

**Surface Trawl Survey Acoustics, O2.28**

**Contact Information**

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**Summary**

This project will quantify forage fish (e.g., juvenile pollock, capelin, herring, and myctophids) distribution on the Bering Sea shelf, and examine how oceanography and climate forcing may influence forage fish distribution, abundance, and ultimately effect apex predator distribution and abundance. We will add acoustics and midwater trawling to the BASIS survey (O2.23) to document density distribution of forage species. We will map forage species distribution using geostatistics and compare distributions and abundances among survey years. These data will complement data collected by the AFSC during Bering Sea shelf surveys for walleye pollock. Finally, we will supply IBM and energetic models with forage fish data as requested.

**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**

Ecosystem-based approaches to fisheries management (EBFM) are advocated in the scientific literature and mandated in the management of aquatic resources (Pikitch et al. 2004; Livingstone et al. 2005). Implicit in the development of EBFM is an increased understanding of ecosystem function and process, which should lead to prediction of inter-species interactions and environmental influences on species abundances (Pikitch et al. 2004). Expanded surveys and assessment of biota and the environment are a necessary first step, but financial and logistic constraints make the monitoring of all species, species interactions, and physical variables impossible. Long-term, multi-trophic level datasets are rare, but studies that include environmental measures through upper trophic level responses have shown concordance over a wide range of spatial and temporal scales (e.g., Aebischer et al. 1990).

In marine ecosystems, monitoring some trophic levels is easier than others. Environmental variables thought to influence production (e.g., sea surface temperature, atmospheric pressure, wind speed, wind direction) can be monitored remotely. Many commercially important fish stocks are surveyed on a regular basis and additional population size and structure information can be obtained using fishery data. Among apex predators such as marine mammals and seabirds, measures of population size, reproductive effort, and occasionally diet, are often monitored at rookeries and colonies.

A critical component missing from many ecosystem datasets is non-commercial species, especially the abundance and distribution of juvenile and adult pelagic fish and large zooplankton (e.g., krill). This trophic guild, commonly called forage fish, fuels production of commercial fish stocks and apex predators (Springer and Speckman 1997), and can respond to environmental forcing (e.g., Barber and Chavez 1983). Information on associations between the environment, primary/secondary production, and forage fish is a necessary prerequisite to formulate ecosystem models. A mechanistic understanding of how changes in forage fish dynamics propagate up to apex predators is essential for successful EBFM.

Forage fish are a critical component of the northeast Bering Sea ecosystem, yet the understanding of their distributions and dynamics is incomplete. As an example, the capelin population abundance estimate (SAFE 2005) was modeled using food habits (i.e. diet) data from piscivorous predators (cf. Yang et al.

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2005). The importance of forage species as harvestable resources (e.g. herring, capelin) and as prey to apex predators (e.g. adult gadoid fish, marine mammals, seabirds) emphasizes the need to understand biological and physical processes influencing forage fish population dynamics and interactions with predators.

Two sets of processes may be acting, independently or in concert, to influence the survival, distribution, and reproductive success of forage fish. Replacement of capelin by gadoids was hypothesized by Anderson and Piatt (1999) to result from predation on a limited prey field. Zooplankton presence reduces predation on forage fish by predators in late spring as early spring hatched gadoids will feed on zooplankton if available, or concentrate foraging on late-spring-hatched, non-gadoid fish larvae. The onset of water column stratification determines the timing of the spring bloom and subsequent secondary production. Ice cover accelerates water column stratification, compared to stratification due to solar heating. Changes in the amount and extent of ice cover may determine the timing of the spring bloom, zooplankton production, and predation pressure on forage species.

The second set of conditions influencing distribution and survival of forage fish is water column temperature gradients. Latitudinal thermal gradients from north to south may spatially separate more tolerant osmerid and clupeoid fish species from less tolerant gadoid species. Annual differences in average water temperatures may also influence a north-south cline in predator and prey population distributions. Analogously, the cold pool and associated front (Wyllie-Echeverria and Wooster 1998) may act as a porous barrier (e.g. Cianelli and Bailey 2005) between the middle and inner domains of the Bering Sea shelf. One documented example shows that Atlantic cod follow warm water corridors up onto the continental shelf in the northwest Atlantic (Rose 1993). The timing and route of the inshore migration is determined by the presence of the corridors. The net result of both predator foraging and temperature fields is increased survival by forage species due to reduced predation pressure and/or the use of thermal refuges by forage fish.

