Toward Long-Term Oceanographic Monitoring of the Gulf of Alaska Ecosystem

Project Number:	01340
Restoration Category:	Monitoring
Proposer:	University of Alaska Fairbanks
Lead Trustee Agency:	ADFG
Cooperating Agencies:	none
Alaska SeaLife Center:	no
Duration:	4th year, 4-year project
Cost FY 01:	$72,000
Cost FY 02:	$20,800
Geographic Area:	Resurrection Bay/Gulf of Alaska shelf
Injured Resource/Service:	All organisms and services

ABSTRACT

Interannual variations in Gulf of Alaska shelf temperature and salinity could significantly influence this ecosystem and hence the recovery and restoration of organisms and services affected by the *Exxon Valdez* oil spill. This variability is best quantified from time series such as the 30-year record at hydrographic station GAK1 near Seward. This project continues this sampling and quantifies this variability. It also attempts to establish relationships between Seward sea level and shelf salinity and regional atmospheric pressure patterns and discharge variability. The data and the analyses will aid in designing a cost-effective ecosystem-monitoring program.

INTRODUCTION

This is a continuation proposal describing the fourth of a proposed four-year effort to maintain the 30-year time series of conductivity-temperature versus depth (CTD) data collected at hydrographic station GAK1. EVOS support for this program began in November 1997 with monthly cruises to station GAK1. These are continuing through September 2000. The monthly data are being supplemented with hourly (or shorter) measurements of temperature and conductivity at six depths using instruments moored at station GAK1. Weingartner (1999, 2000) gives a more complete description and analysis of the data collected thus far. However, the findings thus far indicate:

1. The anomalous summer 1997 warming (amounting to 1-2^{o}C above normal) was confined to the upper 40 m of the ocean. That warming was mainly a result of anomalously clear skies and low winds during the summer of 1997.
2. The abnormally large El Niño-related winter 1998 warming (~2^{o}C) occurred throughout the entire 250 m depth of the shelf. The return to near normal temperatures beginning last May and continuing through the present is being documented.
3. The abnormally large El Niño-related winter 1998 freshening (amounting to a vertically averaged salinity decrease of 0.15 psu) over the upper 200 m of the shelf. Freshening ceased in May and, below 200 m, was replaced with the saltiest waters ever observed at this location. These high salinity waters are enriched in nutrients and potentially available to phytoplankton in the surface layers.
4. A return to near normal temperatures after May 1998 which has continued.
5. The integral time scales for temperature and salinity at GAK1 are about 1 month, which implies that the monthly values (which comprise the historical data set) are not severely aliased.
6. Within-month temperature and salinity variance computed from the moored instruments is no greater than the interannual variability based on the monthly data from the historical record.
7. Variations in freshwater forcing and the baroclinic transport of freshwater are large on seasonal, interannual, and interdecadal time scales. On average freshwater transport increases fivefold between spring and fall. Alaska Coastal Current freshwater transport in spring 1998 (during the 1997-98 El Niño) was twice that of spring 1999.
8. The alongshore baroclinic transport in the upper 75m of the water column and within 30 km of the coast carries at least 50% of the total coastal discharge (as estimated by Royer, 1982) into the Gulf of Alaska.
9. The Alaska Coastal Current could significantly influence the marine ecosystem on the southeast Bering Sea. Our preliminary estimate is that the Alaska Coastal Current contributes about 25% of the Bering Sea freshwater supply. Therefore, improved understanding of environmental variability of the Gulf of Alaska ecosystem could improve our understanding of changes in the Bering Sea ecosystem.
10. Time series of coastal discharge estimates based on Royer’s (1982) method, measured discharge, the leading EOF of precipitable water over the Northeast Pacific Ocean, and coastal salinity data all suggest a decrease in freshwater discharge into the northern Gulf of

Alaska from the late 1950s through the mid-1970s. Discharge increased from the mid-70s through the early-80s; coincident with the regime shift of the 1970s and with the PDO (Mantua, 1997; Overland et al., 1999). These findings add to other suggestions of a freshening across the North Pacific Ocean basin since the 1970s (Wong et al., 1999).

11. Monthly anomalies in the PDO index are coherent with Royer's monthly discharge anomalies at periods of 2 - 4 years and might be related to El Niño events.

12. Monthly sea level anomalies at Seward Alaska are significantly correlated with monthly anomalies of vertically integrated (0-200m) salinity and the 0/200db dynamic height. Hence sea level could serve as a proxy for shelf salinity variations here and perhaps elsewhere in the Gulf of Alaska. The Gulf of Alaska watershed and coastal ocean are severely undersampled with respect to precipitation, river discharge, and salinity. Long-term time series of these are lacking and even the future maintenance of existing discharge and weather stations is uncertain. There is a need to develop proxy variables that can be used to reliably estimate runoff and coastal salinity. A goal of this EVOS program is to determine if sea level can serve as a proxy for ocean salinity variations.

This program will continue the measurements at GAK1 and will continue examining other existing data sets with a particular focus on understanding the temporal and spatial variability in precipitation and runoff related to item 9.

The GAK1 environmental data appear representative of conditions in the northern Gulf of Alaska and the Bering Sea (Royer, 1993) and are being used to assess the role of environmental variability in the ecology of fisheries and marine mammals in these regions. Station GAK1 lies in 260 m of water at the mouth of Resurrection Bay, midway between Prince William Sound and Cook Inlet (Figure 1). GAK1 data should be helpful in placing many of the restoration studies sponsored by the Trustee Council in the context of interannual and interdecadal hydrographic variability. These data complement the goals of the Gulf of Alaska component of the U.S. Global Ocean Ecosystem Dynamics program (GLOBEC), which began in October 1997. As a PI on the Gulf of Alaska GLOBEC program, I have shared data (and sampling resources) from both programs to build a better understanding of the physical environmental variability of this shelf. GLOBEC is supported by the National Science Foundation (NSF) and the National Oceanic and Atmospheric Administration (NOAA). It consists of three components: monitoring, process studies, and modeling. Monitoring began in the Gulf of Alaska in October 1997, with modeling and process studies to follow in 2001. The proposal described here will encourage synthesis of the ecosystem studies supported by the Trustee Council and GLOBEC. In the following paragraphs we summarize the regional oceanography and the historical data from GAK1. This background information provides the context for understanding the rationale and the design of the project described in subsequent sections.

