Assessment of Bivalve Recovery on Treated Mixed-Soft Beaches in Prince William Sound - Submitted Under the BAA

Project Number:	02574-BAA
Restoration Category:	Research and General Restoration
Proposer:	Dennis C. Lees, Littoral Ecological & Environmental Services
Lead Trustee Agency:	
Cooperating Agencies:	None
Alaska SeaLife Center:	No
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Cost FY 02:	$94,800
Cost FY 03:	$35,300
Geographic Area:	Prince William Sound
Injured Resource Services:	Clams, Intertidal Communities, Sediments, Sea Otters, Harlequin Ducks, Subsistence

ABSTRACT

Studies from 1989 through 1997 suggest that bivalve assemblages on beaches in PWS treated with high-pressure hot-water washing remain severely damaged in terms of species composition and function. This project will assess the generality of this apparent injury to these assemblages. A finding that our conclusions are accurate will indicate that a considerable proportion of mixed-soft beaches in treated areas of the sound remains extremely disturbed and that these beaches are functionally impaired in terms of their ability to support foraging by damaged nearshore vertebrate predators such as sea otters and harlequin ducks. The study will also provide insight into the need for remediation of beaches to restore biodiversity and function in these assemblages.

INTRODUCTION

The T/V *Exxon Valdez* ran aground in the northeastern part of Prince William Sound, Alaska, on March 24, 1989. Over the next several weeks, a substantial amount of the nearly 41 million liters of spilled Alaska North Slope crude oil was deposited on beaches in the southern and western portions of the sound and on Gulf of Alaska beaches to the southwest. Shoreline cleanup˘activities were carried out with varying degrees of intensity throughout the summer of 1989 on about 560˘km (Harrison 1991) of the 780 km of oiled shoreline in the sound. A primary method of shoreline treatment in 1989 was hydraulic flushing with water heated to moderate to high temperatures (Lees et al. 1996).

In Prince William Sound, most of the oiled beaches were "cleaned," typically using high-pressure, hot-water washing techniques. The technique involved various methods of dislodging the oil by spraying the intertidal zone with heated sea water (40-60° C) and then skimming up the oil as it flowed down the beach and refloated on the tide. Commonly, the hot water was directed at the beach using hose nozzles or a large spray-head mounted on a mechanical arm.

Recent analyses of infaunal data from the NOAA study of treatment effects and recovery in intertidal sediments in the sound have suggested that infaunal assemblages remained fundamentally impaired as late as 1997. This impairment was most evident in bivalve assemblage but was generally apparent for most major infaunal taxa. While not always apparent from the perspective of overall abundance, the impairment is quite conspicuous from the perspective of species composition and biological function or trophic structure. For bivalves, it appears that larger burrowing suspension and deposit feeders that dominate at unoiled (reference) and oiled but untreated sites have been replaced at sites exposed to high-pressure hot-water (HP-HW) washing by smaller surficial suspension feeders. This means that valuable and preferred species that typically dominate at undisturbed beaches (e.g., the littleneck clam *Protothaca staminea*, and the butter clam *Saxidomus giganteus*, which are favored by sea otters, harlequin ducks, and subsistence gatherers, and various species of *Macoma*) are replaced by a small opportunistic species (i.e., *Hiatella arctica* and a tiny nestling clam *Rochefortia* (= *Mysella*) *tumida*. that are of little or no value to nearshore vertebrate predators. In addition to bivalves, this pattern was still apparent as late as 1997 for polychaetes, echinoderms, snails, and crustaceans. In fact, whole classes or families of invertebrates that dominated at reference and oiled but untreated beaches are lacking in the infauna at treated beaches. Moreover, our studies indicate that a return to the apparent climax assemblage is occurring very slowly, apparently from lack of recruitment by the more favored bivalves, and suggest that recovery is probably delayed by the slow rate of recovery in sediments, which were also seriously disturbed by the effects of HP-HW washing. The impaired condition of intertidal bivalve assemblages may be a contributing factor in the failure of sea otters and harlequin ducks to achieve significant recovery in some areas that were oiled and may be a critical issue in the restoration of those damaged resources. .

NEED FOR THE PROJECT

The primary reason we are proposing this study is that we became concerned about the implications of differences in condition of intertidal infaunal assemblages that we have observed between oiled and treated, oiled but untreated, and unoiled reference sites in western Prince William Sound since 1989. We observed that the assemblages at the treated sites were substantially impoverished relative to those at the reference sites and that they displayed fundamental differences in functional capabilities. Moreover, we postulated that these differences were due primarily to differences in inorganic and organic sediment characteristics rather than hydrocarbons in the sediments.

As a consequence of these differences, the treated beaches that we observed were far less able to support foraging by organisms from higher trophic levels or to serve as subsistence harvest areas for the native or tourist populations in Prince William Sound. The impoverished condition of the bivalve assemblages may, in fact, be an important contributing factor in the failure of sea otters and harlequin ducks to demonstrate recovery in many oiled parts of the sound. Moreover, the increase in harlequin duck populations in other parts of the sound may be a consequence of movement to areas with more adequate food resources.

The geographic scope of our previous studies was, unfortunately, limited and cannot our findings cannot be extrapolated to the rest of the sound. Consequently, we are proposing this study to assess if the conditions that we observed in the intertidal infaunal assemblages and sediments occur generally in sediments on beaches exposed to high-pressure hot-water wash in western Prince William Sound. Determining the answer to that question could also provide helpful information in understanding the dynamics of sea otters and harlequin ducks in areas of the sound that were oiled and treated in 1989-90.

A. Statement of Problem

A large proportion of the mixed-soft sediment habitats in Prince William Sound was exposed to the spilled oil from the *Exxon Valdez* oil spill. Most of the oiled areas, however, were subsequently subjected to either warm- or hot-water washing. This process washed a considerable amount of the oil out of the area but mixed low concentrations of oil into the sediment column. Moreover, the process also flushed the finer sediment fractions and associated organic materials out of the sediment into the water column. Most of these materials were then carried away by the currents, leaving the sediments substantially altered in terms of particle grain size distribution and organic content. This process also flushed large numbers of the infaunal organisms out of the sediments and displaced or damaged them to a point where they were killed (Lees et al. 1996), leaving the infaunal assemblages greatly impoverished (Driskell et al. 1996).

A major objective of the infaunal study was to describe the differences in the structure of the infaunal assemblages existing among these treatment categories. This analysis focuses on the bivalve assemblages. The location of the various sampling sites is shown in Figure 1. Infaunal invertebrates were identified in sediment samples collected from oiled and treated, oiled but untreated, and unoiled (reference) intertidal sediments in Prince William Sound from 1989 through 1997. Invertebrate groups most commonly observed were, in decreasing order of abundance, Mollusca, Polychaeta, and Crustacea. Snails and clams were the most abundant mollusks.

Species composition and functional characteristics of intertidal infaunal assemblages at sites in Prince William Sound exposed to crude oil from the *Exxon Valdez* oil spill appear to have been influenced more by exposure to shoreline treatment than by exposure to oil. Dominance patterns of the infaunal invertebrates, which varied according to type of treatment, appear to provide

Figure 1. Location map

important insights into the effects of the spill, the ensuing treatment, and the recovery process. Life histories and ecological characteristics of the individual species suggest a rationale for the differences in dominance patterns seen among treatments. These patterns suggest that failure to achieve recovery is a consequence of lingering secondary effects from the spill rather than its primary effects.

These patterns are apparent in most of the major taxonomic groups that occur as infauna. For infaunal bivalves, lower values were typically observed at oiled and treated sites whereas highest numbers were observed at reference sites. Species richness, very similar at reference and oiled but untreated sites after 1990, declined slightly during the study. Abundance, also quite similar at reference and oiled but untreated sites, peaked in 1992 or 1993 and then gradually declined through the remaining years. In contrast, averages for species richness and abundance were substantially lower at oiled and treated sites and exhibited no apparent trends representing recovery (Figures 2a and 2b) . Differences in both variables were highly significant between reference and oiled but untreated sites, on one hand, and oiled and treated sites on the other. Similar patterns were observed in polychaetes, snails, and echinoderms. In contrast, these numerical characteristics were similar among the treatment categories for microcrustaceans.

Species richness and abundance of bivalves were significantly higher at reference and oiled but untreated sites than at oiled and treated sites, suggesting that community succession has reached a higher level at the former sites than at oiled and treated sites. All of the bivalve taxa observed were encountered at either reference or oiled but untreated sites whereas only eight taxa were observed at oiled and treated sites.

Dominance patterns and functional characteristics provide further important insights into the effects of the spill, shoreline treatment, and the recovery process. For bivalves, *Mysella tumida, Macoma* spp., and *Protothaca staminea* dominated at reference (unoiled) and oiled but untreated sites but they were far less common at oiled and treated sites. *Mysella* is typically commensal with larger burrowing species that were mostly absent or uncommon at oiled and treated sites. Although small, *Mysella* is relatively long-lived and reproduces slowly. In the absence of the burrowing hosts, it apparently nestles on the surface of the sediment. The other bivalve dominants generally are relatively long-lived, slowly reproducing species that bury up to several centimeters below the surface of stable sediments. In contrast, *Hiatella arctica*, the dominant bivalve at oiled and treated sites, is an opportunist that nestles on the surface of disturbed sediments or newly available substrate.

