EVOS PROPOSAL SUMMARY PAGE

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Project Title: Trophic dynamics of intertidal soft-sediment communities: interaction between bottom-up & top-down processes– submitted under the BAA

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Abstract:

Vast expanses of intertidal sand/mudflats serve as a critical link in the food web of nearshore communities along the southcentral Alaska coastline. The rich abundance of benthic invertebrates residing within the sediments of intertidal flats and the large network of subtidal channels that bisect these flats provide a significant prey resource for numerous species of fish, crabs, birds, and marine mammals. One of the largest expanses of intertidal mud/sand flats occurs in the Copper River Delta and southeastern Prince William Sound (Orca Inlet). Here we propose a large-scale field study that examines the physical/chemical and biological factors that limit and/or regulate invertebrate community dynamics. The largely "bottom-up" approach we propose (physical/chemical parameters – phytoplantkon/epibenthic production – invertebrate production) is balanced by the largely "top-down" focus of a companion project funded by the Prince William Sound Oil Spill Recovery Institute that examines predator dynamics and assesses their role in invertebrate community dynamics.

I. INTRODUCTION

Intertidal mudflats support highly productive habitats characterized by a high densities of invertebrates, which, in turn, provide a critical prey resource for fish, crabs, and migratory shorebirds (Peterson and Peterson 1979; Peterson 1991). The Copper River Delta is such an example of a complex and productive mudflat ecosystem. Located at the eastern edge of Prince William Sound near the port of Cordova, the vast 500-km^2 mudflats stretch almost continuously for 80 km from Egg Island to Castle Island, and from Kokinhenik Island to Softuk Bar. Extensive mudflats also occur in Orca Inlet, a large bay in southeast Prince William Sound also influenced by the Copper River.

Until now, the Copper River Delta, including its shoreline, intertidal mudflats, and its barrier islands have not been developed. Three agreements recognize the importance of the intertidal mudflats on the Delta. Since 1978 the State of Alaska has designated the Copper River Delta, including the intertidal habitats, a State Critical Habitat Area. The Alaska National Interest Lands Conservation Act of 1980 (ANILCA) further mandated that the conservation of fish and wildlife and their habitats shall be the primary purpose for the management of the Copper River Delta. This mandate applies to federal lands, with the USDA Forest Service managing all lands above mean high tide. And third, the 1990 eight-party agreement for the Copper River Delta Hemispheric Shorebird Reserve Memorandum of Understanding designated the delta's intertidal mudflats as part of the Western Hemisphere Shorebird Reserve Network.

The Delta's intertidal mudflats and network of sloughs serve as a critical connection between the Gulf of Alaska and a vast expanse of wetlands, rivers, lakes and glaciers. The tidal flats provide foraging habitat for a variety of migratory (shorebirds and salmonid fish) and resident demersal species (e.g., dungeness crabs *Cancer magister*, and flatfish). Over 4 million shorebirds, the largest spring concentration of shorebirds in the Western Hemisphere (Isleib 1979, Bishop et al. 2000) visit the Copper River flats annually between late April and mid-May on their way to breeding grounds in western Alaska. Aerial monitoring has shown that shorebirds primarily use intertidal areas west of the Copper River (63% of all shorebirds), compared with 5% at Orca Inlet, 7% at the east delta and 25% at Controller Bay, an area just east of Copper River Delta (Bishop *in prep*.).

Some 549 gillnet fishers commercially harvest 3 species of salmon on the Copper River Delta flats: sockeye (*Oncorhynchus nerka),* coho (*O. kisutch),* and chinook (*O. tshawytsch).* The tidal flats serve as both an entry and exit corridor for these salmon. The fish migrate through the delta first as smolts (i.e., late-stage juveniles) leaving freshwater habitats and then again as adults attempting to return to the same freshwater habitats to spawn (Christensen et al., 2000). The duration of stay on the delta is unknown for adult and juvenile salmonids. Given that harpacticoid copepods and amphipods make up a significant portion of smolt diets (Willette, 2002), the tidal flats of the Copper River Delta could serve as a potentially important feeding ground for these fish.

Whereas the Copper River Delta was once thought to be safe from potential pollution events such as oil spills because of the westward flow of the Alaska Coastal Current, recent data show that previous assumptions may be flawed, and that the Delta is, in fact, vulnerable to oiling. Preliminary results of a circulation study in the Gulf of Alaska indicate that sub-surface currents in the vicinity of the Copper River Delta Flats can flow eastward from the Gulf toward the Copper River Delta (Vaughan 1997). In addition, a survey of local commercial fishermen reported that strong sustained westerly winds in summer could shift surface currents eastward in areas of the Copper River Delta flats. The respondents characterized the Delta's currents as having a high degree of localized variability and rapidly changing conditions (Allen et al. 1996).

In 1999 the Alaska Regional Response Team (1999) prepared an oil spill response plan for the Copper River Delta and Flats. The most serious threats to the Copper River Delta and Flats include: a powered oil-tanker grounding at Hinchinbrook Entrance, a loss of tanker power in the Gulf of Alaska during inclement weather (C. Shaw, CDFU, pers. comm., 1998), and an inland spill of the Trans Alaska pipeline in the vicinity of the Tsina and Tiekel Rivers (Alaska Regional Response Team, 1997). In addition, on the eastern side of the Delta near Katalla, future onshore oil and gas exploration and coal mining could trigger an increase in shipping activities and heighten the risk of an oil spill.

In 2000, the Prince William Sound Science Center (PWSSC) and the Institute of Marine Sciences-University of North Carolina at Chapel Hill (UNC) under the auspices of the Prince William Sound Oil Spill Recovery Institute (OSRI) began the first study of the Copper River Delta's intertidal communities. Now in its third season, the purpose of this study is to examine on large spatial and temporal scales the effects of abiotic (e.g. sediment grain size, tidal elevation, salinity) and biotic factors (primarily predation by shorebirds, crabs and flatfish) on the Delta's intertidal mudflats. The study has emphasized and will continue to emphasize the potential role of top-down factors (i.e. predators) in regulating intertidal community structure.

However, a complete understanding of the intertidal community, in particular how the community will respond to local and regional environmental change (i.e. temperature, circulation patterns, major environmental perturbations), is impossible without elucidating the extent to which bottom-up forcing (i.e. primary production) regulates production (biomass produced per unit time) of invertebrates residing within the sediments. Changes in prey production may greatly impact predator usage of intertidal habitats and consequently the condition and production of the predator community, many of which are commercially and/or recreationally exploited. Our intent is to couple the ongoing PWSSC-UNC study, which focuses on the latter issues, with a GEM supported project that focuses on the bottom-up processes and the response of the community to local and regional forcings.

The PWSSC-UNC study has provided the first description of the intertidal benthic community on the western Copper River Delta and at Hartney Bay (Orca Inlet, southeast Prince William Sound). The study has determined that the western Delta's upper and mid-intertidal mudflats are characterized by low species diversity, and are dominated both in biomass and numerical abundance by *Macoma balthica,* a tellinid bivalve. *Macoma balthica* reaches densities greater than 4000 m^{-2} in some parts of the delta. Age-length relationships of *Macoma* indicate slow growth, variable recruitment and longevity of 7-8 yrs. Other important benthic species are polychaetes, primarily the phyllodocid *Eteone longa,* and amphipods, primarily the corophid *Corophium salmonis* and two species of large gammarids (Powers et al. 2002). In the lower, more sandy intertidal zones, softshell clam (*Mya arenaria*) is the dominant bivalve species (Powers et al. *in review*). At Hartney Bay in Orca Inlet, the benthic community is more diverse presumably as a result of more stable salinities and low turbidity (which may affect primary production). Here *M. balthica* also dominates, but high abundances of *M. arenaria* occur across all tidal elevations, extensive beds of *Mytilus edulis* occur at mid-elevations, and a greater diversity and biomass of polychaetes are found compared to the tidal flats on the Delta.

We suspect that a gradient of community change exists from the more brackish, highly turbid areas influenced by the discharge of the Copper River Delta, to the higher salinity, less turbid mudflats characteristic of southeastern Prince William Sound. This gradient, which undoubtedly influences primary production, can be used to examine the dynamics of intertidal communities under the influences of changing environmental conditions and may provide valuable insight in predicting community response to changes in local and regional forcing.

The Gulf Ecosystem Monitoring Program (GEM) hypothesizes that natural forces (such as currents and predation) and human activities (such as increased urbanization and localized pollution) serve as distant and local factors, in causing short-term and long-lasting changes in the community structure and dynamics of intertidal and subtidal habitats. Results from the first two seasons of the PWSSC-UNC study of the Copper River Delta and Orca Inlet mudflats support the GEM hypotheses that natural forces do influence benthic community structure. The PWSSC-UNC study found that spatial patterns of benthic invertebrate abundance are best explained by differences in sediment grain size and tidal inundation, with longer inundation corresponding to greater invertebrate densities (Powers et al. 2002). This pattern is disrupted at lower tidal elevation, possibly as a result of greater access by the epibenthic predators. Temporal changes in abundance of polychaetes, amphipods, and *M. balthica* recruits correspond to increases in sediment temperatures (Powers et al. 2002). However, changes in the biomass of phytoplankton or epibenthic algae, which is driven to a large degree by temperature, may be the more proximate cause.

Whereas larval availability has proven to be a limiting factor in structuring rocky intertidal communities under certain conditions, the population dynamics of soft-sediment invertebrates are largely a function of post-settlement mortality caused by large, epibenthic predators, not larval availability (Olafsson et al. 1994; Powers et al. 2001). Additionally, biotic interaction such as density-dependent inhibition of recruitment by potential colonists by adult deposit-feeders may regulate population density and community structure (Olafsson et al. 1994). On the Copper River Delta mudflats, the high densities of benthic invertebrates (Powers et al. 2002) may also lead to competition for both food (epibenthic algae) and space. Although competition within soft-sediment communities rarely results in competitive exclusion (unless adult-larval interaction are common), increased competition for food and crowding can result in decreased growth of individuals (Peterson 1979, Olafsson et al. 1994). While not affecting survivorship, such decreases in growth of individuals may affect overall production depending on the level of food resources (i.e. conditional density-dependence, see Powers & Peterson 2000).

Preliminary experiments conducted in the summer 2001 by PWSSC-UNC in which both density of *M. balthica* and food levels were manipulated (through additions of nutrients and subsequent increases in epibenthic algae production) indicated that the food limitation/crowding hypothesis may be correct. Plots receiving added nutrients showed high diversity (amphipod numbers increased) and larger *M. balthica.* Additionally, the experiments demonstrated that intense competition for space may occur: large adults quickly colonized vacant space through post-settlement movement.

