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Exxon Valdez Oil Spill
Coastal Habitat Project
Herring Bay Experimental Field Station
1990 Field Experiments: Description of Impact Assessments and Application to Restoration Feasibility Studies

PRINCIPAL INVESTIGATOR: Raymond C. Highsmith

INTRODUCTION: As a part of the Coastal Habitat program, the US Forest Service, through the University of Alaska Fairbanks, established an experimental field station in Herring Bay, Knight Island. The purpose of the station is to provide a research platform for intertidal NRDA and Restoration-related studies.

During the summer of 1990, the University of Alaska Fairbanks implemented five separate studies on 15 pairs of oiled and non-oiled sites in Herring Bay. Careful attention was given to matching pairs of sites, which included similarity in substrate composition, slope, directional and solar aspect, wave exposure, and common biological communities.

One study examined presence/absence differences between common intertidal species on impacted and reference sites. A second study examined differences in the population dynamics of several species of invertebrates between impacted and reference sites. Two separate studies assessed settlement between oiled and non-oiled surfaces, and a fifth study examined differences in algal grazing by limpets between impacted and reference sites. These studies were initiated as a part of natural resource damage assessment; however, these can equally provide useful information toward the feasibility of restoration within spill-impacted areas. A brief summary of each of these studies is discussed below.

METHODS:

Presence/Absence studies

Study sites were characterized by establishing three transects along the site perpendicular to the water line, with quadrats located at three meters of vertical fall along each transect. At each of these quadrats, presence/absence data for all invertebrates and algae were recorded. In addition, hydrocarbon sediment samples were collected. Data for temperature and salinity were collected at each of the study sites on a weekly basis.

Population Dynamics of certain invertebrate species

This study evaluates differences in numbers and recruitment of certain invertebrates with limited dispersal capability, between oiled and non-oiled sites. Limpets were included in this monitoring study because of their importance as grazers to community structure. Permanent plots were established at five pairs of sites: three sheltered rocky and two pairs of sheltered coarse-grained environments. These plots were established at three meters of vertical fall (from MHHW) along six randomly placed transects across the site length. Quadrat dimensions were 20 X 50 cm. Within each of these permanent plots, all limpets, *Nucella* spp., *Littorina sitkana* and *Leptasterias hexactis* were counted.

Barnacles

Within Herring Bay, certain oiled shorelines still possess heavy accumulations of dried tar, especially in the upper intertidal zone, where desiccation and baking by sunlight has resulted in an asphalt condition of the oil. Established colonies of barnacles were obviously impacted along many of these areas.
A study was implemented which tests whether the presence of such tar reduces the settlement capability of cyprid barnacles relative to cleaned areas within the tarred substrate.

Two oiled sites and two reference sites of similar character were selected, and pairs of 10 X 10 cm plots were established, where one member of each pair was scraped to remove all visible tar (or barnacles in the cases of the non-oiled sites). Each site was frequently examined for barnacle settlement, as well as germlings of the alga *Fucus gardneri*. The number of barnacle juveniles and germlings were recorded during each inspection, and each 100 cm^2 area was photographed.

Settlement on oiled and non-oiled substrates

A second study also examined differences in settlement of marine invertebrates and algae between oiled and non-oiled substrates. However, the substrates used in this second study were rocks retrieved from an oiled shoreline in Herring Bay, as well as rocks treated with fresh North Slope crude oil, taken from the T/V *Exxon Valdez* last year. Half of these rocks were cleaned with a solvent, and the other half remained oiled. These were placed along the mid intertidal zone at three pairs of oiled and reference sites. In addition to the rocks, a total of 72 clay tiles were also used in the experiment. The tiles, being uniform in surface composition, served as substrate controls for the rocks. Thirty six of these clay tiles were oiled with fresh North Slope crude oil and the other 36 remained clean. The tiles were placed side-by-side in the field as oiled and un-oiled pairs.

This experiment quantifies differences in the percent cover of barnacles and macro algae, and the number of individuals per unit area (10 cm^2) on the oiled and non-oiled halves of each substrate unit placed within the site pairs. Each unit was monitored weekly during the 1990 field season.

Grazing by Limpets

Studies of previous oil spills have identified the elimination of grazers within the intertidal to be of major consequence to intertidal community structure. Two studies were designed to examine differences in the grazing of algae by limpets between oiled and non-oiled sites, recolonization of algal species, and to monitor survivorship of limpets between these sites.

On seven pairs of impacted and reference sites, fences and cages were constructed of 1/8" steel cloth mesh, and were affixed to the substrate with a two-part marine epoxy.

At each of the sites, algal beds were identified and measured at different tidal contours (i.e. meters of vertical fall). Placement of the first fence at each contour was generated randomly, and subsequent fences were evenly spaced throughout the workable length of the site from the first fence. Each fence location was prepared by scrubbing a small band outside of the 625 cm area, so the epoxy and fencing would adhere to the substrate.

