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E. E. Holmes, L. W. Fritz, A. E. York, and K. Sweeney. 2007. Age-structured modeling reveals long-term declines in the natality of western Steller sea lions. *Ecological Applications* 17:2214-2232.

Appendix C. Life-history matrices.

The structure of the 32 x 32 female-only age-structured life-history matrix for Steller sea lions (**A** in Eq. 3 in the main text) is shown in Table 1 (main text). The matrix is a birth-pulse Leslie matrix where row 1 column *i* is the number of 1-month old pups produced by age *i*+1 females multiplied by the survival rate from age *i* to age *i*+1. Thus when the matrix multiplication, $\mathbf{N}_{t+1} = \mathbf{A} \cdot \mathbf{N}_t$, is performed, the first element of $\mathbf{N}_{t+1}$ is the female pup numbers (at 1-month of age) in year *t*+1. Pups at age of 1-month are termed "age 0". Rows *i*, *i* > 1, in the matrix contain the survivorships from age *i-1* to *i*, along the diagonal. The s_i and f_i terms in **A** have been estimated different ways in different published studies based on data from 1975 to1978 on Marmot Island. These different estimates give rise to the four different life-history matrices that are compared in this study. Three of these matrices, **WT**, **CP** and **Y** are from previously published analyses. We made some slight modifications to these published matrices . First, a linearly increasing juvenile survivorship pattern was used for all matrices so that s_0, which is age 0-1 survival, was specified and then s_1 and s_2 were determined by a linear interpolation between s_0 and s_3 survival. Second, we explicitly included neonate survivorship. The number of female 1-month old pups produced by females of age *i*, was set equal to the late-term pregnancy rate, f_i, times 0.5 to get female fetuses only, multiplied by s_n, the neonate survivorship from late-term fetus to age 1-month when the pup survey occurs. This s_n was estimated as 0.949 from the average of the fraction of dead pups observed during the 1978 and 1979 pup counts in the CGOA: 492 (dead) to 6720 (live) in 1978 and 526 (dead) to 14763 (live) in 1978. The other s_i and f_i terms, which specify the survivorship and fecundity schedule for each matrix, were the same as in the published matrices and are shown in Table C1. The final **A** matrix is given by putting the s_i and f_i terms in Table C1 into Table 1 in the main text. For reference, each **A** matrix is supplied as tab delimited files in the supplement.

A matrix based on Calkins and Pitcher (1982) – **CP** *matrix*

For this matrix, the survivorships, s_i, were those estimated originally by Calkins and Pitcher (1982) as presented in their Table 24. These estimates are from the age-distribution observed in the longitudinal sample of Steller sea lions around Marmot Island in the 1970s, which was done by shooting a random sample of animals from the population. Given their smaller size and lack representation near rookeries, individuals younger than 3 years were not equally sampled and were excluded from the analyses. Age was determined by counting the enamel layers in cross-sections of the canine teeth, and pregnancy rates were determined from pregnancies observed in the sampled females. The survivorships in Table C1 are taken from York (1994) Table 1 with the exception of s_0, s_1 and s_2. Juvenile survivorship could not be estimated directly from the data. Instead, York (1994) and Calkins and Pitcher (1982), set juvenile survivorship such that the resulting matrix would be stable (maximum eigenvalue equals 1.0). York (1994) made juvenile survivorship equal for the 1st three years while Calkins and Pitcher (1982) had juvenile survivorship increasing with age. In this analysis, we used Calkins and Pitcher's method, which eliminates a sudden jump from older juvenile survival to young adult survival. Thus s_1 and s_2 increase linearly from s_0 towards s_3, and s_0 is set so that the matrix is stable. Late-term pregnancy rate, f_i, is based on 'percent mature' x 'birth rate' in Table 26 in Calkins and Pitcher (1982) x 0.5 pup sex ratio. 'birth rate' reported in Calkins and Pitcher (1982) is not actually birth rate, however, rather it is late-term pregnancy rate. The f_i given in Table C1 are from Table 1 in York (1994). Note that the age or *i* column in both York (1994) and Calkins and Pitcher (1982) is confusing since it signifies the age at which females become pregnant; they do not give birth until the next year. Early maturing females first become mature at age 3 but give birth at age 4, so f_i is 0 for age 0-3. The **CP** matrix is provided in the tab delimited text file, CP_matrix.txt, in the supplement.

