2004 Monitoring Report for Sediment Remediation in Ward Cove, Alaska

Prepared for

Ketchikan Pulp Company
Ketchikan, Alaska

Exponent®

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Prepared for

Ketchikan Pulp Company
9487 North Tongass Highway
P.O. Box 6600
Ketchikan, AK 99901

Prepared by

Exponent
15375 SE 30th Place, Suite 250
Bellevue, WA 98007

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Acronyms and Abbreviations

ANOVA	analysis of variance
AOC	area of concern
CoC	chemical of concern
EPA	U.S. Environmental Protection Agency
KPC	Ketchikan Pulp Company
MLLW	mean lower low water
MDRD	minimum detectable relative difference
MDS	multidimensional scaling
RAO	remedial action objective
RI/FS	remedial investigation and feasibility study
ROD	record of decision
TLP	thin layer placement
TOC	total organic carbon
WCSQV	Ward Cove sediment quality values

Executive Summary

This monitoring report has been prepared for Ketchikan Pulp Company in compliance with the CERCLA consent decree (November 2000) and the *Long-Term Monitoring and Reporting Plan for Sediment Remediation in Ward Cove* (September 2001). A remedial investigation and feasibility study (RI/FS) was conducted in Ward Cove between 1996 and 2000 to delineate the area of concern (AOC) in the cove and to evaluate potential remedial alternatives. Remedial action within the 80-acre AOC identified in the RI/FS was performed between October 2000 and February 2001. Enhanced natural recovery using thin layer placement (TLP) with 6–12 in. of clean sand was successfully implemented at approximately 28 acres within Ward Cove. This document presents the results of the 2004 monitoring event, which is the first monitoring event to be conducted since remediation occurred.

The U.S. Environmental Protection Agency (EPA) identified remedial action objectives (RAOs) for Ward Cove in the record of decision. Specifically, the response action was intended to:

- Reduce toxicity of surface sediments
- Enhance recolonization of surface sediment to support healthy marine benthic macroinvertebrate communities with multiple taxonomic groups.

The monitoring program was designed to evaluate progress made in achieving sediment RAOs following completion of remedial activities in Ward Cove. The program was designed to evaluate three major indicators of sediment quality: 1) sediment chemistry, 2) sediment toxicity, and 3) benthic macroinvertebrate communities. The 80-acre AOC was divided into seven benthic strata based on water depth and the kind of remedial action taken: natural recovery (four strata) or TLP (three strata). In addition, two reference area strata were designated within the cove, based on water depth and distance from known sources of chemical contamination.

Monitoring data were evaluated using two types of analyses. Each is intended to address different aspects of progress toward recovery of the benthic macroinvertebrate communities:

- **Comparison of TLP and Natural Recovery Areas to Reference Areas—** Allows definitive decisions to be made regarding recovery in TLP and natural recovery areas
- **Evaluation of Temporal Trends in TLP and Natural Recovery Areas—** Allows progress toward recovery to be evaluated.

The results of the 2004 monitoring event showed that concentrations of both chemicals of concern (CoCs) (i.e., ammonia and 4-methylphenol) were generally low in all TLP areas, as well as in the shallow natural recovery area with thin organic deposits (Stratum 2c). This pattern indicates that the TLP was successful in reducing the concentrations of these CoCs and that natural recovery has occurred in one of the shallow natural recovery areas. The low concentrations of both CoCs found in the TLP areas also indicate that the clean sand amendment is not being noticeably affected by upward migration of the CoCs from the underlying native sediments.

With respect to sediment toxicity, amphipod survival was very high (i.e., 93–96 percent) at most stations sampled in the three TLP areas (Strata 1, 2a, and 3a) and in the shallow natural recovery area with thin organic deposits (Stratum 2c), and mean survival in all four areas did not differ significantly ($P>0.05$) from the reference value. Amphipod survival was lower at most stations sampled in the moderately deep and deep natural recovery areas (Strata 3b and 4, respectively, and mean survival in the two areas differed significantly ($P\leq0.05$) from the reference value. Although mean survival in the shallow natural recovery area with thick organic deposits (Stratum 2b) was relatively high (75 percent), the variability of the data precluded conclusions based on statistical comparisons. With respect to temporal trends evaluated at 13 representative stations in the AOC, amphipod survival in 2004 had increased at most stations compared to the results found during the RI/FS in 1996–1997.

With respect to benthic macroinvertebrate communities, results of statistical comparisons of community metrics indicated that with the exception of the shallow natural recovery area with thick organic deposits, few differences were found between the remediated areas in the Ward Cove AOC and the reference areas. The patterns based on key benthic macroinvertebrate species indicated that benthic communities in the TLP areas (Strata 1, 2a, and 3a) and the shallow natural recovery area with thin organic deposits (Stratum 2c) were characterized primarily by species commonly found in areas where organic enrichment is low or declining. By contrast, communities in the other three natural recovery areas were characterized primarily by species commonly found in organically enriched areas. The communities in the two reference areas were also characterized primarily by species commonly found in organically enriched areas.

On a cove-wide basis, qualitative comparisons with pre-remediation benthic community data collected in 1992 show that communities in 2004 comprised more than twice as many taxa, with individuals distributed more evenly among the taxa. Multivariate analysis of the benthic community data collected in 2004 documented two distinct clusters or groups of benthic strata, each associated with one of the two reference area strata. The benthic groups generally reflected remediation category rather than water depth, with all TLP strata being found in one group and three of the four natural recovery areas found in the other group. These results indicated that TLP in the cove resulted in benthic communities that were similar to the communities in the shallow reference area and the shallow natural recovery area with thin organic deposits (Stratum 2c). Finally, comparisons of taxa richness values at individual stations within each TLP and natural recovery stratum with reference values indicated that communities comprising multiple taxonomic groups were present at most stations in the three TLP strata and the shallow natural recovery area with thin organic deposits.

In summary, the TLP was successful in eliminating sediment toxicity and stimulating colonization of benthic macroinvertebrate species such that diverse communities comprising multiple taxa now inhabit most parts of the TLP areas, and exhibit many similarities with the community found in the shallow reference area. By contrast, benthic communities in most of the natural recovery areas have not progressed as far along the recovery spectrum as those in the

TLP areas. Sediment toxicity is also found at some locations in the natural recovery areas. The exception is the shallow natural recovery area with thin organic deposits, in which sediments are not toxic and benthic communities exhibit many characteristics similar to those in the TLP and shallow reference areas. Given that the three TLP areas and the shallow natural recovery area with thin organic deposits are generally free from chemical contamination and sediment toxicity, there is no reason to suspect that they will not continue to support diverse benthic communities in the future.

Based on the results of the 2004 monitoring event, the following recommendations can be made:

- Monitoring is no longer necessary for the shallow natural recovery area with thin organic deposits (Stratum 2c), because the RAOs have been achieved for this area. That is, sediment toxicity has been reduced and benthic recolonization has been enhanced such that this area now supports healthy benthic communities with multiple taxonomic groups.

- Monitoring should continue for the three TLP areas (Strata 1, 2a, and 3a). The 2004 results demonstrate that RAOs have been achieved for these areas; however, additional data are needed to confirm that reduced toxicity and a healthy benthic community with multiple taxonomic groups can be maintained over time. If the 2007 monitoring results (sediment chemistry, sediment toxicity tests, and benthic community analyses) are consistent with or better than the 2004 data, monitoring of benthic communities, and potentially sediment chemistry and toxicity, in the TLP areas should be discontinued.

- Monitoring should continue in the three remaining natural recovery areas (Strata 2b, 3b, and 4) primarily because sediment toxicity exists in two of the areas (Strata 3b and 4) and multiple taxonomic groups have not yet been observed in these areas.

- Station 67 should be moved so that it is located within the actual TLP area of Stratum 1.

- No changes are recommended for depth strata classifications.

- Based on evaluations of the physical/chemical sediment characteristics, sediment toxicity results, and benthic macroinvertebrate communities found in the two reference areas (Strata 5a and 5b) during the 2004 monitoring event, it was concluded that both strata are representative of the large-scale background conditions found in Ward Cove. It therefore is recommended that Strata 5a and 5b continue to be used as reference areas during future monitoring events.

- Although it is recommended that Strata 5a and 5b continue to be used as reference areas, seven replicate samples should be analyzed for sediment chemistry, sediment toxicity, and benthic communities in each stratum in the future, to enhance the probability that all five replicates used for statistical comparisons with AOC strata will meet all reference area selection criteria.

- *Eohaustorius estuarius* should continue to be used as the sediment toxicity test species because it proved to be a highly responsive test during the 2004 monitoring event, with survival values ranging from 0 to 100 percent.
- The initial draft report should be due to EPA in January of the year following the July sampling, to allow sufficient time for taxonomic analysis, in addition to data analysis and report preparation. All additional deliverables to EPA should be due 30 days after receipt of EPA comments on previous deliverables.

1 Introduction

This monitoring report has been prepared for Ketchikan Pulp Company (KPC), the prior owner of the KPC pulp mill and related operations that were formerly located on the shoreline of Ward Cove, Ketchikan, Alaska (Figure 1). The report addresses the 80-acre area of concern (AOC) in the Marine Operable Unit located offshore from the former KPC facility (Figure 1). The AOC was identified in the detailed technical studies report (Exponent 1999) that was prepared as part of the Ward Cove remedial investigation and feasibility study (RI/FS). The specifications of the long-term monitoring program for the Ward Cove AOC were identified in the monitoring and reporting plan (Exponent 2001).

Remedial action within the Ward Cove AOC was performed between October 2000 and February 2001. Three general categories of remedial action were specified in the U.S. Environmental Protection Agency's (EPA) record of decision (ROD) (U.S. EPA 2000a): thin layer placement (TLP) (estimated at 27 acres maximum), mounding (estimated at 1 acre minimum), and natural recovery (approximately 52 acres). Enhanced natural recovery (as defined in EPA guidance documents) using TLP with 6–12 in. of clean sand was successfully implemented at all locations, including the 1 acre originally designated for mounding. The remaining 52 acres were subjected to monitored natural recovery. Dredging was performed adjacent to the main dock and near the barge access area to address access issues and future use of the docking area. Details of sediment remediation efforts are described in the remedial action work plan, the final construction report, and the final water quality monitoring report (Foster Wheeler 2000, 2001a,b).

This document presents the results of the 2004 monitoring study, which is the first such study to be conducted since remediation occurred in 2000/2001. Field sampling for the 2004 monitoring study was conducted in July 2004. The contents of this document include an initial overview of the monitoring objectives, monitoring approach, and program design for the overall monitoring program, of which the 2004 sampling was the initial monitoring event. The results of the 2004 monitoring event are then discussed, including all departures from the design that occurred in 2004, a summary of the 2004 field sampling activities, and the results of the analysis and interpretation of the data collected during 2004. All data collected in 2004 are presented in Appendix A of this document, and the QA/QC reports for the sediment chemistry, sediment toxicity, and benthic macroinvertebrate evaluations are presented in Appendix B. Details of the statistical analyses discussed in this report are provided in Appendix C.

2 Summary of the Overall Monitoring Program

2.1 Monitoring Objectives

Remedial action objectives (RAOs) provide a general description of what the cleanup action will accomplish and represent EPA's goals for addressing risk at the site. EPA identified RAOs for Ward Cove in the ROD (U.S. EPA 2000a) as the elimination or minimization of the ecological risks associated with the toxicity of Ward Cove sediments to benthic organisms. The response action is intended to:

- Reduce toxicity of surface sediments
- Enhance recolonization of surface sediment to support healthy marine benthic macroinvertebrate communities with multiple taxonomic groups.

The monitoring program was designed to evaluate progress made in achieving sediment RAOs following completion of remedial activities in Ward Cove.

The primary objectives of the overall Ward Cove monitoring program are to:

- Compare sediment toxicity in TLP and natural recovery areas in the AOC with sediment toxicity in reference areas located elsewhere in the cove
- Compare the characteristics of benthic communities in TLP and natural recovery areas in the AOC with the characteristics of communities in reference areas located elsewhere in the cove
- Evaluate temporal trends in sediment toxicity in the TLP and natural recovery areas of the AOC
- Evaluate temporal trends in the characteristics of benthic macroinvertebrate communities found in the TLP and natural recovery areas of the AOC (this comparison was not made in 2004 because benthic communities were not evaluated in the RI/FS)
- Evaluate chemical concentrations and their relationship to sediment toxicity and benthic community structure.

The information collected to satisfy the objectives described above will be used to provide an assessment of how sediment toxicity and benthic communities in TLP and natural recovery areas are changing over time, as well as how similar the evolving communities are to those of reference areas at various points in time. This information will be used to determine the degree to which sediment recovery is occurring.

2.2 Monitoring Approach

The Ward Cove monitoring program was designed to evaluate three major indicators of sediment quality: 1) sediment chemistry, 2) sediment toxicity, and 3) benthic macroinvertebrate communities. These indicators will be evaluated on sediment samples representing the surface (i.e., 0–10 cm horizon) of sediments. Sediment chemistry and toxicity were assessed during the RI/FS and therefore these monitoring components can be compared to pre-remedial conditions as well as to reference areas. Temporal trends in sediment chemistry, sediment toxicity, and benthic macroinvertebrate communities will be evaluated from multiple monitoring events (i.e., 2004, 2007, and 2010 or until RAOs are achieved). Analytical methods for chemistry and toxicity testing will be the same as those used in the RI/FS (Exponent 1999). As noted previously, benthic community measurements in 2004 will be compared only to reference area conditions, because these communities were not evaluated in the RI/FS.

The specific components of sediment quality used for the Ward Cove monitoring program are as follows:

- **Sediment Chemistry—**Each surface sediment sample will be analyzed for ammonia and 4-methylphenol. These analytes were identified as chemicals of concern (CoCs) in the RI/FS and ROD and will assist in the interpretation of sediment toxicity data. Sediments will also be analyzed for grain size distribution, total organic carbon (TOC), and total solids, because these three variables can influence the composition of benthic communities.

- **Sediment Toxicity—**The potential toxicity of each surface sediment sample will be evaluated using a standardized 10-day amphipod test (PSEP 1995; U.S. EPA 1994). Although the test species was originally specified as the amphipod *Rhepoxynius abronius* in the monitoring plan, in 2004 it was necessary to change the test species to an alternative amphipod, *Eohaustorius estuarius*, because of current uncertainties involved with obtaining adequate numbers of healthy *R. abronius* for testing. This change of test species is discussed in greater detail later in this document.

- **Benthic Macroinvertebrate Communities—**The characteristics of benthic macroinvertebrate communities in various parts of Ward Cove will be evaluated directly by collecting and enumerating the organisms found in surface sediment samples collected from the site.

Sampling of the AOC in Ward Cove will occur in July every third year after completion of the remedial activities (i.e., 2004, 2007, and 2010) until RAOs are achieved, as determined by EPA.

2.3 Monitoring Program Design

The design of the Ward Cove monitoring program builds on different categories of benthic strata, which are based on water depth and on the kind of remedial action taken. Multiple sampling stations will be evaluated within each benthic stratum to estimate average (or mean) conditions in the stratum and to provide a measure of within-stratum variability so that statistical analyses can be conducted. The mean values of monitoring variables (e.g., chemical concentrations, sediment toxicity responses, and benthic community characteristics) within each stratum will then be compared statistically on both a temporal and spatial basis. The temporal evaluations will involve comparisons of monitoring variables for each benthic stratum among different sampling periods, whereas the spatial comparisons will involve comparisons of monitoring variables between each TLP or natural recovery area with conditions in the corresponding reference area during the same sampling period.

An additional kind of quantitative comparison will be made for the sediment toxicity responses, in which results at four representative stations (Stations 8, 9, 13, and 38) will be compared with results obtained in 1996–1997 for the RI/FS. These four stations were selected because the 1996–1997 data at these locations showed exceedances of site-specific sediment quality values for CoCs and exceedances of the sediment quality standard for the *Rhepoxynius abronius* toxicity test. The four monitoring stations will be positioned at the same locations used for the RI/FS. Similar comparisons will not be made for benthic community variables because benthic communities were not evaluated in the RI/FS. In the future, any additional monitoring data on sediment chemistry, sediment toxicity, and benthic macroinvertebrate communities will be compared with the information collected in 2004, as well as earlier years.

Qualitative observations of benthic community characteristics will be made to assess whether the evolving communities are following the classical patterns of colonization and recovery for disturbed benthic habitats described in the RI/FS (Exponent 1999). Those patterns include initial colonization by “pioneering” species, subsequent modification of physical/chemical characteristics, and final colonization by deeper dwelling “equilibrium” species (Rhoads et al. 1977, 1978; Pearson and Rosenberg 1978; Rhoads and Boyer 1982).

The characteristics of benthic communities can be influenced by water depth and sediment character. Therefore, the AOC was subdivided into various benthic strata (Table 1) as follows:

- **Water depth (four strata):** Water depth strata are defined as very shallow areas (<20 ft water depth at mean lower low water [MLLW]), shallow areas (20–70 ft MLLW), moderately deep areas (70–120 ft MLLW), and deep areas (>120 ft MLLW)

- **Remedial action (two strata):** Remedial action strata are defined as either TLP areas or natural recovery areas.

The shallow, natural recovery stratum was further subdivided into an area with thick organic deposits (>5 ft) adjacent to the former pulp mill and an area with more limited organic deposits along the north shore near the mouth of the cove.

Reference areas were located in Ward Cove, but outside the AOC, at depths that correspond to the shallow and moderate strata used for the AOC. Reference areas were also located away from other potential sources of contaminants, and in the vicinity of 1996–1997 RI/FS stations that showed no exceedances of sediment quality values for CoCs and toxicity tests.

3 Methods Used during the 2004 Monitoring Event

3.1 Field Methods

Surface sediment samples (upper 10 cm) were collected from 37 stations along the north shoreline of Ward Cove in the 80–acre AOC (Figure 2), following field procedures described in the field sampling plan (Exponent 2001, Appendix A). In addition, 10 surface sediment samples were collected from two reference areas outside the AOC, but within Ward Cove (i.e., five samples from each reference area). Sampling was conducted in July 2004. Oversight was provided on July 21, 2004, by Karen Keeley, of EPA, and Barry Hogarty, KPC's representative.

Station positioning for all sediment and benthic macroinvertebrate sampling was accomplished using a differential global positioning system. Position data were used in real time to provide navigation information to the vessel operator. The planned station locations, and the actual station locations sampled, were displayed in real time on a monitor, along with an indicator to show the distance from the planned station location. Station location coordinates are provided in Table 2.

At each sampling station, sediment was collected using a 0.06-m^2 stainless steel van Veen grab sampler. For chemical and toxicity analyses at each station, the top 10 cm of sediment in one or more grab samples was transferred to a stainless steel bowl and homogenized until uniform in texture and color. Subsamples were then transferred to appropriate containers and shipped to the laboratories for chemical analysis and sediment toxicity evaluations.

Sediments collected for benthic community analysis were sieved sequentially using mesh sizes of 1.0 and 0.5 mm. However, laboratory taxonomic analyses were conducted only on the organisms retained on the 1.0-mm screen, whereas organisms retained on the 0.5-mm screen were archived for potential future analysis. Retained material was transferred to appropriate containers, fixed with formalin, and organisms retained on the 1.0-mm screen were transferred to the laboratory for taxonomic analysis.

Table 2 provides a summary of the general characteristics of each station sampled in Ward Cove in 2004.

3.2 Laboratory Methods

The methods used to analyze sediment samples for ammonia, 4-methylphenol, grain size distribution, TOC, and total solids were consistent with those used in the RI/FS in 1996–1997 and equivalent to those methods specified in the monitoring plan. Differences in the analytical methods referenced in the monitoring plan versus those used by the laboratory are provided in Appendix B. The use of alternate methods did not affect the quality of the data reported. The analyses were completed as follows:

- **Ammonia:** EPA Method 350.1 (U.S. EPA 1983), a potentiometric procedure for ammonia in water, modified to include sediment extraction with 2M potassium chloride (Plumb 1981)
- **4-Methylphenol:** EPA Method 8270C (U.S. EPA 2004), gas chromatography/mass spectrometry with selected ion monitoring
- **Grain size distribution:** PSEP (1986), wet sieving and pipet analysis for gravel, sand, silt, and clay
- **TOC:** PSEP (1986), sample combustion and infrared detection, with modifications to accommodate the sediment matrix
- **Total solids:** EPA Method 160.3M (U.S. EPA 1983), gravimetric analysis.

The methods used to conduct the 10-day sediment toxicity tests based on *Eohaustorius estuarius* were consistent with those used in the RI/FS and those specified in the monitoring plan for *Rhepoxynius abronius*, which are based on PSEP (1995) and U.S. EPA (1994). Although the test species was originally specified as the amphipod *Rhepoxynius abronius* in the monitoring plan, it was necessary to change the test species in 2004 to an alternative amphipod, *Eohaustorius estuarius*, because of current uncertainties involved with obtaining adequate numbers of healthy *R. abronius* for testing (Keeley 2004, pers. comm.).

As specified in the monitoring plan, a single sample was analyzed in the laboratory for sediment toxicity at all but four of the sampling locations. At this subset of four stations (Stations 8, 9, 13, and 38), five replicate samples at each location were analyzed for sediment toxicity so that the results could be compared statistically with the results obtained at those four stations during the RI/FS.

The methods used for the identification and enumeration of benthic macroinvertebrates collected during the 2004 monitoring event were consistent with the methods specified in the monitoring plan and those recommended by U.S. EPA (1987). Major elements of the benthic analyses were that sediment samples were sorted with a minimum accuracy of 95 percent and that taxonomic identifications were made to the lowest taxonomic level practical by qualified taxonomic experts.

4 Modifications to the Monitoring Plan

The following modifications were made to the sediment sampling strategy described in the field sampling plan (Exponent 2001, Appendix A):

- Because of the current location of a float camp in the western corner of Ward Cove (near the former KPC outfall) (see Figure 2), Stations 77 and 78 were repositioned to the outside edge of the float camp. This change in station location was agreed upon by EPA and KPC.

- Because a permanent log boom (i.e., affixed to the shoreline with cables and anchors) prevented access to reference area Station 96 (Stratum 5a), the station was moved slightly to the west and repositioned on the outside edge of the log boom. This change in station location was agreed to by EPA and KPC.

- At the request of EPA, and with the concurrence of KPC, exploratory sediment grab samples were collected to determine the edge of the clean sand amendment used for the TLP between Stations 67 and 68. The edge of the TLP area was located, and the samples were not retained. It did not appear that material used for the TLP was present at Station 67.

- At the request of KPC, exploratory sediment grab samples were collected to determine the location of the clean sand amendment used for the TLP near Station 72. These samples were not retained. All the sediment observed in these samples consisted of a fairly homogenous mixture of fine-grained sand and silt, much of which appeared to be the clean sand amendment used for the TLP.

- Because of recent concerns regarding the feasibility of obtaining sufficient numbers of healthy *Rhepoxynius abronius* for sediment toxicity testing, the sediment toxicity test species was changed to another amphipod (i.e., *Eohaustorius estuarius*), with EPA's concurrence (Keeley 2004, pers. comm.).

- Differences in the analytical methods referenced in the monitoring plan versus those used by the laboratory are summarized in Table B1-2 in Appendix B1 of this document.

5 Data Analysis and Interpretation

Post-remediation monitoring data were evaluated using two primary types of statistically based analyses, each of which is intended to address different aspects of progress toward recovery of benthic macroinvertebrate communities:

- Comparison of TLP and natural recovery areas to reference areas
- Evaluation of temporal trends in TLP and natural recovery areas.

Comparison to reference areas allows decisions to be made regarding recovery in TLP and natural recovery areas. Evaluations of temporal trends allows the rate of recovery to be evaluated. The evaluation processes are presented schematically in Figure 3. In addition to these statistically based evaluations, several other kinds of qualitative and quantitative evaluations were conducted to further elucidate patterns of recovery, particularly for benthic macroinvertebrate communities.

Reference area comparisons were conducted using both sediment toxicity and benthic community data. Evaluation of temporal trends for benthic community data were not made in a quantitative manner in 2004 because benthic data were not collected in 1996–1997 during the RI/FS. However, qualitative comparisons were made with the limited amount of data collected in Ward Cove in 1992 by EVS (1992). Benthic abundances will be given the greatest weight with regard to conclusions reached regarding recovery, because *in situ* conditions are a better reflection of sediment quality.

The status of recovery was determined using results of the sediment toxicity tests (i.e., amphipod survival), as well as results of various kinds of benthic evaluations. The benthic evaluations included comparisons between remediated and reference areas with respect to the following metrics:

- **Total abundance:** Total number of benthic organisms in each sample
- **Total richness:** Total number of benthic taxa in each sample
- **Swartz' dominance index:** Minimum number of taxa that account for 75 percent of total abundance
- **Major taxa abundance:** Total number of organisms in each major taxon (molluscs, polychaetes, crustaceans, echinoderms, and others)
- **Major taxa richness:** Number of taxa in various major taxonomic groups (molluscs, polychaetes, crustaceans, echinoderms, and others).

Qualitative observations of benthic community characteristics were made to determine whether the communities were recolonizing the TLP and natural recovery areas consistent with the classical patterns identified for disturbed benthic habitats. The identities and relative abundances of key benthic species found in the sediments were compared with literature accounts of life history characteristics to assess the stages of recolonization and the degrees of similarity with communities in the reference areas. In addition to the evaluations of benthic metrics and key benthic species described above, benthic macroinvertebrate communities were evaluated using two kinds of multivariate analysis: classification analysis and multidimensional scaling (MDS). Although these analyses were not specified in the monitoring plan (Exponent 2001), they were included in the current document to provide additional perspectives on the characteristics of benthic macroinvertebrate communities in the cove. The key attribute of the multivariate approaches is that they quantify the similarities among various stations or benthic strata based on the abundances of all of the individual benthic taxa found in the resident communities. They therefore use all of the information provided by the numerous taxa found at each location, rather than combining that information into composite variables or metrics such as total abundance or total taxa richness. Norris and George (1993) concluded that multivariate techniques show greater promise than univariate comparisons for detecting and understanding spatial and temporal trends of benthic macroinvertebrate communities.

Temporal patterns of the characteristics of benthic communities were evaluated qualitatively by comparing information collected at five stations in Ward Cove in 1992 (EVS 1992) with the results of the 2004 monitoring event. The data set collected by EVS (1992) represents the only recent quantitative evaluation of these communities prior to the remedial activities conducted in 2000–2001. This data set can therefore provide an estimate of the degree to which benthic communities in the cove have improved as a result of remedial actions, as well as the degree to which the 2004 communities are achieving the RAO of including multiple taxonomic groups.

A final kind of benthic community evaluation was conducted to directly address the RAO that specifies that these communities comprise multiple taxonomic groups. In this evaluation, the taxa richness of the benthic communities at all stations within each TLP and natural recovery area were compared with the ranges of taxa richness found in the two reference areas. The goal was to provide additional information on the number of stations within each TLP and natural recovery area that exhibited taxa richness values either comparable to or greater than the reference values.

6 Results of the 2004 Monitoring Event

6.1 Sediment Chemistry

As discussed previously, two CoCs (i.e., ammonia and 4-methylphenol) and three conventional analytes (i.e., TOC, percent fines, and total solids) were measured for all sediment samples collected in July 2004 in Ward Cove. Mean values for these CoCs and conventional analytes are provided in Table 3. Data collected during the 2004 monitoring event are provided in Appendix A. A quality assurance review of laboratory procedures and results was conducted by Exponent to ensure that the chemical analyses were consistent with the specifications of the test protocols and that the data are acceptable for use in future stages of the monitoring program. The complete quality assurance report of the data is provided in Appendix B1. The spatial and temporal patterns of these variables are described below.

In addition to descriptions of spatial and temporal patterns, concentrations of ammonia and 4-methyphenol were compared with the site-specific Ward Cove sediment quality values (WCSQVs) that were developed during the RI/FS (Exponent 1999). These comparisons were used to determine whether either of the two CoCs may have been responsible for any observed biological effects at the various AOC stations. Two kinds of WCSQVs were developed: WCSQV(1) and WCSQV(2). The former value is analogous to the Washington State sediment quality standards and the latter value is analogous to the Washington State minimum cleanup standards (Ecology 1995). The WCSQV(1) and WCSQV(2) for ammonia are 110 and 120 mg/kg, respectively, and the corresponding values for 4-methylphenol are 1,300 and 1,700 μg/kg, respectively (Exponent 1999).

Temporal comparisons of the CoCs and sediment conventional variables were evaluated by qualitatively comparing the 2004 results with the results found in 1996–1997 during the RI/FS at the eight stations that were sampled during multiple time periods (Table 4).

6.1.1 Chemicals of Concern

6.1.1.1 Ammonia

Concentrations of ammonia at individual stations in the AOC ranged from 1.4 mg/kg at Station 5 in Stratum 1 to 160 mg/kg at Station 85 in Stratum 4 (Figure 4a). Mean concentrations of ammonia in the seven benthic strata in the AOC ranged from 4.9 to 130 mg/kg (Table 3).

Exceedances of the WCSQV(1) for ammonia were found in four benthic strata: 2b, 3b, 4, and 5b (reference). Within the AOC, one exceedance was found in Stratum 2b (the shallow natural recovery area with thick organic deposits), three exceedances were found in Stratum 3b (the moderately deep natural recovery area), and three exceedances were found in Stratum 4 (the deep natural recovery area). A single exceedance was found in Reference Stratum 5b (the moderately deep reference area) (Figure 4b). All eight exceedances of the WCSQV(1) were also exceedances of the WCSQV(2) for ammonia.

