

# Steller Sea Lions (*Eumetopias jubatus*): Causes for their Decline and Factors Limiting their Restoration

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## **Introduction**

Most researchers believe that food shortages are the most likely cause of the decline of Steller sea lions (ASG 1993 – “Is it Food? Conference”). Poor nutrition caused by a lack of abundance, availability or appropriateness of prey can reduce birth rates and increase mortality through disease, predation and starvation. Major changes in the quantity and quality of Steller sea lion prey appear to have been affected by natural changes in the ecosystem, not by fishing activities. Recent results from ecosystem models of the eastern Bering Sea, comparisons of sea lion diets across time and space, and environmental and biological time series data show the following:

- The composition of the Bering Sea changed from an ecosystem dominated by marine mammals, crabs, shrimp and pelagic fishes (e.g., herring and sandlance) in the 1950s to one now dominated by pollock and large flatfish.
- The diet of Steller sea lions changed between the 1950s and 1990s as their populations declined in the Aleutian Islands and Gulf of Alaska. The change in sea lion diet matches the reported change in prey species available in the Bering Sea and Gulf of Alaska.

- Steller sea lion population declines correlate with diet diversity. The greatest declines of Steller sea lions occurred in areas where sea lions consumed a low diversity of prey. Pollock dominate the diet in the Gulf of Alaska. The increasing Steller sea lion populations in southeast Alaska have the most diverse diet of all regions of Alaska.
- There is no evidence that sea lions are competing with fisheries for pollock. Juveniles, the most vulnerable segment of the Steller sea lion population, eat small immature pollock at shallow depths. In contrast, the fishery takes large mature pollock at deeper depths.
- Captive studies and other empirical evidence suggest that sea lions that eat too much pollock may suffer negative health consequences.
- Recovery of Steller sea lions appears linked to their eating a more diverse diet containing a higher proportion of fattier fishes.
- Environmental data suggest the abundance of key species of North Pacific fish was altered by a climatic regime shift that occurred in the mid to late 1970s. Ecosystem modeling supports this explanation. Regime shifts may occur every 18-60 years and may occur soon again. Such a regime shift is likely to restore the fattier fishes that sea lions seem to thrive upon.
- Pollock is currently an important prey in the Aleutians and Gulf of Alaska only because of its dominance in the ecosystem and the apparent lack of other prey types at this time.
- Juvenile Steller sea lions consume juvenile pollock and presumably benefit from the removal of adult pollock. Reducing the cannibalistic adult stock through fishing should result in more juvenile pollock being available to juvenile Steller sea lions.
- Changing the amount and timing of commercial catches of pollock can have unexpected and undesirable consequences for Steller sea lions. The most precautionary action for Steller sea lions may be to protect the fattier fishes and maintain a status quo on catching adult pollock.

The following provides details of these observations and conclusions. Information is presented on how the diets of Steller sea lions have changed over time as the species composition of the Bering Sea also changed. The survival and reproductive consequences for Steller sea lions of changing their diet from a diverse diet with fatty fishes to one dominated by pollock are discussed. The extent of direct competition between sea lions and fisheries is also examined. The review concludes by considering measures that might restore Steller sea lions to their former level of abundance.

## Changes in Steller Sea Lion Diets

Stomach contents and fecal analysis show that Steller sea lions eat a wide range of species such as walleye pollock, Pacific cod, octopus, squid, salmon, Pacific herring, Pacific sandlance, capelin, flatfish, rockfish and Atka mackerel (NMFS 1992). These analyses further suggest distinct regional differences in the diversity and types of prey currently being consumed. The most notable difference between Steller sea lion populations in the Bering Sea and Gulf of Alaska was the dominance of pollock in the diets of animals breeding in the Aleutian Islands, where the sharpest population declines have occurred. This contrasts with the high diversity of prey consumed in Southeast Alaska, where the population has increased (Lowry *et al.* 1989, Merrick and Calkins 1996, Merrick *et al.* 1997, Trites and Calkins – unpubl. data). Merrick *et al.* (1997) found a significant negative correlation between the diversity of diet and the rate of the Steller sea lion population decline across the Aleutian Islands and Gulf of Alaska ( $r = -0.949$ ). They concluded that the sharpest population declines occurred in areas with the lowest diversity of diet, and that sea lions need a variety of prey.