Species Composition

Bivalve assemblages observed in reference and oiled but untreated sites during this study were dominated by species of the bivalve families Montacutidae (a single species), Tellinidae, and Veneridae, both of the latter families represented by several taxa. Thus, reference and oiled but untreated sites have been dominated by relatively long-lived clams, mainly *Mysella tumida*, *Macoma* spp., and *Protothaca staminea* (Table 1). Most of these taxa characteristically burrow in stable sediments (e.g., *Macoma* and *Protothaca*; Peterson and Andre 1980; Houghton 1973; McGreer 1983). In contrast, members of the genus *Mysella* usually live in a commensal relationship in semi-permanent burrows with large burrowing infaunal organisms such as sea cucumbers, sipunculids, echiurans, or shrimp (Ockelmann and Muus 1978). In fact, abundance

Figure 2

Table 1

of *M. tumida* and two burrowing sea cucumbers, with which *Mysella* could have a commensal relationship, exhibited a significant positive correlation.

In contrast, oiled and treated sites were strongly dominated by a single species of the family Hiatellidae (Table 1). *Hiatella arctica*, an opportunistic, widely distributed "weed" species, nestles on the surface of disturbed sediments, on new rocks, or synthetic substrates (Morris et al. 1980; Gulliksen et al. 1980; MacGinitie 1955) and frequently dominates the biota in those habitats.

Temporal Changes of Dominant Taxa

Comparison of abundance patterns for the major species provides little evidence that dominance patterns have been changing in any of the treatment categories, especially at oiled and treated sites. In terms of raw abundance, none of the four species that dominated at reference or oiled but untreated sites showed any indication of significant increases at oiled and treated sites during the eight-year period following EVOS (Figures 3 through 6). In contrast, *Hiatella arctica* remained consistently the dominant species at oiled and treated sites (Figure 7, Table 2). When viewed in terms of relative abundance to reduce the influence of variation in overall abundance, it is still clear that dominance relationships at oiled and treated sites were not changing to any great extent (Table 2).

Mysella tumida

This small long-lived suspension-feeding clam lives near the surface of the sediment or in burrows of burrowing forms such as sea cucumbers, sipunculids, echiurids, or shrimp (Ockelmann and Muus 1978). It was by far the most abundant species at reference and oiled but untreated sites, comprising 66 and 43 percent, respectively, of the total bivalves collected in sites from these categories. Nevertheless, the average number of *Mysella* per sampling event (94.2 individuals) was nearly three times higher in reference sites than at oiled but untreated sites (35.2 individuals; Table 1). *Mysella* was particularly abundant at Outside Bay (Figure 3). The species was twice as abundant as *Protothaca staminea*, the next most abundant species in both categories. In contrast, overall abundance of *Mysella*, comprising only 28 percent of the total number of bivalves at oiled and treated sites, was an order of magnitude less abundant in this category. The average number of *Mysella* per sampling event in oiled and treated sites were an order of magnitude lower than in reference and oiled but untreated sites (Table 1).

Protothaca staminea

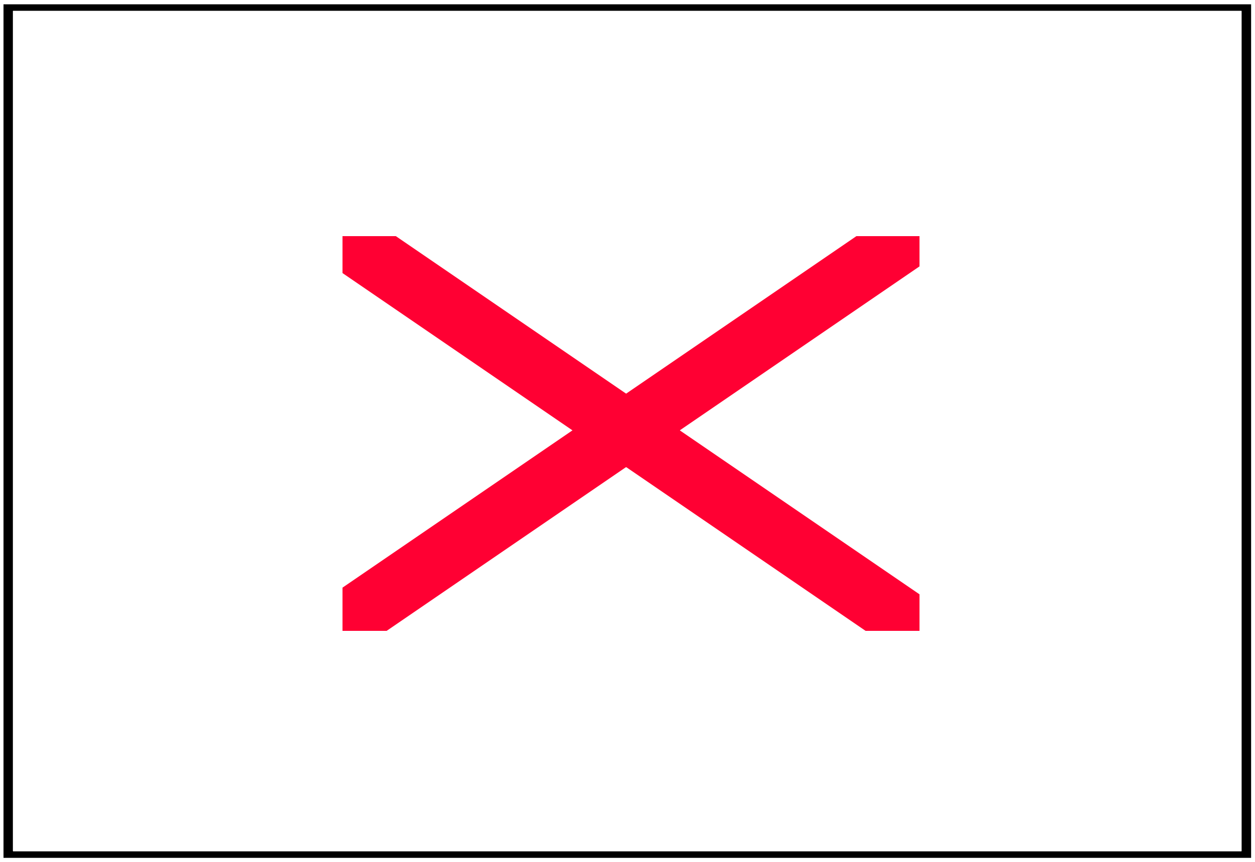
The little-neck clam *Protothaca staminea*, a suspension feeder (Morris et al. 1980; Peterson and Andre 1980), burrows to moderate depths. It probably lives at least 10 years. It was the second most abundant bivalve at reference and oiled but untreated sites, comprising 13 and 19 percent, respectively, of the total bivalves collected in these categories. The average number of *Protothaca* per sampling event, averaging 18.7 and 15.8 individuals per sampling event, respectively, was nearly the same in both categories (Table 1). It was relatively quite abundant at Outside and Sheep Bays, Block Island, and Mussel Beach South but an order of magnitude less abundant at the remaining reference, oiled but untreated, and oiled and treated sites (Figure 4). Although the abundance of *Protothaca* was patchy among reference and oiled but untreated sites, it was consistently sparse at oiled and treated sites, where density was about one-tenth that

Figure 3 & Figure 4

Figure 5 & Figure 6

Table 2

of *Hiatella* (Table 1). Also, with an average of 1.4 individuals per sampling event, it was about an order of magnitude less abundant in oiled and treated than at reference and oiled but untreated sites (Table 1).



At the four sites at which *Protothaca* was more abundant (noted above), its abundance peaked in 1992 and 1993 (Figure 4) and then appeared to decline in the following years. Nevertheless, the abundance of *Protothaca* appeared to remain at a higher level at these stations than at the other stations both before and after this period of peak abundance. It was consistently second or third most abundant at reference and oiled but untreated sites.

Macoma inquinata

This long-lived deposit-feeding clam, likely the deepest burrower of the more abundant bivalve species considered in this discussion, probably lives more than 5 years. It was the third most abundant clam at reference and oiled but untreated sites, comprising 9.5 and 12.9 percent, respectively, of the total bivalves collected in sites from these categories. The average number of individuals per sampling event was also basically the same (13.7 versus 10.6 individuals per event). *Macoma inquinata* was particularly abundant at Outside, Sheep, and Herring Bays and Block Island (Figure 5). Shelter Bay was the only oiled and treated site at which this species occurred.