The circulation on the shelf and over the slope of the Gulf of Alaska is predominantly alongshore and cyclonic (counterclockwise) on average (Reed and Schumacher, 1986). Along the continental slope the flow consists of the Alaska Current, a relatively broad, diffuse current in the north and northeast Gulf which intensifies to become the swift and narrow western boundary current, the Alaskan Stream, in the west and northwest Gulf (Figure 2). Together these currents compose the poleward limb of the North Pacific Ocean's subarctic gyre and provide the oceanic connection between the Alaskan shelf and the Pacific Ocean.

The Alaska Coastal Current is the most striking shelf circulation feature in the Gulf, and station GAK1 is positioned along its inshore edge. The main axis of this swift (0.2–1.8 m s^{-1}) westward-flowing current is within 35 km of the coast (Royer, 1981; Johnson et al., 1988; Stabeno et al., 1995). The coastal current is a perennial feature that circumscribes the Gulf of Alaska shelf for some 2500 km (at a minimum) from its origin on the northern British Columbia shelf (or possibly even the Columbia River depending on the season) to where it enters the Bering Sea in the western Gulf. The current is intimately connected to Prince William Sound, feeding the Sound through Hinchinbrook Entrance and draining it primarily through Montague Strait and the westernmost passes (Niebauer et al., 1994). It is also the source of shelf waters for Cook Inlet and transports inlet waters southwestward through Shelikof Strait (Muench et al., 1981). The Alaska Coastal Current transported much of the oil spilled by the *Exxon Valdez* along the south and west coasts of Alaska (Royer et al., 1990).

The dynamics of the Gulf of Alaska shelf are closely coupled to the Aleutian Low atmospheric pressure system. Storms propagate eastward into the Gulf and are blocked by the mountain ranges of Alaska and British Columbia. Consequently, regional winds are strong and cyclonic and precipitation rates are very high. 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, up to 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 and freshwater discharge (***Figure 3***) is large. (Winds are represented in ***Figure 3*** as the upwelling index, a measure of the strength of cyclonic wind stress in the Gulf. Negative values mean coastal convergence and downwelling while positive values signify coastal divergence and upwelling. With respect to Alaska’s south coast, negative values westward winds and positive values). The mean monthly “upwelling index” at locations on the Gulf of Alaska shelf is negative in most months, indicating the prevalence of coastal convergence. 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 3***) 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 wind and freshwater discharge cycles. ***Figure 4*** contrasts the cross-shore salinity structure in April, July, and December. (Density gradients are important in ocean dynamics and salinity is the predominant influence on ocean density in the Gulf of Alaska.) In April, the vertical and cross-shore density gradients are weak and the front (~10 km offshore) intersects both the surface and the bottom. In July, the vertical density gradients are strong and the cross-shore density gradients are relatively strong. Now the front is confined to the surface and has spread ~40 km offshore. In December, the stratification is moderate, the cross-shore density gradients are large and the front forms a 30-km wide wedge adjacent to the coast. These different frontal structures imply seasonally varying dynamics (e.g., Yankovsky and Chapman, 1997; Chapman and Lentz, 1995) that affect the transport and dispersal of dissolved and suspended material across the shelf. For example, surface drifters released seaward of the ACC drifted onshore (in accordance with Ekman dynamics). Upon encountering the ACC front, they moved in the alongfront direction, which is consistent with the geostrophic tendency implied by the cross-shore density distributions of ***Figure 4*** (Royer et al, 1979). Inshore of the ACC front, the surface layer spreads offshore as discharge increases (Johnson et al., 1988). This cross-shelf circulation pattern could accumulate plankton and attract foraging fish. ***Figure 4*** also shows that near-bottom salinities are higher in summer than in spring and, in fact, maximum bottom salinities occur in fall coincident with minimum surface salinities and maximum inshore stratification (Xiong and Royer, 1984). The source of the high salinity water is the onshore intrusion of slope water when downwelling relaxes in summer (Royer, 1975, 1979). Simple 2-D models of this shelf suggest that the dense water is mixed upward in winter to supply the surface layers with nutrients in early spring (Williams and Weingartner, 1999). The swiftest along shore flows are found within and inshore of the front (Johnson et al., 1988), and most of the total transport is associated with the baroclinic component (Stabeno et al., 1995). The latter result is consistent with the finding that monthly coastal sea level anomalies at Seward are significantly correlated with upper ocean dynamic height and vertically averaged salinity anomalies at GAK1 (Weingartner et al., 2000). Dynamic height is a function of the vertically integrated ocean density. Horizontal gradients of dynamic height are proportional to the pressure gradients that accelerate ocean currents and provide an estimate of the oceanic transport. These findings are remarkable given the different nature of the sampling techniques: the sea level records were sampled hourly and then averaged into monthly means whereas the dynamic heights were from hydrographic measurements at GAK1 occupied several months apart. Royer (1979) also found that sea level and precipitation anomalies were well correlated.

The foregoing results suggest that there might be a relationship between monthly (and perhaps shorter period) *cross-shelf dynamic height (or upper ocean density) gradients* and a number of other variables including winds and/or freshwater discharge. Under GLOBEC support we are finding that there is a significant positive correlation between monthly anomalies in 0/100 db Alaska Coastal Current baroclinic transport and inner shelf (eventually GAK1) dynamic heights. The relationship appears to vary seasonally (although the number of degrees of freedom is small in some seasons): it is largest in fall and early spring ($r > 0.8$), negligible in summer, and negative in winter. Although these findings are promising I do not understand the seasonal changes in the correlations. I suspect that, if real, the seasonally changing correlation is related to the coastal current's response to seasonal changes in winds and discharge. That response is probably not linear. Nevertheless, if a reliable relationship can be constructed between GAK1 dynamic height and Alaska Coastal Current transport, then it might be possible to predict mass and freshwater transports (on at least monthly or longer time scales) from a single hydrographic station or mooring on the inner shelf. We also know that freshwater discharge (Royer, 1982; Weingartner et al., 2000) and winds (Livingstone and Royer; 1980) are coherent over a broad along shore distance. In addition, the integral time scales of temperature and salinity (calculated from the EVOS-supported mooring at GAK1, Weingartner, 1999), are about one month on this highly advective shelf. Because of the broad spatial scales and the long integral time scales it might be possible to construct one or two monitoring sites around the gulf that are representative of a broad along shore region of the shelf. If so the results would be useful for ecosystem monitoring, model evaluation (and perhaps data assimilation) and in retrospective studies.