Because no data exist on the response of forage fish to the timing of the spring bloom and thermal gradients on the continental shelf, it is unknown whether changes in forage fish abundance and distribution, and apex predator demography results from a reduction in forage fish abundance, a change in prey field diversity/abundance, and/or a change in forage fish distribution in the immediate vicinity of apex predators.

### **Species and Geographic Scope**

This project will focus on juvenile pollock, capelin, herring, myctophids, and other forage species within the shelf region of the southeastern Bering Sea surveyed during the BASIS research cruise.

### **Hypotheses**

This project will contribute to BSIERP hypotheses 1-4.

We will map the density distribution of forage species in the inner domain of the Bering Sea. Changes in species distribution and abundance will address bottom-up (1.c, 3.a-c, 4.a) and top-down (2.b-d) hypotheses. Characterization of forage species distribution, predator distribution, and environmental data will be used to address hypotheses on potential climate change effects and predator-prey interactions. Data collected during cruises will be used to estimate abundance and can be used to examine forage fish responses to environmental conditions. Physical conditions – biological response correlations will be used to examine trends in forage fish populations in the Bering Sea and to predict biological responses to environmental changes due to climate change. Natural variation in distributions and abundances among forage fish populations will be used in conjunction with predicted environmental changes to identify species or predator-prey interactions susceptible to climate change.

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Forage fish distribution and abundance data will provide critical input for multiple modeling projects, including the seasonal spatially-explicit bioenergetic models and the predator-prey dynamics.

### **Project Description**

Forage fish distribution and abundance data will be collected during cruises that survey the inner domain of the Bering Sea continental shelf. Acoustic data collection will be integrated with the fall BASIS (Farley et al., Fig. 4) surveys. This will provide 12 weeks of acoustic data collection spanning the Inner Domain between Unalaska Island and Nome, Alaska during calendar years 2008 through 2010. Acoustic backscatter at 38 and 120 kHz (charter vessel) or 18, 38, 70, 120, and 200 kHz (Oscar Dyson) will be collected using Simrad EK60 splitbeam echosounders along predefined BASIS transects. Primary target species include capelin, Pacific herring, myctophids, eulachon, and juvenile walleye pollock. At 15-20 BASIS stations during each cruise, a midwater trawl will be deployed to identify backscatter constituents. In our analysis, we will expand on existing techniques to identify forage fish backscatter. Forage species in the Bering Sea have been acoustically discriminated using multiple frequencies (Gauthier and Horne 2004a, b) and characterized by combining acoustics with direct sampling techniques such as midwater trawl and MultiNet (cf. Sigler et al. 2006). The application of a recently developed probability-based classification technique (Anderson et al. 2007) will be investigated for this project.

Vertical and horizontal density distribution of forage species, to the highest resolution possible, will be mapped for each cruise. Geostatistical variograms and kriging will be used to generate abundance maps. We will use trend analyses, ANOVA, and Generalized Additive Mixed Models (GAMMs) to quantify changes in forage fish distribution and densities over years, using water temperature, sea ice extent, and front location as covariates. We will also compare variogram parameters (nugget, sill, range) to discern differences in distributions among analyses (Mello and Rose 2005). Correlations between forage fish density and environmental parameters in the Bering Sea will be used in GAMMs to predict biological responses to climate-induced environmental changes.

Maps of forage fish density distribution will also be combined with energetic analyses (Seasonal Bioenergetics, O2.24) to predict the distribution of potential energy available to piscivores in the study area. These analyses will evaluate the overlap between forage fish species, environmental parameters, and important piscivorous fish species such as walleye pollock and Pacific cod. Natural variation in forage fish distributions and abundances will be used in conjunction with predicted environmental changes to identify species or predator-prey interactions susceptible to climate change.

Mean density, if possible by species, variance, and forage fish abundance will be estimated for each survey. These data will provide input for multiple modeling projects, including the seasonal spatially-explicit bioenergetic models and predator-prey dynamics.

### **Project Reporting**

Research Products: Density distribution maps of forage species in the Bering Sea Inner shelf region for 2008-2010. If possible, a similar map will be produced for data collected in 2007. Statistical comparison of forage species distribution parameters among years.