The concentration distributions found in the various benthic strata were as follows:

- **TLP areas:** Ammonia concentrations were low (i.e., <20 mg/kg) at all but one station in the three TLP areas (Strata 1, 2a, and 3a). The only exception was the value of 55 mg/kg found at Station 72 in Stratum 2a. All of the ammonia concentrations were less than the WCSQV.

- **Natural recovery areas:** Ammonia concentrations in the shallow natural recovery area with thin organic deposits (Stratum 2c) were low (≤25 mg/kg) at all stations. By contrast, in the shallow natural recovery area with thick organic deposits (Stratum 2b), ammonia concentrations were heterogeneous, ranging from 22 to 140 mg/kg. Concentrations in the moderately deep and deep natural recovery areas (Strata 3b and 4) were generally elevated, with all but one value exceeding 100 mg/kg.

- **Reference areas:** Ammonia concentrations at all but one station in both reference areas were moderately elevated (Figure 4b), ranging from 32 to 86 mg/kg. A high concentration of 170 mg/kg was found at Station 95E in the moderately deep reference area (Reference Stratum 5b). Only one ammonia concentration exceeded the WCSQV.

From a temporal perspective, the ammonia concentrations found in 2004 in all three TLP areas (i.e., 1.4–5.6 mg/kg) were substantially lower than the values found in 1996–1997 (57–300 mg/kg) (Table 4). Ammonia concentrations also declined at all stations sampled in the natural recovery areas, although the magnitude of decline was generally less than that found for the TLP areas. For example, ammonia concentrations in the shallow natural recovery areas declined from 260 to 54 mg/kg at Station 38 and from 120 to 6.7 mg/kg at Station 47. In the moderate and deep natural recovery areas, concentrations declined from 360 to 110 mg/kg at Station 6 and from 280 to 110 mg/kg at Station 13.

In summary, ammonia concentrations in the Ward Cove AOC were generally low in all TLP areas, as well as the shallow natural recovery area with thin organic deposits. This pattern indicates that the TLP was successful in dramatically reducing the concentrations of this CoC and that substantial natural recovery of ammonia concentrations has occurred in one of the shallow natural recovery areas. The low ammonia concentrations found in the TLP areas also indicate that the material used for TLP is not being noticeably affected by ammonia from the underlying native sediments. From a temporal perspective, ammonia concentrations appear to have declined considerably in most parts of the Ward Cove AOC, with the greatest declines found in the TLP areas.

6.1.1.2 4-Methylphenol

Concentrations of 4-methylphenol in the AOC ranged from 4 μg/kg at Station 5 in Stratum 1 to 51,000 μg/kg at Station 78 in Stratum 2b (Figure 4a). Mean concentrations of 4-methylphenol in the seven benthic strata in the AOC ranged from 20 to 12,000 μg/kg (Table 3).

Exceedances of the WCSQV(1) for 4-methylphenol were found in three benthic strata: 2b, 3b, and 4. Six exceedances were found in Stratum 2b (the shallow natural recovery area with thick organic deposits), one exceedance was found in Stratum 3b (the moderately deep natural recovery area), and another single exceedance was found in Stratum 4 (the deep natural recovery area). Seven exceedances of the WCSQV(2) for 4-methylphenol were also found: six in Stratum 2b and one in Stratum 3b.

The concentration distributions found in the various benthic strata were as follows:

- **TLP areas:** 4-Methylphenol concentrations were low (i.e., <150 μg/kg) at most stations in the three TLP areas (Strata 1, 2a, and 3a). The only exception was the value of 210 μg/kg found at Station 72 in Stratum 2a.

- **Natural recovery areas:** 4-Methylphenol concentrations in the shallow natural recovery area with thin organic deposits (Stratum 2c) were heterogeneous, ranging from 85 to 1,200 μg/kg. Concentrations in the moderately deep and deep natural recovery areas (Strata 3b and 4) were moderate , ranging from 450 to 1,300 μg/kg at all but two stations, at which values of 1,700 and 18,000 μg/kg were found (Stations 88 and 6, respectively). 4-Methylphenol concentrations in the shallow natural recovery area with thick organic deposits (Stratum 2b) were generally elevated, ranging from 3,500 to 51,000 μg/kg at all stations except Station 71, at which a value of 900 μg/kg was found.

- **Reference areas:** 4-Methyphenol concentrations at the shallow reference area (Reference Stratum 5a) were generally low (Figure 4b), ranging from 32 to 140 μg/kg. Concentrations at the moderately deep reference area (Reference Stratum 5b) were somewhat higher, ranging from 240 to 490 μg/kg.

From a temporal perspective, the concentrations of 4-methylphenol found in 2004 in all three TLP areas (i.e., 4–11 μg/kg) were substantially lower than the values found in 1996–1997 (1,100–16,000 μg/kg) (Table 4). Concentrations of 4-methylphenol also declined at stations sampled in three of the four natural recovery areas. For example, concentrations in the shallow natural recovery areas declined from 8,300 to 4,100 μg/kg at Station 38 and from 1,800 to 85 μg/kg at Station 47. In the deep natural recovery areas, concentrations declined from 1,700 to 520 μg/kg at Station 13. The only exception to the 2004 decline in concentrations of 4-methylphenol was found in the moderately deep natural recovery area, where concentrations at Station 6 increased from 8,300 in 1996 to 18,000 in 2004.

In summary, 4-methylphenol concentrations in the Ward Cove AOC were generally low in all TLP areas. This indicates that the TLP was successful in dramatically reducing the concentrations of this CoC and that the material used for the TLP is not being noticeably affected by 4-methylphenol from the underlying native sediments. From a temporal perspective, concentrations of 4-methylphenol appear to have declined considerably in most parts of the Ward Cove AOC, with the greatest declines found in the TLP areas.

6.1.2 Conventional Analytes

6.1.2.1 Total Organic Carbon

TOC concentrations in the AOC ranged from 0.26 percent at Station 5 in Stratum 1 to 38 percent at Station 78 in Stratum 2b (Figure 5a). Mean TOC concentrations in the seven benthic strata in the AOC ranged from 0.52 to 23 percent (Table 3).

The patterns found for the various benthic strata were as follows:

- **TLP areas:** TOC concentrations were generally low (i.e., <2 percent) at most stations in the three TLP areas (Strata 1, 2a, and 3a). The only exceptions were the values of 5.3 and 6.3 found at Stations 66 and 67 in Stratum 1, and the value of 10 percent found at Station 72 in Stratum 2a.

- **Natural recovery areas:** TOC concentrations in the shallow natural recovery area with thin organic deposits (Stratum 2c) were heterogeneous, ranging from 1.5 to 14 percent. By contrast, concentrations in the shallow natural recovery area with thick organic deposits (Stratum 2b) and the moderately deep and deep natural recovery areas (Strata 3b and 4) were generally elevated, with all but one value exceeding 9 percent.

- **Reference areas:** TOC concentrations in both reference areas (Reference Strata 5a and 5b) were elevated (Figure 5b), with values at all stations exceeding 15 percent.

From a temporal perspective, the TOC concentrations found in 2004 at stations in all three TLP areas (i.e., 0.26–0.51 percent) were substantially lower than the values found in 1996–1997 (24–38 percent) (Table 4). TOC concentrations also declined at all stations sampled in the natural recovery areas, although the magnitude of decline was generally less than that found for the TLP areas. For example, concentrations in the shallow natural recovery areas declined from 34 to 22 percent at Station 38 and from 26 to 4.5 percent at Station 47. In the moderate and deep natural recovery areas, concentrations declined from 33 to 29 percent at Station 6 and from 23 to 18 percent at Station 13.

In summary, TOC concentrations in the Ward Cove AOC were generally low in all TLP areas, reflecting the low concentrations of TOC in the original TLP material, as well as the relatively low rate of organic deposition onto the TLP areas. From a temporal perspective, TOC concentrations appear to have declined in most parts of the Ward Cove AOC, with the greatest declines found in the TLP areas.

6.1.2.2 Percent Fines

Percent fines in the AOC ranged from 1.4 percent at Station 5 in Stratum 1 to 46 percent at Station 75 in Stratum 2b (Figure 5a). Mean values of percent fines in the seven benthic strata in the AOC ranged from 3.4 to 42 percent (Table 3).

The patterns found for the various strata were as follows:

- **TLP areas:** Percent fines were generally low (i.e., <10 percent) at most stations in the three TLP areas (Strata 1, 2a, and 3a). The only exceptions were the values of 16 percent found at Stations 66 and 67 in Stratum 1, and the value of 24 percent found at Station 72 in Stratum 2a. As discussed above, those three stations also had elevated TOC concentrations relative to the other stations in the TLP areas.

- **Natural recovery areas:** Percent fines in the shallow natural recovery area with thin organic deposits (Stratum 2c) were heterogeneous, ranging from 5.8 to 26 percent. By contrast, percent fines in the shallow natural recovery area with thick organic deposits (Stratum 2b) and the moderately deep and deep natural recovery areas (Strata 3b and 4) were generally higher, with all but one value exceeding 25 percent.

- **Reference areas:** Percent fines throughout both reference areas (Reference Strata 5a and 5b) were greater than 25 percent (Figure 5b).

From a temporal perspective, the values of percent fines found in 2004 in all three TLP areas (i.e., 1.4–3.5 percent) were substantially lower than the values found in 1996–1997 (31–70 percent) (Table 4). percent fines also declined at all stations sampled in the natural recovery areas, although the magnitude of decline was generally less than that found for the TLP areas. For example, concentrations in the shallow natural recovery areas declined from 46 to 45 percent at Station 38 and from 38 to 8.3 percent at Station 47. In the moderate and deep natural recovery areas, concentrations declined from 50 to 30 percent at Station 6 and from 77 to 42 percent at Station 13.

In summary, percent fines in the Ward Cove AOC were generally low in all TLP areas, reflecting the low amounts of fine-grained particles in the original material used for TLP, as well as the relatively low deposition rate of fine-grained material onto the TLP areas. From a temporal perspective, values of percent fines appear to have declined in most parts of the Ward Cove AOC, with the greatest declines found in the TLP areas.

6.1.2.3 Total Solids

Concentrations of total solids in the AOC ranged from 14 percent at Stations 77 and 88 in Strata 2b and 4, respectively, to 81 percent at Station 5 in Stratum 1 (Figure 5a). Mean concentrations of total solids in the seven benthic strata in the AOC ranged from 15 to 75 percent (Table 3).

The patterns found for the various strata were as follows:

- **TLP areas:** Concentrations of total solids were generally high (i.e., >50 percent) at most stations in the three TLP areas (Strata 1, 2a, and 3a). The only exceptions were the values of 38 and 48 percent found at Stations 66 and 67 in Stratum 1, and the value of 25 percent found at

Station 72 in Stratum 2a. As discussed above, those three stations also had elevated TOC concentrations and elevated percent fines relative to the other stations in the TLP areas.

- **Natural recovery areas:** Concentrations of total solids in the shallow natural recovery area with thin organic deposits (Stratum 2c) were heterogeneous, ranging from 26 to 62 percent. By contrast, percent fines in the shallow natural recovery area with thick organic deposits (Stratum 2b) and the moderately deep and deep natural recovery areas (Strata 3b and 4) were generally relatively low, with all but one value less than 30 percent.
- **Reference areas:** Concentrations of total solids at all stations in both reference areas (Reference Strata 5a and 5b) were less than 25 percent (Figure 5b).

From a temporal perspective, the total solids concentrations found in 2004 in all three TLP areas (i.e., 76–81 percent) were substantially higher than the values found in 1996–1997 (14–20 percent) (Table 4). Total solids concentrations also increased at all stations sampled in three of the four natural recovery areas, although the magnitude of increase was generally less than that found for the TLP areas. For example, concentrations in the shallow natural recovery areas increased from 14 to 19 percent at Station 38 and from 18 to 49 percent at Station 47. In the moderately deep natural recovery area, concentrations increased from 12 to 16 percent at Station 6. The only exception to the 2004 increase in concentrations of total solids was found in the deep natural recovery area, where concentrations at Station 13 decreased from 16 percent in 1996 and 1997 to 15 percent in 2004.

In summary, concentrations of total solids in the Ward Cove AOC were generally elevated in all TLP areas, reflecting the coarse nature of the original material used for TLP, as well as the relatively low deposition rate of fine-grained material onto the TLP areas. From a temporal perspective, concentrations of total solids appear to have increased in most parts of the Ward Cove AOC, with the greatest increases found in the TLP areas.

6.1.3 Summary of Sediment Chemistry

Overall, the results of the evaluations of CoCs (i.e., ammonia and 4-methylphenol) and conventional analytes in Ward Cove sediments in 2004 indicate that sedimentary conditions had changed substantially in the TLP areas compared to pre-remediation conditions, but had not changed as greatly in most of the natural recovery areas. Concentrations of both CoCs were generally low in all TLP areas, as well as the shallow natural recovery area with thin organic deposits. This pattern indicates that the TLP was successful in reducing the concentrations of these CoCs and that natural recovery has occurred in one of the shallow strata (i.e., Stratum 2c). The low CoC concentrations found in the TLP areas also indicate that the material used for TLP was not being noticeably affected by either CoC from the underlying native sediments. From a temporal perspective, concentrations of both CoCs appear to have declined in most parts of the Ward Cove AOC relative to pre-remediation conditions.

TOC concentrations and percent fines in the Ward Cove AOC were generally low in all TLP areas, reflecting the low concentrations of TOC and fine-grained sediment in the original TLP material, as well as the relatively low rate of particle deposition onto the TLP areas. Concentrations of total solids in the Ward Cove AOC were generally elevated in all TLP areas, reflecting the coarse nature of the original material used for TLP, as well as the relatively low deposition rate of fine-grained material onto the TLP areas. From a temporal perspective, TOC concentrations and percent fines appear to have declined and concentrations of total solids appear to have increased in most parts of the Ward Cove AOC, relative to pre-remediation conditions.

6.2 Toxicity Testing

As discussed previously, the potential toxicity of sediments collected in Ward Cove during July 2004 was evaluated using the 10-day amphipod test based on *Eohaustorius estuarius*. Data collected during the 2004 monitoring event is provided in Appendix A. A quality assurance review of laboratory procedures and results was conducted by Exponent to ensure that the toxicity tests were consistent with the specifications of the test protocols and that the data are acceptable for use in future stages of the monitoring program. The complete quality assurance report of the data is provided in Appendix B2. The results of the sediment toxicity evaluation are discussed in this section. The discussion includes evaluations of both spatial and temporal trends in sediment toxicity.

6.2.1 Spatial Patterns

The spatial distribution of percent amphipod survival observed in the benthic strata of the Ward Cove AOC in 2004 is presented in Figure 6a. Percent survival in the AOC ranged from 0 percent at Station 85 in Stratum 4 to 100 percent at 10 stations distributed across multiple benthic strata.

The patterns found for the various benthic strata were as follows:

- **TLP areas:** percent survival was very high in all three TLP areas (Strata 1, 2a, and 3a), with values of 90 percent or greater found at all but two stations. The two exceptions were the values of 85 and 80 percent observed at Station 72 in Stratum 2a and Station 94 in Stratum 3a, respectively.

- **Natural recovery areas:** percent survival in the shallow natural recovery area with thin organic deposits (Stratum 2c) was very high, with values of 90 percent or greater found at all stations. By contrast, percent survival was heterogeneous in the shallow natural recovery area with thick organic deposits (Stratum 2b), ranging from 20 to 100 percent. In the moderately deep and deep natural recovery areas (Strata 3b and 4), percent survival was relatively low (i.e., ≤60 percent) at all but two stations. The two exceptions were the values of 95 and 100 percent observed at Station 80 in Stratum 3b and Station 88 in Stratum 4, respectively.

- **Reference areas:** In the moderately deep reference area (Reference Stratum 5b), percent survival was 90 percent or greater at all stations except Station 95E, where a value of 80 percent was found (Figure 6b). In the shallow reference area (Reference Stratum 5a), percent survival was 90 percent or greater at three stations, but was 60 and 65 percent at Stations 96E and 96C, respectively. Evaluations of the CoC concentrations, conventional analytes, and benthic community characteristics present in Stratum 5a provided no potential explanations for the relatively low values of amphipod survival found at Stations 96C and 96E. It therefore was assumed that the relatively low values of survival were reflective of the natural variability sometimes encountered with the amphipod test.

In addition to the descriptions of the station-specific patterns of sediment toxicity in the Ward Cove AOC provided above, the mean value of percent survival observed for each benthic stratum (i.e., all stations were pooled within each stratum) was compared statistically with the mean reference value using ANOVA followed by Dunnett's test. Although mean amphipod survival in the moderately deep reference area was 81 percent and greater than the minimum acceptable value of 75 percent identified in the RI/FS (Exponent 1999), the standard deviation of 17 percent exceeded the minimum acceptable value of 15 percent and would limit the statistical power with which significant differences ($P \leq 0.05$) from the mean value could be determined. Therefore, to be conservative, all comparisons of AOC strata with reference areas were made only with the moderately deep reference area (Reference Stratum 5b), which had a mean survival value of 93 percent with a standard deviation of 8.4 percent. Because sediment toxicity tests are conducted in the laboratory under controlled conditions, it is not necessary to stratify comparisons with reference conditions by water depth in the field, as it is for evaluations of benthic macroinvertebrate communities. It therefore was not necessary to use the laboratory negative controls for these comparisons, as discussed in the monitoring plan (Exponent 2001).

The results of the statistical comparisons of mean amphipod survival between each benthic stratum in the AOC and the reference area stratum are presented in Tables 5 and 6 and Figure 7. All statistical methods were consistent with those specified in the monitoring plan (Exponent 2001). Statistical analysis of amphipod survival included normal probability plots to check for normality and outliers, Shapiro-Wilk's normality test, ratio of variances F-test, analysis of variance (ANOVA), and Dunnett's test. All details are included in Appendix C (Table C-1 and Figures C-1a–r). Analysis was conducted using S-Plus 2000.

As shown in Figure 7, mean amphipod survival in the seven benthic strata of the Ward Cove AOC ranged from 32 percent in the deep natural recovery area (Stratum 4) to 96 percent in the very shallow TLP area (Stratum 1). Mean amphipod survival in the reference area was 93 percent. The results of the statistical analysis showed that mean amphipod survival in each of the three TLP areas (Strata 1, 2a, and 3a) was very high (i.e., 93–96 percent) and was not significantly lower ($P > 0.05$) than the reference value. Mean amphipod survival in the shallow natural recovery areas with thin organic deposits (Stratum 2c) was similarly very high (i.e., 95 percent), and was not significantly lower ($P > 0.05$) than the reference value.

Although mean survival in the shallow natural recovery area with thick organic deposits (Stratum 2b) was only 76 percent, it was not significantly lower ($P > 0.05$) than the reference value. However, because the standard deviation for that stratum (29 percent) exceeded the maximum acceptable value of 15 percent used in the RI/FS (Exponent 1999), the lack of statistical significance was due in part to low statistical power. Examination of the seven individual survival values in that stratum showed that the high standard deviation was not due to a single outlier value that could easily be excluded from the analysis. Instead, the seven values were distributed across a large range (i.e., 20 to 100 percent), with two values (i.e., 20 and 55 percent) being low and three values being very high (i.e., 95, 95, and 100 percent). It therefore was concluded that it could not be determined with confidence that amphipod survival in Stratum 2b was comparable to reference conditions.

By contrast with the moderate to very high values of mean amphipod survival found in the five benthic strata discussed above, mean survival in the moderately deep and deep natural recovery areas (Strata 3b and 4) was relatively low (42 and 32 percent, respectively). In addition, both of those values were significantly lower ($P \leq 0.05$) than the value of 93 percent found for the reference area.

In summary, amphipod survival was very high at most stations sampled in the three TLP areas and in the shallow natural recovery area with thin organic deposits. In addition, mean amphipod survival in all four of those areas was very high (i.e., 93–96 percent) and was not significantly lower ($P > 0.05$) than the reference value. These results indicate that from the standpoint of sediment toxicity, all four of those areas have sufficiently recovered to reference conditions. Although, mean survival in the shallow natural recovery area with thick organic deposits was not significantly lower ($P > 0.05$) than the reference value, the high variability in the station-specific results indicates that this area cannot be considered sufficiently recovered to reference conditions.

By contrast with the five areas described above, amphipod survival was low at most stations sampled in the moderately deep and deep natural recovery areas. In addition, mean survival in each of the two areas was low (i.e., 32–42 percent) and was significantly lower ($P \leq 0.05$) than the reference value.

Table 6 presents an analysis of the statistical power of these comparisons. Statistical comparisons had adequate power for all strata except potentially Stratum 2b. Amphipod survival in Stratum 2b was more variable than in the other shallow strata as discussed previously. Stratum 2a had very low power (1 percent) because the minimum detectable relative difference (MDRD) is very low (–2 percent). Strata 1, 2c, and 3a all had better survival than reference.

6.2.2 Temporal Patterns

To evaluate temporal patterns of sediment toxicity in the Ward Cove AOC, four of the stations sampled in 1996–1997 (i.e., Stations 8, 9, 13, and 38) were sampled again in 2004. The sediments collected in 2004 were subjected to replicated laboratory analyses so that mean amphipod survival could be compared statistically between the current and historical results.

Mean survival was compared between time periods using ANOVA followed by Dunnett's test. Full details of the statistical analyses are included in Appendix C (Table C-2 and Figures C-2a–r).

The results of the temporal comparisons showed that mean amphipod survival had increased at all four stations in 2004 (Figure 8 and Tables 7 and 8). In the shallow and moderately deep TLP areas (Strata 2a and 3a), mean survival at Stations 8 and 9 in 2004 was very high (99 and 91 percent, respectively) and approximately twice the values observed at those two stations in 1996 (43 and 54 percent, respectively). In the shallow natural recovery area with thick organic deposits (Stratum 2b), mean survival at Station 38 was also very high (89 percent) in 2004 and dramatically different from the value of 0 percent observed in 1997. The 2004 values of mean survival at all three of these stations were significantly higher ($P \leq 0.05$) than the historical survival values.

By contrast with the three stations described above, mean survival in 2004 at Station 13 in the deep natural recovery area (Stratum 4) was low (43 percent) despite being higher than the values found in 1996 (36 percent) and 1997 (15 percent). In addition, the 2004 value was not significantly higher than either of the two historical values (ANOVA; $P > 0.05$).

Table 8 summarizes the statistical power of these comparisons. Stations 8 and 9 had adequate statistical power to detect differences between earlier years and 2004. Because Station 38 had a survival value of 0 percent in 1997, only a non-parametric comparison could be made. Although no power calculation was conducted for the non-parametric comparison, the results showed a significantly higher survival in 2004 ($P \leq 0.05$), so low power was not an issue for that station. Amphipod survival at Station 13 in 1997 was highly variable; thus, although survival was approximately three times higher in 2004, the difference was not statistically significant. The high variability in 1997 was due to a single replicate with 55 percent survival, compared to 0 or 5 percent for the remaining replicates. Dixon's outlier test indicated that this value was not an outlier ($P > 0.05$). Survival in 2004 was also higher than in 1996, but the difference was smaller (–9 percent) and thus had lower power.

In addition to the four replicated stations described above, four additional historical stations were reoccupied in 2004 (Stations 5, 6, 47, and 48) and five additional historical stations (Stations 3, 7, 32, 34, and 37) were located within 30 m of stations sampled in 2004 (Stations 66, 72, 73, 74, and 83). Although replicated laboratory analyses were not conducted on the sediment samples from these additional nine stations, qualitative comparisons can be made between the values of mean amphipod survival (based on replicated laboratory analyses) determined at each station in 1996–1997 and the unreplicated values determined in 2004.

As shown in Figure 9, amphipod survival in 2004 was greater than the historical values at all four reoccupied stations. Survival values of 100 percent were found in 2004 at Station 5 in the very shallow TLP area (Stratum 1), Station 47 in the shallow natural recovery area with thin organic deposits (Stratum 2c), and Station 48 in the moderately deep TLP area (Stratum 3a). The historical survival values for these three stations were 25–39 percent, 73 percent, and 5 percent, respectively, indicating that substantial increases in survival had occurred at all three stations in 2004.

By contrast with the three stations described above, amphipod survival in 2004 at Station 6 in the moderately deep natural recovery area (Stratum 3b) was low (15 percent) and not substantially higher than the value of 5 percent observed in 1996.

As shown in Figure 10, amphipod survival in 2004 was greater than the values at all five historical stations located within 30 m of the 2004 stations. Survival values of 100 percent were found in 2004 at Station 66 in the very shallow TLP area (Stratum 1), Station 73 in the shallow TLP area (Stratum 2a), and at Station 83 in the moderately deep TLP area (Stratum 3a). The lowest historical survival values for those stations were 28, 65, and 58 percent, respectively. Survival values of 95 and 85 percent were found in 2004 at Stations 73 and 72 in the shallow TLP area (Stratum 2a), compared to the lowest historical survival values for those stations of 65 and 39 percent, respectively. All of these 2004 survival values indicate that substantial increases in survival had occurred at all five of these stations in 2004.

In summary, the temporal trends of amphipod survival found at 13 selected stations in the Ward Cove AOC indicate that survival had substantially increased in 2004 at most stations, based on both statistical and qualitative comparisons.

6.2.3 Evaluation of Sulfide Concentrations in Pore Water

As noted in the QA/QC review for the sediment toxicity tests conducted in 2004 (Appendix B2), both ammonia and sulfide were evaluated in the pore water of sediments from additional replicate beakers that were set up for each test sample. Measurements were made at test initiation (Day 0), midway through the test (Day 5), and at test termination (Day 10). As noted in Appendix B2, all porewater ammonia concentrations were below the no-effect levels for *Eohaustorius estuarius* specified by U.S. EPA (1994). Although similar no-effect levels are not available for sulfide, it was concluded in Appendix B2 that elevated porewater concentrations of sulfide were observed in some samples and that their potential influence on the results of the sediment toxicity tests should be evaluated during data analysis and interpretation. That evaluation is described in this section.

In general, porewater concentrations of sulfides were highest on Day 0 and then continually declined during the exposure period until the lowest values were found on Day 10. This decline was likely the result of oxidation following extended exposure to the aerated overlying water, which was likely facilitated by the burrowing activity of the test organisms. The highest sulfide concentrations were found in the moderately deep (Stratum 3b, 36–68 mg/L) and deep (Stratum 4, 17–72 mg/L) natural recovery areas on Day 0. In the three TLP areas (Strata 1, 2a, and 3a) and the shallow natural recovery area with thin organic deposits (Stratum 2c), sulfide concentrations at most stations were less than 3 mg/L. The exceptions were values ranging from 17 to 31 mg/L found at Stations 66, 67, and 69 in Stratum 1, the value of 30 mg/L found at Station 72 in Stratum 2a, and the value of 12 mg/L found at Station 92 in Stratum 2c. In the two reference areas, sulfide concentrations in the shallow area (Reference Stratum 5a) ranged from 0.8 to 12 mg/L, and concentrations in the moderately deep area (Reference Stratum 5b) ranged from 6 to 36 mg/L.

The potential influence of porewater sulfide on the results of the sediment toxicity tests was evaluated by comparing amphipod survival and sulfide concentrations at the 10 Ward Cove AOC stations where amphipod toxicity was less than 75 percent, the minimum acceptable reference value used in the RI/FS. Survival at those 10 stations ranged from 0 to 60 percent and porewater sulfide concentrations ranged from 34 to 72 mg/L. Because both variables were normally distributed, the comparison was made using the parametric Pearson product-moment correlation coefficient (r). The results of the comparison showed that amphipod survival declined with increasing porewater sulfide concentrations, and the negative correlation was significant ($r = -0.74$; $P \leq 0.05$).

The results of the correlation analysis indicate that sulfide in pore water may have been partly responsible for the observed sediment toxicity observed in Ward Cove. This potential relationship was also found in the RI/FS. However, a number of uncertainties exist regarding application of the laboratory results to *in situ* conditions in Ward Cove. Because sulfide can be rapidly oxidized, it is uncertain how various sediment handling procedures affected porewater sulfide concentrations. The key handling procedures include the compositing and homogenizing of sediments in the field prior to distribution to sample containers, the storage of sediment at 4°C for up to 14 days prior to toxicity testing, and the equilibration of sediment for 24 hours after being placed in the test chambers and before the test organisms are introduced. Additional uncertainties exist regarding the different exposure conditions experienced by benthic organisms in the laboratory and the field. For example, the toxicity tests were static exposures in which the overlying water was not renewed for the entire 10-day exposure period. By contrast, the water overlying the sediments of Ward Cove is continuously renewed by tidal currents. Therefore, the laboratory conditions likely represent worst-case exposure conditions that may never be experienced by organisms in Ward Cove.

Despite the uncertainties related to porewater sulfide discussed above, the strong correlation found between amphipod survival and porewater sulfide concentrations in this study suggest that sulfide should continue to be monitored in sediment pore water during toxicity testing. In addition, consideration should be given in future monitoring events to potentially modifying the toxicity testing protocols to more closely represent the conditions that are likely encountered in the field. For example, prior to the introduction of the test organisms, the overlying water in the test chambers could be aerated for a sufficient period of time so that oxygen levels in the test chambers at the sediment-water interface better reflect the oxygenated conditions that exist in bottom water overlying sediments in Ward Cove.

