approved TC 8-9-99

Seabird-Oceanographic Relationships in the Northern Gulf of Alaska: Integration with NSF/NOAA Study GLOBEC

Project Number:	00287-BAA
Restoration Category:	Research
Proposer:	R. Day/ABR, Inc.
Lead Trustee Agency:	NOAA
Cooperating Agencies:	None
Alaska SeaLife Center:	No
New or Continued:	New
Duration:	1st yr. 1 yr. project
Cost FY 00:	$151.3
Cost FY 01:	$0.0
Cost FY 02:	$0.0
Geographic Area:	Northern Gulf of Alaska
Injured Resource/Service:	Seabirds, marine mammals

ABSTRACT

This project will conduct a study of seabirds in the Northern Gulf of Alaska (Aialik Bay to Montague Island) by using a ship-of-opportunity sampling platform that is being used by the National Science Foundation/National Oceanographic and Atmospheric Administration project GLOBEC (U.S. Global Ocean Ecosystem Dynamics), which also will provide access to an extensive series of oceanographic data. This project is designed to identify ecological processes affecting temporal (seasonal and interannual) and geographic variability in the distribution and abundance of seabirds, including several species that were injured by the oil spill. It also will be useful to the restoration program by providing data on the year-round status of seabird populations and the processes that influence variability in their numbers.

INTRODUCTION

This study will use an available ship-of-opportunity platform to investigate temporal (seasonal and interannual) and geographic (cross-shelf) patterns of distribution and abundance of seabirds in the Northern Gulf of Alaska (GOA). The Trustee Council will benefit from this study in three ways. First, this study will provide quantitative information on bird communities in the first part of the GOA where the oil went after it left Prince William Sound. Second, I have been offered free space on a ship that is being used for the NSF/NOAA program "GLOBEC" (Global Ocean Ecosystem Dynamics), which is a project that during years 1998-2000 will study temporal and geographic variations in thermohaline, chemical, and biological structure of the Northern GOA shelf (Appendix 1). The overall thrust of the GLOBEC study is to determine ecosystem-level causes (particularly climatic variability) of successful versus unsuccessful recruitment in juvenile salmon. Second, I will provide to this study an extensive data-set that I will have collected for this study over the period 1997–1999. This additional data-set will provide information on interannual variability in the distribution and abundance of seabirds and marine mammals.

The goal of this study will be to identify ecological processes affecting temporal and geographic variability in the distribution and abundance of seabirds by capitalizing on data generated by the GLOBEC study. The proposed research described here is designed to provide new information on the causes of temporal and geographic variability in the distribution and abundance of these seabird species. I believe that this information will be important for effective conservation and management of these species.

The primary reasons for this study are: (1) it will collect ecological data on a diverse suite of seabird resources, including several that the *Exxon Valdez* Oil Spill Trustee Council concluded were injured by the spill (*Exxon Valdez* Oil Spill Trustee Council 1999); (2) these data can be used, not just to examine temporal and geographic variations in distribution, abundance, and species composition of these seabird species, but to examine the effects of ecological processes on those variations; (3) it will describe the natural variability of the ecosystem, particularly with respect to seabirds; and (4) it will be useful in establishing criteria for ecosystem-level monitoring. I also will be able to collect supplementary data on the distribution and abundance of marine mammals, some of which (e.g., Killer Whale) were identified as having been injured by the spill (*Exxon Valdez* Oil Spill Trustee Council 1999). Finally, this is the first opportunity for systematic seasonal and interannual sampling of the cross-shelf distribution of seabirds in the Northern GOA.

NEED FOR THE PROJECT

A. Statement of Problem

This study will examine the distribution and abundance of seabirds and marine mammals in the Northern GOA and will attempt to relate variability in that distribution and abundance to variability in ecosystem-level properties. This variability will be examined temporally (both seasonal and interannual variability) and geographically (i.e., cross-shelf variability). This project also will describe systematically for the first time the seasonal and interannual patterns of occurrence of seabird and marine mammal species on the northern GOA shelf, which was the first place where oil leaving Prince William Sound went. From data collected so far, several species of seabirds and marine mammals that were recorded as being impacted by the *Exxon Valdez* oil spill occur in this region during the winter (e.g., common murre, pigeon guillemot, Kittlitz's murrelet, killer whale), with common murres apparently constituting an important component of this wintering community and a significant percentage of the entire Northern-GOA population of Kittlitz's murrelets wintering out here (Day, unpubl. data). The strength of this proposed study is that it will be used to develop an understanding of those processes that cause variability in the at-sea distribution and abundance of seabirds and that it will lead to a long-term data set that will be examined for the study of variability, yet will cost little because of my ability to use a ship-of-opportunity for sampling and an extensive oceanographic data set for interpreting my data-set in an ecological context.

In addition to the practical applications of learning about the at-sea ecology of seabirds in the area where most of the mortality occurred, understanding the causes for temporal and geographic variability in seabird distribution at sea is one of the greatest challenges facing marine bird researchers. Understanding such variability also is important in determining why and how seabirds may or may not recover from injury such as that following an oil spill: after all, the sea is where they secure food, not only for themselves but also for any young that they produce.

The strength of this proposed study is that it will be used to develop an understanding of those processes that cause variability in the at-sea distribution and abundance of seabirds and that it will lead to a long-term data set that will be examined for the study of variability, yet will cost little because of my ability to use a ship-of-opportunity for sampling and an extensive oceanographic data set for interpreting my data-set in an ecological context. Most importantly, this study will collect data on a large suite of seabird species (and, to a lesser extent, marine mammals), including several species that were impacted by the oil spill.

B. Rationale/Link to Restoration

There are at least 12 reasons why this study is important. First, most of the avian mortality (particularly of murres, but also of many other species) after the *Exxon Valdez* oil spill is believed to have occurred in the Northern GOA, rather than in Prince William Sound (Piatt et al. 1990, Ford et al. 1996, Piatt and Ford 1996). Second, breeding seabird colonies are both larger and more numerous in the Northern GOA than in Prince William Sound (USFWS Seabird Colony Catalog, electronic version), as generally are seabird at-sea densities (Day, unpubl. data). In spite of these facts, however, the amount of effort dedicated to post-spill research in the GOA was a fraction of that dedicated in Prince William Sound. Third, knowing where seabirds occur at different times of the year will enable one to predict those species that probably will be affected by an oil spill. For example, if a spill occurs at the shelf-break off of Hinchinbrook Entrance, one would predict that species concentrated downstream, along the shelf-break within the study area, will be affected more than inshore species will be. Fourth, this study will collect ecological data on a diverse suite of seabird resources that the *Exxon Valdez* Oil Spill Trustee Council concluded were injured by the spill (*Exxon Valdez* Oil Spill Trustee Council 1999), including common loon, cormorants (any or all of three species), common murre, pigeon guillemot, marbled murrelet, and Kittlitz's murrelet, as well as even recording the endangered Short-tailed Albatross. In fact, common murres appear to be a dominant species over the inner and central continental shelf in this region, and Kittlitz's murrelets appear to winter in this sector of the GOA shelf in substantial numbers, with perhaps the entire Prince William Sound population occurring here at that time (Day, unpubl. data). Fifth, this study will provide the first systematic, year-round, and interannual surveys of seabird and marine mammal populations on the shelf of the northern GOA. Sixth, the three years of data collected for this study (including data collected in 1998 and 1999) possibly will lead to another five consecutive years of data collection (funded by NSF and NOAA), thus potentially providing one of the temporally longest sets of at-sea data on seabirds ever collected in one part of Alaska. Seventh, this study also will be able to collect supplementary data on the distribution and abundance of marine mammals, some of which (e.g., killer whale) were found to have been injured by the spill (*Exxon Valdez* Oil Spill Trustee Council 1999). Eighth, this study would enable one to collect data as a long time-series that would enhance one's understanding of the patterns of variability in at-sea communities of seabirds. Understanding these patterns of natural variability in at-sea populations of seabirds will enable realistically measurable recovery criteria to be developed. Determining the natural variability of the system, particularly with respect to seabird abundance, will enable one to measure better what constitutes "recovery" of a species (i.e., take into account the natural "noise" in the system) and to determine what are meaningful recovery and monitoring criteria. Ninth, this study will capitalize on the findings of other GLOBEC researchers to identify causes and sources of this variability in the at-sea distribution and abundance of seabirds. Tenth, because the overall goals of the GLOBEC program are (a) to understand the effects of climate variability and climate change on the distribution, abundance, and production of marine organisms and (b) to incorporate this knowledge into diagnostic and prognostic models (Appendix 1), identifying these relationships may help in the future prediction of seabird distribution, abundance, and productivity in the face of global change, thus enhancing one' ability to manage these resources. Eleventh, this study will examine the seasonal and interannual importance to seabirds of oceanographic frontal structures, which tend to concentrate not only marine organisms and their seabird predators, but also floating pollutants such as oil and marine debris (Bourne and Clark 1984). Twelfth, because the first year of the study (1997–1998) was conducted during the large El Niño event that affected most of the North Pacific, subsequent years also will provide a nice contrast to help one understand the effects of such events on at-sea bird communities.

C. Location

This study will be conducted in the open waters of the continental shelf of the northern GOA, from the Pye Islands to Hinchinbrook Entrance. Because Seward is the home port for the cruises, it will be the primary community that will realize financial benefits from this study. To my knowledge, no communities will be affected by this project other than financially.

COMMUNITY INVOLVEMENT AND TRADITIONAL ECOLOGICAL KNOWLEDGE

Community involvement will encompass the use of Seward as a home port for the research cruises. This is the home port of the R/V *Alpha Helix*, which is the University of Alaska's oceanographic research vessel. When requested, I will provide articles and photographs for the Trustee Council Newsletter and will be available to make public presentations of this study at appropriate forums. (I already have assisted Jody Seitz of Cordova with interviews about Kittlitz's Murrelets for public radio stations throughout the spill-affected area.) These articles and presentations will disseminate information on the objectives and major findings of this study to the general public.

My understanding is that seabirds on the open continental shelf of the Northern GOA play no role in subsistence use by local Natives in Prince William Sound (M. Vlasoff, pers. comm.). I would, however, draw on any local information that is available on these species on the open shelf and, especially, to be able to collect samples from any seabirds that are killed there for subsistence use.

Although no communities would be directly involved in this study, local communities such as Seward would benefit because they are involved in tourist-based industries. These industries are involved in wildlife viewing, with seabird viewing in particular playing a major part in that industry.

PROJECT DESIGN

A. Objectives

The overall goal of this study is to understand better the causes of temporal (seasonal and interannual) and geographic (cross-shelf) variability in the distribution and abundance of seabirds (and, secondarily, marine mammals) in the Northern GOA shelf. Specifically, it aims to relate quantitatively this variability in seabird abundance and distribution to oceanographic parameters, including the thermohaline, chemical, and biological structures of the Northern GOA shelf. The specific objectives of the proposed research program are:

1. To measure and describe temporal (seasonal and interannual) and geographic (cross-shelf) variation in seabird distribution and abundance on the Northern GOA shelf.

2. To relate these patterns of temporal and geographic variation to patterns of contemporaneously collected physical and biological characteristics.

3. To examine the ecological importance to birds of fronts at the outer edge of the Alaska Coastal Current and at the shelf-break.

4. To relate the observed natural variability in seabird populations to an assessment of recovery.

B. Methods

This study proposes using a ship-of-opportunity to collect at-sea transect data that will be used to examine the distribution and abundance of seabirds on the shelf of the Northern GOA during 6 cruises/year. (See letter of support offer from GLOBEC researchers in Appendix 2.) These data will be collected as standard at-sea transect samples as developed by the USFWS and others.

The GLOBEC cruises will be conducted during six periods of biological interest in the region:

- March (upward migration of oceanic zooplankton to surface layers);
- April (spring phytoplankton bloom);
- May (maximal biomass of oceanic copepods in surface layers);
- July/August (juvenile salmon first enter the sea);
- October (juvenile salmon prepare to leave the shelf and enter the Alaska Gyre); and

- December (minimal biological activity).

Each cruise has budgeted enough time to sample the Seward Line of standardized oceanographic stations, which have been sampled irregularly since the mid-1970s (i.e., around the time of the marine regime shift); on that line, Station GAK1 has been sampled nearly continuously for 29 years. Additional station lines (primarily to the east) also are sampled, when possible. These latter station lines are laid out between the Seward Line (which lies off the mouth of Resurrection Bay) and Hinchinbrook Entrance and include (so far) lines south from Cape Fairfield, Cape Suckling, and Cape Cleare, two lines off of the southern entrance of Montague Strait, and two lines south from central and eastern Montague Island. This oceanographic sampling is envisioned to be adjusted to some extent for conditions that are met on each particular cruise; however, the Seward Line always will be sampled on each cruise.

