Exxon Valdez Oil Spill
Restoration Project Annual Report

Recovery Monitoring and Restoration of Oiled Mussel Beds in Prince William Sound, Alaska

Restoration Project 94090
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

Malin M. Babcock
Patricia M. Harris
Stanley D. Rice

National Oceanic and Atmospheric Administration
National Marine Fisheries
Auke Bay Laboratory
11305 Glacier Highway
Juneau, Alaska 99801-8626

Ron J. Bruyere
Diane R. Munson

Alaska Department of Environmental Conservation
645 G Street, Suite 101
Anchorage, Alaska 99501-3451

September 1995

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in Prince William Sound, Alaska

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Study History: This project was initiated in 1992 as Restoration Project 103A and continued as Restoration 93036 and Restoration 94040. " Recovery Monitoring and Restoration of Intertidal Oiled Mussel (*Mytilus trossulus*) Beds in Prince William Sound Impacted by the *Exxon Valdez* Oil Spill" an annual report and an Alaska Fisheries Science Center Processed Report (94-02) with the same title report 1992 findings. The results of the portion of the study that focused on oiled beds in the Gulf of Alaska in 1992 and 1993 are reported by the National Park Service in "Geographical extent and recovery monitoring of intertidal oiled mussel beds in the Gulf of Alaska affected by the *Exxon Valdez* Oil Spill". Two papers based on 1992 and 1993 results, "Persistence of Oiling in Mussel Beds Three and Four Years after the *Exxon Valdez* Oil Spill" and "Within"Bed Distribution of *Exxon Valdez* Crude Oil in Prince William Sound Blue Mussels and Underlying Sediments" have been accepted for publication in the *Exxon Valdez* Symposium proceedings. The annual report for project 93036 is being released concurrently with this present document, which reports 1994 activities and results and incorporates "1994 mussel bed restoration and monitoring (#94090) data report" compiled by Diane Munson, Alaska Department of Environmental Conservation.

Abstract: Twelve mussel beds that were still impacted in 1993 by the *Exxon Valdez* oil spill were cleaned to reduce hydrocarbon exposure to mussels, higher consumers, and subsistence food users. In July and early August 1994 we manually removed oiled mussels, replaced oiled sediments underlying the mussels with clean sediments, and replaced mussels onto the clean sediments. In mid August, all sediments underlying the restored beds had lower petroleum hydrocarbon levels than before cleaning. In seven out of 12 beds, hydrocarbon levels were more than 90% lower in replacement sediments than in original sediments; three out of 12 were 80 to 90% lower. Original sediments lost hydrocarbons as soon as they were exposed to tidal washing. Hydrocarbon levels in original sediments removed from the beds had decreased by more than 50 % in mid August.

Key Words: *Exxon Valdez*, intertidal restoration, mussels, *Mytilus trossulus*, oiling persistence, petroleum hydrocarbons, sediments

Citation: Babcock, M.M., P.M. Harris, S.D. Rice, R.J. Bruyere, and D.R. Munson. 1995. Recovery Monitoring and Restoration of Oiled Mussel Beds in Prince William Sound, Alaska, *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project 94090), National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Auke Bay Laboratory, Juneau, Alaska.

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EXECUTIVE SUMMARY

The possible impacts of persistent high concentrations of *Exxon Valdez* oil in mussel beds on higher consumers prompted the cleaning of 12 oiled mussel beds in 1994. We removed the mussel layer and underlying oiled sediments to sorbent pads in separate areas away from the excavation. The subsequent high tide flushed oil from the surface of the excavation, from removed sediments, and from the mussels. At the next low tide, the excavation was filled with clean replacement sediments and the mussels were replaced.

Ten to twenty nine days after restoration, sediments underlying the mussels remained cleaner than the original sediments and the physical integrity of the beds remained intact. All replacement sediments showed increased hydrocarbon concentrations by mid August, but in 10 out of 12 beds concentrations were more than 80% lower in replacement than in original sediments. Original sediments lost hydrocarbons as soon as they were exposed to tidal washing. Hydrocarbon levels in dispersed sediments decreased by more than 30% in most beds after one or two high tides and by more than 50% in mid August. Mussel densities decreased in seven out of 12 beds; apparent decreases ranged from 9 to 48%.

The criteria to be met in evaluating the effectiveness of bed-wide restoration are reduced hydrocarbon concentrations in mussels and stable mussel densities, ensuring a less contaminated and stable food supply for higher consumers. Based on short-term sediment hydrocarbon and mussel density data, this project has reduced hydrocarbon levels while retaining the integrity of the mussel beds. Analysis of 1995 data is necessary to more adequately evaluate this technique.

INTRODUCTION

Many blue mussel (*Mytilus trossulus*) beds impacted by *Exxon Valdez* oil spill (EVOS) on 23 March 1989 were not cleaned by the EVOS Interagency Shoreline Cleanup Committee because mussels were an important food source and a physically stabilizing element in intertidal areas. It was hoped that natural processes would clean the beds in reasonable time. However substantial amounts of *Exxon Valdez* oil (EVO) still remained in mussels and sediments underlying mussel beds in 1991 (Babcock 1991, Babcock et al. 1994). Persistent, high concentrations of hydrocarbons in mussels were identified as a possible source of impacts in several consumer species and could also impact human subsistence users.

To reduce hydrocarbon levels in the beds, minimally intrusive methods were piloted by this project (R103A, and 93036) and by the Alaska Department of Environmental Conservation (ADEC) in 1992 and 1993. Strips of mussels and sediments attached to byssal threads were removed in several oiled mussel beds to facilitate tidal flushing of oil and patches of mussels were transplanted from oiled beds to clean substrates (Bauer et al. 1992, Babcock et al. 1994). Hydrocarbon levels were reduced in these beds only in or immediately adjacent the strips. Overall, hydrocarbon concentrations in the manipulated beds as well as many survey beds remained high in 1993 (Babcock et al.1994, In press).