6.2.4 Summary of Sediment Toxicity Evaluations

Overall, the results of the sediment toxicity evaluations conducted in 2004 indicate that conditions had improved substantially in the TLP areas compared to pre-remediation conditions, but had not changed as greatly in most of the natural recovery areas. Mean amphipod survival in the TLP areas and in the shallow natural recovery area with thin organic deposits was very high (i.e., 93–96 percent) and was not significantly lower ($P > 0.05$) than the reference value, indicating that from the standpoint of sediment toxicity, all four of those areas have sufficiently recovered to reference conditions. Although, mean survival in the shallow natural recovery area with thick organic deposits was not significantly lower ($P > 0.05$) than the reference value, the high variability in the station-specific results indicates that this area cannot be considered sufficiently recovered to reference conditions. By contrast with the five areas described above, mean amphipod survival in the remaining two natural recovery areas was low (i.e., 32−42 percent) and was significantly lower ($P \leq 0.05$) than the reference value.

From a temporal perspective, amphipod survival found at 13 selected stations in the Ward Cove AOC indicated that survival had substantially increased in 2004 at most stations. This pattern was found based on both statistical and qualitative comparisons.

6.3 Benthic Macroinvertebrate Communities

As specified in the monitoring plan, the benthic macroinvertebrate communities sampled in 2004 were compared statistically between remediated and reference areas using a variety of benthic metrics described above. In addition to the statistical comparisons, qualitative observations of benthic community characteristics and key benthic macroinvertebrate species were made to determine whether the communities appeared to be recovering according to the classical patterns identified for disturbed benthic habitats.

All benthic macroinvertebrate data collected during the 2004 monitoring event is provided in Appendix A. A quality assurance review of laboratory procedures and results was conducted by Exponent to ensure that the benthic community identifications and enumerations were consistent with the specifications of the test protocols and that the data are acceptable for use in future stages of the study. A complete quality assurance report of the data is provided in Appendix B3.

Temporal patterns of the characteristics of benthic communities were evaluated qualitatively by comparing information collected in 1992 (EVS 1992) with the results of the 2004 monitoring event. Multivariate evaluations were also conducted to evaluate similarities among the various benthic strata based on the individual abundances of all benthic taxa collected. Finally, taxa richness values at stations within the remediated areas were compared with the ranges of richness values found in the reference areas to determine the degree to which the RAO based upon the presence of multiple taxonomic groups was achieved. These additional analyses using the benthic information collected by EVS in 1992 were beyond the requirements of the monitoring plan (Exponent 2001).

6.3.1 Overview of Spatial Patterns

A total of 4,951 benthic macroinvertebrates from 122 taxa were sampled as part of the 2004 sampling event. Polychaetes accounted for the most taxa (69), with molluscs accounting for 37 taxa and arthropods accounting for 15 taxa. Polychaetes also exhibited the highest relative abundance, accounting for 76 percent of total abundance. Molluscs accounted for 21 percent of total abundance, whereas arthropods accounted for only 2.7 percent. The only miscellaneous taxon collected during the study was Nemertea, which accounted for less than 1 percent of total abundance. In summary, the benthic communities of Ward Cove were dominated by polychaetes and molluscs, with arthropods and miscellaneous taxa contributing relatively small numbers of individuals.

Figures 11a and 11b show the spatial distributions of total abundance, total richness, and SDI values at the 37 stations sampled in the Ward Cove AOC and the 10 reference area stations. Mean values of benthic invertebrate metrics in each benthic stratum are provided in Table 9. The general patterns of these three community metrics were as follows:

- **Total Abundance:** This metric was >25 individuals/sample at most stations located in the three TLP areas (Strata 1, 2a, and 3a), as well as in the shallow natural recovery area with thin organic deposits (Stratum 2c). Total abundance was <25 individuals/sample at most stations in the remaining three natural recovery areas (Strata 2b, 3b, and 4). A major exception was the value of 960 individuals/ sample found at Station 78 in Stratum 2b, which was the result of the large density of the opportunistic polychaete *Capitella capitata* complex (a group of sibling species) that was found at that station (937 individuals/sample; see Table A-7 in Appendix A). Total abundance differed between the two reference areas, with the shallow area (Reference Stratum 5a) having higher abundances (78–642 individuals/sample) than the moderately deep area (Reference Stratum 5b; 12–40 individuals/sample).

- **Taxa Richness:** This metric was >10 taxa/sample at most stations located in the three TLP areas (Strata 1, 2a, and 3a), as well as in the shallow natural recovery area with thin organic deposits (Stratum 2c). Taxa richness was <10 taxa/sample at all stations in the remaining three natural recovery areas (Strata 2b, 3b, and 4). It is interesting to note that taxa richness was greater than 15 taxa/sample at all stations in the shallow natural recovery area with thin organic deposits, whereas at least one station in each of the three TLP areas had a taxa richness value of 10 or fewer taxa/sample. The range of taxa richness in the shallow reference area (15–29 individuals/sample) was greater than the range found at the moderately deep reference area (3–13 individuals/sample).

- **SDI:** This index was relatively high (>7) at all stations in the shallow natural recovery area with thin organic deposits (Stratum 2c), and half the stations in the moderately deep TLP area (Stratum 3a). The index was moderate (3–7) at the remaining stations in Stratum 3a and at most stations in the other two TLP areas (Strata 1 and 2a). This index was lower (<3) at all but one station in the remaining three natural recovery areas. The SDI index was also low (<3) at most stations in both reference areas.

In summary, all three community indices suggest that benthic macroinvertebrates are rapidly recolonizing the three TLP areas and the shallow natural recovery area with thin organic deposits. Communities in the remaining three natural recovery strata and the two reference areas are generally characteristic of organically enriched environments.

Figures 12a, 12b, 13a, and 13b show the spatial distributions of the abundances and taxa richness of major benthic taxa at the 37 stations sampled in the Ward Cove AOC and the 10 reference area stations. Mean values of total abundance and total richness of major benthic taxonomic groups in each benthic stratum are provided in Table 10.

The general patterns of the major taxa metrics were as follows:

- **Polychaeta:** In general, polychaetes were the most abundant major taxon and had the highest numbers of species at many or most stations in both the TLP and natural recovery areas, as well as the reference areas. The polychaete assemblage in three of the four natural recovery areas and the two reference areas were numerically dominated by two species: *Capitella capitata* complex and *Nephtys cornuta*. The natural recovery areas included the shallow area with thick organic deposits, the moderately deep area, and the deep area. By contrast, the polychaete assemblages in the three TLP areas and the shallow natural recovery area with thin organic deposits included more taxa and more balanced distributions of those taxa.

- **Mollusca:** Molluscs were characterized by relatively high abundances and numbers of taxa at most stations in the three TLP areas, the shallow natural recovery area with thin organic deposits (Stratum 2c), and the two reference areas, but were rare in the remaining three natural recovery areas. The most abundant molluscan species were the deposit feeding bivalves *Axinopsida serricata* and *Parvilucina tenuisculpta.*

- **Arthropoda:** Arthropods were generally rare at all stations sampled in Ward Cove. The arthropod assemblage found at three stations in the natural recovery area with thin organic deposits included the greatest abundances and number of taxa found in the AOC, and included tanaids, amphipods, and pinnotherid crabs.

In summary, benthic communities at the 47 stations sampled in Ward Cove were dominated by polychaetes and molluscs, with relatively few arthropods being found. Molluscs were notably more abundant in the TLP areas and the shallow natural recovery area with thin organic deposits than in the remaining three natural recovery areas. Benthic communities in those three natural recovery areas were generally dominated by two polychaete species. These results suggest that recolonization is occurring in the three TLP areas and the shallow natural recovery area with thin organic deposits, and that molluscs may be an important indicator taxon for monitoring that recovery. These results also indicate that it is unlikely that arthropods will become important components of benthic communities at any of the stations monitored in the cove.

6.3.2 Results of Statistical Comparisons

Comparisons of the benthic metrics between remediated areas of the Ward Cove AOC and the reference areas were conducted according to the methods specified in the monitoring plan. The results of those comparisons are presented in Tables 11, 12, and C-1. Significant differences ($P \leq 0.05$) from reference conditions were found in only three benthic strata:

- **Stratum 1:** This is the very shallow TLP stratum. Only arthropod abundance was significantly lower ($P \leq 0.05$) than the reference value, although the non-parametric test did not show significance. The validity of this difference is somewhat questionable, as arthropods were not important components of benthic macroinvertebrate communities at any of the benthic strata sampled in Ward Cove. In addition, some degree of uncertainty exists in the comparisons of benthic metrics for this particular benthic stratum because it is shallower than its corresponding reference stratum.

- **Stratum 2a:** This is the shallow TLP stratum. Only polychaete taxa richness was significantly lower ($P \leq 0.05$) than the reference value. Although the non-parametric test found a polychaete abundance lower than the reference value, the assumptions of the ANOVA and Dunnett's test were met and no significant difference ($P \leq 0.05$) was found.

- **Stratum 2b:** This is the shallow natural recovery area with thick organic deposits. Seven benthic metrics were significantly lower ($P \leq 0.05$) than reference values, including arthropod abundance, mollusc abundance, total taxa richness, polychaete taxa richness, arthropod taxa richness, mollusc taxa richness, and Swartz' dominance index. Although Dunnett's test concluded no difference with reference for Swartz' dominance index, the underlying assumption of homogeneity of variance was not met for all strata.

In general, there was adequate statistical power for the comparisons with the shallow reference area stratum. By contrast, the comparisons with the moderately deep reference area stratum had generally smaller relative differences and thus lower power levels. Of the 40 comparisons between depth strata in the AOC with benthic metrics lower than reference, 12 had greater than 60 percent statistical power. Further, 5 shallow and 9 moderate depth strata are within 20 percent of their respective reference. The remaining comparisons generally fall into two categories. Five comparisons have lower power due to higher variability at the respective reference stratum, specifically polychaeta abundance for Stratum 1; total abundance for Stratum 2c; and mollusca abundance, total richness, and polychaeta richness for Stratum 3b. Four comparisons have less than 60 percent power for larger relative differences because the actual differences are small, specifically arthropoda richness for Strata 1 and 2a and mollusca richness for Strata 3b and 4. These comparisons have approximately one species less than reference, specifically two species at reference to one species at the respective depth stratum in the AOC. Overall, there is no stratum with a consistent lack of statistical power, and thus the sampling design appears to be adequate.

The results of the statistical comparisons indicate that with the exception of Stratum 2b, few differences were found between the TLP areas in the Ward Cove AOC and the reference areas. Overall, it can be concluded that meaningful differences in benthic metrics between AOC strata and reference strata were found only for Stratum 2b.

6.3.3 Patterns of Key Species

In this section, the spatial patterns of key species found in the various benthic strata in Ward Cove are evaluated to determine whether the strata are being recolonized according to the predicted patterns of benthic recolonization. Several key benthic macroinvertebrate species were identified above, based on their relatively high abundances in various parts of the AOC or in the reference areas, including:

- The polychaete *Capitella capitata*
- The polychaete *Nephtys cornuta*
- The mollusc *Axinopsida serricata*
- The mollusc *Parvilucina tenuisculpta*.

Additional benthic species are identified in Table 13, which provides a summary of the benthic taxa that account for at least 5 percent of total abundance in each benthic stratum.

As shown in Table 13, three or more benthic species accounted for more than 5 percent of total abundance at all three TLP areas and the shallow natural recovery area. In addition, the various species were relatively evenly distributed (with no species accounting for more than 35 percent of total abundance) and included a combination of polychaetes and molluscs. These results indicate that benthic communities in these strata are composed of relatively diverse species assemblages.

By contrast with the four benthic strata described above, benthic communities in the remaining three natural recovery areas were dominated by one or both of two polychaete species (i.e., *Capitella capitata* complex and *Nephtys cornuta*), with no other taxon accounting for more than 5 percent of total abundance. In addition, these species accounted for over 75 percent of total abundance in each stratum. The species pattern observed in the three natural recovery areas is characteristic of organically enriched areas, in which benthic communities are dominated by a few opportunistic species (Pearson and Rosenberg 1978).

In the two reference area strata, benthic communities were dominated by the two polychaetes described above for the three natural recovery areas (i.e., *Capitella capitata* complex and *Nephtys cornuta*), which accounted for more than 60 percent of total abundance in each reference area stratum. In addition, only one other species accounted for more than 5 percent of total abundance in each of those strata. These patterns indicate that the benthic communities found in the two reference area strata are characteristic of the communities found in relatively uncontaminated but organically enriched areas of Ward Cove.

The characteristics of the various benthic strata identified in Table 13 are discussed below, particularly with respect to successional stage. In determining successional stage with respect to organic enrichment or other stressors, information on benthic macroinvertebrate communities collected in California was used, because the most detailed descriptions of species-specific patterns on the West Coast of the United States have been collected in that state. The key characteristics of the various species are as follows, with the species progressing from polychaetes to bivalves to gastropods:

- ***Capitella capitata* complex:** This polychaete taxon comprises small relatively nonselective deposit-feeding individuals that build tubes at or near the sediment surface (Fauchald and Jumars 1979). The taxon is one of the most characteristic indicators of organic enrichment or sediment disturbance in the world (Rosenberg 1976; Pearson and Rosenberg 1978; Rhoads et al. 1978; Pearson 1980). It is an opportunistic pioneering species that initially colonizes organically enriched or disturbed habitats and often numerically dominates the benthic communities that are found in those habitats. Swartz et al. (1986) and Stull et al. (1986) found that *C. capitata* complex was one of the most abundant benthic taxa in communities closest to major sources of organic enrichment in Southern California. In addition, Lowe and Thompson (1999) identified this species as tolerant to environmental stressors in San Francisco Bay.

- ***Nephtys cornuta:*** This polychaete is a free-burrowing species that may periodically form poorly agglutinated burrows (Fauchald and Jumars 1979). Although nephtyids are generally considered to be carnivorous (i.e., preying on small invertebrates), some species have been found to be motile subsurface deposit feeders. Swartz et al. (1986) found that *N. cornuta* was one of the most abundant benthic species in communities closest to major sources of organic enrichment in Southern California. In addition, Lowe and Thompson (1999) identified this species as tolerant to environmental stressors in San Francisco Bay.

- ***Dorvillea annulata:*** This polychaete is a facultative carnivore that can feed on plant material if necessary (Jumars and Fauchald 1979). This species is closely related to *D. longicornis*, which Stull et al. (1986) and Swartz et al. (1986) found to be abundant in benthic communities closest to major sources of organic enrichment in Southern California. In addition, Lowe and Thompson (1999) identified the family Dorvilleidae as tolerant to environmental stressors in San Francisco Bay.

- ***Prionospio steenstrupi:*** This polychaete is a tube-dwelling surface deposit feeder that lives at the sediment surface where it uses its ciliated palps to select food particles (Jumars and Fauchald 1979). Stull et al. (1986) found that *P. steenstrupi* was a member of benthic communities in areas where organic enrichment was declining in Southern California.

- ***Lumbrineris californiensis:*** This polychaete is a free-burrowing subsurface deposit feeder. Unidentified species of the genus *Lumbrineris* were found to be members of benthic communities in areas where organic enrichment was declining in California (Stull et al. 1986).

- ***Owenia fusiformis*:** This polychaete is a tubicolous surface deposit feeder that is capable of both filter feeding and deposit feeding (Jumars and Fauchald 1979). No information was found on its relationship to organically enriched habitats.

- ***Axinopsida serricata:*** This small bivalve is a free-burrowing deposit feeder that resides near the sediment surface (Allen 1958). Stull et al. (1986) and Swartz et al. (1986) found that *A. serricata* was one of the most abundant species in benthic communities in areas where organic enrichment was declining in California.

- ***Parvilucina tenuisculpta:*** This small bivalve is a free-burrowing deposit feeder that resides near the sediment surface (Allen 1958). Stull et al. (1986) and Swartz et al. (1986) found that *P. tenuisculpta* was one of the most abundant species in benthic communities in areas where organic enrichment was declining in Southern California.

- ***Rochefortia tumida:*** This bivalve (also known as *Mysella tumida*) was found to be associated with benthic communities closest to major sources of organic enrichment in Southern California (Stull et al. 1986). In addition, Lowe and Thompson (1999) identified *R. tumida* as tolerant to environmental stressors in San Francisco Bay.

- ***Tellina modesta:*** This bivalve is a surface deposit feeder that lives immediately below the sediment surface and feeds on surface deposits using its inhalent siphon (Yonge 1949). Swartz et al. (1986) found that *T. modesta* was one of the most abundant species in benthic communities in areas where organic enrichment was declining in Southern California.

- ***Acteocina eximea:*** No information was found on the relationship of this gastropod species to organically enriched habitats.

- ***Parvaplustrum* spp.:** No information was found on the relationship of this gastropod genus to organically enriched habitats.

In summary, the key characteristics of the benthic macroinvertebrate species discussed above generally indicate that benthic communities in the TLP areas and the shallow natural recovery area with thin organic deposits were characterized primarily by species commonly found in areas where organic enrichment is declining. These species include the polychaetes *Prionospio steenstrupi* and *Lumbrineris californiensis* and the bivalves *Axinopsida serricata*, *Parvilucina tenuisculpta*, and *Tellina modesta*. By contrast, communities in the other three natural recovery areas were characterized primarily by species commonly found in organically enriched areas, including the polychaetes *Capitella capitata* complex and *Nephtys cornuta*. The communities in the two reference areas were also characterized primarily by species commonly found in organically enriched areas, including *C. capitata*, *N. cornuta*, and *Dorvillea anunulata*.

6.3.4 Comparisons of Benthic Macroinvertebrate Communities Between 1992 and 2004

As noted previously, EVS (1992) sampled benthic macroinvertebrate communities in Ward Cove in 1992, and this data set represents the only recent quantitative evaluation of these communities prior to the remedial activities conducted in 2000–2001. This data set can therefore provide an estimate of the degree to which benthic communities in the cove have improved as a result of remedial actions. Therefore, in this section, the general characteristics of benthic communities throughout the cove in 1992 are compared with the characteristics of the communities found during the 2004 monitoring event. Although benthic communities were sampled using the same general methods in both studies, station locations differed to some degree between the two studies. Comparisons in the present study were therefore made on a cove-wide basis, with the data from each study being expressed on a per-sample basis.

EVS (1992) sampled five stations in the inner part of Ward Cove in January 1992 (Figure 14). The collection and analysis methods were considered comparable to those used in the present study. Sediments were collected using a 0.1-m^2 van Veen grab sampler and subsequently sieved using a mesh size of 1.0 mm. Retained material was preserved in 10 percent buffered formalin and subsequent taxonomic identifications were made to the lowest taxonomic level practical, usually to species. The taxonomic identifications were made under the direction of Mr. Gary Rosenthal (i.e., who directed the identifications for the present study) using the same team of taxonomists that the conducted the identifications for the present study. The quality of the taxonomy used by EVS (1992) is therefore considered comparable to the quality of the taxonomy used during the present study. The only notable methodological difference between the two studies was the use of a smaller van Veen grab sampler (i.e., 0.06 m^2) in the present study. All abundance data collected during 2004 were therefore converted to 0.1-m^2 before comparisons with the 1992 data were made.

EVS (1992) found that polychaetes were the dominant major taxon in Ward Cove in 1992, accounting for 61 percent of total abundance. Nematodes were the second most numerous major taxon, accounting for 38 percent of total abundance. Arthropods and molluscs were nearly absent from the cove, with neither taxon accounting for more than 0.5 percent of total abundance. EVS (1992) noted that polychaetes were dominated by *Capitella capitata* (an opportunistic species indicative of organic enrichment). Nematodes are also considered indicative of organic enrichment. The authors concluded that the characteristics of the benthic macroinvertebrate communities found in Ward Cove in 1992 were standard responses to high levels of organic enrichment.

Figure 15 compares taxa richness of benthic macroinvertebrate communities sampled in Ward Cove in 1992 and 2004. The comparison shows that the total number of taxa per station in 2004 was more than twice the value found in 1992. The largest increase in taxa richness occurred for molluscs, for which mean richness increased by a factor of seven between 1992 and 2004. Mean richness of polychaete taxa approximately doubled between l992 and 2004, whereas mean richness of arthropods tripled. The results of these comparisons indicate that taxa richness of benthic communities in the cove exhibited marked improvement from 1992 to 2004.

Table 14 compares the abundances of major benthic macroinvertebrate taxa in communities sampled in Ward Cove in 1992 and 2004. The comparisons show that although mean total abundance of benthic communities in 1992 was approximately two and one-half times greater than the value found in 2004, this disparity was largely the result of communities in 1992 being dominated by two taxa that accounted for 79 percent of total abundance (i.e., *C. capitata* and nematodes). As discussed previously, both of these taxa are indicative of high levels of organic enrichment. If those two taxa are removed from the comparison for both sampling events, mean total abundance in 1992 (100 individuals per station) is nearly identical to the value found in 2004 (104 individuals per station).

With respect to the individual taxa presented in Table 14, all of the numerically dominant taxa found in 1992 were found in reduced abundances in 2004. The most dramatic declines were found for *Schistomeringos japonica* and nematodes, which were absent from the 2004 communities. In addition, the mean abundance of *C. capitata* in 2004 had declined to 40 percent of its 1992 abundance. Because all three of these taxa are indicators of organic enrichment, their absence from the 2004 communities indicates that the effects of organic enrichment in the cove had declined markedly by 2004.

In contrast to the decline in abundances of indicators of organic enrichment between 1992 and 2004, a number of mollusc and polychaete species that were absent or rare in 1992 had become important members of the benthic communities in Ward Cove in 2004. The most notable increases in abundances were found for molluscs, particularly *Axinopsida serricata* and *Parvilucina tenuisculpta*, which were nearly absent from the cove in 1992. In addition, two polychaete species (*Dorvillea annulata* and *Owenia fusiformis*) were absent in 1992, but became important members of the benthic communities in 2004.

In summary, comparisons of benthic macroinvertebrate communities found throughout Ward Cove in 1992 and 2004 showed that taxa indicative of high levels of organic enrichment had declined substantially during the 12-year period, and that they were replaced by a greater diversity of taxa that were rarely found in the cove in 1992, particularly molluscs. These patterns indicate that, on a cove-wide basis, the benthic macroinvertebrate communities currently found throughout Ward Cove are more diverse than the communities that occupied the cove in the past and are less affected by taxa indicative of organic enrichment.

6.3.5 Multivariate Analysis of Benthic Macroinvertebrate Community Data

Both multivariate techniques used in the present study were conducted using the Bray-Curtis similarity index applied to log-transformed abundances (Bloom 1981; Hruby 1987). A log transformation ($\log_{10}$+1) was used to reduce the potential influence of the most abundant benthic taxa on the results of the analyses. The results of classification analysis are expressed as a one-dimensional dendrogram that displays station clusters based on hierarchical similarities among the stations. The results of MDS are expressed as plots in multidimensional space based on the similarities among stations. In the present study, both kinds of multivariate analysis were conducted using mean abundances of the benthic taxa collected in each of the nine benthic strata sampled in Ward Cove during the 2004 monitoring event.

Figure 16 shows the results of the classification analysis of the benthic macroinvertebrate data collected in 2004. Two clusters of benthic strata were apparent from the dendrogram and were identified as Benthic Groups A and B. Benthic Group A included Reference Stratum 5a (the shallow reference area), whereas Benthic Group B included Reference Stratum 5b (the moderately deep reference area). The characteristics of each benthic group are described below:

- **Benthic Group A—**Within this group, Reference Stratum 5a clustered most closely with Stratum 2c (the shallow natural recovery area near the mouth of Ward Cove). Stratum 1 (the very shallow TLP stratum) was the next most similar stratum to Reference Stratum 5a. Strata 2a and 3a (the shallow and moderately deep TLP strata, respectively) clustered most closely with each other, before joining the other three strata in Group A.

- **Benthic Group B—**Within this group, Reference Stratum 5b clustered most closely with Stratum 3b (the moderately deep natural recovery stratum located at moderate depth). Stratum 4 (the deep natural recovery stratum) was the next most similar stratum to Reference Stratum 5b, followed by Stratum 2b (the shallow natural recovery stratum located offshore from the former KPC facility).

The characteristics of the two benthic groups described above indicate that they were based largely on remedial category rather than depth. All three TLP strata were included in Benthic Group A, whereas three of the four natural recovery strata were included in Benthic Group B. The only exception to this pattern was found for Stratum 2c, which was included in Benthic Group A despite the fact that it was a natural recovery stratum.

Figure 17 shows the MDS results for the benthic macroinvertebrate data collected during the 2004 monitoring event. The two dimensional plot exhibited an r^2 value of 0.92, indicating that it accounted for 92 percent of the variability in the data and that additional dimensions were not needed to adequately characterize the similarity among benthic strata. Two groups of benthic strata were apparent on the MDS plot, and they matched the two benthic groups identified on the basis of the dendrogram presented in Figure 16. The group on the right side of the plot corresponded to Benthic Group A, as defined by the classification analysis. This group included the shallow Reference Stratum 5a, all TLP strata (Strata 1, 2a, and 3a), and the shallow natural recovery stratum near the mouth of Ward Cove (Stratum 2c). The group on the left side of the plot corresponded to Benthic Group B, as defined by the classification analysis. This group included three of the four natural recovery strata (Strata 2b, 3b, and 4).

In summary, results of the multivariate analyses of the benthic macroinvertebrate data collected in Ward Cove in 2004 showed that two distinct clusters or groups of stations were apparent, each associated with one of the two reference area strata. Furthermore, the two groups of stations appeared to cluster primarily by remediation category rather than depth, with all TLP strata being found in one group and three of the four natural recovery strata being found in the other group. These results indicate that TLP in the cove resulted in benthic communities that were different from the communities found in the moderately deep reference stratum and all but one of the natural recovery strata. The benthic communities in the three TLP strata and the shallow natural recovery area near the mouth of the cove clustered closely with the community found in the shallow reference area, indicating that the characteristics of all of those benthic communities were similar.

6.3.6 Evaluation of Taxa Richness at Individual Stations

As discussed previously, taxa richness of benthic communities at individual stations within each TLP and natural recovery stratum were compared to the range of values found in the reference areas. This analysis focused on taxa richness to evaluate the degree to which benthic communities at individual stations are achieving the RAO of containing multiple taxonomic groups. Richness at each station was evaluated for total taxa, molluscs, and polychaetes. Arthropods were not evaluated because few taxa from this group were found anywhere in the cove.

For the very shallow and shallow benthic strata (Figure 18), the following patterns were found for taxa richness:

- **Total Taxa:** Richness values for all five stations in Stratum 2c and for four of the five stations in Stratum 1 were either within the reference range or exceeded the range. The only exception was found for Station 67 in Stratum 1, where only three taxa were found, compared to the minimum reference value of 15 taxa. Richness values for all seven stations in Stratum 2b were well below the minimum reference value, ranging from two to six taxa. Finally, richness values at two of the four stations in Stratum 2a were within the reference range. Although the value of four taxa found at Station 72 in Stratum 2a was well below the minimum reference value, the value of 11 taxa found at Station 74 was close to the minimum reference value. The higher variability at Stratum 2a decreased the statistical power.

- **Molluscs:** Richness values for four of the five stations in both Strata 1 and 2c were either within the reference range or exceeded the range. The only exceptions were found for Station 67 in Stratum 1 and Station 91 in Stratum 2c, where only two taxa were found, compared to the minimum reference value of four taxa. Richness values at three of the four stations in Stratum 2a were either within the reference range or exceeded the range. The only exception was found for Station 72, at which no taxa were found. Finally, richness values for all seven stations in Stratum 2b were below the minimum reference value (i.e., zero or one taxon).

- **Polychaetes:** Richness values for all five stations in Stratum 2c and for four of the five stations in Stratum 1 were either within the reference range or exceeded the range. The only exception was found for Station 67 in Stratum 1, where only one taxon was found, compared to the minimum reference value of 10 taxa. Richness values for all seven stations in Stratum 2b were well below the minimum reference value, ranging from two to five taxa. Finally, richness values at one of the four stations in Stratum 2a was within the reference range. Although the value of three taxa found at Stations 72 and 74 in Stratum 2a was well below the minimum reference value, the value of seven taxa found at Station 9 was close to the minimum reference value. Similar to total taxa richness, the increased variability between stations in Stratum 2a decreased the statistical power of the comparison to reference.

The results of the richness evaluations described above for the very shallow and shallow benthic strata provide a weight of evidence that the benthic communities in Strata 1, 2a, and 2c comprise multiple taxonomic groups that, in most cases, are comparable to the range of values found in the reference area. By contrast, the benthic communities at stations in Stratum 2b uniformly comprise fewer taxa than the values found in the reference area.

For the moderately deep and deep benthic strata (Figure 19), the following patterns were found for taxa richness:

- **Total Taxa:** Richness values for all 6 stations in Stratum 3a and all five stations in Stratum 4 were either within the reference range or exceeded the range. Richness values for three of the four stations in Stratum 3b were within the reference range, whereas the value of two taxa found at Stations 79 and 82 was lower than the minimum reference value of three taxa.

- **Molluscs:** Richness values for all six stations in Stratum 3a were either within the reference range or exceeded the range. Richness values for four of the five stations in Stratum 3b and three of the five stations in Stratum 4 were within the reference range, whereas the value of zero taxa found at Stations 79 in Stratum 3b and Stations 86 and 13 in Stratum 4 was lower than the minimum reference value of one taxon. The low number of molluscan taxa observed at reference and AOC strata accounted for the relatively large MDRD but lower statistical power.

- **Polychaetes:** Richness values for all six stations in Stratum 3a were either within the reference range or exceeded the range. Richness values for all five stations in both Strata 3b and 4 were within the reference range. The low taxa counts at all strata accounted for the relatively large MDRD but lower statistical power.

