative to Year 0 of the No Action alternative. At Year 50, there are significant increases in total mudflat habitat, attributed to increases in the subtidal habitat. So we expect significant increases in the population at Year 50.

The factors that lead to best and worst case scenarios deviating from the above predictions, and the potential ways of mitigating the worst case scenarios, are the same as described for Alternative 2.

Alternative 3b – High sill under Highway 1 bridge to strongly decrease tidal prism

Based on habitat extent changes alone, we predict no significant change in the population because total mudflat area (intertidal + subtidal) is not predicted to change significantly.

The factors that lead to best and worst case scenarios deviating from the above predictions, and the potential ways of mitigating the worst case scenarios, are the same as described for Alternative 2.

Alternative 4 – Decreased tidal prism in Parsons Slough Complex

The predictions for this alternative based on habitat extent changes alone are the same as those for Alternative 1.

The factors that lead to best and worst case scenarios deviating from the above predictions, and the potential ways of mitigating the worst case scenarios, are the same as described for Alternative 1.

Synthesis: ranking management alternatives for this taxon

Overall, it appears that Alternatives 1 and 4 are most likely to optimize sea otter abundance in the Elkhorn Slough area. Habitat extent (intertidal + subtidal mudflats) increases about equally under Alternatives 1, 4, and 3a, but there is the potential for a navigational challenge as well as water quality issues under Alternative 3a. Habitat quality has the potential to increase under Alternatives 1 and 4 due to increasing marine influence, while it has the potential to decrease under Alternative 3a as well as 3b and 2. Of these latter alternatives, Alternatives 2 and 3b are of greatest concern due to the potential for a navigational barrier and decreased water quality. In general, “no action” or conditions and trends similar to the present are better for sea otters than marine engineering projects which decrease the size of the estuarine mouth and/or tidal prism. The ranking of alternatives from the perspective of sea otters is:
Alternative 1 > 4 > 3a > 2 > 3b.

External factors affecting population trends and importance relative to management alternatives

As mentioned earlier, sea otter populations in Elkhorn Slough can be significantly affected by other factors in addition to changes induced by the above management alternatives. For instance, significant changes in prey populations and distributions unrelated to the management alternatives could translate into changes in population size and distribution of the otters in Elkhorn Slough. Any events that occur within the California sea otter range that contribute to significant increase in mortality rates could decrease migration and otherwise have negative implications for sea otter abundance in Elkhorn Slough. Additionally, changes to the population structure (e.g., an influx of reproductive females or the establishment of new adult male territory in the north Moss Landing Harbor area) could lead to changes in abundance and distribution, as described in Section D. Finally, significant changes in human activity causing increased disruption could cause sea otters to abandon, or to stop pupping in, a particular area. Clearly the sea otter population trend in Elkhorn Slough has been strongly influenced by other factors in addition to prey abundance in the Slough. Therefore, it is likely that these factors have the potential to overshadow the habitat changes resulting from the management alternatives.

Targeted restoration actions for these species at Elkhorn Slough

Targeted restoration actions could be undertaken to enhance populations of sea otters, regardless of which management alternative is implemented. For example, habitat for prey species could be enhanced by adding sediment to scoured subtidal areas of the lower main channel or by increasing tidal exchange to areas behind water control structures. However, such increase in tidal exchange may not be desirable due adjacent land uses that could be negatively affected and potential increases to tidal erosion through increase of the tidal prism of the whole estuary. Furthermore, local management decisions have been made to manage some of these historically estuarine wetlands as freshwater habitats.

Restoration actions targeting improved water quality could have important positive implications for the Elkhorn Slough population of sea otters as well as for the statewide population. Improvements might include increased filtration of runoff to reduce pathogen exposure and decreased input of contaminants.