It is very likely that transport variations in the Alaska Coastal Current affect the survival and/or condition of a number of marine organisms. This flow is apparently important in advecting zooplankton to important juvenile fish foraging areas. Napp et al. (1996) and Incze and Ainaire (1994) find that the major cohort of naupliar stage larvae available to first-feeding pollock larvae in Shelikof Strait originate in February–March on the shelf offshore of Prince William Sound and east of GAK1. Other studies indicate that the coastal current is an important feeding and migratory corridor for numerous species of marine mammals (Calkins, 1986) and sea birds (DeGange and Sanger, 1986).

Figure 4 also suggests that near-bottom salinities are higher in fall than in spring and this is the case on annual average. Xiong and Royer (1984) showed that maximum bottom salinities occur in fall and are nearly coincident with minimum surface salinities and maximum inshore stratification (***Figure 5***). Although 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 in response to the seasonal relaxation (or reversal) in downwelling (Royer, 1975; 1979). The deep-water influx in summer from across the continental slope could be important in re-supplying nutrients to the Gulf of Alaska shelf and adjacent embayments and therefore, plays an important role in biological production.

The oceanographic description sketched above stems from research that began in 1970. At that time research vessels from the University of Alaska and other organizations opportunistically sampled station GAK1 while in transit to and from the Seward Marine Center. This ad hoc sampling, conducted at nominally monthly intervals, was the beginning of what is now a 30-year time series for this station. Sampling became more routine (~monthly) in the early 1990s with support from NOAA and the use of a 25-foot vessel operated by the University of Alaska's Institute of Marine Science. EVOS support has systematized the sampling further and the mooring is yielding crucial new information on temporal variability in the thermohaline structure of this shelf. As a result of these efforts the GAK1 data set comprises the longest ocean time series for the high-latitude North Pacific Ocean, and the only one that includes salinity (Royer, 1993). These data reveal substantial interannual and decadal scale variability in both temperature (Royer, 1993) and salinity (Royer, 1996).

For example, Royer (1993) showed pronounced interdecadal temperature variations that included colder water in the 1970s, followed by warmer conditions in the 1980s and a return to normal or cooling conditions in the 1990s. Coincidentally, the relative dominance of 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). 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). Vance et al. (1998) showed that the unusually warm surface waters prevalent throughout the Gulf of Alaska and the Bering Sea in the summer of 1998 were accompanied by observations of species typically associated with mid-latitudes and, in the case of the Bering Sea, with massive changes in the ecosystem.

Royer (1993) also showed that Sitka air temperature variability (for which records extend back to the mid-1800s) correlates with the GAK1 temperature anomalies at 200 and 250 m depths. He found that the 18.6-year lunar nodal tide accounts for a statistically significant fraction of the Sitka air temperature variability. Using the Sitka air temperatures as a proxy for shelf water temperatures, Parker et al. (1995) subsequently showed that the abundance of halibut and other commercially important species varies on a similar time scale and in conjunction with northern

North Pacific Ocean temperatures. While these correlations do not imply causality, they underscore the possible significance of monitoring ocean climate to detect both periodic changes and more radical shifts in the marine environment. Other EVOS-supported investigators studying murre nesting variability (Kettle et al., 1999) have used the data collected recently at GAK1. Other EVOS investigators have showed that warm ocean temperatures enhance survival of young-of-the-year salmon (Willette et al., 1999) and overwintering herring (Norcross et al., 1999). Conceivably the GAK1 record might eventually be used in management decisions.

There are also low-frequency variations in upper ocean salinities at what might be an 11–12 year period, which Royer (1996) ascribed to variations in runoff and precipitation. Much of the interannual variability in precipitation in the Gulf of Alaska is associated with changes in the strength and position of the Aleutian Low (Cayan and Peterson; 1989). Weingartner et al. (2000) also show that much of the low frequency variability is coherent with the Pacific Decadal Oscillation at periods of 2 – 4 years (the El Niño time scale). Changes in upper ocean salinity could affect circulation in the Alaska Coastal Current and also influence biological production by varying frontal properties, circulation strength, the vertical stratification of the water column, and the nutrient concentrations. All of these properties showed considerable differences during the fresh, warm spring of 1998 compared to the salty (but near normal temperatures) of spring 1999 (Weingartner, 2000). The GAK1 data also show substantial interannual variations in bottom water salinities, although these are not linearly correlated with variations in surface salinity. The absence of a correlation is not surprising because near-bottom salinities are linked to shelfbreak processes, while surface variations are associated with precipitation and runoff. Ruehs et al. (1999) are finding that salinity and NO_3 concentrations are positively correlated (***Figure 6***) so that variability in deep water salinity on the shelf probably mean interannual differences in nutrient supply. The GLOBEC program is providing a detailed and year-round description of the nutrients on the Gulf of Alaska shelf. As the amount of these data increase more reliable salinity–nutrient relationships can be established. If these are robust then it might be possible to use the GAK1 salinity time series as a proxy for subsurface nutrient concentrations. This relationship could be exploited in retrospective studies and would aid in the design and maintenance of future monitoring programs because salinity can be accurately measured much more easily (and inexpensively) than nutrients.

In summary, several data sets now suggest that the Gulf of Alaska ecosystem is sensitive to environmental variations on time scales ranging from interannual to interdecadal. Other data sets suggest possible biophysical linkages that cause these ecological responses. However, we lack an adequate characterization of shorter period (seasonal to synoptic) variations that might impinge on the biological components of this ecosystem. Moreover, a mechanistic understanding of the physical dynamics of the Gulf of Alaska shelf and the processes linking environmental variability to ecosystem alterations is lacking. These are complex problems that require a concerted and interdisciplinary approach involving process-specific studies in addition to ecosystem monitoring. Some of these programs (APEX and SEA) are sponsored by the Trustee Council, while a new initiative, the U.S. Global Ocean Ecosystem Dynamics program, began in the fall of 1997 on the Gulf of Alaska shelf. The GLOBEC program is specifically designed to elucidate details of the mechanisms underlying physical and biological environmental change on the shelf. For example, the nutrient cycles and concentrations on the Gulf of Alaska shelf are poorly understood at present (Reeburgh and Kipphut, 1986) but are being investigated in the GLOBEC program. Those results should benefit the monitoring proposed herein. In tandem, the GLOBEC- and Trustee-supported efforts will lead to improvements in ecosystem monitoring.