Predator exclusion studies conducted by previous researchers as well as by the PWSSC-UNC study in the summers 2000 & 2001 demonstrated the potential role of post-settlement processes on the abundance of benthic invertebrates. During the 2001 field season, the PWSSC-UNC tested the hypothesis that avian predators, specifically shorebirds, may structure the Delta's intertidal invertebrate community. Two species of shorebirds, Western Sandpiper, *Calidris mauri*, and Dunlin, *Calidris alpina pacifica*, comprise more than 90% of the more than 4 million shorebirds passing through the Delta (Bishop et al., 2000). While on the delta, both species feed almost exclusively on benthic invertebrates residing within the sediments of mudflats (Senner et al., 1989; Bishop and Powers unpubl. data). As major co-predators on invertebrates, *s*horebirds can potentially structure marine invertebrate communities (Marsh 1986, Cayford and Goss-Custard 1990). Removal of as much as 6-44% of benthic productivity by shorebirds has been documented on intertidal areas (Baird et al. 1985). In 1976 at Hartney Bay in Orca Inlet, the number of *M. balthica* in the 7-12mm size range declined during spring migration, most likely as a result of Dunlin predation (Senner et al. 1989).

In order to test the avian predator hypotheses, a series of $1m^2$ full and partial predator exclosures were installed in mid-April prior to spring migration. Exclosures were sampled after periods of both high (April-May) and low bird abundance (June-August). Results indicated that there were significant differences in *M. balthica* densities between full exclosures (excluding all predators) and controls (allowing free access to all predators) but not between partial exclosures (excluding only avian predators) and controls (Bishop and Powers unpubl. data). Although shorebirds are a major predator on *M. balthica* it does not appear that shorebirds regulate *Macoma* abundance. However, predation on new *M. balthica* recruits by other predators (shrimp, crabs and fishes) does appear to decrease overall abundance of *Macoma*.

In an effort to characterize and document spatial and temporal dynamics of non-avian consumers of benthic invertebrates, the 2002 PWSSC-UNC field effort has included an extensive program of shallow-water trawl, seine, and trap surveys on the western delta and Orca Inlet. In addition to characterizing the spatial and temporal patterns of fish abundance and diversity, collecting standard fisheries data (i.e. length-weight relationships, length at age, cohort growth rate) and fish gut analyses are being conducted to characterize the food web. Such information, coupled to data collected in later years by the proposed GEM project and the ongoing PWSSC/UNC study will then be used to construct a quantitative food web model of the system (i.e. Ecopath, Ecosim). This model can then be used as a predictive tool to examine how disruptions in various components affect higher trophic levels (i.e. shorebirds, crabs, etc.).

While the distribution and demersal predators may be a key determinant in regulating the abundance of benthic invertebrates (at least *M. balthica*), spatial and temporal patterns of primary producers may regulate production (growth) or benthic invertebrates. Stable isotope studies have shown that the Delta's mudflat sediments have very low concentrations of organic matter (<1% in most cases; Clesceri et al. 2001). However, large blooms of epibenthic algae

(*Enteromorpha* sp.) are common in the summer and chlorophyll *a* concentrations in the area's tidal flats may be very high in mid-summer (C. Currin, NOAA, pers. comm. based on chlorophyll *a* samples collected at Kachemak Bay site in July 2002). The low levels of carbon in sediments despite this observed high primary production indicate a tightly linked system in which all available carbon is used up rapidly by the high biomass of benthic invertebrates. Stable isotopes ratios of carbon and nitrogen for the Delta's sediments, macrophytes, and invertebrates, indicate that the intertidal system is dependent on both oceanic and terrestrial inputs of organic material and nutrients (Clesceri et al. 2001).

The ongoing PWSSC-UNC study of the Copper River Delta provides an opportunity for comparisons with a similar intertidal system. At Kachemak Bay's National Estuarine Research Reserve in Cook Inlet, scientists from NOAA are currently investigating tidal flat habitats, in particular nutrient and primary production of these habitats. A study by Lee and others (2001) under the auspices of the Cook Inlet Regional Citizens Advisory Council has documented the intertidal communities in mid and upper Cook Inlet. Similar to the Copper River Delta, *M. balthica* and *M. arenaria* are the dominant bivalve species, in upper and mid Cook Inlet, respectively. And Cook Inlet also hosts a similar predator community. Several hundred thousand shorebirds stopover in mid and upper Cook Inlet each spring (Gill and Tibbits 1999). The same three species of commercially fished salmon: sockeye, chinook, and coho use the Inlet as an entry and exit corridor. And comparable to the Copper River delta, nearly all of the organic matter is probably imported as detritus from other systems (Chester and Larrance 1981; Lees et al 1980, 2001).

II. NEED FOR THE PROJECT

A. Statement of Problem

The rich prey resources provided by intertidal mudflat are critical to many taxa such as salmonids, flatfish, and crabs, species that are important for recreation, commercial, and subsistence users. These mudflats are very important for the commercial salmon industry, especially for the 549 permit holders in the gillnet fishery and for the economy of Cordova, where most of the fleet is moored and the commercial catch processed. These mudflats are also a critical stopover for several million shorebirds and provide foraging habitat for demersal fish and crabs, as well as thousands of breeding waterfowl and seabirds.

The Gulf Ecosystem Monitoring Program (GEM) hypothesizes that natural forces and human activities serve as distant and local factors, in causing short-term and long-lasting changes in the community structure and dynamics of intertidal and subtidal habitats. The intertidal soft-sediment communities of the vast and pristine Copper River Delta have only recently begun to be studied (see Powers et al. 2002, Powers et al. in review). Because of budget limitations, the PWSSC-UNC study of the Copper River Delta/Orca Inlet intertidal mudflats has focused on top-down processes. However, changes in the prey production may greatly impact predator usage of intertidal habitats and consequently the condition and production of the predator community, many of which are commercially and/or recreationally exploited. A complete understanding of the intertidal community, in particular how the community will respond to local and regional environmental change (i.e. temperature, circulation patterns, major environmental perturbations), is impossible without elucidating the extent to which bottom-up forcing (i.e. primary production) regulates production (biomass produced per unit time) of invertebrates residing within the sediments. The Partnership for Interdisciplinary Studies of Coast Oceans (PISCO) focuses on intertidal hard substrates and relies primarily on a “bottom-up” approach (Schoch et al. 2002). Because of the abundance and diversity of predators that utilize soft-sediment habitats and the importance of this link in trophic transfer to many exploited populations, such “bottom-up” investigations need to be balanced by “top-down” studies until the key factors that structure the community can be elucidated.

Our intent is to couple the “top-down” focus of the PWSSC-UNC study of the Copper River Delta and Orca Inlet mudflats, with a GEM-supported project that focuses on the “bottom-up” processes and the response of the community to local and regional forcings. The “bottom-up” approach would complement directly the PWSSC-UNC study, and would allow for a continuation of long-term monitoring of species diversity, abundance, and recruitment. Monitoring benthic invertebrate populations on the Copper River Delta and Orca Inlet with the goal to better understand and ultimately predict temporal and spatial patterns of invertebrate abundance are critical to assessing the resilience of this community to major disturbance events (Powers et al. 2002).

Our overall hypothesis is that the distribution, abundance and production of benthic invertebrates residing in intertidal sediments are controlled by a combination of top-down and bottom-up processes. Specifically, we will test the following predictions as part of our overall hypothesis:

(1) the overall distribution of intertidal species inhabiting soft-sediments is largely determined by abiotic factors (e.g. temperature, tidal inundation, sediment grain size, salinity, etc.);

(2) that within the habitat range of each species, abundance is controlled primarily by demersal predators; and

(3) spatial and temporal patterns of production of benthic invertebrates are tightly linked with patterns of primary production.

Clearly there is substantial support for the first prediction as it represents a cornerstone of modern marine ecology (see Bertness et al. 2001). Quantifying such patterns can lead to improved predicative capabilities in delineating and mapping resources, which is particularly relevant to the creation of GIS-based habitat maps. Predictions 2 and 3 and more importantly their interaction is central to current debates in marine community ecology. We believe the relatively simple prey community (dominated largely by a few species of bivalves) results in a tractable system in which these predictions can be assessed.

At the same time, broad comparisons of community patterns along gradients of productivity, natural disturbances, and abundance of predators or recruitments provide a constructive approach for generating predictions about soft-sediment community patterns and responses to environmental change (Lenhihan & Micheli 2001). The similarities between mid- and upper Cook Inlet habitats such as Kachemak Bay, and the Copper River Delta and southeast Prince

William Sound mudflats provide an unusual opportunity to make such comparisons. Vast expanses of intertidal mudflats dominate both the Copper River Delta and mid-and upper Cook Inlet. Both are large and important geographic areas included in the GEM project. And, both areas have historic data that they can build on (see Powers et al. 2002, Lees et al. 2001). One of the PI's of this proposed project (Powers) is assisting NOAA investigators in their study of the Kachemak Bay site. Included in this NOAA project are investigations of tidal flat habitats, in particular nutrient and primary production of these habitats. Our close association with the NOAA efforts at Kachemak Bay and with Lees and others proposed work in mid and upper Cook Inlet will foster extensive inter-site comparisons.

B. Rationale/Link to Restoration

In establishing the GEM Program, the Trustee Council explicitly recognized that complete recovery from the oil spill may not occur for decades and that full restoration of injured resources will most likely be achieved through long-term observation and, as needed, restoration actions. The Council further recognized that conservation and improved management of injured resources and services will require substantial ongoing investment to improve understanding of the marine and coastal ecosystems that support the resources, as well as the people, of the spill region. In addition, prudent use of the natural resources of the spill area without compromising their health and recovery requires increased knowledge of critical ecological information about the northern Gulf of Alaska. This knowledge can only be provided through a long-term monitoring and research program that will span decades, if not centuries.

We view this project as a logical expansion of the PWSSC-UNC study on the Copper River Delta Flats. By leveraging the funds from the Prince William Sound Oil Spill Recovery Institute, the proposed study will be more comprehensive and will improve understanding of the intertidal coastal ecosystem that is critical to the Cordova and Prince William Sound community economies. Expanding the study provides a cost-efficient and comprehensive method for studying marine invertebrate communities on the Copper River Delta and will provide a sampling protocol that can be used to establish a long-term data set. It will also allow for comparisons with Cook Inlet, a large geographic area with similar habitats.

