Steller Sea Lions:
A Natural Ecosystem Management System

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Abstract

Steller sea lions are a common sight in Kodiak and an important part of the tourism economy and the marine ecosystem. However, they are listed as an endangered species and suffered steep population declines in the past. As ocean warming affects ecosystems in the North Pacific, how can an ecosystem based management plan that protects the Western Steller sea lion population be implemented while dealing with the challenges of ocean warming? To investigate this question, we study the connection between the California sea lion crisis and ocean warming in the California current and give a comparison between ecosystem conditions in the California and Alaska currents. We further study causes of the Steller sea lion population declines in the 1980’s and 1990’s in Alaska and discuss similarities and differences to the recent mortality event in California. The role of sea lions is discussed in the context of the local food web and possible effects of ocean warming induced changes at the phytoplankton level are considered. We discuss the role of ecosystem modeling in management and the limitations and challenges of implementing the ecosystem-based management mandate. Finally, we give suggestions for strategies to inform management of forage fish populations and protect Steller sea lions from unusual mortality events.
Introduction

In Kodiak Steller sea lions (*Eumetopias jubatus*) are abundant and easy to access, because there is a large group that hauls out on a designated dock in St. Herman’s harbor, close to town. According to the National Oceanic and Atmospheric Administration (NOAA) Steller sea lions are the largest of the eared seals (NOAA, 2016a). On October 14, 2016 the Kodiak Tsunami Bowl team took a boat ride through the harbor to view the sea lions. There were approximately 160 animals; young pups, juveniles, females and males. Their sheer size, vocalizations and aura of majesty commanded respect. We observed complex social behavior including nursing, shouting, affection and aggression. Some large males were hauled out on a nearby beach, apparently excluded from the larger group.

Sea lions add to the rich biodiversity of our town, and are one of several marine mammal species, which are listed as endangered (NOAA, 2016a). Visitors who come to Kodiak enjoy the close encounter with these marine mammals and the rare chance for wildlife photography. We asked several people if sea lions are worth protecting in Kodiak. Almost everyone interviewed said that it is our responsibility as humans to protect diversity. Further, sea lions are an important link in the food web and their loss could disrupt the ecological system (D. Winters, K. Allen, personal communications, November 7; J. Matweyou, A. Brown, personal communications, November 9).

The California Sea Lion Crisis

Sea lions are an indicator species for the state of the ecosystem. Their general health can alert to problems in the lower trophic levels. In the Marine Mammal Protection Act of 1972, an unusual mortality event (UME) is defined as a stranding that is unexpected, involves a significant die-off of any marine mammal population, and demands immediate response. Between 2013 and 2016, California had a UME in which higher than normal numbers of California sea lion pups and
yearlings were found stranded on beaches malnourished, dehydrated and often sickly (NOAA, 2016b). The suspected cause was a lack of prey availability, caused by a decrease in the forage fish population (Enticknap et al., 2011). Sea lions had to swim further and dive deeper to find food. Instead of feeding on energy rich pelagic fish, the sea lions switched to market squid and rockfish, which are nutritionally inferior (NOAA, 2016b).

The demand for forage fish by humans for food and nonfood products such as pet food, bait, and aquaculture feed has increased (PEW, 2013). Limited data are available about the status of forage fish stocks; however, Pacific sardine and Pacific mackerel overfish levels were set at less than 4% of biomass at maximum sustainable yield (MSY) even though NMFS guidelines suggested to only fish to 50% of the MSY (Enticknap et al., 2011). This may have largely contributed to the California sea lion UME.

Although the current sea lion crisis is occurring in the California current, it is possible that similar conditions could occur in Alaska. Record high surface temperatures were measured near Kodiak in the summer of 2016 (Kodiak Sea Temperatures). This temperature change combined with fishing pressure could lead to a similar situation for the sea lions in our region. Ecosystem monitoring combined with swift management responses could have prevented the combination of factors that led to the California sea lion crisis and may be able to prevent a repeat of the decline in Steller sea lion populations in Alaska.