Macoma balthica

This deposit-feeding clam (Newell 1965: Taghon 1982) burrows to shallow or moderate depths and can live at least five years (McGreer 1983). The average number of *Macoma balthica* per sampling event ranged from 9.1 at reference sites to 1.0 at oiled and treated sites. This shallow-burrowing clam was most abundant at Block Island and Crab, Herring, and Sheep Bays. It was not observed at either Snug Harbor or Sleepy Bay (Figure 6). It was relatively uncommon in 1989, increased considerably at several stations in 1990 through 1992, and then declined dramatically at most stations from 1993 through 1996 (Figure 6).

Hiatella arctica

This suspension-feeding clam nestles in crevices on rocks at the surface of the substrate (Gulliksen et al. 1980). It was the third most abundant bivalve observed in the infaunal samples. It was the most abundant bivalve at oiled and treated sites, where it was twice as abundant as *Mysella tumida*, the next most abundant bivalve at oiled and treated sites (Table 1; 13.5 versus 6.2 individuals per sampling event). However, it only ranked fourth or fifth in the other categories.

Based on temporal abundance patterns observed in this study, it probably lives less than 3 years. *Hiatella* apparently failed to establish persistent populations wherever it appeared, instead exhibiting one- or two-year pulses at sites when it appeared (Figure 7). Even at oiled and treated sites, *Hiatella* only dominated the bivalve assemblage in 1991 through 1994 and in 1996.

Patterns in Sediment Characteristics

Several physical and chemical characteristics of sediments that can influence development of infaunal assemblages include particle grain size (PGS), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), and polycyclic aromatic hydrocarbons (PAH) were measured.

Generally, sediments at all sampling sites were relatively coarse and most contained substantial quantities of pebbles. Average median grain size was finest at reference sites, where PGS averaged 1.9 mm, and coarsest at oiled but untreated sites, where PGS averaged >5.8 mm. Concentrations of fines in the sediments were generally low, ranging from 21.4 percent at reference sites to 5.0 percent at oiled and treated sites (Table 3).

In addition to fine particulates, sediments at reference and oiled but untreated sites were characterized by higher concentrations of total organic carbon (TOC) and total Kjeldahl nitrogen (TKN) than oiled and treated sites (Table 3). Highest concentrations of organics were measured at oiled but untreated sites and lowest at oiled and treated sites. This condition is probably partially related to whether or not the specific beaches experienced beach washing. These differences are significant except for the comparison of TOC between the reference and oiled and treated sites, percent fines between the reference and oiled but untreated sites, and PGS between reference and oiled and treated sites. The significant differences between reference and oiled but untreated sites in TOC and TKN are probably related to the oil residuals in the sediments and the bacterial flora operating to metabolize the oil.

Comparison of carbon:nitrogen (C:N) ratios provides further insight into the sediment quality at these sites. C:N ratios at reference and oiled but untreated sites are about 50 percent lower than at oiled and treated sites. This indicates that, per unit of carbon, nitrogen concentrations (largely contributed by bacteria on particulates) are lower at oiled and treated sites than elsewhere. This suggests that nutrient quality is poorer for deposit feeders (and selected suspension feeders) at oiled and treated sites than at reference or oiled but untreated sites (e.g., Newell 1965).

Table 3

Comparison of Sediment Characteristics at Infaunal Stations

Category/Site	Elevation Relative to MLLW (feet)	Median Grain Size (mm)	% Fines	PAH (ng/g)	TOC (%)	TKN (%)	C:N Ratio
Reference							
Bainbridge Bight	1.3	2.4	21.5	0.6	1.7	0.041	42.5
Crab Bay	–	1.5	18.6	5.4	2.4	0.047	49.8
Outside Bay	0.3	2.4	20.6	1.4	1.3	0.032	42.1
Sheep Bay	1.3	1.2	24.9	1.4	1.2	0.043	26.5
Average	1.0	1.9	21.4	2.7	1.6	0.041	40.2
Std. Error	0.3	0.4	1.5	0.8	0.3	0.004	5.7
Oiled but Untreated							
Block Island	3.6	2.8	14.6	2547	1.9	0.041	45.7
Herring Bay	-0.1	1.9	24.4	18	1.5	0.040	38.3
Mussel Beach South	-0.7	5.8	9.0	47	2.9	0.079	37.0
Snug Harbor	-0.4	>12.5	14.1	220	3.8	0.196	19.2
Average	0.6	>5.8	15.5	807	2.5	0.089	35.1
Std. Error	1.2	>2.8	3.7	431	0.6	0.043	6.5
Oiled and Treated							
Northwest Bay West Arm	0.5	3.9	3.4	19	0.8	0.009	88.1
Shelter Bay	0.5	3.1	7.2	67	0.8	0.013	57.9
Sleepy Bay	-0.8	3.9	4.2	77	1.9	0.025	76.0
Average	0.1	3.6	5.0	54	1.2	0.016	74.0
Std. Error	0.4	0.3	1.2	17	0.4	0.005	8.8

Because of the remoteness of these beaches from substantial sources of fine particulates, it is likely that the recovery to pre-treatment grain-size distributions could require at least several decades (pers. comm., Dr. M. O. Hayes). All of these beaches are relatively protected from wave action so the coarseness of the sediments on the beaches not exposed to washing is a strong indication that deposition rates are very slow. Although a strong relationship is frequently observed between fine particulates and organics (e.g., Newell 1965; Hartman 1965), it was not apparent is these data. However, as Cammen (1982) reported, neither TOC nor TKN exhibited an appreciable relationship to percent fines.

Average concentrations of PAH in sediments were lowest at reference sites sand highest at oiled but untreated sites and differed substantially among the three categories. Nevertheless, PAH concentrations at oiled but untreated sites (Table 3) are three to four orders of magnitude below concentrations used by Pearson et al. (1981) to assess effects of crab predation on *Protothaca* due to behavioral changes following exposure to oiled sediments. They are also below concentrations reported by Bernem (1982) as not causing mortality in *M. balthica*. The NOAA ER-L for PAH is 4022 ppb (Long et al. 1995), almost two times that of the highest average observed. Furthermore, PAH concentrations at both oiled but untreated and oiled and treated sites were declining by about 25 percent per year.

Possible Factors Influencing Composition Differences

The biological characteristics of the bivalve assemblages differed considerably among the treatment categories (Table 4). Reference and oiled but untreated sites supported relatively diverse robust populations of both suspension and deposit feeders and burrowing species appeared to thrive. In contrast, the relatively impoverished bivalve assemblages at oiled and treated sites were strongly dominated by suspension feeders, especially *Hiatella*, that live mainly at the surface of the sediments (Tables 1 and 4). Abundance of deposit feeders and burrowing species was low. Notably, *Hiatella* was substantially more abundant at oiled but untreated sites than at reference sites.

It is likely that several physicochemical and ecological factors are combining to cause the observed differences in community structure. Possibly physicochemical factors influencing larval recruitment and growth and survival of suspension- and deposit-feeding bivalves at oiled and treated sites include: 1) reduced fines, 2) nutrient concentrations, and 3) nutrient quality. Larvae for the species that dominate at the reference and oiled but untreated sites are more likely to settle out (recruit) in sediments with higher rather than lower concentrations of fine particulates or organics (TOC and/or TKN; e.g., Ockelmann and Muus 1978; Thorson 1957). In fact, except for *Hiatella*, significant recruitment events were lacking at oiled and treated sites (Figure 7). In contrast, they were commonly observed at most reference and oiled but untreated sites for all other dominant bivalve species (Figures 3 through 6).

Deposit feeders require large quantities of fines in order to survive and support growth (Lopez and Levinton 1987). Taghon (1982) reported than many deposit feeders effectively select smaller particles with a protein coating. Based on concentrations of carbon, nitrogen, and the C:N ratio (Table 3), nutrition conditions are considerably more favorable for suspension and deposit feeders at reference and oiled but untreated sites than at oiled and treated sites.

Table 4

Comparison of Relevant Biological Characteristics of Dominant Bivalve Species

Characteristic	Clam Species: *Mysella tumida*	*Protothaca staminea*	*Macoma inquinata*	*Macoma balthica*	*Hiatella arctica*
Potential Longevity (Years)	Up to 7	> 10	> 5	> 5	< 3?
Feeding Type	Suspension	Suspension	Deposit	Deposit	Suspension
Common Burrowing Depth (cm)	Surficial or nestles in host burrows	5 to 8	5 to 15	1 to 15	Nestles on surface of substrate
Dominance Pattern	All Types of Sites	Reference and Oiled but Untreated Sites	Reference and Oiled but Untreated Sites	Reference and Oiled but Untreated Sites	Oiled and Treated

Potentially relevant ecological factors include: 1) the paucity of host species to support *Mysella*, 2) paucity of adult populations to stimulate recruitment, 3) decreased predation on *Hiatella* at oiled but untreated and oiled and treated sites, and 4) predation and/or interference exclusion of the other bivalves by *Hiatella* at oiled and treated sites. The paucity of potential hosts at oiled and treated sites probably accounts in part for the failure of *Mysella* to recolonize these recently disturbed areas. Burrowing organisms such as sea cucumbers, sipunculids, echiurans, and shrimp were considerably less abundant at oiled and treated sites than at reference or oiled but untreated sites (Houghton et al. 1997). Moreover, the presence of adult infaunal organisms has been shown to facilitate recolonization of depauperate sediments (Thrush 1992), but these forms were generally lacking at these sites. Gulliksen et al. (1980) observed that *Hiatella* became dominant in areas with reduced predation. It is possible that the increased density observed for *Hiatella* at oiled but untreated and oiled and treated sites is a consequence of losses of predators following exposure to crude oil and, at oiled and treated sites, shoreline cleaning activities.

