A comparison of Steller sea lion, *Eumetopias jubatus*, pup masses between rookeries with increasing and decreasing populations

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The Steller sea lion, *Eumetopias jubatus*, population in Alaska has decreased by 62% since the late 1970's (Merrick et al., 1987; Loughlin et al., 1992; Sease et al., 1993). Declines occurred at all 33 rookeries in the Gulf of Alaska and Aleutian Islands, although numbers at five rookeries in Southeast Alaska and Oregon increased. The severity of the declines at affected rookeries led the National Marine Fisheries Service (NMFS) to list the species as threatened throughout its range under the Endangered Species Act (1990). The proximate cause for the decline appears to be chronically reduced juvenile (ages 0–3 yr) survival. After the early 1980's, juveniles were in far lower abundance on rookeries than in the 1970's (Merrick et al., 1988; NMFS[1]). During the summers of 1987–88, 424 female pups were marked at the Alaska rookery on Marmot Island. According to the life table constructed for the area from data collected in the 1970's (York, 1994; Calkins and Pitcher[2]), close to 90 females should have survived to 1994. Biologists returning to the site from 1991 through 1994 have relocated less than 25 animals (NMFS[1]). York (1994) found that changes in the population size and the age structure of adult females were consistent with a decrease in juvenile survival. Also, the mass of juvenile animals in the 1980's was significantly less than that found in the 1970's (Calkins and Goodwin[3]).

The age when juvenile survival decreases remains unknown. One hypothesis is that early pup survival has decreased. Although numbers of pups observed dead on the rookeries have been consistently low during and immediately after the pupping season (NMFS[1]), it is difficult to measure early survival of Steller sea lion pups because carcasses rapidly disappear from rookeries (due to storms, tides, and scavengers). An alternative approach to counting dead pups is to study the potential survival of live pups found on the rookeries.

Pup mass provides useful information on juvenile survival because of the presumed relationship between mass and survival. Heavier juvenile mammals have a higher probability of survival than do lighter individuals for a variety of species including grey seals, *Halichoerus grypus*, wolves, *Canis lupus*, humans, *Homo sapiens*, Columbian ground squirrels, *Spermophilus columbianus*, and northern fur seals, *Callorhinus ursinus* (Coulson and Hickling, 1964; van Ballenberghe and Mech, 1975; Terrenato et al., 1981; Murie and Boag, 1984; Baker and Fowler, 1992). Weighing pups also has advantages over measurements of general condition (e.g. blood-based indices)—it is noninvasive, has minimal impacts on rookeries, and can provide a large, widespread

[1] National Marine Mammal Laboratory, National Marine Fisheries Service, 7600 Sand Point Way NE, Seattle, WA 98115. Unpubl. data, 1994.

[2] Calkins, D. G., and K. W. Pitcher. 1982. Population assessment, ecology, and trophic relationships of Steller sea lions in the Gulf of Alaska. *In* Environmental assessment of the Alaskan continental shelf, p. 455–546. Final Rep. 19 to OCSEAP (Outer Continental Shelf Environment Assessment Program).

[3] Calkins, D. G., and E. Goodwin. 1988. Investigations of the decline of Steller sea lions in the Gulf of Alaska. Unpubl. rep., 76 p. Available from National Marine Mammal Laboratory, 7600 Sand Point Way NE, Seattle, WA 98115.

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sample size at minimal cost (when incorporated into other research).

Our hypothesis was that if the cause of the decline affected the health of pups, then pups should be smaller at rookeries with declining populations than at rookeries with increasing populations. We examined this hypothesis by comparing the masses of pups weighed during 1987–94 at rookeries documented as having either increasing (Oregon and Southeast Alaska) or decreasing (Gulf of Alaska and Aleutian Island) populations (NMFS[4]). In this note, we present our analyses of sex-based and temporal variability in pup masses, compare masses obtained from the two groups of rookeries, discuss potential sources of bias in the mass measurements, and conclude with a comment on the possible source(s) of the observed differences in pup masses.