Importance of Elkhorn Slough population sizes

Elkhorn Slough likely plays an important role in recovery of the California sea otter population. The Slough and the adjacent Moss Landing Harbor area host roughly 5% of the statewide population. The population structure appears to be diversifying, and the area is increasingly being used by reproductive adults for breeding and rearing pups. Sea otter foraging can significantly shape ecosystem structures in both rocky and soft-bottom habitats, effecting the diversity and abundance of benthic invertebrate prey. Additionally, the local sea otters are a major attraction for education groups, recreational visitors and patrons of local businesses, and thus they also play an important socioeconomic role in the nearby coastal community.

In contrast, although the habitat functions provided by Elkhorn Slough and the adjacent harbor are important to the recovery of the overall population, the fact the pathogen pollution is thought to be the primary cause of increased mortality rates, possibly limiting population recovery rates, is problematic, because Elkhorn Slough appears to be a “hotspot” for exposure to these pathogens. Therefore, the role played by Elkhorn Slough in the recovery of the California population may be mixed.

Based on the above, significant declines in the otter population are a cause for concern and should be avoided if possible.

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Figure 1. Photo of California sea otter

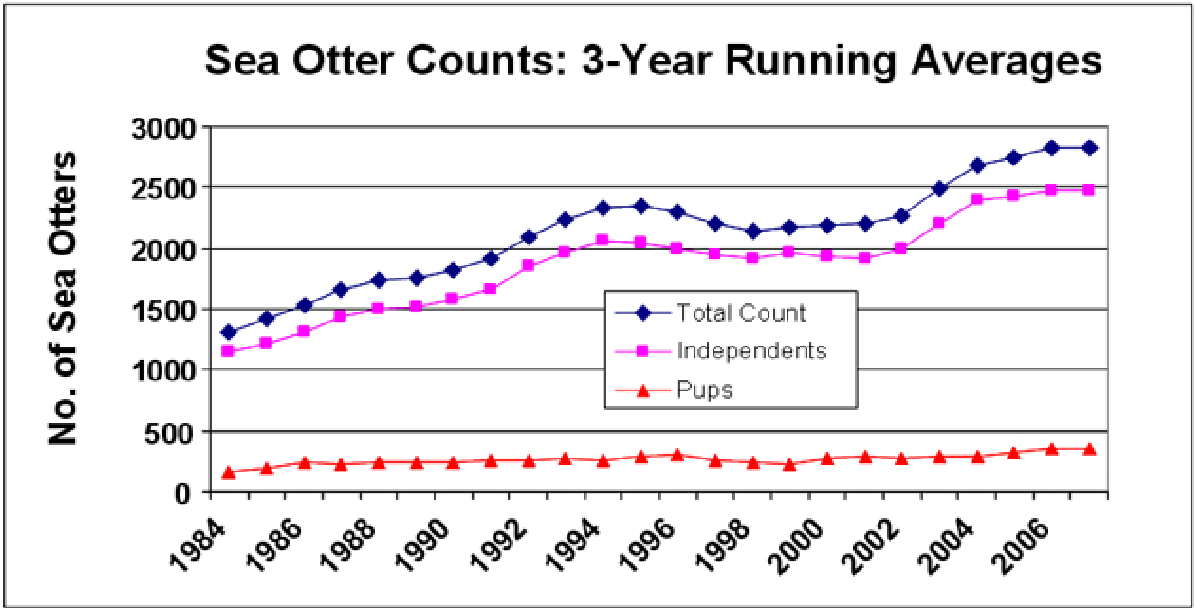

Figure 2. Number of southern sea otters counted during spring range-wide censuses, plotted as 3-year running averages (from Spring 2008 Census Results, USGS-Western Ecological Research Center).