Recovery Predictions

Based on apparent patterns in community structure and sediment characteristics, habitats in greatest need of recovery are sites that were treated similarly to oiled and treated sites, i.e., washed with high pressure hot water. None of the sediment characteristics except PAH appeared to exhibit temporal patterns indicating recovery by 1996. PAH concentrations, however, generally decreased, on average, 25 percent annually at oiled but untreated and oiled and treated sites between 1990 and 1993.

Based on the apparent lack of recruitment in the dominant bivalve species, it is likely that recovery of the bivalve assemblages at the oiled and treated sites will be delayed for a long period of time. Recovery seems to be tied more to re-establishment of initial sediment conditions and community structure disturbed by the shoreline treatment program than to reductions of PAH concentrations.

Conclusions

1. Bivalve assemblages at reference and oiled but untreated sites had significantly higher numbers of species and individuals than those at oiled and treated sites.

2. Species composition and dominance patterns at reference and oiled but untreated sites were very similar but differed markedly from those at oiled and treated sites.

3. Thus, it appears that exposure to oil, by itself, did not result in a significant long-term influence on infaunal bivalve assemblages in intertidal sediments in Prince William Sound.

4. However, it appears that exposure to shoreline treatment aimed at removing oil from the intertidal zone was accompanied by significant long-term impacts to infaunal bivalve assemblages. These impacts are partly a consequence of disruptions to the assemblages existing at the sites prior to the oil spill and to significant alterations of sediment conditions at the sites.

5. Because of the distance from these areas to regions producing substantial quantities of fine particulates, recovery of the sediment structure may take several decades.

6. Because recovery is based on, at least, re-establishment of: 1) complex interspecific interactions in the infaunal assemblages; and 2) sediment conditions, it is likely that recovery of the bivalve (and, concurrently, other components of the infaunal) assemblages in the intertidal zone at treated sites will require many generations of the invertebrate species before it is complete.

B. Rationale/Link to Restoration

What is described above is what we have found for a limited number of sites. At this point, no other studies have been continued long enough to observe the conditions that concern us and these conditions have not been reported elsewhere. Consequently, no other studies have suggested that sediment conditions such as reduced concentrations of fine particles, reduced availability of organic debris, or depressed microbial biomass, may be limiting the nature and rate of recovery of the intertidal infaunal assemblage. However, the implications of these conditions are momentous in terms of the ability of treated beaches to support foraging by higher trophic levels, especially nearshore vertebrate predators such as sea otters or harlequin ducks, and in terms of recovery rates,. We believe they are potentially significant and they need to be investigated to ensure the sound becomes whole again in less than geologic time.

This program is linked closely to the Nearshore Vertebrate Predator program. Personal observations and photographs from western Prince William Sound indicated that sea otters and sea ducks foraged intensively in intertidal areas before the spill. However, sea otters populations are not recovering in bays on northern Knight Island (pg 17, FY 02 Invitation). Harlequin ducks are also not recovering in parts of the sound that were oiled. Inadequate clam resources could be one contributing factor in these recovery failures. However, this has not been investigated satisfactorily for intertidal habitats and may be a critical issue in the restoration of these other damaged resources.

This program provides an important linkage between the basic impact study that was designed to assess the nature of impacts and the rate of recovery, on one hand, and restoration efforts, on the other. Our initial studies have suggested the potential nature of the impacts in infaunal assemblages and have suggested mechanisms that could be responsible for the observed impacts. This program will provide insight into the generality and extent of the reported impact. Moreover, it will provide a detailed examination of some of mechanisms that could be driving the observed impact and could be the key to a restoration effort.

Within the framework of the goals of the Gulf Ecosystem Monitoring (GEM) program planned by the EVOS Trustee Council, this program would address Shorter-term Focused Research (i.e., the lingering effects of EVOS discussed on pg 29 of the GEM Review Draft, March 7, 2000) and long-term monitoring. It would provide insights into whether general restoration projects should be carried out on mixed-soft substrates in order to bring about recovery of intertidal bivalve and other infaunal resources important to nearshore vertebrate predators and human subsistence fishing.

In terms of the long-term monitoring aspects of the planned GEM program, this program can be viewed as a first step for establishing long-term monitoring of intertidal bivalve resources in the region. It would establish a network of sampling sites in Prince William Sound that could be expanded into the Gulf of Alaska (Blying Sound and the Outer Kenai Peninsula), Cook Inlet, and onto Kodiak Island, as discussed on pg 79 of the draft document.

C. Location

Prince William Sound is a protected fjord system located on the southcentral coast of Alaska (Figure 1). The shoreline is heavily dissected and irregular, providing a high diversity of shoreline types and a wide range of exposure. We are proposing to conduct these studies in central, western, and southwestern portions of Prince William Sound, which lay in the path of the oil slick as it flowed through the sound. Areas where sites may be selected include: the Naked Islands, Perry Island, islands in the Knight Island archipelago (i.e., Knight, Eleanor, and Disk Islands, and the smaller islands on the west side of Knight Island), Chenega, Bainbridge, Evans, Elrington, Latouche, and Green Islands, and the mainland bordering the west side of the sound from Port Nellie Juan to Port Bainbridge.

Many beaches on the islands and mainland in this area were oiled. We propose to focus on areas that were moderately to heavily oiled and subsequently exposed to shoreline treatment involving high-pressure hot-water washing. We propose to concentrate our efforts on beaches in protected embayments and small coves that are primarily composed of a mixture of gravel, sand, and silt (mixed-soft). However, we will also sample in relatively more exposed beaches such as Sleepy

Bay. We also propose to intersperse reference (unoiled and untreated) sites throughout the sampling area to the degree possible.

The semi-diurnal tides have an extreme tidal excursion of about 5.5 m. We propose to sample the beaches between Mean Lower Low Water (MLLW = 0 meter) and 0.8 m above MLLW. While the treated sites that we examined during the NOAA study ranged from –0.25 m to +0.15 m relative to MLLW, we are aware that shoreline cleanup crews attempted to avoid washing the lower intertidal. Therefore, we are proposing to sample at a higher level to increase the likelihood of sampling at elevations that were treated. Densities of the littleneck clam and other species were common within or above this elevation range at most of the untreated or reference sites sampled during our NOAA studies. In contrast, infaunal assemblages were impoverished at sites above +1.3 m.

Prince William Sound was recently subjected to another catastrophic event when it was uplifted by the 1964 Good Friday Earthquake. The portion of the sound in which our studies will be conducted was uplifted from ~4 feet in the vicinity of the western mainland and islands to ~10 feet on Latouche Island (Hanna 1971). Heaviest oiling occurred in areas that were uplifted from 4 to 8 feet.

COMMUNITY INVOLVEMENT AND TRADITIONAL KNOWLEDGE

We propose to include a community involvement element for the regional native villages in this program. The purposes of this element are to: 1) disseminate the findings of our previous studies to the natives; 2) describe the objectives of the proposed study; and 3) solicit traditional knowledge from the natives regarding locations of beaches traditionally used for gathering clams. To accomplish the goals of this element, we propose to involve natives from New Chenega, Tatitlek, and possibly Valdez. We propose to contact the native communities by telephone and mail initially and, subsequently, conduct informal meetings in each location if this is deemed desirable. These meetings will be organized with the assistance of Ms. Sarah Ward, the Spill Area-Wide Coordinator for the Trustee Council and Dr. Henry Huntington, the Traditional Ecological Knowledge Specialist for the Council. In mailings, we will describe the findings of our previous studies, our conclusions, and their implications for recovery and restoration of bivalve assemblages on the affected beaches in the sound. We will describe our plans for this program, i.e., where we are going, and what we are trying to achieve. In order to identify historically productive beaches, we will solicit information from the native elders to identify traditional subsistence gathering beaches in and adjacent to the region exposed to the oil spill.

If deemed desirable, we will meet with native groups during our field studies to expand on the information that we have provided. At each meeting, we will make an informal presentation with slides and maps describing our findings.

PROJECT DESIGN

A. Objectives

The purposes of this program are to determine if the impoverished condition of intertidal bivalve assemblages observed in oiled and treated areas during the NOAA 1990-97 studies is general to treated sites throughout the western sound and to examine the sediment characteristics that may be causing it. The program will address two major objectives. The first is to evaluate whether the depressed condition of bivalve assemblages at treated sites observed in our earlier work is general to treated sites throughout western Prince William Sound. The second objective is to evaluate the role that three sediment characteristics may play in the apparent depression of bivalve assemblages in treated sediments. The four major hypotheses that will be tested to compare patterns in bivalve assemblages between oiled and treated and reference sites in western Prince William Sound are listed below:

Bivalve Assemblages

1. H_o = Numerical characteristics of the bivalve assemblage (numbers of taxa and individuals) are similar at treated and reference sites.

