Pollock Conservation Cooperative Research Center

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Changes in Steller Sea Lion Skull Sizes: Testing the Nutritional Stress and Killer Whale Predation Hypotheses

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INTRODUCTION

The two leading hypotheses to explain the decline of Steller sea lions between Prince William Sound and Hokkaido Japan are that 1) they were removed by killer whales, and 2) they died of nutritionally related effects associated with consuming large amounts of low energy prey (i.e., pollock; DeMaster and Atkinson 2002; Trites and Donnelly 2003)

There is compelling evidence supporting both hypotheses. However the evidence is limited in a number of aspects. The killer whale hypotheses for example is supported largely by a mathematical model showing that it is theoretically possible for a small number of whales to have eaten a large number of sea lions (Barrett-Lennard et al. 1995). Efforts are underway to collect the basic information needed to validate the model (i.e., estimates of killer whale numbers, proportion of sea lions in their diets, and energetic needs; Matkin et al. 2007). The nutritional stress hypothesis is similarly limited by a paucity of data (Trites and Donnelly 2003). For the most part the evidence supporting the hypothesis comes from a single sample of sea lions shot in the 1970s and a second sample of animals shot in the 1990s (Calkins et al. 1998). Virtually no information was collected in the field since the late 1980s to further test this hypothesis (Trites and Donnelly 2003).

Our proposal to PCCRC was to measure the sizes of Steller sea lion skulls (1950s to present) housed by NMFS, the University of Alaska, the California Academy of Sciences, and BC Royal Victoria Museum to determine whether body size changed as sea lions declined and whether the changes are consistent between the eastern and western Pacific. We proposed to use these data to test whether changes in body size are consistent with nutritional stress hypothesis or with the killer whale predation hypothesis.

This report summarizes our expenditure and progress on scheduled tasks outlined in our project proposal. The delay we originally experienced in receiving funds to start this study meant that we lost our window of opportunity to dedicate uninterrupted time for travel, measurement, and analyses. As a result, one of the Principal Investigators (T. Isono) took a full time job, and has been subsequently taking leave and holiday time to complete our study.

Our main focus during this reporting period has been to purchase necessary supplies, complete the measurements of skulls, and undertake a preliminary analysis of the data.

PROGRESS OF SCHEDULED TASKS

a) Data collection

We identified several hundred Steller sea lion skulls at various institutions for measurements (Miller et al. 2005). T. Isono visited the following museums and institutes to measure Steller sea lion skulls from late May to late September:

Hokkaido University Faculty of Fisheries, Hakodate, Japan

California Academy of Sciences, California, USA

Raymond Bandar (personal), California, USA

Museum of Vertebrate Zoology, University of California, California, USA

University of British Columbia, Vancouver, Canada

Royal British Columbia Museum, Victoria, Canada

National Marine Mammal Laboratory, NOAA, Seattle, USA

Museum of the North, University of Alaska, Fairbanks, USA

Tetsuro Itoo (personal), Gifu, Japan

National Science Museum, Tokyo, Japan

Dr. Isoto used calipers to measure the lengths of 60 structures on each skull for both sexes and all age groups (accuracy was 0.1mm). The best measure of skull length was condylobasal length (CL).

Ages of skulls (from sectioned teeth) were not available for all of the available specimens. We therefore estimated the relative ages of skulls using a suture index, whereby 9 sutures (Fig.1) were assigned a value between 1–4, according to degree of closure (1=suture fully open; 2=less than half-fused; 3=more than half-fused; and 4=completely fused). These values were then added to provide an overall suture index, ranging from 9–36 (Sivertsen 1954). Comparing the relative age of skulls from the suture index, with the actual age from those with sectioned teeth revealed a significant correlation. Thus we were able to assign an age to all skulls measured.

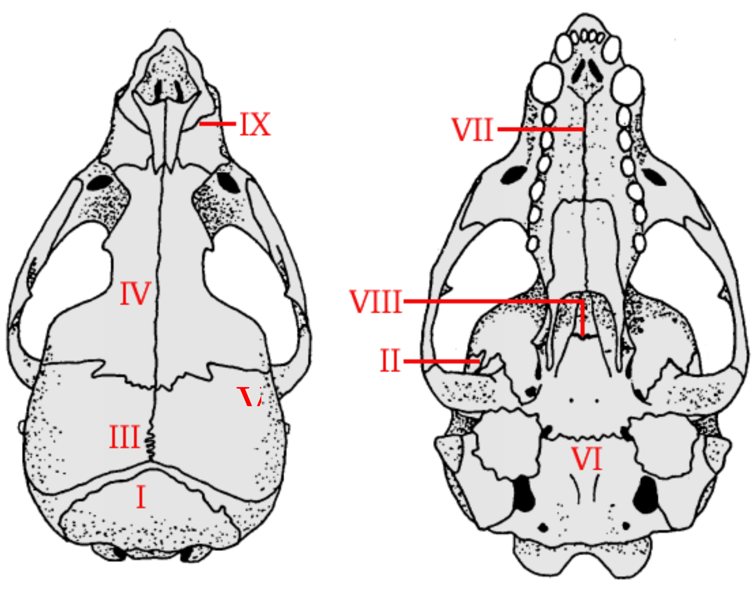

Figure 1. Sutures used to estimate relative age of fur seals: I = occipito-parietal; II = Squamoso-parietal; III = interparietal; IV = interfrontal; V = coronal; VI = basioccipito-basispehnoid; VII = maxillary; VIII = basisphenoid-presphenoid; IX = premaxillary-maxillary.