Methods

Data collection

Steller sea lion pupping is synchronous from central California to the Aleutian Islands (Bigg, 1985; Merrick, 1987). The median pupping date is 12–13 June; viable births begin in late May and continue through the end of June. We weighed pups from 26 June to 8 July, before pups were sufficiently mobile to escape into the water, as part of pup censuses conducted at the rookeries. Pups aggregated into small pods (10–20 pups each) after adult animals had been cleared from the rookery during the census. Individuals in a pod were captured by hand, sexed, tagged on both foreflippers, bagged into a hoop net, and weighed to the nearest kilogram. Lengths were not measured because of the difficulty in obtaining precise measurements from pups that have not been anesthetized. The first pod selected was typically at the fringe of the rookery and subsequent pods were selected from areas progressively closer to the center of the rookery. Pods were sampled until the desired sample size (usually 50 pups per site) was reached.

A total of 1,245 Steller sea lion pups (616 females and 629 males) were weighed at twelve rookeries (Table 1; Fig. 1) in four areas during 1987–94 in Oregon, Southeast Alaska, the Gulf of Alaska, and the Aleutian Islands. During 1987–94, populations at the Oregon and Southeast Alaska sites increased 5–15%, whereas populations at the Gulf of Alaska and Aleutian Island sites decreased 20–50% (Table 1) (Loughlin et al., 1992; Sease et al., 1993; NMFS[4]).

Data analysis

Differences in mean mass by sex of pup were analyzed for each site separately and then for the whole data set. All subsequent analyses were performed separately for each sex.

Short-term interannual variation (during 1987–94) in mean pup mass was tested separately for one rookery in each of three geographic areas—Rogue Reef (Oregon), Marmot Island (Gulf of Alaska), and Ugamak Island (Aleutian Islands). For each of these sites the weight of pups was measured on roughly the same day for two or three years (Table 1). Long-term interannual variation was tested separately for the Sugarloaf and Marmot Island rookeries by comparing their 1992–93 masses with data collected by

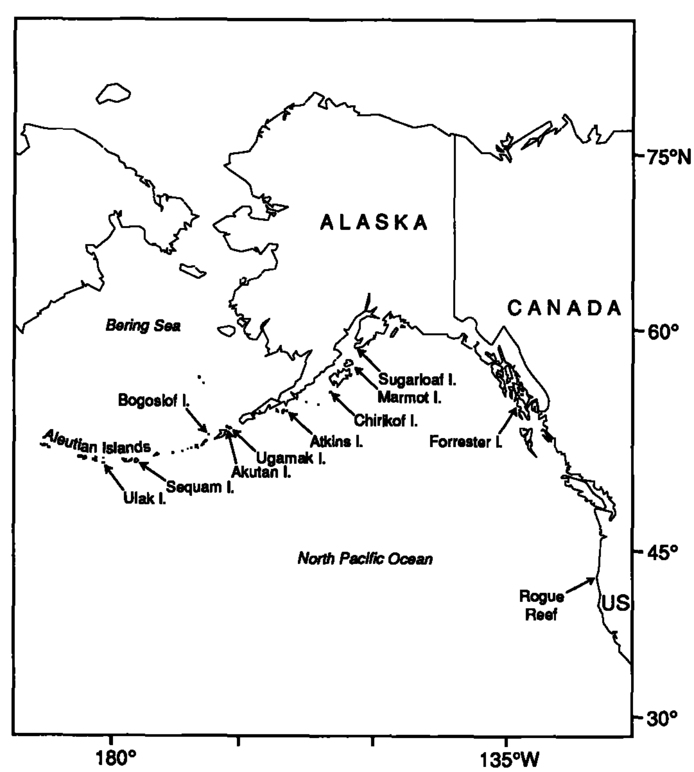

Figure 1
Steller sea lion, *Eumetopias jubatus*, rookeries at which pups were weighed during 1965–94.

[4] NMFS. 1995. Status review of the Steller sea lion (*Eumetopias jubatus*). Unpubl. rep, 120 p. Available from National Marine Mammal Laboratory, 7600 Sand Point Way NE, Seattle, WA 98115.