   H_a = Numerical characteristics of the bivalve assemblage exhibit lower values at treated sites that at reference sites.

A. H_o =Species composition of the bivalve fauna is similar at treated and reference sites.

   H_a = Species composition of the bivalve fauna is more complex and productive at reference sites than at treated sites.

3. H_o = Functional characteristics of the bivalve assemblage (dominance by deposit feeders, tubicolous or burrowing forms) are statistically similar at treated and reference sites. Deposit feeders and tubicolous or burrowing forms are equally abundant at treated and reference sites.

   H_a = Functional characteristics of the bivalve assemblage are dissimilar at treated and reference sites. Deposit feeders and tubicolous or burrowing forms are more abundant at reference sites than at treated sites.

Sediment Characteristics

4. H_o = Sediment characteristics are statistically similar at treated and reference sites. Percent silt/clay, Total Organic Carbon, Total Kjeldahl Nitrogen, , and C:N ratios are similar at treated and reference sites.

   H_a = Sediment characteristics are dissimilar at treated and reference sites. Total Percent silt/clay, Organic Carbon, and Total Kjeldahl Nitrogen are lower at treated than at reference sites., and C:N ratios are higher at treated than at reference sites.

B. Methods

Approach

The approach we are proposing addresses whether the depressed condition of bivalve assemblages observed at treated sites in our earlier work is generally occurring at treated sites throughout western Prince William Sound. It examines species composition and ecological function for the intertidal bivalve assemblages. This study will involve 22 sites throughout western Prince William Sound that were oiled and subsequently treated with high-pressure hot-water wash techniques and 12 reference sites that have not been oiled or treated but are otherwise similar. For this study, we will focus on bivalves. We will also characterize several relevant sediment characteristics at all sampling sites.

Sampling Design

Based on the results of power analyses (see below), we propose to sample at 22 oiled and treated sites and 12 reference sites. We will collect five replicate samples for bivalves and sediment grain size at each of these sites. Samples for important sediment characteristics such as particle grain size, total organic carbon, and total Kjeldahl nitrogen will be collected for each replicate and composited for each site.

Random Selection of Sites

A large proportion of the sites will be selected in a stratified random manner in order to reduce the potential variability that could be experienced if all beaches were considered together. The region will be stratified geographically into northern and southern strata. The east-west oriented portion of Knight Island Passage will act as the dividing line between the southern and northern strata. Each of these strata will be further stratified on the basis of oiling and treatment history. These histories will be reconstructed to the degree practical based on two databases as described below in the section Assessment of Treatment History.

This study is focusing on intertidal mixed-soft sediments[1]. Because most beaches with this sediment type are located in relatively protected areas, the shoreline will be stratified to include embayments and protected passages. Selection of areas with potentially suitable substrate types will be facilitated using both the PDF and GIS versions of NOAA's ESI Atlas for Prince William Sound. The GIS version of the atlas will be queried using the appropriate Shoreline Habitat Rankings employed in the database to identify areas within each stratum that have potentially suitable substrate. These will be further screened to eliminate exposed sites.

Within each of the strata, the potentially suitable sites will be cross-referenced with the shoreline segments in embayments and protected passages identified as having suitable oiling and treatment histories. Segments with favorable characteristics for substrate and oiling and treatment history within each stratum will be assigned an incremental number. The NOAA Shoreline Segment Summary and Department of Natural Resources GIS databases will be used to assist in this process. Finally, these beach segments will also be stratified on the basis of beach elevation. Only beaches on which the

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[1] Sites with predominantly sandy or silty sediments, such as the northern end of Crab Bay, will be eliminated from further consideration because they typically support a substantially different bivalve fauna.

appropriate sediment type is found between 0 and 0.8 m above MLLW will be considered. Because tidal elevation data are not available in the GIS databases, this determination will be finalized during the reconnaissance/site selection survey.

Six sites will be carried over into the sampling design from previous programs due to their historic value. These historic sites will include two reference sites (Outside Bay and Bainbridge Bight) and four oiled and treated sites (Northwest Bay West Arm, Shelter Bay, and Sleepy Bay) from the NOAA recovery and treatment effects program; and a high-pressure hot-water washed site from an Exxon beach cleaner study (Disk Island).

The proposed allocation of sites among strata is shown in Table 5. The number of sampling sites allocated to each cell is based roughly on the amount of shoreline available within each specific stratum. Allocation has also been tempered by the potential for finding suitable sites within a cell and the need to have at least three sites to provide reasonable estimate of variability.

Table 5

Allocation of Potential Sampling Sites Among Geographic and Spill Exposure Strata

Strata	***Oiled and Treated***	***Unoiled Reference***
Northern Insular	8 sites Northwest Bay West Arm, Disk Island + 6 random sites	3 sites Outside Bay + 2 random sites
Northern Mainland	3 random sites	3 random sites
Southern Insular	8 sites Shelter and Sleepy Bays + 6 random sites	3 random sites
Southern Mainland	3 random sites	3 sites Bainbridge Bight + 2 random sites
Total Sampling Sites	22	12
Number of Historic Sites	4	2
Number or New Random Sites	18	10

Assessment of Treatment History

Determining the treatment history for any particular stretch of shoreline is a somewhat difficult and complex task. However, it has been demonstrated by Mearns (1996) for several areas in the sound that it can be accomplished to a reasonable degree. For his analysis, he employed NOAA's Shoreline Segment Summary database. Based on that database, he was able to assign substrate type, relative degree of oiling (no-, light-, moderate-, or heavy oiling), types of treatment (e.g., moderate to high pressure or warm or hot water), number of types of treatment, and number of treatment days on a segment. He did this for 37 shoreline segments in Herring Bay and 31 segments on Eleanor and Ingot Island. He concluded that, although "… treatment varied greatly among shorelines,…treatment effort was generally proportional to the amount of oil present." According to his data for Eleanor and Ingot Islands, 81 percent of the heavily oiled sites were exposed to warm or hot water and 71 percent were exposed to both. In addition, 80 percent of the moderately oiled sites were exposed to warm or hot water. Only about 10 percent of the moderately or heavily oiled segments were not treated or did not have accompanying treatment characterization. From these data, one can conclude that most heavily or moderately oiled sites were washed with hot or warm water. Furthermore, it appears this data set provides relatively good insight into the oiling and treatment history of many shoreline segments.

In addition, an ArcView map set showing many of these same types of data provides similar information. This map set, a 1997 product of the EVOS Trustee Council prepared by Alaska Department of Natural Resources, is included on a compact disk entitled "EVOS Research and Restoration Information Project". This data set will be used in combination with the NOAA data to fill in gaps where possible.

Suitability Criteria for Site Selection

At least 50 sites will be visited and evaluated during the reconnaissance survey to evaluate their suitability as potential candidate sites. As described above, these sites will have been previously screened to assure, to the degree possible, they were moderately or heavily oiled and subsequently treated with high-pressure, hot- or warm-water treatment techniques. This screening will be based on applicable Shoreline Segment Summary databases.

During the visit, the suitability of the sites will be evaluated on the basis of the criteria described below. Unsuitable sites will be omitted from further consideration. Final selection of the random sites will be made by randomly selecting the appropriate number of sites from among the remaining pool of acceptable sites for each stratum.

The following criteria will be evaluated for each site in order to determine its suitability for inclusion in this study.

- Does the site have mixed-soft sediment (mixed fines, sand, pebbles, and boulders) between 0 and +0.8 m (+2.6 feet) above MLLW?
- Is there a 30-m long expanse of suitable sediment available for sampling at the appropriate elevation?
- Is the site located suitability far from any stream, river, or glacier that could expose it to depressed temperatures or a strong or sustained freshwater influence?
- Is the site subject to strong anthropogenic influences other than the effects of the oil spill and shoreline treatment (e.g., mine tailings, log dumps, or marina activities)?

Note that the species composition and abundance of bivalves are not included as suitability criteria. Because two major hypotheses involve species composition and abundance, using these variables as site selection criteria would bias the results, especially for the reference sites.

Bivalve Sampling

Sample Collection and Handling

Samples for the bivalve assemblage will be collected with core samplers 10.7-cm in diameter (0.009 m^2) by 15-cm deep. Five of these cores will be collected at randomly selected locations along a 30-m horizontal transect placed at the appropriate elevation at each site. To the degree possible, the elevation sampled will be standardized among sites.

Each sample will field sieved through a 1.0-mm screen, washed into a double-labeled Ziploc bag, and fixed with buffered 10% formalin-seawater solution. After several days, we will replace the formalin-seawater solution with isopropyl alcohol. The preserved samples will be stored in water-tight plastic buckets and shipped to the taxonomic laboratory at the completion of the field work.