The results of the richness evaluations described above for the moderately deep and deep benthic strata provide a weight of evidence that the benthic communities at stations in Stratum 3a comprise multiple taxonomic groups that, in many cases, exceed the reference range by a substantial degree. Although benthic communities at many stations in Strata 3b and 4 exhibit richness values that fell within the reference range, most of those values were near the lower end of the range.

In summary, the comparisons of taxa richness values at individual stations within each TLP and natural recovery stratum with reference values indicate that communities that comprise multiple taxonomic groups were present at most stations in Strata 1, 2a, 2c, and 3a. By contrast, taxa richness at all or most stations in benthic communities in Strata 2b, 3b, and 4 were either less than or similar to the minimum reference value.

6.3.7 Summary of Benthic Community Evaluations

The various kinds of evaluations of benthic macroinvertebrate communities found in Ward Cove during the 2004 monitoring event indicate that TLP has resulted in the establishment of diverse communities that comprise multiple taxonomic groups. By contrast, most of the natural recovery areas comprise less diverse communities and lower numbers of taxa. The exception was the shallow natural recovery area with thin organic deposits, which was characterized by a diverse benthic community comprising multiple taxa.

Results of statistical comparisons of benthic community metrics between remediation strata and reference strata indicated that with the exception of the shallow natural recovery area with thick organic deposits, few significant differences ($P \leq 0.05$) were found between the two kinds of areas. However, this result should be qualified to some extent because statistical power was relatively low for some of the comparisons. This reduced power was likely the combined result of the inherent variability commonly found for benthic metrics and the specifications of the study design, which called for single unreplicated stations to be distributed throughout each remediation area.

Qualitative evaluations of key species found in the various benthic strata of Ward Cove in 2004 showed that the benthic communities in the three TLP areas and the natural recovery area with thin organic deposits were characterized primarily by species commonly found in areas where organic enrichment is declining. By contrast, communities in the remaining three natural recovery areas were characterized primarily by species commonly found in organically enriched areas.

On a cove-wide basis, qualitative comparisons with pre-remediation benthic community data collected in 1992 show that communities in 2004 comprise more than twice as many taxa (particularly mollusc and polychaete taxa), with individuals distributed more evenly among the taxa. In addition, two of the three numerically dominant taxa found in 1992 that were indicative of high levels of organic enrichment were not collected in the cove in 2004, including the polychaete *Schistomeringos japonica* and nematodes. The fourth taxon that was numerically dominant in 1992, the polychaete *Capitella capitata*, was present in 2004, but at only 40 percent of the density found in 1992.

Multivariate analysis of the benthic community data collected in 2004 documented two distinct clusters of groups of benthic strata, each associated with one of the two reference area strata. The two groups of stations appeared to cluster primarily by remediation category rather than depth, with all TLP strata being found in one group and three of the four natural recovery strata being found in the other group. These results indicate that TLP in the cove resulted in benthic communities that differed from the communities found in the moderately deep reference stratum and all but one of the natural recovery strata. The benthic communities in the three TLP strata and the shallow natural recovery area near the mouth of the cove clustered closely with the community found in the shallow reference area, indicating that the characteristics of all of those benthic communities were similar.

Comparisons of taxa richness values at individual stations within each TLP and natural recovery stratum with reference values indicated that communities comprising multiple taxonomic groups were present at most stations in the three TLP strata and the shallow natural recovery area with thin organic deposits. By contrast, taxa richness at all or most stations in benthic communities in the remaining three natural recovery areas were either less than or similar to the minimum reference values.

In summary, the TLP was successful in stimulating colonization of benthic macroinvertebrate species such that diverse communities comprising multiple taxa now inhabit most parts of the TLP areas, and exhibit many similarities with the community found in the shallow reference area. By contrast, benthic communities in most of the natural recovery areas have not progressed as far along the recovery spectrum as those in the TLP areas. The exception is the natural recovery area with thin organic deposits, in which benthic communities exhibit many characteristics similar to those in the TLP and shallow reference area.

7 Evaluation of Reference Areas

As discussed in the Ward Cove monitoring plan (Exponent 2001), sediments were collected from reference areas within the cove to provide a basis for statistical comparisons of the sediment toxicity and benthic macroinvertebrate community results. Strata 5a and 5b were therefore selected for that purpose. In this section, information collected during the 2004 monitoring event in Ward Cove was used to evaluate the appropriateness of Strata 5a and 5b as reference areas for the monitoring program.

According to U.S. EPA (2001), the definition of reference sediments is as follows:

> "A whole sediment, collected near an area of concern, that is used as a point of comparison to assess sediment conditions exclusive of the material(s) of interest. The reference sediment may be used as an indicator of localized sediment conditions exclusive of the specific pollutant input of concern. Such sediment would be collected near the site of concern and would represent the background conditions resulting from any localized pollutant inputs as well as global pollutant input."

Similar definitions of reference sediments are presented in other guidance documents provided by U.S. EPA (1994, 2000b).

Using the selection criteria identified above, Strata 5a and 5b for the Ward Cove monitoring program were located outside the AOC at depths that corresponded to the shallow and moderately deep benthic strata used for the AOC. In addition, these stations were located away from other potential sources of contaminants in locations where information collected at during the RI/FS in 1995–1996 (Exponent 1999) showed no exceedances of the lowest site-specific sediment quality values for CoCs and no exceedances of the lowest sediment quality values for the sediment toxicity tests.

The appropriateness of Strata 5a and 5b as reference stations for the Ward Cove monitoring program was evaluated using the information on physical/chemical sediment characteristics, sediment toxicity, and benthic macroinvertebrate communities collected during the 2004 monitoring event. The results of those evaluations are described below.

7.1 Physical/Chemical Sediment Characteristics

The evaluations of sediment chemistry focused on the physical/chemical properties of the sediments at Strata 5a and 5b, as well as the concentrations of CoCs in those sediments. As discussed previously, a valid reference area must not only be similar to a test site with respect to such physical/chemical variables as water depth and sediment character, but it also should be relatively unaffected by the site-specific CoCs. In the case of the Ward Cove AOC, the site-specific CoCs as identified in the monitoring plan (Exponent 2001) are ammonia and 4-methylphenol (see Figure 4b). The physical chemical characteristics evaluated in this section include TOC content, sediment grain size distribution (i.e., percent fines), and total solids (see Figure 5b).

The ranges of TOC concentrations found at Strata 5a and 5b (16–19 and 22–26 percent, respectively) were similar to each other and were therefore considered representative of the large-scale background conditions that currently exist in Ward Cove, and will likely continue to exist in the cove in the future. Although the TOC values found at Strata 5a and 5b are elevated compared to most marine sediments, elevated values of TOC are often found in enclosed embayments in Alaska due to such sources as naturally high organic material from peat deposits, plant material introduced from shorelines and tributaries, fish processing wastes, and log storage areas. In the detailed technical studies report (Exponent 1999), TOC concentrations in nearby Moser Bay were found to range from approximately 4 to 6 percent. In Ward Cove, natural background sources of TOC are supplemented by wood and bark debris from log rafting, sunken logs, and releases from a nearby former fish processing plant.

The ranges of percent fine-grained sediment found at Strata 5a and 5b (29–52 and 27–47 percent) were similar to each other, indicating that they also represent large-scale background conditions in the cove. In addition, they are mid-range values, with neither being skewed toward the fine or coarse ends of the grain-size spectrum. The ranges of percent solids found at Strata 5a and 5b (15–22 and 15–19 percent) were similar to each other, indicating that they too represent large-scale background conditions. Therefore, based on the general consistency of the sediment characteristics found at Strata 5a and 5b, it can be concluded that they provide an adequate representation of the large-scale conditions that exist in Ward Cove outside of the AOC in the absence of the CoCs.

Concentrations of 4-methylphenol at all replicate samples collected at Strata 5a and 5b were well below the WCSQV of 1,300 μg/kg, with the range of concentrations at Stratum 5a (32–140 μg/kg) being less than half the range of values found at Stratum 5b (240–490 μg/kg). Ammonia concentrations in all five replicate samples collected at Stratum 5a ranged from 32 to 64 mg/kg and all values were well below the site-specific WCSQV(1) of 110 mg/kg. Ammonia concentrations at four of the five replicate samples collected at Stratum 5b ranged from 42 to 86 mg/kg and were all below the WCSQV(1). By contrast, the ammonia concentrations found at the remaining replicate sample from Stratum 5b (170 mg/kg) exceeded the WCSQV(2) of 120 mg/kg. However, amphipod survival for the replicate sample with the elevated ammonia concentration was 80 percent, which is greater than the minimum acceptable reference value of 75 percent identified in the RI/FS (Exponent 1999). Therefore, the elevated concentration did not result in substantial toxicity. In addition, because ammonia is a natural by-product of the degradation of organic material, it would be expected to be present at some level in any sediment with elevated TOC concentrations.

The results of the evaluation of physical/chemical sediment characteristics at Strata 5a and 5b indicate that general characteristics of sediments (i.e., TOC content, grain size distribution, and total solids) in the two strata are similar to each other and therefore representative of the large-scale background conditions of Ward Cove outside of the AOC. The concentrations of ammonia and 4-methylphenol in sediments from Strata 5a and 5b indicate that, in general, neither reference area is substantially affected by those CoCs.

7.2 Sediment Toxicity

Percent survival of *Eohaustorius estuarius* in Stratum 5b ranged from 80 to 100 percent, with only the minimum value being less than 90 percent (see Figure 6b). However, as noted in the previous section, the minimum value of 80 percent exceeded the minimum acceptable reference value of 75 percent specified for the amphipod test in the RI/FS (Exponent 1999).

Percent survival of *E. estuarius* in Stratum 5a ranged from 60 to 95 percent, with the values for two replicate samples (60 and 65 percent) being less than the minimum acceptable reference value of 75 percent. Percent survival at the remaining three replicate samples was ≥90 percent.

Examination of the chemical data collected in and near Stratum 5a during the 2004 monitoring event and during the RI/FS (Exponent 1999) showed that no signs of substantial chemical contamination were present. The reduced levels of survival in the two replicate samples for Stratum 5a were therefore likely the result of the natural variability sometimes found for the amphipod test. For example, statistically significant outlier replicates were found at six of the stations sampled in Ward Cove in 1997 during the RI/FS, and survival values for all of the outliers were lower than the values found for the remaining four replicates at each station (Exponent 1999). The outliers were therefore removed from the results for each station before statistical comparisons with reference conditions were made.

The results of the sediment quality evaluations indicate that both Strata 5a and 5b should be considered appropriate reference areas. Although reduced survival values were found for two of the replicate samples in Stratum 5a, they appeared to be the result of natural variability in the amphipod test and are not considered a sufficient reason for disqualifying the entire stratum as a reference area.

7.3 Benthic Macroinvertebrate Communities

Evaluations of the benthic macroinvertebrate communities found in Strata 5a and 5b indicate that communities in both strata exhibit characteristics indicative of organic enrichment (see Table 13 and Figures 11b, 12b, and 13b). Communities in both areas are numerically dominated (i.e., >60 percent of total abundance) by a single polychaete species that is known to be indicative of organic enrichment: *Nephtys cornuta* in Stratum 5b and *Capitella capitata* in Stratum 5a. In addition, many of the benthic community metrics evaluated in those two areas exhibit patterns characteristic of organic enrichment, such as elevated abundances of opportunistic species, reduced taxa richness, and increased dominance.

The benthic community in Stratum 5b appears to be affected more by organic enrichment than the community in Stratum 5a, despite the fact that TOC concentrations in Stratum 5b (16−18 percent) are lower than the concentrations found in Stratum 5a (22−26 percent). This could indicate that the organic material in Stratum 5b is more labile than the material in Stratum 5a.

The results of the benthic community evaluations indicate that communities in both reference areas exhibit characteristics indicative of organic enrichment. However, given the fact that background sediment conditions in Ward Cove are characterized by elevated concentrations of TOC, the existing benthic communities in Strata 5a and 5b are considered appropriate representations of reference conditions in Ward Cove.

7.4 Summary of Reference Area Evaluations

Based on the evaluations of the physical/chemical sediment characteristics, sediment toxicity, and benthic macroinvertebrate communities found in Strata 5a and 5b during the 2004 monitoring event in Ward Cove, it is concluded that both strata are appropriate reference areas for the various benthic strata in the AOC. The physical/chemical characteristics of the sediments in both strata were considered representative of the large-scale background conditions in the cove, concentrations of both CoCs were generally below their respective site-specific WCSQVs, no sediment toxicity was observed that could be related to chemical contaminants, and benthic macroinvertebrate communities were considered reflective of the background levels of TOC found in the cove.

Although Strata 5a and 5b are each considered an appropriate reference area taken as a whole, based on the results of the 2004 monitoring event, it was clear that individual replicate samples from both strata could be affected by elevated ammonia concentrations (i.e., as a natural by-product of organic degradation) or by low values of amphipod survival (i.e., as a result of the natural variability sometimes encountered with the toxicity test). It therefore is recommended that seven replicate samples be analyzed for sediment chemistry, sediment toxicity, and benthic communities in each reference area in the future. The first five samples collected would be the preferred samples and would be the ones used for statistical comparisons if they all satisfy the chemical and toxicity criteria for valid reference conditions. However, if a replicate does not meet one of the selection criteria, it would be replaced by the sixth replicate collected, assuming that replicate meets the criteria. If a second replicate also does not meet one of the criteria, it would be replaced by the seventh replicate. In this manner, the probability of obtaining five replicate samples from each reference area that meet all selection criteria will be enhanced.

8 Conclusions and Recommendations

Based on the results of the 2004 monitoring event in Ward Cove, it can be concluded that environmental conditions in many parts of the Ward Cove AOC have improved since the RI/FS was conducted in 1996–1997. The TLP was successful in providing enhanced benthic habitats that have been colonized by numerous benthic taxa, many of which were not found in sediment samples collected in the cove in 1992. By contrast, only one of the four natural recovery areas has shown improvements that are comparable to those found in the three TLP areas.

Figures 20a and 20b provide summaries of the key variables monitored in the benthic strata of Ward Cove in 2004. The figures show that concentrations of the two CoCs (ammonia and 4-methylphenol) are below site-specific sediment quality values in all three TLP areas, as well as the shallow natural recovery area with thin organic deposits. By contrast, both CoCs exceed the sediment quality values in the remaining three natural recovery areas. Sediment toxicity was also not found in the three TLP areas, as well as the shallow natural recovery area with thin organic deposits. However, toxicity was found in two of the remaining three natural recovery areas.

With respect to benthic macroinvertebrate communities, Figures 20a and 20b show that multiple benthic community metrics differed significantly ($P \leq 0.05$) from reference conditions only in the shallow natural recovery area with thick organic deposits. Those results, combined with the results of evaluations of key benthic species, evaluations of temporal patterns in community characteristics, multivariate analysis of benthic communities, and evaluations of taxa richness at individual stations, showed that diverse communities comprising multiple taxa now inhabit most parts of the three TLP areas, as well as the natural recovery area with thin organic deposits. Given that those four areas are generally free from chemical contamination and sediment toxicity, there is no reason to suspect that they will not continue to support such diverse communities in the future. By contrast, benthic communities in the three remaining natural recovery areas have not progressed as far along the recovery spectrum as those in the TLP areas.

Based on the results of the 2004 monitoring event, the following recommendations can be made:

- Monitoring is no longer necessary for the shallow natural recovery area with thin organic deposits (Stratum 2c), because the RAOs have been achieved for this area. That is, sediment toxicity has been reduced and benthic recolonization has been enhanced such that this area now supports healthy benthic communities with multiple taxonomic groups.

- Monitoring should continue for the three TLP areas (Strata 1, 2a, and 3a). The 2004 results demonstrate that RAOs have been achieved for these areas; however, additional data are needed to confirm that reduced toxicity and a healthy benthic community with multiple taxonomic groups can be maintained over time. If the 2007 monitoring results (sediment chemistry, sediment toxicity tests, and benthic community analyses) are consistent with or better than the 2004 data, monitoring of benthic communities, and potentially sediment chemistry and toxicity, in the TLP areas should be discontinued.

- Monitoring should continue in the three remaining natural recovery areas (Strata 2b, 3b, and 4) primarily because sediment toxicity exists in two of the areas (Strata 3b and 4) and multiple taxonomic groups have not yet been observed in these areas.
- Station 67 should be moved so that it is located within the actual TLP area of Stratum 1.
- No changes are recommended for depth strata classifications.
- Based on evaluations of the physical/chemical sediment characteristics, sediment toxicity results, and benthic macroinvertebrate communities found in the two reference areas (Strata 5a and 5b) during the 2004 monitoring event, it was concluded that both strata are representative of the large-scale background conditions found in Ward Cove. It therefore is recommended that Strata 5a and 5b continue to be used as reference areas during future monitoring events.
- Although it is recommended that Strata 5a and 5b continue to be used as reference areas, seven replicate samples should be analyzed for sediment chemistry, sediment toxicity, and benthic communities in each reference stratum in the future, to enhance the probability that all five replicates used for statistical comparisons with AOC strata will meet all reference area selection criteria.
- *Eohaustorius estuarius* should continue to be used as the sediment toxicity test species because it proved to be a highly responsive test during the 2004 monitoring event, with survival values ranging from 0 to 100 percent.
- The initial draft report should be due to EPA in January of the year following the July sampling, to allow sufficient time for taxonomic analysis, in addition to data analysis and report preparation. All additional deliverables to EPA should be due 30 days after receipt of EPA comments on previous deliverables.

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Figures

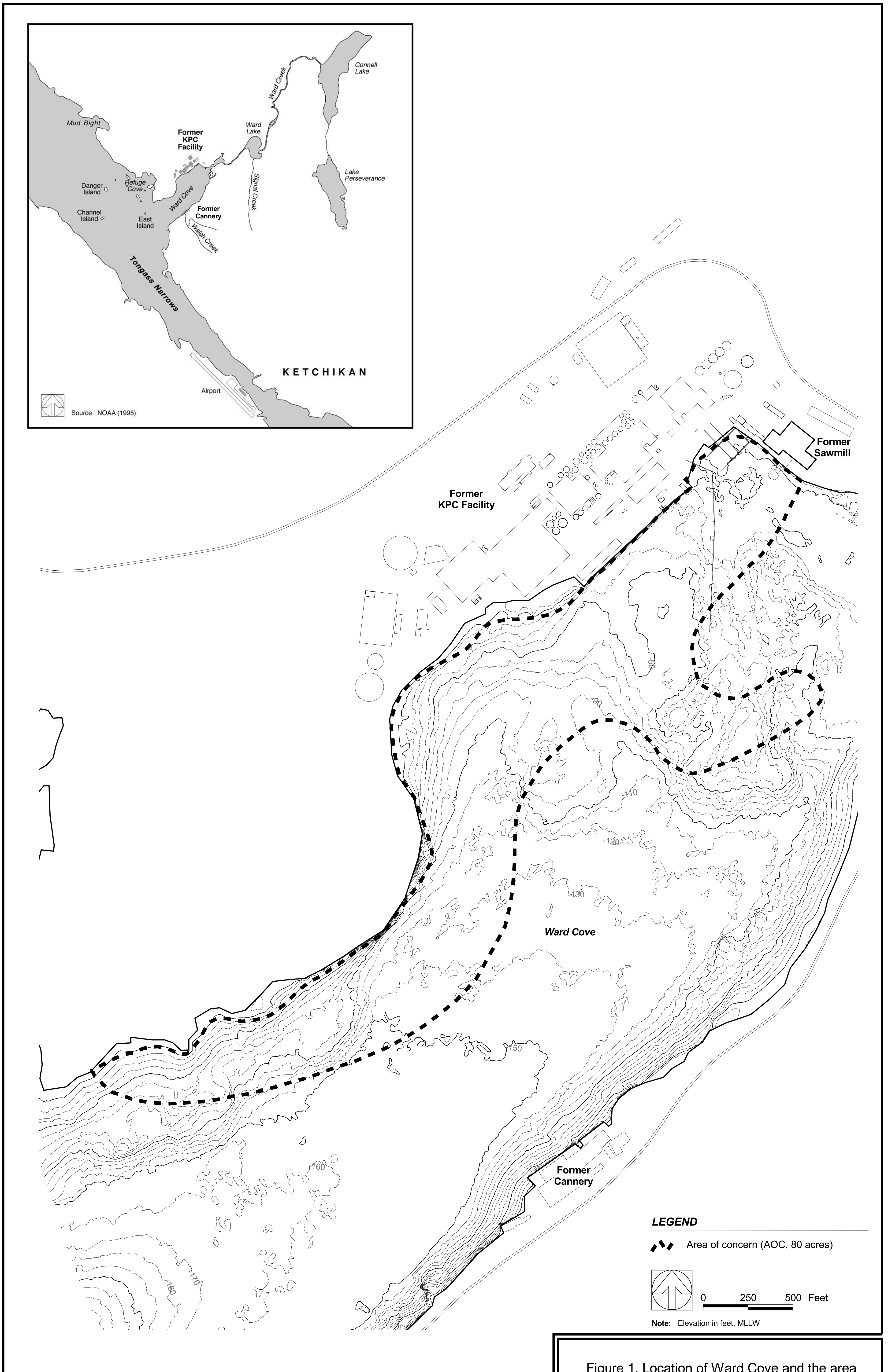

Figure 1. Location of Ward Cove and the area of concern within the cove

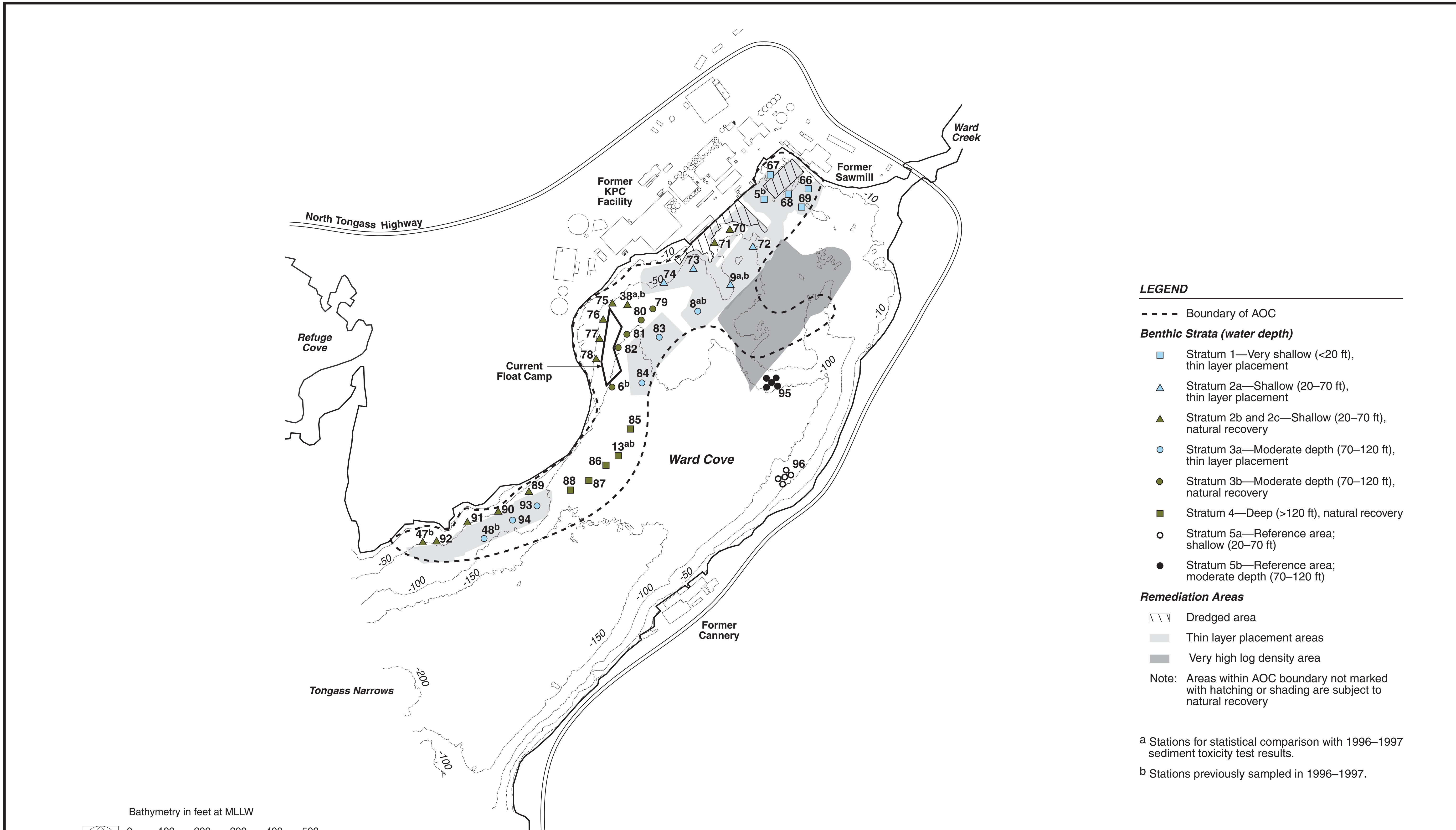

Figure 2. Locations of the Ward Cove AOC; areas of thin layer placement, dredging, natural recovery; and stations sampled in July 2004

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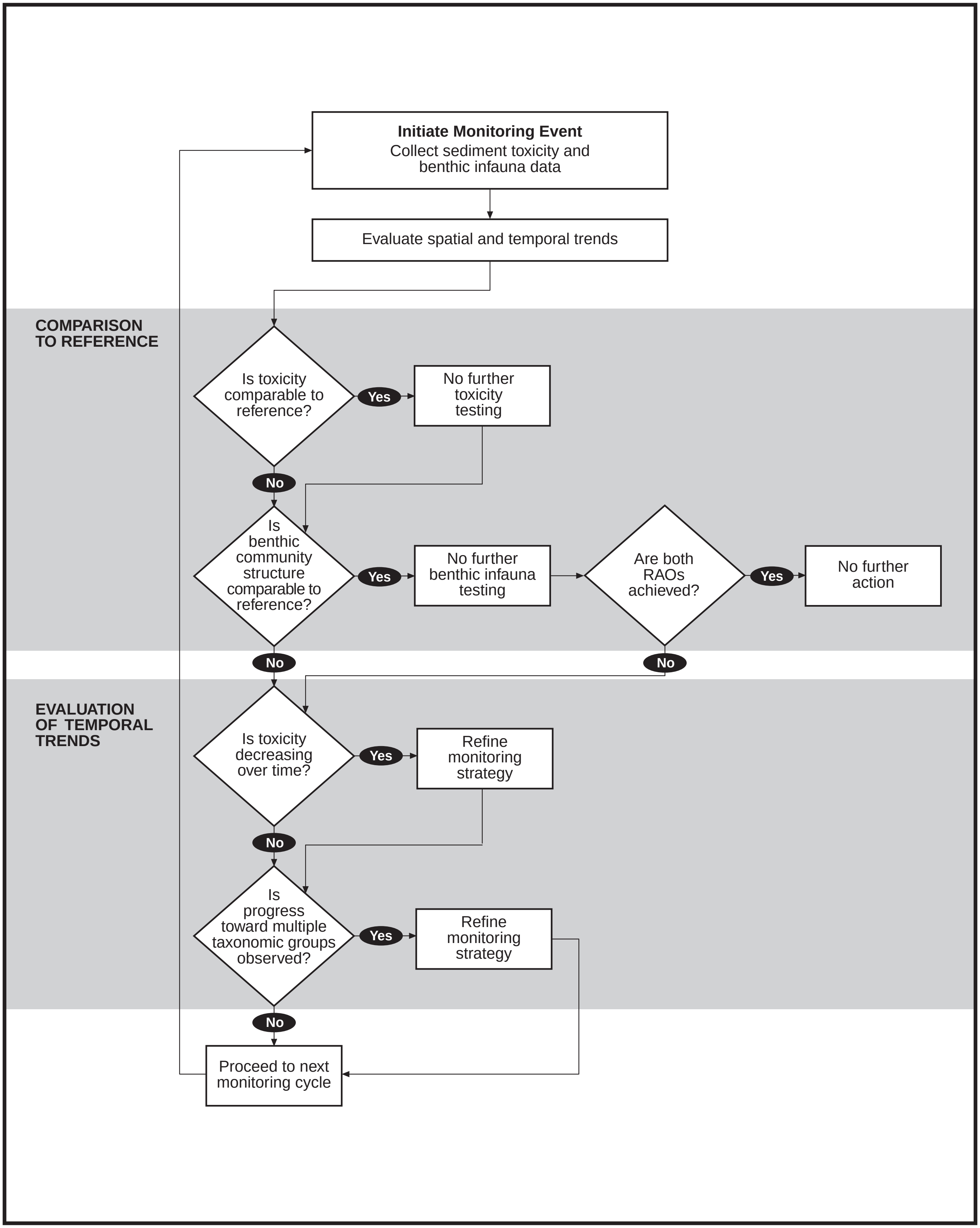