Transects were conducted to determine the average limpet densities at different meters of vertical fall on ten different sites in Herring Bay. The data generated from these transects were used to develop a mean number of limpets per 625 cm area.

Limpets were collected from locations away from the study areas. These limpets were uniquely labeled and tagged. Each limpet was then weighed, and its shell width and length was measured and recorded.

Based upon size and species, limpets were assigned to "batches" that were equal to the mean density per 625 cm. These batches were randomly assigned to the following matrix of treatments at each of the sites. Half of the fences contained algae, and the other half had all algae removed.

	ALGAE	NO ALGAE
DENSITY (X) OF LIMPETS:	2X	2X
	X	X
	X/2	X/2
	0	0

The fences were monitored weekly, and the number of limpets remaining were recorded, and percent algal cover determined. per AH 11/20

DURATION AND SCOPE: The limpet grazing study was terminated in September, and data analysis for this study is currently underway. However, the remaining experiments have been designed to run indefinitely. Study sites and plots are permanently marked, and can be easily accessed from the experimental field station in Herring Bay.

EXPECTED RESULTS: For NRDA, these studies will provide immediately useful data regarding impacts associated with the *Exxon Valdez* spill. It is premature to apply results from these studies toward any manipulative restoration proposal, beyond the continued monitoring of these programs. Nonetheless, the continuance of these and other monitoring programs in 1991 will contribute to the base of knowledge concerning restoration feasibility, especially with respect to determining a rate of recovery to pre-impacted conditions.

CONTINUED COST OF STUDY: (in Thousands of dollars)

Personnel:	150
Air Support:	16
Equipment:	12
Barge Charter:	375
TOTAL COST:	$553

(Note: Barge charter includes insurance, food & fuel and its transportation to Herring Bay)

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Status Report:

FUCUS RESTORATION PROJECT

(University of Alaska, Fairbanks contract No. 53-0109-9-00276 Mod #4)

Prepared by

A.P. De Vogelaere
&
M.S. Foster

Moss Landing Marine Laboratories
P.O. Box 450
Moss Landing, CA 95039

SUMMARY

This is a report on our initial (September 15-24, 1990) field work in Herring Bay, Prince William Sound, Alaska. The objective of our project is to understand the causes of variation in Fucus recovery relative to cleaning techniques and microhabitats in areas affected by the Exxon Valdez oil spill in Prince William Sound. An understanding of Fucus recovery should suggest possible restoration techniques for this dominant intertidal alga. Over a nine day period, high intertidal sites that were subjected to different cleaning intensities (no oil, oil/intense cleaning, oil/less intense cleaning) were sampled for all species, and a series of factors (grazer species and abundance; presence/absence of local Fucus adults; substratum type, slope, and relief) were correlated with the abundance of Fucus recruits. The abundances of most, but not all species, in oiled and cleaned sites were significantly different from un-oiled areas (different: Fucus, Littorina sitkana, L. scutulata, Limpets, tar; not different: Balanus glandula, species richness). There were strong trends indicating that higher cleaning intensity slowed recovery of Fucus, but high between site variability precluded statistically significant results. The preferential substratum for new Fucus recruits was fine rock cracks. No recruits were found growing on high intertidal tar. The presence of adult Fucus plants was positively correlated with local Fucus recruitment. This preliminary study provides a solid background for field experiments to begin in spring, 1991.

OBJECTIVES

The general objectives of this study are to understand the causes of variation in Fucus recovery in areas affected by the Exxon Valdez oil spill in Herring Bay, Prince William Sound, and to document the extent and magnitude of natural recruitment of Fucus in areas subjected to different intensities of cleaning.

INTRODUCTION

The alga Fucus gardneri (Silva) forms large beds throughout the rocky intertidal zone of Prince William Sound. Its canopy ameliorates this harsh habitat, providing food and a place to live for a wide range of intertidal as well as open ocean and terrestrial species. Fucus recovery varied between sites after the Exxon Valdez oil spill. By understanding the causes of this variation, methods to enhance Fucus restoration should become clear. Additionally, by comparing recovery in areas where the intensity of cleaning differed, we are assessing the relative benefits of effectively removing oil versus Fucus recruitment potential.

While some observations were made on the exposed coast at the mouth of Herring Bay, Knight Island, all quantitative data were collected within the bay (Figure 1). This report is on preliminary survey work done during September 15-24, 1990. The correlative data in this report will be used to design field experiments to be done in spring, 1991.

