Search for the Missing Sea Otters: An Ecological Detective Story

Introduction

by
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The Problem

Sea otters are one of the few cute and cuddly creatures in the ocean. Visitors to the coast of the Pacific Northwest love to watch their antics as they float effortlessly on their backs among the floating fronds of kelp (large algae) or frolic with one another in play. They also have some human-like skills. Sea otters place rocks on their chests and crack mussels and clams on them, one of the few examples of tool use by animals other than primates. They also roll spiny sea urchins between their paws to make them easier to eat. It comes as a shock to many to find that this "poster child of marine near-shore ecology," as marine ecologist Robert Paine calls them, may be fighting for its survival in some areas of Alaska.

Dr. James Estes, a marine ecologist with the U. S. Geological Survey, and his coworkers recently found that the sea otter population in the Aleutian Islands of Alaska had crashed since 1990. Although wild animal populations always rise and fall to some degree, a decline of this size cried out to be explained.

Dr. Estes and his colleagues began an ecological detective hunt to uncover the cause of the declining otter population. Their investigation would eventually lead to the culprit, revealing a huge slice of the complexity and scale of nature's interconnectedness: from the sea otter itself to the web of interactions among species in the community around it and to events occurring on vast scales in the open ocean of the North Pacific.

One reason that Dr. Estes and his fellow investigators could eventually come to grips with such a complicated story is that they had been studying sea otters and kelp forest communities across nearly 2,000 miles of Aleutian and Alaskan coast for nearly three decades. During this time, they tracked sea otters' patterns of movement using tags and surgically implanted radio transmitters. They had conducted regular counts of otters across the region, giving them a large-scale and long-term picture of otter population dynamics. By the late 1970s, the researchers had found that otter populations on many islands had recovered strongly from near extinction a century ago by the fur trade, and there was every expectation that they would continue to be robust. So when they began to find declining populations in the early 1990s, Dr. Estes was surprised and perplexed.

The decline in the sizes of sea otter populations inhabiting the Aleutian Islands, which was observed by Dr. Estes and his group, was indeed large. On some islands the sea otter populations declined by 90 percent in fewer than 10 years (see Figures 1 and 2)! What could cause such rapid decline in the number of otters in this island chain of Alaska? Over the next several weeks, we will consider this problem from several perspectives. As we work to solve this mystery, keep in mind the following questions.

What factors could be contributing to such a rapid change in the size of sea otter populations? Should we spend federal and state tax dollars to support scientists and others in their investigations of this problem? Are we wasting money on animals that are merely "cute and fuzzy," or might the loss of sea otters from the Aleutian Islands have effects on other organisms? To begin our search for answers, we first need to know something about sea otter biology and population biology.