Dietary information collected for half a century is summarized in Table 1. The occurrence of gadids (mostly walleye pollock) in stomachs and fecal remains (scats) from the declining sea lion population in the Kodiak Island area increased from 32% in 1976-78, to 60% in 1985-86, and 85% in 1990-93 (Merrick *et al.* 1997). Consumption of flatfish (another low fat fish) also increased in the same area from 0% to 13% from 1976-78 to 1990-93. The occurrence of small schooling fatty fishes (pelagics such as herring, sandlance, capelin and smelt) in scat and stomach samples decreased from 61% in 1976-78, to 18% in 1990-93 (Merrick *et al.* 1997). Looking back further in time to the 1950s and early 1960s shows that Steller sea lions consumed few if any pollock or flatfish (Wilke and Kenyon 1952, Mathisen *et al.* 1962, Thorsteinson and Lensint 1962, Tikhomirov 1964, Fiscus and Baines 1966). Instead, stomach contents reveal that the animals were eating a more diverse diet of capelin, sandlance, herring, smelt, rockfishes, greenlings, crabs, and squid (see review by Alverson 1992). It is these species, not pollock, that Steller sea lions were eating while their populations increased to the highest levels recorded in this century (Trites and Larkin 1996).

Seals and sea lions are generally thought to be good at sampling the marine environment. Thus, changes in the diet of seals and sea lions likely indicates the types and relative abundance of prey present. The story they are telling is that the pollock stock (followed by flatfish stocks) increased between the mid 1960s and late 1970s, while stocks of pelagic fishes (herring, sandlance, capelin, etc.) decreased. These conclusions are consistent with stock assessments conducted by the Soviet Union and the U.S. National Marine Fisheries Service (see Alverson 1992, Trites *et al.* 1998a).

**Table 1. Changes in the frequency of occurrence of major prey types in the diets of Steller sea lions in the Gulf of Alaska.**

Years	Gadids	Flatfish	Pelagics
1950-60s	few	none	mostly
1976-78	32%	0%	61%
1985-86	60%	5%	20%
1990-93	85%	13%	18%

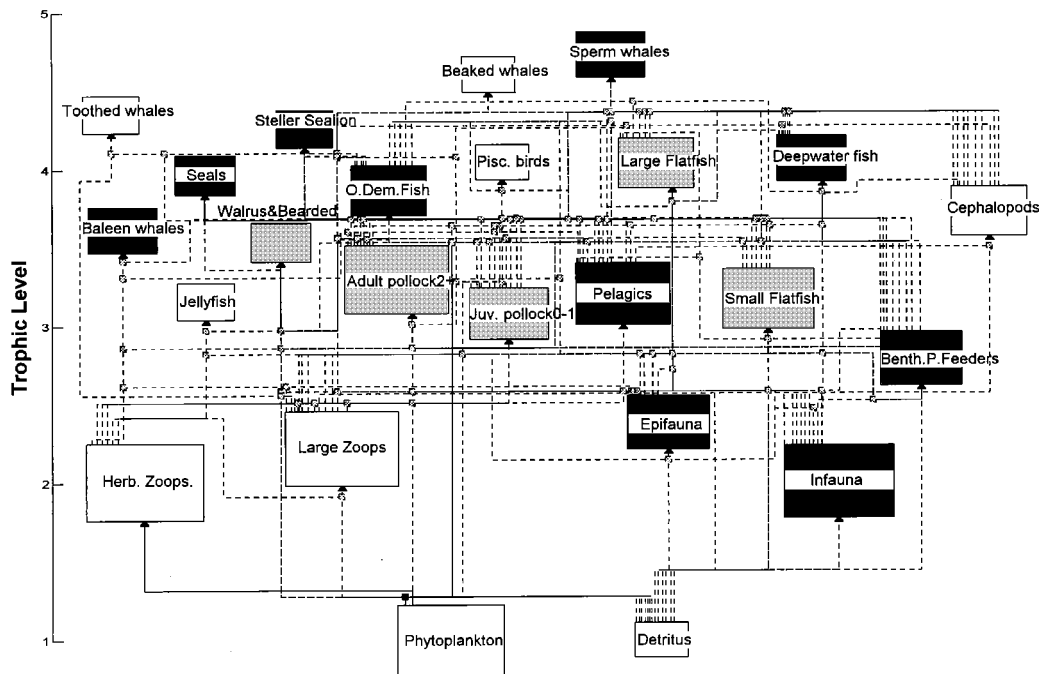
Except for herring, there were no commercial fisheries on other fatty pelagic fishes such as capelin, sandlance, and smelt. The decline of these pelagic fishes appears to be natural. Their reduction in the ecosystem may be linked to the rise in pollock and large flatfish that now dominate the Bering Sea and Gulf of Alaska.

