

Seabird and Cetacean Foraging Response to Prey Persistence (O4.40)

Contact Information

Leader: Mike Sigler

Co-PIs: Kathy Kuletz, Chris Wilson, Nancy Friday

Summary

The ability to predict the location of prey is an important component of foraging behavior of predators. Predictable prey locations reduce search time and thus energetic costs of foraging. In this project (Seabird and Cetacean Foraging Response to Prey Persistence, O4.40), we will analyze data collected from four other projects (Seabird Broad-Scale Distribution, O4.36; Cetacean Broad-Scale Distribution, O4.38; Acoustic Surveys, O2.26; and Seasonal Bioenergetics, O2.24). Seabird (O4.36) and cetacean (O4.38) locations from at-sea visual surveys will be analyzed in relation to pelagic forage species abundance (O2.26) and nutritional energy (O2.24) data from acoustic surveys (Table 1). We will quantify the existence of prey hot spots, whether these hot spots persist across years, and the location of apex predators relative to hot spot persistence based on apex predator frequency of association with persistent hot spots.

This project is one component of the Bering Sea Integrated Ecosystem Research Program (BSIERP). The integrated program hypotheses and projects are listed in Tables 1 and 2.

Background

The ability to predict the location of prey is an important component of foraging behavior of predators (Webb and Marcotte, 1984; Grand and Grant, 1994; Siems and Sikes, 1998; Gende and Sigler, 2006), and this is nowhere more relevant than for air-breathing vertebrates that forage at sea. Faced with physiological and energetic constraints in acquiring prey that may be ephemerally available in time and patchily distributed in a three-dimensional water space, predictable distributions of prey allow foraging marine mammals and seabirds to concentrate search efforts in specific areas during specific time periods, facilitating efficient foraging (Irons, 1998; Davoren et al., 2003). Predictable prey locations reduce search time and thus energetic costs of foraging (Gende and Sigler 2006). Foraging Steller sea lions return to geographic locations where prey are reliably found (Sigler et al. 2004; Womble and Sigler 2006) and vary their dive behavior in response to oceanographic changes (Fadely et al. 2005). Planktivorous seabirds and baleen whales are dependent on reliable concentrations of prey (hot spots) that are affected by the climate-mediated processes (e.g., Croll et al. 1998; Lovvorn et al. 2001; Baumgartner et al. 2003). One mechanism that can contribute to the predictability of prey is when profitable foraging patches persist through time. In the absence of persistence of important foraging areas, predators must approach each foraging trip without knowledge of the location of the important foraging habitat. Persistence thus may be fundamental for predators to locate productive prey areas efficiently.

Although many studies have concluded that the ability to predict the distributions of prey is relevant to the fitness and foraging ecology of marine mammals (Le Boeuf et al., 2000; Guinet et al., 2001; Sinclair and Zepplin, 2002) and seabirds (Skov et al., 2000, Davoren et al. 2003), very few studies have quantified prey persistence for marine predators, particularly across larger time scales (months, seasons, years). In this project (Seabird and Cetacean Foraging Response to Prey Persistence, O4.40), we will analyze data collected from four other projects (Seabird Broad-Scale Distribution, O4.36; Cetacean Broad-Scale Distribution, O4.38; Acoustic Surveys, O2.26; and Seasonal Bioenergetics, O2.24). Our goal is to understand better how the spatial and temporal dynamics of prey influence the foraging ecology and behavior of predators that utilize them. Specifically, we will quantify (1) the existence of prey ‘hot spots’; (2) whether these hot spots persist across years; and (3) the location of predators relative to hot spot persistence.

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Species and Geographic Scope

This project examines pollock, euphausiids, myctophids, capelin, murre, kittiwakes, shearwaters and other seabird species and humpback and fin whales within the southeastern Bering Sea.

Hypotheses

This project addresses BSIERP hypotheses 4a-b (Tables 2 and 3).

Project Description

In this study the spatial distribution and abundance of pelagic forage species will be compared to the spatial distribution of common marine mammal and seabird predators in the southeastern Bering Sea. We will analyze data collected from four other projects (Seabird Broad-Scale Distribution, O4.36; Cetacean Broad-Scale Distribution, O4.38; Acoustic Surveys, O2.26; and Seasonal Bioenergetics, O2.24). The spatial distribution and abundance of pelagic forage species will be measured by acoustic surveys (See Project Description, O2.26). Approximately 11,000 km are surveyed on transects spaced 37 km apart. Pollock, euphausiids, myctophids and capelin will be enumerated. Fish density in weight will then be converted to nutritional energy using size- and species-specific energy conversions (See Project Description, O2.24). Prey results are expressed in terms of energy such that they represent a common 'currency' upon which marine mammals and seabirds are known to base forage decisions (Kacelnik and Krebs, 1985). Trained observers onboard the acoustic survey vessel will conduct standard visual line-transect surveys for cetaceans (See Project Description, O4.38) and visual strip-transect surveys for seabirds (See Project Description, O4.36).

The acoustic data will be grouped into small transects of 0.19 km (0.1 nm) of 10-m depth intervals, and then integrated across the water column, such that each transect has an estimate of prey energy density (in millions of kJ/km²; see Fauchald et al., 2000; Davoren et al., 2003). The transect data will be then grouped into blocks, where each block encompasses a latitudinal minute (e.g. 58°25' to 58°26', a distance of 1.83 km). We then will compute means (and standard errors) using the energy density estimates from transects as data points that constitute each 1-min block. This is the spatial scale at which we will conduct our analyses. We also will examine the sensitivity of analytical results to block size.

We will examine predictability of prey energy density, defined as the degree to which prey energy density in an area predicts the energy density available in that same area at a different time period. We will ask the question of whether the distribution and relative quantity of prey in the study area during one year of surveys is an accurate indicator of the distribution and relative quantity of prey during the following year. We will use the coefficient of determination of linear regression to serve as a measure of predictability: the greater amount of variation explained, the more predictable the prey resources occur across the study area. For example, the prey density will be calculated for each latitudinal block in 2008 and then regressed against the density estimates in the same blocks in 2009. Analyzing the data in this manner thus provides equal weight to areas where prey are consistently present and to areas where prey are consistently absent. In other words, we assume it is equally important for a marine predator to be able to predict where they should forage (consistent high density prey patches), as being able to predict where not to forage (where prey are consistently absent). A slope that is significantly different from zero indicates predictability. This analysis will be completed for each year pairing (2008-2009, 2008-2010, and 2009-2010).

We also will examine the persistence of prey energy density. A block will be defined as 'hot' if it supports greater than average prey densities, where the average is calculated for all blocks within that year (see similar procedures in Davoren et al., 2003). This results in a year-specific binary designation of each block as hot or not. We then will sum across all three years the number of times each block is hot (see also Etnoyer et al., 2004). As all blocks will be surveyed for 3 years, each block can be 'hot' for up to

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3 years maximum. The analysis will be expanded if acoustic surveys before 2008 provide detailed enough data. Persistence of hot spots (blocks) will be calculated by summing the number of years that block is hot divided by the total number of years it was surveyed. Note that we use the term 'blocks' synonymously with 'spot', so that our analysis will examine hot spot (or block) persistence.

We then will examine the persistence of prey hot spots relative to the distribution of murre, kittiwakes, shearwaters and other seabird species and fin and humpback whales. The location of seabirds and cetaceans will be recorded during the acoustic surveys. From these data we will label whether each block contained a predator or not. We will use linear regression to explore the relationship between the presence of predators and the persistence of prey hot spots. We also will examine the sensitivity of the analytical results to predator species.

Project Reporting

Research Products: R^2 and slope values of linear regression of energy in one year regressed against energy in the same area the next year (pelagic prey predictability, millions kJ km⁻²). R^2 and slope values of linear regression of proportion of time a predator was observed in spot (block) foraging vs. hot spot persistence (number of months hot / total years surveyed) (pelagic prey persistence, millions kJ km⁻²) (Table 4).

Research Links: This project depends on pelagic forage species (pollock, euphausiid, myctophid and capelin) abundance and spatial distribution from the acoustic survey (O2.26), nutritional energy data from the seasonal bioenergetic project (O2.24), murre, kittiwake, shearwater and other seabird abundance and spatial distribution from the seabird broad-scale distribution project (O4.36) and fin and humpback whale distribution from the cetacean broad-scale distribution project (O4.38). These projects will collect data during June and July of 2008, 2009 and 2010. Abundance, nutritional energy and location data from these projects are needed by winter 2010 so that our analysis can be completed during the spring of 2011.