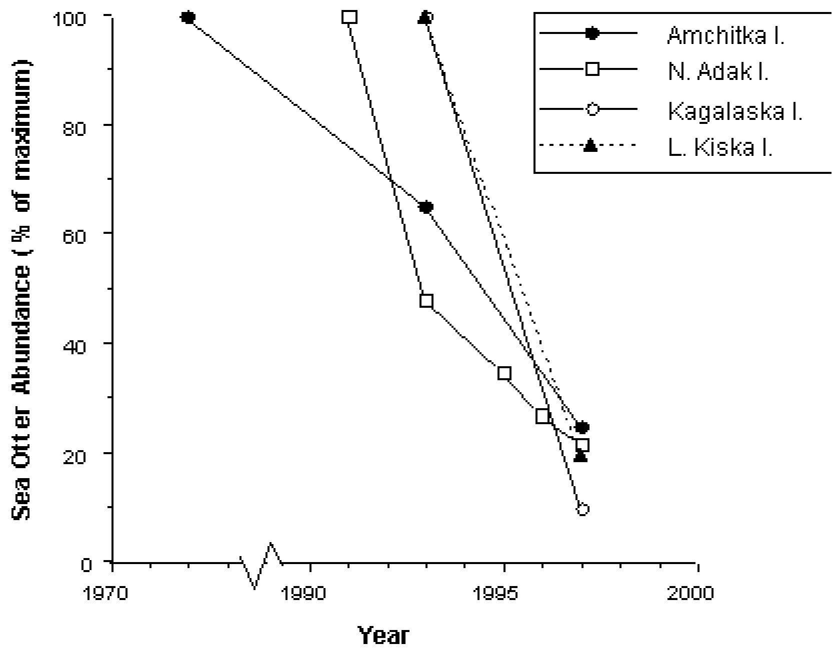

Figure 1. Changes in the relative abundance of sea otters at several locations in the Aleutian Islands, Alaska. (Redrawn from Estes et al., 1998.)

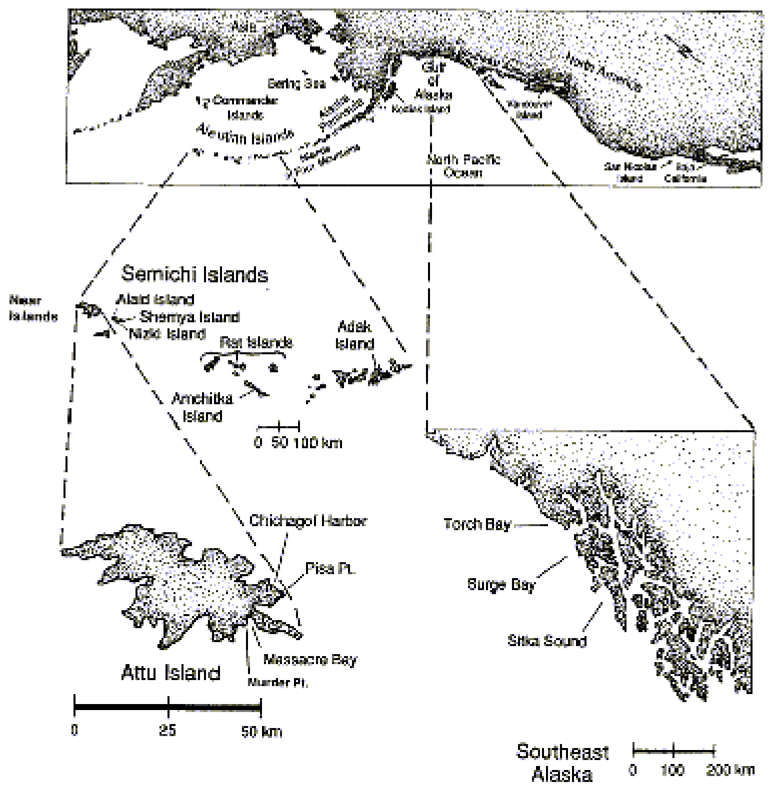

Figure 2. Map of the North Pacific Ocean showing the Aleutian Islands and some specific sea otter study sites. (From Estes, J.A., and D.O. Duggins. 1995. "Sea otters and kelp forests in Alaska: generality and variation in a community ecological paradigm." *Ecological Monographs* 65:75-100. Reproduced with permission of the Ecological Society of America.)

Sea Otters

The sea otter, *Enhydra lutris*, is the smallest marine mammal. Sea otters are distributed throughout the northern Pacific Ocean and are restricted to coastal regions because they collect their food (mostly crabs, clams, mussels, and sea urchins) from the ocean floor. They can remain underwater for only 30 to 90 seconds and so they inhabit areas where depths are shallow enough for short dives to the bottom. Once an otter brings food to the surface, it floats on its back, using its belly as a dinner tray. Otters often use rocks to smash open the hard shells of their prey, an activity that makes them unique among marine mammals.

