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Harbor seals: 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.

Kerstin Wasson served as Editor-in-Chief for this series of reports, with editorial and production assistance from Erin McCarthy and Quinn Labadie. They conducted this work as staff of the Elkhorn Slough National Estuarine Research Reserve, owned and managed by the California Department of Fish and Game in partnership with the National Oceanic and Atmospheric Administration (NOAA). Grants from the Packard Foundation, Resources Legacy Fund Foundation, and the Estuarine Reserves Division of NOAA supported this project.

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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

Pacific harbor seals (*Phoca vitulina richardii,* Figure 1) are abundant along the Pacific Coast of North America. They usually occur in the nearshore environment, commonly in bays, estuaries and occasionally in rivers. They also regularly come ashore, or haul out, on banks and beaches. Harbor seals are near the top of the food web and are voracious predators. They primarily feed on fish (*e.g.*, herring, cod, flounder), cephalopods (*e.g.*, octopus), and invertebrates (*e.g.*, shrimp and amphipods) (Bigg 1981, Oxman 1995, Spalding 1964). Unlike some other pinnipeds, harbor seals do not exhibit marked sexual dimorphism. Males weigh up to 170 kg (370 lb) and reach lengths up to 1.9 m (6 ft. 3 in.); females weigh up to 130 kg (290 lb) and reach up to 1.7 m (5 ft. 7 in.) in length. Harbor seals mate underwater and females typically give birth at haul-out sites that are removed from the main group, which they occupy with their pups for several weeks. In California, pupping occurs primarily during the spring. Pups are able to swim immediately after birth and are weaned within 3-6 weeks. Harbor seals molt each year, and the molting and mating period begins shortly after pupping.

Harbor seals were chosen as a key species to inform decision making about estuarine ecosystem restoration and management for the following reasons: 1) their ecological role, and 2) their socioeconomic role.

Ecological role

Because harbor seals are year-round coastal residents feeding primarily on fishes that inhabit the nearshore ocean and estuarine environments, they have the potential to affect abundance and distribution of prey populations in these areas (Oxman 1995). Harbor seals require a substantial amount of biomass for food, consuming 2.5-6.0% of their body weight per day, amounting up to 1-2 tons of fish per adult per year. Harvey (1987) found that harbor seals off Oregon fed primarily on fishes that inhabited estuaries and the nearshore ocean. In addition to their heavy predation, harbor seals' potential to impact estuarine communities is compounded by the fact that their populations in estuaries have increased substantially since implementation of the Marine Mammal Protection Act (MMPA) in 1972.

Socioeconomic role

Human perceptions and values associated with harbor seals have shifted over time from those related to natural resource extraction to those more focused on their intrinsic, educational and ecological values. Historically, harbor seals were widely valued and hunted for their meat and dense pelts. As fishing industries developed, harbor seals were, and to some extent still are, often perceived as competitors with humans for fish resources. Through heavy foraging, harbor seals have the potential to negatively impact fishery stocks. Harvey (1987) estimated that seals in coastal Oregon consumed about 22% of the commercial catch of flatfishes and 17% of salmonids. Fishing operations, in turn, have the potential to negatively impact harbor seal populations by decreasing food supply and by mortality associated with fishing gear. A recent shift in human perceptions is reflected by conservation management for the species, such as the MMPA (1972) and by restrictions to fishing practices. Harbor seals play an important role in coastal economies by being a major lure for recreational and tourist activity, and the educational value of their presence along the coast is likely substantial.

B. Trends in distribution and abundance

Coastwide Range

Two subspecies of harbor seals exist in the Pacific: *P. v. stejnegeri* in the western North Pacific and *P. v .richardii* in the eastern North Pacific. This report focuses on *v. richardii*, which inhabits nearshore coastal and estuarine areas from the Aleutian Islands, in the Bering Sea, Alaska southward to Baja, Mexico, near Cedros Island (Carretta et al. 2005, Osborn 1985).

Three stocks of *v. richardii* are recognized along the west coast of the continental U.S.: 1) California, 2) Oregon and Washington outer coast waters, and 3) inland waters of Washington. (Lamont et al. 1996). The boundaries defining stocks are largely management-based and have little biological significance. This report focuses on the California stock, occasionally referring to studies conducted in Oregon and Washington.

Abundance

Prior to state and federal protection, North Pacific harbor seals were greatly reduced by commercial hunting by the end of the 19th century. During the last half of the twentieth century, the population increased dramatically to about 300,000 in 1976 (NMFS 1978).

The California stock had been reduced to a few hundred prior to protective legislation (Carretta et al. 2005). The first state-wide census conducted by the California Department of Fish and Game in 1965 was 1,062 (Carlisle and Aplin 1966, Osborn 1985). The California stock increased rapidly after implementation of the MMPA in 1972 and had climbed to over 15,000 by the mid-1980s (Osborn 1985). Based on recent counts, the harbor seal population in California is estimated at 34,233 (Hanan 1996, Lowry et al. 2005) (Figure 2). However, using a correction factor determined by Harvey and Goley (2008), the most recent population estimate for California is 43,449 individuals (Lowry et al. 2008).

Human activities, especially commercial fishing, have contributed considerably to harbor seal injuries and mortalities, or takes. The vast majority of harbor seal takes associated with fisheries are attributed to gillnet fisheries, which have faced increased restrictions since the early 1990s. Gillnet fisheries are currently less active and more restricted, and estimates for deaths associated with commercial gillnet fisheries from 1999-2003 were 386 (Carretta et al. 2005). Other means of seal takes by humans include boat collisions, entrainment in power plants and shootings.

From 1982 to 1995, a period when annual mortality associated with fisheries may have been as high as 5-10%, the population growth rate was estimated as 3.5%. Because human-caused mortality takes a fraction of net production, the current rate of net production is greater than the observed growth rate during this period. Net productivity between 1983 and 1994, calculated as the realized rate of population growth plus human-caused mortality, averaged 9.2%. Carretta et al. (2005) estimate a recent annual maximum growth rate of 12% (Figure 3).

