**Haul-out behavior and detectability of bearded, ribbon, and spotted seals in the Bering and Chukchi Seas**

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**Appendix A. Methods for constructing stable stage distributions for ice-associated seals**

Here, we provide information on methods used to construct stable stage distributions. As indicated in the main text, we calculated , the expected proportion of species *i* that are in each sex (*s*) and age-class (*age*), where we define age-class as young-of year (yoy; under 1 year of age), subadult (sub; older than yoy but sexually immature), and adult (ad; sexually mature). Assuming a 50/50 sex ratio of pups and equal survival schedules for males and females, we write the proportion in each age- and sex-class as

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, and

, respectively.

Here, denotes the proportion of animals of species *i* that are age *a*, and gives the proportion of species *i*, sex s and age *a* that are sexually mature (we thus allow the sexual maturity schedule to differ by sex). We calculated as the dominant eigenvector from a Leslie matrix model (Caswell 2001) calculated for each species. We used a model with a post-breeding census (so that fecundity represents both reproduction and first year survival). We now describe methods used to parameterize natural mortality, recruitment, and maturity schedules.

*Natural morality--*

We used hierarchical meta-analysis (Trukhonova et al. *submitted*) to approximate expected natural mortality schedules. We conducted this analysis exactly as described for ribbon seals in Trukhonova et al., fitting reduced additive Weibull models to a large number of phocid seal mortality datasets (listed in Trukhonova et al.) and then producing posterior predictions for individual species. These models specify a U-shaped mortality curve, with typically high mortality at the beginning of life, followed by a period of low mortality, and finally increasing mortality at older ages corresponding to senescence. We conducted analysis with the highest-ranked DIC model from Trukhonova et al.. which included effects of subfamily, species, and dataset. Predictions of annual survival probabilities () for species *i* and age *a* used in Leslie matrices are provided in Table A1.

*Recruitment--*

We calculated per-capita fertility (*Fa* as described in Caswell 2001) as , where gives young-of-year survival and gives the expected number of births per age *a* seal of species *i*. We estimated using data on reproductive status of hunted seals from the western Bering Sea (Fedoseev et al. 2000; Tables 11, 24, 38, and 47). In particular, we used generalized additive models (Wood 2006) to estimate as a smooth function of age, using the model

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where gives the number of female specimens examined and gives the number of such females that were reported to have parturiated in the current year. Note that the success probability of the binomial is multiplied by 2 to account for a 50:50 sex ratio. We fit these models with the “mgcv” package (Wood 2006) within the R statistical environment (R Development Core Team 2017). In each model, we specified the basis for the smooth effects to have size 3 to prevent “humps” in the fertility-age distribution; to our mind, these would more likely indicate sampling irregularities than underlying processes. Estimated parturition schedules (i.e. ) are presented in Table A2.

*Maturity—*

We based sex-specific maturity schedules for females on the raw proportions of mature females reported in Fedoseev (2000; Tables 11, 24, 38, 47) for the western Bering Sea. Data for proportion of mature ribbon seal males were taken from the text (Fedoseev 2000, pg. 126). Fedoseev (2000) does not provide raw maturity data for spotted, bearded, or ringed males, but does convey rough ranges for age-at-maturity for spotted and bearded seals, noting that they “attain maturity at … 5-6.” We thus developed a maturity schedule where 33% of males are mature at age 5, 66% are mature at age 6, and 100% are mature at age 7. In absence of data on maturity of ringed seal males, we set maturity for males equal to the female maturity schedule. Resulting maturity schedules are reported in Table A.3.

**Literature cited**

Caswell, H. 2001. Matrix population models, 2nd Edition. Sinauer, Sunderland, Massachusetts.

Fedoseev, G.A. 2000. Population biology of ice‐associated forms of seals and their role in the northern Pacific ecosystems. Center for Russian Environmental Policy, Russian Marine Mammal Council; Moscow, Russia.

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R Development Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <http://www.R-project.org>.