Hydrocarbon concentrations in mussels from oiled beds could be expected to decrease if the mussels were no longer exposed to oiled sediments. Therefore, in 1994 we proposed restoring selected mussel beds by replacing oiled sediments with clean "donor" sediments to be evaluated by close monitoring of hydrocarbon levels and mussel densities. We recognized that the proposed cleaning of mussel beds would itself impact the intertidal area and followed guidelines in "Environmental assessment shoreline oil removal and mussel bed restoration and monitoring" prepared by ADEC in March 1995 and accepted by NOAA-Hazmat.

OBJECTIVES

A. To reduce levels of petroleum hydrocarbons in mussels and sediments in selected oiled mussel beds in Prince William Sound (PWS) by manually removing oiled sediments. (ADEC lead).

B. To measure recovery in levels of petroleum hydrocarbons in mussels and underlying sediments treated under Objective (A) and in several untreated oiled beds (NOAA).

C. To measure the physiological and reproductive injury in mussels chronically exposed to petroleum hydrocarbons (NOAA). Note: This objective will be discussed fully in the final report on this four-year project--due September 1996.

D. To determine recovery in levels of petroleum hydrocarbons in mussels and underlying sediments in oiled mussel beds along the Kenai and Alaska Peninsulas. (National Park Service)

This portion of the study consists of analysis of 1992 and 1993 data and is presented by Irvine and Cusick (1995).

METHODS

Site Selection

Twelve oiled mussel beds at five sites in PWS were selected to be cleaned from the 70 beds that had been sampled by this project in 1992 and 1993 (Fig. 1). Primary criteria for selection were continuing high levels of hydrocarbons in sediments (above 10,000 μg/g total petroleum hydrocarbons (TPH) wet weight) underlying fairly dense mussel beds. Total polynuclear aromatic hydrocarbons in mussels in candidate beds ranged from 0.2 to 8.3 ug/g dry weight. Sampling in April and May 1994 confirmed continuing high levels of TPH (2,000 to 18,000 ug/g) in bed sediments and identified potential nearby replacement (donor) sediments. Other selection factors were, bed size, a substrate that could be excavated, and a suitable area for dispersal of oiled sediments. Several beds that were among the most contaminated in 1992 and 1993 (e. g. Foul Bay and Herring Bay islet) were not cleaned because the sites were not physically suitable; additionally several small beds at selected sites were not cleaned and were monitored to compare hydrocarbon levels with levels in cleaned beds.

Selected beds, ranging in size from 9 to 35 square meters, were small enough so that they could be staked, mapped, and excavated during one low tide window (approximately four hours) and donor sediments and mussels could be replaced during the next low tide. Donor sediments had low TPH concentrations (mean = 68 ug/g) and grain size similar to the bed sediments and were within 50 m of beds to be restored. Suitable disposal areas were least 25 m distant from candidate beds and other concentrations of biota, were in the high intertidal, and were generally exposed to higher wave energy than the beds. .

Restoration

Areas within the beds to be restored were staked, measured, and mapped. (Appendix I). We removed the oiled mussel layer and underlying oiled sediments during a low tide window (approximately four hours). Mussels and sediments attached to byssal threads were carefully removed from beds with shovels or trowels, carried in five gallon buckets to sorbent pads in the intertidal adjacent the bed. Care was taken to not break byssal threads holding mussels to each other and to the substrate to provide more stability when mussels were replaced in the bed. Oiled sediments under the mussels were removed to depths of up to 12 cm. Excavation depths varied depending on depth of oil penetration and substrate (Table 1). In some beds where we could not remove all oiled sediment we hoped that the clean replacement material on top of the contaminated sediments would substantially reduce exposure of mussels from that source. After removal, oiled sediments were carried in buckets to sorbent pads in the disposal area. A total of