Table 1

Steller sea lion, *Eumetopias jubatus*, mean pup masses (kg) by date, sex, and rookery, collected during 1987–94. *n* indicates number of pups weighed, and SD indicates standard deviation of the mean value. *T*-value represents the Student's *t* calculated for the comparison of male and female masses for the site and year combination. All *t*-tests were significant at $P<0.01$.

		Female mass			Male mass			
Site	Weighing date	*n*	Mean (kg)	SD	*n*	Mean (kg)	SD	*t*-value
Oregon								
Rogue Reef	30 Jun 1987	56	20.70	3.39	44	24.90	3.33	6.20
	29 Jun 1888	46	20.00	3.38	54	23.40	3.66	4.79
	7 Jul 1990	20	21.38	2.90	25	23.88	3.85	2.41
SE Alaska (Forrester Island Complex)								
North Rock	28 Jun 1990	56	24.10	3.03	49	26.40	4.69	3.02
Cape Horn Rock and Lowrie	29 Jun 1990	64	25.70	3.31	70	29.60	4.89	5.36
Gulf of Alaska								
Sugarloaf	1 Jul 1992	23	23.30	3.57	27	27.30	3.88	5.84
Marmot	30 Jun 1987	89	25.40	3.68	60	29.20	4.20	2.81
	30 Jun 1988	29	26.40	4.05	21	29.70	4.16	3.54
	8 Jul 1993	19	29.70	5.51	32	35.60	5.89	3.77
Chirikof	26 Jun 1990	27	22.20	3.18	34	28.00	4.60	5.50
Atkins	30 Jun 1991	24	28.40	3.70	26	31.60	4.60	2.70
Aleutian Islands								
Ugamak	2 Jul 1990	28	27.40	3.70	22	32.50	6.70	3.42
	3 Jul 1991	25	30.30	3.60	25	36.40	4.30	5.44
	3 Jul 1993	15	28.10	4.05	35	33.90	5.57	3.63
Akutan	7 Jul 1992	20	31.80	4.72	30	37.80	5.75	3.87
Bogoslof	5 Jul 1990	23	28.70	3.90	27	36.00	5.60	5.26
Seguam	27 Jun 1994	27	26.98	5.00	23	35.51	4.96	6.01
Ulak	3 Jul 1994	25	30.44	4.28	25	38.50	5.53	5.79

Alaska Department of Fish and Game (ADF&G[5]) in 1965 and 1975 (Table 2; ADF&G). To our knowledge, these are the only data on pup size that have been collected prior to our study.

Variation in mean pup mass within the 26 June–8 July weighing period was analyzed for Oregon, the Gulf of Alaska, and the Aleutian Islands by using a linear regression of the natural log of mean mass from a weighing against weighing day. Significance and equality of slopes of the regressions were tested with a Student's *t*-statistic.

Mean pup masses collected for the 26–30 June period were compared for the Oregon, Southeast Alaska, and Gulf of Alaska regions by using Student's *t*-statistic. Means and standard errors were calculated for each area's weighings by treating each weighing as a separate strata; calculations were performed by methods of stratified random sampling (Cochran, 1977). Mean pup masses obtained from the Gulf of Alaska and Aleutian Islands were compared by using an analysis of covariance (with weighing day as the covariate) because of the 14-day spread in weighing days at these locations. Note that to use an analysis of covariance, the slopes of the regression of mass against weighing date were first compared for the Gulf of Alaska and Aleutian Islands to ensure homogeneity of slopes.

Results

Male pups ($\bar{x}$=30.5 kg, standard error [SE]=0.3) were significantly heavier (t=318.8, P<0.01) than female pups ($\bar{x}$=26.2 kg, SE=0.212) for all sites combined. Males were also significantly heavier at all individual rookeries in all years sampled (Table 1; P<0.01).