Through the GLOBEC program, I will have access to the following oceanographic data:

- CTD (conductivity, temperature, and depth) data collected at a series of fixed stations that are 10 km apart on the inner half of the shelf and 15 km apart on the outer half;
- ADCP (Acoustic Doppler Current Profiler) data on water-column velocity profiles of currents (continuously collected);
- Through-hull surface property values of sea-surface temperature, salinity, and fluorescence (continuously collected);
- Nutrients and primary productivity (collected at a series of fixed stations);
- Zooplankton and micronekton species composition and biomass collected with CalVET, MOCNESS, and bongo nets (collected at a series of fixed stations);
- Hydroacoustically measured biomass of zooplankton and micronekton (continuously collected); and
- Biomass, species composition, and energy content of fishes (primarily salmon, but also forage fishes) collected with MOCNESS and mid-water trawls (collected at a series of fixed stations; the mid-water trawling will be conducted during the July/August and October cruises only).

During each cruise, I will sample at-sea densities of seabirds with standardized seabird transects (Tasker et al. 1984, Gould et al. 1989, van Franeker 1994). The preferred method is the "snapshot method," which has less bias in density estimates of flying birds, particularly tubenosed birds (albatrosses, fulmars, shearwaters, petrels, and storm–petrels), than do other methods (van Franeker 1994). (Tubenosed birds are common in the sampling area at certain times of the year [Day, unpubl. data].) Transects will be 300 m wide as the ship moves ahead in a fixed and known direction at a fixed and known speed. Then, for analyses, I will calculate the density of birds for each transect by dividing the total count by the total area sampled (trackline length × 0.3 km total width). Initial ("raw") transect units in the field will be 5 min long, with data recorded by minute, as the ship travels between each pair of fixed oceanographic stations or runs between station lines. This is the approximate scale at which the finest-scale data (hydroacoustic biomass of zooplankton) of interest will be collected by the GLOBEC study. Then, for later analyses, these "raw" transect samples can be collapsed into larger "analytical" transect units, depending on the scales at which the other oceanographic data are summarized; because they will have been collected by the minute, the data can be analyzed by minute, if necessary. Such a flexible data collection/analytical program will enable one to examine the distributional data at the scales at which I find oceanographic features of interest (also see Haney and Solow 1992).

I will evaluate three primary hypotheses about seabirds, with additional hypotheses generated by the results of the field work:

H_0 1: There is no temporal (seasonal and interannual) variation in seabird distribution and abundance; if there is, it is independent of seasonal and annual variation in physical and biological oceanographic features.

This is the primary line of investigation of the GLOBEC study and will be an emphasis of this study. I will use the transect data in a series of analyses that will test whether there is seasonal and/or interannual variation in seabird distribution and abundance. As described above, I will test the temporal data at the scales that are most appropriate (i.e., pooling the raw data into larger analytical data sets as needed). At this time, I envision analyzing for temporal differences with a three-way MANOVA on ranked (if necessary) data, with habitat (i.e., water mass), season, and year as the treatments and the species or functional groups as the dependent variables. If pseudoreplication appears to be a problem with the data sets (see Hurlbert 1984), I might explore testing for differences with paired-sample tests (e.g., MANOVAs that use differences in densities between sampling periods as the sampling unit). These tests that use changes in numbers of birds may be used in a "before-after" type of analysis to examine changes in abundance among seasons and years (Stewart-Oaten et al. 1986, Murphy et al. 1997). The use of changes in densities (rather than testing with actual densities) between periods (with 1998 being labeled the "before" period and subsequent years being the "after" periods) results in independent data sets that minimize problems caused by pseudoreplication (Stewart-Oaten et al. 1986, Wiens and Parker 1995).

To examine whether there are relationships between seabird distribution and abundance and physical/biological oceanographic features, I will work with the GLOBEC researchers to use their data products for determining which scales to use in the analyses. First, I will plot seasonal (and interannual) variations in various oceanographic measurements and seabird distribution and abundance and interpret trends visually. Second, I will use a multivariate technique (e.g., MANOVA, MANCOVA, PCA) to test for relationships between multiple oceanographic measurements (e.g., water-column structure [strength of stratification, presence of fronts and other structures]; mixed-layer depth; biomass of zooplankton, micronekton, and fishes) and abundance measurements of multiple seabird species. I envision conducting these analyses on two seabird data sets: individual species and functional groups (guilds). In terms of the latter, I will assign each species to functional groups involving primary feeding method (e.g., surface feeding, pursuit diving) and primary prey type (e.g., zooplankton, fishes, squids) before conducting the analyses.

H_0 2: There is no geographic (cross-shelf) variation in seabird abundance; if there is, it is independent of geographic variation in physical and biological oceanographic features.

This is the secondary line of investigation of the GLOBEC study. I will use the transect data in a series of analyses that will test whether there is geographic variability in seabird distribution and abundance. As described above, I will test the geographic data at the scales that are most appropriate. I will use the oceanographic data to stratify the cross-shelf zone into a series of oceanographic habitats that can be used to test for differences in seabird distribution and abundance. Such habitat stratification has been used successfully in many other seabird–oceanography studies (e.g., Wahl et al. 1989, Haney 1991, Day 1992). At this time, I predict that there will be at least three habitat strata: the Alaska Coastal Current (extending from shore to ≤25 km offshore), the mid-shelf region (whose ecology is poorly understood at this time), and the oceanic region (from around the shelf break to over the continental slope and including at least part of the Alaska Current). Although published literature indicates that densities of zooplankton and larval fishes in Shelikov Strait often are higher in the Alaska Coastal Current than in surrounding areas (Incze and Ainaire 1994, cited in Napp et al. 1996; Napp et al. 1996), my impression from six winter cruises so far is that densities of zooplankton, fishes, and seabirds are highest in the inner half of the mid-shelf water and much lower in the Alaska Coastal Current. Densities also appear to be fairly high around the shelf-break front during most cruises.

Again, I will use the GLOBEC data products for determining which scales to use in the analyses. I will plot cross-shelf variations in various oceanographic measurements and seabird abundance and interpret differences visually. I also will test for differences in habitat use with a multi-factor MANOVA on ranked (if necessary) seabird data. As described in the temporal tests (above), habitat would be one of the factors included in the MANOVA. I also will use the guild data in a similar multi-factor MANOVA.

H_o 3: There is no association between seabird abundance and the location and strength of oceanographic fronts and other physical structures; if there is, it is independent of geographic variation in physical and biological oceanographic features.

Seabirds exhibit variability in at-sea distribution and foraging with respect to oceanographic features: fronts of various types (e.g., Schneider 1982, Haney 1985b; Haney and McGillivary 1985a, b; Harrison et al. 1990, Schneider et al. 1990, Day 1992, Hunt et al. 1996, Mehlum et al. 1998; but also see Loggerwell and Hargreaves 1996, and Mehlum et al. 1996), frontal eddies (Haney 1986a, b), internal waves (Haney 1987), upwelling (either within cyclonic eddies or bathymetrically driven; Haney 1985a), pycnocline topography (Haney 1991), and water masses (e.g., Wahl et al. 1989, Haney 1991, Day 1992, Ribic et al. 1992). Fronts tend to be areas of enhanced productivity and concentration of both zooplankton and larval fishes and squids (e.g., Owen 1981, Munk et al. 1995, Sabatés and Olivar 1996), and seabirds appear to be "physical oceanographers" that are highly efficient at locating such structures. Hence, I will examine the association between seabirds and other physical structures, when possible, in addition to examining the association between seabirds and frontal structures.

I specifically will investigate the importance of these fronts to seabirds on a seasonal and interannual basis. I will use the GLOBEC data products for determining which scales to use in the analyses and will plot cross-shelf variations in various oceanographic measurements and seabird distribution and abundance and interpret differences visually. I also will test for relationships between seabird abundance and the distance from the center of each front with correlation analyses (e.g., Spearman rank correlation; see Day 1992: 36–45).

In addition to the hypothesis testing, I will use the seabird data to conduct power analyses. These analyses will examine the questions: "Given the variance in the data and the sampling scheme that is set up, how small a change in seabird abundance can one detect?" and "Given the variance in the data, how many samples would one need to detect an X% change in abundance?" These calculations will be made at the end of the study, with all three years of data combined. Hence, they will provide insights into criteria that will be useful in ecosystem monitoring.

Although it will not be a primary focus of this study, I also will be able to collect supplementary data on the distribution and abundance of marine mammals concurrently with the seabird data. Because the emphasis will be on seabird data, however, I probably will be unable to collect marine mammal data on standardized surveys. Instead, I will record any marine mammals seen out to the horizon. Such opportunistic data provide relative numbers that are adequate for interannual comparisons, however (Baretta and Hunt 1994).

As an example of the kinds of data that will be available for this study, Figure 1 shows the vertical structure of the water column along the Seward Line during the first GLOBEC cruise in October 1997. There are three primary features along this line: (1) the Alaska Coastal Current from Stations 1 to 3, with a strong salinity and density front at its outer edge; (2) the inner edge of the large Alaska Stream from Stations 9 (the shelf break) to 13; and (3) the poorly understood and sluggish Mid-shelf Water between these two large current systems.

Figure 2 shows an example of data that I was able to collect on the same GLOBEC cruise. The plot is of uncorrected seabird abundance along the Seward Line, which is the primary sampling location for this study. Data points represent individual 5-min transects and are uncorrected for sampling area; because they have not been proofed or corrected and because a few data are off-transect records, these results should be considered to be preliminary at this time. From the individual plots, one can see (1) the concentration of all birds of all species combined at the microscale surface convergence between Stations 3 and 4 and in what is probably the shelf-break front at the inner edge of the Alaska Stream (top); (2) the concentration of fork-tailed storm-petrels in what is probably the shelf-break front at the inner edge of the Alaska Stream (middle); and (3) the concentration of Dall's porpoises in the outer edge of the Alaska Coastal Current and in the front separating that current from the mid-shelf water (bottom). Hence, these preliminary results suggest that there is extensive geographic variability in total seabird abundance and in the abundance of at least some individual species.

Figure 3 shows another example of data along the Seward Line that I was able to collect on the same GLOBEC cruise. In these plots, one can see: (1) the concentration of northern fulmars in the Alaska Coastal Current, in the convergence between Stations 3 and 4, and near what may be a small front near Station 12 (top); (2) the concentration of common murres in the Mid-shelf Water, with peak numbers occurring at the convergence between Stations 3 and 4 (middle); and (3) the non-overlapping distribution of the tufted puffin, which was restricted to the outer shelf and (primarily) the Alaska Stream (bottom).

Figure 4 shows an example of fish data along the Seward Line that were collected during the October 1998 cruise (L. J. Haldorson, University of Alaska, Juneau, AK; unpubl data). In these plots, the CPUE for all fish species combined is shown on the top, and catch per unit effort (CPUE) for selected species groups is shown on the bottom. In both plots, CPUEs are highest in the inner half of the mid-shelf water. This region qualitatively appears to consist of some sort of physical structure, such as an eddy, that seems to be fairly stationary in both time and space. Hence, although this cruise occurred at a time that is different from the above data, similar across-shelf patterns are present.

Although not shown here, data from the March and April 1998 cruises showed dramatic differences from the October 1997 cruise (Day, unpubl. data). For example, species diversity along the Seward Line was high (21 species) in October 1997 but low (only ~8 species) in March 1998 and increasing in April 1998 (~15 species) and May 1998 (~21 species), then decreasing again the following winter (~15 species in December 1998); species richness on the Seward Line in March 1999 was only ~7 species, a number nearly identical to that for March 1998 and suggestive of a pronounced seasonal/annual pattern in species richness. In addition, species evenness clearly had changed from October 1997 to spring 1998, in that the distribution of common murres was restricted to the inner half of the shelf in October, whereas they had become dominant across the shelf and probably represented ~75% of all birds seen in March and ~50% of all seen across the entire Seward Line in April. In addition, they occupied essentially the entire shelf in March and April, whereas tufted puffins were absent at that time, having moved farther offshore, into the deep North Pacific. Clearly, there are oceanographic and ecological reasons for such seasonal and geographic changes in both species diversity and the abundance and distribution of individual species.

C. Cooperating Agencies, Contracts, and Other Agency Assistance

I will have free use (ship-of-opportunity) of a research vessel that is being used by the Institute of Marine Sciences (IMS), University of Alaska, Fairbanks, for the GLOBEC studies. All field and office work will be conducted by ABR, Inc. The Trustees Council will need to pay an outside agency for a Program Manager and for general administration. (These management costs will be funded directly from the Trustee Council to the agency, which is how my other Trustee-funded contracts were set up. Hence, that management money is not listed on the enclosed budget.)

SCHEDULE

A. Measurable Project Tasks for FY00 (October 1, 1999-September 30, 2000)

Deleted per peer reviewers, budget reflects this.