Oceanography

In the North Pacific, the main current flows from west to east and divides into the Alaska and California currents off the north American coast at approximately 40° N 125° W. The Alaska current flows north and the California current flows south. Relative to the surrounding water the Alaska current is warmer and heats the waters in the Gulf of Alaska. The California Current is
relatively cold compared to the surrounding water.

Fig. 1: Sea Surface Temperatures in the North Pacific (Waite & Mueter, 2013; Fig. 5)
In the Gulf of Alaska (north of 40° N) average sea surface temperatures range from approximately 10 - 18 °C. South of 40° N sea surface temperatures range from 18 – 26 °C (Fig. 1; Waite & Mueter, 2013). If one compared the Gulf of Alaska to the waters off the coast of California, the Gulf of Alaska is more nutrient rich and productive due to upwelling, because the ocean conveyor belt brings cold nutrient rich water to the surface. The waters around Kodiak are a very productive area for phytoplankton compared to some of the surrounding waters, especially during the summer months.

The California coastal current is an Eastern boundary current. Because of the Coriolis effect water gets pulled off the shore and is replaced by deep, colder and nutrient rich water. Also, westerly trade winds increase this effect by pushing surface water offshore. During an El Nino year, westerly trade winds weaken allowing warm surface waters to be pushed east towards the west coast of the Americas and warming coastal surface temperatures. (NASA, 2016). The last reported El Nino event occurred in 2015/2016 (Stormfax, 2016). During a La Nina event westerly trade winds pick up, again pushing the warm surface water westerly and causing upwelling of cold water along the west coast of the Americas.

In late 2013, oceanographers observed an unusually warm area of water approximately 1,000 miles wide and long and 300 meters deep in the North Pacific off the coast of North America (Hickey, 2016). This warm water mass, which is 1-4°C above the normal temperature, was named ‘the Blob’ by Nick Bond. It is a long-lived anomaly that has persisted until the present. Because the Blob was lower in nutrients, it had a negative effect on phytoplankton production.
Fig. 2: Wintertime temperature anomalies off the U.S. west coast during the strong El Niños of 1997-98 and 2015-16 (Millstein, 2016).

In 1997-98 the warmer water was relatively shallow with some small areas reaching deeper into the colder water (Fig. 2; Millstein, 2016). In 2015-16 the surface water was all approximately the same temperature and warmest at the deepest points. The warm water area expanded and almost completely displaced the cold water. The combination of the Blob and the effects of the El Nino event have caused unusually warm water conditions along the coast of California in recent years. Temperature induced ecosystem changes have likely contributed to the lack of forage for California sea lions. Ocean warming was also suspected as a contributing factor in prey shifts leading to the decline of Steller sea lion populations in Alaska in the 1980’s (DeMaster & Atkison, 2002).
The Steller Sea Lion Decline

Steller sea lion populations are divided longitudinally into the Western and Eastern population along a line at 144° W (Fig. 3; NOAA n.d.). The Steller sea lion distribution stretches from central Japan to the West Coast of North America. The Western population experienced a steep decline of 80% in the 1980’s to 1990’s (Figure 4; Winter, Foy & Wynne, 2009; National Research Council, 2003). During this time the much smaller Eastern population increased slightly. Steller sea lion counts in the Gulf of Alaska and the Bering Sea/ Aleutians decreased from the late 1970’s until 2000, then began to increase gradually (Table 1; Allen, 2011).

Figure 3: Range of the Steller sea lion; the Western and Eastern population. The triangles show rookery and haul-out sites (NOAA n.d.).