Sea otters spend much of their time in water that can be as cold as -4°F. Consequently, they have evolved several mechanisms for maintaining a constant body temperature that is higher than that of their surroundings. Unlike other marine mammals (sea lions, for example), sea otters do not use an extra fat layer (blubber) to retain heat. Instead they have a double fur coat. The coat closest to the body of the otter, the underfur, is very fine and traps air. Heat released from the otter's body warms the trapped air, which serves as insulation. On top of the underfur are guard hairs, which keep the underfur dry. The guard hairs are much longer than those of the underfur and remain waterproof as long as they are clean, so sea otters spend 48 percent of the daylight hours grooming and cleaning their fur. This is the reason oil spills are so dangerous to sea otters. The oil coats the guard hairs and, since oil cannot be easily removed, the underfur becomes wet, loosing its insulative qualities, and the animal dies of hypothermia.

In addition to their two coats of fur, sea otters also keep their body temperature constant by maintaining high metabolic rates. It takes a lot of energy to maintain high metabolic rates. Consequently adult sea otters must consume 30 percent of their body weight each day. A human weighing 150 lbs would need to eat 45 lbs of food each day to do the same!

Sea otters are social animals although they group largely by gender. A group of otters is called a "raft," probably because they spend much of their time floating on their backs. In Alaska the average size of an otter raft is 100 individuals. Males generally mix with a group of females solely for purposes of mating. Mating is rough business. A male grabs a female with his front paws and flips her, belly-up, onto his belly. The male bites the female's nose, holding onto her in this fashion during the 30 to 60 minutes of copulation. Newly mated females are easily distinguished by their bloody snouts. This proves to be advantageous for scientists studying sea otters, since particular females can often be identified by their distinctive nose scars. A female is pregnant for approximately five months and gives birth to a single pup. The pup will remain with the mother, initially nursing and later eating prey collected by the mother, until it is approximately 12 months old.

Sea otters used to be found all along the Pacific Rim coastline, from northern Japan, through the Kuril Islands (Russia), the Commander Islands (Russia), the Aleutian Islands (part of Alaska), and down the Alaskan, Canadian, and U.S. mainland coasts to the Baja Peninsula (see Figure 2). In the mid-1700s, Russians began hunting otters for their pelts, and by the late 1700s, the English and Americans had also entered this fur trade. Sea otters were hunted nearly to extinction over the next 100 years. In fact, America purchased Alaska from the Russians in 1867 hoping to gain a greater share of the sea otter fur trade. What America did not realize was that Russia was willing to sell the territory because the otter populations had been reduced to a level where it was no longer economically productive to hunt them.

Before the onset of hunting in the mid-1700s, the estimated number of sea otters worldwide was 300,000 individuals. By the end of the 19th century, the number of remaining sea otters had dropped to approximately 1,000 in Alaska and 20 in California. Hunting of these animals ended with the signing of the International Fur Seal Treaty of 1911. The sea otters that remained in the 1900s were scattered amongst 13 relict populations. Several of these populations died out while those in Alaska flourished. The single population remaining in California has grown slowly and at its peak in 1995 consisted of 2,400 individuals. Presently there are sea otter populations on the Kuril Islands, Commander Islands, Aleutian Islands, and small portions of the mainland coasts of Alaska and California. The total worldwide population is currently estimated to be 150,000 individuals.

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Part I - "What Could be the Cause of Decreasing Otter Numbers?"

Around 1991, Dr. James Estes and his colleagues at the University of California, Santa Cruz, noticed that the otter populations they had been studying for over 20 years were beginning to shrink. Sea otter populations inhabiting several of the Aleutian Islands had declined as much as 90 percent in fewer than 10 years (Figure 1). What could cause such a sharp drop in sea otter numbers in this island chain of Alaska?

Read the following excerpt from an article published in the *New York Times* and see if you can determine where all of the missing otters had gone.

