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CARRYING CAPACITY AND PRE-DECLINE ABUNDANCE OF SEA OTTERS (*ENHYDRA LUTRIS KENYONI*) IN THE ALEUTIAN ISLANDS

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Key words: sea otter, *Enhydra lutris kenyoni*, carrying capacity, population decline, Aleutian Islands, Alaska

Sea otters (*Enhydra lutris kenyoni*) have the densest fur of any mammal and were hunted extensively during commercial fur trades that

began with the Bering-Chirikof expedition of 1741 (Kenyon 1969). Once ranging across the Pacific rim from Japan to Mexico, sea otters had been extirpated throughout much of their range until they were finally protected in 1911 by international treaty which prohibited further hunting. The few remaining sea otter colonies began to grow and re-occupy their former range, and by 1965 sea otters were believed to have recovered to pre-exploitation levels at numerous islands in the western and central portions of the Aleutian Islands (Estes 1990). Otters had returned to all major island groups by the mid-1980s, and additional population growth was expected (Calkins and Schneider 1985). However, both aerial and skiff surveys conducted in the 1990s documented a dramatic population decline of sea otters in the Aleutian Islands (Evans and others 1997; Estes and others 1998). The most recent aerial survey conducted in April 2000 indicated that the population declined by 70% from 1992 to 2000 and may currently number fewer than 9000 individuals (Doroff and others 2003). Evidence suggests that the sea otter population decline in the central Aleutians was well underway at the time of the 1992 aerial survey (Evans and others 1997; Doroff and others 2003). Because the aerial survey history of the Aleutians (1965, 1992, and 2000) contains significant gaps in time, an estimate of pre-decline abundance and the overall magnitude of the decline cannot be calculated from survey data alone. The purpose of this study was to examine existing aerial and skiff survey data on sea otters in the Aleutian Islands by using a habitat-based model to estimate carrying capacity (K), pre-decline abundance, and magnitude of the decline.

In August 2000, the US Fish and Wildlife Service designated sea otters in the Aleutian Islands (from Unimak Pass to Attu Island) as a candidate species under the US Endangered Species Act (ESA). This action identified sea otters in the Aleutians as a species of concern that warrants consideration for addition to the endangered species list. Should sea otters in the Aleutian Islands eventually be listed under the ESA, estimates of K and the magnitude of population decline will be essential for planning for population recovery. K is interpreted here to be the maximum number of sea otters that can be supported in the Aleutian Islands.

K for sea otters in California and Washington has been estimated using a Geographic Information System (GIS)-based approach (Laidre and others 2001, 2002). Using a similar method, we estimated K for the Aleutian islands as the product of total area of available habitat, sea otter equilibrium density, and a correction factor for otters not detected by observers.

Unlike calculations of K for the California and Washington populations, we did not stratify sea otter habitat by substrate type. The Aleutian Islands are volcanic in origin with a predominantly rocky substrate. For the purpose of our analysis, we generated a bathymetric data layer from National Ocean Service hydrographic survey data. Following the habitat definition of Bodkin and Udevitz (1999) for high-density survey strata, we delineated sea otter habitat in a GIS as the union of waters <40 m deep, waters ≤ 400 m from the shoreline, and waters in bays and fiords <6 km across. This definition was based on detailed observations of sea otter distribution in Prince William Sound, Alaska, and consists of nearshore, shallow-water feeding areas and sheltered areas used for resting. Using this definition, we identified 6503 km^2 of available habitat in the Aleutian Islands.

To determine the equilibrium density of sea otters in the Aleutians, we reviewed aerial survey data collected prior to the onset of the decline. Equilibrium density has been defined as the average density that is relatively stable over time and can be supported by the habitat (Estes 1990). In 1965, sea otters were believed to have reached equilibrium density at 23 islands ranging from Buldir Island in the west to Great Sitkin Island in the east (Kenyon 1969). We regressed the 1965 sea otter aerial survey counts for each of these islands against available habitat area (as described above) and found a good fit ($r^2 = 0.94$; Fig. 1). To estimate the variability associated with sea otter equilibrium density, we bootstrapped the data with replacement for 100,000 replicates. We used the median of these bootstrapped values (4.52) as our estimate of equilibrium density (Table 1). Ninety-five percent confidence intervals were estimated by removing the outer 2.5% from both tails of the bootstrapped distribution.