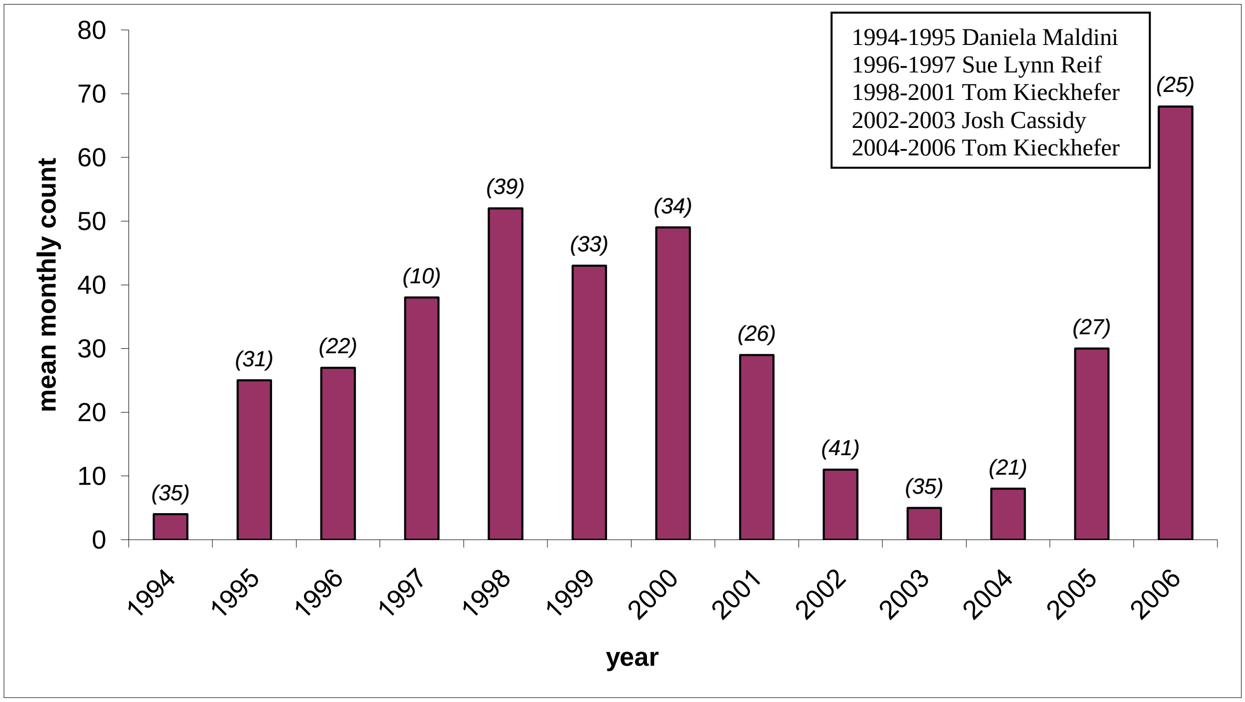

Figure 3. Mean monthly sea otter counts in Elkhorn Slough by year from 1994-2006 (n= sample size, from Kieckhefer et al. 2007).