> **Could the otters simply have migrated from one part of the region to another? To find out, the researchers analyzed populations over a 500-mile-long stretch of the Aleutians from Kiska to Seguam.... By 1993 otter numbers in that whole stretch had been cut by half. Here the geographical scope of the research effort became critical; a smaller region would not have been large enough to reveal the decline. In 1997, they ... found that the population decline had worsened, to about 90 percent....**
>
> **"That told us for sure it was a very large-scale decline, but we were still trying to understand the cause," Dr. Estes said.... The researchers ... ruled out reproductive failure. Their studies enabled them to keep track of how often otters gave birth and how many young survived, and this revealed that reproduction was continuing to re-supply the population.**
>
> **With other possible causes eliminated, ... mortality had to be the explanation. In the past, they had seen temporary declines in otter populations because of starvation, pollution or infectious disease. "In all those cases," Dr. Estes said, "we find lots of bodies. They get weak and tired and come ashore to die." This time not a single dead otter was found -- a clue, he said, that "something really weird was going on."**

(Excerpted from Stevens, William K. "Search for missing sea otters turns up a few surprises." *New York Times*, January 5, 1999.)

Part II - "What Predator Could be Causing the Large Decrease in Otter Numbers?"

A. How would you test a hypothesis?

Dr. Estes and his group hypothesized that increased predation by killer whales was the cause of the sea otter decline. This was an unusual idea, since killer whales and sea otters had been observed together in Alaska for decades with no obvious interactions occurring between them. The first time a killer whale was observed attacking a sea otter was in 1991. Nine more attacks were observed in the next seven years and it was these attacks that finally led Dr. Estes and his colleagues to propose their hypothesis. To test this hypothesis, the scientists needed to have information about the killer whale.

1. Make a list of the types of information about killer whales you believe the scientists might need to test their hypothesis that increased predation by the whales was the cause of the sea otter decline.

2. Describe two experiments that would allow you to test the hypothesis that increased predation by killer whales was the cause of the sea otter decline. Keep in mind the following key components of any good experiment: a control (something to which to compare the treatment), replication (do it more than once), and consideration of confounding factors (what might cause differences other than what you manipulate in your experiment?).

B. What do the data tell you?

Estes and his colleagues estimated the impact of killer whales on sea otter populations by comparing trends in population size and survival rates of individually marked otters between two adjacent locations on Adak Island--Clam Lagoon and Kuluk Bay. Kuluk Bay is on an open coast, so sea otters there are exposed to killer whales. In Clam Lagoon, the entrance from the open sea is too narrow and shallow for killer whales to get in. Based on Figures 3 and 4 below, what can you conclude about the effects of killer whales on sea otter populations? Why do you think the scientists both counted all the sea otters and did the tagging and radio tracking?

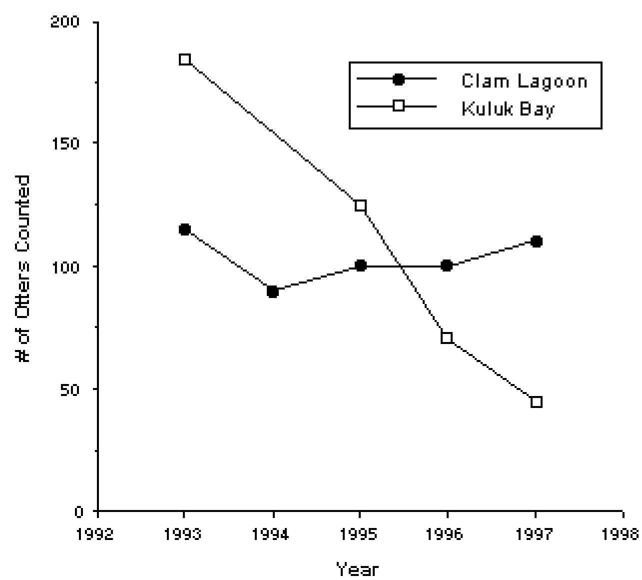

Figure 3. Changes in sea otter population size over time at Clam Lagoon and Kuluk Bay, Adak Island, Alaska. Redrawn from Estes et al., 1998.