Research Reporting: The predictability and persistence analysis will be completed during the spring of 2011 (Table 5). The analysis results will be delivered to the modelers during the summer of 2011. A manuscript will be submitted to a peer-reviewed journal by fall of 2011.

Dissemination: Title of likely peer-reviewed manuscript: "Persistence of forage species 'hot spots' and their association with seabirds and cetaceans in the southeastern Bering Sea".

Graduate Students and Post-docs: None.

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Figures and Tables

Table 1. Project list.

Project	Project Components	Label	Principal Investigators	NPRB (\$)	In-kind (\$)
Lower trophic level	Biophysical moorings (4)	O1.1	Stabeno, Whitledge, Napp	\$ 732,259	\$ 1,707,106
Ichthyoplankton	Ichthyoplankton surveys	O2.7	Hillgruber, Duffy-Anderson, Napp, Matarese, Eisner	\$ 1,068,052	\$ 1,245,612
	Seasonal bioenergetics	O2.24	Heintz	\$ 250,000	\$ 373,400
Fish	Acoustic survey	O2.26	Wilson	\$ 154,499	\$ 2,349,000
	Surface trawl survey	O2.23	Farley	\$ -	\$ 1,516,200
	Surface trawl survey acoustics	O2.28	Horne, Parker-Stetter, Farley	\$ 425,731	\$ -
	Bottom trawl survey (epi-benthic)	O2.25	Lauth	\$ -	\$ 3,240,000
	Pollock & cod distribution	O2.19	Ciannelli, Bailey	\$ 332,313	\$ -
	Functional foraging response	O2.16	Aydin, Farley	\$ 258,260	\$ 23,040
Trophic interactions	Forage distribution & ocean conditions	O2.17	Hollowed, Wilson, Kotwicki, DeRobertis, Ressler, Cokelet	\$ 567,123	\$ 553,311
	Fish, birds & mammals	O3.30	Mueter, Kruse	\$ 286,913	\$ -
	Hot spot persistence	O4.40	Sigler, Kuletz, Wilson	\$ -	\$ 55,200
Seabirds	Seabird telemetry	O4.35	Irons, Byrd, Roby	\$ 600,000	\$ 303,000
	Seabird broad-scale distribution	O4.36	Kuletz	\$ 550,438	\$ 555,000
	Seabird colony-based	O4.37	Byrd	\$ 350,000	\$ 1,179,000
Patch	Patch Dynamics	O4.62	Trites, Jay, Grebmeier, Benoit-Byrd, Heppell, Sampson, Irons, Byrd, Roby, Kytasky, Kuletz	\$ 2,300,000	
Marine mammals	Whale broad-scale distribution	O4.38	Friday, Moore, Zerbini, Clapham	\$ 300,000	\$ -
	Fur Seal colony-based		Ream	\$ -	\$ -
Local and Traditional Knowledge	Local & traditional knowledge	O5.41	Sepez, Hunn, Huntington, Langdon, Zavadil, Fall	\$ 1,000,000	\$ 49,190
Modeling	<i>potential</i>		to be determined	\$ 2,500,000	
	Forage euphausiid (FEAST)	M.47	Aydin		
	Behavioral foraging	M.54	Mangel		
	Biomass dynamics	M.61	Mueter, Kruse		
	Integrate economic-ecological	M.48	Dalton, Aydin, Haynie		
	Spatial fishery choices	M.49	Haynie		
	Management strategy resilience	M.50	Criddle, Valcic, Greenberg		
	Blended forecasts, Management strategy evaluation	M.55	Punt		
Education and Outreach			Deans (NPRB)	\$ 100,000	
Data Management	Data Management		Coyle	\$ 800,000	
Program Management			NPRB	\$ 600,000	
Total				\$ 13,175,588	\$ 13,149,059

Table 2. BSIERP hypotheses: Climate models predict warming over the next 30 years (IPCC 2007). Predictions from climate models show no indication of a strengthening of summer winds. In fact, there has been a decrease in wind strength and lengthening of summer conditions over the last decade (Overland and Stabeno 2004; Stabeno and Overland 2001). Projected warming on the southeastern shelf of the Bering Sea will profoundly alter ecosystem structure by changing pathways of energy flow and the spatial distribution and species composition of fish, seabird and marine mammal communities, thereby affecting commercial and subsistence fisheries.

