

An Accounting of the Sources of Steller Sea Lion, *Eumetopias jubatus*, Mortality

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Introduction

Recent studies have shown that Steller sea lion, *Eumetopias jubatus*, mitochondrial DNA is different across the sea lion's range, suggesting that at least two stocks exist, an eastern one (California through southeastern Alaska), and a western one (Prince William Sound and areas west) (Bickham et al., 1996; Loughlin, 1997). The western stock is declining at about 5% per year, and total population numbers have dropped by over 80% since the late 1960's (Loughlin et al., 1992; Loughlin, 1997; Sease and Loughlin, 1999). The magnitude and continuous nature of the decline resulted in this stock being listed as endangered in 1997 by the National Marine Fisheries Service

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(NMFS) (62 FR 24345). The causes of the decline are not known but likely have changed. During the early phases of the decline, incidental catch of sea lions in trawl fisheries and legal shooting were important sources of mortality (Perez and Loughlin, 1991; Trites and Larkin, 1992).

After the North Pacific Ocean regime shift in the 1970's (Trenberth, 1990), and as U.S. fishery management changed during the mid 1970's and 1980's (Fritz et al., 1995), the cause of the decline was attributed to nutritional stress resulting from either environmental variability that caused a change in prey base, removal of prey by commercial fisheries, or a combination of these two factors (Loughlin, 1998). During the early phases of the decline, the cumulative loss of animals from predation, subsistence harvest, and other anthropogenic sources was considered inconsequential. However, as the western sea lion population continues to decline,

these factors will account for a larger portion of total mortality than before, and thus, estimating the amount of sea lion mortality attributable to nutritional stress or the indirect effects of fisheries may be difficult. Here, we report our efforts to estimate the number of animals lost to the population each year to each of the possible sources of mortality.

Methods

The present rate of decline in the western stock (Table 1) was estimated by regressing the natural logarithm of the 1991–2000 trend-site non-pup counts (NMFS¹) over time. We also calculated the rate of decline by geographic region in the same way (Fig. 1). Estimates of the total number of non-pups in the western stock were calculated by multiplying the number of non-pups counted on trend sites by a correction factor of 1.807 (Loughlin et al., 1992); that factor accounts for animals that were at sea during the survey and for sites that were not surveyed. We approximated sea lion mortalities each year from the western Steller sea lion population using estimates of the total number of non-pups in the population and the observed rate of sea lion decline during 1991–2000, assuming the decline would continue at the same rate.

Based on York's (1994) life table and the assumption that the population was stable, the number of non-pup mortalities would be about 15% per year; this is the level of natural mortality that we would expect if the population instantly stabilized. If the population were stable,

ABSTRACT—During 1991–2000, the western stock of Steller sea lions, *Eumetopias jubatus*, declined at 5.03% (SE = 0.25%) per year, statistically significant rates ($P < 0.10$) in all but the eastern Aleutian Islands region. The greatest rates of declines occurred in the eastern and central Gulf of Alaska and the western Aleutian Islands (> 8.2% per year). Using a published correction factor, we estimated the total non-pup population size in Alaska of the western stock of Steller sea lions during 1991–2000 was about 6,383 animals; of those, 4,718 (74%) are mortalities that would have occurred if the population were stable, and 1,666 (26%)

are additional mortalities that fueled the decline. We tabulated the levels of reported anthropogenic sources of mortality (subsistence, incidental take in fisheries, and research), estimated another (illegal shooting), then approximated levels of predation (killer whales and sharks). We attempted to partition the various sources of "additional" mortalities as anthropogenic and as additional mortality including some predation. We classified 436 anthropogenic mortalities and 769 anthropogenic plus some predation mortalities as "mortality above replacement"; this accounted for 26% and 46% of the estimated total level of "mortality above replacement", respectively. The remaining mortality (74% and 54%, respectively) was not attributed to a specific cause and may be the result of nutritional stress.

¹ Unpublished data available at <http://nmml.afsc.noaa.gov/AlaskaEcosystems/sslhome/index.htm>.

the number of pups recruited into the non-pup population would equal the number of non-pups lost to natural mortality (e.g. no net gain or loss). In a declining population, losses above replacement are “additional” mortality which result from a combination of non-pup and pup mortalities and decreased birth rates, assuming a closed population and no or little emigration, and no density dependence.