Results from a recently completed ecosystem model of the Eastern Bering Sea (Figure 1) reflect the change in diversity of prey, which moved from fatty pelagic species to pollock and large flatfish. The model suggests that pollock consumed over 50% of the prey eaten by all mid-trophic level species<sup>1</sup> during the 1980s compared to only 10% during the 1950s (see Trites *et al.* 1998a for details). In contrast, pelagic fishes (such as herring, sandlance and capelin) contributed nearly 50% of the flow of energy at this level in the 1950s. Dominance of the mid-trophic level appears to have switched from pelagic fishes to pollock. At higher trophic levels (see Figure 1), large flatfish contributed over 60% of the total energy flow during the 1980s, compared to the 1950s when there was a more even distribution of consumption among the flatfish, seals, sea lions, and toothed whales.

Large flatfish and adult pollock may be significant competitors of seals and sea lions, given the large overlaps in their diets (38-50%). There are also significant overlaps in the diets of pollock and baleen whales (73-86%). Thus, competition for food with pollock and flatfish may be a factor impeding the recovery of seals and sea lions. Changes in the biomass of large flatfish and adult pollock may also influence the abundance of pelagic fishes.

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<sup>1</sup> Trophic levels are a way of classifying organisms according to their feeding relationships in a food chain. As shown in Figure 1, the first trophic level includes plants, the second herbivores, and so on. Adult and juvenile pollock share the third trophic level with pelagics, small flatfish and jellyfish.



**Figure 1. Flowchart of trophic interactions in the eastern Bering Sea during the 1980s. The black boxes indicate which groups declined in abundance between the 1950s and the 1980s, and the gray boxes show which species increased between the two time periods. Connecting lines show the major flows of energy between groups of species. Minor flows were omitted. From Trites *et al.* (1998a).**

## Competition?

There is no question that pollock is currently the most important prey of Steller sea lions in the Aleutian Islands in terms of numbers consumed. There is also no doubt that the pollock fishery is one of the most important fisheries in Alaska and harvests fish at sustainable levels. What is not clear is whether the fishery and the sea lions are competing in a manner that impedes the recovery of Steller sea lions.

The sizes (length distributions) of pollock eaten by Steller sea lions have been compared to the sizes of fish commercially caught in 1981 and 1985 (Fritz *et al.* 1995). That comparison shows that Steller sea lions consume primarily small pollock (mean size = 27.1 cm) while the fisheries take primarily large pollock (mean size = 33.7 cm). Mean size of all pollock in the population was 29.4 cm.

There is little overlap in the size of fish caught commercially and the size of fish eaten by juvenile sea lions. Greater overlap occurs between fisheries and adult sea lions. Adult sea lions can capture all sizes of pollock (9–56 cm), but seem to prefer the smaller juvenile sizes (Merrick and Calkins 1996). However, juvenile sea lions appear to rarely capture pollock longer than 25 cm and eat relatively more juvenile pollock than adult sea lions (see Figure 3 in Merrick and Calkins 1996). Average sizes eaten in 1985 were 20.8 cm (by juvenile sea lions) and 27.1 cm (by adult sea lions). Thus, the length-frequency data suggest limited competition between fisheries and juvenile sea lions (the segment of the sea lion population thought to be most at risk), but potentially greater competition with adult sea lions.

The fact that there is an overlap in the size of pollock taken by fisheries and adult sea lions does not necessarily mean that the two are competing. Competition occurs if the resource they are seeking is limited. There is no evidence to suggest that sea lions are not getting enough pollock to eat or that pollock stocks have been depleted by fisheries. There are no reports of sea lions stealing pollock from nets because they cannot capture fish on their own. Furthermore, modelling work by Shima (1996) has shown that the abundance of pollock is sufficient to feed the population of Steller sea lions, and that there is no lack of prey (pollock) biomass. This is consistent with the significant increases reported in the abundance of pollock in the Gulf of Alaska between 1984 and 1990 (Fritz *et al.* 1993). During this time, pollock increased and sea lions declined.

It is also significant that commercial fisheries typically capture pollock at depths far deeper than Steller sea lions dive. Samples of fish caught in trawl fisheries show that pollock typically occurred at depths of 50–500 meters (Fritz *et al.* 1998). The frequency of occurrence of pollock was significantly less in trawls pulled at 1–49 meters. Adult Steller sea lions have been observed diving to a median depth of 21 meters in summer and 24 meters in winter (Merrick and Loughlin 1997). This is in sharp contrast to juvenile Steller sea lions that dove to a median depth of 9 meters. The deepest dive recorded for juvenile sea lions was only 72 meters, with 89% of their dives between 4–10 m and 11% at 10–50 m (Merrick and Loughlin 1997). Adult females had 35% of their dives at 4–10 m, 61% at 10–50 m, and 3% at >50 m. The deepest female dive recorded was over 250 m. Thus, these data suggest that juvenile sea lions do not dive as deep as adults, and that fisheries catch fish at deeper depths than sea lions, thereby limiting any potential direct competition between them.