Figure 3. Overview of process for evaluating monitoring data

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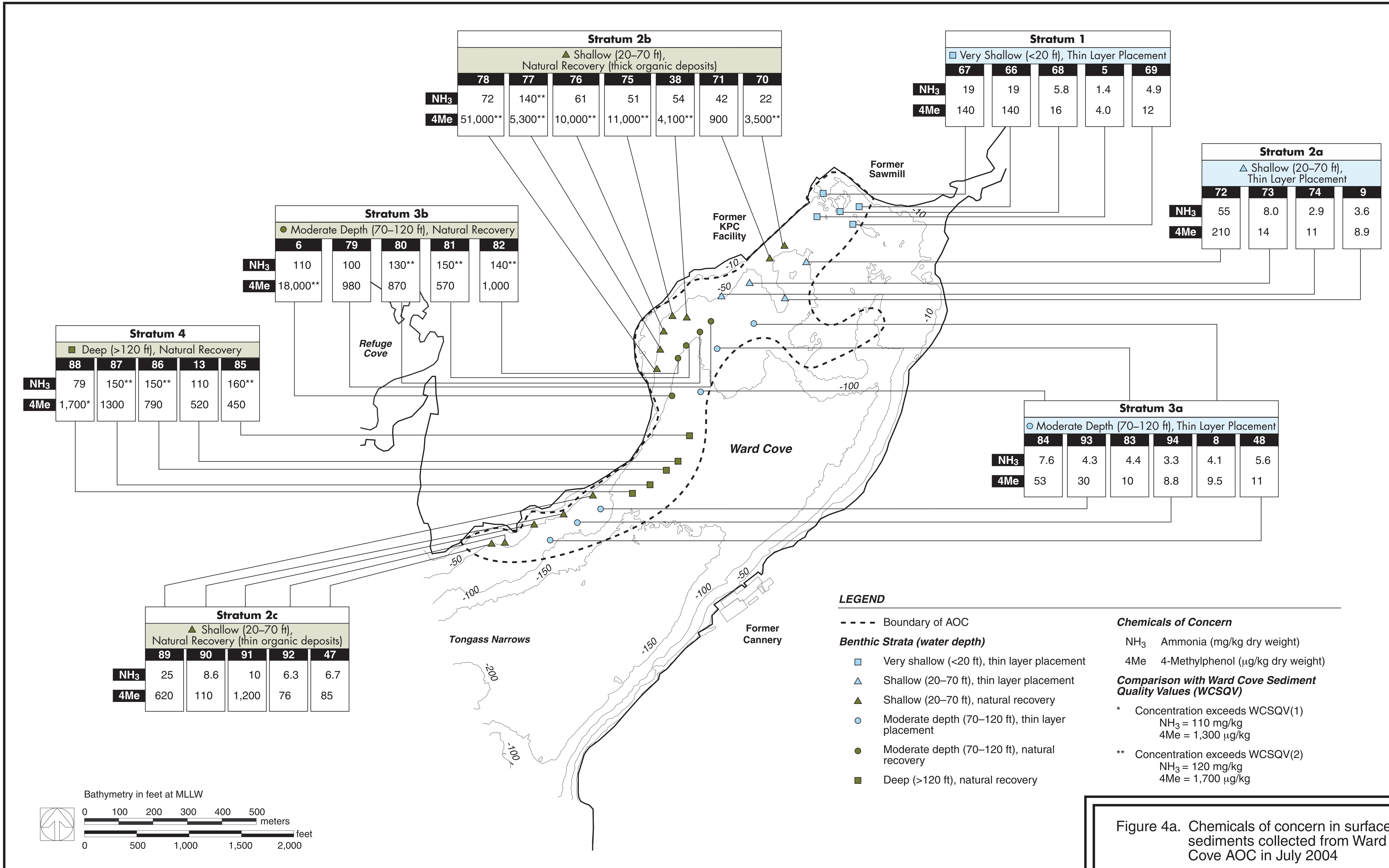

Figure 4a. Chemicals of concern in surface sediments collected from Ward Cove AOC in July 2004

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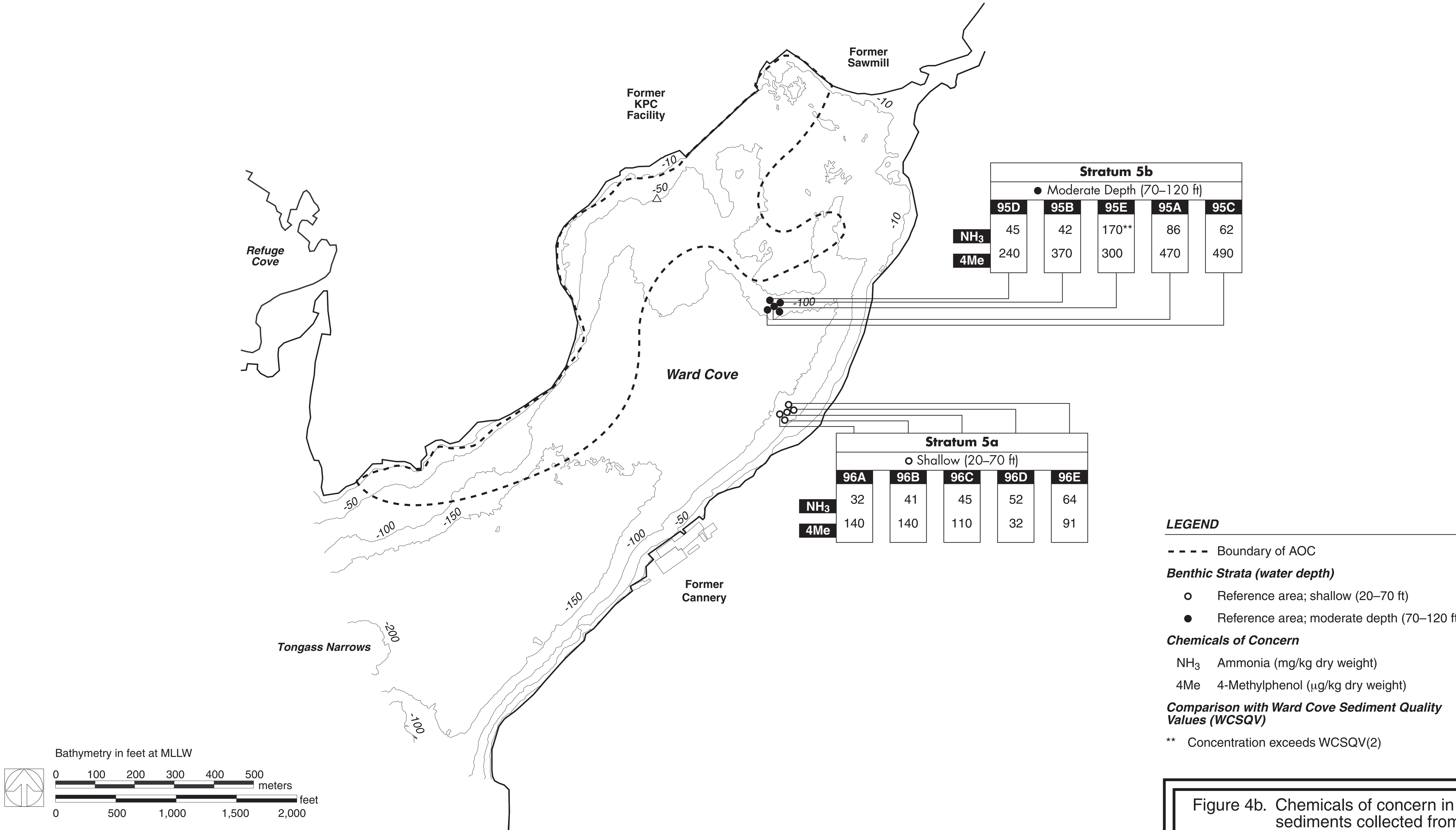

Figure 4b. Chemicals of concern in surface sediments collected from Ward Cove reference areas in July 2004

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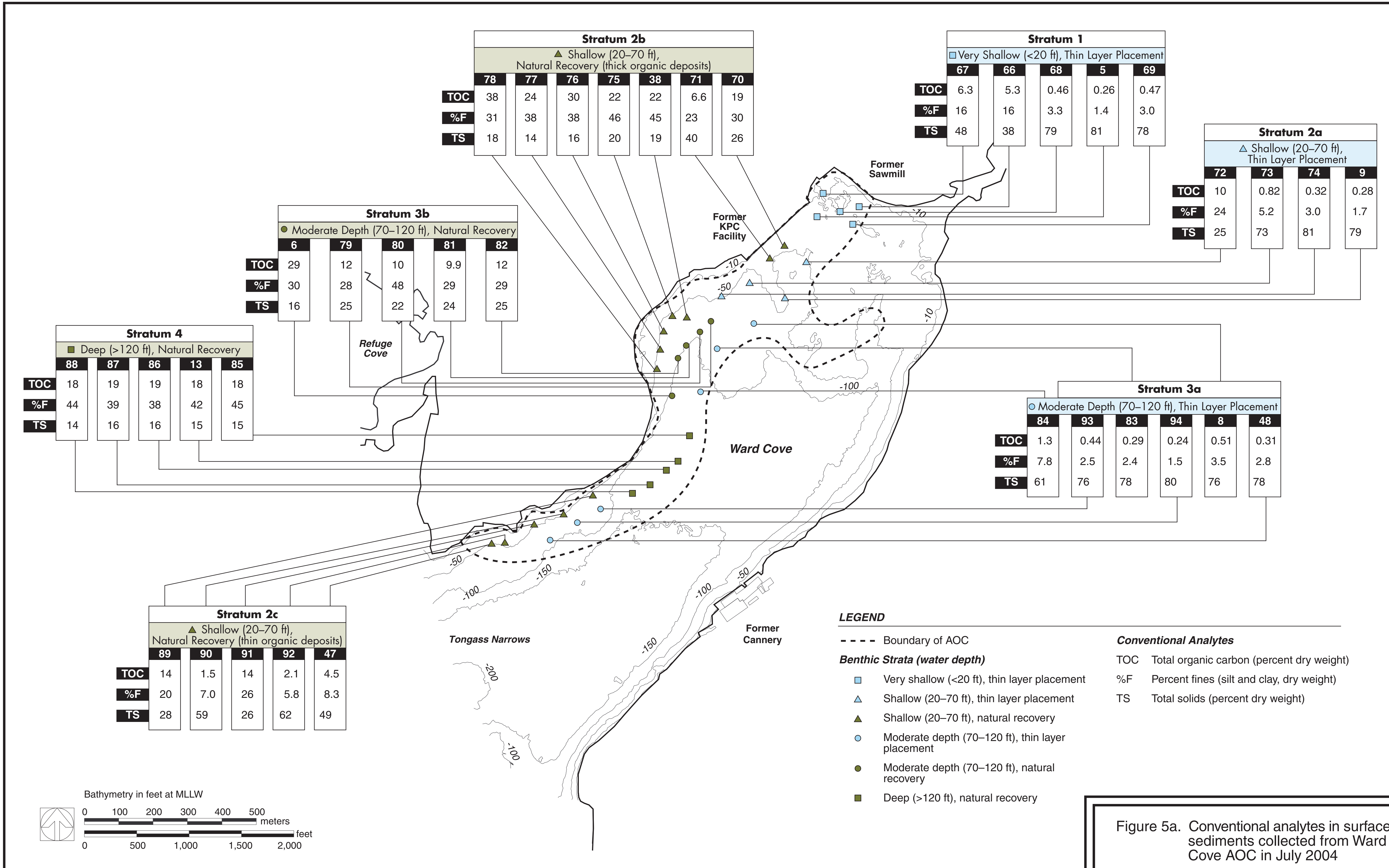

Stratum 2b — Shallow (20–70 ft), Natural Recovery (thick organic deposits)

	78	77	76	75	38	71	70
TOC	38	24	30	22	22	6.6	19
%F	31	38	38	46	45	23	30
TS	18	14	16	20	19	40	26

Stratum 1 — Very Shallow (<20 ft), Thin Layer Placement

	67	66	68	5	69
TOC	6.3	5.3	0.46	0.26	0.47
%F	16	16	3.3	1.4	3.0
TS	48	38	79	81	78

Stratum 2a — Shallow (20–70 ft), Thin Layer Placement

	72	73	74	9
TOC	10	0.82	0.32	0.28
%F	24	5.2	3.0	1.7
TS	25	73	81	79

Stratum 3b — Moderate Depth (70–120 ft), Natural Recovery

	6	79	80	81	82
TOC	29	12	10	9.9	12
%F	30	28	48	29	29
TS	16	25	22	24	25

Stratum 4 — Deep (>120 ft), Natural Recovery

	88	87	86	13	85
TOC	18	19	19	18	18
%F	44	39	38	42	45
TS	14	16	16	15	15

Stratum 3a — Moderate Depth (70–120 ft), Thin Layer Placement

	84	93	83	94	8	48
TOC	1.3	0.44	0.29	0.24	0.51	0.31
%F	7.8	2.5	2.4	1.5	3.5	2.8
TS	61	76	78	80	76	78

Stratum 2c — Shallow (20–70 ft), Natural Recovery (thin organic deposits)

	89	90	91	92	47
TOC	14	1.5	14	2.1	4.5
%F	20	7.0	26	5.8	8.3
TS	28	59	26	62	49

Figure 5a. Conventional analytes in surface sediments collected from Ward Cove AOC in July 2004

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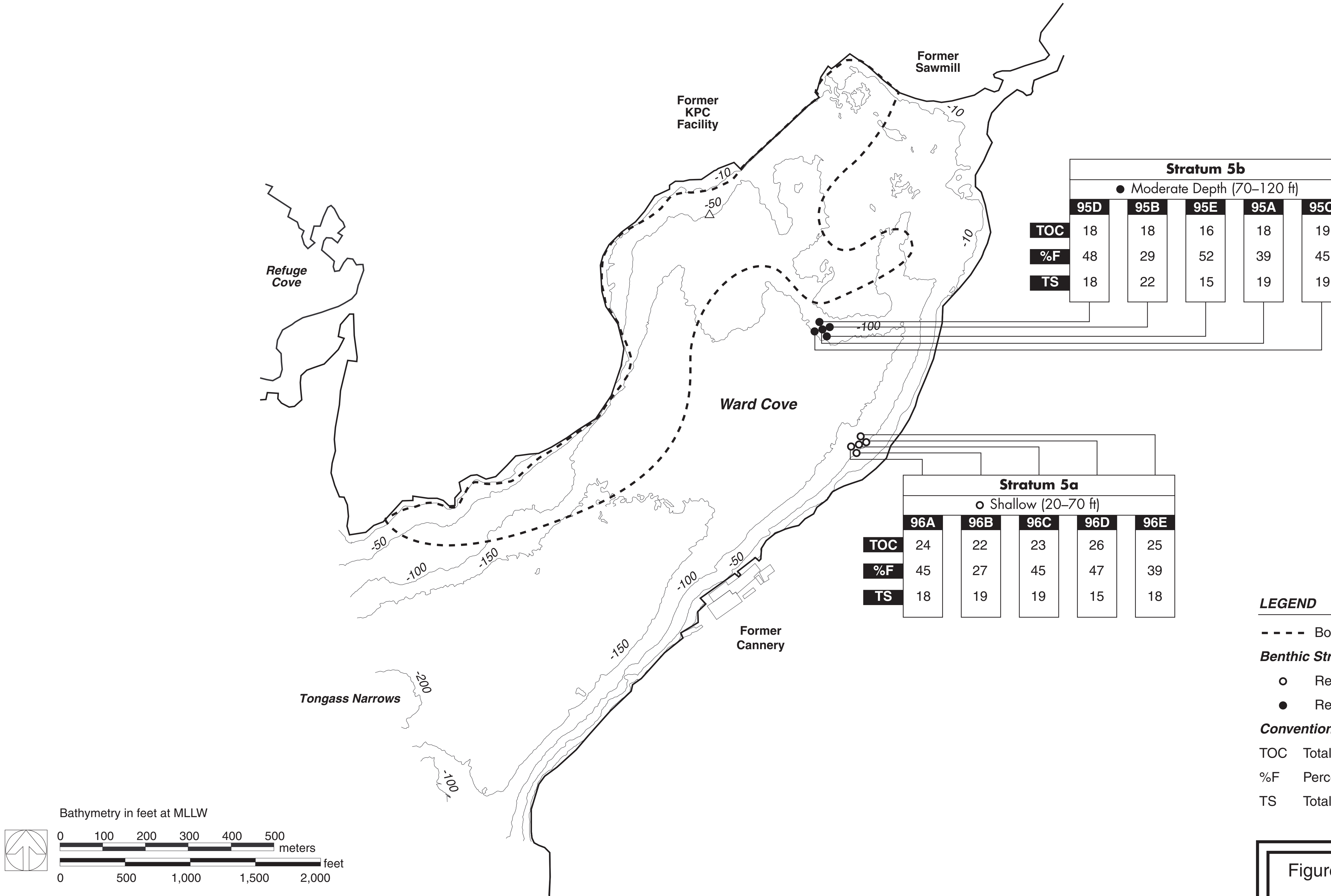

Stratum 5b

● Moderate Depth (70–120 ft)

	95D	95B	95E	95A	95C
TOC	18	18	16	18	19
%F	48	29	52	39	45
TS	18	22	15	19	19

Stratum 5a

○ Shallow (20–70 ft)

	96A	96B	96C	96D	96E
TOC	24	22	23	26	25
%F	45	27	45	47	39
TS	18	19	19	15	18

LEGEND

- - - - Boundary of AOC

Benthic Strata (water depth)

○ Reference area; shallow (20–70 ft)

● Reference area; moderate depth (70–120 ft)

Conventional Analytes

TOC Total organic carbon (percent dry weight)

%F Percent fines (silt and clay, dry weight)

TS Total solids (percent dry weight)

Figure 5b. Conventional analytes in surface sediments collected from Ward Cove reference areas in July 2004

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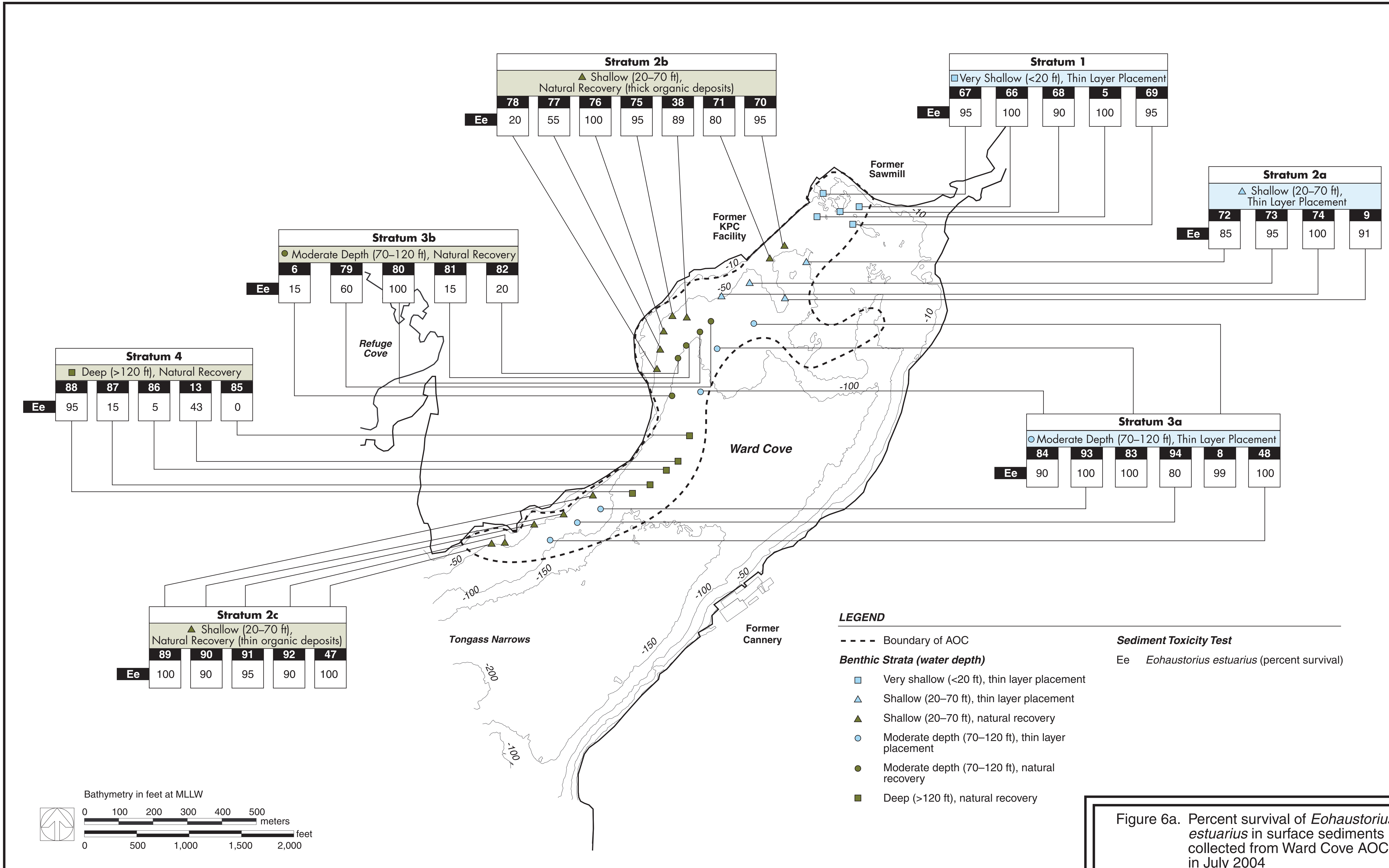

Figure 6a. Percent survival of *Eohaustorius estuarius* in surface sediments collected from Ward Cove AOC in July 2004

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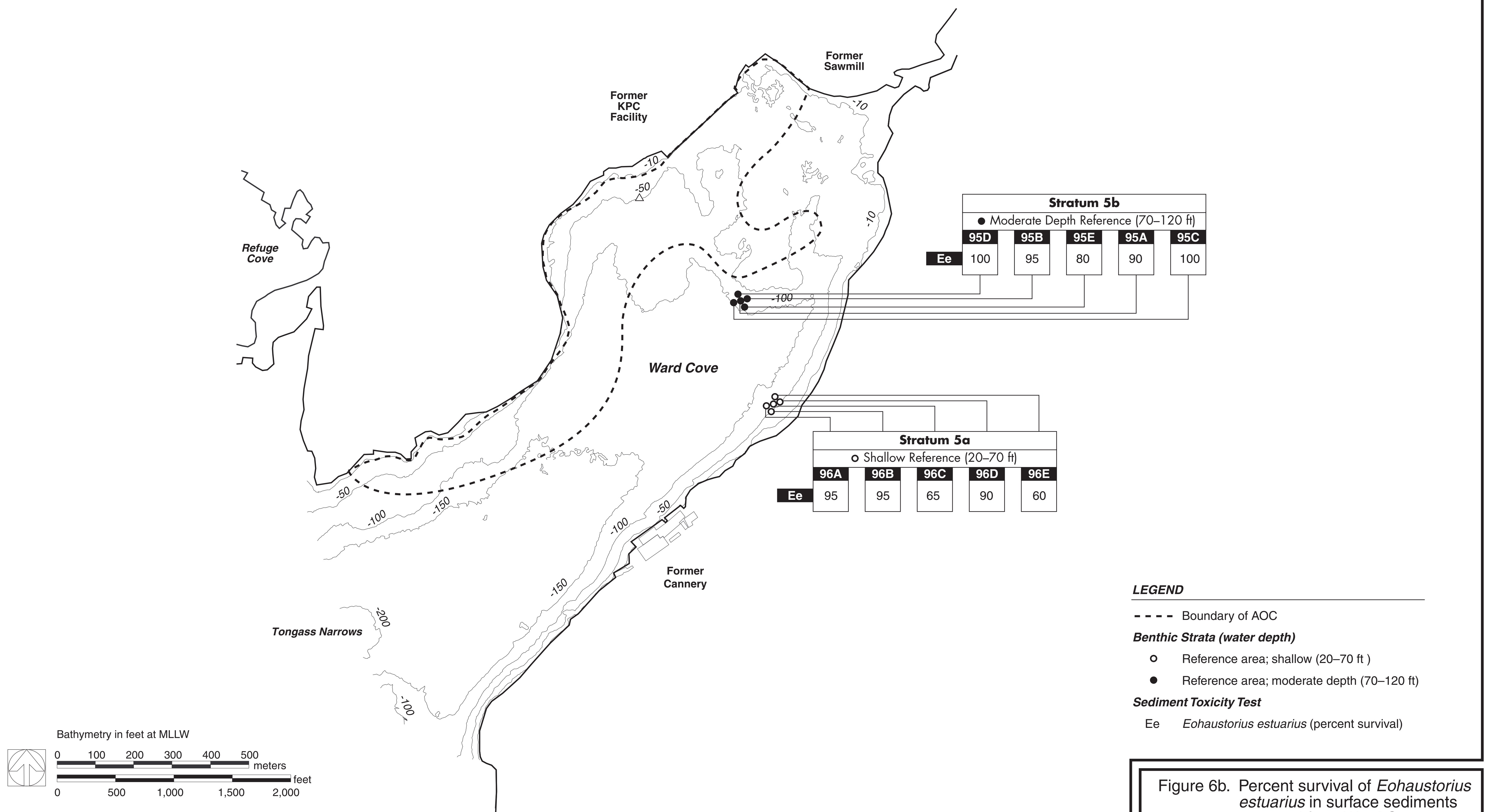

Figure 6b. Percent survival of *Eohaustorius estuarius* in surface sediments collected from Ward Cove reference areas in July 2004

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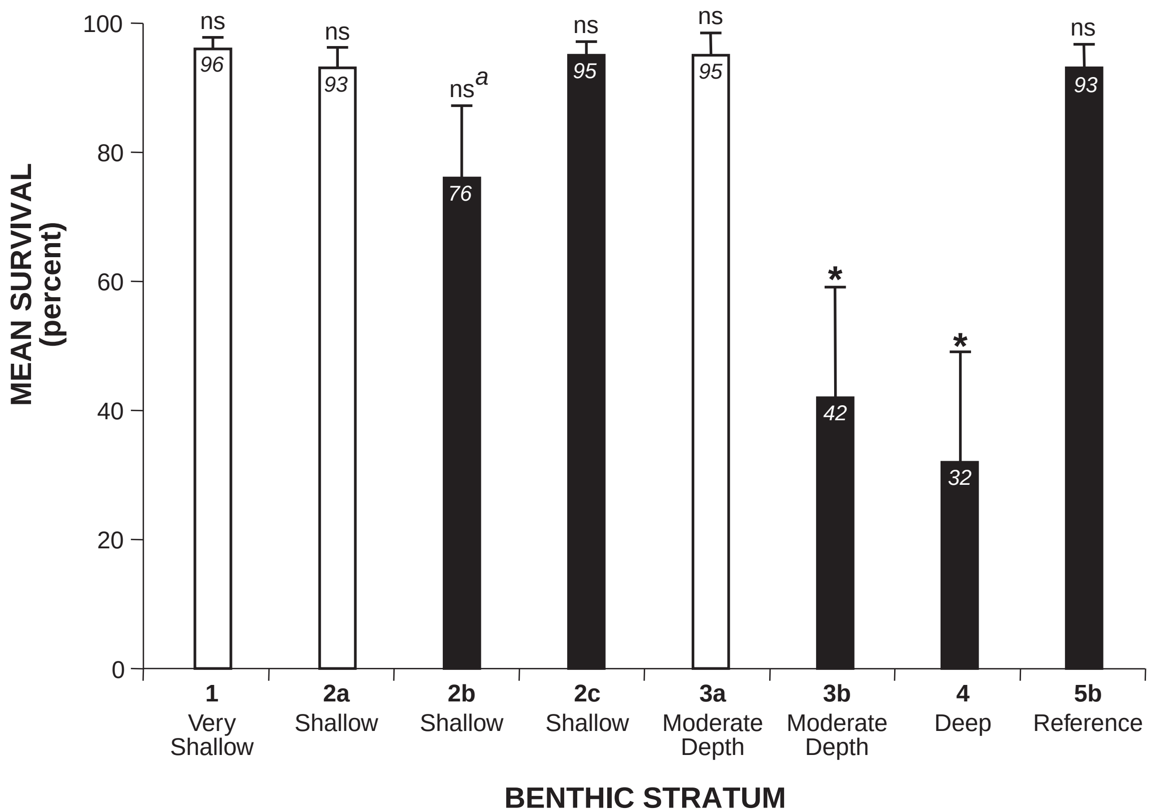

LEGEND

- Thin layer placement area
- Natural recovery area
- Standard error
- * Significantly different ($P \leq 0.05$) from mean reference value
- ns Not significantly different ($P > 0.05$) from mean reference value
- *a* Low statistical power due to high variance

Note: Value of mean amphipod survival is noted at top of each bar

Figure 7. Statistical comparisons of mean amphipod survival between Ward Cove AOC benthic strata and the reference area