C. Link to GEM Program Document

We believe our project is highly responsive to both the long-term goal of GEM and several immediate needs identified in the GEM program document. To accomplish its central mission to "*Sustain a healthy and biologically diverse marine ecosystem in the northern Gulf of Alaska and the human use of the marine resources in that ecosystem through greater understanding of how its productivity is influenced by natural and human activities*" a mechanistic understanding of the biotic and abiotic factors that structure biological communities in nearshore habitats is paramount.

By synoptically examining the influence of primary production (and the factors that explain its variability) and the role of predators on a central point in the foodweb (i.e. the invertebrate prey community), we will:

(1) determine the factors responsible for producing the observed patterns in abundance and distribution of invertebrate prey;
(2) develop the predictive capabilities to map prey resources; and
(3) establish and quantify linkages between the prey community and its predators.

This latter component is critical in addressing the role of these habitats in sustaining the production of marine species that are of importance for human use either from an economic (e.g. fisheries) or aesthetic (e.g. avian and marine mammals) point of view. The predictive capabilities developed by this project have a multitude of uses, many of which are of immediate need for GEM. Predictive relationships between sediment grain size and tidal inundation can be coupled with aerial photography of habitats to map prey resources and potentially the distribution of predators. Baseline population data collected previously in the PWSSC-UNC and the proposed GEM project can be used to assess long term changes in the community.

The project is also central to the mission of the Prince William Sound Science Center. Part of PWSSC's mission is to contribute to the description, monitoring, and understanding of the Copper River Delta and Prince William Sound, and to encourage biological conservation. This study addresses this mission directly by investigating the ecology of intertidal habitats on the Copper River Delta, and adding to the body of knowledge of this region. Given the hemispheric importance of the Delta's intertidal habitats to migratory shorebirds, this study has important conservation applications throughout the Pacific Flyway.

III. PROJECT DESIGN

A. Objectives

There are 4 objectives to our study. Objectives 1, 2, and 4 will be conducted using *Exxon Valdez* Oil Spill Trustee Council GEM funding. Objective 3 will be conducted using funds provided by the Prince William Sound Oil Spill Recovery Institute. The objectives are:

1. Characterize the spatial abundance of macrobenthic species inhabiting intertidal sediments within the Copper River Delta and Orca Inlet, Southeast Prince William Sound.

2. Determine and quantify those factors that best serve as predictors for primary production in the overlying water and within the sediments of tidal flat communities.

3. Characterize the spatial and temporal abundance of demersal and avian consumers and assess the role of epibenthic predation on recruitment of intertidal macroinvertebrates.

4. Assess the generality of our findings through coordination and comparisons with Cook Inlet studies.

B. Procedural Methods

Objective 1. Distribution and abundance of intertidal invertebrates

Our overall hypothesis is that the distribution, abundance and production of benthic invertebrates residing in intertidal sediments are controlled by a combination of "top-down" and "bottom-up" processes. We also hypothesize that the overall distribution of intertidal species inhabiting soft-sediments is largely determined by abiotic factors (e.g. temperature, tidal inundation, sediment grain size, salinity). In order to test this hypothesis, we will establish four study areas: near the outflows of the Copper River (Pete Dahl channel) and Eyak River (Eyak) and near Egg Island (Egg) and Hartney Bay (Hartney). At each area we will sample benthic invertebrates over a range of tidal elevations: high, mid and low tidal elevation.

Within each tidal elevation six replicate 15-cm diameter core samples (our prior studies have shown that a sample size of three is sufficient because of low variability in species richness and abundance) will be taken to a depth of 10 cm to sample infaunal organisms (e.g. bivalves, polychaetes, and amphipods). The six replicate cores for benthic invertebrates will be collected from random location along a 300-m swath (E-W) within each of tidal elevation. Our previous benthic sampling (Powers et al. 2002) has demonstrated surprisingly little variance within a tidal elevation. Replicates generally have 100% agreement in species composition and over 80% agreement in total density. Sediment properties are also similar within tidal elevations. The primary sources of variation in infaunal abundances are tidal elevation followed by sampling area. Three of the study areas (Pete Dahl, Eyak, and Hartney Bay) already have previously been sampled under a similar sampling scheme as part of the PWSSC-UNC study in 2000, 2001, and 2002. Each sampling position will be recorded with a Global Positioning System device. Areas will be accessed via helicopter during low tide. The entire sampling will be repeated three time a year: early April (before shorebird migration, but after spring recruitment and winter mortality), mid-June (after shorebird migration, but before high summer temperatures) and in late September (to determine the number of individuals surviving that year-predator activity drops off substantially before this period).

Upon collection, each core sample for benthic invertebrates will be placed in a pre-labeled plastic bag, placed on ice and transported to PWSSC (generally 3 hour from collection of first sample). Core samples for macroinvertebrates will be washed on a 0.5-mm sieve and the contents placed in a 10% Formalin solution. After 48 hours the formalin will be rinsed from the sample and material stored in a 70% ethanol/rose Bengal solution. The rose Bengal is added to stain the organisms a red color to facilitate sorting of the samples. After initial sorting of the samples (removing stained animals from the background detritus material), analysis of the cores will entail identification and enumeration of all benthic invertebrates (the fauna is relatively simple with few species present and hence can be worked up in an efficient manner). Shell length will be measured to the nearest 0.5 mm for all bivalves. A subset of clams from each area/tidal elevation combination will be aged (external annuli counted, see Powers et al. 2002). For all benthic invertebrates, length vs. dry weight relationships will be quantified. These data coupled to age structure of bivalves and density information will allow calculation of benthic invertebrate production.

Sediment grain size samples, a primary determinant of benthic community structure (Hall 1994) and of shorebird feeding (Quammen 1982), will be collected once each year during the April collection trip from each site where benthic invertebrate samples are collected. A total of 72, 5-cm diameter cores (inserted to a depth of 3 cm) for sediment grain size analysis will be collected (6 samples within each tidal elevation, 3 tidal elevation per area, and 4 areas), placed in plastic sack, labeled and placed on ice. Previous sediment grain size analysis has demonstrated little within year variation in sediment grain size. Similarly sediment grain size is similar within tidal elevation (Powers et al. 2002).

In the laboratory, sediment samples will be washed three times to remove salts and placed in a drying oven. After recording the bulk sample weight, a calgon dispersant will be added and the fine-grained (mud) component (by definition less than 0.063 mm diameter) is rinsed through a #230 mesh wet sieve. The remaining material (sand + gravel/coarse shell) will then be reweighed and prepared for sieve analysis. Prior to sieving the sand-sized fraction, the gravel/coarse shell fraction (by definition more than 2 mm in diameter) will be removed with a #10 mesh sieve and weighed. A Tyler mechanical splitter will be used to obtain a 25 g subsample of the remaining material (sand) which will then sieved at ¼ phi intervals (Carver 1970). Each sieve stack is placed in a mechanical ro-tap for 20 minutes. Individual sieve fractions are then weighed and recorded. Small amounts of fine-grained sediment that had not previously washed through the wet sieve are collected in a pan at the bottom of the sieve stack and, for computational purposes, are included with the wet-sieved material. Percentages of gravel/coarse shell, sand, and fine-grained sediment are then computed from the bulk sample weights, and percentages of each size fraction in the sand range is computed from the 25 g splits that were sieved.

Objective 2. Spatial and temporal patterns of primary production

We hypothesize that spatial and temporal patterns of production of benthic invertebrates are tightly linked with patterns of primary production. Specifically, spatial patterns in primary production will reflect spatial patterns of nutrient inputs. For example our preliminary nutrient survey indicate that high salinity waters represent the primary source of nutrients (a potential generic pattern for subarctic estuaries in Alaska). Consequently, we hypothesize that primary production and higher benthic secondary production increase with proximity to oceanic waters (i.e. Prince William Sound and the Gulf Alaska). Because water clarity increases along this same gradient, nutrient concentrations, light penetration (PAR), and primary producers must be quantified to identify the principal causal factor for this relationship. Primary producers that serve as potential energy sources for benthic invertebrates include larger epibenthic algae (e.g. *Enteromorpha* sp.), smaller epibenthic microalgae that reside on top or within the top 2 cm of the sediment, and suspended phytoplankton in the water column. Benthic microalgae may be the most important of these food sources for infaunal benthic invertebrates (Cahoon 1999, Posey et al. 2002). Measurements of all three groups are included in this component of the project. In addition, water column samples for nutrients (nitrate, ammonia, phosphate) and chlorophyll *a* will be collected and analyzed to discern patterns of primary production. Measurements of nutrient and chlorophyll *a* levels in sediments (chl *a*) and pore water (inorganic nutrients) of the sediments will also be performed for inorganic nutrients.

During each of 8 sampling trips (March, April, May, June, July, August, September and October), 500-ml water samples will be collected from a chartered fishing vessel for nutrient and chlorophyll *a* analyses. At each of the four sampling areas, replicate (n =3) water samples will be collected from 0.5 m below the surface at areas corresponding to the high tide plots and low tide plots. In addition, where water depth is > 3m; we will also collect near-bottom water samples (water shallower than this depth are generally well mixed). Low tide plots correspond to higher salinity water whereas high tide plots are areas with maximum freshwater influence. To evaluate the role of nutrient input from freshwater sources, two stations along each of the Copper and Eyak Rivers and one station at Hartney Creek will be sampled for nutrients and chlorophyll *a* on the same schedule outlined above.

Once collected, water samples will be placed on ice until filtration is possible (~ 4 hours). Then 100 to 150 ml of water will be filtered through Whatman TM GF/C filters. The filter will then be wrapped in aluminum foil and frozen for chlorophyll *a* analysis and a 60 ml sample of the filtered liquid will be frozen for inorganic nutrient analysis. Chlorophyll *a* concentrations will be determined using a Turner Designs Model 10 Fluorometer following the acidification method of Lorenzen (detailed in Strickland and Parsons 1972). Nutrient analyses will be carried out using standard wet chemical techniques (Alpkem Manual 1988) adapted for use on an Alpken RFA/2 Nutrient Autoanalyzer. All chlorophyll *a* and nutrient samples will be analyzed at the University of South Alabama's Dauphin Island Sea Lab. The facility has a complete nutrient and primary productivity lab (Co-Principal Investigator Powers will join their faculty in December 2002).

Sediments for pore-water nutrient samples will be collected 5 times (April, June, July, August, September) from intertidal plots. The April, June and September trips will correspond to the benthic invertebrate collections. On each date replicate sediment samples (n=6) will be collected from each tidal elevation strata in each of the four areas (identical sampling scheme as the benthic invertebrate sampling). Once returned to the lab, sediment samples will be centrifuged in 50-ml plastic vials. Pore water will be decanted off and frozen. Nutrient analysis will follow the methodology described above. Sediment samples for chlorophyll *a* analysis will be sectioned into the two depth zones (0 – 1 cm and 1 - 2cm) and frozen. Samples will remain frozen until pigment analyses for chlorophyll *a* can be conducted.

During these same sampling trips, replicate ¼ m^2 quadrats will be harvested for all large epibenthic algae in an identical sampling scheme as described for sediment chlorophyll *a* analyses. Once returned to the lab, algae will be separated by species and dried at a constant temp for 24 hours. Both wet and dry weight will then be recorded.

Because spatial and temporal patterns in physical/chemical factors can influence primary production and invertebrate species distribution, we will establish a network of unattended monitoring stations. At two of the four study areas (Eyak and Pete Dahl) YSI 6600 Series multi-parameter (temperature, salinity, dissolved oxygen, depth) water quality instruments will be placed on concrete moorings near the high tide and low tide plots. Moorings will be in place from late March to late October. Because inclement weather conditions during the winter prevent successful maintenance and calibration of the instruments, these instruments cannot be set out year round. However, temperature data collected using unattended sampling Hobotemps will be recorded through out the year. One mooring with YSI instrumentation will be placed at both the Egg and Hartney sampling areas. These areas lack any detectable gradient in water quality parameters that are characteristic of the other two sampling areas (i.e. all tidal elevation show high year round salinities and low turbidity as a result of reduced influence from river discharge). With the possible exception of the Hobotemp loggers, accuracy and precision of these instruments are in accordance with the GEM recommendations (as are all of the physical/biological measurements mentioned in this section).

All moorings will be serviced on a monthly basis by chartered vessel at high tide during nutrient and chl *a* sampling trips. Calibration, maintenance and data downloading will be conducted onboard and instruments will be returned to their mooring. Samples will be collected every 15-min by these instruments.

The unattended sampling data will be augmented greatly by hydrocasts made during sampling trips. During each of the 8 monthly (March-October) nutrient/chl *a* collection trips and on 6 other trips funded under the OSRI grant (trawl surveys) hydrocasts will be made in each of the four areas corresponding to high, mid, and low tidal elevation plots. Additional hydrocasts will be made while transiting between areas. Hydrocasts will be made with a YSI model 6000. The instrument will be fitted with probes that measure salinity, temperature, pH, dissolved oxygen, depth, and fluorescence. Photosynthetically active radiation (PAR) will also be measured using a separate meter. Parameters will be measured at 0.25 m depth increments and a duplicate cast will be made at each site.

Because of the high potential for spatial and temporal variability in nutrient and chl *a* measurements, re-evaluation of the level of replication and timing of nutrient and primary production measurements will be performed after the first few collection trips and at the end of year 1. However, any changes in design will more than likely involve re-allocation of sampling effort (budgetary constraints fix the absolute number of samples). The primary purpose of the above sampling is to identify large-scale variation in nutrient inputs and physical/chemical parameters (oceanic vs. riverine) and to identify seasonal signature in nutrient inputs that may correlate to primary production. We strongly believe that the current sampling approach will be successful in documenting these patterns. Additional resolution, which may be achieved with our current sampling plan would be of significant value in evaluating spatial patterns on smaller scales (e.g. among tidal elevation strata), but are not as critical.

Finally, in the second field season (2004) of the project, we will conduct experiments that examine the relative influence of “top-down” and “bottom-up” factors on benthic invertebrate abundance. The basic designs of these experiments follow that of Posey *et al.* 2002 in which nutrient levels and predator access are manipulated in a factorial design. The central hypotheses of these experiments are that (1) resource availability (e.g. nutrients) controls benthic primary production which in turn cascades upward to higher infaunal abundance in the absence of predators and (2) in the presence of predators the abundance of infauna is decreased and consequently benthic microalgae is freed from grazing pressure. These hypotheses are similar to those proposed by others (Cahoon 1999, Micheli 1999, Heck et al. 2000, Posey et al. 2002); however, few experimental tests of these hypotheses have been made for soft-bottom communities (see Posey *et al.* 2002 for discussion). Further, with the exception of work by Beukema and colleagues (Beukema 1991, Beukema and Cadee 1997), these hypotheses have yet to be fully explored for subarctic estuarine systems, which are obviously of particular interest for GEM.

The design of our experiment has a total of 6 treatments: 2 levels of nutrients (ambient and enriched) and 3 levels of predator controls (open plots, full cages, and partial cages). Full cages, which will exclude all predators, will be 1m x 1m x 12.5 cm tall. Six-mm aquaculture mesh will be placed on all four sides and the top of the cage. The mesh, a clear, monofilament line matrix, should allow sufficient light into the area. Partial cage, which will control for cage artifacts by mimicking changes in hydrodynamic regime and shading within the cage, but allowing predator access, will have the same overall dimensions as full cages but will have two sides and half the top open. Small tent spikes will mark the corners of the $1m^2$ open plots. Nutrient enrichment will be achieved by placing four 56-gram fertilizer spikes with a N:P ratio of 16:10 contained with an inert gypsum matrix (Posey et al. 1999, 2002) in a diamond pattern within the $1m^2$ area. The spikes provide gradual nutrient release over a 4 – 6 week period. Four cages for each of the six treatments will be placed at mid-tidal elevation and the experiment will be allowed to run for six weeks. This duration is chosen as a compromise to reduce cage artifacts but allowing enough time for detection of density dependent responses and benthic microalgae response (Posey et al. 2002).

The experiment will be replicated in two areas (Hartney Bay and Pete Dahl). These areas are chosen to represent the two extremes in physical/chemical setting of the tidal flats. The entire experiments (4 replicates x 6 treatments x 2 areas) will be performed twice: late-April to the end of May (a period that coincides with shorebird migration and immediately after spring recruitment) and August-September (a period of high demersal fish abundance). Our previous experiences with cages in the system have demonstrated little hydrodynamic artifact and little fouling of the mesh over a 6-week period. Benthic invertebrate cores will be collected from the area before experiments begin to establish baseline data. At the end of six weeks samples for benthic invertebrates (2 per cage), pore water nutrients (2 per cage), meiofauna (2 per cage), benthic microalgae (2 cores for sediment chl *a*) will be collected from each cage. Samples will be analyzed as previously described. Benthic invertebrate samples will be processed to the species level for all taxa collected by the core.

Objective 3. Predator community.

Our overall hypothesis is that the distribution, abundance and production of benthic invertebrates residing in intertidal sediments are controlled by a combination of “top-down” and “bottom-up” processes. Within the habitat range of each species, we hypothesize that abundance is controlled primarily by demersal fish and crabs. This “top-down” hypothesis will be tested under the auspices of the Prince William Sound Oil Spill Recovery Institute.

From late-April to early October 2003 and 2004, otter trawl surveys will be conducted every 4 weeks (n = 6 survey trips) in and around our 4 study sites on the western Copper River Delta and Orca Inlet. Using a commercial gillnet boat as the platform, a 5m otter trawl will be deployed for 10 minutes. At each site, two sets of 3 replicate trawls will be conducted near the high/mid tide plots and the low tide plots. Our previous work has demonstrated that even with an n of 3 species richness and density show little variance among replicates. Trawl surveys will be conducted during the 2h before and after low tide, when fish and crab are concentrated in the navigable channels.

All fish and crabs caught in trawls will be identified and measured for SL (standard length) and TL (total length) and weighed. A subset of each species will be collected and preserved in 10% buffered formalin for gut contents. An additional subset will be collected and frozen for aging (i.e. otolith analyses). Once back in the laboratory, stomachs will be removed and weighed. Stomach contents will be separated by prey type, and identified to the lowest practical taxon. A modified index of importance (MI) will be determined for each prey type.

Depending on the salmon species and race, early sea life of a juvenile salmon may include a prolonged residence time in estuarine waters. For 2003 and 2004 field seasons, additional sampling on the Delta will target juvenile coho, sockeye and king salmon. Sampling with both Fyke nets and bag seines will be conducted every 2 weeks along shallow channels located near the otter trawl areas. All fish caught will be processed using the same methodology as for the otter trawl surveys.

Based on the results of the 2003 otter trawl surveys and juvenile salmon surveys, in 2004 field season we will also examine the possible effects of predators on *Macoma* production. Predators can influence bivalve population both directly through removal and indirectly by reducing growth rates as a result of predator avoidance strategies adopted by prey (Nakoka 2000). Full exclosures, partial exclosures, and controls will be placed in habitats that have high, medium, and low predator pressure. We will compare variation in *Macoma* abundance and growth rates and survivorship among habitats.

Objective 4. Links with other studies.

Please see description under "E. Coordination and Collaboration with Other Efforts".

C. Statistical Methods

A combination of multivariate and univariate analyses will be utilized to examine distributions of major taxa and determine to what degree physical/chemical and biological parameters explain invertebrate abundance patterns. Analysis of variance ANOVA will be performed to test our *apriori* hypotheses that benthic microalgae (measured by chl *a*), benthic invertebrate abundance (total abundance as well as abundances of specific taxa) vary in response to sampling area (Hartney Bay, Egg Island, Eyak, Pete Dahl) and tidal elevation (high, mid, low). The factors in the ANOVA will be sampling date, sampling area, and tidal elevation. While some effect of date may be evident (as a result of predation or recruitment), we expect no interaction with date (i.e. seasonal effects should not interact with the overall pattern of higher benthic microalgae and benthic invertebrate abundance with area or within tidal elevation. Our *apriori* prediction is that both benthic microalgae and benthic invertebrate abundance will be highest at areas that experience greater nutrient input and light penetration (i.e. Hartney Bay > Egg > Eyak > Pete Dahl). Data from the nutrient and physical/chemical surveys will be used to support the ranking of these sites. Within each area abundances should be highest at mid-tidal elevation reflecting the pattern of greatest benthic microalgae production at these elevations (see Beukema 1988, Beukema and Cadee 1997, Beukema et al. 2002 for support of this prediction). To test the rank order of these predictions, post hoc contrasts will be performed using Student-Newman-Keuls

(SNK) tests. Homogeneity of variances will be verified using a Cochran's test. Square root or log transformations will be used if Cochran's tests reveal heterogeneous variances. Because our statistical analysis includes multiple ANOVA's as well as post-hoc tests on the same data sets, *P* value for determining significance levels will be adjusted accordingly (see Rice et al. 1989).

Analysis of *Macoma* in the above mentioned ANOVA may also be performed on separate size classes of *Macoma*. The dependent variable for *Macoma* abundance may be separated out into small, medium, or large size classes. Analysis will then proceed as described above, but using the abundance of small, medium, and large *Macoma* as separate dependent variables (size class definition will be based on size-distribution data collected in year 1). Birds or other consumers may preferentially select one size class to feed upon; previous studies have failed to address this possibility in their analyses. For example, small clams may be the most susceptible to predation creating a size-induced refuge from predation for larger *Macoma.* Finally growth curves will be generated for each area/plot. The slopes of these curves can then be tested against each other to determine which area/tidal elevation combination result in faster growth.

Principal Components Analysis (PCA) and cluster analysis will be used to explore patterns in the overall data sets (Gauch 1981). PCA analysis will be used to address large-scale patterns and determine which sets of the many variables measured best explain the greatest percentage of the variance in the community. Cluster analysis will be used to discern overall similarities in the various response variables (invertebrate abundance, primary production patterns, physical chemical parameters) between areas and tidal elevation. Both multivariate approaches can be used to formulate specific hypotheses that can then be tested using analysis of variance (ANOVA) and also discern covariates that may be appropriate to incorporate in ANCOVA. Correlation, simple and multiple regressions between various parameters (nutrient concentrations, primary production levels, benthic abundances, predator abundances) will be used to evaluate specific relationships identified by the PCA and cluster analyses.

A three factor-ANOVA (area, nutrient level, predator access) will be used to analyze the nutrient enrichment experiment. Dependent variables will include benthic microalgae biomass, benthic invertebrate abundance (which may then be further separated by functional groups or specific taxa). Two separate analyses will be performed for the separate periods (April-May, Aug-Sept). Results of the two runs will be compared qualitatively. Post hoc contrasts will be performed using Student-Newman-Keuls (SNK) tests. Homogeneity of variances will be verified using a Cochran's test. Square root or log transformations will be used if Cochran's tests reveal heterogeneous variances.

D. Description of Study Area

This study will take place on the Copper River Delta and in Orca Inlet. Three study areas with replicate transects have already been established as part of the PWSSC-UNC study for the Oil Spill Recovery Institute. These include intertidal mudflats: a) near the Copper River along Pete Dahl Channel, b) near the outflow of Eyak River, and c) Hartney Bay, Orca Inlet. In addition, one new sampling area will be established on intertidal mudflats near Egg Island:

Site Name	*Approx Locations*
Pete Dahl	60 21’N 145 29’W
Eyak	60 25’N 145 38’W
Egg Island	60 23’N 145 50’W
Hartney Bay, Orca Inlet	60 30’N 145 52’W

This proposal will provide benefits to the local fishing communities including: Cordova, Tatitlek, Chenega, Valdez, and Whittier. Field work and data analyses will be conducted out of Cordova. The City of Cordova is located on Orca Inlet in southeast Prince William Sound, and serves as the gateway to the nearby Copper River Delta. Over 500 fishers own gillnet permits for the Delta salmon fishery and most boats are moored in the Cordova Boat Harbor.

E. Coordination and Collaboration with Other Efforts

The proposed study would directly complement the Prince William Sound Science Center-University of North Carolina (PWSSC-UNC) study on the epibenthic predators on the intertidal mudflats. The PWSSC-UNC study is being sponsored by the Prince William Sound Oil Spill Recovery Institute. All aspects of field work would be coordinated and integrated with the PWSSC-UNC study. The GEM study would utilize the same study areas, and would sample the same plots. The GEM portion would allow for continuous long-term monitoring of species diversity, abundance, and recruitment of the benthic invertebrate communities. All data from both projects will be archived by the project staff in accordance with GEM standardized procedures. The field results from the GEM study will be integrated into the PWSSC-UNC numerical and analytical models of the Copper River Delta ecosystem that include primary production parameters and benthic invertebrate distributions. In addition, an ongoing study of razor clam distribution in the sandy portions of the Copper River Delta being conducted by PWSSC and UNC will provide additional information that can be integrated into this study.

This project will also be able to access meteorological and oceanographic data. In August 2002 the first meteorological station was placed on the Copper River Delta at Grass Island (western Copper River Delta) under the auspices of the Oil Spill Recovery Institute. And, the PWSSC maintains oceanographic moorings at Hinchinbrook Island that will provide data applicable to this project. .

In addition, the similarities between mid- and upper Cook Inlet and the Copper River Delta and southeast Prince William Sound mudflats provide an unusual opportunity to make comparisons. Vast expanses of intertidal mudflats dominate both the Copper River Delta and mid-and upper Cook Inlet. Both are large and important geographic areas included in the GEM project. A proposal will be submitted to EVOS by Dennis Lees of Littoral Ecological and Environmental Services for EVOS consideration in January 2003. This Cook Inlet intertidal project will test similar hypotheses and will provide data that can be compared with the Copper River Delta project. One of the PI’s of this proposed project (Powers) is also assisting NOAA investigators in their study of the Kachemak Bay NERRS site. Included in this NOAA project are investigations of tidal flat habitats, in particular nutrient and primary production of these habitats. In addition, we are aware of at least 2 studies by Dr. Brenda Konar (Univ. Alaska

Fairbanks) at Cook Inlet's Kachemak Bay that will generate data that could be compared with the Copper River Delta. These include, "Freeze tolerance and survival of intertidal invertebrates from Kachemak Bay", and "Influence of turbidity and salinity on the spatial distribution of kelp beds in Kachemak Bay". Our close association with these ongoing and proposed studies will foster extensive inter-site comparisons.

IV. SCHEDULE

A. Project Milestones

Objective 1. Characterize the spatial abundance of macrobenthic species inhabiting intertidal sediments within the Copper River Delta and Orca Inlet, Southeast Prince William Sound. To be met by February 2005.

Objective 2. Determine and quantify those factors that best serve as predictors for primary production in the overlying water and within the sediments of tidal flat communities. To be met by February 2005

Objective 3. Characterize the spatial and temporal abundance of demersal and avian consumers and assess the role of epibenthic predation on recruitment of intertidal macroinvertebrates. To be met by December 2004

Objective 4. Assess the generality of our findings through coordination and comparisons with Cook Inlet studies. To be met by February 2005

B. Measurable Project Tasks

FY 03, 1st quarter (October 1, 2002-December 31, 2002)

November 25:	Project funding approved by Trustee Council

FY 03, 2nd quarter (January 1, 2003-March 31, 2003)

January 13-17:	Annual EVOS Workshop
March 20-30	Field work (Primary Productivity Sampling, Moorings)

FY 03, 3rd quarter (April 1, 2003-June 30, 2003)

April 15-June 30	Field Work (benthic & sediment cores, primary productivity, CTD moorings, fish surveys)

FY 03, 4th quarter (July 1, 2003-September 30, 2003)

July 1-September 30	Field Work (benthic & sediment cores, primary productivity sampling, CTD moorings, fish surveys)
September 1	Submit annual report to EVOS

FY 04, 1st quarter (October 1, 2003-December 31, 2003)

October 1-5	Field work (fish surveys)

October 20-30	Field work (primary productivity, remove CTDs)
December 31:	Finish lab analyses

FY 04, 2nd quarter (January 1, 2004-March 31, 2004)

(dates tba)	Annual EVOS Workshop
March 20-30	Field work (Primary Productivity Sampling, Moorings, install experimental exclosures)

FY 04, 3rd quarter (April 1, 2004-June 30, 2004)

April 15-June 30	Field Work (benthic & sediment cores, primary productivity, CTD moorings, fish surveys)

FY 04, 4th quarter (July 1, 2003-September 30, 2003)

July 1-September 30	Field Work (benthic & sediment cores, primary productivity sampling, CTD moorings, fish surveys)
September 1	Submit annual report to EVOS

FY 05, 1st quarter (October 1, 2003-December 31, 2003)

October 1-5	Field work (fish surveys, remove experimental exclosures)
October 20-30	Field work (primary productivity sampling, remove CTDs)
December 31:	Finish lab analyses

FY 05, 2nd quarter (January 1, 2004-March 31, 2004)

(dates tba)	Annual EVOS Workshop
January –March 31	Prepare 2 manuscripts

FY 05, 3rd quarter (April 1, 2004-June 30, 2004)

April 30	Submit final report to EVOS (will consist of 2 draft manuscripts for publication)

V. RESPONSIVENESS TO KEY TRUSTEE COUNCIL STRATEGIES

A. Community Involvement and Traditional Ecological Knowledge (TEK)

Because of the extensive knowledge of local fishers and the historic knowledge of native Alaskans, an interactive exchange with local fishermen will be of great benefit to the project. Direct input to the project will be solicited from the local fishing community via the EVOS-sponsored Prince William Sound Fisheries Research Application and Planning group (PWSFRAP). Results of the project will also be fully available to the local fishing community through presentations at PWSFRAP workshops and public seminars given through the Prince William Sound Science Center.

Articles will also be written for the local newspaper, *The Cordova Times*, and for *The Breakwater*, the newsletter of the Prince William Sound Science Center informing the public of the study. The *Cordova Times* is publicly available. Prince William Sound Science Center's newsletter, *The Breakwater* is distributed to over 500 individuals and organizations, including Science Center members, past and current funders, stakeholders, and community leaders in the central Gulf of Alaska area. The Prince William Science Center also maintains a regional science education and outreach program. Our project will also use the education/outreach program to communicate the need and benefits of conservation of marine resources to the public and visiting student groups.

As part of its outreach program, the Prince William Sound Science Center maintains an extensive web site. This GEM project would be featured on the web, and would have links to the EVOS web site as well as links to any other projects it was coordinating with (e.g. Kachemak Bay NERR web page).

Cordova has the logistical capability to access both the delta and southeast Prince William Sound. Many of the gillnet boats have 6 pack licenses for research-charter opportunities. There is a local commercial helicopter charter service (Wilderness Helicopters) that we can charter on an hourly basis to access the plots with at low tide. One research technician would be hired locally to assist with the project. Principal Investigator Bishop has also been a resident of Cordova since 1990.

B. Resource Management Applications

Three species of salmon: sockeye, chinook, and salmon are commercially fished on the Copper River Delta by a gillnet fleet numbering 549 permitees. Dungeness Crabs and razor clams (*Siliqua patula*) were commercially fished, but these fisheries have been closed for > 10 years due to depleted stocks. The tidal flats of the Copper River Delta serve may serve as essential habitat for a variety of fish, crab and waterfowl species. Many of these species are in desperate need of management plans that incorporate ecosystem level approaches. The results of our study would be of significant value within this context. Data from the GEM project will be coupled to the PWSSC/UNC "top down" study to construct a quantitative food web model of the system (i.e. Ecopath, Ecosim). This model can then be used as a predictive tool to examine how disruptions in various components affect higher trophic levels (i.e. shorebirds, crabs, etc.). And. the standard fisheries data collected from the companion PWSSC/UNC companion study can be used to assist in current fisheries management.

In the case of an oil spill or some other catastrophe (e.g., an earthquake), this data would be critical in assessing change caused by the event. Nearshore ecosystems such as tidal flats are often the repository for oil spills. Once thought to be safe from potential oil spills, the Copper River Delta has been largely ignored as an area of potential risk. Current data shows that previous assumptions may be flawed and that the Delta has potential for oiling.

The potential for an oil spill on the Copper River Delta mudflats creates serious problems for wildlife and fisheries management. As seen after the *Exxon Valdez* oil spill, one of the biggest difficulties in assessing post-spill effects on wildlife, fisheries, and marine invertebrate populations was the paucity of pre-spill information. With no baseline records with which to compare post-spill data, definitive conclusions were difficult to make.

In his synthesis of EVOS-related studies, Peterson (2001) demonstrated that changes in the abundance of invertebrates due to the effects of the *Exxon Valdez* oiling could lead to changes throughout the food web. Further, he found that these changes were often complex with a host of direct and indirect effects that could persist for years. Additionally, Peterson et al. (2001) demonstrated the difficulty in assessing such ecological impacts of oiling without rigorous (statistically) studies. Most impacts studies adopt a BACI statistical design (Before-After-Control-Impact; Underwood 1991, 1992) the quality of such assessment depends to a large extent on the availability of well-designed, pre-spill data.

By monitoring natural variation in intertidal invertebrate, their predator populations, and primary productivity on the Copper River Delta, this study will establish a solid baseline from which damages can be assessed in the case of an oil spill. The study's data will enable efficient and effective deployment of response and containment resources to best protect critical intertidal habitats in the event of a spill.

And finally, our study will quantify patterns of primary productivity, abundance and distribution of invertebrate communities, and abiotic factors influencing communities such as sediment grain size. These data can lead to improved predicative capabilities in delineating and mapping resources, which is particularly relevant to the creation of GIS-based habitat maps that resource managers can use in planning and decision-making.

VI. PUBLICATIONS AND REPORTS

In addition to quarterly and annual reports, we foresee at least 3 peer-reviewed publications produced from this study. These are:

Trophic dynamics of intertidal soft-sediment communities: interaction between bottom-up & top-down processes *Marine Ecology Progress Series.* Submit: December 2004.

Linking benthic prey production to primary production in a sub-arctic intertidal system. *Limnology and Oceanography.* Submit: January 2005.

The importance of experimental approaches for elucidating the relative importance of "top-down" versus "bottom-up" regulation of marine benthic communities. *Journal of Experimental Marine Biology and Ecology.* March 2005

VII. PROFESSIONAL CONFERENCES

Name: Estuarine Research Federation
When: November 2003

Where: Seattle Washington
Session Chair (Powers)

Name: American Fisheries Society
When: August 2003
Where: Quebec Canada,
Topic: Connecting primary production to demersal fisheries: the importance of benthic prey in supporting demersal fisheries. (Powers)

VIII. PERSONNEL

A. Principal Investigators

Mary Anne Bishop, Ph.D.
Prince William Sound Science Center
PO Box 705
Cordova, Alaska 99574
907-424-5800 fax: 907-424-5820
mbishop@pwssc.gen.ak.us
Bishop will oversee the project and coordinate with other intertidal studies. She will have primary responsibility for contract management, field work (benthic & epibenthic sampling), data integration, and completion of final products. She will supervise the biological technician including invertebrate sorting and identification. Along with Powers and Peterson, she will be responsible for project design, statistical analysis and data interpretation, and preparation of manuscripts.

Sean P. Powers, Ph.D.
Asst. Professor, Dept. Marine Sciences
University South Alabama & Sr. Marine Scientist, Dauphin Island Sea Lab
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(252) 726-6841 (voice) – 2426 (fax)
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Dr. Powers will be responsible for the design and execution of the experimental components of the project as well as assisting Dr. Bishop in the survey component of the project. He will also have primary responsibility for statistical analysis, data interpretation and preparation of manuscripts. Dr. Powers will also assist Dr. Bishop and the PWSSC technician in the identification of benthic invertebrates. Nutrient and chlorophyll *a* analyses will be performed under Dr. Powers supervision through the Dauphin Island Sea Lab.

B. Other Key Personnel

Charles "Pete" Peterson, Ph.D., University of North Carolina at Chapel Hill, Institute of Marine Sciences, Morehead City, North Carolina. Peterson will serve as a consultant for this study. Dr. Peterson will assist on all aspects of experimental design, data analysis, and publication.

Peterson is the Co-Principal Investigator with Bishop on the “top-down” study being conducted under the auspices of the Prince William Sound Oil Spill Recovery Institute.

<u>Research Technician:</u> A field technician will be employed at PWSSC to assist with analyses of the benthic samples (primarily the preliminary sorting and picking of the samples) and data entry. Efforts will be made to hire a qualified, local Cordovan for this position.

<u>Graduate Student:</u> A portion of this project will also serve as dissertation research for a Ph.D. student under the direction of Dr. Powers at the University of South Alabama. Dr. Peterson will also serve on the students’ graduate committee.

<u>Undergraduate students</u>: The University of South Alabama/Dauphin Island operates a large program designed to give undergraduate students, particularly those from historically under-represented groups, “hands-on” research experience. Through the OSRI and GEM supported projects Dr. Powers will bring selected students from this program to assist in fieldwork in the summer.

C. Contracts

University of South Alabama. This contract is to the Co-Principal Investigator, Sean Powers. Under this contract Dr. Powers will receive partial compensation for his summer salary, partial support for a graduate student (a graduate fellowship from OSRI will provide the bulk of support for the student), funds to pay for nutrient and chlorophyll *a* lab analyses, and travel funds.

Charles Peterson, PhD. Consulting Ecologist. Funds are requested to compensate Dr. Peterson for time spent on this project. Peterson will assist with all aspects of experimental design, data analysis, and publications.

Vessel Charter – Each field seasons, a contract for vessel charter will be issued following a competitive-bid process. We foresee a local gill-net boat being awarded this subcontract. This vessel charter will be used for conducting field work, including collecting water samples and downloading and servicing CTDs.

IX. PRINCIPAL INVESTIGATORS QUALIFICATIONS

<u>Co- Principal Investigator</u>. Mary Anne Bishop, Ph.D., Ecologist. Prince William Sound Science Center, Cordova, Alaska. Since 1990 Bishop has been Principal Investigator for 11 major studies on the Copper River Delta and in Prince William Sound. From 1994-1999 she was the Principal Investigator for 2 major studies on avian predation on resources in nearshore areas of Prince William Sound for the *Exxon Valdez* Oil Spill Trustee Council. The first project, Avian Predation on Herring Spawn was part of the Sound Ecosystem Assessment (SEA) Study. Her second study, Avian Predation on Blue Mussels was part of the Nearshore Vertebrate Predator Project (NVPP). In addition, Bishop was the Principal Investigator for an EVOS project investigating the status of seabird colonies in Northeast Prince William Sound. On the Copper

River Delta Bishop's research has focused on benthic invertebrates and shorebird use of the tidal flats. Since 2000, she has been Co-Principal Investigator with C. Pete Peterson (Univ. North Carolina at Chapel Hill Institute of Marine Sciences) on the first study of the soft-sediment communities on the Copper River Delta. Bishop has authored more than 25 scientific publications, including 11 peer-reviewed manuscripts. A brief curriculum vitae is attached.

Co- Principal Investigator. Sean Powers, Ph.D., University of North Carolina at Chapel Hill Institute of Marine Sciences, Morehead City, North Carolina. Dr. Powers' research interest focuses on the dynamics of soft-sediment communities and the role they play in supporting marine fisheries. Dr. Powers is currently completing a post-doctorate appointment with Dr. Charles "Pete" Peterson. Powers has accepted a position as Assistant Professor at the University of South Alabama beginning in December 2002. Since receiving his Ph.D. in 1998 he has been responsible for coordination and management of 8 major research projects supported by a variety of federal and state agency (including NSF, NOAA, and Seagrant). He has conducted fieldwork in coastal Alaska for the last three years. In addition to his Alaska work, current research projects focus on the impacts of large demersal predators on benthic communities, enhancement of oyster, hard clam and bay scallop populations in coastal North Carolina. A brief curriculum vitae is attached.

Consultant: Charles "Pete" Peterson, Ph.D., University of North Carolina at Chapel Hill, Institute of Marine Sciences, Morehead City, North Carolina. Dr. Peterson is Alumni Distinguished Professor of Marine Sciences, Ecology and Biology. He has conducted research on the dynamics of soft-sediment communities and the impact of chronic and acute disturbances on these communities for the last 30 years. Peterson is the Co-Principal Investigator with Bishop on the "top-down" study being conducted under the auspices of the Prince William Sound Oil Spill Recovery Institute. For the GEM-study, Peterson will serve as a consultant, assisting with all aspects of experimental design, data analysis, and publication. A brief curriculum vitae is attached.

MARY ANNE BISHOP

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EDUCATION

Ph.D. Wildlife Ecology, Department of Wildlife & Range Sciences, University of Florida, Gainesville, 1988.

M.S. Wildlife & Fisheries Sciences, Department of Wildlife and Fisheries Sciences, Texas A & M University, College Station, 1984.

B.B.A. School of Business, University of Wisconsin-Madison, 1974.

PROFESSIONAL EXPERIENCE

6/99-present Research Ecologist, Prince William Sound Science Center, Cordova, Alaska.

11/88-present Research Associate & Principal Investigator for Tibet Black-necked Crane Study, Intl. Crane Foundation, Baraboo, Wisconsin (location: Tibet, PR China).

3/97-5/99 Research Wildlife Biologist, Pacific Northwest Research Station, U.S. Forest Service, Cordova, Alaska

4/94-3/97 Research Wildlife Biologist, Dept. Fisheries and Center Streamside Studies, Univ. Washington assigned to Copper River Delta Institute, US Forest Service

4/90-4/94 Research Wildlife Biologist, Copper River Delta Institute, Pacific Northwest Research Station, U.S. Forest Service, Cordova, Alaska.

5/92-4/93 Acting Manager, Copper River Delta Institute, Pacific Northwest Research Station, U.S. Forest Service, Cordova, Alaska.

7/89-4/90 Wildlife Biologist, Forestry and Range Sciences Laboratory, Pacific Northwest Research Station, U.S. Forest Service, LaGrande, Oregon.

9/88-6/89 Biological Technician, Malacology Lab, Florida Museum of Natural History, Gainesville, Florida.

8/83-8/88 Project Biologist, Department of Wildlife and Range Sciences, University of Florida, Gainesville.

AWARDS:

U.S. Forest Service National *Taking Wing* Awards:

2001 Capacity Building Category;
1999 Public Awareness & Community Involvement Category
1997 Research Investigations Category
1993 Research Investigations Category

Tibet Autonomous Region, PR China:

1994 *Development of Science and Technology in Tibet* Award (2nd Place)

Wildlife Conservation Society: 1993 Research Fellow

The Wildlife Society

1992 Monograph Publication Award for "A conservation strategy for the Northern Spotted Owl," Interagency Scientific Committee (Team Member).

1991 Group Achievement Award for Participation as Team Member in Interagency Scientific Committee to Address the Conservation of the Northern Spotted Owl

SELECTED PEER-REVIEWED PUBLICATIONS (5 OF 12)

Powers, S.P., ***M.A. Bishop***, J.H. Grabowski, and C.H. Peterson. 2002. *Intertidal benthic resources of the Copper River Delta, Alaska, USA.* Journal Sea Research. 47: 13-23.

Bishop, M.A. and S.P. Green. 2001. *Predation on Pacific herring (Clupea pallasi) spawn by birds in Prince William Sound, Alaska.* Fisheries Oceanography 10(1):149-158.

Bishop, M.A., P. Meyers, and P.F. McNeley. 2000. *A method to estimate shorebird numbers on the Copper River Delta, Alaska.* Journal Field Ornithology 71(4): 627-637.

Bishop, M.A. and N. Warnock. 1998. *Migration of Western Sandpipers: links between their Alaskan stopover areas and breeding grounds.* Wilson Bulletin 110(4): 457-462.

Warnock, N. and ***M.A. Bishop***. 1998. *Spring stopover ecology of migrant Western Sandpipers.* Condor 100(3): 456-467.

SELECTED RECENT RESEARCH PROJECTS (AS PRINCIPAL INVESTIGATOR)

2000-2003 *Ecology of tidal flat communities of the Copper River Delta, Alaska*
Prince William Sound Oil Spill Recovery Institute

2001-2003 *Conservation and Restoration of Razor Clams (Siliqua patula) on the Copper River Delta*
US Fish & Wildlife Service, NOAA, and Ocean Trust

2001-2002 *Conservation of Medium & Small Shorebirds along the Pacific Flyway*
USDA Forest Service, US Fish & Wildlife Service, Chase Wildlife Foundation, National Fish and Wildlife Foundation

1996-1998 *Nearshore Vertebrate Predator Project: Avian Predation on Blue Mussels*
Exxon Valdez Oil Spill Trustee Council

TEAM MEMBERSHIPS

United States Shorebird Conservation Plan, Research and Monitoring Working Group (since 1998)

Scientific Advisory Board, Western Hemisphere Shorebird Reserve Network (since 1998)

Crane Specialist Group, IUCN Species Survival Commission (since 1995)

Platte River Whooping Crane Maintenance Trust, Science Review Panel (since 1999)

Board of Directors, North American Crane Working Group (since 1991)

SEAN P. POWERS

Current Address

Institute of Marine Sciences
University of North Carolina-Chapel Hill
3431 Arendell Street
Morehead City, NC 28557
(252) 726-6841 (voice) – 2426 (fax)
spowers@email.unc.edu

Address as of 12/01/02

Dauphin Island Sea Lab
University of South Alabama
Bienville Street
Mobile, AL 36688

spowers@disl.org

Education

1998 ***Doctor of Philosophy***, Department of Biology, Texas A&M Univ. College Station
Areas of Specialization: Ecology &Evolution, Zoology, Biostatistics

1992 ***Master of Science*** in Biological Sciences, University of New Orleans

1990 ***Bachelor of Science with Honors*** in Biology and Chemistry, Loyola University

Research Interest

My principal research interests are in the ecology of marine benthic communities. Specifically my research focuses on evaluating the relative importance of top-down and bottom-up processes in structuring these communities.

Professional Experience

2002- Assistant Professor, Department of Marine Sciences, University of South Alabama, & Senior Marine Scientist, Dauphin Island Sea Lab.

2002-2003. Research Assistant Professor, Institute of Marine Sciences, University of North Carolina at Chapel Hill.

1999-2001. Post-doctoral Research Associate, Institute of Marine Science, University of North Carolina-Chapel Hill. Post-doctoral advisor: C.H. Peterson.

1998. Oceanographer (Assistant Program Manager), Division of Ocean Sciences, National Science Foundation.

1997-1998. NOAA Seagrant Dean John A. Knauss Marine Policy Fellow, Division of Ocean Sciences, National Science Foundation.

Publications (5 of 16 total)

Borsuk, M. E., ***S. P. Powers*** and C. H. Peterson. 2002. A survival model of the effects of bottom-water hypoxia on the population density of an estuarine clam (*Macoma balthica*). *Canadian Journal of Fisheries and Aquatic Sciences,* 59: 1266-1274.

Powers, S.P., M. Sperduto, M. Donlan, and C. Hebert. 2002. Scaling restoration actions to achieve quantitative enhancement of loon, seaduck, and seabird populations. *Marine Ecology Progress Series,* In press.

Powers, S. P. and J. N. Kittinger. 2002. Hydrodynamic mediation of predator-prey interactions: differential patterns of prey susceptibility and predator success explained by variation in water flow. *Journal of Experimental Marine Biology and Ecology*. 273: 171-187.

Powers, S. P., M. A. Bishop, J.H. Grabowski and C.H. Peterson. 2002. Intertidal benthic resources of the Copper River Delta, Alaska. *Journal of Sea Research* 47: 13-23.

Powers, S. P. and C. H. Peterson. 2000. Conditional density dependence: The flow trigger to expression of density-dependent emigration in bay scallops. *Limnology and Oceanography*, Vol. 45 (3): 727-732.

Selected Recent Research Projects:

2000-2004 *Ecology of tidal flat communities of the Copper River Delta, Alaska*
Prince William Sound Oil Spill Recovery Institute

2001-2003 *Conservation and restoration of razor clams in the Cordova, Alaska Area*
USFWS & NOAA Ocean Trust

1998-2002 *The role of hydrodynamic processes in structuring of soft-sediment communities*
National Science Foundation

CHARLES H. PETERSON
Consulting Ecologist

University of North Carolina at Chapel Hill
Institute of Marine Sciences
Morehead City, NC 28557 USA

Phone: (252) 726-6841, ext. 130
FAX: (252) 726-2426
Email: cpeters@email.unc.edu

Education

AB - 1968, Princeton, Phi Beta Kappa, Cum Laude (Biology).
MS - 1970, PhD 1972, Univ. Calif. (Santa Barbara): NSF and Woodrow Wilson Predoctoral Fellowships; Major: Population Biology. Minors: Oceanography, Biometry, Paeleoecology.
Postdoc - 1972, Univ. of Calif. (Santa Barbara): Ford Foundation Postdoctoral Fellowship.
Advisors: R. H. MacArthur (undergrad.); J. H. Connell (grad.); W. W. Murdoch (postdoc.).

Professional Experience

Positions: Univ. Maryland Baltimore Co., Asst. Prof. 1972-76; Univ. North Carolina, Assoc. Prof. 1976-1982, Prof. 1983-, Alumni Distinguished Prof. 1997-. [Depts.: Marine Sciences, Biology, Ecology]

Visiting Fellowships: Univ. Western Australia 1983; Univ. Georgia 1988; Univ. Nagasaki 1990: Japan Society for Promotion of Science Fellowship.

Awards: NSF Special Creativity Award: 1990-93; PEW Charitable Trust Scholar in Conservation and the Environment: 1994-98.

Scientific Steering and Advisory Committees: UNC Marine Council 1985-91; LMER 1986; NSF ACOS 1987-90; NC Governor's Task Force on Aquaculture 1988; ESA's Sustainable Biosphere Initiative (SBI) Committee 1989-91; CIFO (Duke-UNC-NOAA Coop. Inst. Fish. Oceanogr.) 1989-; GLOBEC (chair) 1989-92; CoOP 1990-91; Canadian OPEN 1990-94; Univ. Calif. Coastal Toxicology Program 1991-; Australian Research Council Ecology Retrospective Review Panel 1992; Scientific Advisory Board to Exxon Valdez Oil Spill Trustee Council 1993-; ESA's Ecosystem Management Committee 1993-94; Lindbergh Fund Review Panel 1994-98; NSF National Center for Ecological Analysis and Synthesis (NCEAS) 1995-99 (chair 1997-99); Packard Foundation Marine Conservation Advisor 1997; NSF Futures Committee for Biol. Oce. 1998; EDF Environmental Science Advisory Committee 1999-.

Study Panels: National Academy NRC Options for Preserving the Cape Hatteras Lighthouse 1987-88; National Academy NRC Sea Turtle Conservation 1988-89; U.S. DOI North Carolina Environmental Sciences Review for OCS Oil and Gas Exploitation 1990-91; National Academy NRC Bering Sea Ecosystem 1993-95.

Management Bodies: NC Marine Fisheries Commission 1985-87, 1993-97; ICES Shellfish, Mariculture Committees 1987-1992; NC Environmental Management Commission 1989-, and Water Quality Chair 1993-; NC Sedimentation Control Commission 1993-94.

Selected publications (5 of 110):

Peterson, C.H. 2001. A synthesis of direct and indirect or chronic delayed effects of the Exxon Valdez oil spill. Adv. Mar. Biol. ***39:*** 1-103.

Peterson, C.H., L.L. McDonald, R.H. Green, and W.P. Erickson. 2001. Sampling design begets conclusions: the statistical basis for detection of injury to and recovery of shoreline communities after the Exxon Valdez oil spill. Mar. Ecol. Prog. Ser.***210***: 267-295.

Botsford, L. W., J. C. Castilla, and ***C. H. Peterson.*** 1997. The management of fisheries and marine ecosystems. Science ***277***: 509-515.

Underwood, A. J., and ***C. H. Peterson.*** 1988. Towards an ecological framework for investigating pollution. Mar. Ecol. Prog. Ser. ***46***: 227-234.

Peterson, C. H. 1979. Predation, competitive exclusion, and diversity in the soft-sediment benthic communities of estuaries and lagoons, in R. J. Livingston (ed.), Ecological Processes in Coastal and Marine Systems. Plenum Press, NY, pp. 233-264.

