

BSIERP Project O2.7, Ichthyoplankton: Horizontal, vertical, and temporal distribution of larvae and juveniles of walleye pollock, Pacific cod, and arrowtooth flounder, and transport pathways between nursery areas

Ichthyoplankton Surveys, O2.7

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Summary

This project (O2.7) 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.

Transport and dispersal of early life stages from spawning areas to suitable nursery habitats is one critical component of the marine fish recruitment process, and factors experienced by the early life stages and those influencing the transport process have the potential to significantly impact larval mortality. Atmospheric and hydrographic changes in the Eastern Bering Sea (EBS) that may result from climatic changes may critically affect larval distribution and survival by altering current patterns, flow rates, and flow trajectories. Our project component will examine seasonal linkages between spring spawning areas, early summer distribution patterns, and late summer/early fall occurrences for three key fish species in the EBS: walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), and arrowtooth flounder (ATF; *Atheresthes stomias*). Specifically, horizontal and vertical distribution and abundance of eggs, larvae, and age-0 juveniles will be examined seasonally (spring, early summer, late summer/early fall) over three field years, 2008-2010. Spring work will emphasize horizontal and vertical distribution of eggs and larvae, summer cruises will examine dispersal and abundance of post-larvae and pre-settlement juveniles, and late summer cruises will use a large surface trawl to collect age-0 and age-1 pelagic juveniles of walleye pollock and Pacific cod. We will use concurrently collected abiotic (temperature, salinity, current direction and velocity) and biotic variables (fluorometry) to describe patterns in fish abundance and distribution. In addition, we will use lower trophic level information collected during the spring cruises to better describe rearing conditions for early life stages of the target species. To date, it is not clear if those data will also be provided on the summer cruises. In the fall, lower trophic level information may be available if collected as part of NOAA's BASIS program. Finally, data on distribution and abundance of age-1 walleye pollock and, to a lesser degree, Pacific cod will be available from NOAA's acoustic (O2.26) and surface trawl (O2.23, O2.28) surveys and will be assessed in 2009 and 2010, thus following cohorts of these species to evaluate overwinter mortality. We will synthesize biotic and abiotic data to provide a better understanding of the potential effects of hydrographic variations in rearing conditions and on transport, dispersal, and distribution of early life stages of key marine fish species in the EBS.

Background

The successful recruitment of fish larvae to suitable juvenile nursery areas is a necessary condition for growth, energy storage, survival, and subsequently recruitment to the adult populations. Climate variability, which may change existing meteorological and oceanographic conditions, will likely impact transport mechanisms between these areas. Without a better understanding of these transport pathways, larval behavior during the transport process, and delivery mechanisms (including settlement for flatfish), it will be impossible to predict the impact of changing climate conditions on recruitment success to the adult populations

Broad-scale geographic distributional data on eggs and larvae in the EBS in springtime have been summarized for walleye pollock and Pacific cod (Matarese et al. 2003), and two transport models exist for the region (wind driven - Wilderbuer et al. 2002; baroclinic - Lanksbury et al. 2007). However, a full, seasonal examination of egg and larval distribution of walleye pollock, Pacific cod, and arrowtooth flounder on the EBS shelf has not been accomplished, nor has there been any in-depth study of seasonal variations in the vertical distribution of fish larvae, with associated depth-discrete effects on larval transport. Finally, there are significant gaps in our knowledge of the ecology of the juveniles of any of these species (but see Norcross and Holladay 2005) and of the connectivity between larval and juvenile rearing areas. This project will fill many of those gaps in understanding by describing the vertical and

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horizontal distribution of early life stages of the three target species in spring, summer, and fall over the EBS shelf, elucidating potential mechanisms by which offspring are transported from spawning areas to favorable juvenile nursery grounds, and assessing what the possible effects of changing climate might be on larval dispersal, juvenile settlement, and overall recruitment success in these species.

Species and Geographic Scope

This project will examine walleye pollock (eggs, larvae, age-0), Pacific cod (larvae, age-0), and arrowtooth flounder (larvae, postlarvae) within the southeastern Bering Sea. The spring cruises will focus on the spawning grounds along the Alaska Peninsula for walleye pollock and Pacific cod, and on the shelf break for arrowtooth flounder. If possible, the summer cruise will use position information from drifters released in patches of larvae during spring to help direct work on its survey, and the fall sampling from the surface trawl surveys (O2.23) are from a fixed grid of stations from the Alaska Peninsula to Norton Sound.