Despite its rapid growth, the population's net production in California decreased from 1982 to 1994, and this period coincides with a decrease in human-caused mortality (Carretta et al. 2007). It has been suggested but not formally determined, that this decrease in productivity indicates that the California stock is approaching its environmental carrying capacity. Oregon and Washington stocks show a similar trend.

Distribution

Harbor seals are year-round residents of California's nearshore rocky outcrops and islands, inshore embayments and coves, and inland tidal channels, estuaries and lagoons. Occasionally, they are spotted in freshwater systems, including rivers (Osborn 1985).

Although harbor seals off California do not make extensive pelagic migrations, they do travel great distances (300-500 km) to find suitable breeding areas and to forage (Hanan 1996, Herder 1986). Radio-tagged individuals have moved distances of 480 km from Point Reyes, California (Allen et al. 1987) and in the Monterey Bay, harbor seals often move substantial distances (10-20 km) to foraging areas each night (Oxman 1995, Trumble 1995).

Harbor seals regularly haul out on shore, an activity important for metabolic regulation, sleep and rest, predator avoidance, and skin and pelt growth and maintenance (Feltz and Fay 1966, Terhune 1985). Physical features that shelter water and/or adjacent shores including sandbars, lagoons, rivermouths, embayments, marshes, jetties, levees and islands can provide haul-out habitat. Approximately 400-600 harbor seal haul-out sites are widely distributed along mainland California and on offshore islands (Lowry et al. 2005). These sites have grown in number and in occupancy, likely the result of increased overall abundance and increased competition for space. Likewise, studies in Oregon and Washington show an increase in the abundance and number of haul-out sites in bays and estuaries since the MMPA (Harvey et al. 1990, Jeffries 1986, Oxman 1995).

Seasonal trends in abundance

Seasonal fluctuations in abundance are common throughout the harbor seals' range and are associated with site use, reproductive status, molt and prey availability (Osborn 1985, Oxman 1995). Habitats used for reproduction and molt are more isolated from human activity.

Use of Pacific estuaries

Estuaries provide important habitat used for hauling out, molting, socializing and foraging, as well as for reproduction and pup rearing (Allen et al. 1984, Beach et al. 1985, Brown and Mate 1983, Oxman 1995). Harbor seal abundance in California estuaries was probably low before 1972 because they were harassed and driven away from these areas (Newby 1973). Abandonment of these sites and associated mom/pup separation led to lower reproductive rates and pup survival. Decreased harassment has allowed seals to return to these areas, affording increased reproductive success and population expansion (Harvey et al. 1990, Oxman 1995).

Feeding

Harbor seals in estuaries often exhibit diurnal feeding patterns, with foraging usually occurring at night and maximum numbers of seals hauled out midday. Seals inhabiting estuaries may forage in the estuary, at the mouth of an estuary or river, or may travel to the nearshore waters nightly to feed. They generally feed opportunistically on benthic dwelling species; benthic fish are a dominant food source, as well as invertebrates like crustaceans and squid (Studer 2000).

Harbor seals forage in estuarine channels, at the mouths of estuaries or rivers, or use these areas as corridors to reach foraging grounds in the nearshore environment. In Elkhorn Slough, harbor seals use the corridor created by the main channel of the Slough to travel to primary foraging grounds in the Monterey Bay, with limited foraging occurring in the main channel near the mouth. (Oxman 1995, Harvey et al. 1990). At the Klamath River mouth and estuary, harbor seals capture prey in the river mouth, and appear to use hydrodynamics to assist in prey capture, positioning themselves in eddies and darting into the flowing channel when prey swim by (Holzwarth 2001). Harbor seals in the San Francisco Bay use numerous foraging grounds within the bay and some travel to the open ocean to forage. (Kopec and Harvey 1995).

C. Factors affecting estuarine abundance

Harbor seal abundance and densities in an estuary are affected by factors outside as well as inside the estuary. In most cases, a combination of these factors influence the presence or density of seals in a given estuary, and the relative affect of each factor may be site-specific.

Factors outside the estuary

Overall abundance

One of the most important predictors of harbor seal abundance inside estuaries is probably their overall abundance coastwide. Trends in abundance in California estuaries have reflected trends in the overall population, with less harbor seals in estuaries prior to the recovery of the population during the late 1900s, and more after their recovery. The overall increase may lead to greater competition for space at crowded haul-out sites as well as greater competition for food, resulting in migration and population expansion.

Migration

Harbor seals are generally considered to be site-specific with limited local movement as well as adults travelling to breeding areas, but juveniles tend to move greater distances (Lander et al. 2002). Increases in abundance of seals at some estuaries have been attributed to dispersal of juveniles (Oxman 1995).

Factors within the estuary

Human disturbance

Disturbance to harbor seals by humans is a significant factor affecting abundance and distribution of harbor seals in estuaries. Disturbance can occur to individuals or entire groups with responses ranging from lifting the head, shifting the body position or location, or temporarily or permanently abandoning a site (flight). Impacts resulting from flight due to disturbance include: 1-change in haul-out pattern (which can in turn affect feeding patterns), 2-site abandonment, and 3-reduced pup survival due to mother/pup separation and interrupted suckling bouts. Sources of disturbance include motor boats, paddle boats, loud and unfamiliar noises, human presence, and presence of domestic animals. These activities may be associated with commercial or recreational fisheries, with other recreational activities or with industrial activities. Management limiting human activity in areas used by seals has a positive affect on seal abundance.

The level of human disturbance to seals can depend on how a site is used by seals. Human disturbance can have greater negative impacts in areas of limited haul-out space and at pupping locations (Suryan and Harvey 1999). Decreased haul-out time leads to increased energy expenditure, which has the greatest impacts on pups during nursing and on adults and sub-adults during molting periods (Suryan and Harvey 1999). Disturbance over a period of time, especially in areas used for pup rearing, may have significant negative effects, and may ultimately lead to site abandonment and/or decreased reproductive success (Richardson et al. 1995, Suryan and Harvey 1999).

Level of disturbance is also dependent on proximity. Suryan and Harvey (1999) reported that harbor seals in Washington detected motor boats at a distance of 264 meters, and fled the site at 144 meters. In the Elkhorn Slough, Osborn (1985) documented a critical zone of less than 100 meters for harassment by humans, and Allen et al. (1984) reported the same distance for disturbances occurring in Bolinas Lagoon.