1. Climate-induced changes in physical forcing will modify the availability and partitioning of food for all trophic levels through bottom-up processes. Specifically:
 - a. Earlier sea ice retreat expected as a result of warming will result in a later (May-June), warm-water spring phytoplankton bloom, increased coupling with zooplankton and greater pelagic secondary productivity. Benthic secondary productivity will decrease.
 - b. Reduced frequency and intensity of summer storms will reduce surface mixing and increase sea surface temperature, thereby increasing stratification. A substantial decrease in summer winds will result in a mixed layer that is shallower than the euphotic zone, extensive subsurface primary production and depletion of nutrients in the entire water column. There will be no fall phytoplankton bloom. A moderate decrease or no change in the intensity of summer storms will reduce replenishment of nutrients to the euphotic zone, lowering summer primary and secondary production. Both scenarios will reduce juvenile fish production by reducing their condition (energy density) and over-wintering capability.
 - c. Earlier spring transition will lengthen the period of time of organized onshore flow along the Alaska Peninsula, thus transporting larvae away from outer domain piscivores.
2. Climate and ocean conditions influencing water temperature, circulation patterns and domain boundaries impact fish reproduction, survival and distribution, the intensity of predator-prey relationships and the location of zoogeographic provinces through bottom-up processes. Specifically:
 - a. As heat content increases, the area suitable for spawning and foraging by subarctic species will expand northward and subarctic species will occupy areas formerly occupied by Arctic species.
 - b. Reduced cold pool extent will increase overlap of inner domain forage fish and outer domain piscivores.
 - c. Strength of frontal boundaries will weaken due to absence of the summer cold pool, allowing expansion of the inner domain and juvenile and forage fish habitat there. Weaker winds will enhance this effect.
 - d. Sporadic reversals to cold conditions (e.g., 1999) will have strong effects on the subarctic community and result in increased interannual variability in abundance and pelagic productivity of piscivorous fish, seabirds and marine mammals.
 - e. Expected decreases in benthic productivity will negatively affect feeding and survival of small flatfish and crab thereby lowering population levels.
3. Later spring phytoplankton blooms as a result of early ice retreat will increase zooplankton production, thereby resulting in increased abundances of piscivorous fish (pollock, cod and arrowtooth flounder) and a community controlled by top-down processes [Oscillating Control Hypothesis] with the possible trophic consequences:
 - a. Competition with abundant, piscivorous fish species for forage species will lead to a decline in murre, kittiwakes and fur seals.
 - b. Growing populations of humpback and fin whales increasingly will both consume and compete with forage fish (juvenile pollock) for zooplankton (euphausiids and copepods). By reducing the prey base of forage fish, whales not only reduce the amount of forage fish available to other predators, but also their quality (lipid content).
 - c. In a top-down control community, fishing will reduce the degree of top-down control of forage species (including juvenile pollock) by adult pollock, cod and arrowtooth flounder. Owing to light exploitation rates, top-down control by arrowtooth flounder will increase, as will their level

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- of competition with piscivorous fish, seabirds and marine mammals. As a result of these two processes, arrowtooth flounder will determine ultimate community composition, such that the climax community will be arrowtooth flounder-dominated (similar to the Gulf of Alaska).
4. Climate and ocean conditions influencing circulation patterns and domain boundaries will affect the distribution, frequency and persistence of fronts and other prey-concentrating features and thus the foraging success of marine birds and mammals largely through bottom-up processes. Specifically:
 - a. Climate-ocean changes will displace predictably located, abundant prey (hot spots) necessary for successful foraging by central place (seabirds and fur seals while nurturing young) and hot spot (baleen whales, walrus) foragers.
 - b. Central place foragers will shift their diet, foraging locations or rookery locations to increase foraging opportunities (based on differential foraging success).
 5. Climate-ocean conditions will change and thus affect the abundance and distribution of commercial and subsistence fisheries. Specifically:
 - a. For commercial fishermen, these changes will lead to: 1) a change in home ports and distribution of fishing vessel rents, 2) vessels traveling further, incurring greater fuel costs and peril at sea and 3) greater burden on smaller vessels.
 - b. For subsistence users, these changes will lead to: 1) greater reliance on owners of larger vessels that can travel farther to harvest and distribute subsistence goods, 2) decreased consumption of species with decreased local abundance and 3) adoption of new species into the diet as these species colonize local areas.
 - c. Current management strategies for fish, seabirds and marine mammals in the Bering Sea are robust to climate scenarios (range of frequencies of cold and warm years) and associated range of trophic relationships and spatial redistributions.