Hypotheses

Data from the proposed research component will be used to test the following BSIERP hypotheses (Table 2):

1b. 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.

This hypothesis will be addressed in collaboration with component O2.24 (Heintz). Whenever possible, egg, larval, and juvenile samples will be collected and preserved in accordance with protocols necessary for a full biochemical analysis of condition. Age-1 assessments made the following year will provide estimates of overwinter mortality.

1c. Earlier spring transition will lengthen the period of time of organized onshore flow along the Alaska Peninsula.

Wilderbuer et al. (2002) hypothesized that shoreward wind-driven advection to favorable nursery habitat increases larval and juvenile flatfish survival. Further, (Wespestad et al. 2000) hypothesized that onshore currents separate juvenile fish from outer domain piscivores by transporting larvae inshore, away from adults. Accordingly, we would anticipate that increases in duration of organized flow along the Alaska Peninsula would result in increases in shoreward transport of larvae, increases in delivery of juveniles to favorable nursery areas, reductions in predator-mediated mortality, and increases in overall survival.

2c. 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.

A weakened inner front could open gateways to the inner domain for predators from the middle and outer domains (Ciannelli and Bailey 2005), or it could allow an expansion of inner domain habitat outwards, increase the carrying capacity of the inner domain for age-0 juveniles. This hypothesis will be addressed using seasonal measurements of distribution and abundance of pre-and post-settlement juveniles.

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2e. Expected decreases in benthic productivity will negatively affect feeding and survival of small flatfish and crab thereby lowering population levels.

In addition, this project will address the hypotheses that:

- (1) The Bering Slope Current and the Bering Coastal Current affect demographic connectivity of target fish taxa by influencing the transport and advection of ELH stages between spawning grounds and juvenile nursery habitats.
- (2) The scale and trajectory of larval dispersal is influenced not only by prevailing atmospheric and oceanographic conditions, but also by larval ontogeny and behavior, particularly as related vertical distribution behavior.
- (3) The vertical distribution of larval stages is a function of their ontogeny and the vertical structure of biotic and abiotic variables in the water column, such as light level, prey availability, temperature, and turbulence.
- (4) Settlement areas and nursery habitats are located inshore of spawning grounds, and post-larval and settlement stages will exhibit patterns of vertical distribution that maximize the probability of delivery inshore.

Project Description

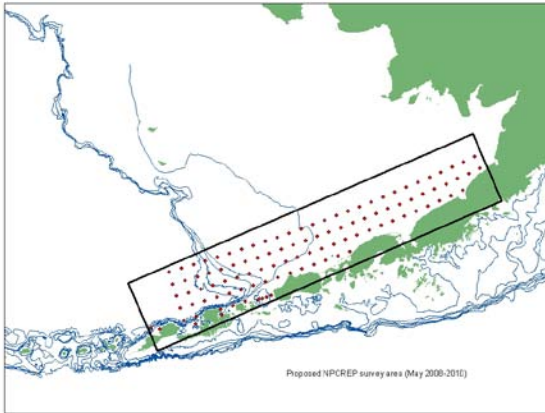
Larval and age-0 juveniles will be collected on three research cruises per year, 2008-2010. Seasonal coverage leverages two existing NOAA programs NPCREP (North Pacific Climate Regimes and Ecosystem Productivity; early May) and BASIS (Bering Aleutian Island Salmon International Survey; late August, a surface trawl survey (O2.23)). It also incorporates a summer cruise (June/July) as part of the NSF-BEST program to collect post-larvae and early juvenile fishes. In addition, a summer acoustic survey (AFSC, MACE, O2.26) will provide information distribution and abundance of age-0 juveniles in 2008-2010 and of age-1 overwinter survivors from the previous year's spawning in 2009 and 2010 and will provide samples to assess condition of age-1 fish.