Results

The western population of Steller sea lions has declined at about 5.03% (SE = 0.25%) per year while the eastern stock in southeastern Alaska increased at about 1.72% (SE = 0.96%) per year during 1991–2000 (Table 1). The western stock declined at statistically significant rates ($P < 0.10$) in all regions except the eastern Aleutian Islands. The greatest rates of decline occurred in the eastern and central Gulf of Alaska (GOA) and the western Aleutian Islands (all greater than 8.2% per year). Using a published correction factor (Loughlin et al., 1992), we estimated the total population size of the western stock of non-pup Steller sea lions to be about 33,000 animals. Our estimate of total annual mortality for a stable population is 4,718 Steller sea lions in 2001 (Table 2). Our estimates of “additional” annual mortality, to account for the 5.03% rate of annual decline, suggest that in 2001 the declining western Steller sea lion population would lose about 1,666 animals above replacement (“additional” mortality). Thus, for 2001 the total estimated mortality is about 6,383 Steller sea lions (Table 2). The additional mortality represents about 26% of all Steller sea lion mortalities. Over the next 20 years, as the population and total mortalities continue to decline, the “additional” mortality category would decline to a low of 625 animals in 2020.

Mortality is not uniform across the range of the western stock but is likely to vary based on population distribution, predation, subsistence harvest rates, and other factors. To estimate the relative mortality based on sea lion distribution, we apportioned the estimated loss in 2001 using data from the NMFS 2000 breeding season aerial survey (Sease et

Table 1.—Annual trends and standard errors of the numbers of non-pup Steller sea lions in Alaska, 1991–2000. Trends were statistically significant ($P < 0.05$) for the western stock as a whole and separately in the eastern and central Gulf of Alaska and the central and western Aleutian Islands.

Region	Annual trend (%)	SE (%)	t value	P(> t)
Eastern Gulf of Alaska	-9.98	1.19	-8.414	<0.001
Central Gulf of Alaska	-8.27	0.72	-11.451	<0.001
Western Gulf of Alaska	-2.26	0.95	-2.373	0.064
Eastern Aleutian Islands	-1.73	1.10	-1.568	0.192
Central Aleutian Islands	-3.14	1.00	-3.139	0.035
Western Aleutian Islands	-8.66	1.75	-4.942	0.008
Total Western stock	-5.03	0.25	-20.390	<0.001
Southeastern Alaska	1.72	0.96	1.801	0.147

Table 2.—Projected counts of non-pup Steller sea lions at trend sites and estimates of the total population size for 2001–20 in Alaska if trends continue as they did in 1991–2000, assuming a 5.03% (SE = 0.25%) annual decrease in the western stock and a 1.72% (SE = 0.96%) annual increase in southeast Alaska (part of the eastern stock). Projected counts were computed from a base of actual counts in 2000.

Year	Western Stock-Alaska					Eastern Stock-Alaska		
	Count	Estimated population	Additional losses	Stable population	Total mortalities	Count	Estimated population	Gain
2000	18,325	33,116				9,862	17,822	
2001	17,403	31,450	1,666	4,718	6,383	10,032	18,129	307
2002	16,528	29,868	1,582	4,480	6,062	10,204	18,440	312
2003	15,697	28,366	1,502	4,255	5,757	10,380	18,758	317
2004	14,907	26,939	1,427	4,041	5,468	10,558	19,080	323
2005	14,157	25,584	1,355	3,838	5,193	10,740	19,408	328
2006	13,445	24,297	1,287	3,645	4,931	10,925	19,742	334
2007	12,769	23,075	1,222	3,461	4,683	11,112	20,082	340
2008	12,127	21,914	1,161	3,287	4,448	11,304	20,427	345
2009	11,517	20,812	1,102	3,122	4,224	11,498	20,778	351
2010	10,937	19,765	1,047	2,965	4,012	11,696	21,136	357
2011	10,387	18,771	994	2,816	3,810	11,897	21,499	364
2012	9,865	17,827	944	2,674	3,618	12,102	21,869	370
2013	9,368	16,930	897	2,540	3,436	12,310	22,245	376
2014	8,897	16,078	852	2,412	3,263	12,521	22,628	383
2015	8,450	15,270	809	2,290	3,099	12,737	23,017	389
2016	8,025	14,502	768	2,175	2,943	12,956	23,413	396
2017	7,621	13,772	729	2,066	2,795	13,179	23,816	403
2018	7,238	13,080	693	1,962	2,655	13,405	24,225	410
2019	6,874	12,422	658	1,863	2,521	13,636	24,642	417
2020	6,528	11,797	625	1,770	2,394	13,870	25,066	424

al., 2001) and calculated the proportion of the counted population in each of the NMFS designated geographic areas (Fig. 1). We did this in two ways. The first procedure assumed uniform mortality across Alaska and the second prorated the losses within each area based on the decline rates in Table 1. For each area, the two estimates of Steller sea lion losses are shown in Table 3.