Osborn (1985) identified additional factors influencing how seals respond to disturbance, such as the duration and frequency of disturbances. According to Osborn (1985), harbor seals may tolerate (return to haul-out site) a disturbance occurring two days/week (e.g., due to increased human activity on the weekends), but not throughout the week. This tolerance may be lower during pupping season. The amount of time required for seals to re-haul is influenced by the presence/behavior of other seals, tide height, boat presence, number of previous disturbances, time and ages (Osborn 1985).

Fishing gear

Because humans and seals are sometimes competitors for fish resources, rivermouths and estuaries can be areas of frequent seal-human interactions. Boat collisions, hook and line gear and gillnets can cause injury and mortality to seals. Although more restrictions are now imposed on commercial gillnet use, they are still used in some Native American fisheries in areas where seal activity is prevalent, such as the Klamath Rivermouth and Estuary, California.

Haul-out habitat extent

Harbor seal abundance is dependent upon the extent of haul-out habitat, which includes acreage of sheltered mud, marsh, sand bars, rocky islets, tidal reefs, and sand and gravel beaches (Oxman 1995). The exposed surface area of these substrates during flood tides, combined with the space requirements for harbor seals, is generally a limiting factor to haul-out capacity (although some sites are used more frequently or only on high tides). Steeper substrates like buoys, docks and boulders may be more difficult for seals to access.

Proximity to foraging areas

Harbor seals exhibit diurnal feeding behavior so estuaries and embayments are either used as foraging grounds, or provide a corridor to access foraging grounds located within reasonable distance for diurnal migration.

Prey abundance

Several studies have demonstrated a positive correlation between prey abundance and harbor seal abundance within estuaries. In the Elkhorn Slough, increased harbor seal abundance during summer months coincided with a marked increase in fish diversity and abundance (Oxman 1995). Allen et al. (1984) also noted a direct correlation between harbor seal abundance and fish abundance in Bolinas Lagoon. In Netarts Bay, Oregon, Brown and Mate (1983) observed that harbor seal abundance was associated with chum salmon abundance during autumn.

Water Quality

Water quality conditions may also affect harbor seal densities in coastal inlets by negatively impacting survival and reproductive rates directly, and by decreasing the abundance and quality of prey species.

Contaminants

Harbor seals are subject to a great deal of toxin exposure. They are tertiary consumers feeding on prey with accumulated toxins (much of which are benthic fishes associated with potentially toxic sediments), have a thick fat layer with an affinity for organic pollutants, and inhabit estuarine systems that receive high inputs of pollutants from coastal urban activity and agriculture. Harmful toxins may include trace elements such as mercury, lead or cadmium, and persistent organic pollutants such as organochlorine pesticides, PCBs, tributyltin and polycyclic aromatic hydrocarbons.

Toxins may reduce reproductive success, contribute to pup mortality and impair physiological processes making seals more susceptible to pathogens and other environmental stressors. Studies indicate that polycyclic aromatic hydrocarbon could impair seals' immunity against viral pathogens (Neale 2003). Organochlorines are associated with reduced reproduction and immune suppression. PCB contamination contributed to a reduced birth rate in a harbor seal population in Europe (Helle 1976, Reijnders 1980 and 1986, Kopec and Harvey 1995). Kopec and Harvey (1995) determined that toxicity is a likely contributor to the relatively slow growth rate of harbor seals in the San Francisco Bay, California.

D. Factors affecting estuarine distribution

Some of the factors that affect harbor seal abundance and density in an estuary also affect their distribution, such as human disturbance and some physical characteristics. Site usage also plays in important role in driving estuarine distribution.

Tidal influence

In an estuarine environment, harbor seals are usually absent from areas behind water control structures. This is probably due to inaccessibility of these areas and low abundance of food in freshwater-influenced environments.

Acreage of haul-out habitat

Because the extent of haul-out habitat and space requirements for seals can limit densities at a particular location, limited extent of habitat within Mean High Water and Mean High High Water can also lead to increased distribution due to competition for space and migration.

Proximity to foraging areas

Habitat extent within close proximity to foraging grounds and corridors may drive changes in seal distribution, reflecting their preference for food accessibility, except during reproduction, pup rearing and molt.

Corridors

Corridors from the estuary to the open ocean or bay are used to forage, find breeding grounds, or for migration. They are often used on a daily basis. Altering a corridor such that it diminishes ease of transport from an estuary to the open ocean could cause harbor seals to permanently abandon an estuary, or prohibit harbor seals from inhabiting an estuary, thereby decreasing overall harbor seal distribution and abundance, and increasing densities at alternate estuaries and foraging grounds.

Because estuaries play a role in the life cycles of many harbor seal prey species, altering a corridor such that it diminishes transport of prey species could lead to decreased prey abundance in both the estuary and in the nearshore ocean, which may negatively impact seal abundance in the estuary.

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

Ecosystem-based estuarine restoration efforts may affect seals by altering corridors (described above), and may alter habitat extent and water quality having the potential impacts described below.

Changes to habitat extent

Conversion of subtidal habitats to intertidal mudflat and marsh by raising the elevation or minimizing tidal inundation could increase the extent of haul-out habitat. If acreage of haul-out habitat is not limited in an estuary, abundance and distribution may only be affected if the new habitat is in closer proximity to foraging grounds, corridors, and/or further from human activities relative to existing haul-out sites. Conversely, loss of haul-out habitat close to foraging areas, corridors, or removed from human activity, could lead to site abandonment.

Changes to water quality

Since benthic fish are a primary food source for seals and because seals are tertiary consumers, decreased toxin inputs in estuarine watersheds and sediments would likely be reflected by decreased toxin concentrations in seal tissues, likely resulting in decreased mortality and increased reproductive success. The effect would be an overall increase in abundance, with site- specific impacts to density and distribution, depending upon habitat availability and space requirements. Improved water quality could also positively impact prey abundance, which may in turn positively influence harbor seal abundance and distribution.