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Table A1. Annual survival probabilities () predicted by hierarchical meta-analysis of phocid seal natural mortality.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Age** | **Bearded** | **Ribbon** | **Ringed** | **Spotted** |
| 0 | 0.59 | 0.52 | 0.64 | 0.44 |
| 1 | 0.90 | 0.88 | 0.91 | 0.85 |
| 2 | 0.93 | 0.91 | 0.94 | 0.89 |
| 3 | 0.94 | 0.93 | 0.95 | 0.91 |
| 4 | 0.95 | 0.94 | 0.96 | 0.93 |
| 5 | 0.95 | 0.94 | 0.96 | 0.93 |
| 6 | 0.95 | 0.94 | 0.96 | 0.93 |
| 7 | 0.95 | 0.94 | 0.96 | 0.93 |
| 8 | 0.95 | 0.94 | 0.96 | 0.92 |
| 9 | 0.94 | 0.93 | 0.96 | 0.91 |
| 10 | 0.94 | 0.92 | 0.95 | 0.90 |
| 11 | 0.93 | 0.91 | 0.94 | 0.89 |
| 12 | 0.91 | 0.90 | 0.93 | 0.87 |
| 13 | 0.90 | 0.88 | 0.92 | 0.85 |
| 14 | 0.89 | 0.86 | 0.91 | 0.83 |
| 15 | 0.87 | 0.84 | 0.89 | 0.81 |
| 16 | 0.85 | 0.82 | 0.87 | 0.78 |
| 17 | 0.83 | 0.79 | 0.86 | 0.75 |
| 18 | 0.80 | 0.76 | 0.84 | 0.72 |
| 19 | 0.78 | 0.72 | 0.81 | 0.68 |
| 20 | 0.75 | 0.70 | 0.79 | 0.65 |
| 21 | 0.72 | 0.67 | 0.76 | 0.62 |
| 22 | 0.69 | 0.64 | 0.74 | 0.58 |
| 23 | 0.66 | 0.61 | 0.71 | 0.54 |
| 24 | 0.63 | 0.56 | 0.68 | 0.50 |
| 25 | 0.59 | 0.52 | 0.65 | 0.46 |
| 26 | 0.56 | 0.48 | 0.62 | 0.42 |
| 27 | 0.53 | 0.45 | 0.59 | 0.39 |
| 28 | 0.49 | 0.42 | 0.56 | 0.35 |
| 29 | 0.46 | 0.38 | 0.53 | 0.32 |
| 30 | 0.43 | 0.34 | 0.50 | 0.28 |
| 31 | 0.40 | 0.31 | 0.47 | 0.25 |
| 32 | 0.37 | 0.28 | 0.44 | 0.22 |
| 33 | 0.34 | 0.25 | 0.40 | 0.19 |
| 34 | 0.31 | 0.22 | 0.37 | 0.16 |
| 35 | 0.28 | 0.19 | 0.34 | 0.14 |
| 36 | 0.26 | 0.17 | 0.31 | 0.12 |
| 37 | 0.23 | 0.15 | 0.29 | 0.11 |
| 38 | 0.20 | 0.13 | 0.26 | 0.09 |
| 39+ | 0.18 | 0.11 | 0.23 | 0.07 |

Table A2. Expected per capita births as a function of seal age, as modeled using data from the western Bering Sea (Fedoseev et al. 2000).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Age** | **Bearded** | **Ribbon** | **Ringed** | **Spotted** |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 0.00 | 0.03 | 0.00 | 0.00 |
| 3 | 0.00 | 0.30 | 0.00 | 0.01 |
| 4 | 0.01 | 0.46 | 0.00 | 0.06 |
| 5 | 0.07 | 0.48 | 0.02 | 0.23 |
| 6 | 0.25 | 0.48 | 0.10 | 0.39 |
| 7 | 0.40 | 0.48 | 0.27 | 0.46 |
| 8 | 0.46 | 0.48 | 0.38 | 0.48 |
| 9+ | 0.48 | 0.48 | 0.44 | 0.49 |

Table A3. Proportion of mature male (**♂)** and female (♀) seals used to calculate the expected proportion of age 1+ seals that are immature (i.e. subadult) vs. mature (i.e. adult).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Age** | **Bearded-♀** | **Bearded-♂** | **Ribbon-♀** | **Ribbon-♂** | **Ringed-♀** | **Ringed-♂** | **Spotted-♀** | **Spotted-♂** |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 0.03 | 0.00 | 0.03 | 0.15 | 0.00 | 0.00 | 0.01 | 0.00 |
| 2 | 0.10 | 0.00 | 0.74 | 0.84 | 0.00 | 0.00 | 0.21 | 0.00 |
| 3 | 0.41 | 0.00 | 0.97 | 1.00 | 0.00 | 0.00 | 0.73 | 0.00 |
| 4 | 0.68 | 0.33 | 1.00 | 1.00 | 0.00 | 0.00 | 0.92 | 0.33 |
| 5 | 0.82 | 0.67 | 1.00 | 1.00 | 0.55 | 0.55 | 0.98 | 0.67 |
| 6 | 1.00 | 1.00 | 1.00 | 1.00 | 0.75 | 0.75 | 1.00 | 1.00 |
| 7 | 1.00 | 1.00 | 1.00 | 1.00 | 0.84 | 0.84 | 1.00 | 1.00 |
| 8 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 9+ | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |