Fur seal foraging behavior reflects prey stock structure, abundance, and responses to variable oceanography and storms

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Abstract

Climate models predict increasing Bering Sea temperatures and declines in recruitment of walleye pollock. Predicting the impact on the northern fur seal, a species heavily reliant on pollock for food, requires the need for multiyear observational data linking climate, pollock, and fur seal foraging to help inform numerical ecosystem models, which is the goal of this study. Two northern fur seal studies conducted on the Pribilof Islands during the breeding seasons of 1995 and 1996 and 2005 and 2006 set out to better understand how the biophysical environment affects fur seal foraging success. These two studies focused on 136 adult females provisioning dependent pups and recorded 83,136 hours and 595,236 dives during 502 foraging trips to sea. Growth rates of 107 pups of these females were determined at the end of the season. Oceanographically, 1995 and 2006 were similar with respect to below average Bering Sea shelf bottom water temperatures and extensive cold pools. In contrast, 1996 and 2005 were oceanographically warm with much smaller cold pools residing farther to the NE and out of fur seal foraging range. In all years, available prey for fur seals differed demographically and spatially, resulting in fur seal behavioral responses that tracked the known age-related behavior, distribution, and abundance of walleye pollock and the variable cold pool occupancy of Pacific herring. Approximately 40% of fur seal dives occurred in the Bering Sea basin, a region dominated by mesoscale variability. Basin eddy and edge determination helped explain fur seal movement and dive behavior as well as interannual variability in basin occupancy. Eddy edges, type, and alignment within fur seal foraging habitat were all important factors (see animation). In 2005 and 2006, storms altered fur seal foraging behavior, causing seals in the basin to seek foraging opportunities on the shelf or deeper into the basin, while shelf foraging hotspots were abandoned, resulting in longer trips to sea. The results of this study show the interrelationships between the fur seal foraging behavior, variable prey fields, and climate states and highlights how these factors affect pup growth. Future work seeks to aid ongoing Bering Sea ecosystem modeling efforts and provide indices to help explain past and current demography.

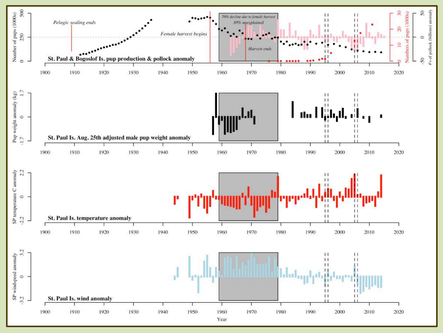

Figure 1. St. Paul I. (black dots) and Bogoslof I. (red dots) pup production, and anomalies in numbers of pollock (pink bars), St. Paul male pup weight (black bars), temperature (red bars) and windspeed (blue bars) anomalies. Vertical dashed lines are the years of this study.

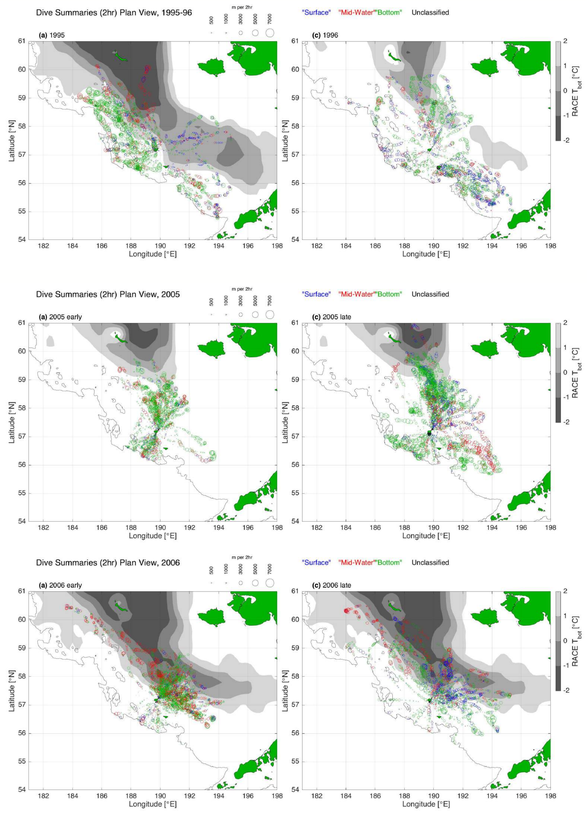

Figure 3. Spatial distribution plots of fur seal dive classifications for 1995 and 1996 (top) and before and after September storms in 2005 (middle) and 2006 (bottom).

Results

"…over 500 otoliths from St. Paul were nearly all from small gadids ranging in length from 4-5 inches to a foot."

Kenyon and Wilke 1957

- Time adult females foraged and nursed pups affected pup growth, thus factors affecting trip behavior are key to understanding pup growth (Fig. 2).
- Cold pools in 1995 & 2006 caused seals to forage more to the west and south. In warm years 1996 & 2005 seals foraged more to the northeast (Fig. 3).
- In all years (only 2006 shown in Fig.4) foraging effort was concentrated in similar thermal zones as was pollock biomass concentration.
- Dives were deepest in 1995 (40.1 ± 2.2 m SE), followed by 2005 (32.4 ± 2.5 m SE) and 2006 (27.8 ± 2.6 m SE). Shallow dives occurred in 1996 (26.6 ± 2.9 m SE; Fig. 5).
- Eddies in 1996 moved along the shelf break and led to shorter trips and more time spent in eddies. More time in eddies was related to greater pup growth (Fig. 6).
- Storms in 2005 & 2006 altered trips. Seals responded by returning to the colony or extending their trips (Figs. 3 & 7).
- Diving depth varied seasonally and changed during storms by shifting away from the bottom toward the surface (only '06 shown Fig. 8).
- 1996 eddy vs. shelf trip durations were similar (Fig. 7), there were few storms, a good eddy field, shallow diving, more pollock, and average air temperatures.
- Trip durations to the basin in other years were generally longer than shelf trips, with 2006 showing the greatest difference due to a poor eddy field (Figs. 6 & 7).
- Pup growth increased with increasing numbers of pollock (Fig. 9). Although this study covered only 4 years, other studies supported our results (Peterson 1965 & Gentry 1984). Linear models also showed sex, temperature, and numbers of pollock explained 76% of the St. Paul I. pup weight variability.
- Residual pup growth in 2005 reflected warm summer air temperatures (Figs. 1 & 9).

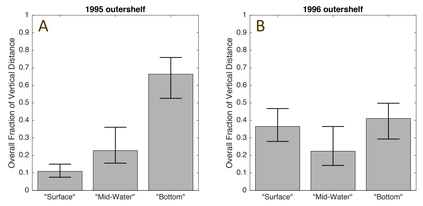

Figure 5. Fraction of vertical distance traveled grouped by dive depth classification in (A) 1995 and (B) 1996. More effort was classified on the bottom in 1995, while more effort occurred above the thermocline and near surface in 1996. The large 1992 (age-3) year class was distributed in the outer shelf habitat and near bottom where dives occurred. In contrast, 1996 had an above average age-0 year class and age-0 pollock typically occupy waters above the thermocline and gradually migrate to mid-water as they grow.

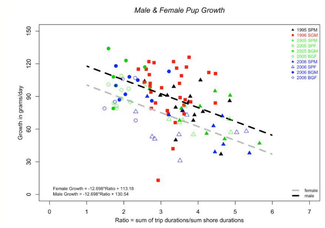

Figure 2. Pup growth vs. mom foraging behavior at the Pribilofs and Bogoslof.

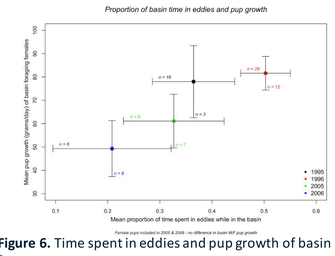

Figure 6. Time spent in eddies and pup growth of basin foragers.

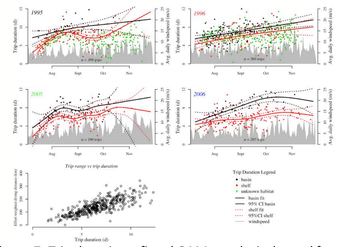

Figure 7. Trip durations, fitted GAMs, and windspeed for all seals in all years.

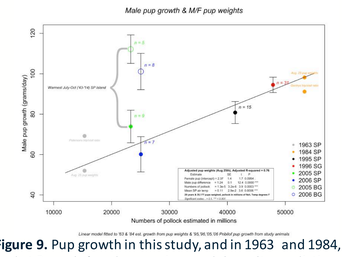

Figure 9. Pup growth in this study, and in 1963 and 1984, and at Bogoslof, and regression model results predicting pup weights.

Fur seals and pollock

"…while in streaks in discolored water…The mate reported seeing an abundance of Alaska pollock jumping and many traveling seals in pursuit of them"

A.B. Alexander 1894

- Diet studies date back to the 1890s
- Pollock and squid occur most frequently
- Species consumption varies spatially – more pollock consumed on the shelf and more squid in the basin
- Contents of seal stomach samples matched dominant pollock year classes
- Diet collections of stomachs, scats, and spews indicate seals consume both juvenile and adult pollock
- Duration of seal trips were shorter in years with large pollock year classes
- Climate change predictions indicate significant declines in pollock recruitment in the Bering Sea
- Some studies conclude juvenile pollock are, "likely detrimental to their [fur seals] population health and reproductive fitness"