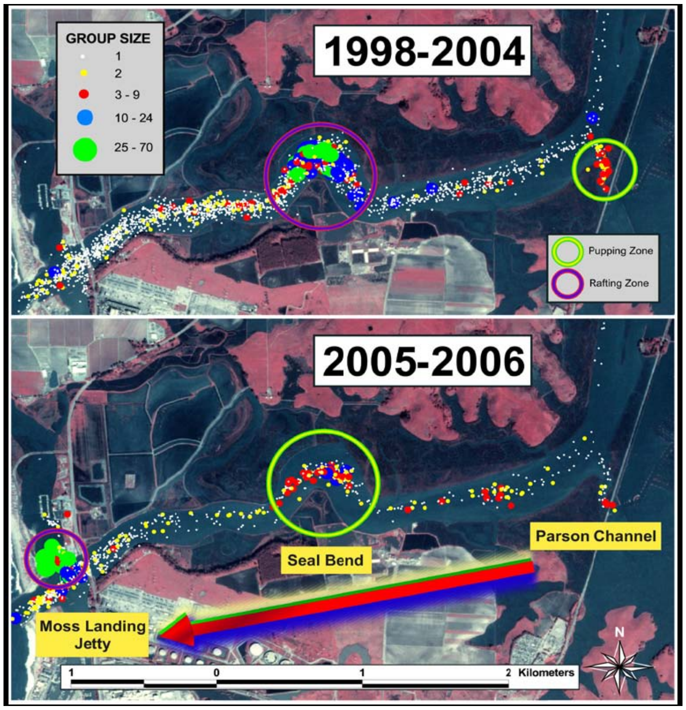

Figure 4. Sea otters main pupping and rafting areas shift down-slough (from Kieckhefer et al. 2007).

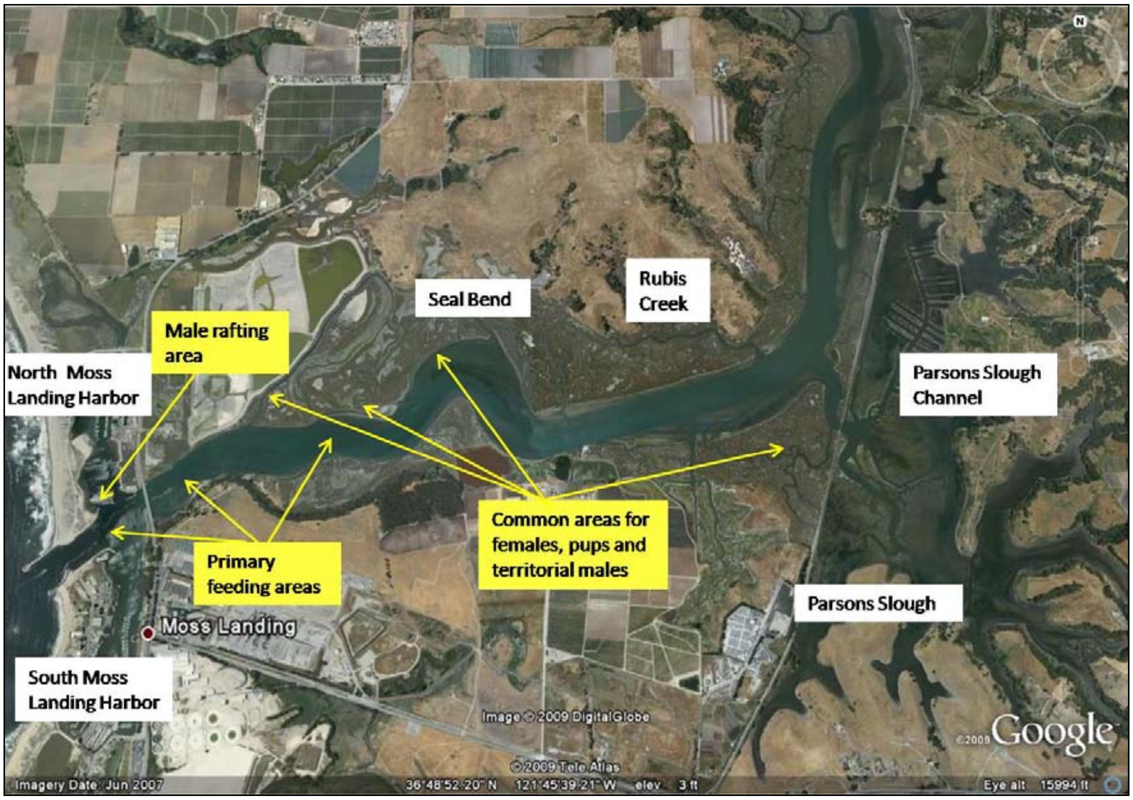

Figure 5. Locations used by sea otters in lower Elkhorn Slough (K. Mayer, pers. comm., R. Eby, pers. comm. 2008).