Mar 2000:	First cruise (emphasis: upward migration of oceanic zooplankton)
Apr 2000:	Second cruise (emphasis: spring phytoplankton bloom)
May 2000:	Third cruise (emphasis: maximal biomass of oceanic copepods)
~~July/August 2000:~~	~~Fourth cruise (emphasis: juvenile salmon first at sea)~~
Oct 2000:	Fifth cruise (emphasis: juvenile salmon prepare to leave the shelf)
Dec 2000:	Sixth cruise (emphasis: minimal biological activity)
Mar-Dec 2000:	Keypunch data and QA/QC (after each cruise)
Dec 2000–Jan 2001:	Data analysis
Jan-Apr 2001:	Preparation of Final Report
January–February 2001:	Presentation of paper at scientific meeting
15 April 2001:	Submit Final Report

B. Project Milestones and Endpoints

1. "To measure and describe temporal (seasonal and interannual) and geographic (cross-shelf) variation in seabird distribution and abundance on the Northern GOA shelf." Densities will be estimated and will be tested for seasonal and geographic differences during each year of

the study (FY00). Interannual differences will be tested during the one year of the study with data collected that year (FY00) and the two earlier years.

2. "To relate these patterns of temporal and geographic variation to patterns of contemporaneously collected physical and biological characteristics." Relationships will be tested, both among seasons within years and during the same season among years, during the one year of the study, with data collected that year (FY00) and the two earlier years.

3. "To examine the ecological importance to birds of fronts at the outer edge of the Alaska Coastal Current and at the shelf-break." Relationships between the location of fronts and the abundance of seabirds will be tested, both among seasons within years and during the same season among years, during the one year of the study with data collected that year (FY00) and the two earlier years.

4. "To relate the observed natural variability in seabird populations to previous assessments of impact and recovery." At the end of the study, analysis of variability and power calculations will be done for each year separately and for all years of the study combined (i.e., FY00).

C. Completion Date

Sampling for the project will be completed in FY00. Data analysis and preparation of the Final Report and publications will be completed in FY00.

PUBLICATIONS AND REPORTS

I will submit a Final Report to the Chief Scientist no later than 15 April 2001. This Final Report will synthesize results from the study. I also will prepare one or more manuscripts reflecting the results of this study. I envision that these manuscripts generally will be written with one or more of the GLOBEC researchers as co-authors.

PROFESSIONAL CONFERENCES

To save money, I do not plan to attend a scientific conference in FY00.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

I hope to be able to integrate the results of this study with those of the SEA study and the APEX study. My understanding is that SEA will be ended and that APEX will be in the final year of its funding by the time this project begins, so the chances for extensive interaction and integration may be small. Further, those projects are concentrated on the summer months, whereas most of the data collected for this study are collected during the winter, making many comparisons difficult. In addition, the SEA study was entirely concentrated within Prince William Sound, as was most of the APEX study, whereas this study will be conducted in the Northern GOA. Nevertheless, I will have a great opportunity to build on some of their findings.

The NSF/NOAA oceanographic study GLOBEC is co-funding this proposed study. It will provide an oceanographic platform (at the cost of $12,500/day) and an extensive set of oceanographic data that will cost ~$1,500,000 and take 3 years to collect.

This project will describe the natural variability of the system, particularly with respect to seabirds, enabling one to know better what natural variability in patterns of abundance are. Knowing this variability will enable researchers to predict better what sorts of differences might be detected in the wake of a large ecological perturbation, such as the *Exxon Valdez* oil spill or a large El Niño. Further, knowing this variability and its causes may affect interpretations of what constitutes "recovery" of a species (i.e., if determining recovery is an objective, one need to know what is the natural "noise" in the system is, since impact analysis involves comparing "signal-to-noise" ratios).

Although the *Exxon Valdez* Oil Spill Trustee Council expressed interest in this study in FY98, funding was not allocated for the first and second years of this project. Because of the importance of collecting as many data as possible so that the time-series is as extensive as possible, ABR has funded four cruises of data collection so far (October 1997 and March, April, and May 1998), and the Principal Investigator (RHD) has funded the December 1998 and March 1999 cruises and will fund at least the April, May, October, and December 1999 cruises. Hence, ABR and RHD will have invested a great deal of money and time in co-funding this study. Thus, in addition to the strong co-funding component in the form of ship-of-opportunity sampling coming from NSF and NOAA, there will be a strong co-funding component coming from both ABR and the Principal Investigator. Consequently, I will have the strongest and most complete data set available for testing these hypotheses.

EXPLANATION OF CHANGES IN CONTINUING PROJECTS

This is a proposed 1-year project. Hence, there are no proposed changes in this year. Please note that the budget includes additional time and money for analyses of the extensive data set that already will have been collected in 1997–1999 (~11 cruises worth of data). Additional time also has been budgeted for necessary coordination and synthesis of oceanographic information that will help to determine the direction of some of the analyses. This coordination will occur with other investigators on the GLOBEC study.

PRINCIPAL INVESTIGATOR

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PRINCIPAL INVESTIGATOR AND KEY PERSONNEL

Dr. Robert H. Day will be the Principal Investigator for the project. Bob has conducted research on seabirds, marine ecology, impacts of marine pollution, and marine conservation topics in Alaska and the North Pacific since 1975. His research topics have included the biology of poorly known seabirds in Alaska; the ecology of seabirds at sea in relation to oceanography (the topic of his Ph.D. dissertation); the ingestion of plastic pollutants by seabirds in Alaska; the mortality of seabirds in the high-seas drift-gillnet fishery of the North Pacific; and the distribution, abundance, and decomposition of plastic pollution and other marine debris in the North Pacific. Recently, he conducted several years of research on impacts of the *Exxon Valdez* oil spill on habitat use by marine-oriented birds and on bird communities (sponsored by Exxon Company, USA) and on the ecology of Kittlitz's Murrelet (sponsored by the *Exxon Valdez* Oil Spill Trustee Council). Dr. Day also has provided expert consultation to the USFWS as a member of the Spectacled Eider Endangered Species recovery Team, as an author of the Draft Steller's Eider Recovery Plan, and as a reviewer of the Short-tailed Albatross listing proposal.

Dr. Day is employed by ABR, Inc., Environmental Research and Services (formerly Alaska Biological Research, Inc.). ABR is an Alaskan-owned small business—headquartered in Fairbanks since its formation in 1976—that specializes in environmental research and services. During more than two decades of operation in Alaska, ABR has served a variety of clients, including private industry, state and federal government agencies, and the University of Alaska. During this time, ABR has developed a reputation for conducting objective research that provides the basis for sound management decisions. ABR remains committed to the goals of providing timely, accurate, and cost-effective information to those who manage or develop our natural resources.

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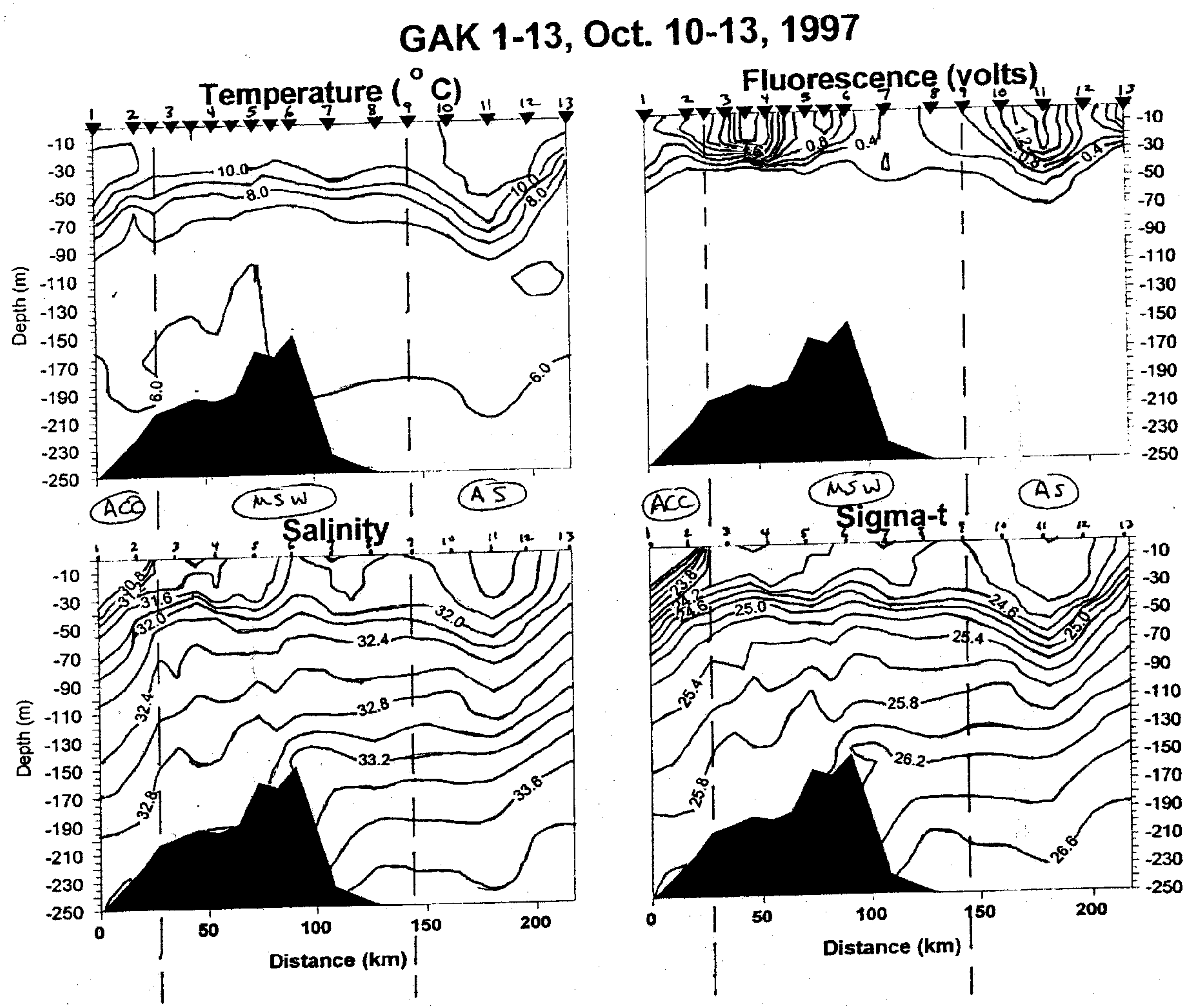


Figure 1. Vertical cross-sections of temperature, salinity, density (sigma-t), and fluorescence along the Seward Line, October 1997 (T. Weingartner, University of Alaska, Fairbanks, unpubl. data). Data are plotted with inshore on the left end of the plots. Abbreviations are: ACC = Alaska Coastal Current; MSW = Mid-shelf Water; AS = Alaska Stream. Inshore is on the left side of this plot.

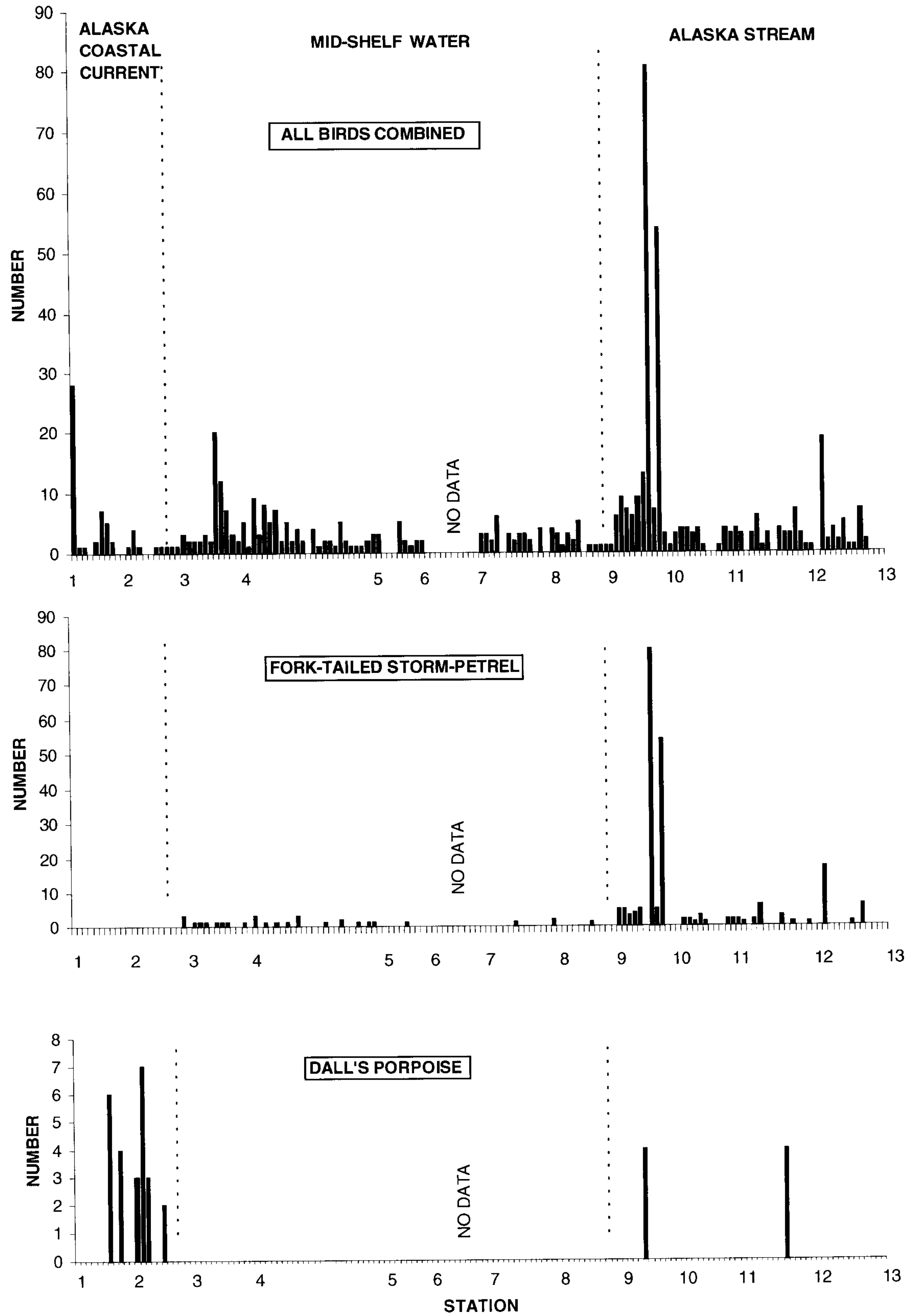


Figure 2. Cross-shelf distribution and abundance of all seabird species combined, fork-tailed storm-petrels, and Dall's porpoises along the Seward Line, October 1997. Data are preliminary and are not to be cited. Inshore is on the left side of this plot.