Selected Grants

2000-2004	Prince William Sound Oil Spill Recovery Institute Ecology of tidal flat communities of the Copper River Delta, Alaska
1997-2002	NSF Polar Programs Grant Diagnostic indicators of biological community stress using benthic community analysis to tense apart impacts of organic enrichment and toxicity: an experimental test in McMurdo Sound, Antarctica
1998-2002	NSF Biological Oceanography Program Importance of secondary dispersal in determining patterns of spatial abundance in macro-invertebrate communities"

X. LITERATURE CITED

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Alaska Regional Response Team. 1997. The Alaska Federal and State Preparedness Plan for Response to Oil and Hazardous Substance Discharges and Releases Unified Plan Vol. 2, Prince William Sound Subarea Contingency Plan.

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Baird, D., P. R. Evans, H. Milne, M. W. Pienkowski. 1985. Utilization by shorebirds of benthic invertebrate production in intertidal areas. Oceanogr. Mar. Biol. Ann. Rev. 23:573-597.

Bertness, M.D., S.D. Gaines, and M.E. Hay, eds. 2001. *Marine community ecology*. Sinauer Assoc. Inc., Publ., Sunderland, MA. 560pp.

Beukema, J.J. 1988. An evaluation of the AC-method (abundance/biomass comparison) as applied to macrozoobenthic communities living on tidal flats in the Dutch Wadden Sea. Mar. Biol. 99: 425-433.

Beukema, J. 1999. Changes in species composition of bottom fauna of a tidal flat area during a period of eutrophication. Mar. Biol. 111: 292-302.

Beukema, J.J. 2002. Expected changes in the benthic fauna of the Wadden Sea tidal flats as a result of sea-level rise or bottom subsistence. J. Sea Res. 47: in press.

Beukema, J.J. and G.C. Cadee. 1997. Local differences in macrozoobenthic communities responses to enhanced food supply caused by mild eutrophication in a Wadden Sea area: food is only locally limiting. Limnol. Oceangr. 42: 1424-1435.

Bishop, M.A., Meyers, P.M., McNeily, P.F., 2000. A method to estimate migrant shorebird numbers on the Copper River Delta, Alaska. J. Field Ornithol. 71, 627-637.

Boehm, P.D., J.E. Barak, D.L. Fiest, and A.A. Elskus. 1982. A chemical investigation of the transport and fate of petroleum hydrocarbons in the littoral and benthic environments: the Tsesis oil spill. Mar. Env. Res. 6:157-188.

Broman, D. and B. Ganning. 1986. Uptake and release of petroleum hydrocarbons by two brackish water bivalves, *Mytilus edulis* (L.) and *Macoma balthica* (L.). Ophelia 25:49-57.

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Clesceri, E.J., J.H. Grabowski, S. Powers, C.H. Peterson, C.S. Martens, M. Bishop. 2001. Carbon and nitrogen isotopic tracing of organic matter flow in two intertidal estuaries of

southcentral Alaska. North American Benthological Society Meeting, LaCrosse, Wisc.
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Lenihan, H.S., and F. Micheli. 2001. Soft-sediment communities. Pages 253-287 in M. Bertness, S.D. Gaines, and M.E. Hay, eds. Marine community ecology. Sinauer Assoc. Inc., Publ., Sunderland, MA.
McDowell, J. E., B. A. Lancaster, D. F. Leavitt, P. Rantamaki, and B. Ripley. 1999. The effects of lipophilic organic contaminants on reproductive physiology and disease processes in marine bivalve molluscs. Limnol. Oceanogr. 44(3):903-909.
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Nakaoka, M. 2000. Nonlethal effects of predators on prey populations: Predator-mediated change in bivalve growth. *Ecology* 81: 1031-1045.
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Olafsson, E.B., C.H. Peterson, and W. G. Ambrose Jr. 1994. Does recruitment limitation structure populations and communities of macro-invertebrates in marine soft sediments: the relative significance of pre-and post-settlement processes. Oceanogr. Mar. Biol. Ann. Rev. 32:65-109.
Peterson, C.H. 1991. Intertidal zonation of marine invertebrates in sand and mud. Am. Scientist 79: 236-249.
Peterson, C.H. 2001. A synthesis of direct and indirect or chronic delayed effects of the Exxon Valdez oil spill. Adv. Mar. Biol. 39: 1-103.

Peterson, C.H., and N. A. Peterson. 1979. The ecology of intertidal flats of North Carolina: a community profile. U. S. Fish Wildl. Serv., Office of Biological Services FWS/OBS-79/39. 73 pp.

Peterson, C.H., L.L. McDonald, R.H. Green, and W.P. Erickson. 2001. Sampling design begets conclusions: the statistical basis for detection of injury to and recovery of shoreline communities after the Exxon Valdez oil spill. Mar. Ecol. Prog. Ser.210: 267-295.

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Posey, M.H., T.D. Alphin, L.B. Cahoon, D.G. Lindquist, M.A. Mallin, and M.NB. Nevers. 2002. Top-down versus bottom-up limitation in benthic infaunal communities: Direct and indirect effects. Estuaries 25: 999-1014.

Powers, S.P. and C.H. Peterson. 2000. Conditional density dependence: the flow trigger to expression of density-dependent migration in bay scallops. Limnol. Oceanogr. 45(3): 727-732.

Powers, S.P., D.E. Harper, Jr. and N.N. Rabalais. 2001. Effect of large-scale hypoxia/anoxia on supply-settlement relationships of benthic invertebrate larvae. Pages 185 - 210, In: N.N. Rabalais and R.E. Turner (eds.), *Coastal Hypoxia: Consequences for Living Resources and Ecosystems*. Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D.C.

Powers, S.P., M.A. Bishop, J.H. Grabowski, and C.H. Peterson. 2002. Intertidal benthic resources of the Copper River Delta, Alaska, USA. J. Sea Research. 47: 13-23.

Powers, S.P., M.A. Bishop, J.H. Grabowski, and L. Manning. in review. Growth, recruitment, and population dynamics of *Mya arenaria*, an invasive species on the Copper River Delta. J. Shellfish Research.

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Sewell, M. A. 1996. Detection of the impacts of predation by migratory shorebirds: an experimental test in the Fraser River estuary, British Columbia (Canada). Mar. Ecol. Prog. Ser. 144:23-40.

Shaw, D. G., A. J. Paul, L. M. Cheek, and H. M Feder. 1976. *Macoma balthica*: an indicator of oil pollution. Mar. Pollut. Bull. 7:29-31.

Shaw, D. G.,, T. E. Hogan, and D. J. McIntosh. 1986. Hydrocarbons in the bivalve mollusks of Port Valdez, Alaska: consequences of five years' permitted discharge. Est. Coastal and Shelf Sci. 23:863-872.

Strickland, J.D. and T.R. Parsons. A practical handbook for seawater analysis. Fish. Res. Brd. Can. Bull. 167, 310 p.

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Underwood, A. J. 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. J. Exp. Mar. Biol. Ecol. 161:145-178.
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EXXON VALDEZ OIL SPILL TRUSTEE COUNCIL
PROJECT BUDGET

Budget Category:		Proposed FY 04
Personnel		$57,150.0
Travel		$973.0
Contractual		$80,000.0
Commodities		$3,100.0
Equipment		$0.0
Subtotal		$141,223.0
Indirect		$28,062.4
Project Total		$169,285.4
Other Funds	**anticipated OSRI**	$99,990.0

Comments:
joint project with Dr. Sean Powers, Assistant Professor of Dept. Fisheries at Univ. South Alabama, & Sr. Scientist at Dauphin Island Sea Lab
funding leveraged with $99,990 from Prince William Sound Oil Spill Recovery Institute that funds "top-down" portion of study
MTID estimated at 28% pending FY02 IDC proposal submission. 2nd year excludes U of S. Alabama from IDC Formula as per MTDC rules.

NOTE: NOAA GA (9%) OF $16.8 NEEDS TO BE ADDED TO THIS PROJECT FOR TOTAL OF $186.1

FY04

Prepared:11/28/02

Project Number: G - 030635
Project Title: Trophic dynamics of intertidal soft-sediment communities: interaction between bottom-up & top-down processes
Name: Prince William Sound Science Center

EXXON VALDEZ OIL SPILL TRUSTEE COUNCIL
PROJECT BUDGET

Personnel Costs:			Months	Monthly	
Name	Description		Budgeted	Costs	Overtin
M.A. Bishop	Principal Investigator		5.0	7350.0	
Research Technician	Research Technician		6.0	3400.0	
	Subtotal		11.0	10750.0	C
					Personnel To

Travel Costs:	Ticket	Round	Total	Da
Description	Price	Trips	Days	Per Die
Cordova to Anchorage - EVOS Workshop, January 2004 Co-Pi Bishop	325.0	1	4	162
				Travel To

FY04

Prepared: 11/28/02

Project Number: G - 030635
Project Title: Trophic dynamics of intertidal soft-sediment communities: interaction between bottom-up & top-down processes
Name: Prince William Sound Science Center

Contractual Costs:
Description
Univ. S. Alabama Dauphin Island Marine Lab, Co-PI Powers
C. Pete Peterson, consultant, 1 mo
field plot sampling helicopter flights (5 sampling periods @ 7h/ea @ $600/h)
vessel charters for servicing CTD moorings, downloading data & recalibration 10 @ $800 ea
network costs (based on $100/mo x staff months)
phone/fax/and copying charges ($100/mo @ 5 mo)
Mail/Freight/shipping Samples
Contractual To

Commodities Costs:
Description
mooring replacement parts
office supplies, field notebooks & rite in rain, computer cd & diskettes
sampling & lab supplies
Prince William Sound Science Center Truck Gas - Cordova
replacement probes for CTD
Commodities Tot

FY04

Prepared: 11/28/02

Project Number: G - 030635
Project Title: Trophic dynamics of intertidal soft-sediment communities: interaction between bottom-up & top-down processes
Name: Prince William Sound Science Center

New Equipment Purchases:	Number	U
Description	of Units	Pri
Indicate replacement equipment purchases with an R.	New Equipment To	

Existing Equipment Usage:	Numb
Description	of Un
Computers & software (PWSSC 1, Univ. S. Alabama 2)	
CTD Univ. S. Alabama (2)	
Laboratory - Prince william Sound Science Center	
Laboratory - Dauphin Island Sea Lab, Univ. S. Alabama	
Safety equipment - Prince William Sound Science Center & Univ. S. Alabama	
CHN Analyzer - Univ. S. Alabama	

FY04

Prepared: 11/28/02

Project Number: G - 030635
Project Title: Trophic dynamics of intertidal soft-sediment communities: interaction between bottom-up & top-down processes
Name: Prince William Sound Science Center