AN ACCOUNTING OF THE SOURCES OF STELLER SEA LION MORTALITY

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Abstract

During 1991-2000, the western stock of Steller sea lions (Eumetopias jubatus) declined at 5.2% (SE = 0.3%) per year. The population declined at statistically significant rates ($P < 0.10$) in all regions except the eastern Aleutian Islands. The greatest rates of declines occurred in the eastern and central Gulf of Alaska and the western Aleutian Islands (all greater than 8.6% per year). Using a published correction factor, we estimated the total population size of the western stock of Steller sea lions to be about 33,000 animals. Based on a published life table and the current rate of decline, we estimate that the total number of mortalities of non-pup Steller sea lions is about 6,425 animals; of those, 4,710 (73%) are mortalities that would have occurred if the population were stable, and 1,715 (27%) are additional mortalities that fuel the decline. We tabulated the levels of reported anthropogenic sources of mortality (subsistence, incidental take in fisheries, and research), guessed at 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 438 anthropogenic mortalities and 779 anthropogenic plus some predation mortalities as "mortality above replacement"; this accounted for 25% and 45 % of the estimated total level of "mortality above replacement." The remaining mortality (75% and 55%, respectively) was not attributed to a specific cause and may be the result of nutritional stress.

Introduction

The western stock of Steller sea lions (Eumetopias jubatus) is declining at about 5% per year and total population numbers have dropped by over 80% since the late 1960s (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 (NMFS). The cause of the decline is not known but likely has 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 1970s, and as U.S. fishery management changed during the mid-1970s and 1980s, 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 were considered inconsequential. However, as the 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. Our purpose here is to 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 count (NMFS, unpublished) on time. We also calculated the rate of decline by geographic region in the same way. 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 the number of 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 we would expect if the population instantly stabilized. If the population were stable, 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 declined at about 5.2% (SE = 0.3%) per year while the eastern stock in southeastern Alaska is increasing at about 1.7% (SE = 1%) per year during 1991-2000 (Table 1). The population declined at statistically significant rates ($P < 0.10$) in all regions except the eastern Aleutian Islands. The greatest rates of declines occurred in the eastern and central Gulf of Alaska and the western Aleutian Islands (all greater than 8.6% per year). Using a published correction factor, we estimated the total population size of the western stock of Steller sea lions to be about 33,000 animals. Our estimate of total annual mortality for a stable population is about 4,710 Steller sea lions in 2001 (Table 2). Our estimates of "additional" annual mortality, to account for the 5.2% rate of annual decline, suggest that in 2001 the declining western Steller sea lion population will lose about 1,715 animals above replacement ("additional" mortality). Thus for 2001 the total estimated mortality is about 6,425 Steller sea lions (Table 2). The additional mortality represents about 27% 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 624 animals in 2020.

Mortality is not uniform across the range but is likely to vary based on population distribution, predation and 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 (NMFS, unpublished) 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 assumes uniform mortality across Alaska and the second prorates the losses within each area based on the decline rates in Table 1. For each area, the two estimates of losses of Steller sea lions 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 and 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 since 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 man were "additional." We also decided that some portion of predation could also be unnatural. For instance, observations of killer whale predation have increased due to the large number of floating processors and factory trawlers that attract sea lions (and people who observe them). Killer whales are drawn to these ships to eat sea lions, and sea lions, in turn, are drawn there to consume fish products emitted as waste from the ship. 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. The Alaska Department of Fish and Game conducted studies to estimate subsistence use of Steller sea lions state-wide during 1992-1999 (Wolfe and Mishler 1997, Wolfe and Hutchinson-Scarbrough, 1999). 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 subsistence 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 ~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 and other groundfish. Some are taken in seine and gill net fisheries associated with herring or salmon 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., 1986.).

Shooting Steller sea lions was legal prior to passage of the Marine Mammal Protection Act (MMPA) in 1972 and estimates on the magnitude of the take vary widely. But even after MMPA restrictions were in place, fishers were allowed to shoot sea lions (and other marine mammals) that were destroying their gear or causing a threat to human safety. It was not until 1990 that a prohibition was implemented on the discharge of firearms near Steller sea lions. Recent court cases in Alaska testify to the fact that illegal shooting still occurs, but the overall magnitude of this source of mortality is difficult to evaluate. In January 2000, an Alaskan 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 found guilty of killing one sea lion. Estimates of mortality from shooting range from 1,180 in

1985 to zero (Trites and Larkin 1992). We believe the annual mortality level is at least 50 animals per year, but that is a guess on our part. However, even if illegal killing of sea lions is not a common occurrence, the magnitude of this mortality is exacerbated when sea lions are taken 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 but are the easiest targets for shooting. Killing young females which are just beginning to reproduce 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.

Steller sea lions may 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.

Predation by killer whales (<u>Orcinus</u> <u>orca</u>) and sharks may now be an important source of mortality and may exceed what was earlier considered "natural." Predation is often focused in small areas, e.g., 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 we tagged as pups in 1988 in the stomach of a single dead killer whale in Prince William Sound is well chronicled (Sauritus 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. 1994) suggest that 18% of all sea lion mortality could be attributed to killer whale predation. For the 2001 Steller population, this amounts to 848 sea lions in the nominally stable population (4,710*0.18) or 1,157 sea lions in the declining population (6425*0.18). Another approach is to assume that some portion of the predation is "additional." For this approach we estimated the difference in mortality due to killer whale predation between a stable population and a sea lion population declining at 5.2% as 309 animals (1157 - 848). Yet another approach is to take into account that the Barrett-Lennard et al. (1994) estimates were made in 1994 when there were approximately 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*4,710, or 1,119 sea lions. If killer whales have continued to eat the same number of sea lions, we could attribute the difference between 1,119 and 848 or 271 animals to "additional" mortality. This number is similar to 309 or 18% of above replacement losses. In Table 3 we tabulate killer whale predation as a range of possibilities.