## Quantity versus Quality of Prey

Discussions of fisheries and Steller sea lions tend to only emphasise the quantities of individual fish species available to sea lions, or the quantity removed from their ecosystem. Little or no consideration is given to the diversity or quality of prey available.

Pollock appear to be abundant and available to Steller sea lions. However, pollock, the dominant prey being consumed in the areas of sharpest population decline of sea lions, are generally poor in energy and nutritional content. They have about half the energy content of herring (Perez 1994). They also have less usable energy due to the greater difficulty of digesting pollock (Rosen and Trites unpubl. data). The overall quantity of pollock present or removed by fisheries is, by itself, an inappropriate unit for distinguishing impacts of fisheries on Steller sea lions or other marine mammals.

As noted above, fatty fishes have traditionally been the dominant component of the diets of Steller sea lions and other pinnipeds. Fatty fishes provide higher food energy (per unit weight) than pollock or flatfish (Alverson 1992). Differences in energy content would require a Steller seal lion to consume 35–50% more pollock than herring to achieve the same gross energy intake (Rosen and Trites, unpubl. data). Moreover, captive feeding trials with pollock have shown that Steller sea lions lose three ways when they eat pollock and that the sea lions must actually compensate by eating 50–65% more pollock than herring to maintain similar net energy intakes. First, the pollock contain less energy than the herring. Second, the sea lions burn more energy digesting pollock than herring. Third, it costs a sea lion more energy to digest the larger quantity of fish needed to compensate for the lower energy content (Rosen and Trites 1997).

A further complication for Steller sea lions eating pollock, beyond the lower net energy gain they receive, is the possibility that gadid fish, such as pollock, hake or cod, adversely affect the health of pinnipeds if consumed in large amounts (Thompson *et al.* 1998). Andersen (1966) and Geraci (1975) have suggested that the composition of gadids (e.g. amino acids, vitamins and minerals) may lead to health problems in marine mammals, such as iron deficiency. Such abnormal blood chemistries have also been reported in harbor seal populations and are thought to be linked to gadid diets (Thompson *et al.* 1997). Similar phenomena were observed when another mammalian species, mink, were fed gadids (Stout *et al.* 1960). The gadid diet resulted in mink having poor quality fur, low birth rates and high mortality rates.

Questions about the composition of pollock and the nutrition that Steller sea lions can derive from it are under investigation at the Vancouver Aquarium and the

University of British Columbia. Tests showed that feeding Steller sea lions (age 0.9 – 4.5 years) only pollock for short periods (9 – 23 days) caused them to lose an average of 0.55 kg per day (Rosen and Trites 1998). The 6 animals under study lost an average of 6.2% of their initial body mass over an average feeding trial of 14.5 days (initial mass averaged 125 kg). The animals were allowed to eat as much pollock as they wanted but did not increase their food intake to compensate for the low energy they were receiving. The sea lions that ate pollock showed progressive metabolic depression (i.e., they lowered their metabolism to survive longer) as they lost body mass and would have presumably eventually reached a steady but sub-optimal body mass on a pollock-only-diet. This has serious implications for Steller sea lions that eat primarily pollock in the Aleutians and Gulf of Alaska.

The pollock fed to the Steller sea lions by Rosen and Trites (1998) had an energy density ranging from 4.54–4.72 kilojoules-per-gram (kJ/g). Fadely *et al.* (1994) found pollock with average lengths of 25.4 and 28.6 cm length had similar energy densities of 4.40 and 4.80 kJ/g, respectively. Smith *et al.* (1988) found that ripe, mature male and female pollock (93.6 and 96.2 cm, respectively) had energy densities of 3.68 and 4.03 kJ/g, respectively, while spent adult males and females had an energy density of 3.41 and 3.27 kJ/g. Thus, it would appear from these limited samples that young pollock may contain more energy than the roe bearing adults.

The feeding studies conducted to date, and observations from other species, suggest that a diet dominated by pollock may be unhealthy for Steller sea lions. It suggests that the problem facing Stellers is not that they cannot get enough pollock to eat, but that they may be consuming too much. This is not to say that Steller sea lions should not eat pollock, because it is clearly part of a balanced diet as shown by the range of species, including pollock, that are consumed by the increasing population of Steller sea lions in Southeast Alaska (Trites and Calkins, unpubl. data).

The high proportion of pollock in the diets of Steller sea lions in the Gulf of Alaska and Aleutian Islands suggests that pollock are readily available to them, but that other prey types are not. Unfortunately, eating too much pollock likely stunts growth, increases susceptibility to disease and predation, and raises the likelihood of reproductive failure (e.g., reabsorptions / abortions). Thus, the return of Steller sea lions to higher population levels in the Gulf of Alaska and Bering Sea is probably linked to consuming more fatty fishes and fewer pollock.