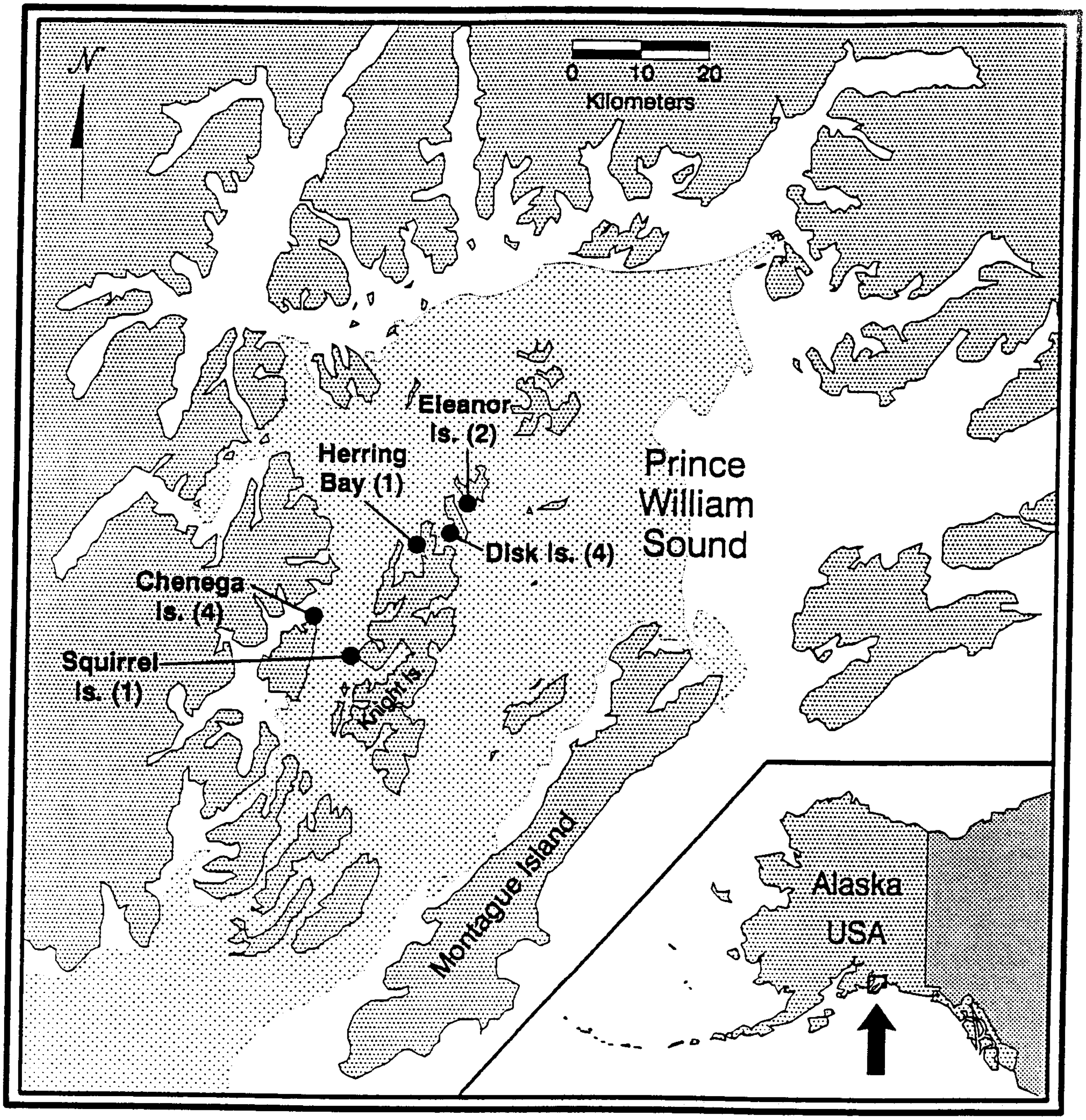

Figure 1. Mussel beds in PWS where oiled sediments were removed and replaced with clean sediments and mussels replaced. Numbers in parentheses indicate the number of beds at each site that were restored. Shaded area indicates EVOS impact area.

Table 1. Area, mean depths, volume, and weight (metric tons) of excavated sediments in PWS mussel beds restored in 1994. Bed designation incorporates beach segment numbers used by the EVOS Interagency Shoreline Cleanup Committee.

Location	Bed	Area m^2	Mean Depth m	Volume m^3	Weight MT
Chenega Island	CH010B-2AL	19.70	0.11	2.23	3.92
Chenega Island	CH010B-2AR	19.71	0.11	2.11	3.71
Chenega Island	CH010B-2B	8.93	0.10	0.86	1.52
Chenega Island	CH010B-2C	9.07	0.11	0.95	1.68
Disk Island	DI067A-1	18.60	0.10	1.86	3.27
Disk Island	DI067A-2AL	26.88	0.09	2.28	4.02
Disk Island	DI067A-2AR	35.04	0.07	2.45	4.32
Disk Island	DI067A-2B	16.12	0.06	0.89	1.56
Eleanor Island	EL011A-2B	13.58	0.11	1.49	2.63
Eleanor Island	EL011A-2C	13.95	0.10	1.44	2.53
Herring Bay	KN113B	9.24	0.09	0.85	1.50
Squirrel Island	SL001D-2	17.18	0.09	1.60	2.81
Total		208.00	19.01		33.47

19.01 m^3 of sediment weighing an estimated 33 metric tons was removed and dispersed. The subsequent high tide flushed oil from the surface of the excavation, from removed sediments, and from the mussels. Sorbent boom and pads were placed in the lower intertidal to adsorb oil as it washed from mussels and oily sediments. Oiled sorbent material was bagged and removed from the site.

At the next low tide, the excavation was filled with clean replacement sediments and the mussels were replaced as evenly as possible. Restored beds were left slightly higher than the uncleaned parts of the bed to allow for settling of the sediments. Dispersed sediments were removed from sorbent pads in the disposal area and raked to expose new surfaces to tidal washing. At all restored beds revisited, mussels had reattached to other mussels and the replaced substrate after one high tide. Paths to sediment dispersal, mussel clean up, and donor sediment areas avoided uncleaned areas of the beds to reduce impact on the beds.

Cleaning and restoration was done by a crew of eleven from Chenega Village under the direction of ADEC (six persons/cruise). Skiffs were used to transport donor sediments at the Eleanor Island site where there were no suitable sediments within practical walking distance. A chartered vessel, Pacific Star, provided all support (including housing) to the crew during the two cleanup/restoration cruises which occurred in late July and early August.

<u>Sampling</u>

In April and May 1994, we sampled sediments at two depths (0-2 cm and 4-7 cm) at four spots within each candidate bed to verify high TPH levels in sediments, to delineate areas that should be cleaned, to determine excavation depths, and to provide a baseline to evaluate effectiveness of cleaning. In spot sampling, samples are not pooled across the area sampled, rather each sample represents hydrocarbon concentrations at a specific spot.

At most beds, sediment samples were taken before excavation in the areas of the bed that were to be restored. Samples were also taken at the surface of the excavation immediately after excavation and of excavated sediments in the disposal area after one or more tides. Mussels and donor sediments were sampled after placement in the beds and mussel densities were estimated by counting live mussels in two quarters of a .25 m x .25 m quadrat at six random spots in the bed. Mussels on adjacent bedrock were also sampled for hydrocarbons; not on contaminated sediments, these mussels are generally much cleaner than mussels from the beds (Harris et al. In press); increased hydrocarbon levels in these mussels would indicate short-term increased oiling resulting from the cleaning.

In mid August, mussel, bed surface sediment, and dispersed sediment samples were collected at all beds, except at the Knight Island 113B site where dispersed sediments had been completely washed away. Mussel densities were determined and mussel samples in the bed and from bedrock were collected. Pooled sampling methods were adapted from protocol developed previously by Auke Bay Laboratory (ABL) (Karinen et al. 1993, Babcock et al. 1994, In press).