F. Status and Trends of Elkhorn Slough populations

A few hundred harbor seals occupy the Elkhorn Slough year-round (Jones et al. 2002). They use the Slough for hauling out, resting, socializing and foraging, and are increasingly using the Slough for molting and reproduction- behaviors more sensitive to human disturbance.

Although a limited amount of foraging occurs in the Slough, it is mainly used as a staging area for primary foraging grounds in the Monterey Bay. Harbor seals use the corridor from the mouth of the Slough through the Moss Landing Harbor entrance to travel to the Bay to feed nightly. There is likely also some foraging that occurs throughout the lower Slough (J. Harvey, pers. comm.).

Harbor seal diets in Elkhorn Slough are comparable to those in other areas of California (Harvey et al. 1995). Research conducted by Harvey et al. (1995) on harbor seal diet contents from 1975-1977 identified 35 species. Among them were topsmelt, white croaker, spotted cusk-eel, night smelt, bocaccio, Pacific herring, a brachyuran crustacean, and 4 genera of mollusks. Oxman (1995) identified 40 prey species in 325 fecal samples: 61% were cephalopods and 39% were fishes. Most cephalopods were octopus (*Octopus* sp.), followed by market squid *(Loligo opalescens)*. Fishes consumed were predominantly flatfishes (Pleuronectidiae and Bothidiae), cusk-eels (Ophidiidae), and rockfishes (Scorpaenidae).

Harbor seal abundance in the Slough may change seasonally according to prey abundance, molt, and reproduction. Some seals may depart during pupping/breeding season which peaks in May on the central California coast. Some seals in Elkhorn Slough likely head 25km south to Cypress point, Carmel, or 60 km north to Año Nuevo to pup and breed (Osborn 1992, Oxman 1995).

Current distribution, abundance, growth and recruitment

Consistent with state-wide trends, the harbor seal population in Elkhorn Slough has increased in abundance and distribution over the last several decades, with increasing diversification of site usage.

Long-term trends in abundance

Historic presence of harbor seals in and near the Elkhorn Slough watershed is evidenced by archaeological remains found both within the watershed and along the open coast. Harbor seal artifacts in these areas date back to at least 600 B.C.-A.D. 1000, when they were harvested by native peoples who used their meat, skins and bones (Jones et al. 2002).

Studies on more recent harbor seal activity between 1975 and 1997, have documented the increasing use of Elkhorn Slough by a resident population. Harbor seals likely inhabited Elkhorn Slough in the 1970s because it provided a good alternative to crowded coastal haul-out sites, has numerous mudflats and minimal disturbance. Records of counts began in 1975 and averaged about 30 seals (Harvey et al. 1995, Oxman 1995). Counts conducted by Osborn (1985) in 1984 averaged 35, and during 1991, maximum counts reported by Oxman (1995) were five times greater. Oxman also reported a 20% increase between 1990 and 1991, from 150 to 180 seals. Average counts remained comparable from 1994 through 1997, with peaks coinciding with pupping and molting seasons. A count of 339 seals was reported in 1997 (Jones et al. 2002, Richman 1997). Harvey et al. recently counted 345 seals (J. Harvey, pers. comm. 2009), which amounts to about 530 when applying a correction factor of 1.54 (J. Harvey, in publication) (Figure 4).

Harbor seals have used the Elkhorn Slough for reproduction for the past two decades. According to Osborn (1985) prior to the 1980s, high frequency of disturbance by humans was prohibiting pupping in Elkhorn Slough. She predicted that if recreational activity was halted, seals would pup in the Slough. The first pup was sighted in Elkhorn Slough in 1989. By 1991, a total of 7 pups were born. During 1995-1997 there was a significant annual increase in pups, from 14 in 1995 to 29 in 1997 (Richman 1997). Recently more than 50 pups were counted in Elkhorn Slough (J. Harvey unpublished data). This increase may or may not be related to less human activity due to the removal of restrooms from the Seal Bend area in the early 1990s (Figure 5).

Factors affecting long-term abundance trends

The growth of the Elkhorn Slough population and the increased pupping frequency are likely attributed to a combination of three major factors: Overall increase in abundance leading to increased competition for space and population expansion, migration of young seals to the area and decreased harassment by humans.

Increased abundance/migration

Protective legislation and the subsequent increase in abundance of the California harbor seal population has likely lead to population expansion and increased abundance in Elkhorn Slough.

Oxman (1995) attributes the population increase in Elkhorn Slough during the 1980s and 1990s to recruitment of young seals through migration. This is evidenced by the preponderance of immature seals in Elkhorn Slough (about 80% in 1984) and the low pupping rate during that time. The migration is likely driven by both their natural tendencies and by overcrowding of pupping and haul-out areas due to overall population increase. Other studies also show increases due to dispersal of juveniles (see Oxman 1995).

Decreased harassment

Decreased harassment by humans has led to increased reproductive success and has made Elkhorn Slough more inviting habitat with some areas suitable for pupping and molting (Harvey et al. 1990, Oxman 1995). Haul-out counts during molt may be a good indicator of the level of disturbance at a haul-out site. Osborn (1985) reported a drop in abundance during the molt period in 1984 while Oxman (1995) and Richman (1997) reported peak abundances during molt periods (July) during the 1990s. It is possible that decreased human disturbance near Seal Bend due to the closure of public restrooms in the early 1990s led to more use of Elkhorn Slough for molting.

Distribution trends

Harbor seals inhabit Elkhorn Slough year-round and occur individually or in groups. They usually occupy areas just beyond the mouth of the Slough in the Moss Landing harbor and in the Salinas River channel south of the Moss Landing bridge, and the lower portion of the Slough extending up to Parsons Slough and Rubis Creek (Figure 5). They are rarely seen in tidally restricted areas.

Haul-outs
Sites used by harbor seals since their establishment in Elkhorn Slough have increased in number and changed in location. Seal Bend was the most frequented haul-out site for more than 60 years prior to the mid-1980s. It is located about 2 km from the Slough mouth, and had two mud terraces rising from the water that seals hauled out on (Vierra, pers. comm., 1977 from Harvey 1995). Between 1984 and 1988, harbor seals abandoned the haul-out site after a nearby dike was breached creating a more isolated haul-out area (Harvey et al. 1995). Norris (1991) noted use of an additional location on a beach in the north harbor. From 1994-1997, Richman (1997) observed regular use of the Rubis Creek area mudflat, and intermittent use of Seal Point (across from Seal Bend). Recently established haul-out sites also exist near the entrance to Parsons Slough (west of the railroad tracks) and inside Parsons Slough (east of the railroad tracks), and seals are regularly observed in tidal creeks within the Parsons Slough complex (Figure 5).