Background and Methods

- Harvest strategies explained the Pribilof Is. fur seal decline and recovery in the late 19th and early 20th centuries and 70% of the first of two declines beginning in the late 1950s (Fig. 1).
- Pup production now is ~ 25% of its peak and the current decline remains unexplained.
- The interaction between summer and winter foraging conditions could be responsible for the most recent declines (Fig. 1 top).
- We examined aspects of the feeding environment, effects on adult female behavior, and pup growth with the aim to inform numerical ecosystem models and explain Pribilof fur seal demography.
- Seal Argos and dive data were modeled to produce hourly locations and dive locations. Dive depths were classified as bottom, midwater, and surface.
- Gentry 1984 and Sinclair et al. 1994 showed that diving and diet tracked pollock year class strength. Alexander 1894, Serobaba 1970, and Wyllie-Echeverria 1998 showed that seal and pollock distributions shift in response to the location of the Bering Sea cold pool. We predicted that dive depths and locations would track pollock spatial and vertical distributions.
- An eddy detection and edge determination algorithm was applied to AVISO SSH data to identify, track, and explain seal behavior relative to eddies.
- NCEP wind speed and direction were examined with respect to seal behavior.
- Seal behaviors and pup growth rates were compared to Bogoslof I., Bering Sea, AK, a fur seal colony experiencing significant population growth since 1980 (Fig. 1 top).
- Results were compared to pup weights, numbers of pollock, St. Paul windspeeds and temperature data, and other years with female trip durations and pup weights.

"…seals always travel with a fair wind."

C.L Hooper 1892

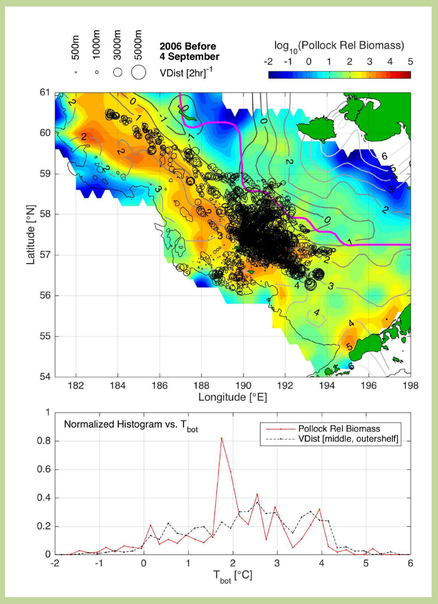

Figure 4. Seal vertical distance traveled (dive effort) overlaid on Kotwicki's combined bottom trawl, mid-water pollock biomass assessment, and bottom temperature isotherms (top). Normalized thermal zones of pollock biomass and fur seal effort (bottom).

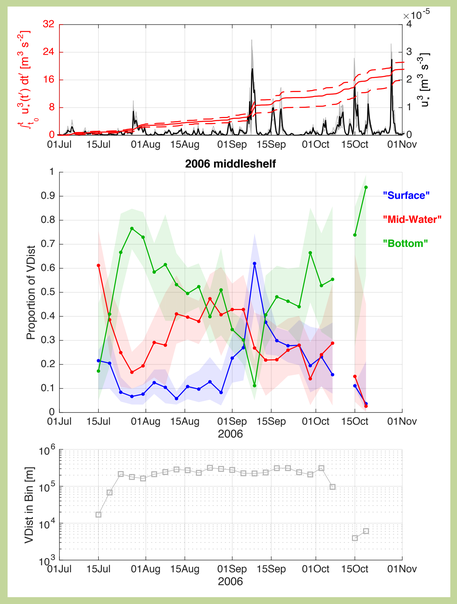

Figure 8. Seasonal proportion of seal vertical distance traveled (dive effort) grouped by dive classifications (middle) and aligned with friction velocity (windspeed) cubed (top).

Conclusions

"In terms of prey species composition, the summer diet of females and juvenile male fur seals does not appear to have changed since the turn of the century." Sinclair et al. 1994

- Fur seal foraging behavior reflected both the physical environment and its effect on pollock, their primary prey.
- Cold pools, eddy fields, storms, and pollock stock structure affected seal diving, foraging location, and trip durations.
- Trip and shore time spent with pups, and air temperatures at the colonies influence pup growth.
- Higher pup weights and pup growth rates were seen in years with greater numbers of pollock and with along-shelf break eddy fields.
- Models indicate pup growth increases from 0.3 – 1.1 grams per day for each additional billion pollock.
- This adds 1.2 - 4.6 kg to pup weaning mass when going from an average pollock year to a year of max estimate of 87 billion fish.
- Put into context of the most recent declines of fur seals, 1984 had the second largest pup weight anomaly. Pup production had stabilized and begun to increase following the 1978, 1982, and 1984 large pollock year classes, suggesting good recruitment from those years; and where St. Paul I. air temps and winds were normal. Diving and diets reflected large pollock year classes.
- Conversely, 30% of the decline from 1956-1979 is unexplained. Air temperatures, pup weights, and pollock numbers were all low, while windspeeds and trip durations were high. We believe this likely explains part of the 30% decline given our results.
- Bogoslof pup growth rates provide insights into optimal conditions leading to good recruitment.

Acknowledgments

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