A generic Steller sea lion matrix based on Calkins and Pitcher (1982) – ***WT*** *matrix*

Winship and Trites (2006) used a very generic model of Steller sea lions based on the Calkins and Pitcher survivorship and fecundity schedules. The matrix has high adult survivorship, lower age 1-3 survivorship, and a uniform late-term pregnancy rate after age 5 (Table C1). For this study, we changed juvenile survivorship so that juvenile survivorship increased linearly from s_0 to s_3 as for the other matrices. No animals are allowed to live beyond age 20 in the **WT** matrix. The **WT** matrix is provided in the tab delimited text file, WT_matrix.txt, in the supplement.

Matrix based on York (1994)'s re-analysis of survivorship rates – ***Y*** *matrix*

The Calkins and Pitcher (1982) survivorships result in an equilibrium age-distribution that does not precisely fit the observed age-distribution. York (1994) re-estimated the age-specific survivorships using a Weibull hazard model which is a standard model for survivorship. The re-estimated survivorships result in an age-distribution that closely matches the observed cumulative age-distribution in the 1975-1978 sample off Marmot Island. Table C1 gives the re-estimated survivorship schedule from Table 1 in York (1994).

There are two differences between the matrix used in this paper and the matrix published in York (1994) in Table 1 in that paper. York (1994) made juvenile survivorship equal for the 1st three years. Here, we used Calkins and Pitcher's method and allowed juvenile survivorship to increase with age. Thus s_1 and s_2 were set to increase linearly from s_0 towards s_3, and s_0 adjusted so that the matrix is stable. The second difference is in the f_i terms. In the matrix described in York (1994), females erroneously give birth the year that they become pregnant, whereas in actuality, females give birth the year after becoming pregnant. Thus the f_i terms should be shifted forward by one year. This same error appears in the matrix given in Holmes and York (2003). This error does not change the conclusions of either paper, although it does change slightly the estimated natality rate in Holmes and York (2003). The **Y** matrix is provided in the tab delimited text file, Y_matrix.txt, in the supplement.

Matrix based on a re-analysis of the pregnancy rates – **HFYS** *matrix*

For this paper, we re-analyzed the pregnancy data from the late-1970s Marmot samples. This analysis is discussed in the main text. The resulting fecundity schedule includes fecundity senescence and fits the observed late-term pregnancy data better. The survivorship schedule is the same as for the York (1994) matrix. The **HFYS** matrix is provided in the tab delimited text file, HFYS_matrix.txt, in the supplement.

REFERENCES

Calkins, D. G., and K. W. Pitcher. 1982. Population assessment, ecology and trophic relationships of Steller sea lions in the Gulf of Alaska. Final Report 17, U.S. Department of Commerce, Washington, D. C.

Holmes, E. E., and A. E. York. 2003. Using age structure to detect impacts on threatened populations: a case study using Steller sea lions. Conservation Biology **17**:1794-1806.

Winship, A. J., and A. W. Trites. 2006. Risk of extripation of Steller sea lions in the Gulf of Alaska and Aleutian Islands: a population viability analysis based on alternative hypotheses for why sea lions declined in Western Alaska. Marine Mammal Science **23**:124-155.

York, A. E. 1994. The population dynamics of northern sea lions, 1975–1985. Marine Mammal Science **10**:38–51.