Reproduction
During the pupping season, reproductive females tend to remove themselves from the large group to give birth and then return to the group within a week. The areas mothers and pups can be found have expanded up-slough over time, into various mudflats and in tidal and subtidal creeks, such as Rubis Creek and in the Parsons Slough (Richman 1997) (Figure 5). More data is needed to better understand how these areas are used.

Factors affecting distribution in Elkhorn Slough

Foraging locations
Harbor seal distributions within the estuary reflect foraging locations to some extent. Research by Oxman (1995) and Harvey et al. (1995) comparing catch rates from trawls conducted in the Slough (Orre et al. 2005, Yoklavich et al. 1991) to species detected in seal scat indicates that they primarily feed between Seal Bend and the oceanic nearshore shelf in Monterey Bay. Additionally, Oxman (1995) radio-tagged seals and found that they all spent their nights diving within 0.5 to 7 km of shore, most (88%) 1.25 km south of the Slough entrance, with the others (12%) either 4 km north at the Pajaro Rivermouth, or 7.25 km north at Sunset Beach, Santa Cruz. In conclusion, harbor seals may conduct limited foraging near the Slough mouth, but most is done in the nearshore oceanic, which may explain why haul-out sites are located in the lower half of the estuary.

Tidal barriers
Harbor seals are concentrated in the lower reaches of the Slough, up to the Parsons complex and Rubis Creek areas, all open to full tidal exchange. They were not observed in the Parsons complex prior to removal of the tidal barrier, and they are generally not observed behind water control structures, as those areas are largely inaccessible. Removal of tidal barriers, or breaching of a levee, can lead to expansion into areas with tidal exchange and can lead to creation of new haul-out habitat. Additionally, modification of the slope and geography of mudflats over time may contribute to shifts in haul-out locations.

Human disturbance

The expansion of the harbor seals into more areas of Elkhorn Slough may be partially related to decreased disturbance by humans. Closure of a trail and restroom near Seal Bend has resulted in less human presence in this area and a portion of the lower slough was recently closed to fishing. The increase in kayak traffic in the last ten years may also have caused subtle shifts over time.

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 30 cm of sea level rise over 50 years, 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 harbor seals in Elkhorn Slough haul-out and pup on intertidal mudflats and navigate, rear pups and conduct limited foraging in deep and shallow subtidal areas, we used "total mud" habitat (intertidal mudflat + subtidal) to make these predictions (part E of Table 1). The predictions based on habitat extent alone are indicated with "H" and shown in blue in Figure 6. Because harbor seals move in and out of the Slough and because their population in the Slough is more strongly influenced by external factors (i.e., overall population size) as well as by changes to habitat quality as opposed to extent of habitat at appropriate tidal elevation within the Slough, there probably is a very weak correlation between population size and extent of habitat of the appropriate tidal elevation. Further, harbor seals use a very small percentage of the potential haul-out habitat that currently exists in Elkhorn Slough and are also not limited by subtidal habitat. Therefore, it would probably require huge losses of extent of these habitats for them to become limiting to the population, and losses of that magnitude do not occur under any of the alternatives described.

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.

Water quality could be altered as a consequence of some of the alternatives, which could have implications for harbor seals. It is possible that stratification of the water column could occur under Alternatives 2-3 (mouth re-route and low and high sill), and prey populations (such as flatfish which breed in the Slough and otherwise occupy the nearshore ocean) might be subject to prolonged hypoxia, which would decrease abundance. Alternatives 3a and 3b (low and high sill) could increase residence time for water behind flow restriction devices, and combined with the high nutrient concentrations in the Slough, this could lead to anoxic conditions that could affect prey stocks (some of the prey species that seals feed on offshore breed in the Slough). Additionally, if alternatives lead to decreased water circulation, as is possible with 3a and 3b, contaminant concentrations in the Slough could increase, negatively affecting seal mortality and reproductive success through direct exposure and/or through consumption of contaminated prey. Therefore it is plausible that harbor seal abundance in Elkhorn Slough could decrease over time after implementation of Alternatives 2-3 due to eutrophication leading to suboxic conditions and/or higher contaminant concentrations in the subtidal Slough (these scenarios are marked with "+e" for increased eutrophication in Figure 6).

Alternatives 2 and 3 may pose navigational challenges for harbor seals traveling between the Slough and the Monterey Bay. Alternative 2 (the mouth re-route) entails a complete dam at the current channel between the harbor and the Slough, and Alternatives 3a and 3b (low and high sill) might create areas of high velocity between the harbor area and the Slough. These alternatives, particularly Alternative 3b (a high sill would lead to higher velocities than a low sill), may pose navigational challenges for both harbor seals and potentially for prey populations as well. This could lead to decreased harbor seal abundance in the Slough and/or shifts in distribution. Because there are few other protected inland areas for seals south of San Francisco Bay, complete abandonment of Elkhorn Slough is not likely unless access is entirely obstructed (J. Harvey, pers. comm.). Additionally, Alternative 4 (Parsons) could result in a navigational challenges at the entrance to the Parsons Complex, an area used for pupping. (These scenarios are marked with "+b" for "barrier to movement of mammals and fish" in Figure 6.)

Harbor seals are mainly distributed in marine influenced areas with full tidal exchange. Under Alternative 1 (no action) and Alternative 4 (Parsons), the proportion of the estuary which has strong tidal flushing is likely to increase in years 10 and 50 as a result of continued increase in tidal prism. This may positively affect harbor seal abundance by increasing connectivity with the ocean and by favoring prey species which require strong marine influence including flatfish and large clams and crabs. (These scenarios are marked with "+m" for "increased extent of marine-influenced habitats" in Figure 6.)