We also recognize that mortality may be density dependent (e.g. predation) or independent (e.g. shooting). However, because of the overall paucity of data related to these factors, we made no attempt to model mortality as either density dependent or independent.

After estimating the level of sea lion mortality, we attempted to identify the sources of mortality and their magnitude. The possible sources of mortality

that we consider here include subsistence harvest, incidental take, entanglement in debris, shooting, and predation. Those for which we do not provide estimates include mortalities resulting from lack of prey caused by environmental variability or the indirect effects of commercial fisheries. We do not include estimates of loss due to commercial harvest of adult and pup sea lions because neither activity has occurred since 1972 (Merrick et al., 1987), nor do we discuss potential mortalities resulting from disease and contaminants for which data are lacking.

Determining which of these sources of mortality are “natural” or “additional” is problematic. We decided that those attributable to humans (or human action) were “additional.” We also decided that some portion of predation could also be

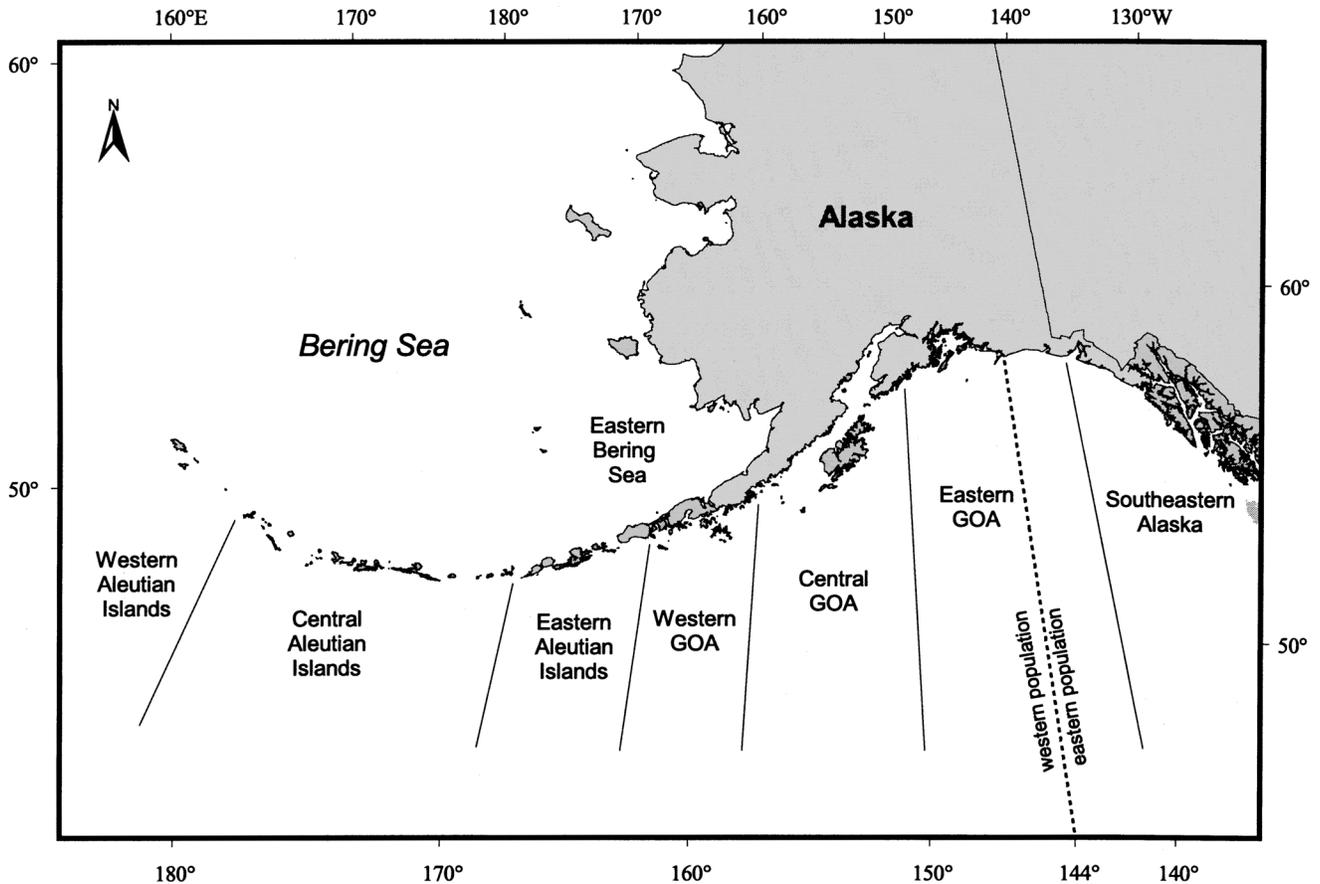


Figure 1.—Steller sea lion subareas in the Aleutian Islands and Gulf of Alaska (GOA) waters. The western stock and eastern stock are separated at 144°W longitude.

unnatural. For instance, observations of killer whale, *Orcinus orca*, predation have increased due to the large number of floating fish processing vessels and factory trawlers that attract sea lions (and people who observe them). Killer whales appear to be drawn to these ships, and sea lions, are drawn there to consume fish products discarded as waste from these ships. In our view, this situation makes foraging sea lions more susceptible to predation, and we consider some portion of this killer whale predation as not “natural.”

The highest level of known mortality from an anthropogenic source is subsistence harvest which may account for ~350 or more sea lions annually (Table 4). The Alaska Department of Fish and Game conducted studies to estimate subsistence use of Steller sea lions state-wide during 1992–99 (Wolfe and