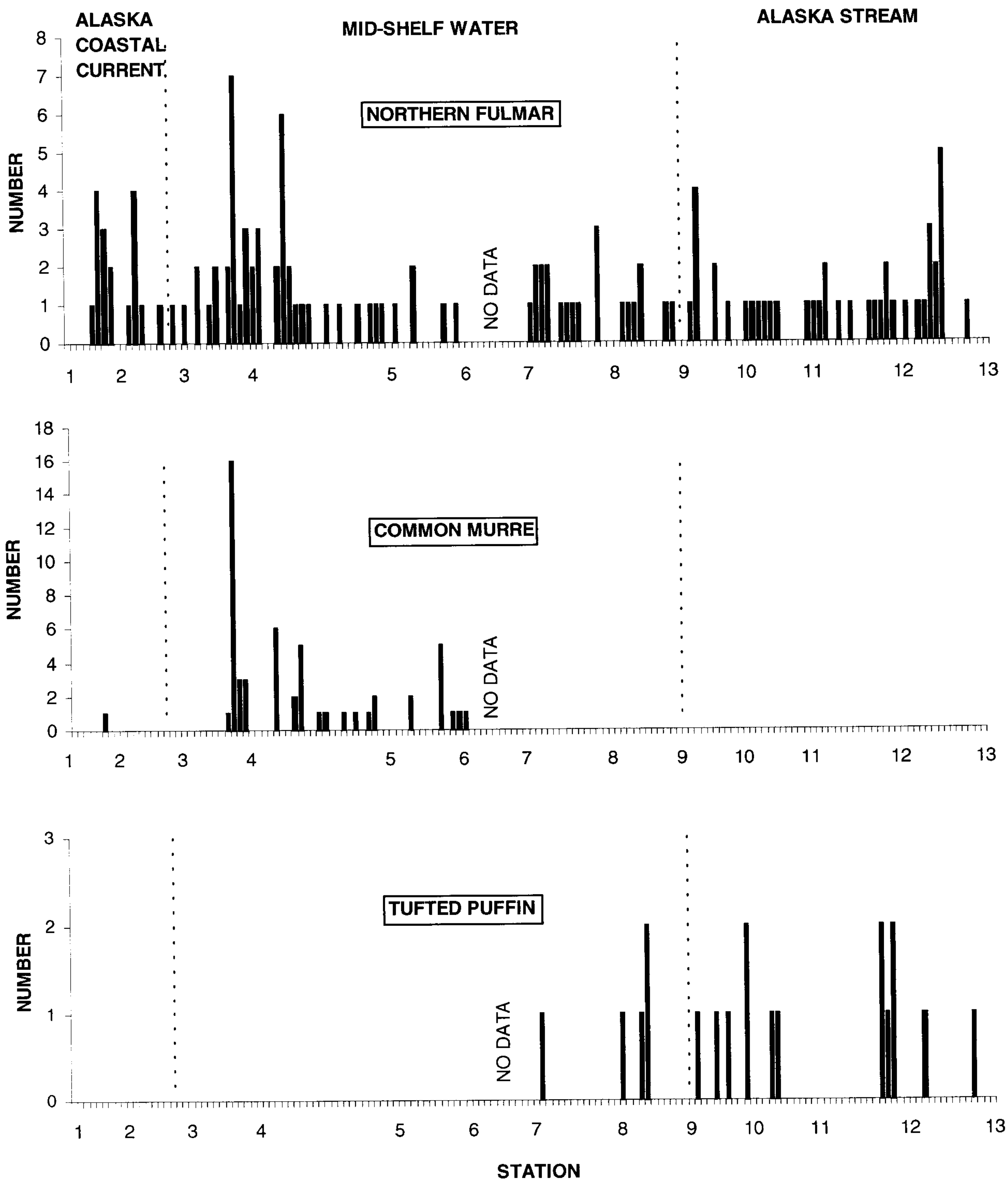


Figure 3. Cross-shelf distribution and abundance of northern fulmars, common murres, and tufted puffins along the Seward Line, October 1997. Data are preliminary and are not to be cited. Inshore is on the left side of this plot.

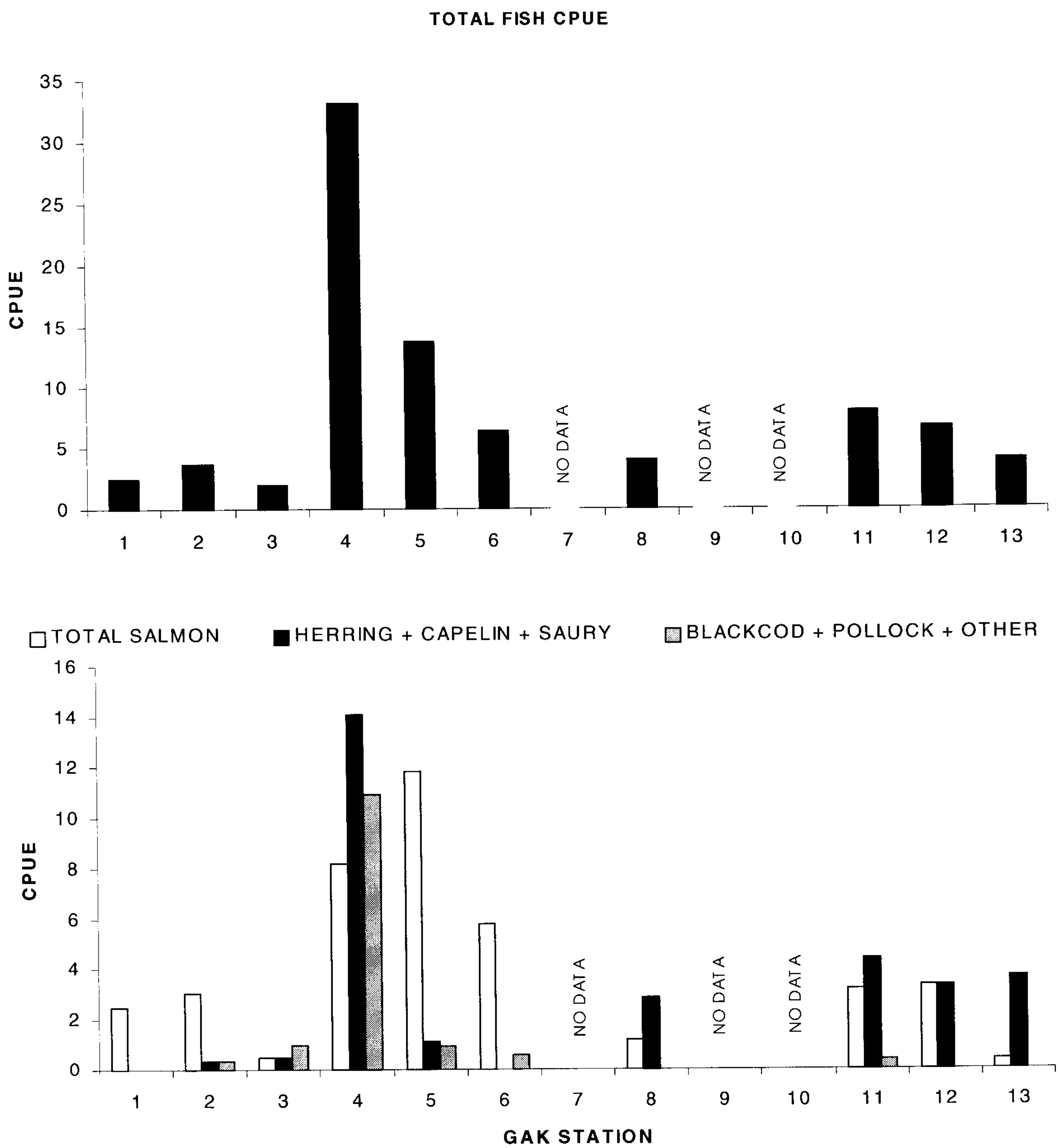


Figure 4. Cross-shelf distribution and abundance of all fish species combined and of three ecological groups along the Seward Line, October 1998 (L. J. Haldorson, University of Alaska, Juneau, AK; unpubl. data). Data are preliminary and are not to be cited. Inshore is on the left side of this plot.

APPENDIX 1. "GLOBEC" PROPOSAL SUBMITTED TO NSF BY INSTITUTE OF MARINE SCIENCES, UNIVERSITY OF ALASKA, FAIRBANKS

1. INTRODUCTION

Climate change and its potential effects on ecosystems are of international concern. In response to this issue the Global Ocean Ecosystem Dynamics (GLOBEC) program addresses the physical and biological interactions linking ecosystem alterations to climate change. The GLOBEC program goals are: 1) to understand the effects of climate variability and climate change on the distribution, abundance and production of marine organisms, and 2) to incorporate this understanding into diagnostic and prognostic models. To achieve these goals the U.S. GLOBEC Scientific Steering Committee prepared the Northeast Pacific Implementation Plan (U.S. GLOBEC Report Number 17, 1996) outlining the required studies for the U.S. west coast and Alaska. One aspect of this plan involves the development of a long-term monitoring program. This proposal describes a monitoring program for the northern Gulf of Alaska (GOA) in accordance with the GLOBEC implementation plan.

The GOA shelf supports a diverse ecosystem that includes several commercially important fisheries such as crab, shrimp, pollock, salmon and halibut (OCSEAP Staff, 1986; Anon., 1993). In aggregate these stocks imply that the gulf is among the world's largest fisheries, with annual catches exceeding 300 g 1000 m^{-2} (Brodeur and Ware, 1992). The mechanisms that underlie this high productivity are not known and, in fact, are somewhat enigmatic because the GOA shelf is a coastal "downwelling" shelf. By contrast, the rich fisheries along the eastern boundaries of the Pacific Ocean are supported by vigorous, wind-driven coastal upwelling whereby the euphotic zone is regularly replenished with nutrients advected from depth.

Intriguingly, the relative dominance of the commercially important fish species changed in the mid-1970s: crab and shrimp declined while salmon and groundfish populations increased (Albers and Anderson, 1985; Blau, 1986; Hollowed et al., 1994; Thompson and Zenger, 1994; Francis and Hare, 1994). These population shifts coincided with the beginning of a decadal North Pacific change in the atmosphere and ocean (Trenberth and Hurrell, 1994). From the human perspective these alterations required the commercial fishing industry to invest substantially in infrastructure adjustments so as to remain economically viable. Subsequent changes in this ecosystem followed in the 1980s with substantial declines in populations of sea lions (Merrick et al., 1987) and puffins (Hatch and Sanger, 1992). Dramatic though this "regime shift" was, Parker et al. (1995) show evidence that the abundance of halibut and other commercially important species varies on decadal time scales in conjunction with northern North Pacific Ocean temperatures (e.g., Royer, 1993). These correlations and the regime shift suggest that the GOA ecosystem is sensitive to climate variations on time scales ranging from interannual to interdecadal; however, the specific mechanisms linking climate to ecosystem alterations are unknown. Elucidation of these mechanisms requires an understanding of the seasonal cycle of the principal physical, chemical and biological variables. To date such a description is largely lacking for the GOA shelf.

Our monitoring plan will obtain a multi-year data set that will lead to a better understanding of the seasonal cycle and interannual variability in the physical-chemical structures and biological productivity of this shelf. It will include occupation of station GAK1, for which there exists a 26-year CTD time series (Royer, 1996). Further, our program is designed to yield information essential in guiding: 1) the interpretation of historical data sets that will be used by investigators in retrospective studies, 2) the design of a cost-effective long-term monitoring program, and 3) the design of process specific studies necessary to develop ecosystem models for this shelf. As outlined in Section 3, our monitoring program is formulated around several specific objectives. In Section 2, we provide background information on the GOA shelf which summarizes the present state of knowledge about the GOA ecosystem.