Table C1. Fecundity and survivorships terms used in the four life-history matrices. Matrix codes refer to matrices based on different papers: **WT** (Winship and Trites 2006), **CP** (Calkins and Pitcher 1982), **Y** (York 1994), and **HFYS** (this paper). In all matrices, s_n = 0.949. This table is provided as a tab delimited text file, tableC1.txt, in the supplement.

i age	f_i **WT**	f_i **CP**	f_i **Y**	f_i **HFYS**	s_i **WT**	s_i **CP**	s_i **Y**	s_i **HFYS**
0*	0	0	0	0	0.8001[3]	0.7625[3]	0.7895[3]	0.8060[3]
1	0	0	0	0	0.8334[3]	0.7977[3]	0.8364[3]	0.8474[3]
2	0	0	0	0	0.8667[3]	0.8328[3]	0.8833[3]	0.8888[3]
3	0	0	0	0	0.9	0.8680[1]	0.9302[1]	0.9302[1]
4	0	0.1008[1]	0.1008[1]	0.0480[2]	0.9	0.8790	0.9092	0.9092
5	0	0.17955	0.17955	0.1695	0.9	0.8880	0.8951	0.8951
6	0.315	0.26145	0.26145	0.2215	0.9	0.8930	0.8839	0.8839
7	0.315	0.315	0.315	0.27950	0.9	0.8980	0.8746	0.8746
8	0.315	0.315	0.315	0.3285	0.9	0.8740	0.8665	0.8665
9	0.315	0.315	0.315	0.3285	0.9	0.8990	0.8593	0.8593
10	0.315	0.315	0.315	0.3285	0.9	0.8930	0.8527	0.8527
11	0.315	0.315	0.315	0.385	0.9	0.8960	0.8468	0.8468
12	0.315	0.315	0.315	0.385	0.9	0.8950	0.8412	0.8412
13	0.315	0.315	0.315	0.385	0.9	0.8950	0.8360	0.8360
14	0.315	0.315	0.315	0.385	0.9	0.8950	0.8312	0.8312
15	0.315	0.315	0.315	0.385	0.9	0.8950	0.8266	0.8266
16	0.315	0.315	0.315	0.385	0.9	0.8950	0.8223	0.8223
17	0.315	0.315	0.315	0. 2570	0.9	0.8950	0.8182	0.8182
18	0.315	0.315	0.315	0.2570	0.9	0.8950	0.8142	0.8142
19	0.315	0.315	0.315	0.2570	0.9	0.8950	0.8105	0.8105

20	0.315	0.315	0.315	0.2570	0	0.8950	0.8069	0.8069
21	0.315	0.315	0.315	0.2570	0	0.8950	0.8034	0.8034
22	0	0.315	0.315	00	0	0.8950	0.8001	0.8001
23	0	0.315	0.315	0	0	0.8950	0.7968	0.7968
24	0	0.315	0.315	0	0	0.8950	0.7937	0.7937
25	0	0.315	0.315	0	0	0.8950	0.7907	0.7907
26	0	0.315	0.315	0	0	0.8950	0.7878	0.7878
27	0	0.315	0.315	0	0	0.8950	0.7850	0.7850
28	0	0.315	0.315	0	0	0.8950	0.7822	0.7822
29	0	0.315	0.315	0	0	0.8950	0.7795	0.7795
30	0	0.315	0.315	0	0	0.8950	0.7769	0.7769
31	0	0.315	0.315	0	0	0	0	0

f_i is the fraction of age *i* females with late-term pregnancies x 0.5 to get female fetuses only (note age *i* females mate and become impregnated at age *i*-1). s_i is the survivorship from age *i* to *i*+1.

* age 0 denotes 1-month of age which is the age of pups when the survey occurs.

1. Table 1 from York (1994). Note that in Table 1 (York 1994) the age 'To' column represents the numbering for f_i, whereas the age 'From' column represents the numbering for s_i.
2. Re-estimated in this paper from the original 1970s data. See main text.
3. s_1 and s_2 increase linearly from s_0 towards s_3, and s_0 is set so that the dominant eigenvalue of the matrix is equal to 1 (meaning a stable population).

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