Table 3.—Estimated Steller sea lion mortality above replacement in the western population during 2001. Mortalities specified in Table 4 were assumed to be above replacement values. We allocated mortalities by region in two ways: 1) proportionally by population size in 2000, and 2) using estimated rates of decline in Table 1. We also allocated mortality based on “additional” mortality without predation (column A) and with predation (column B) as in Table 4. The difference between the total in column (A) and (B) represents the “additional” mortality that is not attributed to a specific cause (1,230 and 897 sea lions, respectively).

Region	Sea lion losses above replacement						
	% of 2000 survey	Proportional allocation	A ¹	B ²	Proportional with regional decline	A ¹	B ²
Eastern Gulf of Alaska	9.0%	150	39	69	385	101	178
Central Gulf of Alaska	18.7%	312	82	144	513	134	237
Western Gulf of Alaska	18.1%	302	79	139	125	33	58
Eastern Aleutian Islands	19.8%	330	86	152	130	34	60
Central Aleutian Islands	27.8%	463	121	214	332	87	153
Western Aleutian Islands	6.6%	109	29	51	181	47	83
Total	100.0%	1,666	436	769	1,666	436	769

¹ Assumes all predation is in the natural category.

² Assumes some portion of predation is “additional” mortality. See text for explanation.

Hutchinson-Scarborough, 1999; Wolfe and Mishler²). Estimates of take ranged from a high of 549 in 1992 to a low of 164 in 1997 with a mean of 353. Sea lions were taken in 17 of 62 surveyed communities; the primary source of subsis-

² Wolfe, R. J., and C. Mishler. 1997. The subsistence harvest of harbor seal and sea lion by Alaska Natives in 1996. Draft final report for year five, subsistence study and monitor system (contract No. 50ABNF400080) for the NMFS. Available from Alaska Department of Fish and Game, Division of Subsistence, Juneau.

Table 4.—Estimates and source of Steller sea lion mortality during 2001 and that mortality expressed as a percentage of all estimated mortality above replacement (1,666).

Source	Estimated mortality (A ¹)	Estimated mortality (B ²)	Estimated mortality above replacement (%)
Subsistence harvest	353	353	21.2
Incidental to fishing	30	30	1.8
Illegal shooting	50	50	3.0
Research	3	3	0.2
Predation by killer whales	0	300	0.0/18.0
Predation by sharks	0	33	0.0/2.0
Total	436	769	26.2/46.2

¹ Assumes all predation is in the natural category.

² Assumes some portion of predation is "additional" to natural, as explained in text.

tence use was on the Pribilof Islands, Kodiak Island, and a few native villages in the Aleutian Islands.