## **Ecosystem Change: What Happened?**

Two useful approaches have been taken to glean some insight into the current state of the Gulf of Alaska and Bering Sea. The first constructed an ecosystem model of the eastern Bering Sea, explored how the system differed between the 1950s and 1980s, and considered the mechanisms that might have changed the ecosystem (Trites *et al.* 1998a). The second approach contrasted the Gulf of Alaska ecosystem to three other ecosystems in other parts of the world that supported large trawl fisheries, but also had large pinniped populations (Shima 1996). The goal of that approach was to understand what was different about the Gulf of Alaska.

Trites *et al.* (1998a) used their ecosystem models to test whether commercial whaling was responsible for the build up of pollock stocks (the theory being that pollock are eating the zooplankton and other prey once consumed by baleen whales). They also considered whether changes in the ecosystem were caused by fishing or natural environmental factors (i.e., a regime shift).

The models indicate that removing whales from the Bering Sea would have resulted in more pollock, but nothing near the magnitude of what was observed. Similarly, the model showed that fishing at commercial levels could not change the ecosystem from its 1950s state to its 1980s state. Overall, the simulations were unable to account for changes that occurred between the 1950s and the 1980s through trophic interactions alone (i.e., by manipulating the abundance of predators and prey). Instead, the most likely explanation for the build-up of flatfish and pollock, and the decline of pelagic fishes was environmental change. However, whaling or fisheries (such as for herring) may have intensified the speed and magnitude of the observed changes. Changes in the abundance of key species can in turn affect the abundance of other species in the food web, such as has been recently observed when killer whales began reducing sea otter populations following declines of their major prey – seals and sea lions (Estes *et al.* 1998).

The ecosystem models developed by Trites *et al.* (1998a) are based on the best available data and have been used in a simple and rigorous modeling framework (Ecopath) that has a number of checks and balances to ensure consistency (Christensen and Pauly 1993, 1995, Pauly and Christensen 1996, Walters *et al.* 1997). Thus, sound conclusions can be drawn about some of the general and fundamental properties of the Bering Sea, despite incomplete knowledge of the past and present (Trites *et al.* 1998b). For example, the models imply that the Bering Sea may be relatively resilient and resistant to change over long periods of time compared to more tropical ecosystems (see Vasconcellos *et al.* 1997). However, the Bering Sea also appears to be a system that is susceptible to dramatic and sudden decadal shifts. The models further suggest that the Bering Sea is a

system where the cumulative effects of changes in the abundance of one species on others are sluggish and may be small compared to the magnitude of change that the environment can produce on recruitment or primary production. They also provide a good means of contrasting the striking differences in the abundance of different fish and mammal species present in the 1950s and 1980s.

The second means of gaining insight into the Bering Sea and Gulf of Alaska ecosystems is to compare them to other ecosystems that have significant marine mammal populations and large trawl fisheries. Shima (1996) compared the Gulf of Alaska with three similar ecosystems – the Barents Sea (north of Norway), the California Current (California), and the Benguela Current (off the southwest coast of Africa). Seals are currently abundant in all of these ecosystems except in the Gulf of Alaska. It is also interesting to note that seals are abundant in Atlantic Canada (a system which she did not compare) where cod fish (another gadid) have declined due to over-fishing. Shima found harvest levels of groundfish were at the low end of the scale in the Gulf of Alaska compared to the Barents Sea and Benguela Current. She also found that direct interactions (shootings and entanglements) between Stellers and fishing boats in the Gulf of Alaska were negligible in comparison with the other ecosystems.

The most significant difference Shima found between the ecosystems she compared concerned the diversity of prey eaten by the pinnipeds in each system. Only in the Gulf of Alaska was the diet dominated by a single prey (pollock). Elsewhere, the pinnipeds consumed a variety of prey such as cod, herring and capelin in the Barents Sea. These findings further support the view that diversity of diet and consumption of fatty fishes are central to maintaining large pinniped populations.

## **Reduced Carrying Capacity**

There is mounting evidence that the carrying capacity of Steller sea lions and other pinnipeds in the Bering Sea and Gulf of Alaska is considerably lower today than it was during the 1950s and 1960s. What appears to be limiting the size of their populations is a shortage of fatty pelagic fishes. The biomass of pollock is high but does not appear to be of sufficient quality to support large populations of pinnipeds.