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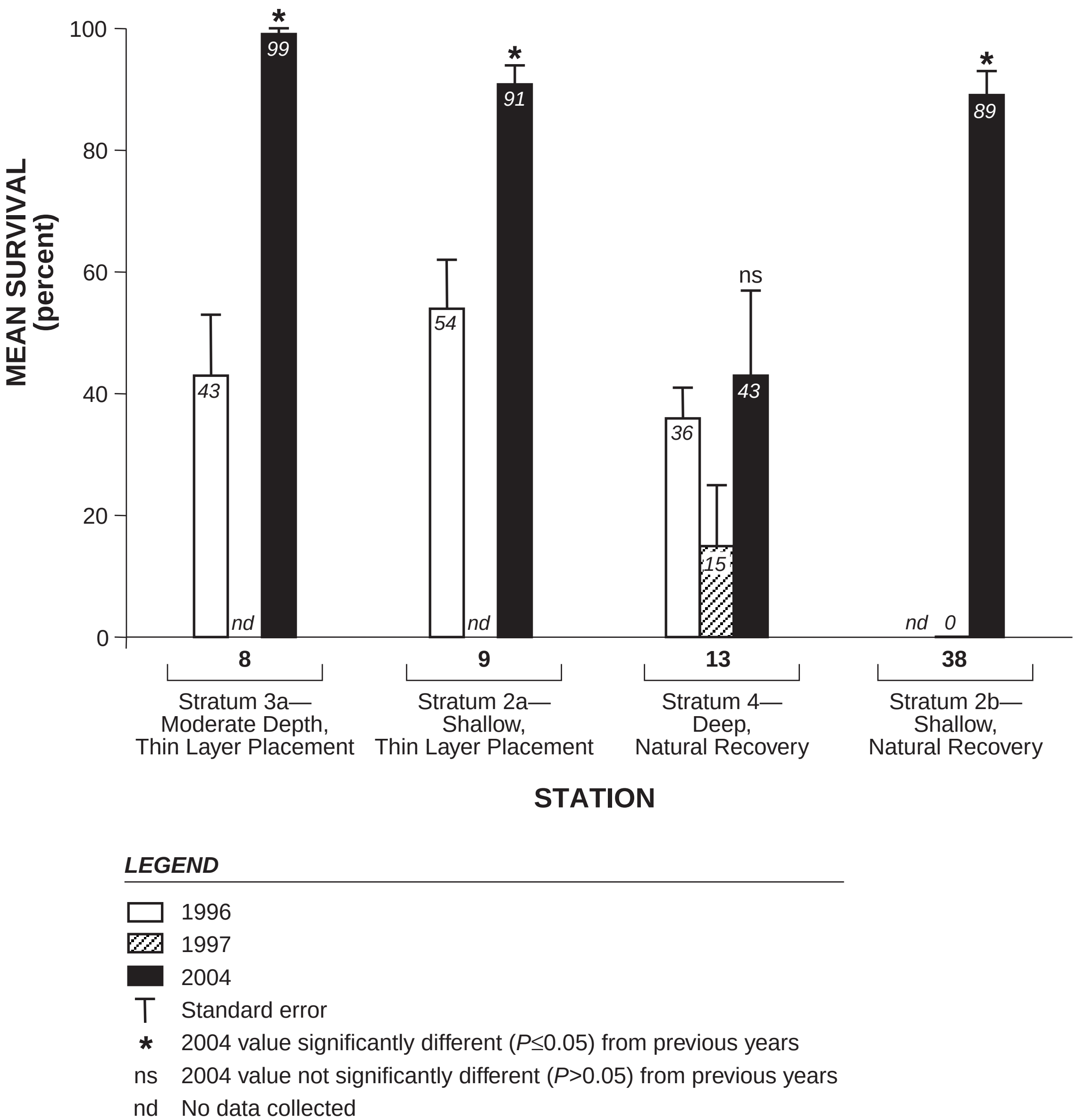

Note: Value of mean amphipod survival is noted at top of each bar

Figure 8. Statistical comparisons of mean amphipod survival between 1996–1997 and 2004

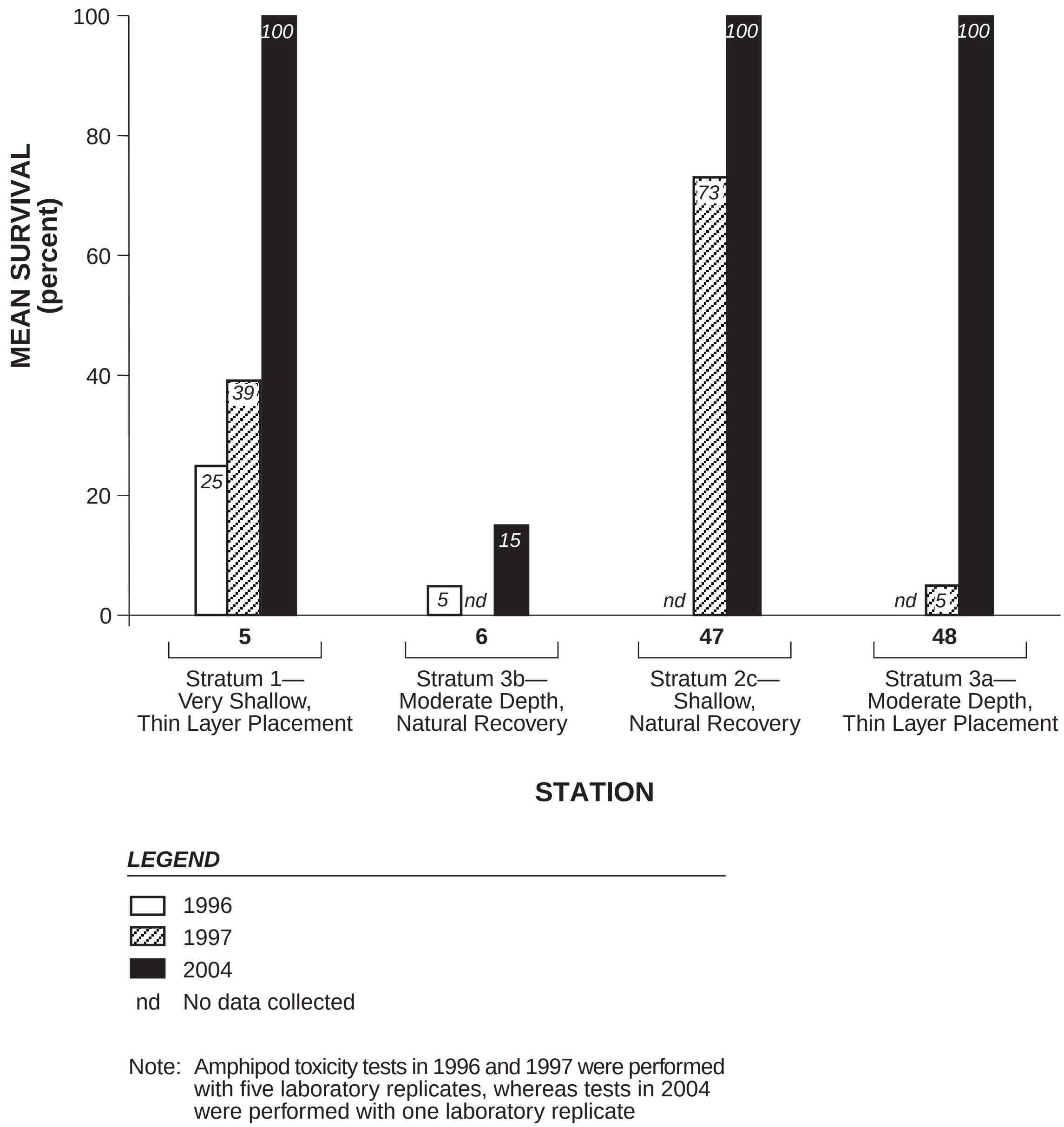

Figure 9. Qualitative comparisons of mean amphipod survival between 1996–1997 and 2004

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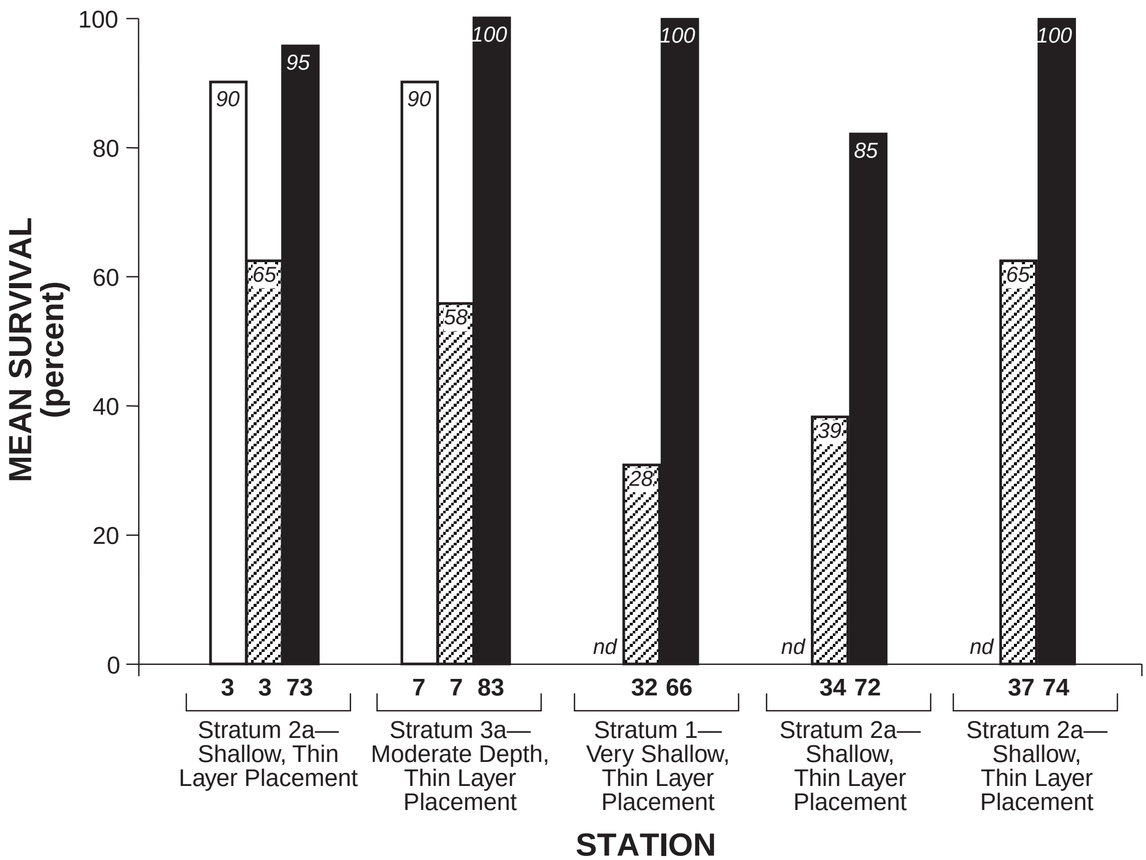


LEGEND

- 1996
- 1997
- 2004
- nd No data collected

Note: Amphipod toxicity tests in 1996 and 1997 were performed with five laboratory replicates, whereas tests in 2004 were performed with one laboratory replicate.

Figure 10. Qualitative comparisons of mean amphipod survival between 1996–1997 stations and 2004 stations estimated to be within 30 m of one another and located within thin layer placement strata

Stratum 2b

Shallow (20–70 ft), Natural Recovery (thick organic deposits)

	78	77	76	75	38	71	70
TA	960	9	13	6	109	14	7
TR	6	4	4	2	2	2	3
SDI	1	2	2	2	1	1	2

Stratum 1

Very Shallow (<20 ft), Thin Layer Placement

	67	66	68	5	69
TA	20	170	341	175	188
TR	3	23	26	28	29
SDI	1	4	4	4	6

Stratum 2a

Shallow (20–70 ft), Thin Layer Placement

	72	73	74	9
TA	18	127	26	27
TR	4	25	11	14
SDI	2	7	6	8

Stratum 3b

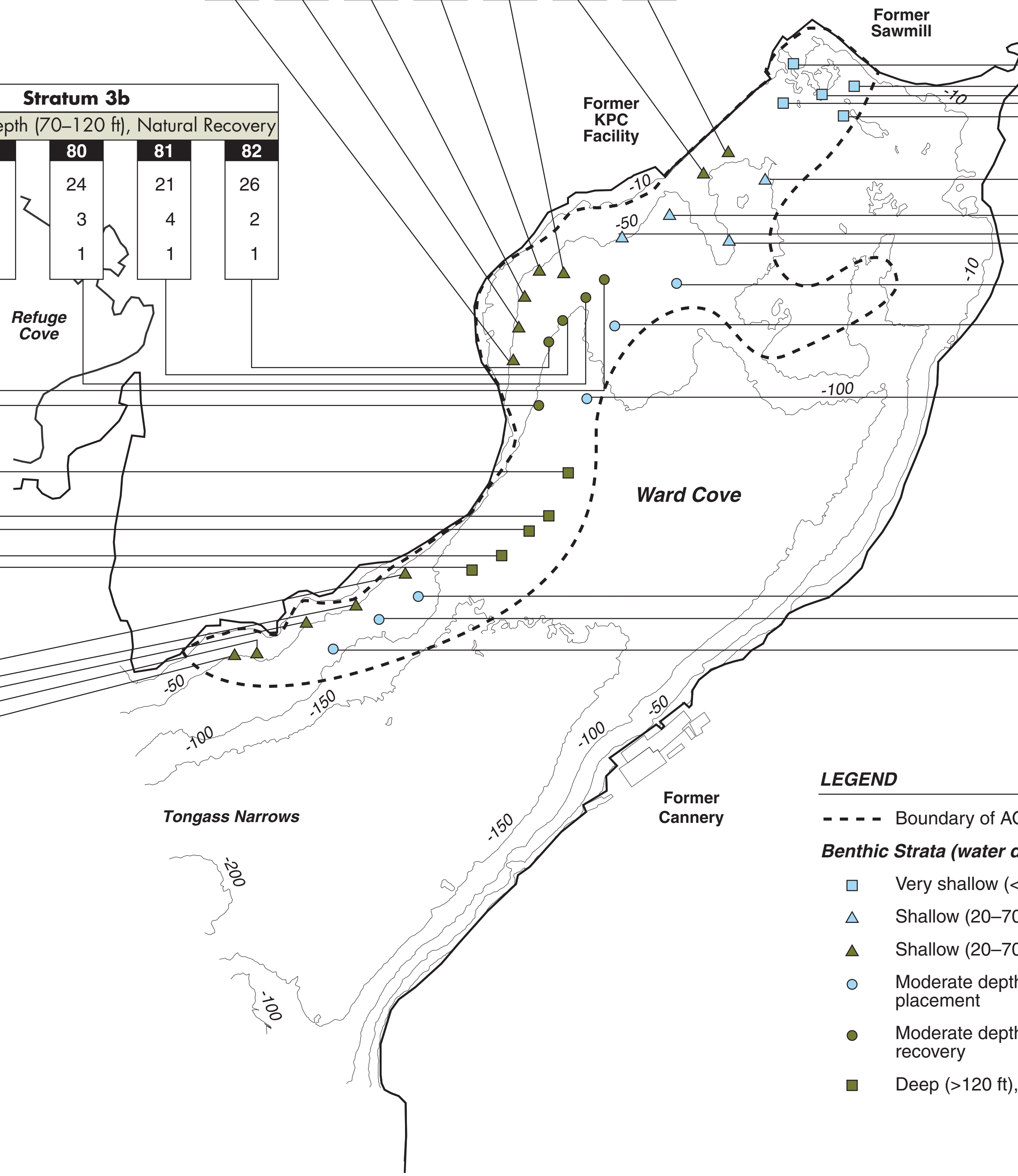
Moderate Depth (70–120 ft), Natural Recovery

	6	79	80	81	82
TA	7	16	24	21	26
TR	5	2	3	4	2
SDI	4	1	1	1	1

Stratum 4

Deep (>120 ft), Natural Recovery

	88	87	86	13	85
TA	11	32	5	12	27
TR	3	7	3	5	6
SDI	1	2	2	2	1



Stratum 3a

Moderate Depth (70–120 ft), Thin Layer Placement

	84	93	83	94	8	48
TA	19	62	106	49	42	115
TR	13	19	30	18	10	29
SDI	9	6	11	6	3	10

Stratum 2c

Shallow (20–70 ft), Natural Recovery (thin organic deposits)

	89	90	91	92	47
TA	97	128	31	32	117
TR	30	39	17	19	28
SDI	12	14	10	11	10

LEGEND

- - - - Boundary of AOC

Benthic Strata (water depth)

- Very shallow (<20 ft), thin layer placement
- Shallow (20–70 ft), thin layer placement
- Shallow (20–70 ft), natural recovery
- Moderate depth (70–120 ft), thin layer placement
- Moderate depth (70–120 ft), natural recovery
- Deep (>120 ft), natural recovery

Benthic Metrics

TA Total abundance
TR Total richness
SDI Swartz' dominance index

Bathymetry in feet at MLLW

0 100 200 300 400 500 meters

0 500 1,000 1,500 2,000 feet

Figure 11a. Total abundance, total richness, and Swartz' dominance index for benthic communities sampled in Ward Cove AOC in July 2004

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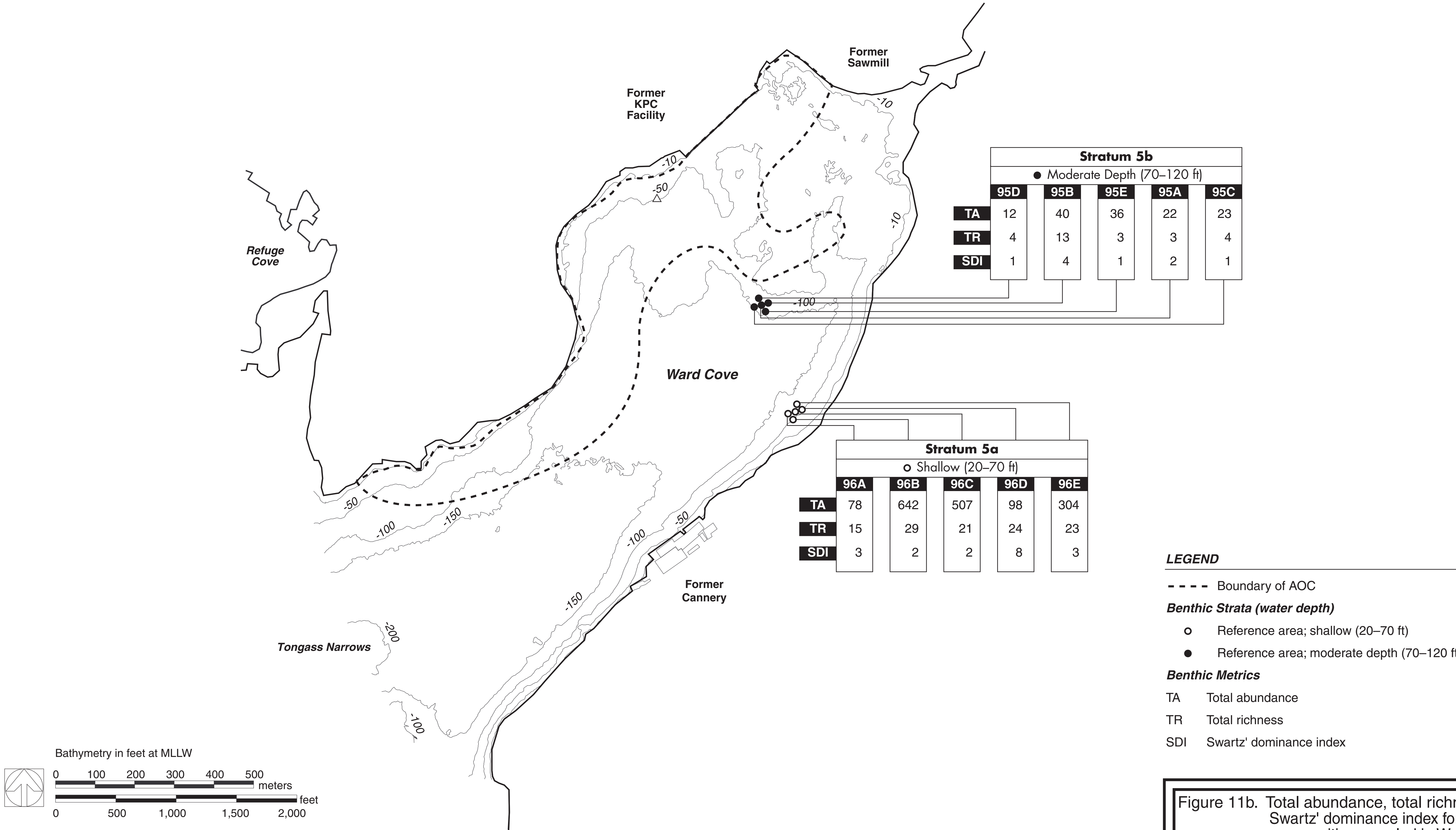

Stratum 5b — ● Moderate Depth (70–120 ft)

	95D	95B	95E	95A	95C
TA	12	40	36	22	23
TR	4	13	3	3	4
SDI	1	4	1	2	1

Stratum 5a — ○ Shallow (20–70 ft)

	96A	96B	96C	96D	96E
TA	78	642	507	98	304
TR	15	29	21	24	23
SDI	3	2	2	8	3

Figure 11b. Total abundance, total richness, and Swartz' dominance index for benthic communities sampled in Ward Cove reference areas in July 2004

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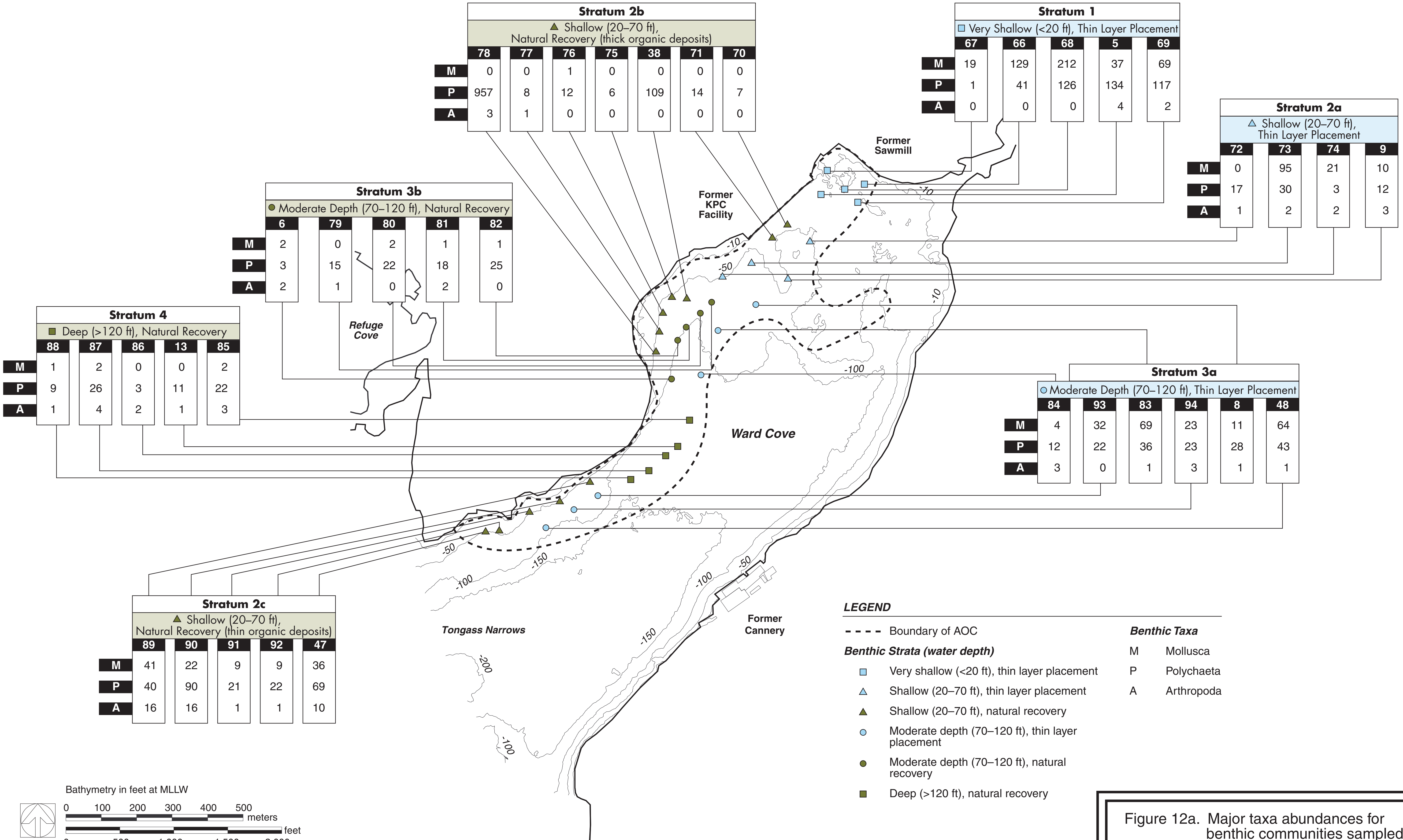


Stratum 2b
Shallow (20–70 ft), Natural Recovery (thick organic deposits)

	78	77	76	75	38	71	70
M	0	0	1	0	0	0	0
P	957	8	12	6	109	14	7
A	3	1	0	0	0	0	0

Stratum 1
Very Shallow (<20 ft), Thin Layer Placement

	67	66	68	5	69
M	19	129	212	37	69
P	1	41	126	134	117
A	0	0	0	4	2

Stratum 2a
Shallow (20–70 ft), Thin Layer Placement

	72	73	74	9
M	0	95	21	10
P	17	30	3	12
A	1	2	2	3

Stratum 3b
Moderate Depth (70–120 ft), Natural Recovery

	6	79	80	81	82
M	2	0	2	1	1
P	3	15	22	18	25
A	2	1	0	2	0

Stratum 4
Deep (>120 ft), Natural Recovery

	88	87	86	13	85
M	1	2	0	0	2
P	9	26	3	11	22
A	1	4	2	1	3

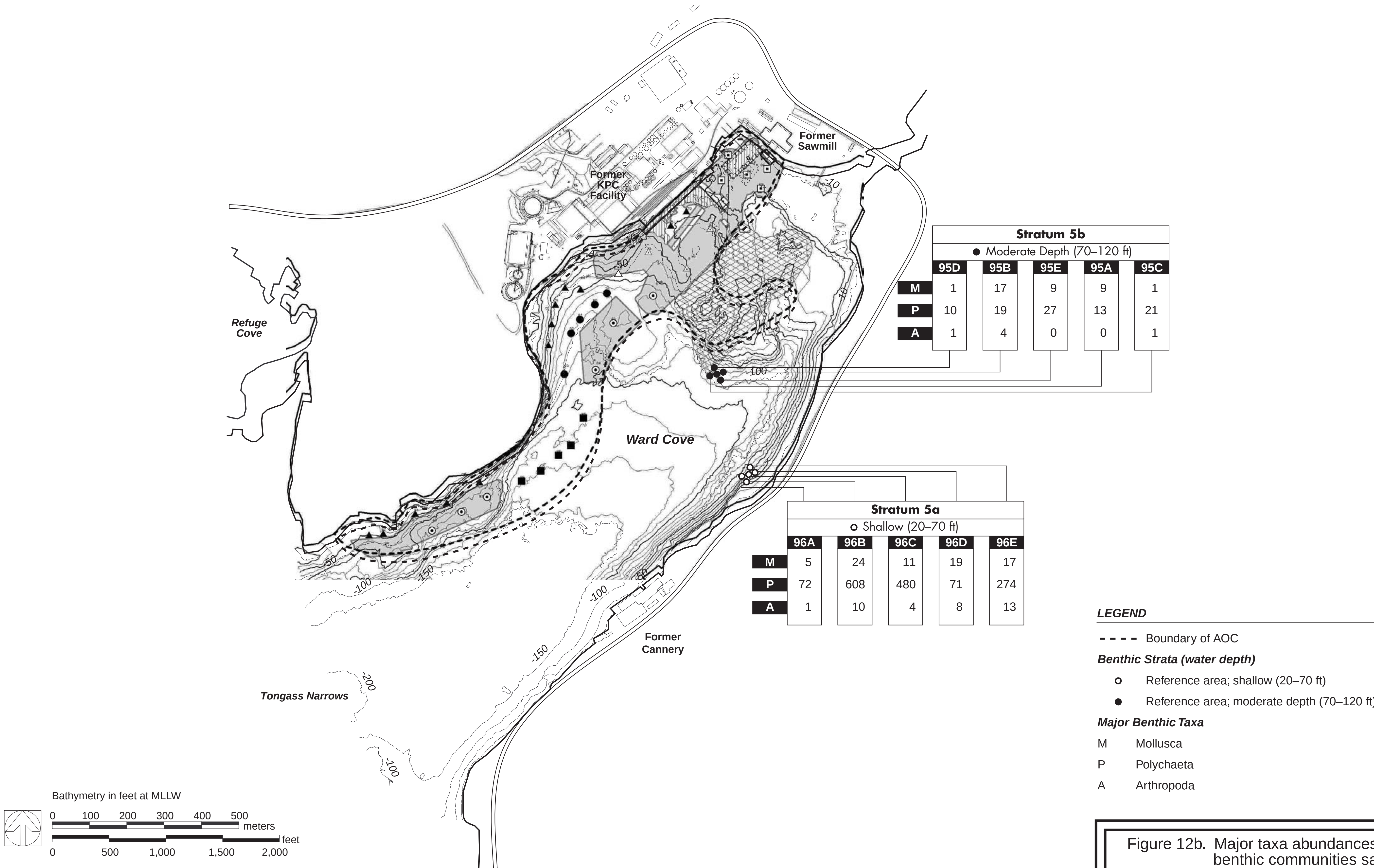
Stratum 3a
Moderate Depth (70–120 ft), Thin Layer Placement

	84	93	83	94	8	48
M	4	32	69	23	11	64
P	12	22	36	23	28	43
A	3	0	1	3	1	1

Stratum 2c
Shallow (20–70 ft), Natural Recovery (thin organic deposits)