Lab Analysis

Following receipt of the samples in the laboratory, they will be washed by elutriation and the bivalves will be preserved in isopropyl alcohol. The remainder of each sample will be discarded. The bivalves subsequently will be sorted, identified to the lowest appropriate taxon, and enumerated.

A representative sample of each bivalve taxon will also be measured to provide insight into the size structure and biomass of the populations living at each site. Length measurements will be made with vernier calipers or ocular micrometers, as appropriate.

Sediment Characteristics

Whole sediment samples will be collected at all sites for analysis of particle grain size, total organic carbon (TOC), and total Kjeldahl nitrogen (TKN). These samples will be composited from surficial sediments scooped approximately 2 cm deep at points immediately adjacent to the randomly selected sampling locations for collection of the bivalve cores. Thus, the single composite sample will not provide a measure of within-site variance for the sediment variables but this measure is not viewed as necessary for the purposes of this study. Each composited sample will be preserved by freezing.

These will be analyzed to provide information on a suite of pertinent sediment property covariates that appeared important to the development of infaunal assemblages in our previous studies.

Particle Grain Size

Particle grain size distributions will be determined using a pipette method (Plumb 1981) modified to correct for dissolved solids (i.e., salinity and the dispersant added to keep silt/clay particles from clumping).

Organic Nutrients (Total Organic Carbon and Total Kjeldahl Nitrogen

The samples used for analysis of organic nutrients in the sediments will be purged of inorganic carbon, dried at 70°C, ground, and sieved through a 120-mesh screen. TOC will be measured on a Dohrman DC-180 Carbon Analyzer using EPA method 415.1/5310B. TKN will be measured using EPA Method 351.4.

Statistical Analysis

Two types of statistical analyses will be used in this study, namely inferential and exploratory analyses. The inferential statistics will test, for example, specific values or indices (e.g., species richness or density of an indicator bivalve species) to measure the significance of the difference between the controls and treated sites. Where possible, an exact probability and the power of the statistic will be stated. Typically, we prefer to use randomization or permutation statistics (Edington 1987; Manly 1997) in contrast to the classical parametric techniques. These computer-intensive methods require none of the assumptions of equality of variance or normal distribution of data as do the parametric techniques. They rely solely on a truly random sample and the empirical distribution of the data to calculate the exact significance of the statistic.

Most of the inferential statistics will be either two-sample t-tests or simple ANOVAs although the procedures can be modified for more novel designs. The tests will be either one- or two-tailed, depending on our ability to predict the impacts from prior data. While acknowledging the inherent dangers of multi-comparison testing (i.e., you are likely to find some positive results based solely on probability rather than a real effect; also termed losing control of the alpha error), we will be looking for overall trends of significant effects and supporting evidence from the exploratory analyses rather than relying on any "critical" inferential decision result. Thus, Bonferroni corrections to experiment-wise alpha will not be used.

Exploratory analyses would include some appropriate combination of multivariate analyses. It might be as simple as graphically looking at various stratum- or species-specific histograms for the bivalve species or as complex as a full-blown ordination and clustering exercise using multi-species biological and physical data (Clarke 1993). This form of analysis can be quite useful to discern and interpret common or correlated patterns in the data but is difficult to quantify with probability values. However, exploratory analyses are invaluable for providing an understanding of the natural processes that is sufficient to interpret the inferential findings and to formulate testable hypotheses.

Statistical Power

Power analyses are useful to this project for two purposes: to estimate the number of replicates appropriate to study's statistical goals, and after data are collected, to understand the sensitivity of the inferential tests.

First, using as pilot data the latest available set of infauna data (NOAA, 1996), the sampling variances can be used to calculate the sampling intensity (number of replicates) required to detect an appropriate size of effect. The statistic of concern is the difference in individual species abundance (or species richness, total abundance, sediment fraction, TPAH, etc.) between reference and oiled and treated sites. The infauna pilot data set contains 3 sites (replicate means) in each category, n= 3, 3. Power analyses projected combinations of replication up to n = 25, 25 using the reported sampling variances. The species with the best power to detect an effect (i.e., highest power for lowest practical effect) are suggested as primary indicator species for discriminating the reference from the oiled and treated sites (Table 6).

Table 6

Power to detect proportional differences in species abundance between reference and oiled and treated sites. Calculations are based on 1996 data (n = 3,3), for a 2-sample t-test for the difference of means using alpha = 0.10, pooled variance and sampling intensity of n = 10 and 20 replicates, respectively, for reference and oiled and treated sites. Values with power exceeding 50% and potential indicator species are bold formatted.

	Reference		***Oiled and Treated***		***Proportionate Detectable Effect (percent)***				
Taxon	***Mean***	***Std Dev***	***Mean***	***Std Dev***	***100***	***75***	***50***	***25***	***10***
Diplodonta aleutica	0.0	0.0	0.7	1.2	***81***	***60***	35	17	11
Mysella tumida	50.0	75.5	4.0	3.6	***83***	***62***	37	17	11
Macoma spp.	9.0	7.8	0.0	0.0	***100***	***98***	***81***	35	14
Macoma balthica	17.0	14.9	0.0	0.0	***100***	***98***	***81***	35	14
Saxidomus gigantea	0.7	1.2	0.0	0.0	***81***	***60***	35	17	11
Protothaca staminea	12.7	11.2	1.0	1.0	***100***	***100***	***97***	***54***	18
Mya arenaria	1.0	1.0	0.0	0.0	***100***	***97***	***76***	32	14
Hiatella arctica	1.7	2.1	21.3	24.4	***91***	***72***	44	19	11

The second utility of power analyses comes during *post-hoc* calculations wherein the actual power of the significant results is reported. For example, a difference in the abundance of a single species between two treatment categories may be statistically significant ($p < 0.05$); however, the ability to detect a meaningful change may not be very powerful. If the power analysis reported a power of 0.50 for a 100% change in a species abundance, it means that although you have only a 5% chance of wrongly proclaiming the change was real, you also have a 50% chance of missing a real change that was less than a 100% difference.

A concern arises in estimating power for randomization statistics; currently no formula are available s to use for the calculations. However, based on the knowledge that a randomization test produces precisely the same result as a comparable parametric test when applied to normally distributed data, the power of randomization tests is inferred to be equal to parametric tests in that ideal case. As a data distribution deviates from normality, the assumptions for the parametric test are violated and power is compromised. However, under these circumstances, the randomization test results are unaffected and power is assumed to remain roughly the same. For our purposes, we must rely on calculations of parametric power to estimate the power of the randomization tests.

Bivalve Variables

Inferential testing for comparing bivalve variables between reference and oiled and treated sites will be accomplished using 2-sample t-tests for the selected indicator species and population indexes. If needed, size frequencies will be tested using either a Kolmogorov-Smirnov test or the alternative weighted Anderson-Darling test. Two-way ANOVAs will be used to test for stratified category effects. Multivariate analyses will likely follow the combined NMDS and clustering techniques described in Clarke (1993).

Sediment Characteristics

Physicochemical sediment characteristics will be tested for category effects using 2-sample t-tests. The data will also be examined for correlations with various species and as covariates to the multivariate ordinations.

Comparison Between Site Categories

The following categories will be compared , using 2-sample t-tests or stratified 2-way ANOVAs:

- All oiled and treated vs all reference sites
- New oiled and treated vs new reference sites
- New oiled and treated and NOAA Category 3 (oiled & treated sites carried over from previous studies)

C. Cooperating Agencies, Contracts, and Other Agency Assistance

Not Applicable

SCHEDULE

The first year of this project will focus on three major items. These include: 1) selection of appropriate sampling locations, 2) conduct of the field sampling program, and 3) laboratory analysis of bivalve and sediment samples. The field work (reconnaissance survey and field sampling program) will be conducted during the two spring tide series in June 2002.

The samples will be received by the laboratories in July 2001 so it is unlikely that results will be available until October 2002. Consequently, we do not anticipate completion of data entry and database development until December 2002.

A. Measurable Project Tasks for FY 02 (October 1, 2001 – September 30, 2002

December 1 –15, 2001 Arrange and finalize contracts with subcontractors

December 16 Commence sampling site selection process by review of appropriate SCAT and shoreline treatment records

January 14 - 23 (2 days) Attend Annual Restoration Workshop; initiate dialog with knowledgeable native regarding location of historical subsistence clam harvest sites

March/April Arrange air/vessel support logistics and contracts

April 13 Submit progress report; no data available for FY 02 at this point.

May 15 Finalize list of candidate sampling sites

June 9 – 16 Conduct reconnaissance survey to finalize selection of sampling sites

June 22 - 30 Conduct field sampling program

June 30 Ship bivalve and sediment samples to respective labs for analysis

July 15 – 30 October Analysis of bivalve and sediment samples

Most of the data analysis, report and manuscript preparation, and presentation of the results at the annual restoration workshop and at a national conference, will occur during the second year of the project (FY 03).