2. BACKGROUND

2.1 Physical Oceanography

The alongshore flow on the shelf and slope of the GOA is in the cyclonic sense on average (Reed and Schumacher, 1986). Flow over the continental slope consists of the Alaska Current, a relatively broad, diffuse flow in the north and northeast GOA, and the Alaskan Stream, a swift, narrow, western boundary current in the west and northwest GOA (Figure 1). Together these currents comprise the poleward limb of the North Pacific Ocean's subarctic gyre and provide the oceanic connection between the GOA shelf and the Pacific Ocean. Reed and Schumacher (1986) suggest that flow in the Alaskan Stream is relatively constant year round. However, Musgrave et al. (1992) and Okkonen (1992) show that sometimes the Alaskan Stream captures large eddies or forms prominent meanders and Royer (1981a) suggests that the seasonal signal in baroclinic transport is less than 10% of the mean flow. In the northeast gulf, the "Sitka Eddy" (Tabata, 1982) occasionally forms and slowly propagates westward across the GOA. To the extent that these low-frequency features impinge on the shelfbreak they could contribute to the shelf circulation and exchange of water masses.

The most striking feature of the shelf circulation is the Alaska Coastal Current (Figure 1), a swift (0.2–1.8 m s^{-1}), coastally constrained flow, typically found within 35 km of the coast, (Royer, 1981b; Johnson et al., 1988; Stabeno et al.. 1995). This current persists throughout the year and circumscribes the GOA shelf for at least ~2500 km from where it originates on the northern British Columbia shelf (or possibly the Columbia River depending on the season) to where it enters the Bering Sea in the western gulf (Figure 1). In contrast to the coastal current, the shelf flow between the offshore edge of the coastal current and the shelfbreak is weaker and more variable (Niebauer et al.. 1981). The source of this variability is uncertain, but potential mechanisms include separation of the coastal current as it flows around coastal promontories (Ahlnes et al.. 1987), baroclinic instability of the coastal jet (Barth. submitted: Mysak et al.. 1981) or meandering of the Alaska Current along the shelfbreak (Niebauer et al., 1981).

The dynamics of the basin and the shelf are closely coupled to the Aleutian Low pressure system. Storm systems propagate eastward into the GOA and are blocked by the mountain ranges of Alaska and British Columbia. Thus the regional winds are strong and cyclonic and the precipitation rates are very high. The positive wind-stress curl forces cyclonic circulation in the deep GOA, while on the shelf these winds impel an onshore surface Ekman drift and establish a cross-shore pressure gradient that forces the Alaska Coastal Current. The high rates of precipitation, which can be as great as 8 m yr^{-1}, cause an enormous freshwater flux (~20% larger than the average Mississippi River discharge) that feeds the shelf as a "coastal line source" extending from southeast Alaska to Kodiak Island (Royer, 1982). The seasonal variability in winds (represented in Figure 2 as the upwelling index) and freshwater discharge (Figure 2) are large. The mean monthly "upwelling index" at locations on the GOA shelf is negative in most months, indicating the prevalence of coastal convergence (e.g., this index is a measure of the strength of cyclonic wind stress in the GOA). As implied by Figure 2, cyclonic winds are strongest from November through March and feeble or even weakly anticyclonic in summer when the Aleutian Low is displaced by the North Pacific High (Royer, 1975; Wilson and Overland, 1986). The seasonal runoff cycle (Figure 2) exhibits slightly different phasing from the winds: it is maximum in early fall, decreases rapidly through winter when precipitation is stored as snow, and attains a secondary maximum in spring due to snowmelt (Royer, 1982).

The shelf hydrography and circulation vary seasonally and are linked to the annual cycles of wind and freshwater discharge. Figure 3 contrasts the cross-shore salinity structure (which mimics density on the GOA shelf) in April and September, 1983. In April, the stratification and the offshore front, defined here to be the surface intersection of the 32.0 isohaline, are relatively weak. By contrast, in September a 25 km wide wedge of strongly stratified water lies adjacent to the coast and is bounded on the offshore side by a prominent front. Royer et al. (1979) showed that surface drifters released on the shelf seaward of the front drifted onshore in accordance with Ekman dynamics. Upon encountering the front the drifters moved in the alongfront (e.g. ~westward) direction consistent with the geostrophic tendency implied by the cross-shore density distributions of Figure 3. Royer et al. (1979) hypothesized that ageostrophic offshore spreading of the dilute surface layer occurred on the inshore side of the front. In their analysis of currents measured inshore of the front, Johnson et al. (1988) found that this is indeed the case and that surface offshore flow was positively (and significantly) correlated with discharge.

These studies imply that near-surface waters converge from either side of the front. This pattern of cross-shelf circulation would tend to accumulate plankton which might then attract foraging fish. Moreover, the front and region inshore of it might be an area of enhanced productivity because entrainment (Royer et al., 1979; Johnson et al., 1988) and/or frontal instability (Barth, submitted) could resupply the surface layer with nutrients from depth. Royer (1979) also showed that monthly coastal sea level variations at Seward are in-phase with, and have nearly the same amplitude as, the local dynamic height. This was not expected given the difference in sampling techniques: the sea level records were sampled hourly and then averaged into monthly means, whereas the dynamic heights were from hydrographic measurements at a single station occupied several months apart. Further, Royer (1979) found that sea-level and precipitation anomalies were well-correlated. These results suggest examining the relationship between monthly or seasonal characteristics of the cross-shelf dynamic height gradients, winds and freshwater discharge. A firm relationship among these factors may allow the calculation of alongshelf baroclinic transport (on monthly or longer time scales) from a single hydrographic station or mooring at the coast. The result would be enormously useful for model evaluation (and perhaps data assimilation) and in retrospective studies. The alongshore transport appears to be important in advecting zooplankton to important juvenile fish foraging areas (see Section 2.3).

Figure 3 also indicates that near-bottom salinities are higher in fall than spring. Xiong and Royer (1984) showed that, on average, maximum bottom salinities occur in fall and are nearly coincident with minimum surface salinities and maximum inshore stratification (Figure 4). Although the surface waters are diluted by coastal discharge (which peaks in fall), the source of the high salinity water is the onshore intrusion of slope water (Figure 5) in response to the seasonal relaxation (or reversal) in downwelling (Royer, 1975, 1979).

Royer's (1996) analysis of monthly anomalies from the GOA shelf shows very low-frequency (interdecadal) variations in bottom water salinity that imply interannual variability in the onshore flux of slope water and/or differences in slope water properties. We argue below that these differences likely result in differences in the onshore flux of nutrients to the GOA shelf.

2.2 Primary Productivity and Nutrient Cycles

There are few primary production measurements from the GOA and those that exist are from widely varying locations and times. While Sambrotto and Lorenzen (1986) and Parsons (1986) concluded that the largest production rates occur on the shelf, there are no data on interannual variability. A nearly complete lack of nutrient data, particularly from the shelf (Reeburgh and Kipphut, 1986), is an additional limitation to understanding production. The major nutrient source to the shelf is probably the deep ocean because nutrient concentrations in the coastal runoff are very low (Sambrotto and Lorenzen, 1986). Such low concentrations are not unexpected given the steep, mountainous coastline and the extensive snowfields. The shelf euphotic zone, especially in inshore waters, probably becomes nutrient depleted, but we emphasize that this is speculation at this time (Reeburgh and Kipphut, 1986).

Although little is known about surface nutrient concentrations, there are suggestions of large year-to-year differences in subsurface nutrient concentrations. Incze and Ainair (1994) showed large interannual differences in nutrient concentrations at depths >150 m along one section in Shelikof Strait (in the western GOA) occupied each spring between 1985–1989. Because of the unique bathymetry of this area, it is unclear if these differences apply to other GOA shelf regions. However, the interannual salinity variations shown by Royer (1996) imply variability in deep water nutrient concentrations, as indicated from the WOCE P17N section of May–June 1993. These nutrient data are the only synoptic deep ocean and shelf nutrient data available for the northern GOA. Figure 6 shows the salinity-NO_3 relationship using data from between 125 and 450 m depth at stations within the Alaskan Stream and on the western shelf. This depth interval covers the range of bottom water salinities observed by Royer (1996) and Xiong and Royer (1984). The correlation appears to be good and we note that a change in salinity from 32.0 to 33.0 involves nearly a doubling in the NO_3 concentration. If salinity-macronutrient relationships can be statistically quantified for the shelf, then it might be possible to use the 26-year salinity time series from GAK1 as a proxy for subsurface nutrient concentrations.

2.3 Zooplankton

Zooplankton are a critical link in the transfer of energy from primary producers to apex predators. Any process influencing the abundance and distribution of zooplankton can ultimately impact on fisheries. Zooplankton are therefore a critical component of any monitoring study that attempts to relate long-term climate variations to fish production.

The zooplankton community on the shelf of the Gulf of Alaska is dominated by a combination of oceanic and neritic herbivorous and omnivorous copepod stocks (Cooney, 1986a, 1986b; Incze et al., 1996). The major oceanic species include *Neocalanus plumchrus*, *N. flemingeri*, *N. cristatus*, *Eucalanus bungii* and *Metridia pacifica*. Neritic taxa are dominated by *Pseudocalanus* spp. and *Calanus marshallae*, with lesser amounts of *Acartia* spp., *Centrapoges abdominalis* and *Calanus pacificus*. In addition to copepods, a number of micronektonic species contribute substantially to the overall density of forage for fish on the GOA shelf. The euphausiid species include primarily *Thysanoessa inermis*, *T. spinifera* and *Euphausia pacifica*, with lower densities of *Thysanoessa raschii*, *T. longipes*, *T. inspinata*, *Tessarabrachion oculatum* and *Euphausia pacifica*. Amphipods include *Cyphocaris challengeri*, *Parathemisto pacifica*, and *Primno macropa* (Incze et al., 1996). Oceanographic conditions affecting the transport and production of these taxa influence their absolute and relative densities and distribution over the shelf, and thus their availability to fish predators.

During spring and summer, 25–78% of the copepod biomass over the shelf is dominated by the oceanic species complex (Cooney, 1986a, 1986b; Incze et al., 1996). The distribution of oceanic relative to neritic copepods is determined to a large extent by cross-shelf transport (Cooney, 1986a) and water mass type (Incze et al., 1996; Napp et al., 1996). Although most of the copepod biomass in lower Shelikof Strait occurred consistently in the Alaska Coastal Current from 1986–1989, there was a fourfold (3–12 g C m^{-2}) interannual variation in maximum biomass (Incze et al., 1996; Napp et al., 1996). Zooplankton biomass on the shelf outside of Prince William Sound in May 1996 varied by up to an order of magnitude, with maximum values occurring in the shelf water offshore of the Alaska Coastal Current (Figure 7).

In addition to late copepodid stages of the major copepod taxa, the early naupliar stages are the primary forage for the first-feeding larval stages of a variety of fish. Based on water temperature, copepod development rates and flow rates of the Alaska Coastal Current, copepods producing the major cohort of naupliar stage larvae available to first-feeding pollock larvae in Shelikof Strait originated during February–March on the shelf off of Prince William Sound and east of GAK1 (Napp et al., 1996; Incze and Ainaire, 1994). Nauplii consumed by first-feeding fish larvae are produced primarily by the neritic zooplankton community. Therefore, pre-bloom conditions on the north central GOA shelf may crucially influence survival of larval fish further downstream (west and south) near Kodiak Island.

No data are available on interannual differences in zooplankton biomass for the north central GOA shelf. However, a multi-year data set of zooplankton settled volumes measured during April and May near Ester Island, in the southern end of Prince William Sound, is available. The zooplankton community in the southern sound is influenced primarily by advection from the GOA shelf. Cooney (pers. comm.) found a significant positive correlation (Figure 8) between the logarithm of the average settled zooplankton volume for April and May and the average of the upwelling index off Hinchinbrook Entrance (Figure 2). There are a number of possible explanations for the above correlation. Oceanic species of the genus *Neocalanus* dominate zooplankton biomass in April and May, suggesting that anomalously weak springtime downwelling may enhance subsurface onshore transport of oceanic copepods from the shelfbreak. Alternatively, weakened downwelling may permit advection of nutrients onshore and into the photic zone during the spring months, thereby elevating primary production and providing a more continuous and abundant food supply to herbivorous zooplankton. An anomalously positive April–May upwelling index implies reduced wind stress, precipitation rates, cloud cover and possibly higher air temperatures. All these variables influence upper ocean stratification through wind mixing, surface heat flux and coastal discharge. Stratification influences the vertical distribution of plant cells and, along with light availability, influences primary production rates. These physical variables, through their influence on phytoplankton food quality and/or abundance, would affect zooplankton.