Biological predictions for different management alternatives

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 extent of habitat at appropriate tidal elevation alone, we expect no significant change at Year 0 or at Year 10, because acreage of total mud habitat (subtidal + intertidal mudflat) does not change significantly. At Year 50, habitat extent increases significantly, and assuming a linear relationship, we would expect abundance to increase. However, the prediction based solely on extent of habitat at appropriate tidal elevation is probably not very accurate. More likely, under Alternative 1 we would expect increasing population trends as described above in Section F to continue or to stabilize, because the state-wide population growth rate appears to be slowing (see External Factors section below).

In the best case scenario, estuary-wide distribution of harbor seals might increase (arrows marked with "+m" in Figure 6), because extent of total mud habitat with strong marine influence might expand up the estuarine gradient, leading to increased connectivity between haul-out sites and the ocean, and increased abundance of prey (e.g., flatfish) along this corridor. There are no factors under this alternative expected to contribute to a worst case scenario.

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

Under Alternative 2, there is no significant change in total mud habitat at any time period. We would therefore not expect significant changes in harbor seal abundance and distribution based on habitat changes alone. There are no environmental impacts expected under this alternative that would benefit the seal population.

In the worst case scenario, harbor seal abundance might decrease under Alternative 2 if loss of extent of habitat with strong tidal flushing negatively impacts prey populations, such as flatfish (arrows marked with "-m" in Figure 6). Additionally, stratification of the water column could occur with this alternative, and prey populations could be negatively affected by hypoxia or anoxia due to eutrophication (arrows marked with "+e" in Figure 6). Design refinements of this alternative that would prevent water column stratification and algal mat accumulation would help mitigate these potential impacts.

The new inlet scenario also entails a permanent barrier at the current channel between the Slough and the Monterey Bay, and the new inlet might require human intervention to prevent periodic closure. Decreased harbor seal abundance could occur due to maintenance of the new inlet, or to the barrier at the existing channel (arrows marked with "+b" in Figure 6). If human intervention is required to maintain an opening, it should be minimally disturbing.

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 harbor seal abundance until Year 50, when total mud habitat increases.

It is possible that harbor seals could use a constricted Slough mouth to their advantage by conducting more efficient foraging. This could be done by waiting on one side of the sill, for example, and grabbing fish as they swim by. This is similar to the foraging behavior described for seals at the Klamath River mouth in Section B. However, primary prey species at the Klamath River mouth are salmonids, which probably cross the river mouth in more concentrated numbers seasonally, and so a similar method may not be as useful at the Slough entrance. This potential benefit is not included in Figure 6 due to the high level of uncertainty associated with it.

Factors potentially contributing to a worst case scenario are similar to those described for Alternative 2. A sill could pose a navigational challenge to harbor seals and/or to prey species, resulting in decreased abundance (arrows marked with "+b). This could be mitigated by refining a sill design to allow passage of harbor seals and prey species under all tidal conditions. The potential for a sill to lead to stratification of the water column could have negative effects on prey species, as described above for Alternative 2 (arrows marked with "+e" in Figure 6).

Alternative 3b – High sill under Highway 1 bridge to strongly decrease tidal prism
There is no significant change in total mud habitat extent under Alternative 3b at all time intervals.

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 3a.

Alternative 4 – Decreased tidal prism in Parsons Complex
The effects of Alternative 4 on harbor seal abundance and distribution are the same as those described for Alternative 1, No Action.

The potential benefits that might occur beyond these habitat-based changes are the same as those described for Alternative 1, as well as that described for Alternative 3a (using a constricted channel at Parsons Slough as a staging area for foraging).

Research is needed in order to better understand how the Parsons complex is used by seals. However, they are known to haul-out and pup in the area and are frequently spotted in the subtidal region (R. Eby, pers. comm.). This alternative could lead to decreased accessibility to this area.

Synthesis: ranking management alternatives for this taxon

Overall, it appears that Alternatives 1 and 4 are most likely to optimize harbor seal abundance in the estuary, and there may be decreased access to some currently used sites

in Parsons Slough under Alternative 4. Alternatives 1, 3a and 4 all contribute to increased extent of total mud habitat. Habitat quality has the potential to increase as well under Alternatives 1 and 4 due to increasing marine influence which may positively affect prey populations as well as harbor seal distribution. Marine influence as well as navigability has the potential to decrease under Alternatives 2, 3a and 3b. Of these latter Alternatives, Alternatives 3b and 3a (in that order) are of concern due to the potential barrier to navigation as well as water quality issues. Alternative 2 is also of concern if the new inlet closes or requires human intervention to remain open. The potential benefit of using a sill as a feeding area is not factored into these rankings due to the high degree of uncertainty about that possibility. In general, conditions and trends similar to the present, and engineering projects that entail minimal reduction of the size of the estuarine mouth, are better for harbor seals. The ranking of alternatives from the perspective of harbor seals is:
Alternative 1 > 4 > 3a >2 > 3b.

External factors affecting population trends and importance relative to management alternatives

Harbor seal populations may be significantly affected by other factors unrelated to the potential changes caused by Alternatives 1-4 over the next decades. More time and research will be needed to determine if recent decreased statewide population growth rates are sustained and if those changes are reflected in the Elkhorn Slough population. However, harbor seal abundance in Elkhorn Slough is expected to be more significantly impacted by changes to statewide populations (population growth rates and/or migration) and changes in prey resources in Monterey Bay than by changes to extent of habitat at appropriate tidal elevation under Alternative 1 (no action) and Alternative 4 (Parsons). The significance of changes in statewide population trends under Alternatives 2, 3a and 3b (new inlet, low and high sill respectively) would depend on the relative significance of other potential impacts to seals or prey species including eutrophication and barriers to navigation. Each of these factors is very likely to have more significant impacts than changes in extent of habitat at appropriate elevation.

Targeted restoration actions for these species at Elkhorn Slough

Targeted restoration actions could be undertaken to enhance the population of harbor seals, regardless of which management alternative is implemented. The current population is limited to areas of full tidal exchange, and increase in extent and accessibility of these areas could lead to greater distribution, but would probably have little effect on abundance since extent of these areas are currently not a limiting factor. However, such increase in tidal exchange may not be desirable due to 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 that resulted in increased abundance of prey species using the Slough could also enhance seal populations. Such actions might include improved water quality and flatfish habitat restoration.