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Table 3. Project links to BSIERP hypotheses. The BSIERP hypotheses are numbered 1-5 and are described in the BSIERP study plan.

Projects	Label	1a	1b	1c	2a	2b	2c	2d	2e	3a	3b	3c	4a	4b	5a	5b	5c
Biophysical moorings (4)	O1.1																
Summer plankton survey	O1.2																
Ichthyoplankton	O2.7, O2.24																
Fish	O2.26, O2.23, O2.28, O2.25, O2.19, O2.16, O2.17																
Trophic interactions	O3.30, O4.40																
Seabirds	O4.35, O4.36, O4.37																
Patch dynamics	O4.62																
Marine mammals	O4.38																
Local and Traditional Knowledge	O5.41, O5.42																
Lower trophic level modeling	M.3, M.4, M.5																
Forage euphausiid (FEAST)	M.47																
Behavioral foraging	M.54																
Biomass dynamics	M.61																
Economic-ecological spatial	M.48, M.49																
Management strategy resilience	M.50																
Blended forecasts, Management strategy evaluation	M.55																

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Table 5. The proposed timeline for research reporting by quarter is summarized below. Highlighted cells denote quarters when activities occur, x's denote specific deliverables to be completed by the end of the indicated quarter as described below. The schedules for some research activities are generalized; for example, seasonal bioenergetics (O2.24) samples are collected during several surveys (e.g., Spring ichthyoplankton survey) and analyzed in the laboratory (Laboratory analysis activity). Semi-annual reports are due January 15 and July 15 each year.

Research activity or project	2007				2008				2009				2010				2011				2012			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Initial planning meeting																								
Annual meeting																								
Laboratory analyses																								
Data analyses																								
Modeling & retrospective analyses																								
Field data to models																								
Model outputs to fieldwork planning																								
Preparation of manuscripts																								
Synthesis																								
Semi-annual reports																								
Final report																								

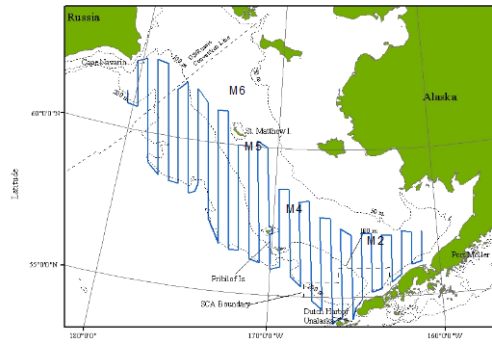


Fig. 1. Acoustic survey (O2.26) transects and 4 biophysical mooring (O1.1) locations (M).



Fig. 2. At-sea seabird visual survey (O4.36) data from previous NPRB-funded seabird broad-scale distribution studies.

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Womble, J.N., and M.F. Sigler. 2006. Seasonal availability of abundant, energy-rich prey influences the abundance and diet of a marine predator, the Steller sea lion *Eumetopias jubatus*. *Mar. Ecol. Prog. Ser.* 325:281-293.

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Budget Narrative – O4.40 Hot spot persistence

Budget Narrative – Alaska Fisheries Science Center

Personnel/Salaries: None

Personnel/Fringe Benefits: None

Travel: None

Equipment: None

Supplies: None

Contractual/Consultants: None

Other: None

Indirect Costs: None

Total Funds requested for AFSC: \$0

Other Support/In kind Contributions:

AFSC will contribute labor costs for Sigler to analyze and prepare a manuscript (2 months each in 2008 and 2010) and to travel to the Marine Science Symposium (2009 and 2011) to present the results (\$44,000). 28% Benefits applies rate applies to Sigler's salary.

Total In-Kind funds for AFSC: \$55,200