Research Links: This project will require information on oceanographic parameters from projects O1.1, and O2.17.

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Research Reporting: Density distribution maps will be available within 6 months of survey completion (April of the year following the survey). Comparison of distributions among years will be completed in 2011. We anticipate at least 2 peer-reviewed publications from this work to be completed in 2011.

Dissemination: Likely titles for peer-reviewed manuscripts include: Distribution of forage fish species in the Bering Sea, and Potential response of pelagic fish to climate change in a boreal ecosystem.

Graduate Students and Post-docs: Sandra Parker-Stetter (Post-Doc) will be supported on this project for 4 months (FY2007) and 6 months (FY2008-2012) per year.

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### Figures and Tables

Table 1. Project list.

Project	Project Components	Label	Principal Investigators	NPRB (\$)	In-kind (\$)
<b>Lower trophic level</b>	Biophysical moorings (4)	O1.1	Stabeno, Whitledge, Napp	\$ 732,259	\$ 1,707,106
<b>Ichthyoplankton</b>	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
<b>Fish</b>	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
	Forage distribution & ocean conditions	O2.17	Hollowed, Wilson, Kotwicki, DeRobertis, Ressler, Cokelet	\$ 567,123	\$ 553,311
<b>Trophic interactions</b>	Fish, birds & mammals	O3.30	Mueter, Kruse	\$ 286,913	\$ -
	Hot spot persistence	O4.40	Sigler, Kuletz, Wilson	\$ -	\$ 55,200
<b>Seabirds</b>	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
<b>Patch</b>	Patch Dynamics	O4.62	Trites, Jay, Grebmeier, Benoit-Byrd, Heppell, Sampson, Irons, Byrd, Roby, Kytasky, Kuletz	\$ 2,300,000	
<b>Marine mammals</b>	Whale broad-scale distribution	O4.38	Friday, Moore, Zerbini, Clapham	\$ 300,000	\$ -
	Fur Seal colony-based		Ream	\$ -	\$ -
<b>Local and Traditional Knowledge</b>	Local & traditional knowledge	O5.41	Sepez, Hunn, Huntington, Langdon, Zavadil, Fall	\$ 1,000,000	\$ 49,190
<b>Modeling</b>			to be determined	\$ 2,500,000	
	<i>potential</i>	<i>potential</i>			
	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			
<b>Education and Outreach</b>			Deans (NPRB)	\$ 100,000	
<b>Data Management</b>	Data Management		Coyle	\$ 800,000	
<b>Program Management</b>			NPRB	\$ 600,000	
<b>Total</b>				<b>\$ 13,175,588</b>	<b>\$ 13,149,059</b>

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.

**References**

- Anderson, C.I.H., J.K. Horne, and J. Boyle. 2007. Applying a robust probabilistic classification technique to multi-frequency fisheries acoustic data. *Journal of the Acoustical Society of America*. 121: EL230-237.
- Gauthier, S. and J.K. Horne. 2004a. Potential acoustic discrimination of boreal fish assemblages. *ICES Journal of Marine Science* 61: 836-845.
- Gauthier, S. and J.K. Horne. 2004b. Acoustic characteristics of forage fish species in the Gulf of Alaska and Bering Sea. *Canadian Journal of Aquatic and Fishery Science* 61: 1839-1850.
- Lloyd, M. 1967. Mean crowding. *Journal of Animal Ecology* 36:1-30.
- Mello, L.G.S. and G.A. Rose. 2005. Using geostatistics to quantify seasonal distribution and aggregation patterns of fishes: an example of Atlantic cod (*Gadus morhua*). *Canadian Journal of Aquatic and Fishery Science* 62:659-670.
- O'Driscoll, R.L., D.C. Schneider, G.A. Rose, and G.R. Lilly. 2000. Potential contact statistics for measuring scale-dependent spatial pattern and association: an example of northern cod (*Gadus morhua*) and capelin (*Mallotus villosus*). *Canadian Journal of Aquatic and Fishery Science* 57:1355-1368.
- Sigler, M.F., M.C. Benfield, E.D. Brown, J.H. Churnside, N. Hillgruber, J.K. Horne, and S. Parker-Stetter. 2006. Survey strategies for assessment of Bering Sea forage species. North Pacific Research Board Final Report, 137 pp.