At six to eight spots within the area to be sampled, triplicate pooled samples of 15-20 mussels were collected and placed in three hydrocarbon-free jars. After mussels were removed, triplicate pooled samples of sediment were collected (0-2 cm deep) by scooping sediment from each exposed location with a hydrocarbon-free stainless steel spoon into each of three 118-ml, hydrocarbon-free glass jars. All samples were immediately cooled, and frozen within 2-4 h.

Chemistry

Sediment samples were analyzed by ultraviolet fluorescence (Babcock et al. 1994). Data are reported as $\mu g/g$ wet weight total petroleum hydrocarbon (TPH). Selected sediments and all mussels were analyzed by gas chromatography/mass spectroscopy (GC/MS) (Babcock et al. 1994). Units used in this paper are $\mu g/g$ dry weight total polynuclear aromatic hydrocarbons (TPAH), which represents the sum of all measured aromatic hydrocarbons except perylene (produced by biogenic sources). All data have an N of three unless otherwise noted.

RESULTS

Sediments

Donor sediments in mid August were cleaner than the sediments they had replaced (Table 2). Before excavation, surface sediment hydrocarbon levels ranged from 18,077 ug/g to 2,000 ug/g TPH; in mid August surface sediments (donors) ranged from 71 ug/g to 16,767 ug/g TPH. In 7 out of 12 beds, TPH levels were more than 90% lower in donor sediments than original sediments; 3 out of 12 were 80 to 90% lower. Before placement in the bed, TPH concentrations in donor sediments ranged from 0 to 170 ug/g. In some beds, donors rapidly picked up hydrocarbons. Hydrocarbon levels in donor sediments in the four Disk Island beds were over 1000 ug/g one high tide after mussel replacement. Increases in other beds were more gradual and varied, but all donors showed increased TPH concentrations by mid August.

Original sediments lost hydrocarbons as soon as they were exposed to tidal washing. In the disposal area (Table 2). Hydrocarbon levels in dispersed sediments decreased by more than 30% in most beds after one or two high tides and by more than 50% in mid August. In one treated bed, sediment on the surface of the excavation lost 70% of its TPH with one tidal washing.

Mussels

All mussel samples have been analyzed on schedule, but filtered data is not yet available from the database. This data as well as GC/MS analysis of selected sediments will be presented in this project's final report. These analyses will enable the comparison of oil in samples to EVO and to examine the weathering that occurs in dispersed sediments. Mussel densities decreased in 7 out of 12 beds between replacement and mid August; apparent decreases ranged from 9 to 48%.

Table 2. Mean concentrations of total petroleum hydrocarbons (ug/g wet weight of sample) in sediments from restored mussel beds in PWS, Alaska, 1994. Bed designations incorporated beach segment numbers assigned by *the* EVOS Interagency Shoreline Cleanup Committee. Bed sediments are associated with restored beds. Dispersed sediments are those sediments removed from the bed and taken to a dispersal area. N = number of samples used to calculate the mean in the preceding column. Donor sediments are clean sediments that replaced original oiled sediments in the beds. Donor "0" sediments are sampled before placement in the bed. Donor "end" are those same sediments sampled 10 to 29 days after restoration. Sampling depths are 0-2 cm except for the original dispersed sediments, where concentrations are the mean concentrations of both shallow (0-2 cm) and deep (4-7 cm) original sediments to approximate concentrations in the newly excavated sediment. %> = the relative decrease in total hydrocarbon concentrations from restoration to mid August 1994 (end).

		Bed Sediments							Dispersed Sediments			
Location	Bed	Original	N	Donor 0	N	Donor End	N	%>	Original	End	N	%>
Chenega Island	CH010B-2AL	14584	9	10	3	1169	3	92	9961	2263	3	77
Chenega Island	CH010B-2AR	9397	9	10	3	911	3	90	9961	4933	3	50
Chenega Island	CH010B-2B	18077	4	10	3	16767	3	7	12745	1236	3	90
Chenega Island	CH010B-2C	8150	4	10	3	2262	3	72		3785	3	
Disk Island	DI067A-1	1615	1	170	1	181	3	89	2916	1924	3	34
Disk Island	DI067A-2AL	7808	4	158	1	748	3	90	5820	2343	3	60
Disk Island	DI067A-2AR	7808	4	158	1	1573	3	80	5820	2343	3	60
Disk Island	DI067A-2B	7808	4	158	1	1423	3	82	5820	2343	3	60
Eleanor Island	EL011A-2B	2673	3	56	2	198	3	93	3521	2598	3	26
Eleanor Island	EL011A-2C	2226	3	56	2	71	3	97	3521	2598	3	26
Herring Bay	KN113B	17710	4	26	1	1761	3	90				
Squirrel Island	SL001D-2	11555	1	0	1	48	3	100	8252	386	3	95

DISCUSSION

The criteria to be met in evaluating the effectiveness of bed-wide cleaning are reduced TPAH levels in mussels and stable mussel density, ensuring a less contaminated and stable food supply for higher consumers. Based on short term TPH and mussel density data, this technique looks encouraging because it t has reduced bed hydrocarbons while retaining the integrity of the mussel beds.

However, a more complete picture of the effectiveness of this technique must await analysis of 1995 data. Because restoration was completed fairly late in the summer, end of season monitoring occurred only a week after cleaning in some cases. Mussels collected in mid August could have increased TPAH levels due to the increased amount of mobile oil available for a short time while oiled sediments were being exposed and tidally washed. Since the half life of hydrocarbons in tissue is approximately 3 to 20 days (Fossato and Canzonier, 1976) and it may take more than 90 d for mussels to reach equilibrium with surrounding seawater (Smith and Burns, 1978), concentrations in mussels in mid August will be highly varied. Proportions (relative to TPAH) of individual hydrocarbons with longer half lives could be expected to be higher than less persistent compounds. Beds cleaned in July should be closer to equilibrium and should show relatively lower TPAH levels and perhaps differing proportions of individual PAHs to TPAH than those cleaned in August. This situation provides an opportunity for *in situ* study of depuration. In general, the relative contamination of mussels and donor sediments can not be expected to show the relationship found in undisturbed beds: mussel TPAH is generally 1% of surface sediment TPAH (Harris et al., In press) until the bed has reached equilibrium.