The only significant interannual variation in mean pup masses for 1987–94 was for female pups at Ugamak Island (F=4.15, P=0.04). No significant inter-

[5] Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, AK 99518. Unpubl. data, 1976.

annual differences were found in mean female mass at the other three sites or in male masses at any site. Both female (F=8.6, P<0.01) and male (F=12.9, P<0.01) pups weighed at Marmot Island in 1993 were significantly heavier than pups weighed at the rookery in 1975, though the weighings occurred a week later in 1975. Mean mass of pups weighed at Sugarloaf Island in 1965, 1975, and 1992 were not significantly different for either female (F=3.1, P=0.1) or male (F=1.3, P=0.5) pups. However, two of the 1965 and 1975 weighings were conducted two weeks later than the 1992 weighing.

Table 2

Steller sea lion, *Eumetopias jubatus*, pup masses (kg) by date, sex, and rookery, collected during 1965 and 1975 at Sugarloaf and Marmot Islands in the Gulf of Alaska. *n* indicates number of pups weighed, and SD indicates standard deviation of the mean value.

		Female mass			Male mass		
Site	Weighing date	*n*	Mean (kg)	SD	*n*	Mean (kg)	SD
Sugarloaf	1 Jul 1965	7	19.70	2.27	13	24.90	2.73
	14 Jul 1965	9	23.80	3.13	11	29.30	5.83
	13 Jul 1975	16	23.90	3.04	35	27.40	6.99
Marmot	17 Jul 1975	21	25.30	3.92	29	30.80	4.35

Mean male mass increased significantly in the Gulf of Alaska during the 26 June–8 July weighing period (t=2.9, P=0.05, r^2=0.68). However, there was not a significant relationship between weighing day and mean mass for males in Oregon or the Aleutian Islands, nor for females in any of the three geographic areas. The slopes of the regression of mean pup mass against weighing day were not significantly different for the Gulf of Alaska and Aleutian Islands for female (t=0.26, P>0.5) and male (t=0.57, P>0.5) pups.

Mean mass increased significantly for both sexes from Oregon to Southeast Alaska to the Gulf of Alaska and Aleutian Islands. Oregon female (t=105.1, P<0.01) and male (t=79.3, P<0.01) pups were significantly lighter than their counterparts in Southeast Alaska (Fig. 2). Mean mass of Southeast Alaska female (t=29.4, P<0.01) and male (t=36.9, P<0.01) pups was significantly less than that of Gulf of Alaska pups. Gulf of Alaska female and male pups were both significantly lighter than Aleutian Island female (F=6.0, P=0.03) and male (F=16.3, P<0.01) pups.

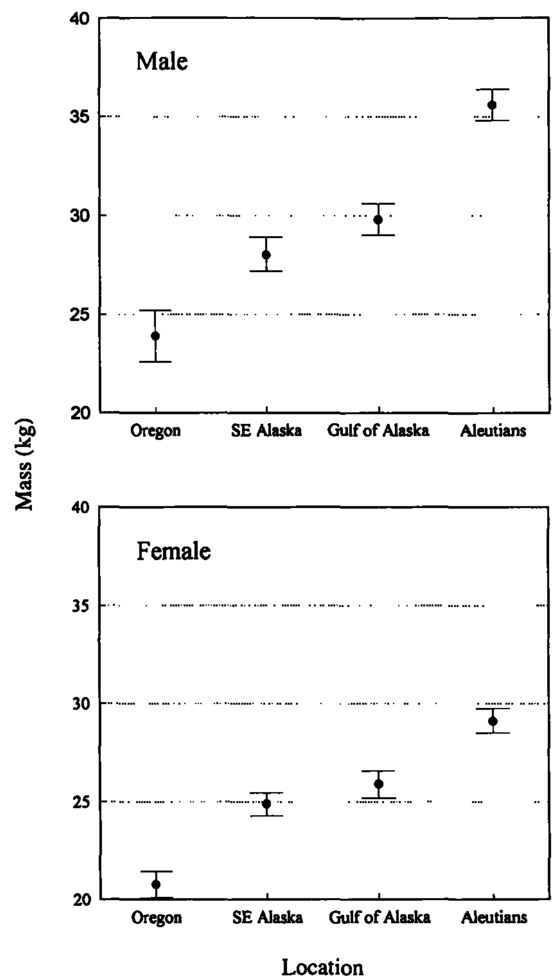

Figure 2

Steller sea lion, *Eumetopias jubatus*, mean pup masses (kg) by sex and area during 1987–94. Error bars represent 95% confidence intervals around the mean.