METHODS

Cleaning Intensity Versus Recovery

Three site treatment categories (based on cleaning intensity) were chosen: (1) Controls- no oil and no cleaning (2) Intensely cleaned- no distinct continuous oil band on the high intertidal zone, apparently severely damaged mid intertidal zone (based on number of Fucus holdfast remnants and maturity of present Fucus plants) (3) Less intensely cleaned- distinct oil band on the high intertidal zone, apparently healthier mid-intertidal Fucus. Though it is impossible to pin-point intertidal clean up history at the scale of meters, available ADEC shoreline assessment information indicates that our intensely cleaned category of sites received relatively higher pressure and warmer water cleaning. The sites all had similar wave and wind exposure.

Sampling was accomplished in two replicate sites of each cleaning intensity category. A transect tape was laid across each study site at the + 8-9 ft tidal mark in the high Fucus zone. Tidal height was found using a stadia rod, line level, and tidal charts. Five 50 x 50 cm quadrats were placed randomly along each transect tape. In each quadrat, percent cover was estimated by identifying species which came in contact with a pin lowered at 16 points delimited by evenly spaced cross-hairs in the quadrat. Macro-grazers and individual Fucus plants were also counted and the quadrat was photographed.

Some areas were permanently marked to monitor recovery on tar versus directly adjacent cleaned rock in the high Fucus zone. Thirty-five pairs of tar and non-tar areas were marked with numbered tags epoxied to the rock, recruitment on tar was noted, and photographs were taken. In the future these same areas will be re-sampled.

Microhabitat Correlates With Fucus Recruitment

In addition to different cleaning intensities, many microhabitat factors could cause variable Fucus recruitment. The following data were also collected in the above quadrats to correlate with the abundance of Fucus recruits: slope of the quadrat, presence/absence of conspecific adults (> 15 cm) within one meter of the quadrat, and visual percent cover estimates of substratum relief categories (smooth, cracks, high relief). Finally, the length and attachment substratum (smooth rock, crack in rock, tar, barnacle) was noted for 10 Fucus plants closest to the upper left corner of each quadrat.

Deviations From The Proposed Research Plan

We did not arrive in Prince William Sound until the last weeks of the field season because of funding delays. As a result of the time and foul weather constraints, we were not able to do quantitative work at exposed sites, sample the mid Fucus zone, or obtain as many replicate sites as proposed. However, enough information was collected to make some statistically significant conclusions about the effects of cleaning intensity on recovery in the high Fucus zone (where recovery seems slowest), and correlations indicated which factors should be considered for next seasons recruitment experiments.

Data Analysis

The data were analyzed with standard figures and statistical methods. To test for differences between cleaning treatments on individual species, an analysis of variance was used in which sites were nested within treatments. Replicate sites within treatments were pooled for the figures when no statistically significant difference was found between sites. The assumption of equality of variances was addressed with Cochran tests and the data were transformed (arcsin on % cover, square root on counts) when necessary before performing the analyses. The more simple tests are described with the results.

RESULTS

Cleaning Intensity Versus Recovery

Oil and different cleaning intensities influenced Fucus abundance, but the effects were variable on the other common high intertidal species (Figure 2 and Table 1). As might be predicted, more intense cleaning effectively resulted in less tar on the intertidal, and no oil was found in the controls (Figure 2a, Table 1). The percent cover of Fucus was much higher in the controls than in the cleaned sites because of the characteristic large canopies formed in mature stands. There was no difference in Fucus cover between the two cleaning intensities (Figure 2b); however, there tended to be more individuals recruiting into less intensely cleaned sites (Figure 2c). There are no statistical differences in treatment effects for Fucus densities because of the high site variability (Table 1). Balanus glandula rapidly colonized the oiled sites and seems to have recovered (Figure 2d, Table 1). Littorina sitkana and limpets were more abundant in the control sites (Figures 1e,g), while L. scutulata was more abundant in the oiled and cleaned sites (Figure 2f). The number of species sampled were not significantly different between controls and oiled sites (Figure 2h, Table 1). This was surprising compared to other oil spill studies, and is probably a result of the generally low diversity in this high Fucus zone. Abundances of less common species at each site are listed in Appendix 1.

Microhabitats And Fucus Recruitment

The number of Fucus recruits was strongly correlated with substratum relief and presence/absence of local adults, but the correlation with grazer densities was poor. Most of the Fucus recruits (<5 cm) were found growing in fine rock cracks, and none were growing on tar in the high intertidal zone (Figure 3). Visual estimates of cover indicated that the rank of available substratum was, from highest to lowest: smooth rock, tar, cracks in rock, and barnacles. The number of Fucus recruits in cleaned sites was significantly higher if adult conspecifics (> 15 cm) were within one meter of the quadrat (Figure 4, t test, $p << 0.01$). The rest of the factors correlated poorly with the number of Fucus recruits in the cleaned sites (Littorina sitkana, $r = -0.3$; L. scutulata, $r = 0.04$; all limpets combined, $r = 0.4$; slope, $r = 0.02$). However, it appears that intermediate slopes have more abundant recruits than steep or flat slopes (Figure 5). Qualitative field observations also indicated that fresh water runoff and wave exposure also influence recruitment or subsequent growth.