Spring sampling

In May, ichthyoplankton will be collected during the annual NPCREP cruise conducted by the NOAA-EcoFOCI program. On a station grid of fixed stations located east and north of Unimak Island and extending eastwards along the Alaska Peninsula towards Bristol Bay (Figure 1). This cruise is located over the spawning grounds of walleye pollock, Pacific cod, and arrowtooth flounder.

Figure 1. Proposed spring sampling area over the EBS slope, outer, and middle shelves.

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Physical oceanographic (SeaCat) and larval fish prey (CalVET and bongo nets) will be collected in conjunction with ichthyoplankton samples (Bongo oblique tows, MOCNESS vertically stratified tows, and Neuston surface tows). In addition, satellite-tracked drifters will be deployed to follow current trajectories to examine larval dispersal mechanisms. Data from this cruise will be used to document the vertical and horizontal distributions of larvae. These data will be used to ground truth and parameterize IBM coupled biophysical models. Measurements of physical variables will be made at selected stations using a CTD rosette with water bottles. Additionally zooplankton data from the cruise will be merged with comparable data from the BEST component cruises to understand how the prey fields for larval and juvenile fish change in time. Egg and larval walleye pollock and larval Pacific cod will be identified to species at the Plankton Sorting and Identification Center (ZSIOP) in Szczecin, Poland, verified in Seattle, and quality controlled before being placed in the AFSC and BSIERP/BEST databases.

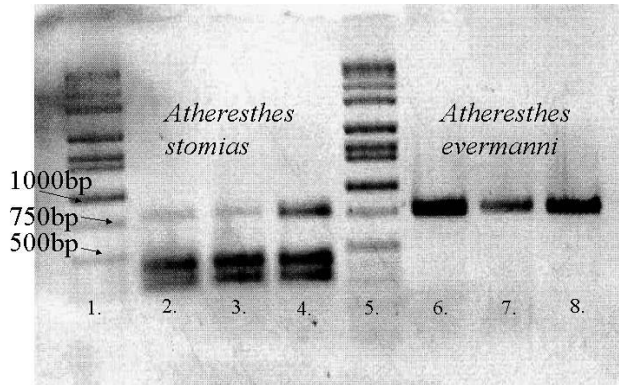
To date, egg and larval ATF cannot be distinguished by visual examination from early life stages of Kamchatka flounder (*Atheresthes evermanni*). We will collaborate with Dr. Michael Canino and Ms. Ingrid Spies (both of the AFSC) to develop a DNA-based method to provide unequivocal species identity of ATF and Kamchatka flounder eggs and larvae during ichthyoplankton surveys in nearly-real time. Preliminary results of genetic analyses on a subset of previously-collected samples indicate that *A. stomias* and *A. evermanni* larvae do co-occur (Rjoe, pers. comm.) in the sampling region of interest (southern EBS shelf), making immediate at-sea identification critical. We have developed an at-sea DNA-based assay to distinguish between these two species, which will enable rapid, conclusive species identification of these two species.

This assay is based on examination of the mtDNA region cytochrome c oxidase subunit I (*COI*) in vouchered adults of both species. This gene region has been shown to contain unique sequence information for most of the 32,000 species examined to date (www.boldsystems.org). We found that *A. stomias* contained a nucleotide sequence in *COI* that was not found in *A. evermanni*. The differences between the two species can be screened using a method called restriction fragment length polymorphism (RFLP). In this method, the polymerase chain reaction (PCR) is used to amplify the mtDNA segment of interest. Then a restriction enzyme is selected that will cut the DNA at the site containing specific nucleotides. We selected a restriction site that would cut the nucleotide sequence unique to *A. stomias*; the enzyme cuts the *COI* segment of *A. stomias* in to two fragments, but leaves the *A. evermanni* *COI* segment whole (see Figure 2).

Figure 2: PCR-RFLP of a 750 base pair (bp) fragment of the cytochrome oxidase subunit I (*COI*) mitochondrial gene discriminates between arrowtooth flounder (*Atheresthes stomias*, lanes 2-4) and

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Kamchatka flounder (*A. evermanni*, lanes 6-8), using restriction enzyme *BmtI*. Lanes 1 and 5 are a molecular size standard.