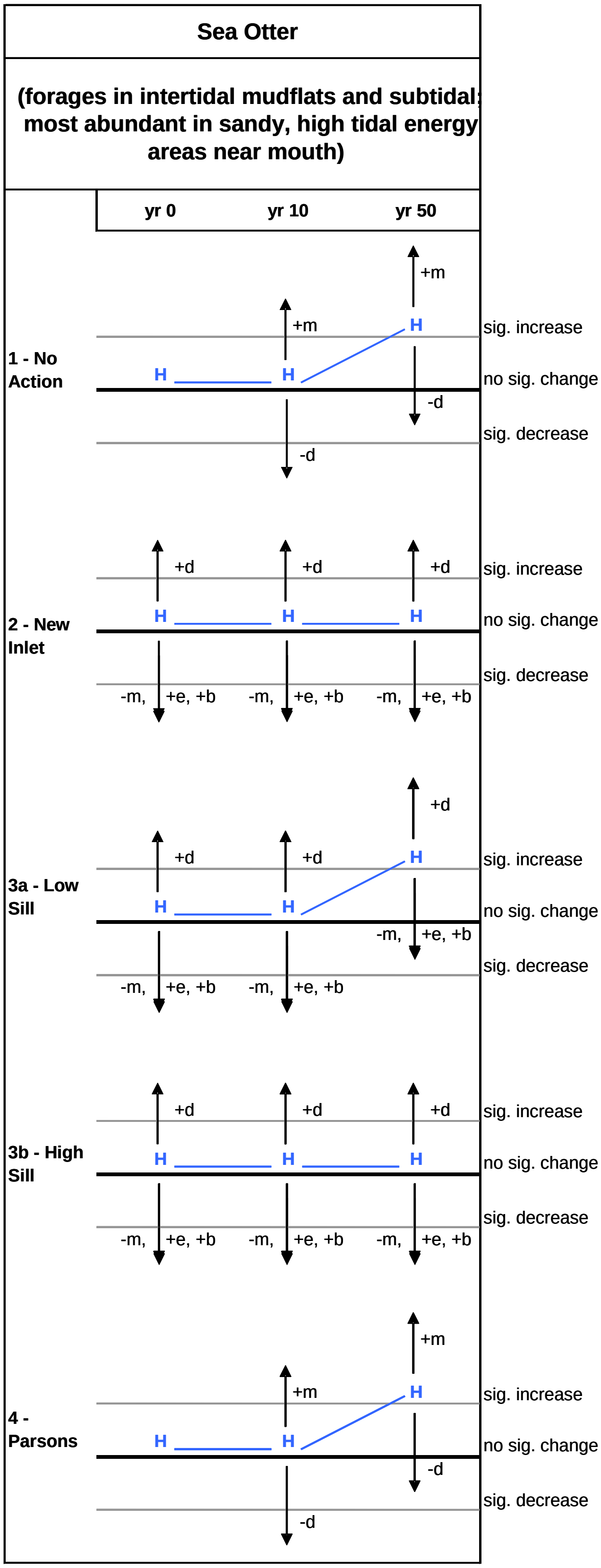

Figure 6. Predicted response of sea otters in Elkhorn Slough for each management alternative.

Legend for Figure 6

For species, predictions made solely based on habitat extent are shown with a blue "H". These predictions make the simplified assumption of a linear relationship between estuary-wide population size and aerial extent of habitat of the appropriate tidal elevation. Thus a significant increase or decrease in habitat area translates to a significant change in population size.

The habitat predictions summarized in Largay and McCarthy 2009 were used for these projections. For sea otters, total mudflat (intertidal mudflats + subtidal) were used as the basis for predictions.

A significant change in habitat area was defined as an increase or decrease of 20% or greater over year 0, No Action (Alternative 1) acreages. Likewise, a significant change in population size of the species was defined as an increase or decrease of 20% or greater over the average population size over the past decade (1999-2008).