While the GAK1 time series has illuminated ocean variations having potentially significant ramifications for the marine ecosystem, the monthly sampling will not detect what might be important variations on shorter time scales. Present-day technology now allows inexpensive and accurate sampling at high temporal resolution of temperature and salinity from moorings deployed year round. In combination with monthly CTD sampling, this technology will enhance the value of the historical record, maintain the GAK1 time series, and contribute to the design of long-term ecosystem monitoring programs. The collection of these data forms the basis of this proposal.

NEED FOR THE PROJECT

A. Statement of Problem

The GAK1 monthly time series portrays the very large interannual and interdecadal variability of the high latitude North Pacific. With a greater sampling rate, shorter period variations can be detected, revealing any temporal aliasing problems. The results will enhance interpretations of the historical data and place the magnitude of previous anomalies in a better statistical framework. Moreover, the time series could serve as a proxy for transport in the Alaska Coastal Current. Variability in the marine environment, as reflected in ocean temperatures and salinities, and, if possible, shelf circulation, need to be quantified to understand the structure of, and changes in, the northern Gulf of Alaska marine ecosystem. Such changes might influence the recovery of many of the marine species and marine services listed in Table 4 of the Proposal Invitation. Indeed, several EVOS-supported investigators underscored the need to understand natural climate variability and its influence on the recovery of species injured by the oil spill (Purcell et al., 1999; Piatt and Irons, 1999; Duffy, 1999; Anderson et al., 1999). In conjunction with the historical data set from GAK1, the monitoring program described below will provide a useful data set to EVOS investigators and others concerned with ocean climate variations.

B. Rationale/Link to Restoration

This monitoring proposal provides an information service to current and future investigators working in the Gulf of Alaska and adjacent waters who need information on environmental variability. The information will help assess recovery and restoration progress by allowing these issues to be analyzed within the context of the long-term variability of the physical environment. The GAK1 data set provides some of that information and the proposed measurements will enable continuation of these efforts by collecting time series at GAK1 of:

1. Monthly temperature and salinity at every meter throughout the water column using a conductivity–temperature–depth (CTD) instrument.

2. Hourly temperature and salinity at several fixed depths distributed throughout the water column.

This information will assist in:

1. Understanding thermohaline variability on time scales ranging from the tidal to the interdecadal.

2. Interpreting historical data sets for use in retrospective studies.

3. Configuring a cost-effective, long-term monitoring program.

4. Designing process studies necessary to develop ecosystem models for this shelf.

C. Location

The fieldwork will be conducted at Station GAK1 at the mouth of Resurrection Bay. Both the CTD work and the mooring deployment and recovery operations will be conducted from the Seward Marine Center using the 25-foot vessel, *Little Dipper*. All data collected as part of this program will be available to any who desire it via files on the internet. The monthly CTD data will be combined with the existing historical data that are on the Institute of Marine Science webpage: http://www.ims.alaska.edu:8000/gak1/gak.dat. A new homepage will be created for the hourly time series after mooring recovery and editing of the data. The homepages will be linked.

COMMUNITY INVOLVEMENT AND TRADITIONAL ECOLOGICAL KNOWLEDGE

We do not see any overt connection to traditional ecological knowledge. However, the most expedient way to share these data with both the public and scientific communities is via the internet. Such a link will allow easy access to the data for those working at the community level and with traditional ecological knowledge. We have recently learned that the Alaska Department of Environmental Conservation (ADEC) maintains a VHF radio repeater on Rugged Island and within 1.5 miles of GAK1. The ADEC has indicated that the repeater station could be shared with other users. If technical obstacles can be overcome, we will seek to upgrade GAK1 so that data collected from this mooring could be transmitted, via VHF signal, in near real time directly into Seward (preferably the Alaska SeaLife Center) for immediate use and display. A VHF transmission would be considerably cheaper than data links via ARGOS or cell phone.

PROJECT DESIGN

A. Objectives

Two objectives motivate this multi-year program. First, we want to continue the 30-year time series at station GAK1 through a combination of monthly CTD measurements and through yearlong deployments of a mooring containing temperature and conductivity (T/C) recorders. Second, we want to contribute to the design of a cost-effective monitoring program for the Gulf of Alaska shelf. The sampling schemes complement one another with one providing high vertical resolution at monthly time scales and the other providing high temporal but relatively low vertical resolution. We recognize that our generic goal of ecosystem monitoring is a long-term undertaking requiring incremental efforts and so view our efforts as essential steps toward that goal. To guide our efforts we formulated several project-specific objectives, several of which are underway, and discussed them in the first and second year's annual reports (Weingartner, 1999; 2000). These are:

1. Determine the rate of change of water mass properties (temperature and salinity) and the phasing of these changes at different depths. Some of these features, which are not resolved by monthly sampling, reflect important changes whose timing could be significant to the ecosystem. The data files will be made available on the time series homepage for downloading and as a graphical display. Key events will be highlighted and discussed as part of the graphical display.
2. Determine the basic statistical properties of the moored data and how variances in temperature, salinity, and dynamic height are distributed over depth and seasonally. Are there distinct vertical "modes" of variability that change with season? These results will also be summarized in a file containing textual, tabulated, and graphical information and will be accessible via the time series homepage.
3. We want to improve upon the understanding achieved this past year with respect to long-term freshwater forcing variations in the Gulf of Alaska. One approach to doing this is to compare simple atmospheric pressure patterns or indices with long term precipitation and/or stream flow measurements from around the gulf. Pressure patterns over the Northern Hemisphere have been reconstructed back to 1900. However, there is only one virtually continuous streamflow record for the northern Gulf of Alaska since ~1920 and continuous precipitation records date to 1930. Thus quantifying decadal scale variability is hampered by the lack of precipitation and discharge records. If proxies for these variables can be established then a surrogate discharge time series for the gulf can be reconstructed for the past 100 years. I anticipate that pressure patterns favoring northward atmospheric transport into the Gulf of Alaska might be highly correlated with regional runoff and precipitation. If such an index results then it would serve as a proxy for discharge variability dating to the early 1900s. Note that we are not trying to duplicate other indices (such as the PDO) which characterize hemispheric scales but rather to construct a more local (e.g., Gulf of Alaska) index that would be a better predictor of regional streamflow variations. These results will be made accessible on the homepage.

The first two objectives rely on continued sampling at GAK1. The last objective represents an exploratory study precipitated by the GAK1 data set and the results from Year 2 of this study reported by Weingartner (2000) and presented at the EVOS workshop and the AGU-ASLO Ocean Sciences meeting in 2000.