	89	90	91	92	47
M	41	22	9	9	36
P	40	90	21	22	69
A	16	16	1	1	10

Figure 12a. Major taxa abundances for benthic communities sampled in Ward Cove AOC in July 2004



Stratum 5b — Moderate Depth (70–120 ft)

	95D	95B	95E	95A	95C
M	1	17	9	9	1
P	10	19	27	13	21
A	1	4	0	0	1

Stratum 5a — Shallow (20–70 ft)

	96A	96B	96C	96D	96E
M	5	24	11	19	17
P	72	608	480	71	274
A	1	10	4	8	13

Figure 12b. Major taxa abundances for benthic communities sampled in Ward Cove reference areas in July 2004

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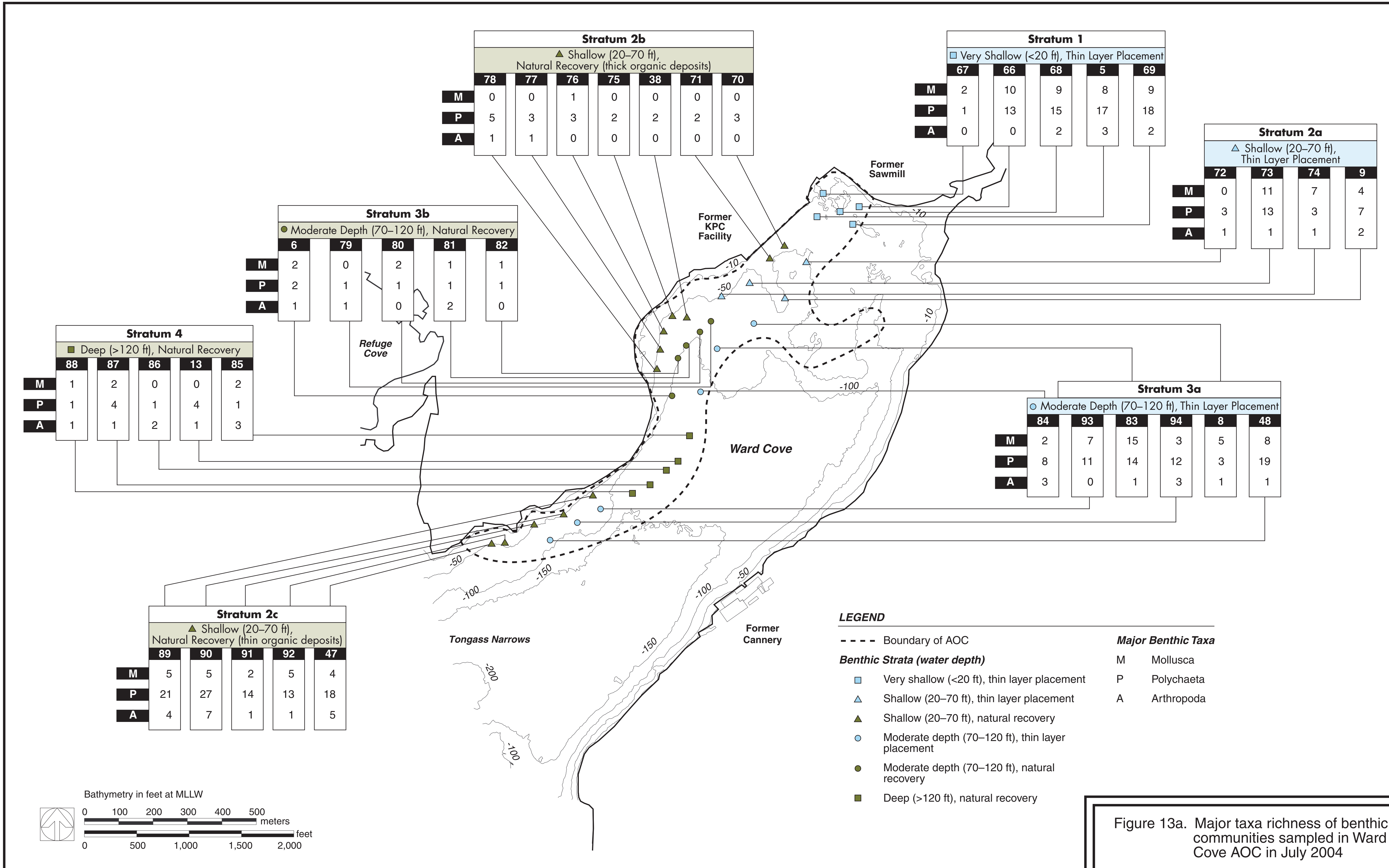

Figure 13a. Major taxa richness of benthic communities sampled in Ward Cove AOC in July 2004

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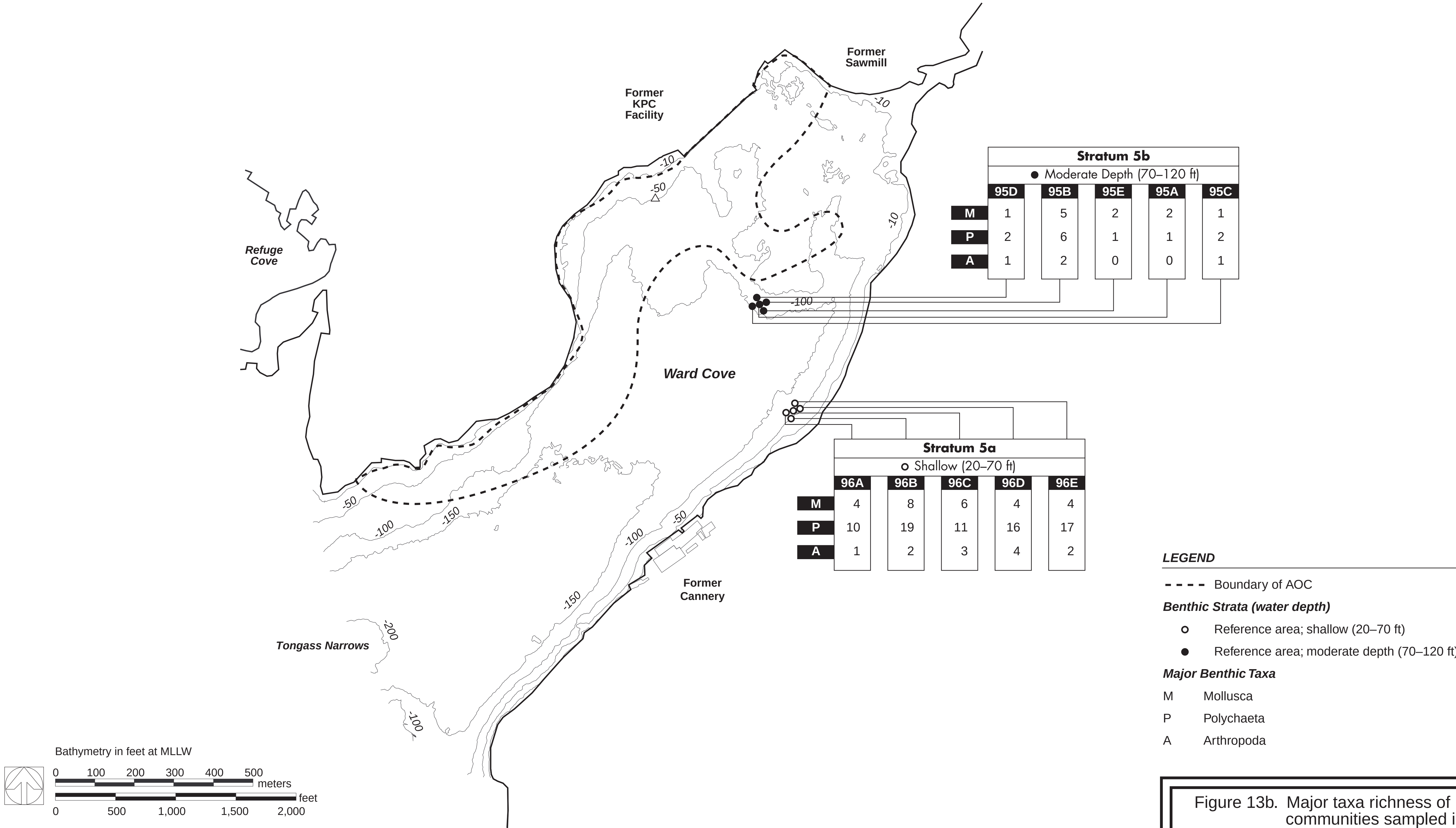


Figure 13b. Major taxa richness of benthic communities sampled in Ward Cove reference areas in July 2004

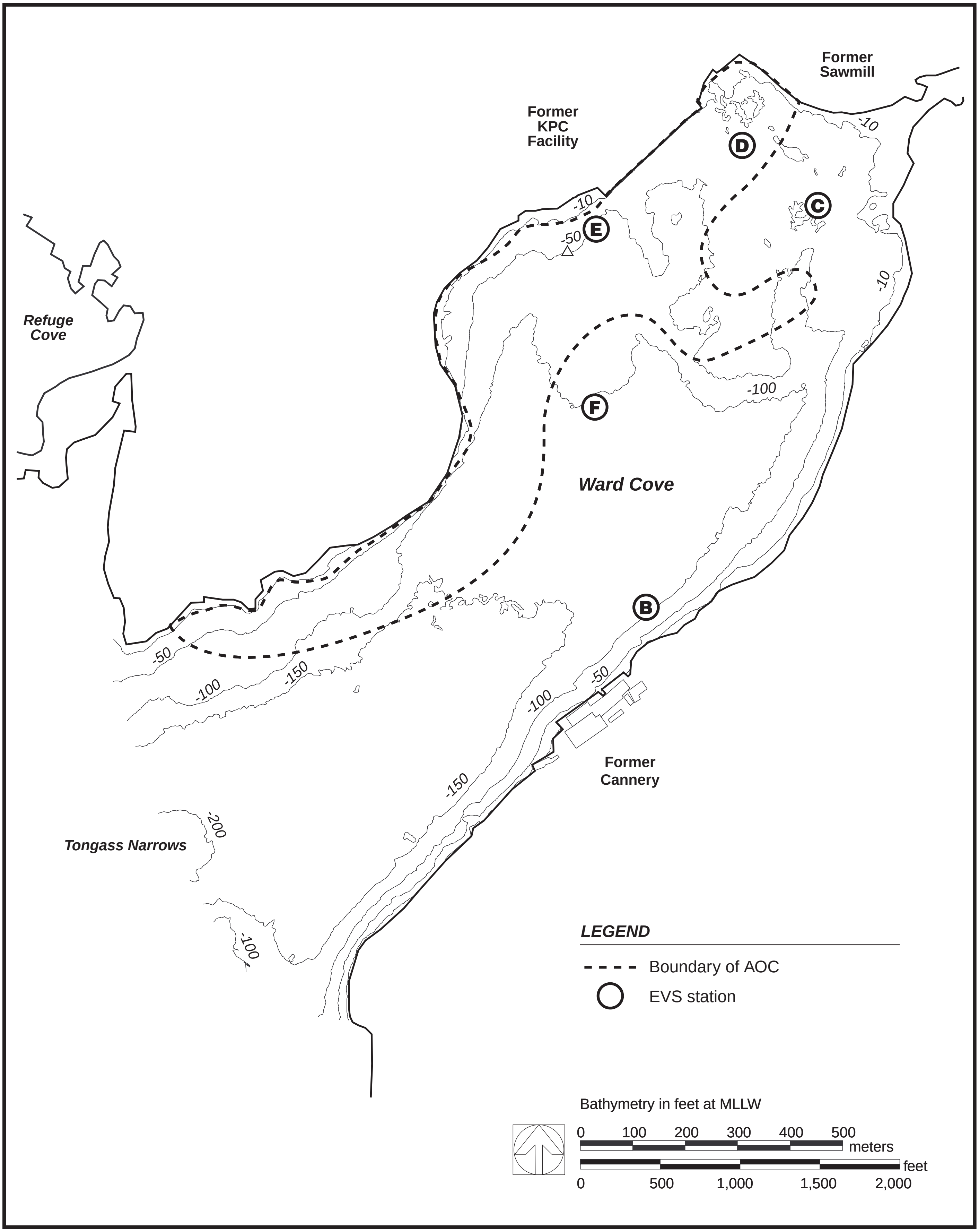


Figure 14. Approximate locations of stations sampled in Ward Cove for benthic macroinvertebrate communities in 1992 by EVS (1992)

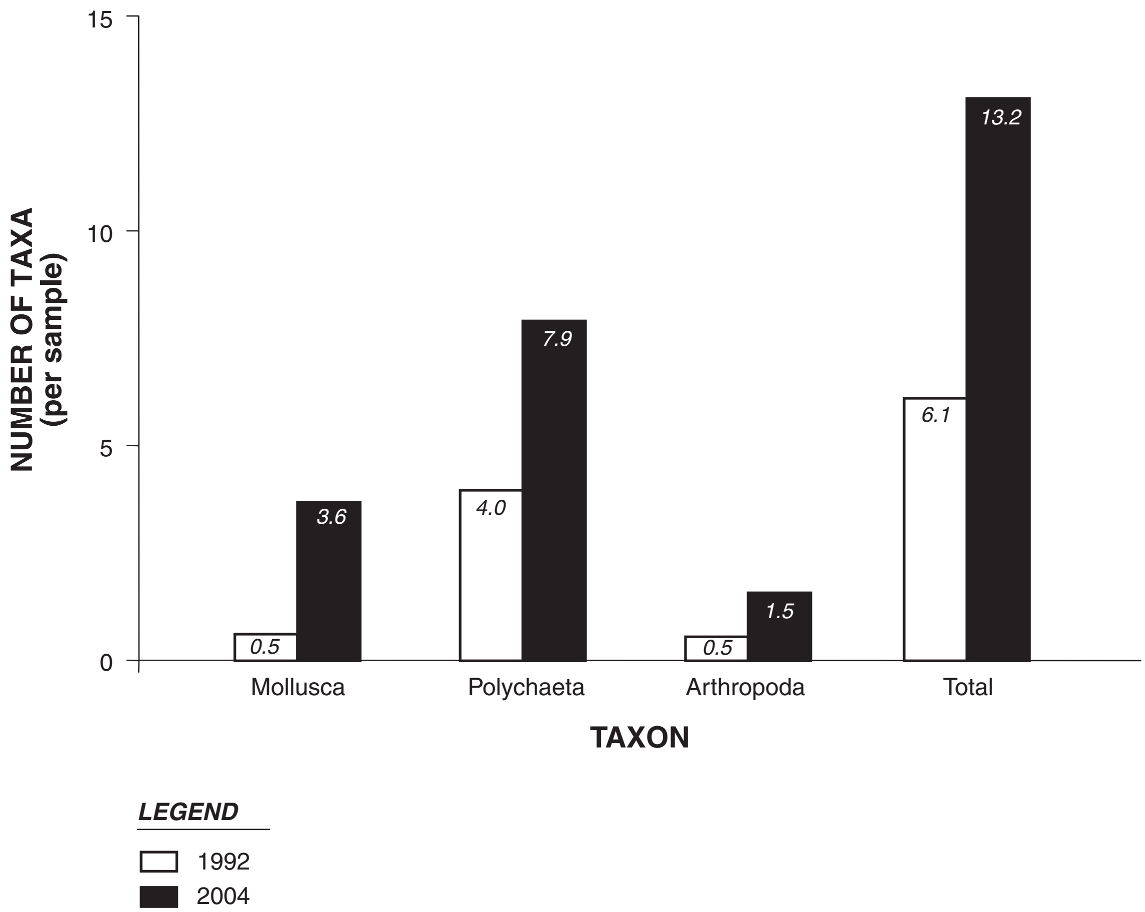
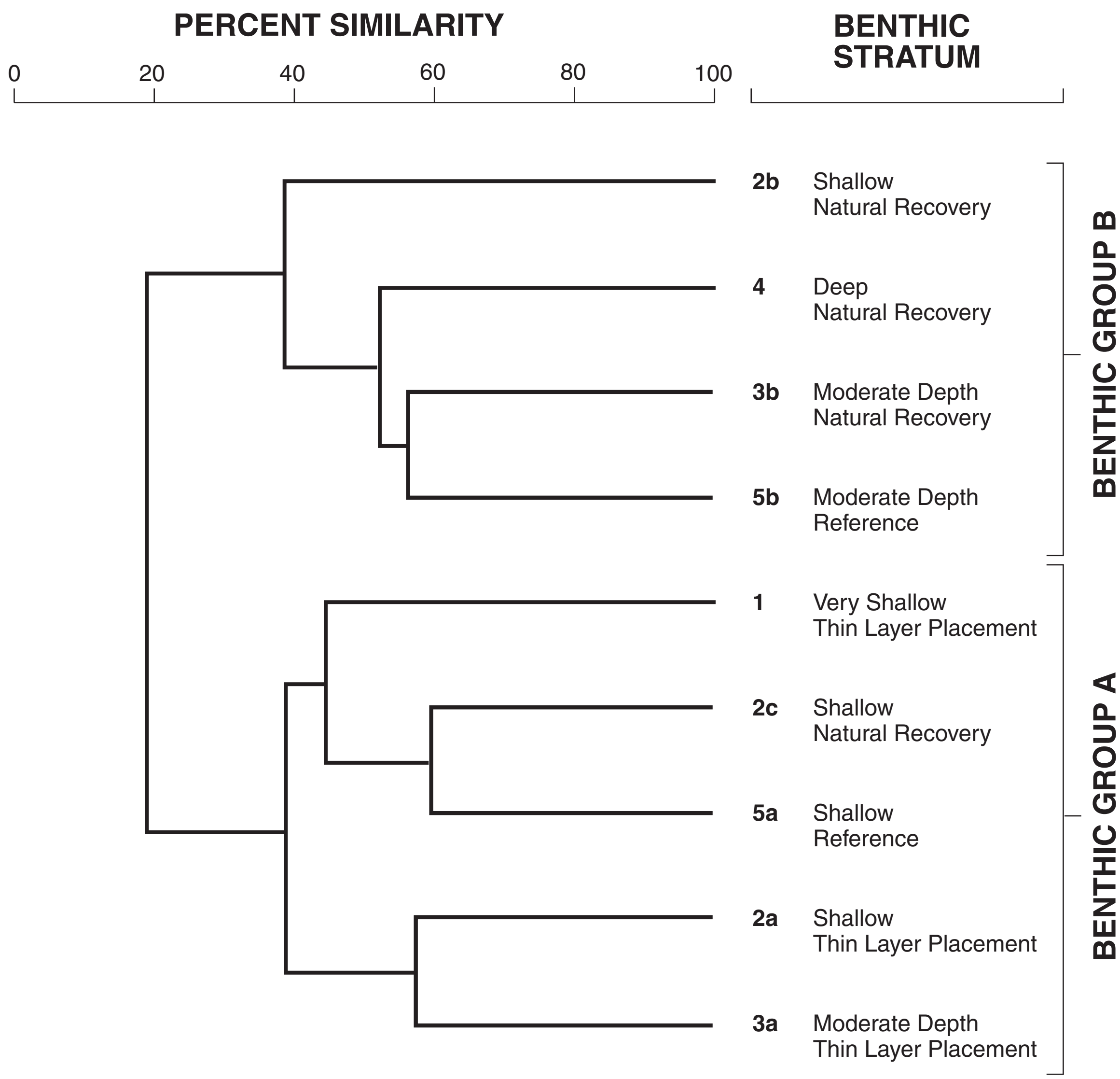


Figure 15. Comparison of taxa richness throughout Ward Cove between 1992 (EVS 1992) and 2004 (present study)



Note: Classification analysis was based on the Bray-Curtis similarity index applied to log-transformed abundances of benthic macroinvertebrate taxa.

Figure 16. Results of classification analysis of benthic macroinvertebrate communities in various benthic strata of Ward Cove in July 2004

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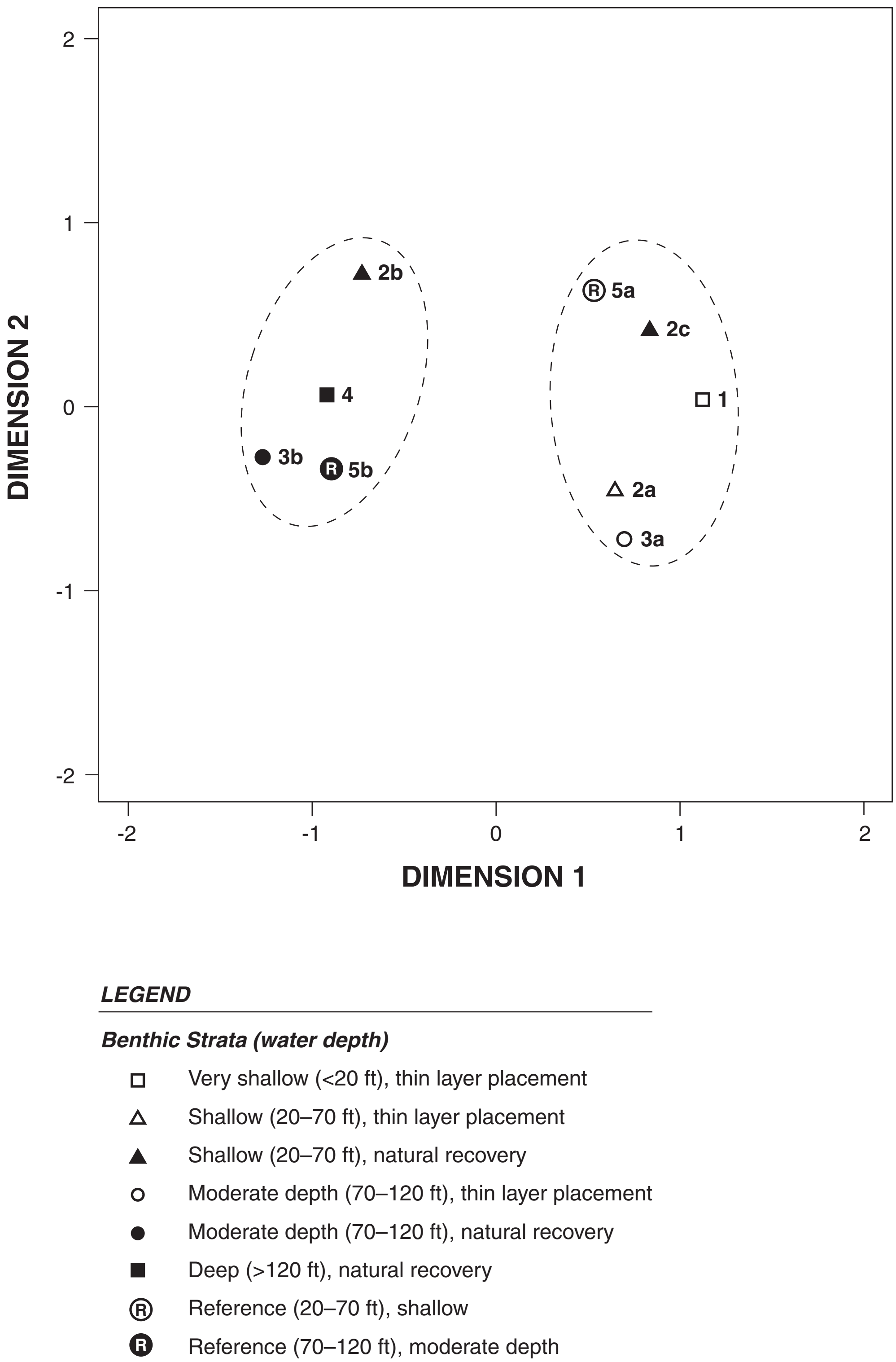

Figure 17. Results of multidimensional scaling analysis of benthic macroinvertebrate communities in various benthic strata of Ward Cove in July 2004

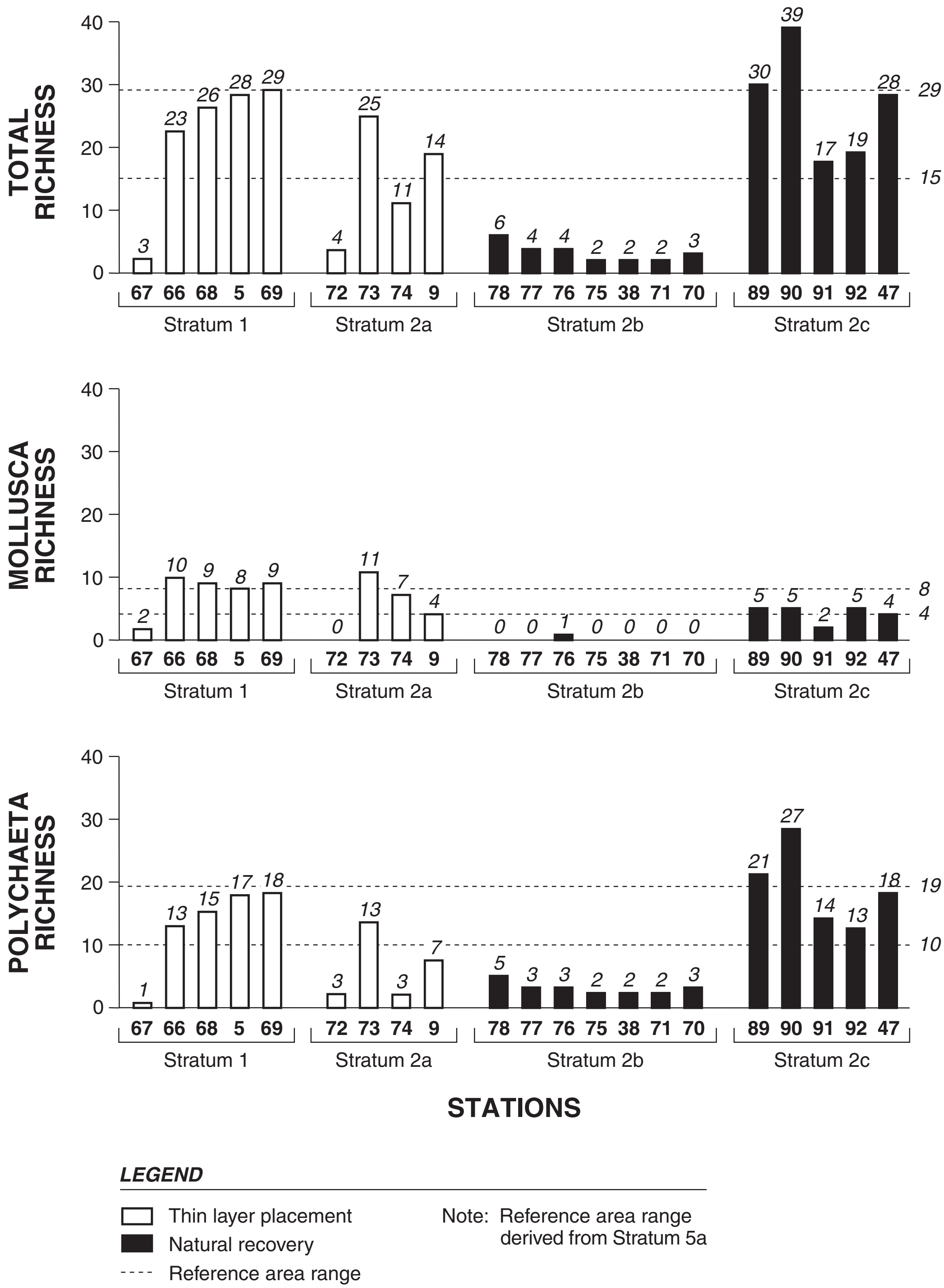

Figure 18. Overview of taxa richness of benthic macroinvertebrate communities in very shallow and shallow depth strata in Ward Cove AOC in July 2004