If cross-shelf advection is a major source of zooplankton biomass on the shelf, then conditions that enhance zooplankton biomass at the shelfbreak should also enhance shelf zooplankton densities when favorable onshore transport conditions occur. Comparisons of zooplankton densities in the GOA between 1956–1962 and 1980–1989 revealed a doubling in average biomass around the GOA perimeter since the early 1960s (Brodeur and Ware, 1992). The reason for this increase is uncertain. However, suggested hypotheses include greater primary productivity due to a rise in winter wind stress and elevated summer winds, increasing the speed of the subarctic current and displacing it northward, further into the GOA during the 1980s (Brodeur and Ware, 1992). A positive correlation between zooplankton densities and surface salinities (Frost, 1983; Wickett, 1967) implies stronger vertical mixing (Brodeur and Ware, 1992), leading to enhanced new production and better feeding conditions for herbivorous zooplankton. Primary production rates were apparently 3–4 times higher in the GOA in 1987–1988 than earlier measurements indicated (Welschmeyer et al., 1993). Although Welschmeyer et al. (1993) attributed the differences to methodology, the zooplankton and wind data cited above suggest that there might have been real decadal variation in annual production rates.

A doubling of the salmon production between the 1950s and 1980s (Rogers, 1987) indicates that salmon benefited from elevated zooplankton densities. The major environmental shift suggested by the collapse of the crustacean fishery and its replacement by a groundfish fishery in the late 1970s and early 1980s (see Introduction) could also be a consequence of enhanced zooplankton biomass because the early life history stages of demersal fishes feed on zooplankton.

2.4 Fish

The epipelagic zone of the Northeast Pacific Ocean provides the energy of production for five Pacific salmon species that spawn and are harvested in Alaskan waters. Since the 1920s, abundance of salmon in Alaska has undergone one complete cycle, with high levels in the 1930s, low in the 1960s, and a return to high abundance in the 1980s. This relatively long-term cycle may be related to harvest practices, changes in freshwater spawning habitats and changes in the marine environment. Several indicators suggest the marine environment may be a factor in abundance cycles, and that the present exceptionally high abundances of salmon may reflect long-term climatic changes that have affected the planktonic production system of the Northeast Pacific Ocean. For example, since the mid-1970s water temperatures have increased (Royer, 1989), primary and secondary production levels are higher (Brodeur and Ware, 1992), and growth rates of salmon are declining (Helle and Hoffman, 1995). Several of these indicators appear to have conflicting trends, especially the observation that salmon growth rates are declining while secondary production has increased. Processes that may be responsible for these observations include physical effects such as variability in oceanographic features that concentrate prey or the energetic demands of higher water temperatures, and biotic effects such as density dependent growth associated with competitive interactions among planktivorous fishes. Presently there is no clear understanding of what processes are controlling salmon production in the Northeast Pacific Ocean.

In the marine environment, salmon coexist with a variety of other planktivorous fishes and invertebrates. Non-salmonid species that co-occur with juvenile salmon include sablefish (*Anopiopomna fimbria*), rockfishes (*Sebastes* spp.), walleye pollock (*Theragra chalcogramma*), herring (*Clupea harengus*) and capelin (*Mallotus villosus*)

(Carlson et al., 1996). In addition, a group of diel-migrating mesopelagic fishes, such as myctophids, may be important nocturnal planktivores in near-surface waters. Inclusion of non-salmonid species in marine monitoring studies should provide increased opportunity to observe patterns important in the production of planktivorous fishes.

Typically, high latitude fishes store energy during spring and summer, whereas in the winter they reallocate energy to maintenance and reproduction (Smith et al., 1988, 1990). Juvenile salmon in the Gulf of Alaska seek feeding areas that sustain the rapid growth needed to avoid predators and gain maturity. Certain oceanographic parameters, such as fronts, currents and temperatures, play important roles in zooplankton productivity and aggregation. The effects of food limitation may be subtle and measures of feeding variability require diagnostic tools that are sensitive enough to see small differences in fish condition. Measures of whole-body energy content provide a standardized and accurate measure of fish health and growth. The amount of energy stored by fishes during seasonal growth periods has been used to determine if populations are food limited (Diana and Salz, 1990), and is an important parameter in energetics models (Wang and Houde, 1994). This approach requires documentation of energy content at the start and end of the period of interest. For this reason, YOY (young of the year) fishes are especially interesting, as they are assumed to have started the season of growth (typically spring and summer) at the same point, with very little energy. Measuring the energy storage of YOY fishes in mid-summer and end of summer should indicate how conditions in that year affected the productivity of salmonids and other planktivorous fishes.

3. PROJECT OBJECTIVES

Although decadal-scale shifts are evident or implied in physical oceanographic, zooplankton and fisheries data sets, the connections among these ecosystem components on the GOA shelf are poorly understood. GLOBEC is an integrated program involving retrospective analyses, monitoring, modeling and process studies designed to improve our understanding these connections. The general objective of our monitoring plan is to better understand the temporal (seasonal and interannual) and cross-shelf variations in the thermohaline, chemical and biological structures of this shelf. At the same time our data will help: 1) interpret historical data sets that will be used by investigators in retrospective studies, 2) design a cost-effective long-term monitoring program, 3) identify particular processes that would serve as the basis for follow-on GLOBEC process studies scheduled to begin in year four of the GLOBEC Program for the GOA shelf (U.S. GLOBEC, 1996), and 4) provide boundary conditions and/or hindcast data sets for modeling studies.

As a practical approach to achieving these generic goals we have identified the following specific objectives that guide our sampling and analysis:

1. determine the seasonal (and interannual) changes in the cross-shelf distribution of temperature, salinity, mixed-layer depth, light transmission, photosynthetically active radiation (PAR), and the concentration of chlorophyll and nutrients;
2. determine the statistical relationship between seawater salinity and nutrient concentrations on the GOA shelf and slope;
3. use water mass properties (temperature, salinity, and DO) to determine the offshore depth of upwelled water observed on the shelf;
4. determine the relationship between anomalies of dynamic height and the cross-shelf dynamic height gradient, wind, and freshwater discharge on seasonal time scales;
5. determine seasonal chlorophyll concentration and primary productivity responses to cross-shelf thermohaline structure and nutrient enrichment processes;
6. determine quantitatively and taxonomically the seasonal and cross-shelf distribution of zooplankton in relation to oceanographic features and the distribution and concentration of chlorophyll;
7. determine quantitatively the summer-fall distribution of juvenile salmonids and other small planktivorous fishes in relation to oceanographic features and the distribution of zooplankton;
8. determine the seasonal and cross-shelf energy content of small pelagic fishes, especially young of the year (YOY) salmonids, examine energy content in relation to oceanographic features, zooplankton density and composition, and existing laboratory measures of energy storage capacity; and
9. quantify the diets of small pelagic fishes, especially YOY salmonids, as a function of season and cross-shelf position and compare these diets with oceanographic features, zooplankton density and composition.

4. APPROACH

4.1 General Considerations

To attain these objectives we will sample the physical, chemical and biological parameters on identical time and space scales with the protocols developed by the GLOBEC SSC (U.S. GLOBEC, 1996). We will occupy 13 stations on the Seward Line (Figure 9) that extends across the shelf break from the coast at Seward to within the Alaska Stream. The bottom depth at most stations along this line is from 200 to over 1500 m which will allow deep ocean nutrient data to be collected. The Seward Line was frequently occupied in the 1970s as part of the Outer Continental Shelf Environmental Assessment Program (OCSEAP), so historical hydrographic data are available for comparison with our results. Six cruises per year are requested so that we can capture the seasonal cycle in the important physical and biological variables. We will sample in February/March when zooplankton migrate from depth at the shelf break and begin to be advected onshore, in April during the spring phytoplankton bloom, in May when the biomass of oceanic copepods is maximum, in July and October when YOY salmon are on the shelf, and in late November/early December when we expect biological activity to be minimal. Our sampling methods follow the protocols specified in the implementation plan (see Table 5 of U.S. GLOBEC, 1996), however, we will not sample particle size spectra using a through-hull system, deploy drifters, or observe marine birds and mammals. Under separate submission, J. Napp of NOAA/NMFS Alaska Fisheries Science Center (Seattle) is proposing to measure particle size spectra with an instrument that would be deployed with our CTD while on station. R. Day (Alaska Biological Research, Inc., Fairbanks), a seabird biologist long involved in regional seabird studies, will propose to the Exxon Valdez Oil Spill Trustee Council (EVOS) to make mammal and seabird observations during our cruises.

All oceanographic observations will be made from the R/V *Alpha Helix*, whose home port is Seward: therefore transit time to the Seward Line will be negligible. A fishing vessel configured for mid-water trawling will be chartered for two cruises in July and early October to sample YOY salmonids and juvenile fishes. The trawl vessel will work in conjunction with the R/V *Alpha Helix* so that measurements of oceanic parameters and zooplankton are obtained concurrently, thus ensuring that the data sets are compatible in time and space. The remaining four cruises (February/March, April, May and November/December) will involve only oceanographic and zooplankton sampling. We expect to spend 36 days per year at sea: with each cruise of 6 days duration. The ocean sampling should actually require ~3 days and the excess time reflects weather day budgeting. Should these days not be needed we will use the extra time to sample additional cross-shelf transects east of the Seward Line or we will occupy 25 hour time series stations.

4.2 Physical, Chemical and Phytoplankton

Shipboard hydrography will be done by Weingartner and Royer. Measurements will include CTD (Seabird 9/11 with redundant temperature and conductivity sensors), fluorometry, PAR, transmissivity, and discrete bottle samples for nutrients, chlorophyll, and dissolved oxygen, at a station spacing of ~10 km on the inner half of the shelf and at ~15 km intervals over the outer half. Continuous through-hull measurements of surface temperature, salinity, and fluorescence; and water column velocities determined with an acoustic Doppler current profiler (ADCP) will be included. The R/V *Alpha Helix* carries a 300 kHz ADCP system that can bottom track over the continental shelf. The ADCP velocity profiles and through-hull surface property values are displayed in real-time and these will help identify the location and width of the Alaska Coastal Current and the front. Together with the hydrographic cast data, these data will be used to adjust the CTD station locations during each cruise to optimize sampling for the features of interest and to guide the fish and zooplankton sampling.

The physical parameters (including transmissivity and PAR) obtained from the CTD will be used to examine seasonal and cross-shelf distribution of water masses and to aid in interpreting the distribution of biological variables. We will also compute dynamic heights and baroclinic transports for use in the retrospective study described below. The ADCP data from a single occupation of a transect, as proposed here, are not easily amenable to detiding. However, the M_2 tide is the dominant tidal constituent on this part of the GOA shelf with an amplitude of ~0.1 m s^{-1}. The dominant velocity signal on this shelf is the Alaska Coastal Current. The magnitude of both the mean speed and typical subtidal-frequency variability of the Alaska Coastal Current is several times greater than the tidal signal. To the extent that weather permits, sampling along additional transects might permit us to apply tidal removal procedures (Candela et al., 1992) to the ADCP data. The continuous ADCP and surface measurements will be used to examine small scale physical features that might be of biological importance. These parameters, when analyzed in conjunction with hydroacoustic data, are especially helpful in interpreting zooplankton patches (Coyle and Cooney, 1993; Coyle et al., 1992).

Retrospective studies of the hydrographic and climatic variability done in conjunction with this pilot monitoring program will give it spatial and temporal contexts. These studies will also determine if future monitoring can be accomplished through the use of more generally recorded environmental factors such as coastal tidal height; wind:

barometric pressure: air temperature: precipitation: cloudiness: remote sensing of sea surface temperature. color and altimetry: and volunteer observing ship measurements of ocean temperatures.

The data from the monitoring program will be added to the existing GAK1 hydrographic time series (http://www.ims.alaska.edu:8000/GAK1). which will then be the focus of the retrospective analyses. This will provide a history beginning in 1970 of the temperature and salinity variability at GAK1: from this history. changes in the density structure. mixed layer depth. heat and salt content. and dynamic height will be determined. The relationships between dynamic height and sea level observed by Royer (1979) will be reexamined using the additional 18 years of data to determine if the dynamic height and baroclinic transport on the shelf can be derived from tidal height data.

The relationship between the mixed layer depth and both sea level measurements and freshwater discharge will be examined. The regional hydrology model of Royer (1982) will be used in the retrospective studies to calculate the coastal discharge from records of air temperature and precipitation. since there is little monitoring of such fresh water flux in the GOA. The variability of the mixed layer depth is especially important to studies of primary and secondary production. since it can affect the vertical fluxes of nutrients and the depth of phytoplankton distribution (Mann and Lazier. 1991). The ability to hindcast the mixed layer depth from the freshwater discharge model would permit determination of the mixed layer depth variability back to 1931. the earliest date of the climatic records used by the model. The mixed layer depth record could then be compared to fisheries data sets during this period. such as salmon catches.

To place the Seward Line measurements in a spatial context. the historical hydrographic data for this shelf will be reexamined along with the XBT and BT data available for the region from the WOCE (World Ocean Circulation Experiment) Volunteer Observing Ship (VOS) program. More than five years of VOS coverage is now available. Interdecadal time scales will be addressed through the use of sea surface temperatures (available from Scripps since 1947). Sitka air temperatures (since 1828). upwelling indices (from the Pacific Oceanographic Group/NOAA since 1946). the North Pacific Index (from NCAR since 1900) and oceanographic buoy data (from NOAA since ca. 1975).