Counts of sea lions at rookeries in the western Gulf of Alaska and eastern Aleutian Islands indicate that the population decline has slowed since 1989, and suggest that the population may be approaching a lower level of carrying capacity (Trites and Larkin 1996). Indications that the carrying capacity of Steller sea lions dropped through the 1980s come from reduced body growth, a drop in birth rates,

and an apparent reduction in the survival of young sea lions. These changes are consistent with density dependent responses reported in several pinniped species (see review in Trites 1990). They are also consistent with the sequential changes that Eberhardt (1977) predicted would occur as populations rise and fall. He speculated that behavioral modification (feeding time, aggressive behavior) should be the first population characteristic altered by abundance, followed by individual characteristics (body growth, incidence of diseases and parasites), reproductive effects (birth rates, age of first reproduction), and finally population aspects (survival rates, distribution).

Calkins and Goodwin (1988), Castellini and Calkins (1993) and Calkins *et al.* (1998) concluded that Steller sea lions were physically smaller in the mid 1980s compared to sea lions sampled in the mid 1970s. Their conclusion was further supported by morphometric measurements (body lengths and weights) of sea lions caught in the Gulf of Alaska (Perez and Loughlin 1991). These studies indicate that sea lions may not have obtained adequate nutrition during the 1980s, and give credence to the hypothesis that Steller sea lions are limited by food.

Pregnancy rates, another density dependent response to lower carrying capacity, also dropped as the Steller sea lion population declined. Samples of sexually mature females shot in the 1970s and 1980s were nearly all (97%) pregnant during early gestation (Pitcher *et al.* 1998). However, by late gestation, pregnancy rates had declined due to abortions and re-absorptions. Birth rates were approximately 67% in the 1970s and dropped to 55% in the 1980s. Low pregnancy rates were associated with poor body condition (low weights and thin blubber layers). Pitcher *et al.* (1998) concluded that the drop in pregnancy rates was because the prey base was inadequate to support the Steller sea lion's "energetically expensive reproductive strategy". Steller sea lions presumably need to consume more of the scarcer, fatter pelagic fishes, and less of the abundant but nutritionally poor pollock.

The third significant change that appears to have occurred as the sea lion population declined concerns an increase in the mortality of young sea lions. York (1994) examined the difference in the age structure of the samples of sea lions taken in the 1970s and 1980s. She concluded that the most likely explanation for the change in age was due to a higher mortality of young sea lions during the 1980s compared to the 1970s.

The lowering of Steller sea lion birth and survival rates, and the stunting of body growth, are indicative of a population that is at the limit of the ability of the environment to support it (i.e., at carrying capacity). Steller sea lions are not alone in this regard. Northern fur seals and harbor seals also declined at the same time as Steller sea lions (Pitcher 1990, Trites 1992) and also appear to be at new and lower levels of carrying capacity (Figure 2). Interestingly, all three species declined at roughly the same time (Figure 2) suggesting they are linked by a common factor—the naturally occurring regime shift of the late 1970s (see below).

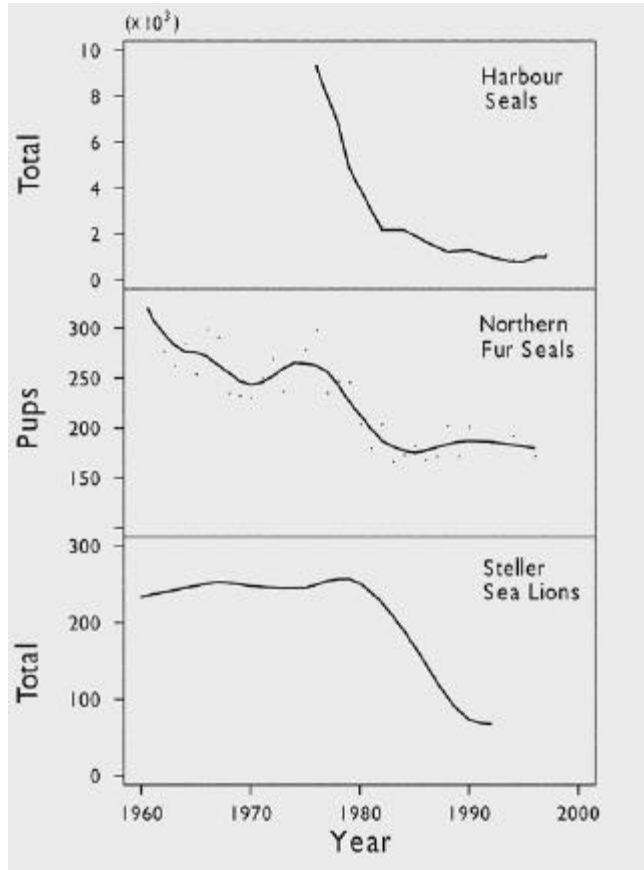


Figure 2. Pinniped population trends in the Gulf of Alaska. Numbers of harbor seals were counted on Tugidak Island by the Alaska Department of Fish and Game. Changes in the size of the western stock of Steller sea lions were estimated by Trites and Larkin (1996) from aerial survey data. Pup counts of northern fur seals are from the St. Paul Island and were estimated by the National Marine Fisheries Service.