The number of sea lions killed incidentally in trawl and other net fisheries is presently very low, perhaps about 30 per year (Ferrero et al., 2000). These takes are typically in the Gulf of Alaska and southeastern Bering Sea and are associated with the trawl fisheries for walleye pollock, *Theragra chalcogramma*, and other groundfish. Some are taken in seine and gillnet fisheries associated with Pacific herring, *Clupea pallasii*, or Pacific salmon, *Oncorhynchus*, fishing, but because of their large size, sea lions often escape from these nets; generally, the herring and salmon boats are small and do not carry fisheries observers. Entanglement of sea lions in marine debris (packing bands, net debris, etc.) is not now nor has it been considered a contributing factor in the Steller sea lion decline (Calkins, 1985; Loughlin et al.³).

Prior to passage of the Marine Mammal Protection Act (MMPA) in 1972, shooting Steller sea lions was legal, and estimates on the magnitude of that take vary widely. But even after MMPA restrictions were in place, fishermen were allowed to shoot sea lions (and other marine mammals) that were destroying their gear or causing a threat to human safety. Only in 1990 was a prohibition on the discharge of firearms near

Steller sea lions implemented. Recent court cases in Alaska testify to the fact that illegal shooting still occurs, but the overall magnitude of this source of mortality remains difficult to evaluate. In January 2000, an Alaska fisherman was convicted of firing about 80 rounds at Steller sea lions during summer 1999. The actual number of animals killed as a result of this action was not known, but the fisherman was convicted of killing one sea lion (*Anchorage Daily News*, 2001). Estimates of mortality from shooting range from 1,180 in 1985 to zero in 1956–1978 (Trites and Larkin, 1992). Our own estimate of the annual mortality from this cause is at least 50 animals per year. However, even if illegal killing of sea lions is not a common occurrence, the magnitude of this mortality is exacerbated when sea lions taken are from certain sex and age classes. At sea and near fishing vessels, Steller sea lions tend to aggregate in groups of young animals and mature females (Loughlin and Nelson, 1986). These are the very animals that are most critical for recovery of the population, and they are also the easiest targets of opportunity. Killing young females as they enter their reproductive years is the most efficient way to reduce a population, because those animals have the highest reproductive value (York and Hartley, 1981). Not only are they removed from the population, their future reproductive potential is also eliminated.

Some Steller sea lions may also die accidentally as a result of Federally permitted research. The level of the mortality rarely exceeds 5 animals annually but typically is about 3 per year (Sease⁴).

Predation by killer whales and sharks (Squalidae) may now be an important

source of mortality and may exceed what was earlier considered "natural." Predation is often focused in small areas as mentioned (i.e. where sea lions are localized near large fish processing vessels), resulting in exacerbation of local declines. The occurrence of 14 flipper tags from sea lions that were tagged as pups in 1988 in the stomach of a single dead killer whale in Prince William Sound has also been chronicled (Saulitis et al., 2000).

There are various ways to estimate Steller sea lion mortality by killer whales, one of which is to assume that all predation is natural. Estimates of sea lion mortality by transient-type killer whales (Barrett-Lennard et al.⁵) suggest that 18% of all sea lion mortality could be attributed to killer whale predation. For the 2001 Steller sea lion population, this would amount to 849 sea lions in the nominally stable population ($4,718 \times 0.18$) or 1,149 sea lions in the declining population ($6,383 \times 0.18$).

Another approach is to assume that some portion of the predation is "additional." For this, we estimated the difference in mortality due to killer whale predation between a stable population and a sea lion population declining at 5.03% as 300 animals (1,149–849).

Yet another approach takes into account that the Barrett-Lennard et al.⁵ estimates were made in 1994 when there were about 32% more sea lions. The estimated natural mortality from killer whale predation in a stable population in 1994 would have been about 18% of $1.32 \times 4,718$, or 1,121 sea lions. If killer whales have continued to eat the same number of sea lions, we could attribute the difference between 1,121 and 849, or 272 animals, to "additional" mortality. This number is similar to 300 or 18% of above replacement losses. In Tables 3 and 4, we tabulate killer whale predation as a range of possibilities.

⁴ Sease, John, National Marine Mammal Laboratory, NMFS Alaska Fisheries Science Center, Seattle, WA. Personal commun.

⁵ Barrett-Lennard, L. G., K. Heise, E. Saulitis, G. Ellis, and C. Matkin. 1994. The impact of killer whale predation on Steller sea lion populations in British Columbia and Alaska. Fish. Cent., Univ. Brit. Col., Vancouver. Rep. to N. Pac. Univ. Mar. Mammal Res. Consortium, 66 p. B.C., Canada, V6T 1Z4.