Whitledge is responsible for nutrient and primary productivity measurements. Nutrients will be analyzed onboard using an Alpkem Rapid Flow Analyzer (Whitledge et al.. 1981) and will conform to WOCE standards (Gordon et al.. 1993). Chlorophyll *a* concentrations will be measured at all stations to calibrate the *in vivo* fluorescence profiles. The samples will be collected from CTD upcasts using the rosette sampler. Extracted chlorophyll *a* will be determined fluorometrically on board ship (Parsons et al.. 1984). Extracted chlorophyll samples will also be used to calibrate the flow-through fluorometer by collecting discrete samples periodically from the through-hull sampling system.

Daily measurement of primary production rates will be estimated for large (>20 µm) and small (<20 µm) size classes by the modified ^{14}C-uptake technique (Evans et al.. 1987). Primary production estimates well be made at 4–6 stations along the Seward Line. Water samples inoculated with 20 µCi ^{14}C-labeled sodium bicarbonate will be incubated in 1-liter polycarbonate bottles under natural light. using an on-deck incubator. Following the incubations. both light and dark samples will be filtered and purged of labeled inorganic carbon. The residual ^{14}C activity will be determined by liquid scintillation counting to assess organic carbon release rates. Hourly and daily estimates of primary production rates will be calculated for each sampling site. Concurrent assessments of phytoplankton nutrient utilization will be performed using nutrients (nitrogen. phosphorus and silicate) and trace metals. Emphasis will be placed on iron enrichments in order to assess potential effects on primary productivity rates. Particulate carbon and nitrogen samples will be obtained for each productivity sample.

4.3 Zooplankton

Coyle will perform the zooplankton work. Zooplankton samples will be collected with a 25 cm diameter CalVET net (Smith et al.. 1985) equipped with General Oceanics digital flowmeters and 0.16 mm mesh nets. The CalVET net has the following advantages over a ring net for obtaining integrated zooplankton samples: 1) it can be hung on the CTD cable. allowing for quick and efficient deployment of gear: 2) a CTD record can be obtained concurrently with the zooplankton sample: 3) the net can be equipped with flowmeters to estimate sampling efficiency: and 4) the sample is small. thus requiring a minimum of splitting during analysis. The CalVET net will sample small. abundant zooplankton. especially early copepodid stages of calanoids (e.g., Coyle et al.. 1990).

A 0.7 m bongo net with 0.5 mm mesh and a depth recorder with an on-deck readout will be towed double obliquely from the surface to within 10 m of the bottom. The bongo net will sample large calanoids. micronekton and larval fish. It will be equipped with a General Oceanics digital flowmeter to estimate volume filtered.

Copepod nauplii will be sampled with a 10-liter Niskin bottle at four depth intervals in the upper mixed layer. The entire contents of the bottle will be filtered through a 0.05 mm mesh bag net.

All samples will be preserved in 10% formalin for later processing. As directed, separate samples will be collected, preserved in alcohol, and stored for future genetic analysis (U.S. GLOBEC, 1996). The formalin-preserved samples will be split with a Folsom splitter, consecutive fractions will be sorted for abundant taxa, and the material will be identified to the lowest taxonomic category possible. The copepods and euphausiids will be staged and the sex ratio of adults determined.

Preservation of zooplankton with formalin can markedly affect dry weight biomass estimates (Steedman, 1976; Omari and Ikeda, 1984). Because the amount of loss can vary with respect to taxa, formalin concentration, pH, duration of preservation and animal:liquid ratio, the amount of weight loss due to preservation cannot be predicted. However, minimal changes occur in copepod wet weight biomass due to formalin preservation with respect to wet weight estimates of fresh material (Omari, 1970). We will therefore measure the blotted wet weight of the formalin preserved specimens to estimate biomass. The wet weight of highly variable taxa (euphausiids, amphipods, chaetognaths, etc.) will be estimated for each sample. Average wet weight will be measured and used to estimate biomass of taxa of a constant size (e.g. copepod copepodid stages). Large gelatinous zooplankton will be counted, species composition determined and volume measured, and then discarded at sea. Data analysis will be done using an INGRES database and FORTRAN, with calls to IMSL libraries or SAS statistical packages.

Acoustic data will be collected with a Hydroacoustic Technology Inc. (HTI) model 244 split-beam system at 38, 120 and 200 kHz and a single beam at 420 kHz. The system includes a 38 kHz 10° split-beam transducer, a 120 and a 200 kHz 6° split-beam transducer, and a 420 kHz 6° single beam transducer. This frequency range should permit us to estimate densities of fish, micronekton and large calanoids. We have chosen relatively narrow beam transducers to ensure that discrete targets can be isolated for target strength measurements. We will not deploy a split beam 420 kHz transducer due to the difficulty of isolating discrete targets at reasonable ranges with high frequency transducers. The transducers will be towed beside the vessel at 6 knots in a dead-weight tow body about 4 m from the hull and 2 m below the surface. The system will collect simultaneous 20 and 40 log R data for both target strength and integration. Data will be integrated at 30–60 second time intervals and at 1 m depth intervals to produce horizontal and vertical estimates of volume scattering. All return signals are corrected for sound cone spreading and absorption of sound by seawater. Additional corrections for system calibration are applied before writing the averaged voltages to computer files. GPS positions from the ship's navigation system will be written to each record before writing the data to disk, thus permitting accurate integration of bioacoustic data with ADCP and sea surface data. All raw data will be written to digital tape, both to back the data and to permit re-analysis of selected sections during post processing. The systems will be calibrated using standard target procedures before and after each cruise (Traynor and Ehrenberg, 1990).

A 1-m^2 MOCNESS net equipped with 500 mm mesh nets will be fished during day and night, concurrently with acoustic measurements at selected sites, to identify and sample zooplankton and micronekton targets in the scattering layers. The MOCNESS system is equipped with nine nets which can be opened and closed electronically from the deck. The system simultaneously collects data on salinity, temperature, fluorescence, depth, net angle, volume sampled, time and GPS position. All data are written to a computer for later processing. The MOCNESS is fished off the stern and will sample mid-water layers from 5 m below the surface to 10 m above the bottom. MOCNESS samples will be analyzed as described above.

4.4 Fish

Haldorson and Paul are responsible for the fish studies. Planktivorous fish distribution will be assessed using a mid-water trawl equipped with a net-monitor system that provides real-time location of the net in the water column. Most of the net sampling will be at locations where the acoustic equipment has identified the presence of fishes. Acoustic sampling may not be able to identify near-surface fishes; consequently, a series of three near-surface mid-water trawl samples will be collected randomly at each of the fixed stations on the transect lines.

Once caught, fish larger than about 50 mm will be identified in the field. We will sort samples to species and measure all fish, unless net hauls contain large numbers of individuals of some species. In the case of large catches we will randomly subsample and measure 100–200 individuals of each species. Length-stratified subsamples of all fish species will be frozen and returned to the laboratory for condition and energetics studies. A second series of length-stratified subsamples will be preserved in formalin for diet studies. As directed by GLOBEC, other samples will be collected, preserved in alcohol, and stored for future genetic analysis (U.S. GLOBEC, 1996).

In the laboratory the fish will be partially thawed, just enough for handling, but not enough to lose fluids. Otoliths will be removed and stored in glycerine. The stomach will be opened and the contents removed and placed in 10% formalin. The standard length, wet weight, dry weight, whole body energy content and condition factor [CF = g wet wt x 100/(cm standard length)^3] will be determined for each individual. After freeze drying, the bodies will be placed in a convection oven at 60°C until they reach a constant weight. Individual wet and dry weight values will be used to calculate the moisture content. Dried tissues will be ground in a mill and caloric content measured by bomb calorimetry.

Condition is assessed by examining weight as a function of length. Techniques range from application of indices, such as the Fulton condition index, to comparisons of length-weight regression parameters. We will use a Fulton condition index to compare individuals of the same species in the same age class. We will also compare slopes of length-weight regressions, especially when the size range of specimens is wide enough to render the Fulton-type indices unreliable. Length-weight regressions using analysis of covariance provide the most robust approach to comparing condition among samples (Cone, 1989).

Feeding of salmonids and other planktivorous fishes will be quantified by analyses of stomach contents from formalin-preserved specimens. Ten to 15 individuals from each species-age class-sample site will be processed. The specimens will be measured for fork and standard length, and weighed. Stomachs will be excised and the contents removed and weighed. Stomach contents will be sorted and counted by prey type, with sample splitting in the case of exceptionally high numbers of prey. Prey will be identified to the lowest feasible taxon. Weight of prey types will be estimated by measuring all or a subsample of items, and using size-weight relationships from the literature.

5. SIGNIFICANCE OF THE RESEARCH AND RELATION TO OTHER PROGRAMS

The research proposed here is the first interdisciplinary program designed to understand seasonal and interannual changes in the physical-chemical structures of the Gulf of Alaska shelf and their relationship to zooplankton and planktivorous fish, especially juvenile salmon. The mechanisms that support the high productivity of this shelf are unknown and puzzling because the GOA shelf is a "downwelling" system. By providing us with an understanding of seasonal variability from an interannual perspective, this monitoring program is critical to elucidating the specific mechanisms fueling production on this downwelling shelf. The results from the research proposed here will enable us to better define a suite of easily measured variables useful in ecosystem monitoring in the future. In conjunction with the results from similar programs along the North American west coast, this set of variables will contribute towards a better understanding of the marine system of the Northeast Pacific Ocean and its response to changes in climate.

The following is a list of existing and planned programs with which data and information gathered by our monitoring program will be shared:

1) Weingartner has submitted a proposal under an ONR Broad Agency Announcement to the National Ocean Partnership Program, to deploy a buoy that would collect hourly bottom pressure, temperature and conductivity data throughout the water column, PAR and fluorescence data in the upper 50 m, and wind velocity, air temperature and pressure at the sea surface at station GAK1. The buoy will serve as a platform for additional sensors in the future and as the foundation of a long-term monitoring platform. J. Napp's shipboard measurement program is designed in part to guide the future incorporation of an acoustic sensor for zooplankton monitoring on the GAK1 mooring. The buoy will transmit data via Argos in real-time. Data from the mooring will be valuable in guiding sampling during this program and in future GLOBEC process studies on the GOA shelf. The buoy data will complement this proposal by providing information on the shorter period variability that we cannot address with the sampling plan proposed here.

2) We will compare our monitoring data from the northern shelf with measurements by the Canadians (E. Carmack, IOS, Sidney) from the British Columbian shelf in the southeast GOA. This comparison will improve our understanding of the spatial domain over which observed variations occur.

3) B. Finney (University of Alaska) is proposing to use paleorecords and stable isotopes to examine historical biological production in the GOA. We will provide him with samples of chlorophyll, fish, and zooplankton from our surveys for characterization of present-day seasonal isotopic composition of organisms on this shelf.

4) Three of us, Paul, Coyle, and Haldorson, are involved with the EVOS-supported SEA (Sound Ecosystem Assessment) and APEX (Alaska Predator Ecosystem Experiment) projects. These programs are examining primary production rates and the abundance and distribution of zooplankton, herring, YOY pink salmon, YOY pollock and other forage fish during spring and summer in Prince William Sound. Although the above studies are limited primarily to the sound and will end in 1998, the involvement of our research staff in the EVOS programs will facilitate scientific collaboration and integration of the resulting data sets gathered by EVOS and the monitoring program proposed here. The resulting integration of effort will substantially contribute to our understanding of coastal processes on the GOA shelf as a whole.

5) Our program complements the Ocean Carrying Capacity (OCC) program conducted by NMFS's Auke Bay Lab. The OCC program will work primarily in southeast Alaska, thereby extending the GOA spatial coverage. Haldorson is an external PI on the OCC program and will provide salmonid otoliths to OCC investigators along with size and condition data from those specimens.