Importance of Elkhorn Slough population sizes

Considering that there are roughly 34,000 harbor seals statewide and that the population may be reaching carrying capacity, the several hundred harbor seals in Elkhorn Slough may not play as important of a role statewide as they do on a smaller scale. If harbor seals abandoned Elkhorn Slough, they would probably migrate to alternative haul-out areas or establish new ones. However, the Elkhorn Slough population may play an important ecologic role locally by limiting growth rates of prey species through heavy predation. Catch rates and value of fisheries landings in the surrounding area would likely be impacted by significant changes in the size of the local population. Finally, based on surveys conducted during 2008, harbor seals are a major draw for recreational visitors, tourists and other interest groups, and have economic and educational value for the surrounding communities. Based on all of the above, significant declines in this species are a cause for concern and should be avoided if possible.

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Figure 1. Drawing of harbor seal

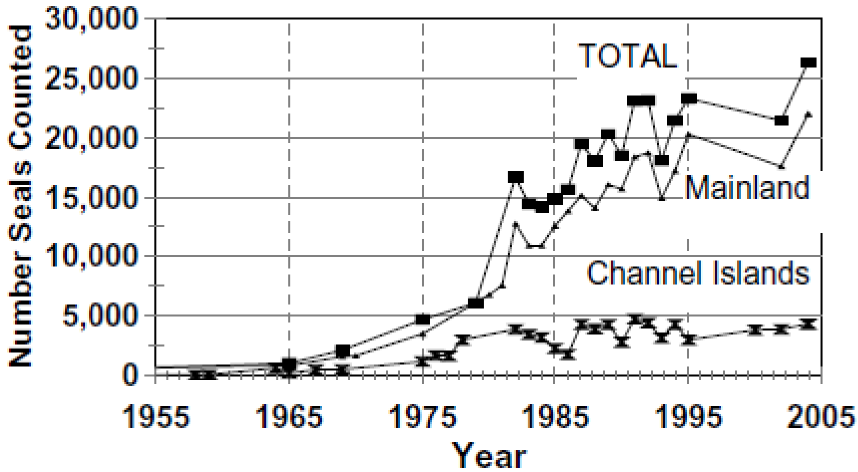

Figure 2. Harbor seal haul-out counts in California during May/June (Hanan 1996; R. Read, CDFG unpubl. data; NMFS unpubl. data from 2002 and 2004 surveys- from Carretta et al. 2005)

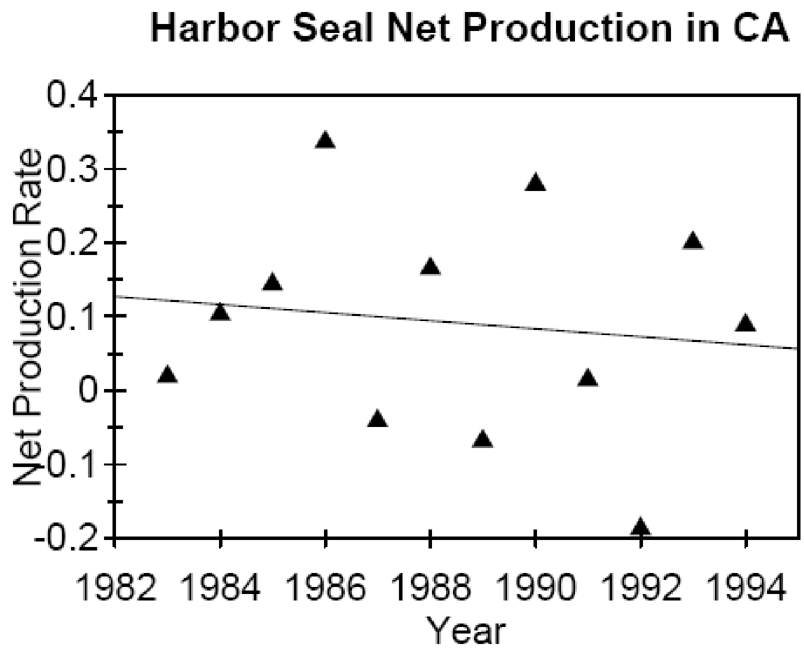

Figure 3. Harbor seal net production rates (population growth rates) and regression line estimated from haul-out counts and fishery mortality (from Caretta et al. 2005).

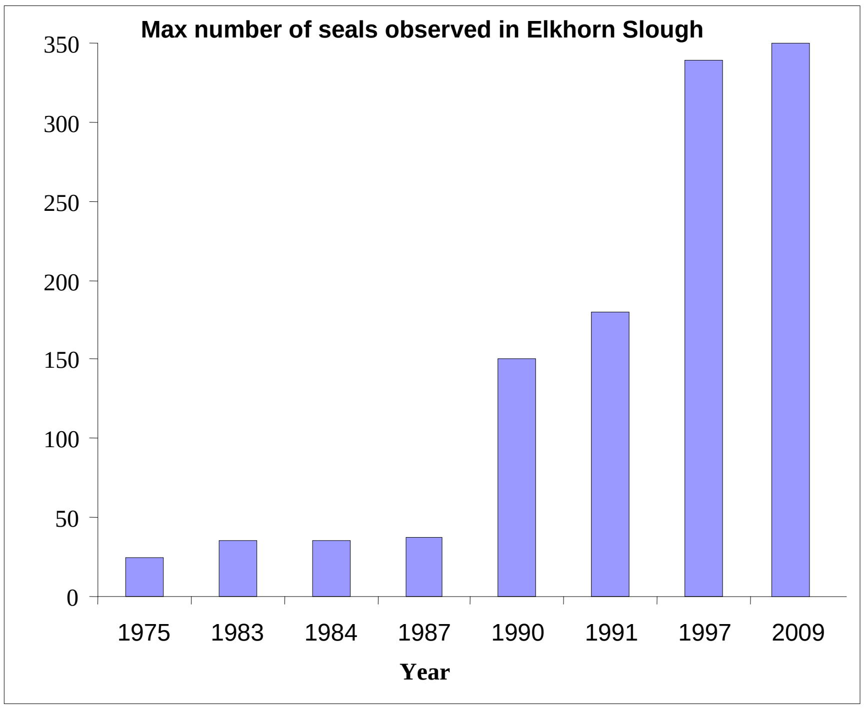

Figure 4. Maximum number of seals observed in Elkhorn Slough. Count data from Harvey et al., Osborn (1985), Hanan et al. (1993), Oxman (1995), Richman (1997) and Harvey, pers. comm. 2009).