CONCLUSIONS AND CONTINUING STUDIES

Several conclusions can be made from this initial phase of our study of the high Fucus zone in protected sites of Knight Island, Prince William Sound: oiled and cleaned sites had significantly lower percent cover of Fucus and fewer limpets, while having greater abundances of Littorina scutulata than un-oiled areas; the more intensely cleaned sites had significantly less tar; there were some strong trends indicating that higher cleaning intensity slows recovery of Fucus, but the differences were not statistically significant; new Fucus recruits were more abundant in rock cracks and not found on tar; and the presence of adult Fucus enhanced local recruitment.

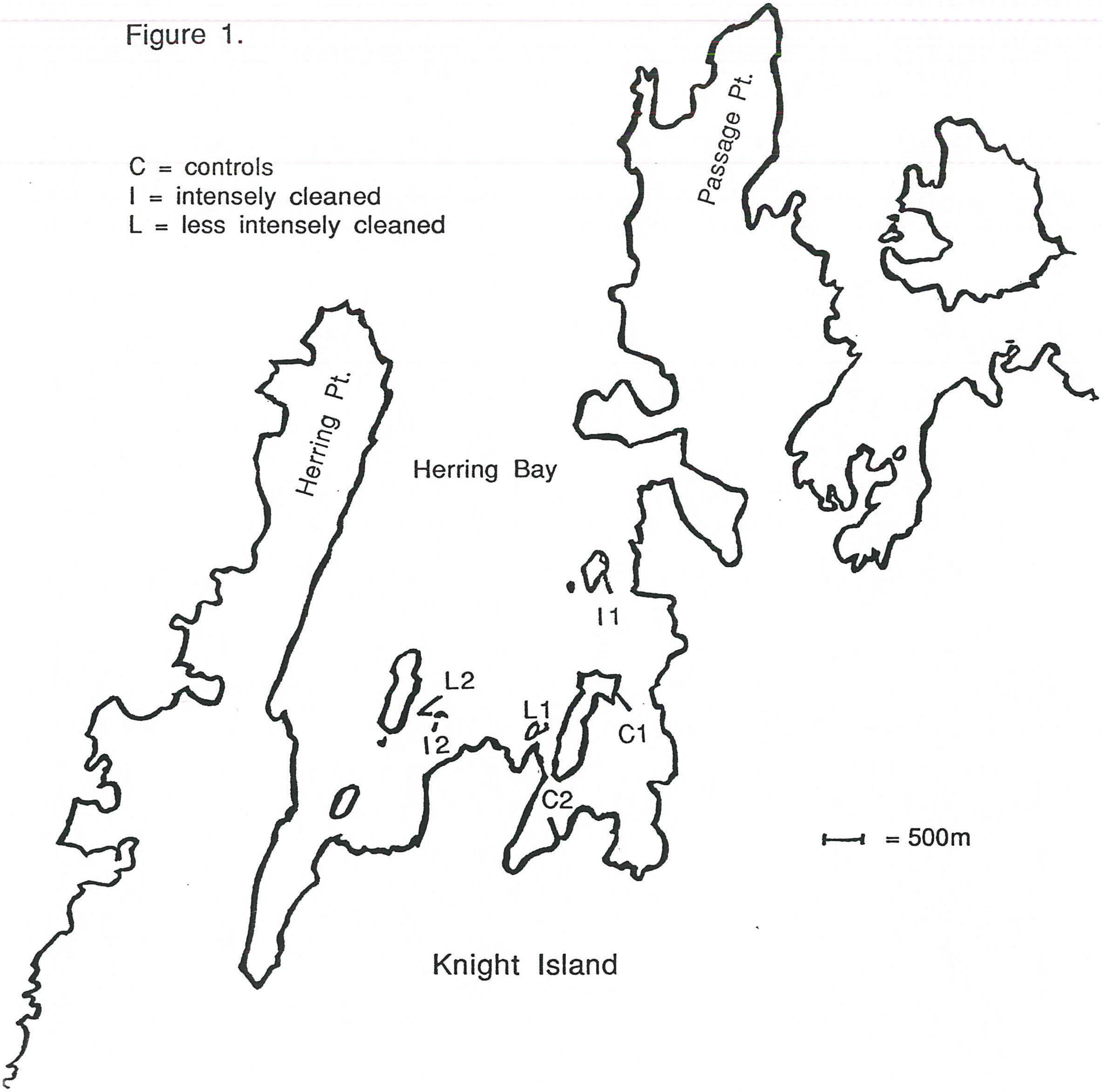
In Spring 1991, we will continue to monitor recovery on the permanently marked pairs of tar patches and adjacent cleaned areas. Based on the results of this preliminary study, we plan to set up field experiments to test the effects of substratum relief, substratum slope, local adults, and wave exposure on already present Fucus juveniles and new recruits. Additionally, we will initiate Fucus covered boulder transplant experiments between and within sites as a possible restoration method.