B. Project Milestones and Endpoints

The objectives for this program are to evaluate: 1) whether or not the depressed condition of bivalve assemblages at treated sites observed in our earlier work is general to treated sites throughout western Prince William Sound; and 2). the role that several sediment characteristics in may play in the apparent depression of bivalve assemblages in treated sediments. The objectives for this program will be addressed concurrently starting in June 2001 by collecting bivalve and sediment samples at numerous oiled and treated and unoiled reference sites in western Prince William Sound.

FY 02

January 14 - 23 (2 days) Attend Annual Restoration Workshop

April 15 Arrange air/vessel support logistics and contracts

May 15 Finalize list of candidate sampling sites

June 16 Complete reconnaissance survey.

June 20 Finalize selection of sampling sites

June 30 Complete field sampling program

July 2 Ship bivalve and sediment samples to laboratories

October 30 Complete analysis of bivalve and sediment samples

FY 03

November 1 Commence data entry and analysis

December 31 Complete analyses of bivalve and sediment data

January 15, 2003 Commence preparation of annual report describing findings of the FY 02 field survey

February 15 Commence preparation of presentation describing the findings of the bivalve studies

April 13 Submit annual report (FY 02 findings)

May 1 Commence preparation of manuscript for peer-reviewed journal describing the findings of the bivalve studies

Laboratory analysis of those samples will require at least 3 months, following which we evaluate the data to address the questions posed by the objectives.

C. Completion Date

The program described in this proposal will be completed in the 3rd quarter of FY 03, in time for presenting final results and conclusions in the annual report describing FY 02 findings. The findings will be submitted as a manuscript to a national peer-reviewed journal and at a national conference during FY 03.

PUBLICATIONS AND REPORTS

At least two deliverables will be produced from the proposed research. The first will be the April 2003 annual report to EVOS Trustee Council for project activities in FY 2002. This annual report will be the final report for this program.

Moreover, assuming this research is funded, we will prepare a publication for a peer-reviewed journal. This paper, combining the findings of this work with those of the NOAA studies, will be submitted in Fall 2003 to Marine Ecology Progress Series or Ecological Applications. The title of this paper will be “Long-term Recovery Patterns in Prince William Sound Intertidal Bivalves Following *Exxon Valdez* Oiling and Shoreline Treatments, 1989 through 2002,” If this proposal is not funded, a paper entitles “Response and Recovery of Intertidal Infaunal Bivalves Exposed to the *Exxon Valdez* Oil Spill and Related Shoreline Treatment at Selected Sites in Prince William Sound,” based solely on the NOAA studies, will be submitted in Summer 2002 to one of the same journals.

Concerns that the results from this research might not be published were summarized in the initial review of this proposal. Reviewers should be aware that the team that participated in NOAA's initial studies on the effect of shoreline treatment in Prince William Sound has recently published the first of a series of papers on our studies of the *Exxon Valdez* Oil Spill. This paper (Driskell, W. B., J. L. Ruesink, D. C. Lees, J. P. Houghton, and S. C. Lindstrom. 2001. Long-term signal of disturbance: *Fucus gardneri* after the *Exxon Valdez* oil spill. Ecological Applications 11:815-827) examines synchronized senility in individual plants forming a population. Synchronized senility led to population crashes about 4-5 years following the cleanup. We demonstrated that these crashes were a consequence of reduced diversity in age structure resulting from obliteration of pre-cleanup populations of rockweed. Continued surveys in the region observed similar but weaker declines in 2000 (Dr. Alan Mearns, pers. comm.)

Regarding other publications of the NOAA studies, Mr. Lees currently has a manuscript about 80-percent complete on the response and recovery of intertidal infaunal bivalves exposed to the *Exxon Valdez* Oil Spill and related shoreline treatment (indicated as a manuscript above). We have delayed completing this paper until we know the decision on this proposal. The conclusions of that paper, reflected in both the presentations that we have made at national conferences and in this proposal, are that shoreline treatment has caused considerable disturbance to the intertidal bivalve assemblages at treated sites, and that these assemblages are recovering only at a very slow rate, in contrast to assemblages at oiled but untreated sites. Because the objective of this proposal is to determine if this pattern is, in fact, general to the treated areas in Prince William Sound, it seems that the best approach for publishing the results would be to combine both data sets into a single paper. This strategy has benefits whether the results of the effort proposed herein either confirm or refute the findings of the NOAA studies. Either alternative can be addressed and integrated in the same paper and we would avoid placing potentially erroneous conclusions into the oil-spill literature by premature publication of the NOAA conclusions. If the findings of this research are ultimately supportive, publication of the results of the EVOS-funded work in a separate and subsequent paper would seem more like an afterthought to the original paper.

Finally, rather than allowing this concern to deny funding for the proposed study, we would suggest specifying in the contract a hold on payment of a reasonable proportion of the second year's funding until the proposed integrated manuscript is submitted for review by a peer-reviewed journal.

PROFESSIONAL CONFERENCES

No funds requested at this time. Probable attendance at the 2003 International Oil Spill Conference and the 2003 SETAC Conference to present papers on findings of this program.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

We have coordinated with Dr. Henry Huntington to develop a Community Involvement program and gain access to traditional knowledge that we intend to use in selection of sample sites. Those aspects are described above in this proposal.

We anticipate sharing information with Steven Jewett, Univ. of Alaska, Fairbanks, James L. Bodkin, USGS, and Thomas Dean, Coastal Resources Associated, Inc. Furthermore, we will discuss our findings with Glenn VanBlaricom and Allan Fukuyama to exchange with information with their subtidal programs.

PROPOSED PRINCIPAL INVESTIGATOR

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PRINCIPAL INVESTIGATOR

Dennis C. Lees

With over 30 years of national and international experience, Mr. Lees has extensive capabilities in the study and evaluation of nearshore and intertidal benthic systems ranging from the Beaufort Sea and Chukchi Sea in Alaska to California, Micronesia, and the Arabian Gulf. He has been a pioneer in the research of intertidal and shallow subtidal ecology in Cook Inlet and Prince William Sound and has performed intertidal or subtidal surveys at numerous other locations in the state including Prudhoe Bay, the eastern Chukchi Sea, the Bering Sea, Unalaska, Akutan, Shelikof Strait, and the Outer Kenai Peninsula. He has participated in a variety of field, analytical, and reporting activities as a principal investigator or project manager. He has assessed or predicted impacts for a wide spectrum of industrial development activities on coastal marine habitats around the world. He has strong experience in evaluation of impacts from oil-and-gas and mining exploration and development, oil and ore spills and related clean-up and treatment activities, especially in Alaska, construction and operation of petrochemical, power, desalination, and wastewater treatment facilities, and port and airport construction and operation.

Specific experience related to oil spills and Alaskan marine systems includes:

- Recent experience in oil spill assessment and evaluation of treatment methodologies on the *Exxon Valdez* Oil Spill in Prince William Sound, the outer Kenai Peninsula, and Cook Inlet for NOAA and Exxon.

- Baseline studies of intertidal biota in Prince William Sound, Outer Kenai Peninsula, and upper and lower Cook Inlet.

- Completion of an important reconnaissance survey and comprehensive analysis of factors controlling infaunal assemblages in upper Cook Inlet.

- Completion of an Ecological Risk Assessment evaluating risks to the water column and intertidal habitats of coal-water fuel spills in upper Cook Inlet.

- Recent and continuing experience in pre- and post-abandonment (decommissioning) projects in the Santa Barbara Channel with special emphasis on surveying and restoration efforts for kelp, eelgrass, and surfgrass resources.

- Extensive experience in sampling and analysis of sediment contamination and benthic and demersal fish communities associated with rocky and soft substrates and kelp beds along the west coast of the United States and Alaska.

- Extensive experience with environmental assessments for the development phase of offshore and coastal oil and gas development and refinery operations in California, Alaska, and the Arabian Gulf

Mr. Lees obtained his B.A. in Zoology from UCSB, an M.S. in Biology from San Diego State University (SDSU), and completed all but the dissertation requirements for a Ph.D. in a joint doctoral program for SDSU and University of California, Riverside.

Mr. Lees participates in and manages a variety of marine science and environmental activities focusing on marine ecological risk assessment, habitat restoration, sediment and effluent toxicity testing, as well as traditional marine ecological assessment of benthic and nearshore fish communities. His research experience has been concentrated in evaluation of contaminant impacts in intertidal and nearshore biological systems in bays, estuaries, and coastal regions ranging from Alaska and California to the Arabian Gulf. From 1989 to 1996, he served as a project manager and principal investigator on a series of multi-year marine biological studies of intertidal and shallow subtidal habitats in Prince William Sound to study: 1) the initial impacts of the *Exxon Valdez* oil spill; 2) biological costs and effects of shoreline treatment following the oil spill; and 3) long-term effects and recovery of the biota. He participated in a major ecotoxicological study to determine the effects of spilled copper ore on the biota in marine sediments in San Diego Bay. Other sediment quality studies in which he has participated include dredging feasibility studies at the Sub Base, 32nd Street, and Continental Maritime of San Diego, and PCB evaluations at Convair Lagoon. Recently, he has been involved in eelgrass and kelp resource assessments and subsequent restoration and mitigation programs. He has assessed or predicted impacts on nearshore marine habitats from a wide variety of industrial development activities, including construction and operation of port facilities, power, desalination, petrochemical, and wastewater treatment facilities, oil development, oil spills and related clean-up and treatment activities. He participated in development of ecological risk assessment programs for Pearl Harbor and Guam as part of Ogden's Navy CLEAN program for PACDIV. He was project manager and principal investigator on major biological studies of the demersal fishes, zooplankton, benthic assemblages, wetlands, and coral reefs in two regions in the Arabian Gulf to monitor the development of a major petrochemical industrial complex, associated large power and desalination plants, and operation of a major supertanker port.