B. Methods

Funds are requested to monitor Gulf of Alaska temperature and salinity through FY 01, at which time a restructuring of the program described here will probably occur. By this time, the APEX and SEA programs will be completed and preliminary results from the U.S. GLOBEC-sponsored Gulf of Alaska monitoring component will be available (U.S. GLOBEC, 1996). Accomplishments from these programs (and from the work proposed herein) will catalyze a reconsideration of the monitoring effort. In addition, researchers working at the Alaska SeaLife Center will probably have monitoring interests to be considered as well.

We propose to collect data monthly with the Institute of Marine Science's 25-foot *Little Dipper* using a Seabird SBE-25 internally-recording CTD deployed from the vessel's winch. The sensors on this CTD are calibrated annually by the manufacturer. Field checks on the conductivity sensor are made from bottle salinities collected during each cast and analyzed on the salinometer at the Seward Marine Center. This procedure allows detection of CTD drift between calibrations by the manufacturer. The historical salinity data have an accuracy of ~0.01 or better using this instrument and these procedures. Temperatures are accurate to within 0.005°C.

The monthly sampling will be complemented by hourly measurements from six temperature/conductivity recorders (Seabird MicroCats; SBE model 37-SM) incorporated in a taut-wire, subsurface mooring at GAK1. The mooring can be deployed and recovered by the *Little Dipper* during the CTD cruises. The instruments will make hourly measurements at nominal depths of 30, 50, 100, 150, 200, and 250 meters. This distribution covers the near-surface (30 m), the upper ocean (30–100 m), mid-depth (150–200 m) and bottom (200–250 m) of the water column. (Although observations at the surface would be useful, obtaining these would entail a mooring with substantially higher hardware and fabrication costs and the need for a larger vessel for servicing.) While results from the first year indicate that mooring motion is unimportant, this is monitored with a pressure on the MicroCat at 30-m depth. Our prior experience with these and similar instruments (SeaCats) indicate that temperature and salinity drifts are generally <0.02°C and <0.03 psu/year, respectively.

The analyses of the data sets are straightforward.

Objective 1 is largely concerned with temporal aliasing issues associated with monthly sampling. Among the important processes that might be aliased are the summer onshelf influx of dense bottom water, changes in upper ocean stratification throughout the year as a consequence of winds and runoff, and the response of the thermohaline structure of the water column to synoptic scale forcing by the wind.

Objective 2 will be achieved by examining the empirical orthogonal functions (EOFs) of the temperature and salinity time series. The EOFs decompose the system variance into a set of linearly independent functions, with each describing a unique spatial and temporal structure. For the mooring data the system variance would be that computed from the salinity (or temperature) time series at all depths. Six EOF modes will result from the analysis because six depths are sampled. The modes are ordered according to the proportion of the total system variance that each comprise. Thus the first mode accounts for the greatest fraction of system variance and the sixth mode accounts for the smallest proportion. Often, only a few modes are required to describe the system variance, and the significance of a given mode will be assessed following Overland and Preisendorfer (1982). The spatial structure of a mode describes the distribution of amplitude with depth, while its temporal structure describes how the mode varies through time. The EOFs are useful in consolidating large and complicated data sets into smaller correlated subsets that facilitate physical interpretation. They might also contribute to future monitoring design by suggesting times and/or depths that are either over- or under-sampled. In the latter case, the EOFs could identify potential temporal or spatial aliasing problems.

For objective 3 I will use~40 years of monthly atmospheric precipitable water and atmospheric pressure indices obtained from the NCEP/NCAR reanalyzed meteorological fields interpolated onto a 2.5^o grid between 65^o-35^{o}N and 160^o-120^{o}W. (The website containing these data is http://www.cdc.noaa.gov./cdc/data.nmc.reanalysis.html#surface). The purpose is to construct statistical relationships between atmospheric pressure indices and precipitable water and stream discharge. Data for the latter are obtainable from the USGS website: http://2o-nwisw.er.usgs.gov/nwis-w/AK/. We will also use Royer's Gulf of Alaska discharge time series in this analysis.

SCHEDULE

A. Measurable Project Tasks for FY 01 (October 1, 2000 – September 30, 2001)

October 15:	Monthly CTD surveys scheduled at mid-month; update homepage as CTD data are processed and edited; prepare wind fields and acquire meteorological fields.
November–December:	Deploy mooring (the mooring will be deployed as soon as instruments can be delivered from the manufacturer) during this month's CTD sampling.
September:	Field work is completed; mooring will be recovered.

B. Project Milestones and Endpoints

The data collected as part of this project will be available to a broad community of users. We anticipate that some will want "immediate" access to it. This desire often conflicts with the goal (and required time) of producing data of the highest possible quality. In the past, the final CTD data have generally been placed online 1–2 months after collection. The final edited temperature and salinity data from the mooring should be ready three months after instrument recovery. The delays arise because of post-calibration requirements (performed by the manufacturer) and final editing of the data sets (performed at the Institute of Marine Science). We intend to make much of the data, along with preliminary results, available for rapid dissemination. From a practical point of view this approach is prudent because for many users the differences between the raw and the final edited product are insignificant. We will attach appropriate warnings concerning data quality to both preliminary and final data products. Thus, we anticipate making most of the data available on the homepage one month after recovery of the mooring. However, data will not be released if there are severe concerns regarding its quality unless and until such concerns are resolved. In addition to these general considerations, we anticipate the following project milestones:

1. The first objective is to examine rates of change of water mass properties (temperature and salinity) and the phasing of these changes at different depths. This work is largely descriptive and will begin immediately after instrument recovery. Graphical data displays will be made available within 1–2 months of recovery. These will include textural information indicating features of interest. Displays will be updated periodically as new findings emerge. Eventually these results will be merged with those of the third objective.

2. The second objective pertains to basic statistical results and provides the modal description of system variance. The results will be made available in both preliminary and final fashion. These calculations are straightforward and the results and preliminary interpretations would be made available within two months of mooring recovery. When the final data product is

ready, we will update the GAK1 CTD homepage describing these statistics and their relevance to historical GAK1 data.

3. The third objective requires considerably more effort and will be completed by the end of the project.

If the mooring is recovered in September 2000, all objectives will be reached by early April 2001. If the mooring is recovered as scheduled in December 2000, all objectives and the report will be reached by early April 2002.

C. Completion Date

This project will be completed in FY 02.