Salmon sharks (<u>Lamna</u> <u>ditropis</u>) and Pacific sleeper sharks (<u>Somniosus</u> <u>pacificus</u>) have recently been implicated in Steller sea lion mortality. There are presently no estimates for this mortality but it is not considered by us 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 129 sea lion deaths would be attributed to shark predation. We have arbitrarily assigned all of these mortalities to natural mortality, but a small fraction (2% of 1,715 = 34 sea lions) might be attributable to "additional" mortality.

Discussion

If our estimations are in the "ball park", then the estimated "additional" mortality that can be accounted for sums to about 436 for identified anthropogenic sources. If we add 343 mortalities attributable to predation by killer whales and sharks that we consider unnatural mortality, then the total "additional" mortality is 779 Steller sea lions annually, or about 45% of the mortality above replacement. We subtracted this sum from the estimated mortality in 2001 (1,715) resulting in about 936 Steller sea lions that may die from an unknown source and possibly 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 25% of the "additional" mortality resulting in 1,279 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: is it 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 25% and 45% 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, attributable to other causes such as environmental change or commercial fisheries. To detect a significant improvement of 3.7% or 2.7% 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. It is interesting that if our estimates of mortality are correct, then why are so few dead sea lions observed? Over six thousand 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 population is less than 33,000 animals, known anthropogenic sources of mortality can explain about 25% of the missing sea lions (Table 4); if those numbers do not change, they would account for more of the missing sea lions in 20 years.

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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	Pr(>|t|)
Eastern Gulf of Alaska	-10.52	1.25	-8.416	<0.001
Central Gulf of Alaska	-8.63	0.75	-11.450	<0.001
Western Gulf of Alaska	-2.29	0.96	-2.378	0.063
Eastern Aleutian Islands	-1.75	1.11	-1.574	0.191
Central Aleutian Islands	-3.19	1.02	-3.144	0.035
Western Aleutian Islands	-9.08	1.83	-4.950	0.008
Western stock	-5.16	0.25	-20.389	<0.001
South eastern Alaska	1.70	0.95	1.796	0.147

Table 2. Projected counts of non-pup Steller sea lions at trend sites and estimates of the total population size for 2001-2020 in Alaska if trends continue as they have in 1991-2000; a 5.2% (SE - 0.25%) annual decrease in the western stock and a 1.7% (SE = 0.95%) annual increase in southeast Alaska (part of the eastern stock); projected counts were computed from a base of actual counts in 2000.

	Western Alaska Population					SE Alaska Population		
Year	Count	Estimated population	Additional losses	Stable population	Total mortalities	Count	Estimated population	Gain
2000	18325	33116				9862	17822	
2001	17376	31400	1715	4710	6425	10030	18143	321
2002	16476	29774	1627	4466	6093	10210	18469	327
2003	15622	28232	1542	4235	5777	10394	18802	332
2004	14813	26769	1462	4015	5478	10581	19140	338
2005	14046	25383	1387	3807	5194	10772	19485	345
2006	13318	24068	1315	3610	4925	10965	19835	351
2007	12628	22821	1247	3423	4670	11163	20193	357
2008	11974	21639	1182	3246	4428	11364	20556	363
2009	11354	20518	1121	3078	4199	11568	20926	370
2010	10766	19455	1063	2918	3981	11776	21303	377
2011	10208	18447	1008	2767	3775	11988	21686	383
2012	9679	17492	956	2624	3579	12204	22076	390
2013	9178	16586	906	2488	3394	12424	22474	397
2014	8702	15727	859	2359	3218	12648	22878	405
2015	8252	14912	815	2237	3051	12875	23290	412
2016	7824	14140	772	2121	2893	13107	23709	419
2017	7419	13407	732	2011	2743	13343	24136	427
2018	7035	12713	694	1907	2601	13583	24571	434
2019	6670	12054	659	1808	2467	13828	25013	442
2020	6325	11430	624	1714	2339	14076	25463	450

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 of column (a) and (b) represents the "additional" mortality that is not attributed to a specific cause (1,277 and 936 sea lions, respectively)

	Sea lion losses above replacement						
Region	% of 2000 survey	Proportional allocation	(a)	(b)	Proportional with regional decline	(a)	(b)
Eastern Gulf of Alaska	9.0%	154	39	70	403	103	183
Central Gulf of Alaska	18.7%	321	82	146	532	136	242
Western Gulf of Alaska	18.1%	310	79	141	126	32	57
Eastern Aleutian Islands	19.8%	340	87	154	130	33	59
Central Aleutian Islands	27.8%	477	122	217	335	86	152
Western Aleutian Islands	6.6%	113	29	51	189	48	86
Total	100.0%	1715	438	779	1715	438	779

[a]Assumes all predation is in the natural category

[b]Assumes some portion of predation is "additional" mortality. See text for explanation.

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 (1,715).

Source	Estimated mortality[a]	Estimated mortality[b]	As percent estimated mortality above replacement
Subsistence harvest	353	353	20.6
Incidental to fishing	30	30	1.7
Illegal shooting	50	50	2.9
Research	3	3	0.2
Predation by killer whales	0	309	0.0/18.0
Predation by sharks	0	34	0.0/2.0
Total	438	779	25.4/45.4

[a]Assumes all predation is in the natural category

[b]Assumes some portion of predation is "additional" to natural. See text for explanation.

Figure 1. Steller sea lion subareas within Alaska.