Northern fur seals, like Steller sea lions, are showing signs of stunted growth not seen since the 1950s when the population had peaked at twice its current level (Trites 1998). Pollock biomass was low and fatty pelagic fish abundance was high in the 1950s compared to now when pollock dominate and pelagic fishes are relatively scarce. This presumably means that the North Pacific could support more northern fur seals in the 1950s than now. There are also reports from Alaskan native hunters that harbor seals have much thinner blubber layers now than in the past (Monica Riedel, Alaska Harbor Seal Commission, pers. comm.). Other evidence of reduced carrying capacity in the North Pacific comes from the stable isotope studies conducted on the baleen of bowhead whales, and the whiskers, tissues and bones of pinnipeds. (Hirons and Schell 1998a,b; Schell 1998).

The changes observed in Steller sea lions, northern fur seals and harbor seals suggest that the carrying capacity for these species has been reduced by 50% or more in the Gulf of Alaska and Bering Sea. The timing of these changes corresponds to the mid to late 1970s and has not been related by any researchers

to fishing. Instead, the available data have led an increasing number of researchers to conclude that cascading effects have occurred due to a major natural oceanic regime shift (Francis and Hare 1994, NRC 1996, Piatt and Anderson 1996, Springer 1998, Trites 1998, Pitcher *et al.* 1998) based on a long time series of oceanographic and atmospheric data (Kerr 1992, Ebbesmeyer *et al.* 1991, Trenberth and Hurrell 1995, Ware 1995).

In this regard, a variety of evidence, including air and water temperature, atmospheric dust levels, carbon dioxide concentrations, and ice cover suggests that the Gulf of Alaska and Bering Sea experienced a stepwise environmental shift sometime in the late 1970s. This has been referred to as a climatic regime shift. A number of studies (see the recently published review by Francis *et al.* 1998) have related environmental regime shifts to changes in most of the major components of the North Pacific marine ecosystem – primary and secondary producers, forage species and several levels of predators (Brodeur and Ware 1992, Beamish 1993, Polovina *et al.* 1995, Roemmich and McGowan 1995, Brodeur *et al.* 1996; forage species: Hollowed and Wooster 1992, 1995; McFarlane and Beamish 1992, Beamish and Bouillin 1993, Hare and Francis 1995, Wooster and Hollowed 1995 Anderson *et al.* 1997; and predators: Springer 1992, ASG 1993, Piatt and Anderson 1996, Hunt *et al.* 1996, Pitcher *et al.* 1998, Trites 1998).

Springer (1998), in summarizing recent research into regime shifts, notes a “recurring pattern of climate variability over the Pacific Ocean that includes an alternation of the Aleutian low pressure system between two quasi-stable states of intensity and location lasting between about 15-30 years. Transitions between regimes are rapid and are associated with a wide variety of equally rapid physical and biological responses in ecosystems.” The strength and position of the Aleutian low may affect ocean properties and circulation, and create conditions that lead to more or less primary and secondary production across a broad region of the North Pacific. Sea surface temperature may also cycle between warmer and cooler conditions every 6–15 years and create another layer of environmental instability. Francis *et al.* (1998) note that “the kind of decadal-scale atmospheric forcing in the North Pacific that we have seen during the 20<sup>th</sup> century has probably persisted for centuries.”

## Mitigating the Sea Lion Decline

People would like to do something to reverse the decline of Steller sea lions. One of the means that has been proposed is to reduce the amount of pollock caught by fishermen if that would make more pollock available to Steller sea lions. Another is to alter fishing effort to produce more of the fatty fishes that sea lions seem to thrive on. There are few other options beyond altering *or not* altering fishing rates and/or the timing and location of fishing. Possible consequences of such actions can be explored with mathematical ecosystem models.

Ecosystem models can be used to consider what might happen to other species, such as sea lions or pelagic fishes, if fishing pressure on pollock was changed. They are tools to ask “What if?” questions. Trites *et al.* (1998a) explored what might happen to the eastern Bering Sea if the amount of pollock caught was changed. They considered how the ecosystem might respond if the proportion of adult pollock taken by fisheries was increased over a range of 10 – 50%. They also considered what might happen if pollock were over-fished to the point that all the juvenile and adult pollock were removed. Finally, they considered how the Bering Sea ecosystem might look if pollock were not caught at all. All simulations were run over 30 years.