The at-sea protocol will involve DNA extraction of the unknown eggs and larvae using either chelex DNA extraction or FTA® DNA extraction cards (Whatman). Samples will be PCR amplified using *coxI_RajaF* and *coxI_RajaR* primers in a MJ research PTC-200 thermocycler (MJ Research). The restriction digest will be carried out using the restriction enzyme *BmtI* (New England Biolabs) at 37°C, according to manufacturer's instructions. Samples will be run on an Agilent 2100 Bioanalyzer and fragments will be analyzed to determine species identification.

This real-time capability will enable accurate assessment of larval/egg numbers in spawning areas and provide critical information for use in adaptive survey strategies. At-sea DNA-based identification tools have been used successfully to identify rockfishes at sea (Vetter, pers. comm.).

The implementation of a genetic method to identify ATF eggs and larvae to species would not only provide conclusive information on this species from the proposed series of cruises above, but it could also potentially allow the AFSC to retroactively examine all of its larval *Atheresthes* spp. collections from the Bering Sea and conclusively re-classify those (over 700 hauls). If it is determined that Kamchatka flounder larvae do co-occur with ATF larvae in the geographic areas examined, then all historical records of *Atheresthes* spp. larvae from those regions would be re-examined. This would make available over 10 years of ATF egg and larval collections from the southern Bering Sea, which could be added to information on ATF. This potential long-term data set on ATF early life stages is of particular importance in the light of changing climatic conditions and their potential impacts on larval ATF distribution patterns, changes in transport pathways and changes in ATF abundances, as observed in recent years.

Summer sampling

The second cruise of the seasonal cycle (2008 – 2010) will be conducted in June-July in conjunction with the physical/chemical oceanography and lower trophic level components of the BEST program. When possible, data from the drifters deployed in May will be used to construct the sampling grid for post-larval/juvenile fish; however, it is probable that the grid will overlap with the May and August grids connecting the Alaska Peninsula and inner Bristol Bay areas. For the purposes of this proposal, the BEST component will define the physical and biological attributes of the water column, make measurements on the strengths of the currents, identify frontal structures and determine their strength, and provide a platform to survey larval/juvenile fishes (*Hillgruber*). It is also anticipated, but to date not confirmed, that BEST-funded scientists will provide data to quantify prey abundance and composition available to the pre-settlement fishes. Pelagic larvae and post-larvae will be collected with a 0.25 m² multiple

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opening/closing MultiNet®, (MN, HydroBios) equipped with five, 1,000 µm mesh net bags. Flowmeters will be used to monitor the volume of water filtered. The MN will be fished in a double oblique manner, collecting ichthyoplankton over five depth ranges on the up-cast. Upon retrieval, the five nets will be rinsed, and concentrated samples will be fixed in 5% buffered formalin seawater solution. Larval fish will be identified to species at the ZSIOP; identifications will be verified in Juneau by a UAF Ph.D. student who will be working on this project.

Late summer/fall sampling

The third cruise of the seasonal cycle (2008-2010), which will be conducted in late August/early September (NOAA/BASIS), will sample juvenile fish over the EBS shelf with a surface trawl (O2.23). Pelagic juvenile fish distribution and abundance data will be collected during comprehensive, shelf-wide surveys of the Bering Sea epipelagic ecosystem. While the focus of BASIS research is on juvenile salmon, the broad spatial coverage of oceanographic and biological data collected during late summer and early fall provide insight into how the pelagic ecosystem on the eastern Bering Sea shelf responds to changes in spring productivity. Of particular relevance to this project, age-0 fish (primarily walleye pollock and Pacific cod) are collected concurrently with juvenile salmon (Feldmann et al. 2006), and data on gadid distributions and abundances will be synthesized as part of the ongoing BASIS program and dove-tailed with observations made on earlier cruises in the season. Since ATF settle out of the water column in late summer, we do not expect meaningful numbers of individuals of this species to be retrieved from the BASIS cruises. Additional acoustic data on pelagic juvenile fish distribution and abundance will also be collected BASIS cruises (surface trawl survey, O2.28) during calendar years 2008 through 2010. Data will be made available to the BSIERP to provide more information on pelagic nursery areas for juvenile fishes on the EBS shelf.