Existing bed structure was unavoidably changed by the restoration even though donor sediments were generally similar physically to the oiled sediments they replaced. The fine bed sediments that had been produced by mussels themselves were largely washed away by tidal and manual washing of the mussels, and could not be replaced. Other fauna originally associated with the beds, (e.g. infaunal ribbon worms and littorine snails) were probably dispersed with oiled sediments or washed into the lower intertidal. Although replaced mussels byssaled down during the subsequent high tide, the overall stabilizing effect of the mussel layer was probably reduced for a short time, which may have made mussels more vulnerable to predation, but would also have allowed continued tidal removal of oil from the bed..

CONCLUSIONS

Manual cleaning of selected oiled mussel beds appears to be logistically feasible and effective for reducing hydrocarbon levels in bed sediments. A more comprehensive evaluation will be possible after 1995 sampling and data analysis.

ACKNOWLEDGMENTS

Special thanks to Charles Selanoff Jr., Clint Gregorioff, Sheri Boyles, Tom Sherman, Richard Kompkoff Jr., Donald Kompkoff Jr., Larry Evanoff, Janice Balluta, Pete Kompkoff Jr., Vern Totemoff, and Darryl Totemoff of the Chenega Village and to Karen Klinge of the U.S. Forest Service who moved 66 MT of sediment. Thanks to ABL's staff, Jeffrey Short, Marie Larsen, Larry Holland and Josefina Lunasin for consistently producing quality analytical data and to Christine Brodersen for producing high quality graphics.