Discussion

Our expectations in this study were either that there would be no significant differences in mean pup mass between rookeries or that pups at rookeries with declining populations would be smaller than pups at rookeries with increasing populations. Considerable research by scientists at NMFS, ADF&G, and other research facilities has focused on comparing the condition of pups between Southeast Alaska and the Gulf of Alaska, because it has been assumed that the opposing population trends in the two areas were a result of some limiting factor (e.g. lack of food or disease) affecting only the Gulf of Alaska population, and that this factor could be expressed in the condition of the pups.

We were surprised to find that pups were heavier at rookeries with decreasing populations (i.e. in the Gulf of Alaska and Aleutian Islands) than at rookeries with increasing populations (i.e. in Southeast Alaska and Oregon). We were also surprised to find that mean pup mass at Marmot and Sugarloaf Island in 1992–93 was equal to or greater than that of pups weighed at the sites in 1965 and 1975 (prior to the onset of the decline).

The implications of these findings to the search for the ultimate cause of the Alaskan Steller sea lion population decline are twofold. First, the large size of pups in the areas of declining population suggests that pup condition is not compromised in the first month postpartum and that the factor reducing juvenile survival acts after the neonatal period. Second, the larger pup size in declining populations implies that pregnant and early postpartum females in those populations are not having difficulty finding prey.

We have considered possible biases that could have influenced these results (Trites, 1991). Some bias may be associated with the unknown birth date of the pups weighed. To obtain masses of known-age animals, it is necessary to capture pups soon after birth. The cost of obtaining a large, geographically representative sample by such an approach is prohibitive. Such an approach would increase the mortalities of weighed pups (due to abandonment), would greatly disrupt the rookeries (days of repeated captures would be necessary), and would be very expensive. Because pupping is synchronized throughout the range, a random selection of pups from each site during the same time period should provide samples that are representative of the same age structure.

A biased sample could also result if pups were not selected at random. Lighter pups have been selected from pup pods by handlers in some studies of northern fur seal pups (Roppel et al.[6]). However, all pups from a pod were weighed in our study. A bias could still remain if pup mass varied systematically through the rookery (e.g. smaller pups aggregated at the periphery, larger pups in the center), or if pups aggregated by size within the rookery. We selected pups from pods at both the periphery and the center of rookeries. In addition, pups at the time of the weighings had not yet begun to group together. The lack of significant interannual variation during this study indicates that the bias was (if present) consistent over time.

The variation in mean pup mass at rookeries and between the 1970's and the present appears to be real and could be explained in several ways. First, the increase of two years in the average age of Gulf of Alaska adult females since 1976–78 (York, 1994) has probably increased the average size of reproducing female sea lions (Calkins and Pitcher[2]). Northern fur seal data suggest that larger females produce larger pups (NMFS[4]). If Steller sea lions are similarly affected, then the increase in mean size of pups in the Gulf of Alaska since 1976–78 would be partly due to the increased average size of reproducing females. There are no data on female age or size from Southeast Alaska or Oregon with which to evaluate the contribution of this factor to differences between geographic areas. In addition, the larger size of pups in the Gulf of Alaska to Aleutian Island area could be a phenotypic expression of the genetic differences found between this area and the Southeast Alaska to Oregon area (Bickham et al., in press). Finally, the greater mass of pups at rookeries with reduced populations could be a density-dependent response to reduced competition among adult females for food. Studies of the foraging effort of postpartum females currently being conducted in Southeast Alaska and the Gulf of Alaska will be useful in testing this hypothesis.

[6] Roppel, A. Y., P. Kozloff, and A. E. York. 1981. Population assessment, Pribilof Islands: pup weighing. *In* P. Kozloff (ed.), Fur seal investigations, p. 16–21. U.S. Dep. Commer., NOAA, Nat. Mar. Fish. Serv., Northwest Alaska Fish. Sci. Cent. Processed Rep. 81-2.

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