³ Loughlin, T. R., P. J. Gearin, R. L. DeLong, and R. L. Merrick. 1986. Assessment of net entanglement on northern sea lions in the Aleutian Islands, 25 June–15 July 1985. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., NWAF C Processed Rep. 86-02, 50 p. Available from Alaska Fish. Sci. Cent., 7600 Sand Point Way N.E., Seattle WA 98115.

Salmon sharks, *Lamna ditropis*, and Pacific sleeper sharks, *Somniosus pacificus*, have recently been implicated in Steller sea lion mortality. There are presently no estimates for this mortality, but we do not consider it to be substantial. However, if we assume that 1% of all mortalities in 2001 were attributed to each of these shark species (total = 2%), then 128 (6,383 × 0.02) sea lion deaths would be attributed to shark predation. We have arbitrarily assigned all of these mortalities to natural mortality, but a small fraction (perhaps 2% of 1,666 = 33 sea lions) might be attributable to “additional” mortality.

Discussion

If our estimations are in the “ball park,” then the estimated “additional” Steller sea lion mortality that can be accounted for equals about 436 for identified anthropogenic sources. If we add 333 mortalities attributable to predation by killer whales and sharks (Table 4) that we consider unnatural mortality, then the total “additional” mortality is 769 Steller sea lions annually, or about 46% of the mortality above replacement. We subtracted this sum from the estimated mortality in 2001 (1,666) resulting in about 897 Steller sea lions that may die from an unknown source and possibly be attributable to environmental changes, the indirect effect of fisheries, or other factors yet to be recognized. However, if all predation remains in the “natural” mortality category then the anthropogenic source (436 sea lions) represents 26% of the “additional” mortality resulting in 1,230 (1,666–436) dead sea lions in the unknown source category. We also apportioned these values for unspecified cause of mortality geographically (Table 3).

If these estimates of “additional” losses are reasonable, the question then becomes whether it is possible to detect an improvement in the trajectory of the Steller sea lion population over the next 5–10 years. Our estimates of the various causes of mortality above replacement represent 26% and 46% of the 5% annual decline or 1.3% and 2.3% per year, respectively, over the range of the western stock. This leaves about 3.7% and 2.7% per year, respectively, attrib-

utable to other causes such as environmental change or commercial fisheries. To detect a significant improvement upon the 3.7% or 2.7% levels would be extremely difficult given present survey techniques and the haulout patterns of young sea lions. The aerial surveys conducted to monitor population status and trends will have to be redesigned to detect such a small rate of change over a specific time period (e.g. 5–10 years).

On a regional basis, detecting an improvement in the population trajectory could be very difficult. For example, if population stabilization (or increase) occurs (unlikely in the near term), then all the missing animals will be available to be counted. But more realistically, a slowing of the decline will occur and only a small portion of the sea lions estimated to be lost will survive. We also note that the rates of decline are not uniform in the western stock (Table 1) and that the probability of detecting an improvement in Steller sea lion trends would be greater in those areas where the decline is stronger and the population is larger. Thus, we suggest that the area where it is most likely that an improvement could be detected is the central Gulf of Alaska, followed by the eastern Gulf of Alaska and the western Aleutian Islands (Table 3).

Our estimates of known removals from the western Steller sea lion population do not fully explain the current decline. An interesting question is, that if our estimates of mortality are correct, then why are so few dead sea lions observed? Over 6,000 dead sea lions per year far exceeds our expectations of mortality based on the number of observed carcasses, yet we believe the values are correct given the present knowledge of Steller sea lion population status and trends.

To us the area of possible contention is not the level of mortality but the categorization and magnitude of mortality. As the difficulties of categorizing killer whale mortality exemplify, there are other important interactions among the causes of mortality. For example, if sea lions are nutritionally stressed, mortality from predation could increase because sea lions spend more time at sea searching for food. Similarly, mortality

from disease could increase because of greater nutritional stress or stress from avoiding predators.

Also puzzling is the population in southeastern Alaska which continues to increase even though it probably experiences similar types of removals from the same causes (except for subsistence harvests). As the western population continues to decline, mortality attributable to “additional” losses will become smaller and those attributable to known removals, if constant, become more important. Now that the western Steller sea lion non-pup population is less than 33,000 animals, known anthropogenic sources of mortality can explain about 26% of the missing sea lions (Table 4); if those numbers do not change, they could account for more of the missing sea lions in 20 years.

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