The massive decline of the Western population triggered multiple theories and studies to discover the cause. These included nutritional stress, direct anthropogenic effects, and predation. Nutritional stress may affect sea lion pup survival and nutrients in a female sea lion’s milk, as well as the health of juvenile and adult Steller sea lions. The causes for the nutritional stress may include
Table 1: Steller sea lion counts observed at rookery and haulout sites of adult and juvenile sea lions, since the late 1970’s by geographical area and by year of the Western U. S. stock (Allen, 2011; Table 1)

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<tbody>
<tr>
<td>Gulf of Alaska</td>
<td>65,296</td>
<td>16,409</td>
<td>14,598</td>
<td>13,193</td>
<td>11,862</td>
<td>9,784</td>
<td>8,937</td>
<td>7,995</td>
<td>9,087</td>
<td>8,993</td>
<td>10,931</td>
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<tr>
<td>Bering Sea/ Aleutians</td>
<td>44,584</td>
<td>14,116</td>
<td>14,807</td>
<td>14,106</td>
<td>12,274</td>
<td>12,426</td>
<td>11,501</td>
<td>10,330</td>
<td>10,253</td>
<td>11,507</td>
<td>10,559</td>
</tr>
<tr>
<td>Total</td>
<td>109,880</td>
<td>30,525</td>
<td>29,405</td>
<td>27,299</td>
<td>24,136</td>
<td>22,210</td>
<td>20,438</td>
<td>18,325</td>
<td>19,340</td>
<td>20,500</td>
<td>21,489</td>
</tr>
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Figure 4: Steller sea lion stock; the Western and Eastern population (Winter, 2009)

changes in the distribution and quality of prey (McKenzie & Wynne, 2008). A 2009 sea lion prey study near Kodiak found selective feeding for high energy prey species such as capelin, herring and sand lance (Winter, Foy & Wynne, 2009). The closest breeding rookery to Kodiak is on
Marmot Island and pupping females remain there until the pups are old enough to travel. Prey resources nearby get depleted over the course of the breeding season. Also, as juvenile sea lions learn to hunt, close nearshore resources are specifically valuable. Commercial fishing activities around rookeries were considered potential competition for food. Management actions included a 20 nautical mile radius around rookeries and major haulouts to be closed for all commercial and sport fisheries and to keep boat traffic from affecting sea lion behavior (Laughlin & York, 2016).

Direct anthropogenic effects such as accidental catch in trawl gear and illegal shooting affect direct mortality of Steller sea lions. Death from trawl incidents number about 30 sea lions per year, but many animals escape alive. Illegal shooting of young females may significantly affect the population because of their reproductive potential. According to fishermen reports 80 rounds were fired at sea lions in the summer of 1999, but it is unknown how many animals were killed (Laughlin & York, 2016).

An alternative theory contributing to the sea lion decline was predation by orcas and sleeper sharks, but little information is available about the importance of this factor in the decline. It has been generally known that transient orcas prey on Steller sea lions. In Western Alaska, the percentage of sea lions in orca diet was estimated between 5 and 20% (Matkin et al., 2002). In the stomachs of sleeper sharks harbor seals, cetacean tissue, and the complete fetus and female genitals of a right whale dolphin were found (Hulbert et al., 2002). In August 2001, samples with Steller sea lion tissue were recovered from Pacific sleeper shark stomachs. Because of the secretive lifestyle of the deepwater sleeper shark, the extent of predation by sharks on Steller sea lions is largely unknown. In Kodiak, predation on Steller sea lions by transient orca whales has been witnessed (Fiala, personal communication, July 2016).
Steller Sea Lion and Human Food Web Interactions

The Steller sea lion is a predator near the top of the food web (Figure 5). As mentioned before, the most common predators of sea lions in Kodiak are killer whales and direct and indirect human interactions can also reduce sea lion numbers. Sea lions feed on many different organisms including pelagic and benthic species. Pelagic species include Pacific herring, capelin, Walleye pollock, Pacific sand lance, and salmon. Examples for benthic prey are Pacific octopus, various clam and crab species, arrowtooth flounder, and Pacific cod (Winter, Foy & Wynne, 2009). Competitors for the same prey are whales (in Kodiak primarily humpback), seals, sea otters, octopus and others. Fisheries may also target these prey species (Fig. 5).