Table 1. Number of skulls measured by relative age (Suture Index) and region of collection (A. Asia, B. Bering Sea, Aleutians, Gulf of Alaska, and C. California to SE Alaska).

Area A, Male																											
Suture Index	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	Total
Before 1976	3	4	1	2	2		2	2	2	1	1	4		1	1		2	2	1	2	2			1	1	1	38
After 1977	4	6	6	8	7	3	8	1	5	2	2		5	2		3		1	2	1	2	1		1			70
Total	7	10	7	10	9	3	10	3	7	3	3	4	5	3	1	3	2	3	3	3	4	1	0	2	1	1	108
Area B, Male																											
Suture Index	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	Total
Before 1976	8	3	3	4	5	3	5		4	1	1	3	2	2	1	3				1			1	2	1		53
After 1977	21	8	4	4	3	5	2	1			1		1	2		1		1		2	1	2					59
Total	29	11	7	8	8	8	7	1	4	1	2	3	3	4	1	4	0	1	0	3	1	2	1	2	1	0	112
Area C, Male																											
Suture Index	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	Total
Before 1976	11		2			1	3	1			1	3	1			2		1		1	1	1	2	1	2	1	35
After 1977	8					1	2	2	1	3	2		1	2	2	2	1								1		28
Total	19	0	2	0	0	2	5	3	1	3	3	3	2	2	2	4	1	1	0	1	1	1	2	1	3	1	63
Area A, Female																											
Suture Index	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	Total
Before 1976	3		4	1	3	1	1	1	2	2	2		1		2	1	1	1		1			1		1		29
After 1977	2	1	5	5	3	4	5	5	4	4	13	12	4		1	2	4	2	2	5	3	2	2	1	1		92
Total	5	1	9	6	6	5	6	6	6	6	15	12	5	0	3	3	5	3	2	6	3	2	3	1	2	0	121
Area B, Female																											
Suture Index	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	Total
Before 1976	7	4	5	1	4	1	3	2	5	2	8	6	2	7	4	5	3	1	1				1				72
After 1977	6	4	5	4	3	2	5	3	1		2	1				1				1							38
Total	13	8	10	5	7	3	8	5	6	2	10	7	2	7	4	6	3	1	1	1	0	0	1	0	0	0	110
Area C, Female																											
Suture Index	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	Total
Before 1976	12	2	2				2	1		3	3	2		2	2		1	2		1	3	6	3	4	1		52
After 1977	9		1		3	1	1	2		2	1	1	2		1	2	1			1		2					30
Total	21	2	3	0	3	1	3	3	0	5	4	3	2	2	3	2	2	2	0	2	3	8	3	4	1	0	82

A total of 691 skulls (343 males, 345 females, and 3 unknown) were obtained, but only 597 (283 males and 314 females and) had information about sex, place of capture, location, suture index, and condylobasal length (Table 1). Of thee skulls, only 333 were intact so that all 60 parts could be measured (152 males and 181 females).

Skulls were geographically grouped according to genetic stock discrimination into three: Asia, Western (Aleutian Islands and Gulf of Alaska) and Eastern (Southeast Alaska to California).

Growth models were fit to log transformed length data using a stepwise regression procedure (Myers 1990), Growth curves were calculated for animals that grew prior to the 1976/1977 oceanic regime shift, and were compared with growth that occurred following the regime shift while the sea lion population declined. Preliminary results indicate that females became larger following the regime shift in Asia and Western Alaska, as did males in Western Alaska. However, no difference was detected over time in the Eastern population.

The increase in growth we detected following the regime shift runs counter to the conclusion of Calkins et al. (1998) that Steller sea lions became smaller.

In addition to calculating growth curves, we also calculated an index of directional asymmetry. Stress factors known to distort the symmetry of skulls include various chemicals, including pesticides (Valentine and Soule 1973), polluted habitats (Weiner and Rago 1987), extreme temperatures (Parsons 1962; Siegel and Doyle 1975; Sciulli *et al.* 1979), audiogenic stress (Sciulli *et al.* 1979), and food deficiency either in terms of quality or quantity (Parsons 1990). Asymmetry in the skeletal traits of offspring can also be caused by severe restrictions in the availability of nutrients to females during pregnancy (Sciulli *et al.* 1979).

The lengths of 6 skull features were measured on the left and right sides of the skull. An index of directional asymmetry (DA) was calculated according to Galatius and Jespersen (2005) as DA= [2(left-right)/(left+right)]*100

The value of DA is positive if the skull turns right, and is negative if it turns left.

Preliminary analysis indicates that the Steller sea lion face tends to turn and lean towards the right. The most significant directional asymmetry was found in Asia, and is consistent with the higher levels of contaminants reported for the tissues of sea lions sampled in this region.

FOCUS OF WORK OVER THE NEXT 12 MONTHS

Dr. Isono will spend two weeks with Dr. Trites and the University of British Columbia in April to review all analyses and prepare a draft manuscript for publication in a peer reviewed journal. Dr. Brunner will assist with revisions and will provide guidance regarding analysis and interpretation of the data.

Further analyses will be undertaken to determine why our preliminary findings differ from those of Calkins et al. (1998). Data will be further partitioned to test for differences in variance (as well as means). We will also stratify the location of kills to directly compare our skull measurements for the same locations where Calkins et al collected their samples. Finally, we will determine which of the hypotheses proposed to explain the decline of Steller sea lions is most consistent with our findings.

We expect to have a manuscript submitted to a scientific journal for peer review by September 2007.

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