To estimate the proportion of animals not detected during aerial surveys, Doroff and others (2003) compared skiff and aerial survey counts of the same areas at 6 islands in 2000. We boot-

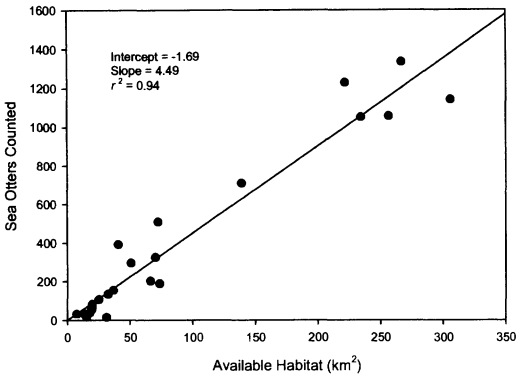

FIGURE 1. Relationship between available habitat and sea otter counts at 23 islands in the western and central Aleutian Islands believed to be at equilibrium density in 1965. Sea otter counts are from the aerial survey of Kenyon (1969) and are uncorrected for otters not detected by observers.

strapped the ratio of the paired aerial and skiff counts from these islands with replacement for 100,000 replicates. The median value of these replicates indicates that skiff-based observers recorded 3.58 times as many sea otters as aerial observers (Table 1). We recognize that this air-skiff correction factor is likely biased low, as skiff observers probably did not see every sea otter present (Udevitz and others 1995).

We estimated K for the Aleutians as the product of the total available habitat (6503 km^2), equilibrium density (4.52 otters/km^2), and the air-skiff correction factor for undetected otters (3.58), which equals 105,391 sea otters (Table 1). The most recent population estimate from a complete aerial survey in April 2000, corrected for otters not detected by observers, is 8742 (Doroff and others 2003). From these data it appears that the current sea otter population in the Aleutian Islands has declined to 8.2% of K.

It is likely that not all islands had reached equilibrium density at the onset of the current population decline. In order to estimate the magnitude of the decline, we needed to estimate the pre-decline abundance of sea otters which occurred at some point between the 1965 and 1992 aerial surveys. To do this, we considered 3 categories of islands. The 1st category consisted of the 23 islands believed to have been at equilibrium density in 1965 (Estes 1990). For this group, we used the 1965 counts as the pre-decline abundance. The 2nd category consisted of 10 islands believed to have reached equilibrium density after the 1965 survey but prior to the onset of the decline (Estes 1990), for which we use the estimated K.

The 3rd group consisted of 18 islands that were re-colonized after 1965 but likely did not reach equilibrium density prior to the onset of the decline. Doroff and others (2003) estimated that the decline began between 1986 and 1991 and proceeded at a rate of −17.5%/y. Therefore, to estimate the pre-decline abundance for this 3rd group of islands, we hindcast the 1992 aerial survey counts backwards in time at a rate of 17.5%/y. We randomly selected the onset of the decline from 1986 to 1991 and bootstrapped this calculation for 100,000 replicates, using the median value as our estimate. Summing the estimates for the 3 categories of islands yields an overall pre-decline abundance estimate with a 95% confidence interval that ranges from 55,608 to 94,973, with a median of 73,752 (Table 1). Our estimate is comparable to the 55,100 to 73,700 individuals estimated for the Aleutian population by Calkins and Schnieder (1985) who summarized survey data collected through 1976. As sea otters had not yet reached equilibrium density at all islands in the Aleutians by 1976, it is likely that additional population growth occurred prior to the onset of the decline.

Based on our estimate of pre-decline abundance, it appears that there has been a net loss of approximately 47,000 to 86,000 (median = 65,280) sea otters in the Aleutian islands in the

TABLE 1. Bootstrapped parameter estimates and 95% confidence intervals (CI) used to estimate carrying capacity and pre-decline abundance of sea otters in the Aleutian Islands. All bootstrapping calculations were conducted with 100,000 replicates.

Parameter	Median	95% CI
Equilibrium density (otters/km^2)	4.52	4.09–4.98
Air-skiff correction factor	3.58	2.52–4.90
Carrying capacity	105,391	73,589–146,607
Pre-decline abundance	73,752	55,608–94,973

past 10 to 15 y. As it is likely that skiff survey observers did not see all sea otters present, these values should be considered conservative minimum estimates. Udevitz and others (1995) calculated that skiff surveys may miss 30% of the sea otters present in a given area; therefore, the net loss in the Aleutian Islands may well exceed 90,000 sea otters. We recognize that these estimates are based on a number of simplifying assumptions; however, the magnitude and precipitous rate of the decline are clear signs that management actions to conserve the remaining sea otter population in the Aleutians are necessary.

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SEXUAL AGGRESSION BY A MALE NORTHERN ELEPHANT SEAL ON HARBOR SEAL PUPS IN WASHINGTON

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Key words: northern elephant seal, *Mirounga angustirostris*, harbor seal, *Phoca vitulina*, sexual aggression, Washington

Protection Island, Washington, serves as a haul-out and pupping site for hundreds of harbor seals (*Phoca vitulina*) (Kroll 1993; Jeffries

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Killer Whale Predation on Sea Otters Linking Oceanic and Nearshore Ecosystems

J. A. Estes; M. T. Tinker; T. M. Williams; D. F. Doak

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Estimates of Carrying Capacity for Sea Otters in Washington State

Kristin L. Laidre; Ronald J. Jameson; Steven J. Jeffries; Roderick C. Hobbs; C. Edward Bowlby; Glenn R. VanBlaricom

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