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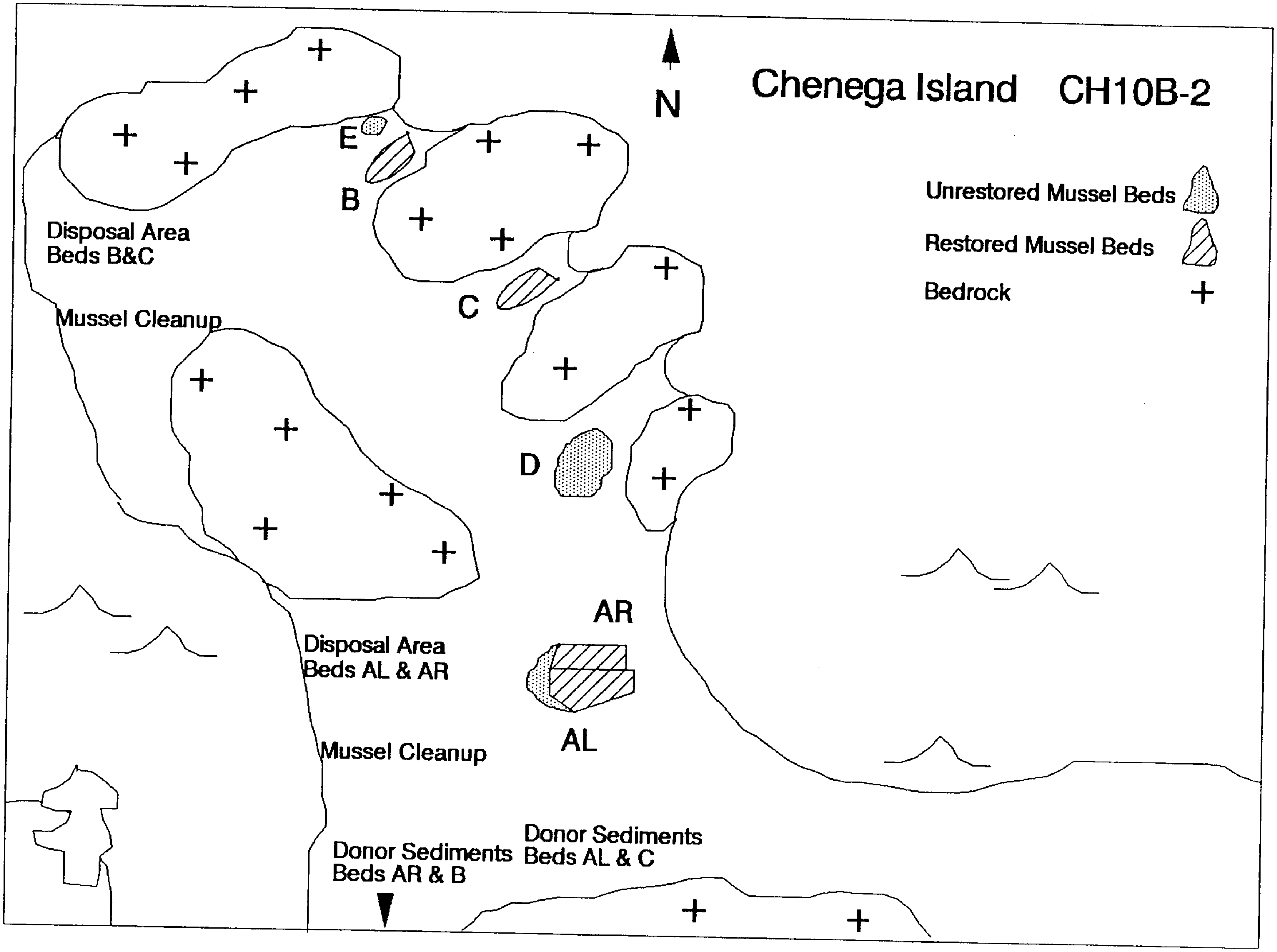
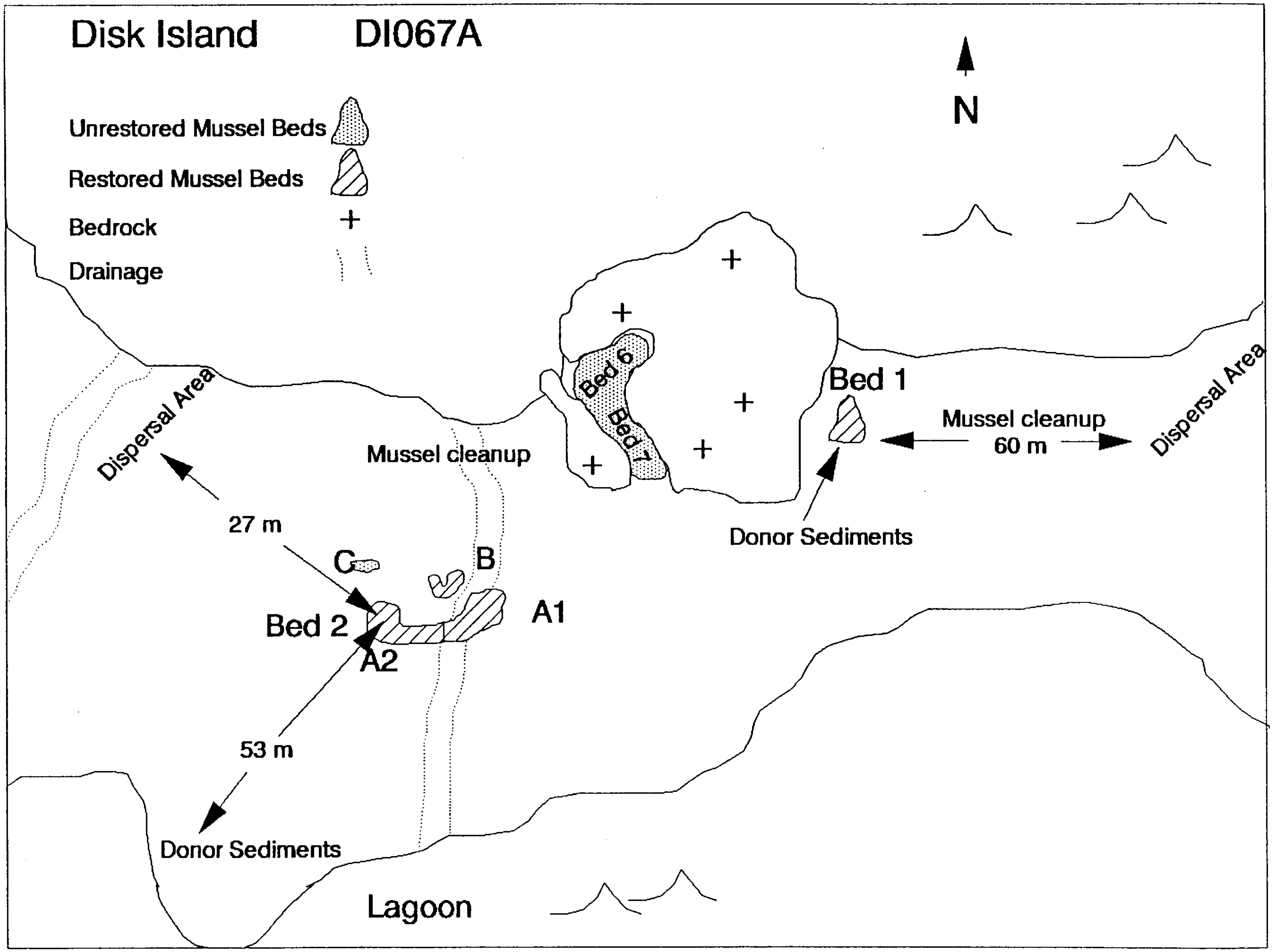
APPENDIX I