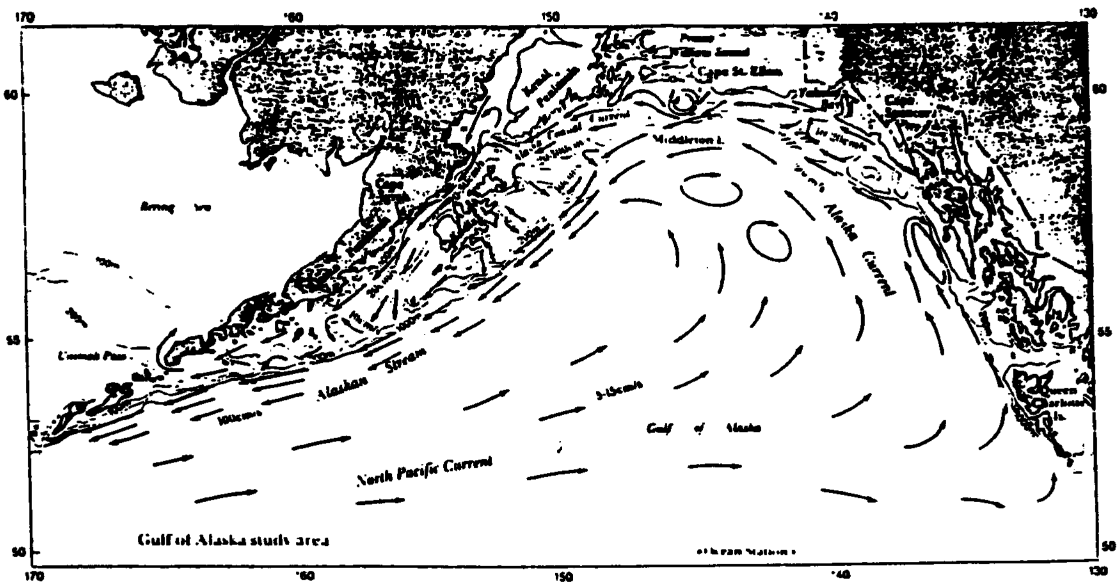


Figure 1. Schematic circulation of the Gulf of Alaska. (from Reed and Schumacher, 1986)

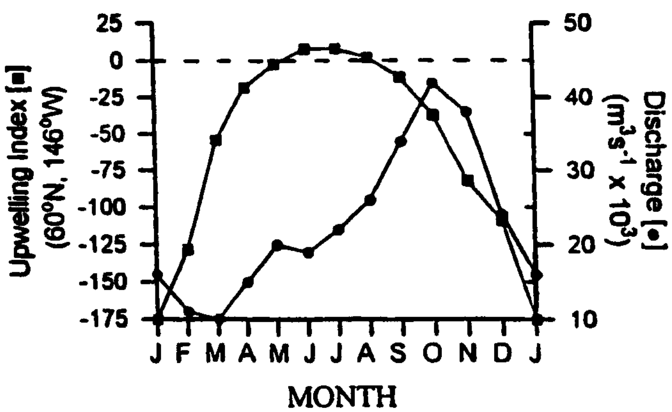


Figure 2. Mean monthly values of the upwelling index (from 1965–1992) and the estimated freshwater discharge (from 1930–1992) into the GOA using the hydrology model of Royer (1982).

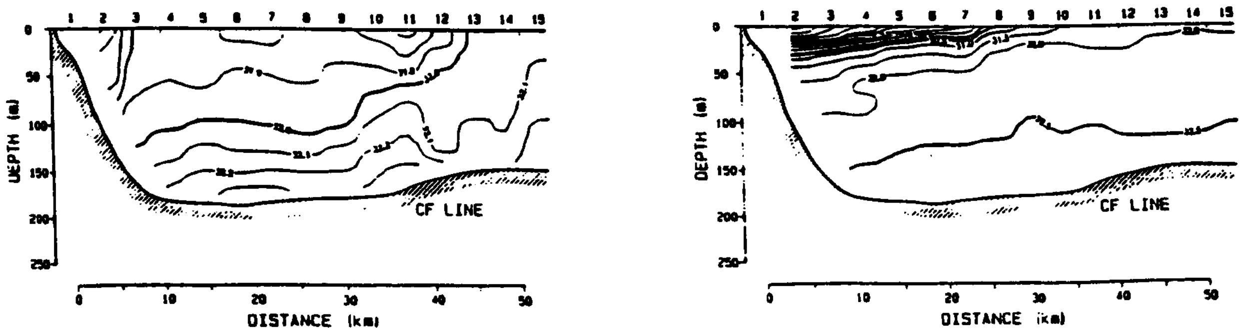


Figure 3. Cross-shelf salinity distribution in 1983; April (left) and September (right). (from Johnson et al., 1988)

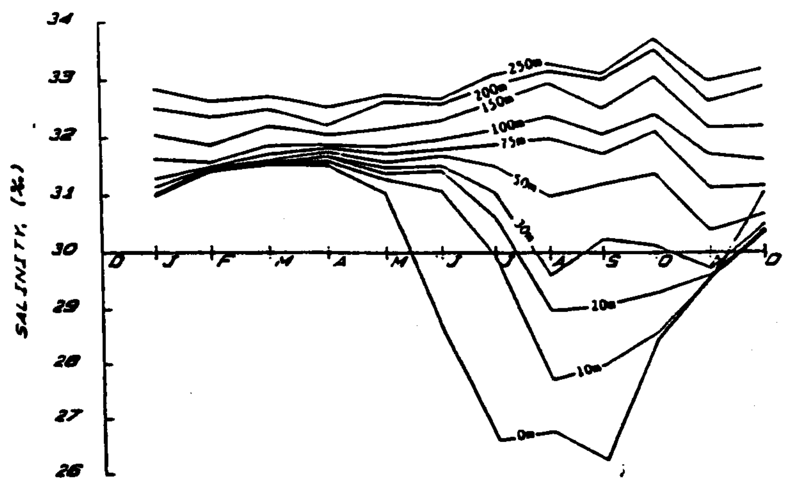


Figure 4. Mean monthly salinity at selected depths at GAK1 from 1970–1983. (from Xiong and Royer, 1984)

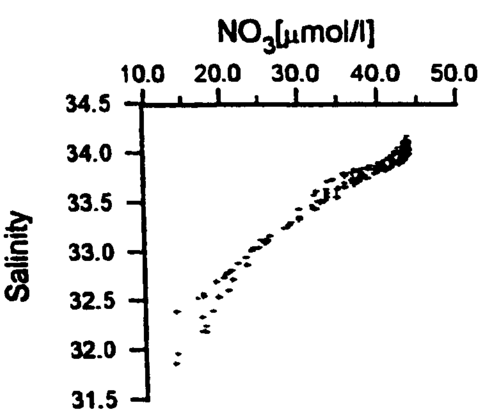
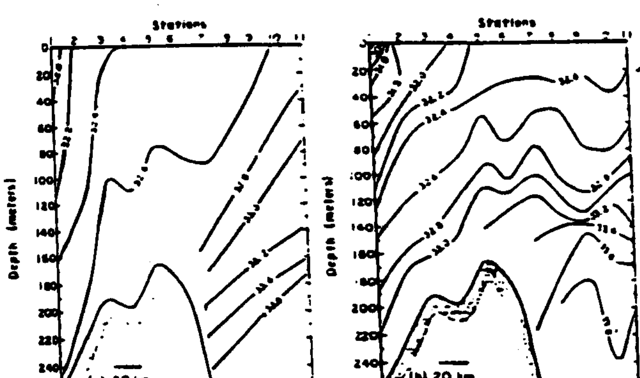


Figure 5. Vertical section of salinity along the Seward Line for winter (left and summer (right) showing inshore intrusion of saline water in summer. (from Royer, 1975)



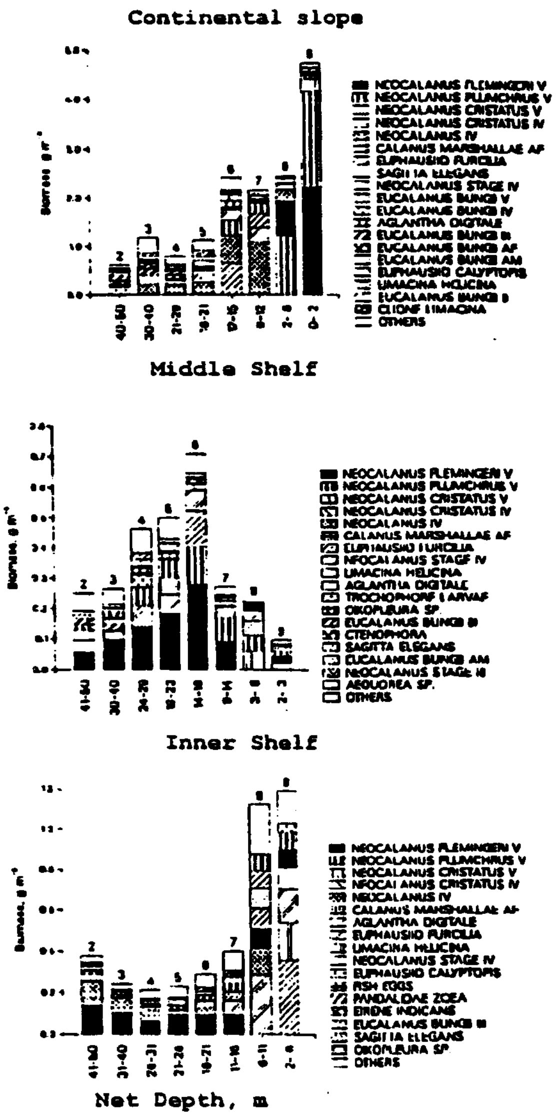


Figure 6. Salinity-NO_3 relationship from Alaska Stream and western GOA shelf stations occupied during WOCE P17N. Only data between 125 and 450 m are plotted.

Figure 7. Zooplankton abundance and taxa at various locations across the north central GOA shelf. The data were collected in May, 1996.

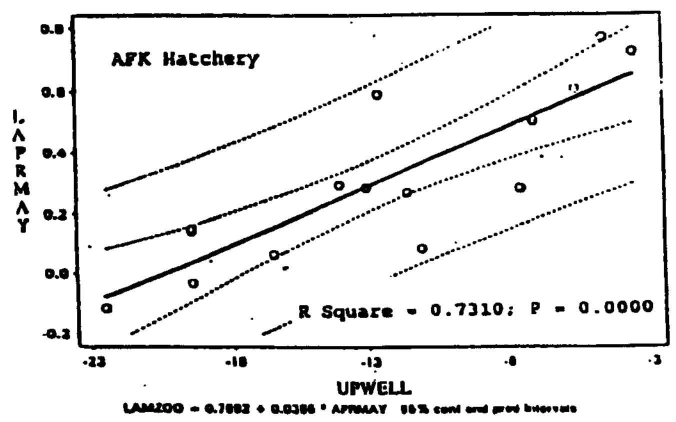


Figure 8. Regression plot of the logarithm of the April–May averaged phytoplankton settled volume against the April–May average upwelling index. (T. Cooney, pers. comm.)

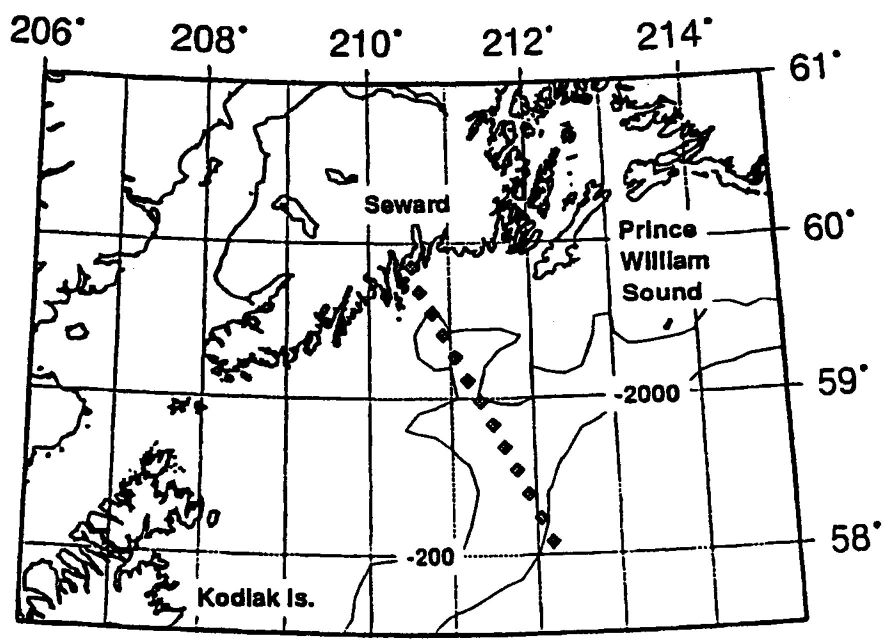


Figure 9. Location of the Seward Line with nominal locations of the proposed CTD and water sampling stations included (depths are in meters).

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APPENDIX 2. LETTER OF SUPPORT OFFER FROM GLOBEC PRINCIPAL INVESTIGATOR TO ROBERT H. DAY OF ABR

INSTITUTE OF MARINE SCIENCE

UNIVERSITY OF ALASKA-FAIRBANKS
FAIRBANKS, ALASKA 99775-1080

March 31, 1999

Dr. Robert H. Day
ABR, Inc.
Fairbanks, AK 99708

Dear Dr. Day,

On behalf of my co-investigators, I am writing to inform you that we welcome your participation in our NSF-NOAA funded GLOBEC program to the Gulf of Alaska. Your proposal to the EVOS Trustees Council, "Seabird-Oceanographic relationships in the northern Gulf of Alaska", provides an important and complementary data set to the GLOBEC program. We believe that your efforts, in conjunction with ours, will yield mutually beneficial results and a truly unique data set from the Gulf of Alaska. We are encouraged that our assessments of distinct shelf habitats and spatial scales of biological production appear to be corroborated by your seabird observations. We will support your project by providing you a berth on each of our cruises and by sharing our data with you. We look forward to this collaboration.

Sincerely,

Thomas J. Weingartner

Thomas J. Weingartner