Table 1. Data manipulations and statistical results.

	ANOVA Results		Scheffe A Posteriori test	Cochran test for heteroscedasticity
	Treatment effect	Replicate site effect	Control (C) Intense clean (I) Less clean (L) different than (*)	homoscedasticity (=) heteroscedasticity (//) arcsin transformation (a) square root transfomation (x) no transformation (0)
% Tar	p<<0.01	None	C * I; C * L; I * L	=, a
% Fucus	p<<0.01	None	C * I; C * L	=, a
# Fucus	None	p<0.05	None	=, 0
% Balanus	None	None	None	=, 0
# Littorina sitkana	None	P<<0.01	None	//, x
# Littorina scutulata	p<0.01	None	C * L	=, x
# Limpets	p<0.05	None	C * I; C*L	=, x
# Species	None	None	None	=, 0

Figure 1.

C = controls
I = intensely cleaned
L = less intensely cleaned



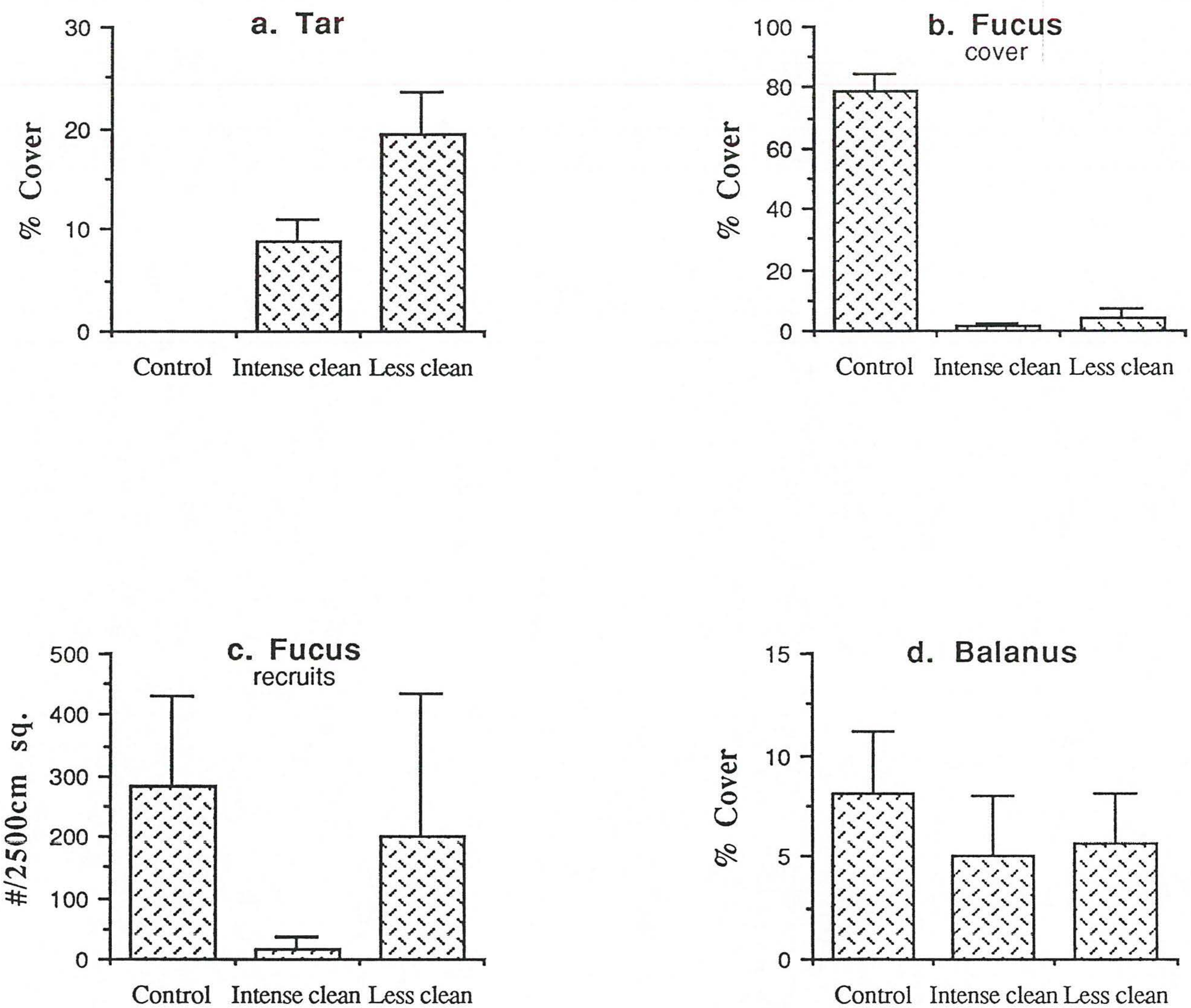


Figure 2. Cleaning intensity effects on (a) % tar (b) % Fucus (c) # Fucus (d) % Balanus. Abundance values are means + 1 S.E.[n = 10 except for # Fucus where n = 2 because site differences (Table 1) made pooling inappropriate].

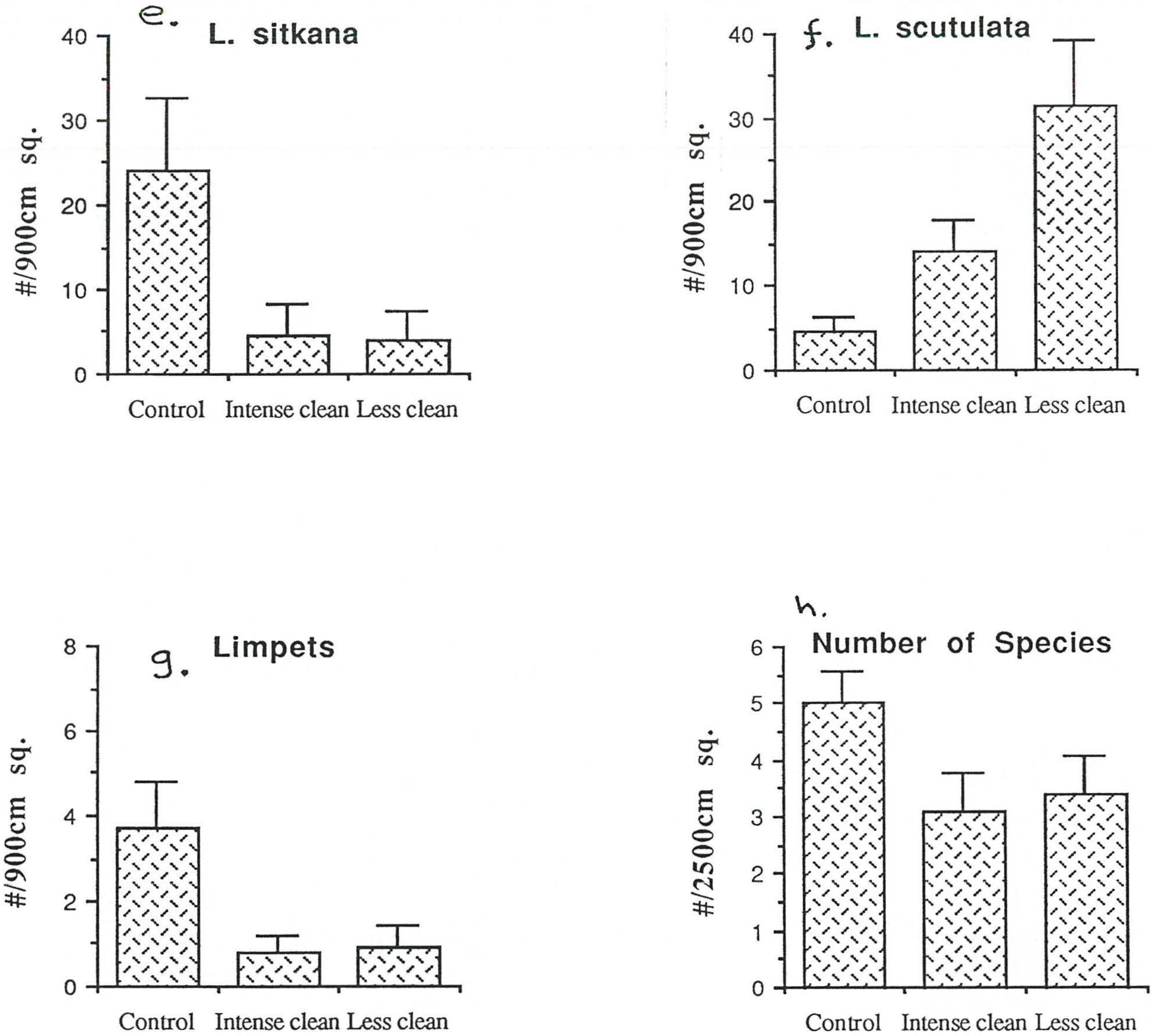


Figure 2 (continued). Cleaning intensity effects on (e) Littorina sitkana (f) L. scutulata (g) # limpets (f) # species. Abundance values are means + 1 S.E. [n = 10 except for L. sitkana where n = 2 because site differences (Table 1) made pooling inappropriate].