Ecosystems rely on primary production for energy. The solar energy absorbed by phytoplankton determines the energy budget for the entire biomass production of the system. There are two main categories of phytoplankton organisms: diatoms and dinoflagellates (Middleton & Bursch, 2013). Diatoms are one-celled organisms ranging from 2 to about 500 microns in size and have silica shells. Dinoflagellates are also one-celled organisms, but only about one tenth the size of diatoms. During the winter the diatoms go to deeper water, cease reproduction because of lack of sunlight, but store nutrients. With the return of sunlight in the spring the diatoms ascend to the surface and rapidly grow in population (Hallegraeff, 2010).

As the season proceeds, the diatom bloom decreases because the nutrients get exploited. Because of their lesser size dinoflagellates can grow and bloom in lower nutrient concentrations. In late summer production is at a minimum until microbial activity replenishes some of the nutrients in the surface water and a second smaller bloom commences (Hallegraeff, 2010). The extent and duration of phytoplankton blooms depends on water temperature, nutrient supply and sunlight.
Figure 5: Simplified schematic of food web interactions of Steller sea lions (red arrows) and human fisheries (green arrows). Background colors indicate different trophic levels.

Under certain conditions some species of diatoms (i.e. *Pseudo-nitzschia* sp.) and dinoflagellates (i.e. *Alexandrium* sp., *Dinophysis* sp.) can become toxic. Presently, only *Pseudo-nitzschia* and *Alexandrium* affect Alaska. *Pseudo-nitzschia* produces domoic acid, while *Alexandrium* produces saxitoxin. Filter feeders and zooplankton that feed on toxic phytoplankton can bioaccumulate the toxins. At higher trophic levels the concentrations of toxin can cause serious health effects and even death. If people eat shellfish that have accumulated saxitoxin, they can suffer paralytic shellfish poisoning. In 2015, sea otters in Homer were observed dying with tremors affecting their whole bodies; the suspected cause was domoic acid poisoning (Welch, 2016). Sea lions are also
at a high trophic level and feed on both benthic filter feeders and pelagic prey, which may increase their risk of exposure to toxins. If climate change-caused ecosystem imbalance increases the frequency of toxic algae blooms, sea lions and other food web components could be at risk. Ecosystem monitoring and modeling may provide an early warning system.

Ecosystem Modeling

The limiting factors with regards to modeling are how to get new data and how to use the existing data. The data collection poses a problem, because data might be needed that were never before sampled such as long term monitoring on diatom species or commercially unimportant fish. The even greater difficulty is finding accurate connections between the variables in the ecosystem and how they affect population numbers. This is because confounding is a major issue when looking at observational studies (Watkins, Schaeffer and Cobb, 2011). Confounding is when an effect is due to two or more variables and it is impossible to prove which caused the observed change or how much each of the variables contributed. There are three applications of models in ecosystem based management (Watt, 1968): The first is to use the values we observe to predict population trends. The second is to modify the values for a better understanding of how factors influence a population and what course of action can be taken to achieve a desired population trend. The third is to improve current model-based predictions. This application helps decrease the margin of error by allowing a comparison of models and testing ways of incorporating new data.

Once the issue of confounding is resolved ecosystem based models are more accurate than their single species counterparts to predict beneficial and harmful effects on population developments, because more data is taken into consideration. Any model is only as good as the data inserted into it. This calls for improved, standardized and consistent monitoring systems. A good starting point for ecosystem based management would be incorporating water and air
temperature, nutrients, wind and weather, and pH. These and other abiotic factors are easier to understand and predict than the more complex biotic interactions. Therefore, continuous monitoring of the abiotic factors is achievable and models could provide predictions about environmental conditions which act upon the biota in the ecosystem. Another reason for monitoring of abiotic parameters is that the collected data could be used to predict the population trends of all biotic species if the correlations were completely understood. This would increase the cost effectiveness of data relative to their usefulness.