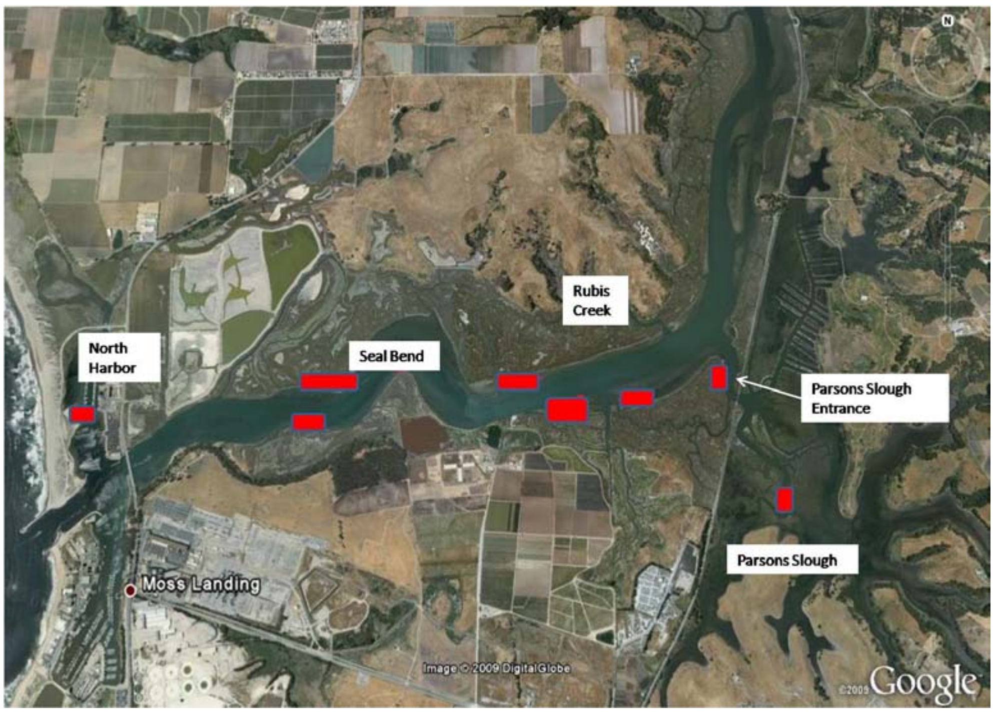

Figure 5. Map of areas used by harbor seals for hauling-out (red boxes) in Elkhorn Slough (Eby pers. comm., 2008).

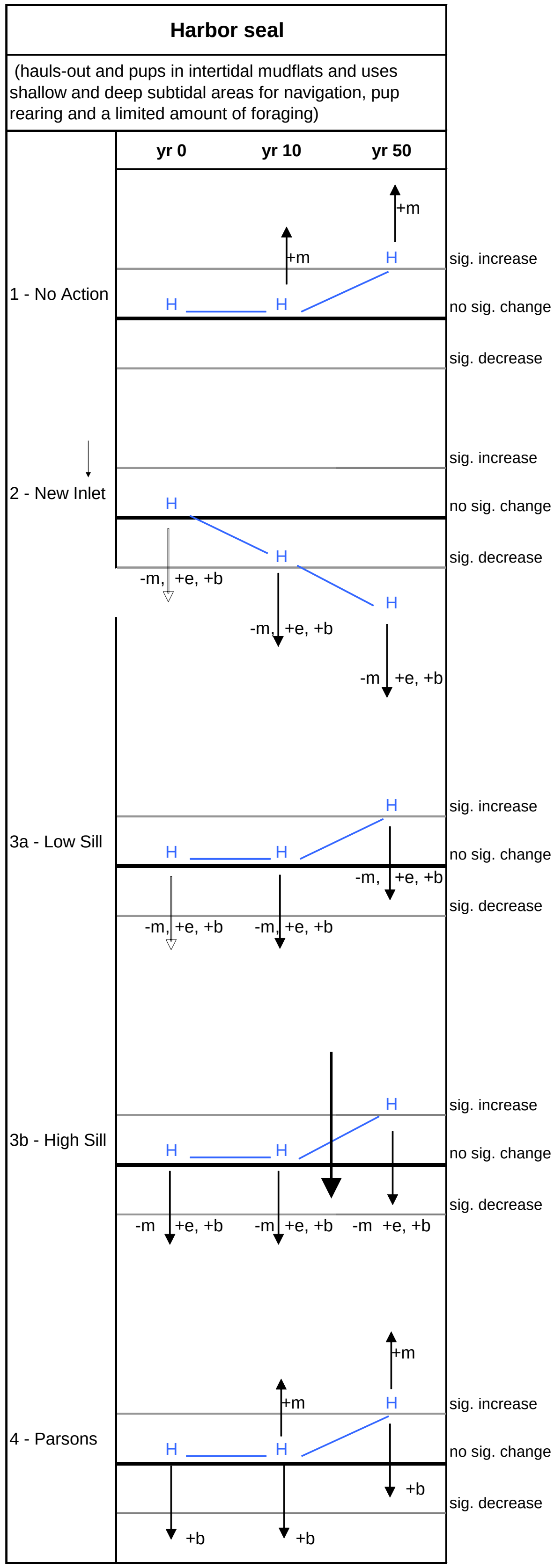

Figure 6. Predicted response of marine mammal species to management alternatives

Figure 6 Legend

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 & McCarthy 2009 were used for these projections. For sea otters, total mudflat (intertidal mudflats + subtidal) were used as the basis for predictions; for harbor seals, XX was used.

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

"+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%