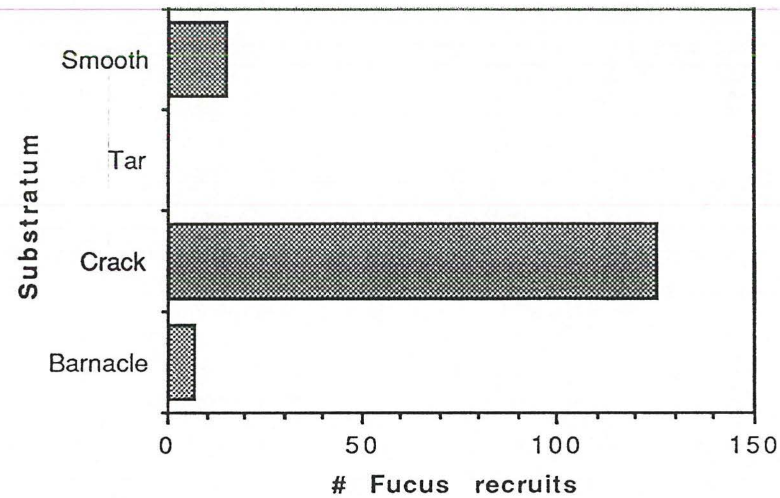


Figure 3. Substratum affects on Fucus recruits (<5 cm) from all sites combined. Smooth and crack indicate rock substratum relief.

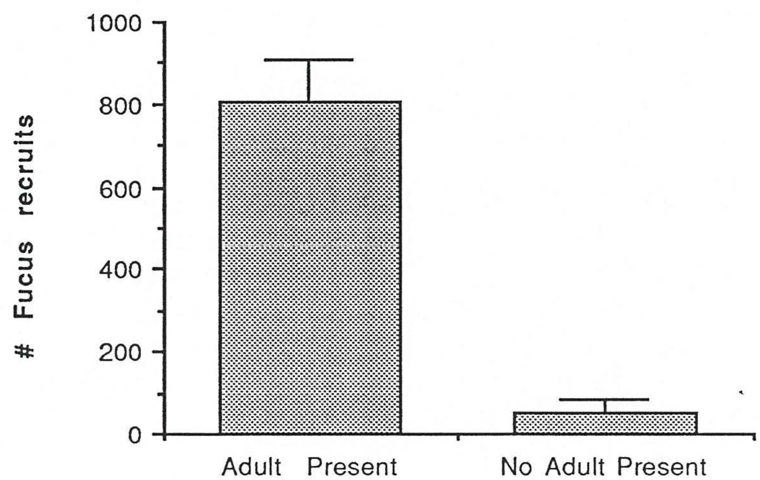


Figure 4. New recruits are more abundant when adults are within one meter of the sample area (means + 1 S.E., 50 x 50 cm area).

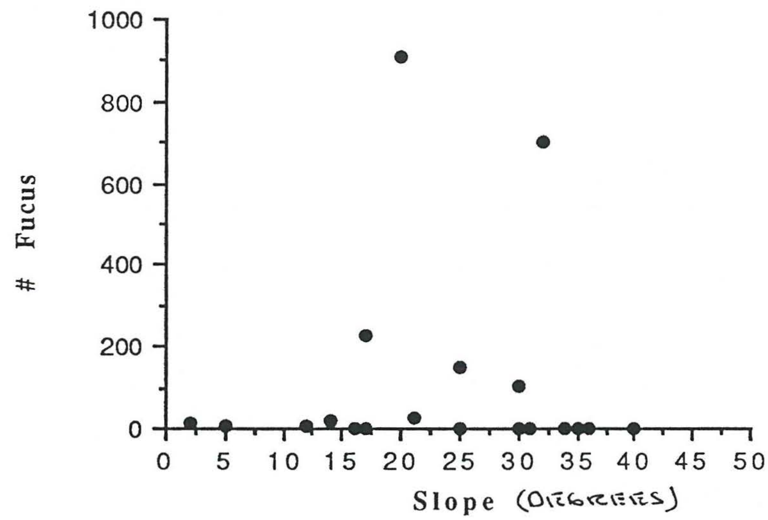


Figure 5. Correlation between Fucus recruits (<5cm) and substratum slope in cleaned sites. Note that the highest values are located at intermediate slopes.

Appendix 1. Descriptive statistics for all species sampled in control, intensely cleaned, and less intensely cleaned sites.