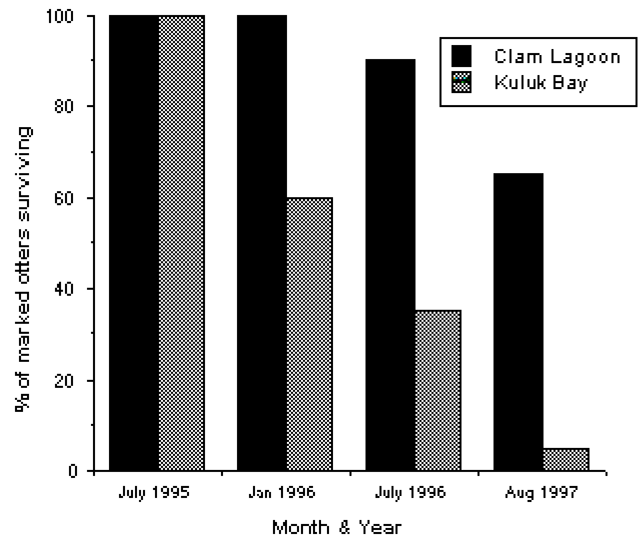

Figure 4. Survival rates of sea otters individually marked in 1995 with flipper tags and radio transmitters at Clam Lagoon and Kuluk Bay, Adak Island, Alaska. Redrawn from Estes et al., 1998.

C. Could predation by killer whales account for a 90 percent decrease in otter numbers?

If increased predation by killer whales was the primary cause of the sea otter decline in Alaska from 1990-1996, as Estes and his group suspected, killer whales would have to have eaten 40,000 sea otters in six years! How many killer whales would it take to eat this many sea otters? We know that killer whales travel in groups ranging from five to 25 individuals. Would it take one such group or 100? This is an important question to answer to determine whether killer whale predation could account for all of the missing sea otters. Using data provided in the table below, calculate how many whales feeding exclusively on sea otters it would take to eat 40,000 sea otters.

Table 1. Killer whale and sea otter energetics

Estimated number of Aleutian Island sea otters eaten, 1990-1996	40,000
Adult sea otters	
average caloric content	1.81 kcal/gram wet weight
average mass, male	34 kg
average mass, female	23 kg
Killer whales	
average field metabolic rate	55 kcal/kg of whale/day
average mass, male	5600 kg
average mass, female	3400 kg

Data from Estes, J.A., M.T. Tinker, T.M. Williams, and D.F. Doak. 1998. "Killer whale predation on sea otters linking oceanic ecosystems." *Science* 282: 473-476.

Part III - "Why Are Killer Whales Eating Sea Otters Now?"

All the evidence collected by Estes and his coworkers points to killer whales as the cause of the decline in sea otters: the increase in observed killer whale attacks on sea otters, the differences in sea otter survival and population trends at the two locations on Adak Island (Figures 3 and 4), and the energetics data (Table 1). Yet prior to the 1990s, killer whales and sea otters had co-existed peacefully for decades. What do you think has caused the killer whales to start eating sea otters? Discuss this question with your group and develop some working hypotheses to share with the class.

Part IV - "Who Cares if Otter Numbers are Decreasing?"

The data below are from a long-term and large-scale study of sea otters and kelp forest communities in southeast Alaska and the Aleutian Islands. Figure 5 and Tables 2 and 3 compare sea urchin and kelp abundances in areas with and without sea otters (see Figure 2 for a map showing the locations). Although sea otters formerly were found at all of these locations, they were exterminated from most of their range by hunting during the 19th century. Amchitka and Adak Islands in the Aleutians were locations of some of the few remnant populations at the time otters were protected in the early 1900s. Sea otters were re-introduced to southeast Alaska in 1968-71. That population expanded into Surge Bay by the early 1970s and into Torch Bay in 1985.