Discussion

How can an ecosystem based management plan that protects the Western Steller sea lion population be implemented while dealing with the challenges of ocean warming? At present, the Western Sea lion population is listed under the endangered species act, which prohibits their hunting, killing and harassment (Environmental Protection Agency, 2016). In addition, Steller sea lions are protected under the Marine Mammal Protection Act of 1972. The original act to protect marine mammals was signed by president Richard Nixon and was the first act of congress to mandate ecosystem based management, because it called for protection of habitat and food resources (Gunther, 2010). Further protections for Steller sea lions implemented after the decline of the Western population preserve their food sources from competition by local fisheries. A fishery exclusion zone of 10 nautical miles around sea lion rookeries and major haulout sites remains in place. Sea lions in Kodiak and much of the Western population were experiencing stable or increasing numbers in a survey conducted in 2000 to 2004 (ADF&G, 2016). This indicates that the enforcement of species protection in Alaska has been adequate under current environmental conditions.
The California sea lion crisis had some nutritional and recruitment patterns in common with the Steller sea lion decline. California sea lions are smaller in size and weight, they have a shorter nursing period, and only about half the lifespan (~15 years; Harrison, Hubbard, Petersen et al., 1968). However, California and Steller sea lions occupy a similar niche in their respective ecosystems. Both species’ mothers could not find the necessary nutrients in food for their pups because of multiple factors, one of which was probably overfishing (Welch, 2016; DeMaster & Atkison, 2002). Both went on a ‘junk food’ diet, swimming out farther, and diving deeper which in turn starved the pups. These events could have been avoided if the fisheries managers had paid more attention to the maximum sustainable yield (MSY) and the interactions of the ecosystem as a whole.

As sea surface temperatures have risen in recent years the frequency of toxic algal blooms has increased. For information about toxic algae a monitoring program is needed so that plans can be made to react to toxic algal blooms (Hallegraeff, 2010). Though it was a controversial action, in the past the fishermen took it upon themselves to control the population of predators such as the Steller sea lions by shooting them (Loughlin, 2016). It is debatable whether or not this increased the number of fish that they could harvest or if predator control should be a part of ecosystem based management. To continue to maximize harvest levels in a changing ocean environment a research and management plan needs to incorporate what the sea lions eat and how the increasingly common phytoplankton toxins affect the various components of the food web.

In Ecosystem based management (EBM), every key species is managed whether or not they are commercially viable, because spending the money to make the ecosystem more productive and resilient would increase profits overall. Failure to maintain ecosystem diversity and health has the hidden cost of harvest losses and cost of restoration programs (Pikitch et al., 2004). In EBM approaches we integrate human - ecosystem interactions. Fishing activities are viewed as
predation and competition instead of disconnected single species harvest. Maintenance of long term monitoring projects is more important than the start of new projects because of the value of long term data sets (James Jackson ADF&G, personal communication).

EBM is a big task and the management of data could be more effective (Barnes, 2008; Collie et al. 2014; Levin, Fogarty, Murawski, & Fluharty, 2009). We suggest to create data analyst positions to look at past data and find correlations in data sets from previous years and various fisheries. Their job is not to come up with current stock predictions, but only to find correlations to make ecosystem models more accurate. Data analysts can not be ‘attached’ to fisheries management outcomes. We further suggest the development of special programs in which data analysts are trained in advanced statistics in a combination of university courses and internship programs. The correlations are then taken to the managers of the target species to apply to their own models and manage their species in a more efficient manner. By using models we can predict and modify our options to maximize profit of fisheries and tourism, stability along with sustainability of the ecosystem.

The effect of the ocean warming on Steller sea lions is not yet fully understood. Until we have a better understanding we suggest to maintain MSY of fisheries along with limits to boat traffic around rookeries and major haulouts. These enforcements should be modified according to Steller sea lion population. If the sea lion population is doing well, the restriction can be loosened upon the fisheries. If the population is doing poorly then the restrictions should be increased. If a lowering of the MSY is expected, fishermen meetings should be held and economical alternatives discussed to assist with the expected loss of income. In this approach, consistent and long-term monitoring is required to use sea lion populations as a natural indicator for sustainable fisheries management.
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