	Control 1		Control 2	
Species	**mean**	**S.E.** (n = 5)	**mean**	**S.E.** (n = 5)
% *Fucus gardneri*	76.25	10.09	82.50	5.69
% *Balanus glandula*	12.50	5.20	3.75	1.52
% Green lichen	0	0	1.25	1.24
% Brown crust	0	0	1.25	1.25
% Red crust	1.25	1.24	1.25	1.24
# *Littorina sitkana* /900 cm^2	18.80	6.68	29.20	2.97
# *Littorina scutulata* /900 cm^2	3.00	1.30	6.40	2.62
# *Tectura persona* /2500 cm^2	5.00	1.60	1.80	0.80
# *Lottia pelta* /2500 cm2	0.40	0.24	0.20	0.20
Pagurus spp.	present		0	0
Amphipods	present		0	0

	Less Intense Clean 1		Less Intense Clean 2	
% Tar	26.25	7.71	10.00	2.48
% *Balanus glandula*	5.00	2.32	6.25	4.81
% *Cthamalus* spp.	0	0	2.50	2.50
% *Mytilus edulis*	0	0	1.25	1.24
% *Gloeopeltis* sp.	0	0	5.00	3.62
% *Leathesia* sp.	0	0	1.25	1.24
% Brwon crust	0	0	1.25	1.24
# *Littorina sitkana*	7.80	1.82	0.40	0.40
# *Littorina scutulata*	42.8	12.70	20.00	5.95
# *Tectura persona*	0	0	1.40	0.67
# *Lottia pelta*	0	0	0.40	0.24

Appendix 1 (continued).

Species	Intense Clean 1 mean	Intense Clean 1 S.E. (n = 5)	Intense Clean 2 mean	Intense Clean 2 S.E. (n = 5)
% Tar	12.50	3.40	5.00	2.32
% *Balanus glandula*	10.00	5.05	0	0
% *Fucus gardneri*	2.50	1.52	0	0
% *Neorhodomella aculeata*	0	0	1.25	1.24
% *Gloeopeltis* sp.	0	0	1.25	1.24
% Brown crust	5.00	3.62	1.24	1.25
% Red crust	1.25	1.24	0	0
# *Littorina sitkana* /900 cm^2	6.80	1.79	1.20	1.19
# *Littorina scutulata* /900 cm^2	19.00	7.15	9.00	2.31
# *Tectura persona* /2500 cm^2	0	0	0.40	0.40
# *Lottia pelta* /2500 cm2	0.80	0.37	0	0
Juvenile limpets	0.20	0.20	0.20	0.20
Paguras spp.	0	0	Present	

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RESTORATION FEASIBILITY STUDY NUMBER 2

Study Title: Re-establishment of Critical Fauna in Rocky Intertidal Ecosystems

Lead Agency: USFS

Cooperating Agency: EPA

INTRODUCTION

Intertidal ecosystems on rocky shores, including both fauna and flora, were seriously affected by the oil spill and cleanup activities. Initial results suggest that certain key faunal species, such as grazers and predators, that are likely to structure these intertidal communities, were moderately to heavily affected. Natural restoration processes in these communities will be limited by recolonization rates of these key species, which in some cases are known to be quite low. Re-establishment of *Fucus* alone may therefore not be sufficient to ensure a return to pre-spill conditions on ecologically meaningful time scales. Before a restoration plan is proposed, we should demonstrate the feasibility of enhancing the rate of recovery of the intertidal community by the re-establishment of key grazers and predators. If the natural recoveries of *Fucus* and intertidal fauna can be augmented by restoration projects, it will be of fundamental benefit to the marine ecosystem.

OBJECTIVES

A. Compare rates of recovery of rocky intertidal communities with and without key faunal species and combinations of species.

B. Demonstrate the feasibility of restoring rocky intertidal communities by enhancing colonization by key faunal species.

C. Determine the costs of implementing a full-scale restoration project to re-establish key faunal species in rocky intertidal ecosystems.

Relationships with Other Studies:

This study will be carried out in conjunction with the *Fucus* study, R/F 1, and it is related to several other NRDA studies, particularly CH 1.

METHODS

Based on results of NRDA studies, limpets have been identified as important grazers that were harmed by the oil spill in rocky intertidal ecosystems. Predators, such as *Nucella* and *Leptasterius*, also could be important in structuring these intertidal communities. Rates of recovery of intertidal areas with and without key species and combinations of species will be compared. Grazer, predator, and grazer-predator exclusion and enhancement plots will be established in habitats that experienced differing degrees of oiling or were subjected to different cleanup techniques (e.g., bioremediated, hot-water high-pressure cleaned). A key aspect of the study will be demonstrating the feasibility of enhancing colonization by key species.

BUDGET: USFS

Salaries	$ 0.0
Travel	5.0
Contractual Services	65.0
Supplies	2.0
Equipment	3.0
TOTAL	75.0