OTHER KEY PERSONNEL

All of the key personnel worked together in Alaska on major projects reaching back to 1975. We have well established working relationships.

A. William B. Driskell – Sampling Design and Statistical Approach

Mr. William Driskell will design the sampling program for this study. Moreover, he will be in charge of the various databases required for the various kinds of data and statistical analyses. In 1988, Mr. Driskell began a computer and marine biological consulting business in Seattle dealing primarily with scientific databases and statistical analyses ranging from sampling designs to multivariate statistics. He has worked as a marine biologist for the past 25 years, principally in the south-central Alaska and the Puget Sound regions but interrupted by a three-year sojourn in the Middle East where he participated in major baseline and effluent effects studies. He has been working in Prince William Sound since 1977 and on the *Exxon Valdez* oil spill since March 1989. His specialties applicable to this program are statistics, data management and computer programming. His expertise also includes: taxonomy of North Pacific and Arabian Gulf marine invertebrates and fish; biological survey techniques including trawl, seine, diving, benthic grab, dredge and box core, underwater television and still photography; and bird identification.

B. Laboratories

Bivalve Assemblages – Littoral Ecological & Environmental Services

Sorting, identification, and measurement of the bivalves in the samples obtained in July 2002 will be conducted in the laboratory of Littoral Ecological & Environmental Services, under the direct supervision of Mr. Dennis Lees.

Sediment Characteristics – To Be Determined

The laboratories in which these routine analyses (particle grain size, total organic carbon, and total Kjeldahl nitrogen), will be conducted will be determined after contract award.

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FY 02 *EXXON VALDEZ* TRUSTEE COUNCIL PROJECT BUDGET

October 1, 2001 - September 30, 2002

Budget Category:	Authorized FY 2001	Proposed FY 2002						
Personnel		$42.2						
Travel		$6.6						
Contractual		$37.5						
Commodities		$2.3						
Equipment		$0.0	LONG RANGE FUNDING REQUIREMENTS					
Subtotal	$0.0	$88.6	Estimated FY 2003					
Indirect								
Project Total	$0.0	$88.6	$33.0					
Full-time Equivalents (FTE)		0.3						
	Dollar amounts are shown in thousands of dollars.							
Other Resources								

Comments:

FY02

Prepared: 4/9/01

Project Number: 02574-BAA
Project Title: Assessment of Bivalve Recovery on Treated Mixed Soft Beaches in Prince William Sound
Name: Dennis C. Lees

Personnel Costs:				Months	Monthly		Pro
	Name	Position Description		Budgeted	Costs	Overtime	F'
	D. Lees	Principal Investigator, Infaunal Analyses		1.9563	12.8		

W. Driskell	Sampling Design and Statistics		1.3563	9.6		
Unid. Field Techs	Sample collection and processing		0.6563	6.4		
	Subtotal		4.0	28.8	0.0	
					Personnel Total	

Travel Costs:	Ticket	Round	Total	Daily	Prc
Description	Price	Trips	Days	Per Diem	F'
D. Lees, San Diego to Anchorage, annual Restoration mtng	0.8	1			
D. Lees, San Diego to Anchorage, Travel to point of departure for field	0.8	1			
W. Driskell, Seattle to Anchorage, Travel to point of departure for field	0.65	1			
Field tech, San Diego to Anchorage, Travel to point of departure for fie	0.8	1			
Auto rental during meeting and field study	0.04	8			
Per diem			27	0.12	
				Travel Total	

FY02

Prepared: 4/9/01

Project Number: Not Assigned
Project Title: Assessment of Bivalve Recovery on Treated Mixed-Soft Beaches in Prince William Sound
Name: Dennis C. Lees

FY 02 *EXXON VALDEZ* TRUSTEE COUNCIL PROJECT BUDGET
October 1, 2001 - September 30, 2002

Contractual Costs:	Prc
Description	F'
Sediment Grain Size, 34 samples	
Infaunal Analyses, 170 samples	
Air Charter, 42 hours of air support for reconnaissance	
Vessel Charter, 8 days charter, providing transportation, lodging, and food for field crew	
Contractual Total	

Commodities Costs:	Prc
Description	F'
Shipment of equipment and samples	
Film & Processing	
Field Supplies & Expendables	
Printing, xerox, and phone	
Commodities Total	

FY02

Prepared: 4/9/01

Project Number: Not Assigned
Project Title: Assessment of Bivalve Recovery on Treated Mixed-Soft Beaches in Prince William Sound
Name: Dennis C. Lees

FY 02 *EXXON VALDEZ* TRUSTEE COUNCIL PROJECT BUDGET
October 1, 2001 - September 30, 2002

New Equipment Purchases: Description	Number of Units	Unit Price	Prc F'
Not Applilcable			
Those purchases associated with replacement equipment should be indicated by placement of an R.		**New Equipment Total**	

Existing Equipment Usage: Description	Number of Units	
Not Applilcable		

FY02

Prepared: 4/9/01

Project Number: Not Assigned
Project Title: Assessment of Bivalve Recovery on Treated Mixed-Soft Beaches in Prince William Sound
Name: Dennis C. Lees

Table 2

Temporal Patterns in Relative Abundance of Infaunal Bivalves
Relative to Treatment Category

Percent of Total Abundance in Category by Year

Category/Taxon	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average	Std. Error
Reference Sites											
Hiatella arctica	2.6	5.1	7.7	3.2	1.0	1.9	0.0	4.0	3.7	3.2	0.81
Macoma balthica	1.0	10.2	5.6	7.4	0.0	6.3	5.8	17.1	1.2	6.1	1.88
Macoma inquinata	26.7	6.2	11.7	7.0	5.7	10.6	13.0	10.7	4.9	10.7	2.35
Mysella tumida	44.6	56.9	58.7	63.9	80.4	65.2	75.4	52.0	75.3	63.6	4.19
Protothaca staminea	19.5	10.6	12.8	16.2	11.6	14.7	4.3	14.4	14.9	13.2	1.50
Saxidomus giganteus	5.1	1.8	1.0	0.7	0.7	1.1	0.4	0.7	0.0	1.3	0.54
Total Individuals by Year	195	274	196	554	718	368	276	298	328	356.3	61.13
Ave. No./Sampling Event*	97.5	137.0	65.3	184.7	359.0	92.0	138.0	74.5	82.0	136.7	
Oiled but Untreated Sites											
Hiatella arctica	37.2	39.2	10.4	2.4	6.5	4.7	6.5	4.2	8.9	13.3	5.06
Macoma balthica	3.2	11.0	16.2	11.0	0.5	0.6	0.0	0.0	0.7	4.8	2.20
Macoma inquinata	8.5	4.0	9.1	15.6	12.7	17.4	18.1	15.8	0.5	11.3	2.19
Mysella tumida	35.1	26.9	25.6	44.2	58.6	48.9	47.7	47.3	78.4	45.9	5.76
Protothaca staminea	12.8	11.6	17.2	22.0	16.5	23.7	22.7	26.1	11.5	18.2	1.97
Saxidomus giganteus	1.1	2.0	2.6	1.4	2.0	0.3	0.9	2.4	0.0	1.4	0.32
Total Individuals by Year	94	301	308	500	401	317	216	165	436	304.2	46.20
Ave. No./Sampling Event*	31.3	75.3	77.0	125.0	100.3	79.3	54.0	41.3	109.0	76.9	
Oiled and Treated Sites											
Hiatella arctica	15.8	31.6	86.8	83.3	89.9	51.6	11.8	79.0	94.1	60.4	11.75
Macoma balthica	15.8	52.6	5.3	0.0	3.4	0.0	1.0	0.0	0.0	8.7	6.10
Macoma inquinata	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.4	0.38
Mysella tumida	57.9	0.0	0.0	10.6	0.0	29.0	83.3	14.8	2.5	22.0	10.54
Protothaca staminea	10.5	15.8	7.9	6.1	5.6	12.9	2.9	3.7	3.4	7.7	1.60
Saxidomus giganteus	0.0	0.0	0.0	0.0	1.1	3.2	0.0	0.0	0.0	0.5	0.39
Total Individuals by Year	19	19	38	66	89	31	102	81	203	72.0	20.51
Ave. No./Sampling Event*	9.5	9.5	12.7	22.0	29.7	10.3	34.0	27.0	67.7	24.7	

* Number includes taxa not included in this summary table