PUBLICATIONS AND REPORTS

No manuscripts will be submitted in FY 00. Data and results will be provided via internet as indicated above. If a pressure index – discharge relationship for the Gulf of Alaska (Objective 3) can be established these results would provide the basis for a paper examining long-term discharge (the past 100 years) variability in the Gulf of Alaska.

PROFESSIONAL CONFERENCES

Portions of the research will be presented at the international meeting, The Eastern Pacific Ocean Conference to be held in September 2000 in Sidney, British Columbia. The PI has been invited to chair a session on observations of biological and physical interactions in the eastern Pacific Ocean.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

We have discussed aspects of the GAK1 historical data with several investigators supported by the Trustee Council. Many have expressed interest in these data and know how to access it. Other scientists are aware of these data through papers and meetings, (e.g., the American Geophysical Union which serves primarily the U.S. oceanographic community and the North Pacific Marine Science Organization [PICES] composed of marine scientists from around the Pacific Rim). Though we have discussed in previous sections how we would make these data available, we welcome advice from the Trustee Council on additional ways to share these data with other investigators and/or the public.

Several UAF scientists are co-investigators on a GLOBEC proposal whose results would complement this proposal. The UAF investigators (Coyle, Paul, Haldorson, Whitledge, Weingartner) along with Royer (Old Dominion University) have funding from the NSF NOAA GLOBEC program to examine the Gulf of Alaska shelf ecosystem for the period October 1997–December 2000. This work includes six R/V *Alpha Helix* cruises spaced throughout the year to examine the cross-shelf hydrography (including nutrients) and the distribution of phytoplankton, primary production, zooplankton and fish (mainly juvenile salmon and forage fish) in relation to the physical environment. These investigators have submitted a proposal to NSF-NOAA to continue the GLOBEC monitoring work in the Gulf of Alaska for the 2001 – 2004 period. Our new proposal seeks support for seven cruises/year to sample the Gulf of Alaska shelf including GAK 1. We emphasize that there is a possibility for considerable cost-sharing through GLOBEC of the monthly sampling at GAK 1. *If our GLOBEC proposal is renewed, then the GLOBEC cruises will sample GAK 1 seven times each year and reduce the number of cruises required on the Little Dipper. The enclosed budget, which seeks support for 12 Little Dipper cruises/year could then be reduced.*

We see these programs as highly complementary in several ways. First, the cross-shelf hydrography will provide a basis for comparison with variations observed at GAK1. Second, a sufficient number of cross-shelf dynamic height *gradients* (proportional to the ocean transport) would be available (68 including the historical data and those under the new GLOBEC proposal) to examine the correlation between this gradient and dynamic height at GAK1. This result will help determine if dynamic height at a single station can provide an index of transport in the Alaska Coastal Current. Third, a comprehensive nutrient data set will be made available for establishing the type of correlations alluded to in the introduction. If significant correlations are obtained at several depths in the water column, then the GAK1 data would be a proxy indicator of historical variations in nutrient concentrations (for some depths).

The GLOBEC proposal makes connections with other investigators. For example, we have offered berth space on the *Alpha Helix* during our GLOBEC cruises to Robert Day of Alaska Biological Research, Inc., Fairbanks, for his sea bird and marine mammal studies. (Dr. Day is submitting a proposal to the Trustee Council for this project.) Thomas Kline of the Prince William Sound Science Center participated in four GLOBEC cruise and plans to participate in this year's cruises also.

The effort described in this proposal takes a modest but important step toward achieving the goal of long-term, comprehensive ecosystem monitoring. There are compelling scientific and logistical reasons for believing that GAK1 will be a long-term site and that the sampling will eventually expand to include other disciplines. Resurrection Bay and the adjacent ocean are paradigmatic for much of the Gulf of Alaska shelf, and this area is easily accessible by marine scientists at Seward. Although our understanding of chemical cycling and biological processes on this shelf is limited at the moment, programs such as SEA, APEX, and GLOBEC will provide substantial new information for these disciplines. Results from these programs and those anticipated from the work proposed herein will contribute to the design of a comprehensive long-term monitoring strategy. Additional impetus for expanding the monitoring activities at GAK1 will occur as programs at the Alaska SeaLife Center evolve.

PROPOSED PRINCIPAL INVESTIGATOR

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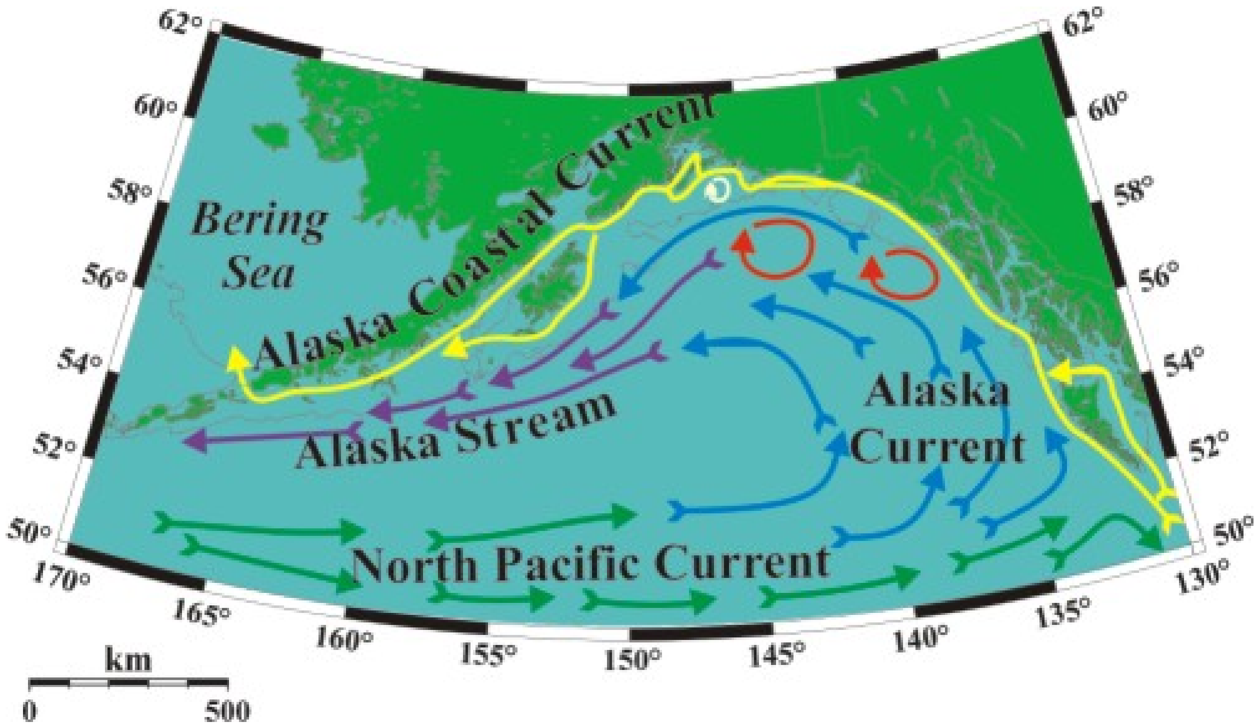

Figure 1. Schematic of the circulation of the Northeast Pacific and Gulf of Alaska.