Table 4 summarizes data from several studies on the diet of sea otters. What do these data tell you about the role of sea otters in their community? How do you think the sea otters are affecting these two groups of species? What effects do you expect sea otters to have on the rest of the kelp forest community?

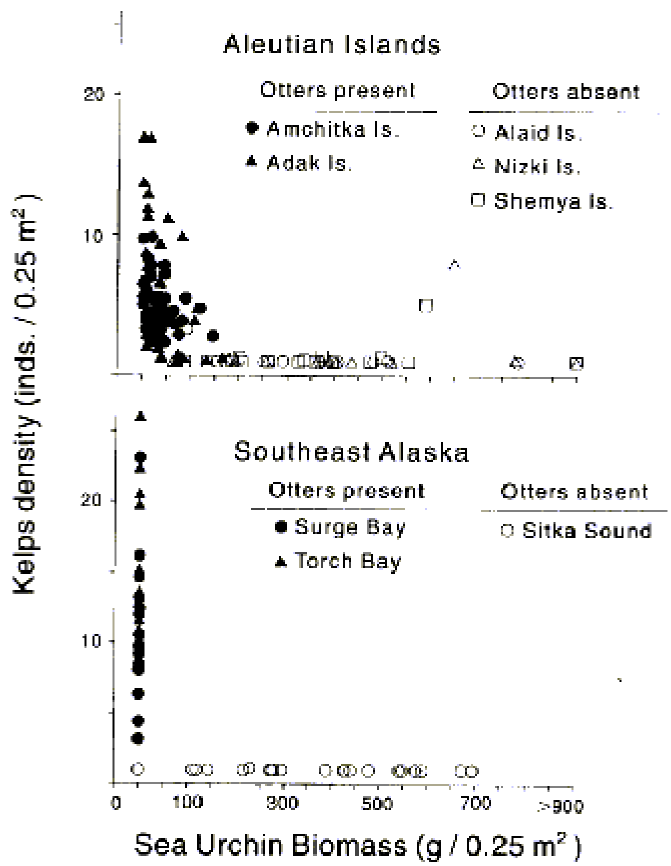

Figure 5. Kelp density (individuals/0.25 m^2) plotted against estimated sea urchin biomass (g/0.25 m^2) for the Aleutian Islands and southeast Alaska (see Figure 2 for map). Points represent averages for sites at each location. Sea urchin biomass was estimated from samples of population density, size-frequency distribution, and the relationship between urchin diameter and wet mass. (From Estes, J.A., and D.O. Duggins. 1995. "Sea otters and kelp forests in Alaska: generality and variation in a community ecological paradigm." *Ecological Monographs* 65:75-100. Reproduced with permission of the Ecological Society of America.)

Table 2. Abundance and population characteristics of kelps and sea urchins at two locations in the Aleutians, Amchitka and Shemya Islands, in 1972 and 1987 (shown as means ± 1 standard error). The same four sites at Amchitka and two sites at Shemya were sampled in both years*. Sea otters were continuously abundant at Amchitka and absent from Shemya during the 15-yr period. (From Estes, J.A., and D.O. Duggins. 1995. "Sea otters and kelp forests in Alaska: generality and variation in a community ecological paradigm." *Ecological Monographs* 65:75-100.)