Diagrams of Restored Beds

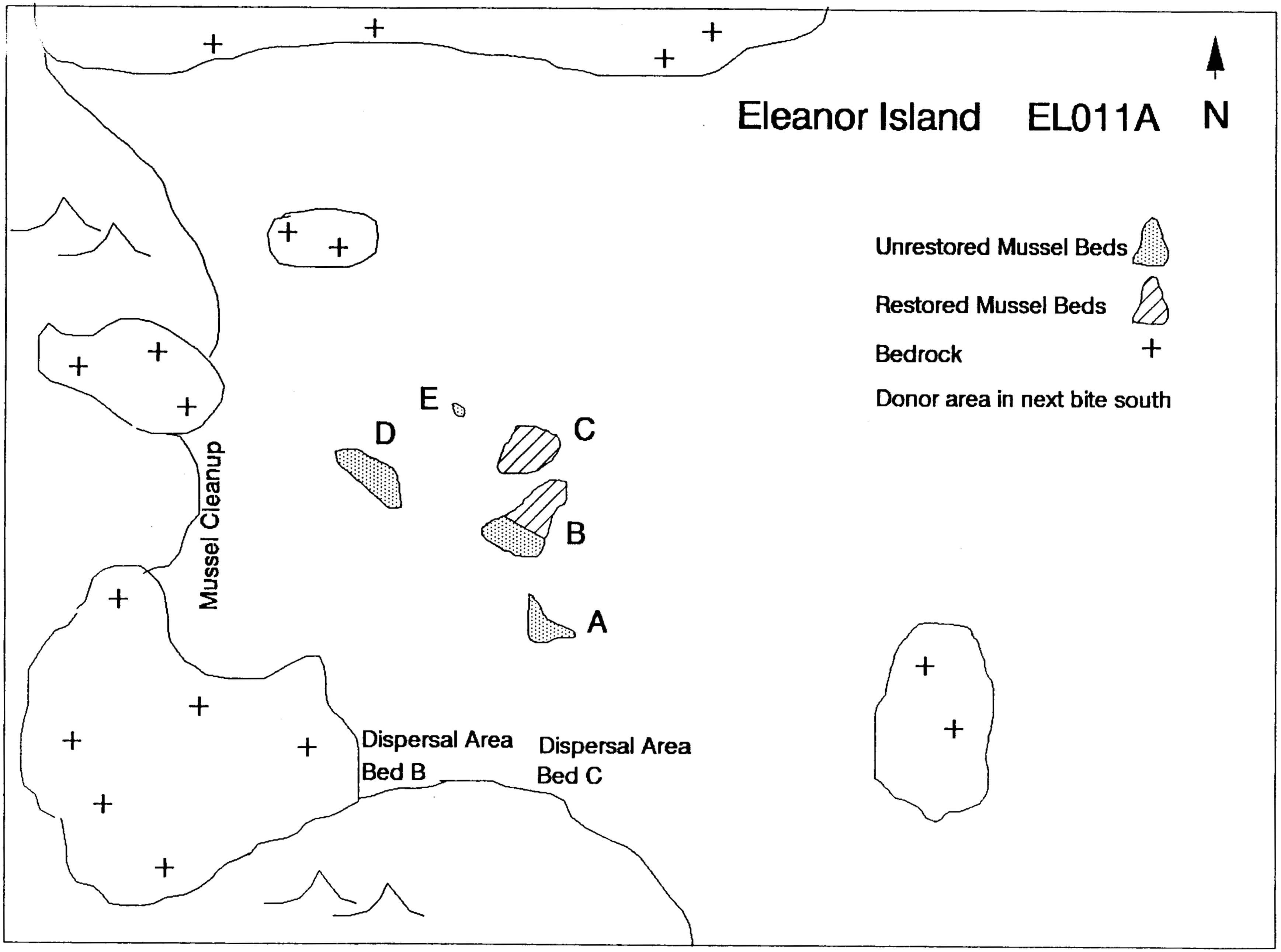
The five figures contained in this appendix depict the relationships of the oiled mussel beds that were restored in 1994 to sediment dispersal areas, donor sediments, and mussel cleanup areas at each site. Where there is more than one bed at a site, beds are designated A, B, etc; where beds were divided into smaller units, these are designated L (Left) vs R (right) or 1 vs 2 (e.g. CH010B2-AL). Please note drawings are not to scale; bed areas are given in Table 1.