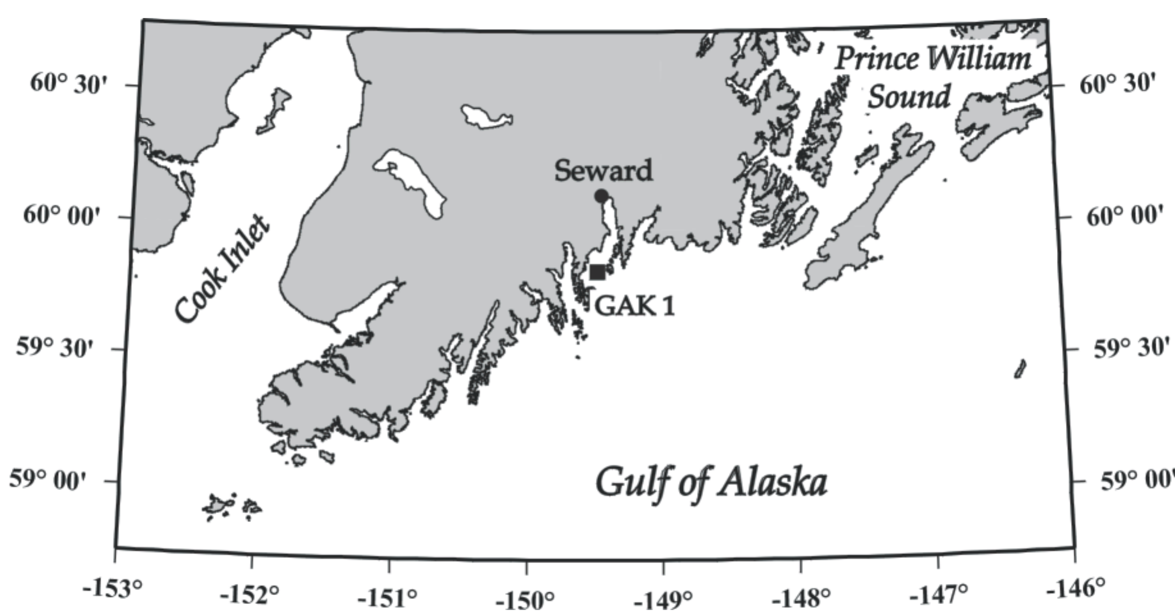

Figure 2. Map showing location of hydrographic station GAK1 in relation to Prince William Sound, Cook Inlet and Seward.

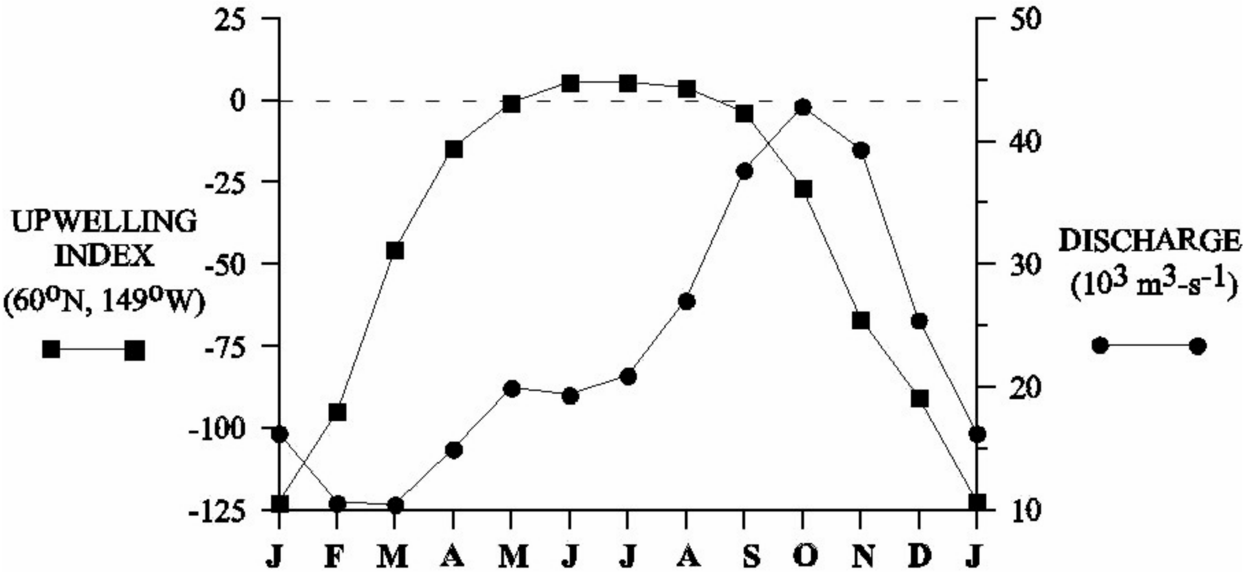

Figure 3. Mean monthly values of the upwelling index (from 1946–1995) and the estimated freshwater discharge (from 1930–1992) into the Gulf of Alaska using the hydrology model of Royer (1982).