	Amchitka Island		**Shemya Island**	
	1972	**1987**	**1972**	**1987**
Kelp species (inds./0.25 m^2)				
Alaria fistulosa	1.6 ± 1.30	0.3 ± 0.22	0	0.5
Laminaria spp.	2.3 ± 0.49	3.9 ± 0.95	0	0
Agarum cribrosum	1.2 ± 0.61	0.5 ± 0.42	0	0
Thalassiophyllum clathrus	0.1	0	0	0
Total kelps	5.1 ± 0.66	4.7 ± 1.15	0	0.5
Sea urchins				
Maximum test diameter (mm)	30.5 ± 1.34	27.3 ± 3.24	72.5 ± 0.71	70.5 ± 4.95
Biomass (g/0.25 m^2)	45.1 ± 16.9	36.7 ± 15.0	368.2 ± 151.7	369.3 ± 14.3
Density (inds./0.25 m^2)	27.9 ± 14.5	23.4 ± 7.5	50.0 ± 14.6	38.6 ± 1.4

*The 1972 data were obtained from 10 haphazardly placed 0.25-m^2 quadrats/site, the 1987 data from 20 randomly placed 0.25-m^2 quadrats/site.

Table 3. Abundance and population characteristics of kelp and sea urchins at two locations in southeast Alaska, Torch Bay (1976-1978) and Surge Bay (1978 and 1988), shown as means ± 1 standard error. Sea otters were continuously absent at Torch Bay and present at Surge Bay during these time periods. (From Estes, J.A., and D.O. Duggins. 1995. Sea otters and kelp forests in Alaska: generality and variation in a community ecological paradigm. *Ecological Monographs* 65:75-100.)

	Torch Bay			**Surge Bay**	
	1976	**1977**	**1978**	**1978**	**1988**
Kelps (inds./m^2)					
Annuals*	2.1 ± 1.39	0.2 ± 0.25	11.6 ± 6.69	2.1 ± 0.45	3.7 ± 2.34
Perennials**	0.1 ± 0.11	0	0.9 ± 1.14	48.4 ± 6.33	50.3 ± 7.46
Total	2.2	0.2	12.5 ± 5.56	50.5 ± 6.43	54.0 ± 9.33
Sea urchins (inds./m^2)					
S. franciscanus	3.6 ± 3.05	3.8 ± 2.55	4.9 ± 3.71	0	0
S. purpuratus	1.0 ± 0.75	2.3 ± 2.52	0.3 ± 0.41	0	0
S. droebachensis	3.4 ± 2.24	1.5 ± 0.95	0.2 ± 0.18	0.02	0.04
Total	8.0 ± 4.56	7.6 ± 5.78	5.4 ± 4.27	0.02	0.04

*Primarily *Alaria fistulosa* and *Nereocystis leutkeana*.
**Primarily *Laminaria groenlandica*.

Table 4. Occurrence of prey items in sea otter stomachs and feces. (From Estes, J.A., N.S. Smith, and J.F. Palmisano. 1978. "Sea otter predation and community organization in the western Aleutian Islands, Alaska." *Ecology* 59:822-833.)

Source	**Wilke 1957**	**Kenyon 1969**	**Kenyon 1969**	**Burgner and Nakatani 1972**	**Barahash-Nikiforov 1947**	**Williams 1938**
Location	Amchitka	Amchitka	Amchitka	Amchitka	Commander Islands	Western Aleutians
Sample period	1954	1962-1963	1962-1963	1970	1930-1932	1936
Sample type	Stomach	Stomach	Stomach	Stomach	Feces	Feces
Sample size	5	309	309	49	500	70
Analysis	**Percent of total volume**	**Percent of total volume**	**Percent of total number of prey item**	**Percent of stomachs containing food item***	**Percent of total volume**	**Percent of total volume**
Prey item						
Annelids	0	1	2	2	0	0
Arthropods						
Crabs	0	< 1	4	22	10	4
Others	0	0	3	0	0	0
Mollusks	8	37	31	38	23	13
Echinoderms						
Sea urchins	86	11	21	82	59	78
Others	0	0	16	0	0	0
Fish	6	50	22	44	7	3
Others	0	< 1	1	0	1	2
Total	100	100	100	-	100	100

*Percent of total volume: carnivores 65 (including fish 62.2) and herbivores 35.

Image Credit: Photo of sea otter by Warren and Leora Worthington, courtesy of Friends of the Sea Otter, used with permission.
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