For the habitat and species predictions, the geographic boundaries are all the fully tidal estuarine habitats of Elkhorn Slough excluding the Parsons complex (predictions do not include tidally restricted areas).

In addition to the habitat-based predictions, we illustrate a range of worst case and best case scenarios using arrows. These represent qualitative assessments of potential factors related to the management alternatives that might increase or decrease populations in ways other than predicted based on habitat extent alone; the exact length or location of the arrow has no quantitative significance. Each arrow is marked with a letter; legend for letters below. See text for more detail.

"+m" MARINE-INFLUENCED, SANDY HABITAT EXTENT WITH LOW RESIDENCE TIME increases as a result of increased tidal prism

"-m" MARINE-INFLUENCED, SANDY HABITAT EXTENT WITH LOW RESIDENCE TIME decreases as a result of decreased tidal prism

"-d" DEPTH OF UNCONSOLIDATED SEDIMENT AND SEDIMENT DEPOSITION RATE decreases as a result of increased tidal energy

"+d" DEPTH OF UNCONSOLIDATED SEDIMENT AND SEDIMENT DEPOSITION RATE increases as a result of decreased tidal energy

"+e" EUTROPHICATION symptoms such as hypoxia, water column chloropyll and macroalgal accumulation increase as result of lower tidal energy

"+b" BARRIER TO PASSAGE FROM OCEAN OR HARBOR TO SLOUGH might decrease movement of marine mammals or fish

TABLE 1. Predicted habitat extent under management alternatives.

The numbers represent percent change from baseline conditions (Year 0, No Action alternative) as predicted by H.T. Harvey and Associates and summarized in Largay and McCarthy 2009. Habitats were defined based tidal elevation zones. The area of habitat considered excludes the Parsons Slough complex and all wetlands behind water control structures.

To facilitate perusal of trends, significant increases are coded with warm colors (20% or greater = orange, 50% or greater = red). Significant decreases are coded with cool colors (20% or greater = light blue, 50% or greater = dark blue).

HABITAT PREDICTIONS FOR SINGLE HABITAT TYPES

	A. Deep (>2 m) subtidal			B. Shallow subtidal			C. Intertidal mudflat			D. Salt marsh		
ALTERNATIVE	yr 0	yr 10	yr 50	yr 0	yr 10	yr 50	yr 0	yr 10	yr 50	yr 0	yr 10	yr 50
1 - No Action	0%	9%	42%	0%	8%	15%	0%	3%	22%	0%	-7%	-65%
2 - New Inlet	54%	65%	105%	53%	70%	108%	-39%	-36%	-32%	18%	6%	-40%
3a - Low Sill	9%	12%	20%	8%	22%	72%	-10%	-3%	14%	9%	0%	-55%
3b - High Sill	39%	28%	6%	39%	75%	182%	-34%	-28%	-16%	22%	18%	-36%
4 - Parsons	1%	6%	38%	0%	5%	10%	0%	3%	19%	-1%	-6%	-61%

HABITAT PREDICTIONS FOR COMBINED HABITAT TYPES

	E. Total mud (A+B+C)			F. Shallow mud (B+C)			G. Subtidal (A+B)			H. Intertidal (C+D)		
ALTERNATIVE	yr 0	yr 10	yr 50	yr 0	yr 10	yr 50	yr 0	yr 10	yr 50	yr 0	yr 10	yr 50
1 - No Action	0%	5%	25%	0%	4%	21%	0%	8%	32%	0%	-1%	-12%
2 - New Inlet	-8%	-1%	15%	-24%	-19%	-9%	53%	67%	106%	-17%	-20%	-35%
3a - Low Sill	-4%	3%	23%	-7%	1%	23%	8%	16%	40%	-2%	-2%	-13%
3b - High Sill	-9%	-3%	14%	-22%	-11%	16%	39%	45%	72%	-12%	-10%	-24%
4 - Parsons	0%	4%	22%	0%	4%	18%	1%	6%	27%	0%	0%	-12%