PRINCIPAL INVESTIGATOR

Thomas J. Weingartner

EDUCATION

Ph.D. Physical Oceanography, 1990, North Carolina State University
M.S. Physical Oceanography, 1980, University of Alaska
B.S. Biology, 1974, Cornell University

MEMBERSHIPS

American Geophysical Union; American Meteorological Society

PUBLIC SERVICE

Member, Science Steering Committee, NSF - Arctic System Science-Ocean Atmosphere Ice Interaction (OAII) component
Member, Science Steering Committee, NSF - ARCSS-OAII Shelf-Basin Initiative
Member, Science Steering Committee, NSF - ARCSS-Human Dimensions of the Arctic component
Member, UNOLS - Fleet Improvement Committee

PROFESSIONAL EXPERIENCE

Assistant Professor; Institute of Marine Science, School of Fisheries and Ocean Sciences, U. of Alaska Fairbanks, Alaska; 11/93 - present
Research Associate; Institute of Marine Science, School of Fisheries and Ocean Sciences, U. of Alaska Fairbanks, Alaska; 9/91 - 10/93
Postdoctoral Student; Institute of Marine Science, School of Fisheries and Ocean Sciences, U. of Alaska Fairbanks, Alaska; 7/88 - 8/91
Graduate Research Assistant; Department of Marine, Earth and Atmospheric Sciences, North Carolina State U.; Raleigh, North Carolina; and Department of Marine Science, U. of South Florida; St. Petersburg, Florida; 8/84 - 10/88

PROFESSIONAL INTERESTS

Physical oceanography of the Arctic and North Pacific Ocean and the adjacent shelves, biophysical linkages in oceanography; public education.

PUBLICATIONS

Weingartner, T. J., S. Danielson, Y. Sasaki, V. Pavlov, and M. Kulakov. The Siberian Coastal Current: a wind and buoyancy-forced arctic coastal current. *J. Geophys. Res.,* ***104***: 29697 – 29713, 1999.

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Niebauer, H. J., Royer, T. C., and T. J. Weingartner. 1994. Circulation of Prince William Sound, Alaska. *J. Geophys. Res*.. 99:14113-14126

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Musgrave, D. L., T. J. Weingartner, and T. C. Royer. 1992. Circulation and hydrography in the northwest Gulf of Alaska. Deep-Sea Res. 39:1499-1519.

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Weingartner, T. J., K. Aagaard, D. J. Cavalieri, and Y. Sasaki. Winter baroclinic processes on the northeast Chukchi Sea shelf.

Weingartner, T. J., K. Aagaard, and Y. Sasaki. Circulation in Barrow Canyon and implications on shelf-basin exchange.

OTHER KEY PERSONNEL

Mr. David Leech is the Seward based mooring and marine technician responsible for the design and deployment of the mooring. He will also conduct the monthly CTD sampling from the *Little Dipper*. Mr. Mark Vallarino is the computer programmer who will assist in data processing, analyses, and maintain the web page. Both are employees of the Institute of Marine Science.

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2001 EXXON VALDEZ TRUSTEE COUNCIL PROJECT BUDGET
October 1, 2000 - September 30, 2001

Budget Category:	Authorized FY 2000	Proposed FY 2001						
Personnel		$0.0						
Travel		$0.0						
Contractual		$67.3						
Commodities		$0.0						
Equipment		$0.0	LONG RANGE FUNDING REQUIREMENTS					
Subtotal		$67.3			Estimated FY 2002	Estimated FY 2003		
General Administration		$4.7						
Project Total		$72.0						
Full-time Equivalents (FTE)		0.5						
	Dollar amounts are shown in thousands of dollars.							
Other Resources								

Comments:

FY01

Prepared:

Project Number: 01340 Revised
Project Title: Toward Long-Term Oceanographic Monitoring of the Gulf of Alaska Ecosystem
Agency: Alaska Department of Fish and Game

Budget Category:	Authorized FY 1999	Proposed FY 2000

2001 EXXON VALDEZ TRUSTEE COUNCIL PROJECT BUDGET

October 1, 2000 - September 30, 2001

Personnel		$39.4							
Travel		$0.7							
Contractual		$11.7							
Commodities		$2.1							
Equipment		$0.0	LONG RANGE FUNDING REQUIREMENTS						
Subtotal		$53.9			Estimated FY 2001	Estimated FY 2002			
Indirect		$13.4							
Project Total		$67.3							
Full-time Equivalents (FTE)		0.5							
	Dollar amounts are shown in thousands of dollars.								
Other Resources									

Comments:

The indirect rate is 25% TDC, as negotiated by the *Exxon Valdez* Oil Spill Trustee Council with the University of Alaska.

The budget costs include time for the PI and the technicians to complete the data analysis and report writing after the instruments are recovered from the ocean. Calibrations would be completed by December 2001 and the final report completed by the end of March 2002. The PI will spend 1.5 months on the project between December 2001 and March 2002, and Vallarino will devote a month of his time to this project between December 2001 and March 2002.

FY01

Prepared:

Project Number: 01340 Revised
Project Title: Toward Long-Term Oceanographic Monitoring of the Gulf of Alaska Ecosystem
Name: Thomas J. Weingartner

Personnel Costs:						
Name	Position Description		Months Budgeted	Monthly Costs	Overtime	
Weingartner, T.	Principal Investigator/Assistant Prof.		2.0	6.8		
Vallarino, M.	Computer programmer		2.0	5.7		

	Leech, D.	Mooring and marine technician		2.3	5.7	0.3	
		Subtotal		6.3	18.2	0.3	
						Personnel Total	

Travel Costs:		Ticket	Round	Total	Daily	
	Description	Price	Trips	Days	Per Diem	
	R/T Fairbanks to Anchorage	300.0	1	3	120.0	
					Travel Total	

FY01

Prepared:

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Contractual Costs:	
Description	
Little Dipper (6 full days @ $500/day and 6 half days @ $250/hday)*	
CTD calibration (SBE-25)	
Microcat calibration (6 @ $600 ea.)	
Shipping (R/T Seward to Seattle, CTD and MicroCats)	

Shipping (R/T Seward to Boston)	
Acoustic release alignment	
*This estimate would be revised downward if the GLOBEC monitoring proposal submitted by Weingartner and colleagues is funded. In that case, GLOBEC will fund seven cruises/year on the RV *Alpha Helix* . Little Dipper cost would be for 3 full days and 2 half-days to total $2,000.	
Contractual Total	

Commodities Costs:	
Description	
Batteries, O-rings, tools	
Shackles, sling links, thimbles	
Standard seawater (6 @ $30/vial)	
Mooring anchor and lashing chain	
Commodities Total	

FY01

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2001 EXXON VALDEZ TRUSTEE COUNCIL PROJECT BUDGET
October 1, 2000 - September 30, 2001

New Equipment Purchases:	Number	Unit	
Description	of Units	Price	
Those purchases associated with replacement equipment should be indicated by placement of an R.		**New Equipment Total**	

Existing Equipment Usage:	Number	
Description	of Units	

FY01

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