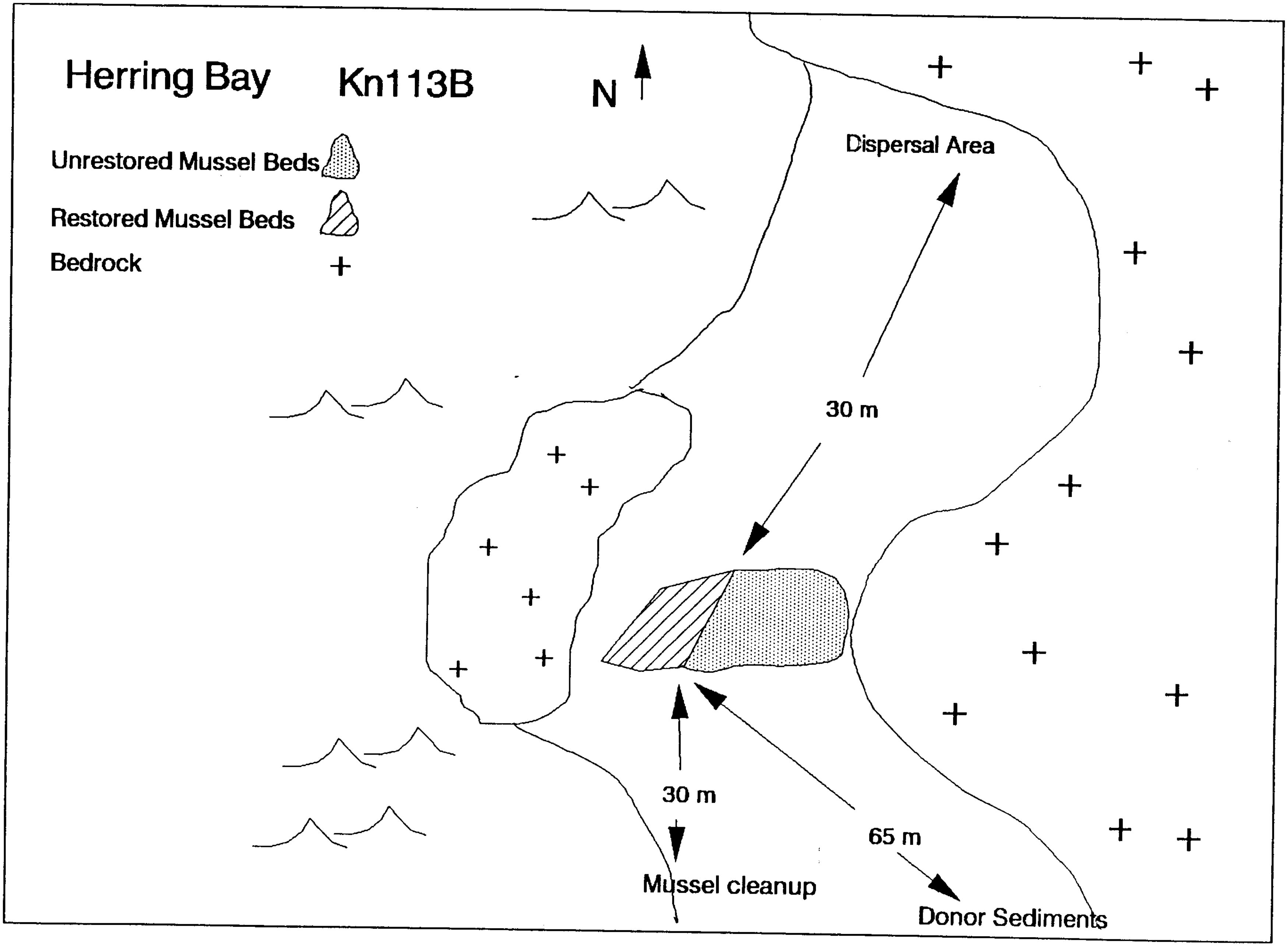


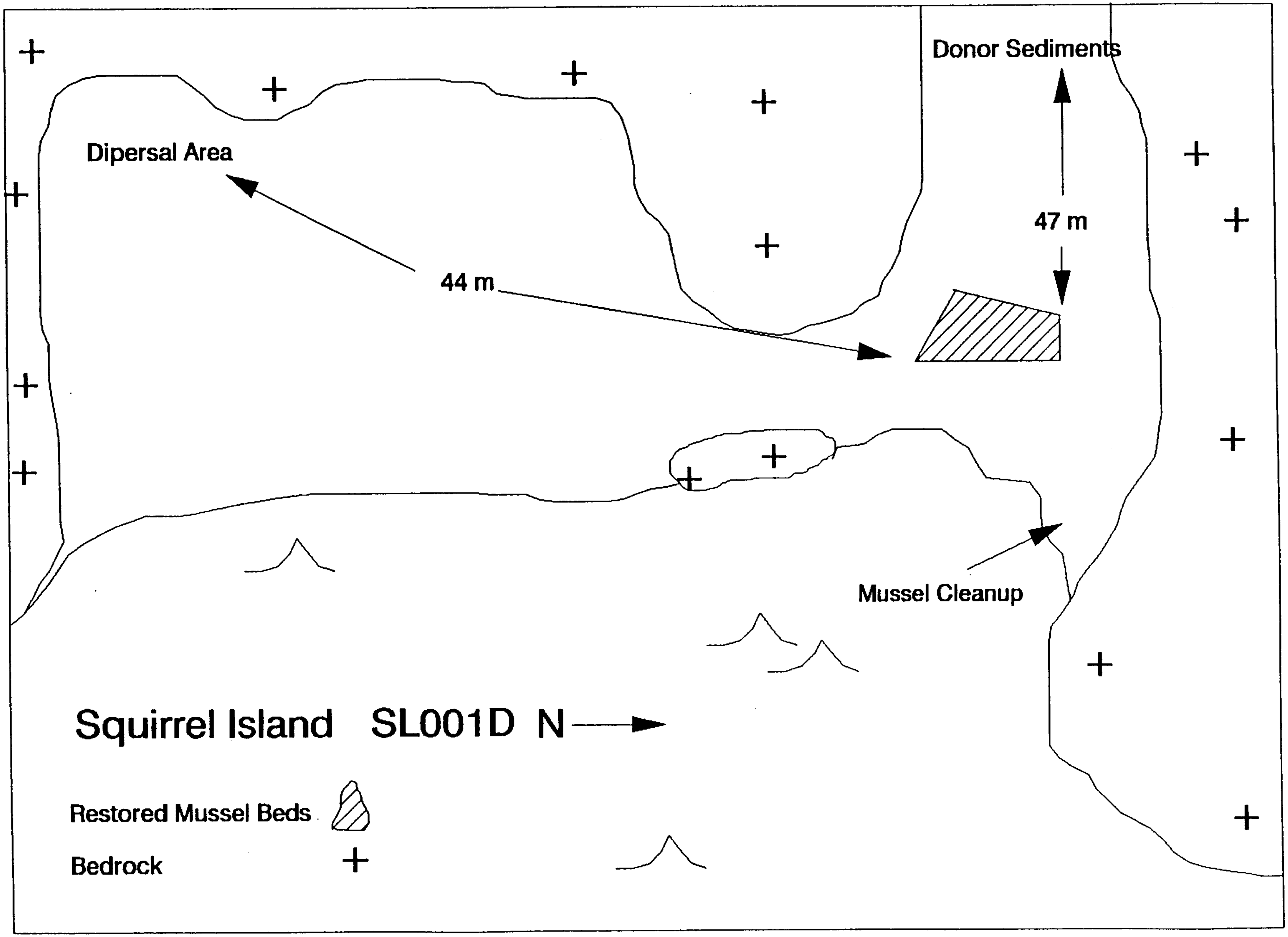
Chenega Island CH10B-2
N
Unrestored Mussel Beds
Restored Mussel Beds
Bedrock
E
B
C
D
AR
AL
Disposal Area
Beds B&C
Mussel Cleanup
Disposal Area
Beds AL & AR
Mussel Cleanup
Donor Sediments
Beds AR & B
Donor Sediments
Beds AL & C



Disk Island
DI067A
Unrestored Mussel Beds
Restored Mussel Beds
Bedrock
Drainage
N
Bed 6
Bed 7
Bed 1
Mussel cleanup
60 m
Dispersal Area
Donor Sediments
Dispersal Area
Mussel cleanup
27 m
C
B
A1
Bed 2
A2
53 m
Donor Sediments
Lagoon


Eleanor Island EL011A
N
Unrestored Mussel Beds
Restored Mussel Beds
Bedrock
Donor area in next bite south
E
D
C
B
A
Mussel Cleanup
Dispersal Area
Bed B
Dispersal Area
Bed C


Herring Bay
Kn113B
N
Unrestored Mussel Beds
Restored Mussel Beds
Bedrock
Dispersal Area
30 m
30 m
65 m
Mussel cleanup
Donor Sediments


Donor Sediments
Dipersal Area
47 m
44 m
Mussel Cleanup
Squirrel Island SL001D N
Restored Mussel Beds
Bedrock