The simulation results suggest that increased fishing pressure on pollock would have only a small effect on the future adult pollock biomass due to a continuous replenishment from the juvenile stock. Juvenile pollock benefit from reduced cannibalism (by removing adult pollock). System-wide effects are minimal because the size of the adult pollock stock does not change appreciably. However, the model predicts that seals, sea lions and fish-eating birds would respond favorably to an increase in the abundance of juvenile pollock.

Overfishing pollock to the point of extinction would lead to an increase in the abundance of pelagic (fatty) fishes, but a decline in seabirds consuming juvenile pollock if they did not switch to eating pelagic fishes. However, the model predicts that reducing the biomass of just adult pollock by 50% would have a positive effect on seals, sea lions and fish-eating birds because the abundance of juvenile pollock, which they consume, increases as cannibalism by adult pollock is reduced. It also results in a small increase in pelagic fishes because more zooplankton, previously consumed by pollock, would be available to them. Major system-wide effects are minimal because the adult pollock stock does not change appreciably.

Stopping pollock fishing results in a larger adult population and a smaller juvenile pollock population. Reducing the juvenile pollock population has a negative effect on seabirds and a small negative effect on marine mammals.

Results from these three simulations highlight how changing fishing could have unexpected and unwanted results for Steller sea lions. It also provides some insight into how important cannibalism by adult pollock on juvenile pollock might be to the dynamics of pollock in areas designated as Steller sea lion critical habitat. The model gives credence to the view that high harvest rates of adult pollock in critical habitat areas should result in more prey being available to Steller sea lions. If depletion of adult pollock occurred, it should reduce cannibalism and increase the abundance of juvenile pollock that sea lions could consume. Attempts to create a better mix of prey species (i.e., more fatty fishes) for Steller sea lions by manipulating trophic interactions in the model through fishing failed to produce significantly more fattier fishes and fewer gadids (Trites *et al.* 1998a). It appears that the most powerful operating force in the Bering Sea is nature, not man.

None of the evidence suggests that the availability of pollock to Steller sea lions is limited, or that adding more pollock to the system will improve things for Steller sea lions. The environmental shift that is thought to be responsible for the high abundance of pollock and large flatfish, and the low abundance of fattier pelagic fishes, may flip in the next few years. If the theories are correct, the species composition will change again in favor of Steller sea lions and other mammals.

Trawling for pollock at greater depths than those used by juvenile sea lions is one means of ensuring minimal competition between the two. Steller sea lions would also presumably benefit by actions that increase the abundance and availability of fattier fishes, such as herring. Ultimately, however, the solution to restoring the numbers of Steller sea lions is probably out of human control.

It is important that people do not make the situation worse by tinkering with things we do not understand. The most precautionary action that we could take might be to maintain the status quo. Moving fisheries in time and space might, for example, lead to high by-catches of herring and other fattier fishes that are more critical to sea lion survival than pollock. It is thus important to consider the other components of the ecosystem and the uncertainty that our actions may produce. As noted by Boyd (1995), management measures have as much chance of being harmful to Steller sea lions as they do of aiding recovery. It is, therefore, important to proceed cautiously.

## Conclusions

Hatch, quoted by Francis *et al.* (1998), states that “the principal factor responsible for unfavorable trends in marine birds and pinnipeds in the Gulf of Alaska is availability of suitable food resources. Food limitation, in turn, may be caused by recent climatically driven ecosystem shifts forcing increased production of pelagic and demersal predatory fish (e.g., adult pollock, cod, salmon, and various flatfishes, especially arrow tooth flounder and halibut) at the expense of forage species (capelin, sandlance, juvenile pollock, herring, and myctophids) on which marine bird and mammal species depend.” Reviewing the available information concerning Steller sea lions supports this view and provides no indication that Steller sea lions are limited because they cannot get enough pollock to eat. The data indicate the following:

- The composition of major predator and prey populations in the Gulf of Alaska and Bering Sea underwent a rapid change beginning in the mid 1970s.
- The diet of Steller sea lions reflects this change in prey available to them and shows a relationship between high rates of decline and consumption of large amounts of pollock.
- There is no evidence that pollock are in short supply for either fisheries or sea lions, or that the two are competing. Catching adult pollock appears to reduce cannibalism and results in more juvenile pollock being available to Steller sea lions and other top predators.
- There appear to be negative health consequences for Steller sea lions if they eat primarily pollock.
- Recovery of Steller sea lions will probably occur if they can obtain a more diverse diet of fattier fishes. This appears to be a function of natural changes in the marine environment and not something that can be controlled by humans.
- Changes that people can invoke by altering amounts of pollock caught in time and space can have unexpected and undesirable results.

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