Additional data sources

A fourth cruise (AFSC/MACE) will conduct an extensive echo integration-trawl survey over the EBS shelf in July (acoustic survey, O2.26). Age-1 walleye pollock data from acoustic surveys in 2009 and 2010 will be used to provide information on overwinter survival of juvenile walleye pollock from the previous year's spawning (2008 and 2009). In addition, MACE-led Methot trawls may yield supplementary samples of age-0 and age-1 pelagic juveniles.

Any other relevant data collected from other ongoing NPCREP cruises in the EBS (February, September) will also be added to the project to provide as much information as possible on spawning, dispersal, transport, and settlement of ATF, Pacific cod, and walleye pollock on the southern EBS shelf.

Project Reporting

Research Products: Identification between *Atheresthes stomias* and *A. evermanni* will be conclusive. Results will provide information on depth-discrete distribution of ELH stages of walleye pollock, Pacific cod, and arrowtooth flounder in the EBS during spring, summer, and autumn. Potential spawning locations, seasonality, size, and growth will also be elucidated. Potential effects of climate variability on spawning, distribution, transport and recruitment in these species will be evaluated. These research products will also be available as input into the integrated modeling.

Research Links: We will work closely with Ciannelli and Bailey (O2.19) to integrate our data with theirs for a more complete understanding of spatio-temporal changes in spawning ecology for the three target species in the Bering Sea. A close collaboration with Heintz (O2.24) is anticipated to collect early life stages of target fish from cruises across seasons that will be used for bioenergetics analyses. This work will provide more information on larval/juvenile fish condition prior to the onset of first winter. We will work with Hollowed et al. (O2.17) to dove-tail our observations on walleye pollock age-0 distribution and

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abundance with their efforts to examine whether climate variations have broad-scale effects on walleye pollock distribution. Finally, the data and new understanding resulting from our research component will be directly integrated into several BSIERP/BEST models (M.4 – spatial ocean (ROMS), M.5 – NPZ lower trophic level, M.47 – FEAST) to predict the effect of future climate change on the eastern Bering Sea ecosystem. Our data will provide the means to ground truth these models and to compare modeled results with observed field data. As a result, this project will enhance our understanding of the distribution of early life stages of three ecologically and economically important Bering Sea fish taxa, provide information on the transport pathways between larval and juvenile nursery grounds, examine the mechanisms involved in the transport, and evaluate the effects of climate change of larval dispersal.

Research Reporting: include semi-annual reports (due January 15 and July 15 each year), the final project report and delivering field data to the modeling group due January 15 each year. Data will be compiled annually. Final analysis will begin in 2010, and papers submitted for publication by 2012.

Dissemination: Potential Manuscript Titles

Seasonal variation of larval fish assemblages in relation to oceanographic conditions in the Eastern Bering Sea

Niche partitioning between early life stages of walleye pollock and Pacific cod in the eastern Bering Sea

Transport and dispersal of larval gadids (walleye pollock and Pacific cod) on the eastern Bering Sea shelf: relationships with hydrography and implications for recruitment

Slope and shelf spawning flatfishes in the Eastern Bering Sea: a comparison of larval dispersal strategies and mechanisms

Early life history stages of *Atheresthes stomias* and *A. evermannii* in the Eastern Bering Sea

Annual variation in patterns of distribution and abundance of larval and juvenile fishes in the eastern Bering Sea: cold vs. warm years

Temporal evolution of spring conditions along the Alaska Peninsula of the southeastern Bering Sea: currents, mixing, and plankton

Graduate Students and Post-docs:

PhD Student (UAF) 4 years of support

Postdoctoral Associate (UW/JISAO) 2.5 years of support

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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, Whitedge, 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
	Forage distribution & ocean conditions	O2.17	Hollowed, Wilson, Kotwicki, DeRobertis, Ressler, Cokelet	\$ 567,123	\$ 553,311
Trophic interactions	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			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		
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

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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

BSIERP Project O2.7, Ichthyoplankton: Horizontal, vertical, and temporal distribution of larvae and juveniles of walleye pollock, Pacific cod, and arrowtooth flounder, and transport pathways between nursery areas

- light exploitation rates, top-down control by arrowtooth flounder will increase, as will their level 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.