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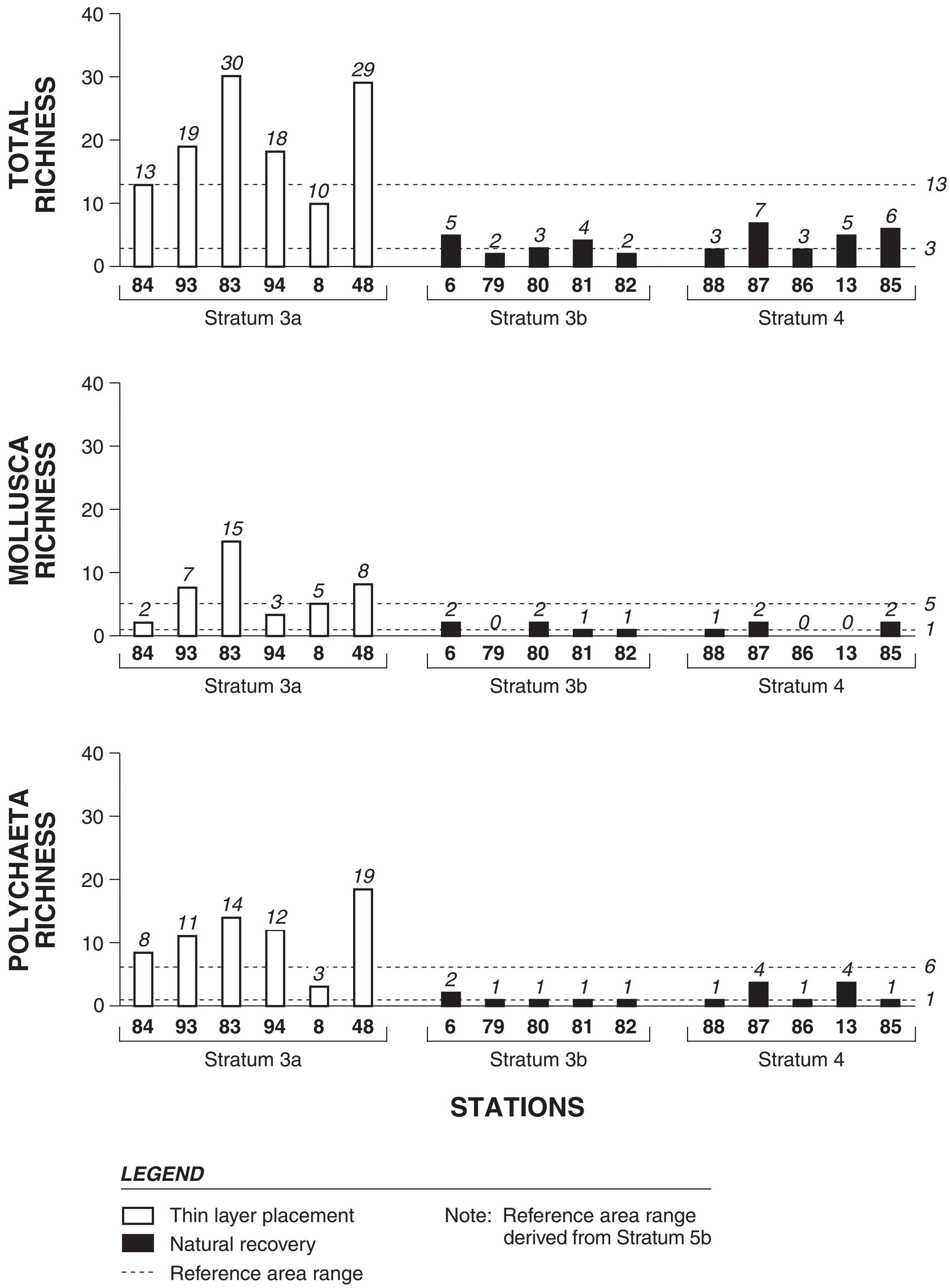

Figure 19. Overview of taxa richness of benthic macroinvertebrate communities in moderate depth and deep strata in Ward Cove AOC in July 2004

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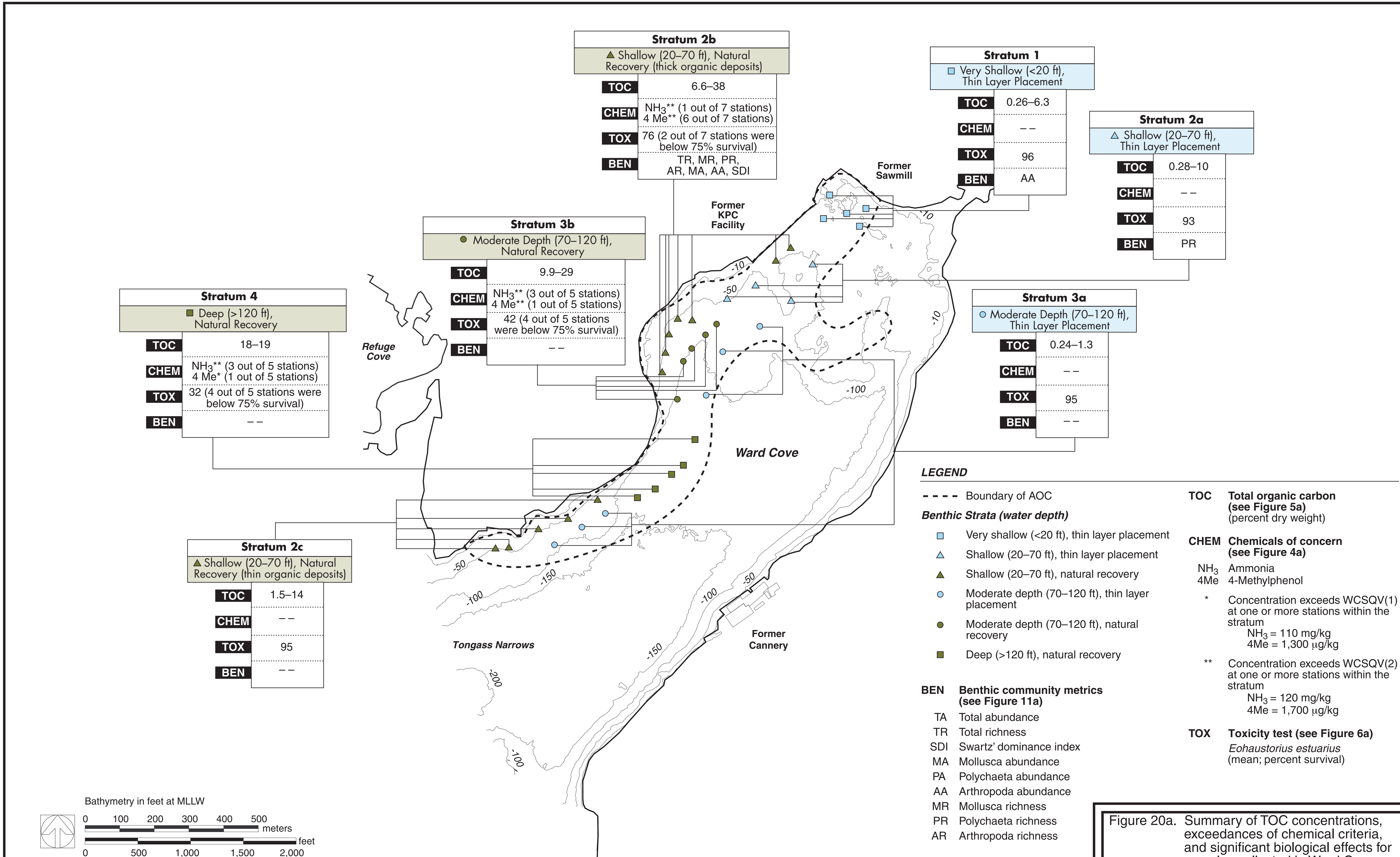

Figure 20a. Summary of TOC concentrations, exceedances of chemical criteria, and significant biological effects for samples collected in Ward Cove AOC in July 2004

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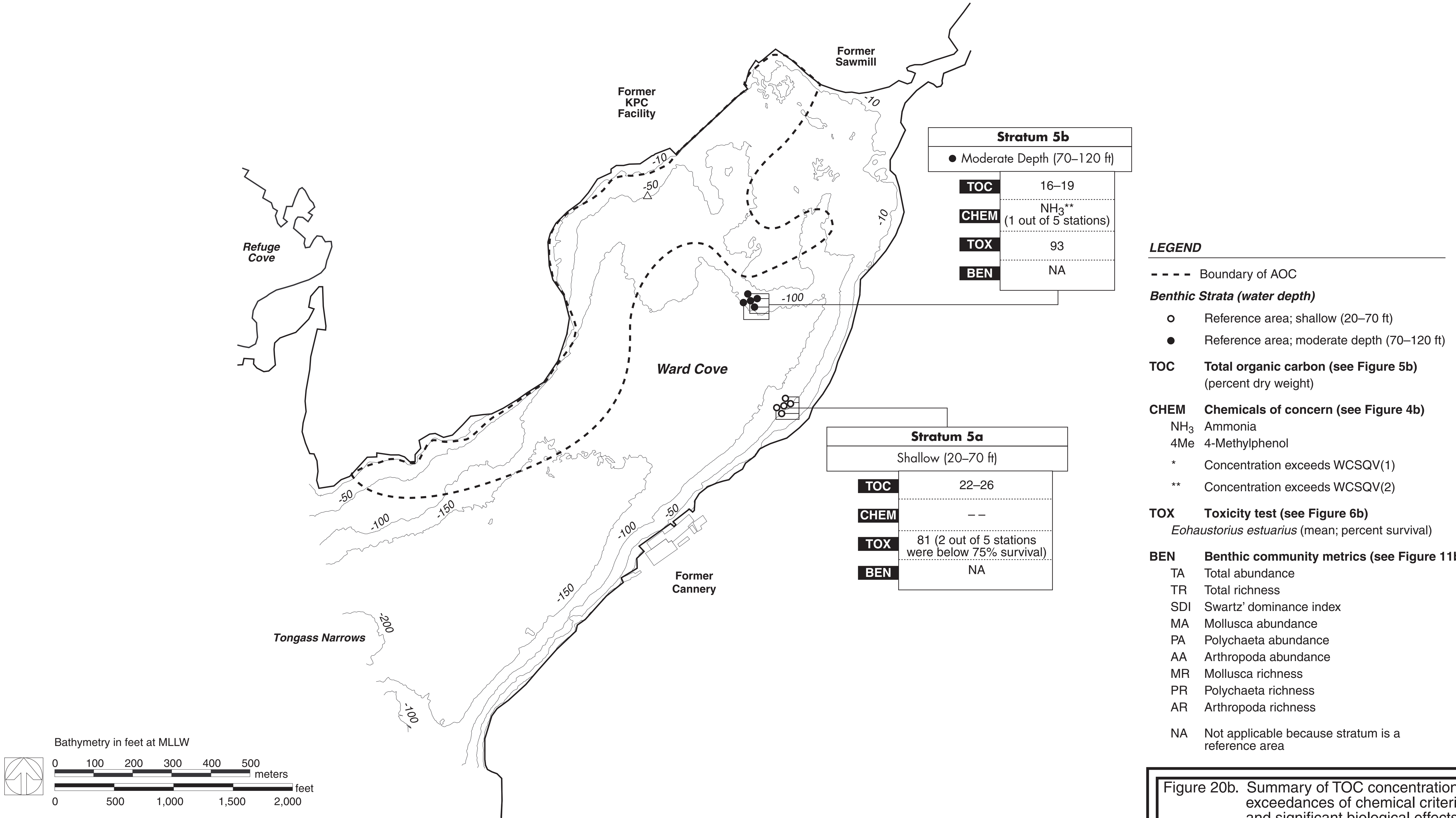

Figure 20b. Summary of TOC concentrations, exceedances of chemical criteria, and significant biological effects for samples collected in Ward Cove reference areas in July 2004

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Tables

Table 1. Overview of benthic strata used in the Ward Cove monitoring program

Benthic Stratum	Depth Category (ft MLLW)	Remediation Category	Benthic Community Stations	Toxicity Test Stations (laboratory replicates)
1	Very shallow (<20)	TLP	5, 66, 67, 68, 69	5 (1), 66 (1), 67 (1), 68 (1), 69 (1)
2a	Shallow (20–70)	TLP	9, 72, 73, 74	9 (5), 72 (1), 73 (1), 74 (1)
2b	Shallow (20–70)	Natural recovery (thick organic deposits)	38, 70, 71, 75, 76, 77, 78	38 (5), 70 (1), 71 (1), 75 (1), 76 (1), 77 (1), 78 (1)
2c	Shallow (20–70)	Natural recovery (thin organic deposits)	47, 89, 90, 91, 92	47 (1), 89 (1), 90 (1) 91 (1), 92 (1)
3a	Moderate depth (70–120)	TLP	8, 48, 83, 84, 93, 94	8 (5), 48 (1), 83 (1), 84 (1), 93 (1), 94 (1)
3b	Moderate depth (70–120)	Natural recovery	6, 79, 80, 81, 82	6 (1), 79 (1), 80 (1), 81 (1), 82 (1)
4	Deep (>120)	Natural recovery	13, 85, 86, 87, 88	13 (5), 85 (1), 86 (1), 87 (1), 88 (1)
5a	Shallow (20–70)	Reference	96 (5 field replicates)	96 (5 field replicates, 1 laboratory replicate each)
5b	Moderate depth (70–120)	Reference	95 (5 field replicates)	95 (5 field replicates, 1 laboratory replicate each)

Note: MLLW - mean lower low water
TLP - thin layer placement

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Table 2. Station locations, water depths, and general sample characteristics for surface sediments sampled in Ward Cove in July 2004

		Location							
		Longitude		Latitude					
Station	Sample Collection Date	Degrees	Minutes	Degrees	Minutes	Water Depth (m)	Tide (above MLLW)	Adjusted Water Depth (m)	General Sediment Characteristics[a]
AOC Stations									
5	7/21/2004	–131	43.3931	55	24.4443	8.2	1.994	6.0	Very dark gray color; coarse grain sand with some fine grain sediment; worms; normal odor
6	7/24/2004	–131	43.9010	55	24.1440	33	2.805	30	Very dark gray color; soft, fine grain sediment; wood debris (bark and leaf); shell fragments; sheen observed on surface of composite; strong reducing odor
8	7/22/2004	–131	43.5757	55	24.2801	31	2.648	29	Very dark gray color; mixed fine and coarse grain sand with some fine grain sediment; brittle star; worms; a little wood debris; shell fragments; faint sulfide odor
9	7/22/2004	–131	43.4882	55	24.3189	17	3.802	14	Very dark gray color; mixed fine and coarse grain sand with some fine grain sediment; small pebbles; worms; worm tubes on surface of grab; shell fragments; normal odor
13	7/24/2004	–131	43.7950	55	24.0677	44	3.466	40	Very dark gray color; soft, fine grain sediment; sea anemones; wood debris; white fibers on surface; sulfide odor
38	7/23/2004	–131	43.7580	55	24.2925	24	3.925	20	Very dark gray color; very fine, soft, sediment with very little fine grain sand; worm; wood debris (chips); shell fragments; sheen; reducing odor
47	7/20/2004	–131	44.3116	55	23.9469	15	4.014	11	Black color; fine grain sediment; wood debris (bark and twigs); sulfide odor
48	7/20/2004	–131	44.1521	55	23.9503	31	3.665	28	Very dark gray color; soft, fine grain sediment with a little sand; worm casing on sediment surface; some wood debris; small pine cone; some small gravel; few shell fragments; normal odor
66	7/21/2004	–131	43.2769	55	24.4590	7.8	2.903	4.9	Very dark gray color; fine grain sediment with fine to coarse grain sand; worms on surface of grab; small pebbles; shell fragments; sulfide odor

Table 2. (cont.)

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Station	Sample Collection Date	Location: Longitude Degrees	Location: Longitude Minutes	Location: Latitude Degrees	Location: Latitude Minutes	Water Depth (m)	Tide (above MLLW)	Adjusted Water Depth (m)	General Sediment Characteristics[a]
67	7/21/2004	–131	43.3742	55	24.4805	5.1	4.301	1.0	Black color; fine grain sediment; wood debris (bark and twigs); sulfide odor
68	7/21/2004	–131	43.4150	55	24.4190	5.0	3.497	1.5	Very dark gray color; fine to coarse grain sand with some fine grain sediment; small sea pen and worm tube on surface of grab; several worms; few small pebbles; shell fragments; normal to slight sulfide odor
69	7/21/2004	–131	43.2943	55	24.4310	7.6	3.700	4.0	Very dark gray color; fine grain sediment with fine to coarse grain sand; small pebbles; normal odor
70	7/21/2004	–131	43.4847	55	24.4006	15	0.770	15	Black color with very little fine grain sand; wood debris (chips, fine wood particles, and twigs); sheen; reducing odor
71	7/22/2004	–131	43.5256	55	24.3808	15	4.100	11	Black color; soft, fine grain sediment with a little fine grain sand; wood debris (bark); white fibers on surface; sulfide odor
72	7/22/2004	–131	43.4259	55	24.3748	17	3.262	14	Black color; soft, fine grain sediment with a little fine grain sand; wood debris (bark); sulfide odor
73	7/21/2004	–131	43.5842	55	24.3439	19	2.301	16	Very dark gray color; fine to coarse grain sand with some fine grain sediment; small sea pen and worm tube on surface of sample; several worms; few small pebbles; shell fragments; normal to slight sulfide odor
74	7/22/2004	–131	43.6621	55	24.3246	19	1.469	17	Very dark gray color; mixed fine and coarse grain sand with some fine grain sediment; worms; leaf on surface; shell fragments; normal odor
75	7/23/2004	–131	43.7979	55	24.2958	23	1.928	21	Black color; very fine, soft, moist sediment; white fibers on surface; wood debris (bark); sheen in benthic sieve; reducing odor
76	7/23/2004	–131	43.9030	55	24.2460	26	1.331	25	Black color; very fine, soft, moist sediment; wood debris (bark); reducing odor
77	7/24/2004	–131	43.8980	55	24.2210	27	1.618	25	Very dark gray color; soft, fine grain sediment; wood debris; shell fragments; sheen observed on surface of composite; strong reducing odor

Table 2. (cont.)

Station	Sample Collection Date	Location: Longitude Degrees	Location: Longitude Minutes	Location: Latitude Degrees	Location: Latitude Minutes	Water Depth (m)	Tide (above MLLW)	Adjusted Water Depth (m)	General Sediment Characteristics[a]
78	7/26/2004	–131	43.9460	55	24.1700	17	1.713	16	Very dark gray color; soft, fine grain sediment; worms; lots of wood debris (bark and leaves); shell fragments; sulfide odor
79	7/23/2004	–131	43.6924	55	24.2857	28	3.200	25	Black color; very fine, soft, moist sediment; white fibers on surface; strong reducing odor
80	7/23/2004	–131	43.7238	55	24.2700	33	3.360	30	Black color; soft, fine grain sediment; white fibers on surface; wood debris; shell fragments; sulfide odor
81	7/24/2004	–131	43.7624	55	24.2489	34	0.835	34	Black color; very fine, soft, moist sediment; white fibers on surface; a little wood debris; sheen observed on surface of composite and benthic sieve; strong reducing odor
82	7/24/2004	–131	43.7855	55	24.2296	34	0.922	33	Black color; very fine, soft, moist sediment; white fibers on surface; a little wood debris; shell fragments; sheen observed on surface of overlying water in grab; strong reducing odor
83	7/23/2004	–131	43.6778	55	24.2427	29	0.839	28	Very dark gray color; mixed fine and coarse grain sand with some fine grain sediment; jellyfish; brittle star; worm tubes on surface of sample; shell fragments; normal odor
84	7/23/2004	–131	43.7340	55	24.1883	38	1.258	37	Very dark gray color; mixed fine grain sand with soft fine grain sediment; worms; wood debris (chips and sticks); shell fragments; sheen on surface of composite; faint sulfide odor
85	7/24/2004	–131	43.7615	55	24.1067	41	3.678	37	Very dark gray color; soft, fine grain sediment; wood debris; shell fragments; white fibers on surface; sheen observed on surface of composite; sulfide odor
86	7/25/2004	–131	43.8271	55	24.0538	45	1.203	44	Very dark gray color; soft, fine grain sediment; wood debris; shell fragments; white fibers on surface; sheen observed on surface of composite; sulfide odor
87	7/25/2004	–131	43.8730	55	24.0322	47	0.867	46	Very dark gray color; soft, fine grain sediment; wood debris; shell fragments; white fibers on surface; sheen observed on surface of composite; sulfide odor

Table 2. (cont.)

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Station	Sample Collection Date	Location				Water Depth (m)	Tide (above MLLW)	Adjusted Water Depth (m)	General Sediment Characteristics[a]
		Longitude		Latitude					
		Degrees	Minutes	Degrees	Minutes				
88	7/25/2004	–131	43.9220	55	24.0179	46	0.675	45	Very dark gray color; soft, fine grain sediment; wood debris; shell fragments; white fibers on surface; sheen observed on surface of composite; sulfide odor
89	7/22/2004	–131	44.0281	55	24.0188	20	1.220	19	Black color; fine grain sediment with a little fine grain sand; lots of wood debris (bark); shells and shell fragments; strong sulfide odor
90	7/20/2004	–131	44.1860	55	23.9660	19	0.463	19	Dark gray color; large red worm; lots of wood debris (bark); faint sulfide odor
91	7/20/2004	–131	44.1928	55	23.9758	17	2.448	15	Very dark gray color; soft, fine grain sediment with a little sand; some wood debris (pine needles and leaves); slight sulfide odor
92	7/20/2004	–131	44.2754	55	23.9486	15	4.599	10	Very dark gray brown color; silt with a little sand; brittle star; wood debris (bark and twigs); small rocks; shell fragments; normal odor
93	7/22/2004	–131	44.0102	55	23.9968	27	2.069	25	Dark gray brown color; fine grain sand mixed with coarse grain sand and with fine grain sediment; small pebbles; jellyfish; worm tube on surface; wood debris; shell fragments; normal odor
94	7/20/2004	–131	44.0762	55	23.9764	35	-0.245	35	Black to very dark gray color; fine grain sediment with sand; small shrimp; several small worms; some pine needles; few shell fragments
Reference Stations									
95A	7/25/2004	–131	43.4280	55	24.0110	32	1.066	31	Very dark gray color; soft, fine grain sediment; wood debris; shell fragments; sulfide odor
95B	7/25/2004	–131	43.5010	55	24.1480	29	1.402	28	Very dark gray color; soft, fine grain sediment; wood debris; no odor
95C	7/25/2004	–131	43.5130	55	24.1370	33	2.602	30	Very dark gray color; soft, fine grain sediment; wood debris (bark); sulfide odor
95D	7/25/2004	–131	43.5170	55	24.1470	31	3.036	28	Very dark gray color; soft, fine grain sediment; wood debris (bark); few white fibers on surface; sulfide odor

Table 2. (cont.)

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Station	Sample Collection Date	Location				Water Depth (m)	Tide (above MLLW)	Adjusted Water Depth (m)	General Sediment Characteristics[a]
		Longitude		Latitude					
		Degrees	Minutes	Degrees	Minutes				
95E	7/25/2004	–131	43.4960	55	24.1390	32	3.360	29	Very dark gray color; soft, fine grain sediment; wood debris; shell fragments; white fibers on surface; sulfide odor
96A	7/25/2004	–131	43.4280	55	24.0110	20	3.335	16	Very dark gray color; soft, fine grain sediment mixed with a very little clay; worms; wood debris (bark); shell fragments; sulfide odor
96B	7/25/2004	–131	43.4200	55	24.0060	19	1.914	17	Very dark gray color; soft, fine grain sediment; kelp; worm; wood debris (bark); shell fragments; sulfide odor
96C	7/26/2004	–131	43.4160	55	24.0150	21	1.656	19	Very dark gray color; soft, fine grain sediment; worms; lots of wood debris (bark); no odor
96D	7/26/2004	–131	43.4340	55	24.0170	24	0.940	23	Very dark gray color; soft, fine grain sediment; worms; wood debris (bark); shell fragments; faint sulfide odor
96E	7/26/2004	–131	43.4380	55	24.0080	23	0.414	22	Very dark gray color; soft, fine grain sediment; worms; lots of wood debris (bark); shell fragments; sulfide odor

Note: Samples collected from 0–10 cm.

MLLW - mean lower low water

[a] Wood debris - small wood chips and bark (unless otherwise noted).

Table 3. Mean values of chemicals of concern and conventional analytes in surface sediments collected in July 2004 in each benthic stratum in Ward Cove

			Mean Concentrations and Percentages				
Benthic Stratum	Depth Category	Remediation Category	Ammonia (mg/kg dry)	4-Methyl-phenol (μg/kg dry)[a]	Total Organic Carbon (percent)	Percent Fines (percent)	Total Solids (percent)
AOC Strata							
1	Very shallow	TLP	10	62	2.6	7.8	65
2a	Shallow	TLP	17	61	2.9	8.4	64
2b	Shallow	Natural recovery	63	12,000	23	36	22
2c	Shallow	Natural recovery	11	420	7.2	13	45
3a	Moderate depth	TLP	4.9	20	0.52	3.4	75
3b	Moderate depth	Natural recovery	130	4,300	14	33	22
4	Deep	Natural recovery	130	950	19	42	15
Reference Area Strata							
5a	Shallow	--	47	100	24	42	18
5b	Moderate depth	--	81	370	18	42	19

Note: TLP - thin layer placement

[a] 3- and 4-methylphenol results were quantified as 4-methylphenol.

Table 4. Comparison of chemicals of concern and conventional analytes in surface sediments collected in 1996, 1997, and 2004 in Ward Cove[a]

Benthic Stratum	Depth Category	Remediation Category	Station	Sampling Event	Ammonia (mg/kg)	4-Methylphenol (µg/kg)[b]	Total Organic Carbon (percent)	Percent Fines (percent)	Total Solids (percent)
AOC Strata									
1	Very shallow	TLP	5	1996	67	860	36	31	20
				1997	57	16,000	38	55	18
				2004	1.4	4.0	0.26	1.4	81
2a	Shallow	LP	9	1996	82	1,400	27	56	18
				2004	3.6	8.9	0.28	1.7	79
2b	Shallow	Natural recovery	38	1997	260	8,300	34	46	14
				2004[c]	54	4,100	22	45	19
2c	Shallow	Natural recovery	47	1997	120	1,800	26	38	18
				2004	6.7	85	4.5	8.3	49
3a	Moderate depth	TLP	8	1996	100	1,400	24	66	18
				2004	4.1	9.5	0.51	3.5	76
			48	1997	300	1,100	25	70	14
				2004[c]	5.6	11	0.31	2.8	78
3b	Moderate depth	Natural recovery	6	1996	360	8,300	33	50	12
				2004	110	18,000	29	30	16
4	Deep	Natural recovery	13	1996	150	390	22	77	16
				1997[c]	280	1,700	23	68	16
				2004	110	520	18	42	15

Note: TLP - thin layer placement

[a] Not all stations were sampled every year.

[b] 3- and 4-methylphenol results were quantified as 4-methylphenol.

[c] Field replicates were averaged.

Table 5. Summary of statistical comparisons of amphipod (*Eohaustorius estuarius)* survival for Ward Cove in 2004

Benthic Stratum	Depth Category	Remediation Category	Percent Survival Mean	Standard Deviation	CV	Dunnett's[a]	High Variance[b]
AOC Strata							
1	Very shallow	TLP	96	4.2	0.044	no	no
2a	Shallow	TLP	93	6.3	0.068	no	no
2b	Shallow	Natural recovery	76	29	0.38	no	yes
2c	Shallow	Natural recovery	95	5.0	0.053	no	no
3a	Moderate depth	TLP	95	8.3	0.087	no	no
3b	Moderate depth	Natural recovery	42	38	0.89	yes	--
4	Deep	Natural recovery	32	39	1.2	yes	--
Reference Area Strata							
5b	Moderate depth	--	93	8.4	0.090	--	--

Note: CV - coefficient of variation
TLP - thin layer placement

Percent survival was analyzed using ANOVA followed by Dunnett's test. Significance was determined at a 0.05 overall level. Pairwise comparisons were one-sided to test only whether site stations were significantly lower than reference.

Appendix C provides all statistical test results and supporting analyses. All analyses were conducted using S-Plus 2000.

[a] Dunnett's multiple comparison tests were conducted following an overall ANOVA indicating differences (P =0.0002).

[b] High variance strata were those not significantly different from reference conditions (P >0.05), but with a standard deviation >15 percent of the mean (CV>0.15).

Table 6. Statistical power evaluation of amphipod (*Eohaustorius estuarius)* survival in Ward Cove in 2004

Benthic Stratum	Depth Category	Remediation Category	N	Percent Survival			Transform	Dunnett's[a]	Actual			MDRD for power levels		
				Mean	Std.Dev.	CV			MDRD	Power		60%	70%	80%
AOC Strata														
1	Very shallow	TLP	5	96	4.2	0.044	asin-sqrt	no	>Reference			--	--	--
2a	Shallow	TLP	4	93	6.3	0.068		no	-2%	1%	*	-25%	-27%	-30%
2b	Shallow	Natural recovery	7	76	29	0.38		no	-18%	15%	*	-33%	-36%	-40%
2c	Shallow	Natural recovery	5	95	5.0	0.053		no	>Reference			--	--	--
3a	Moderate depth	TLP	6	95	8.3	0.087		no	>Reference			--	--	--
3b	Moderate depth	Natural recovery	5	42	38	0.89		yes	-46%	55%		-48%	-53%	-59%
4	Deep	Natural recovery	5	32	39	1.2		yes	-61%	81%		-49%	-54%	-60%
Reference Area Stratum														
5b	Moderate depth	--	5	93	8.4	0.090								

Note:
- * - qualitative interpretation recommended
- AOC - area of concern
- CV - coefficient of variation
- MDRD - minimum detectable relative difference, calculated relative to reference; MDRD is the minimum detectable difference divided by the reference mean
- TLP - thin layer placement

MDRD and power calculations were conducted for one-sided comparisons between each AOC stratum and the reference area stratum based on transformed data.

An adjusted alpha level of 0.0071 = 0.05/7 was used to account for multiple comparisons

Power levels were very low or zero for strata with survival higher than the reference value because comparisons were one-sided to test only whether survival at each AOC stratum was lower than the reference value.

[a] Dunnett's multiple comparison tests were conducted following an overall ANOVA indicating differences (P =0.0002).

Table 7. Comparison of amphipod survival among different sampling periods in Ward Cove

Station	Benthic Stratum	Depth Category	Remediation Category	Year	Species	Percent Survival Mean	Percent Survival Standard Deviation	Percent Survival CV	Significantly Lower
8	3a	Moderate depth	TLP	1996	*Rhepoxynius abronius*	43	23	0.53	yes
				2004	*Eohaustorius estuarius*	99	2.2	0.023	
9	2a	Shallow	TLP	1996	*Rhepoxynius abronius*	54	18	0.33	yes
				2004	*Eohaustorius estuarius*	91	7.4	0.081	
13	4	Deep	Natural recovery	1996	*Rhepoxynius abronius*	36	11	0.30	no
				1997	*Rhepoxynius abronius*	15	23	1.5	no
				2004	*Eohaustorius estuarius*	43	31	0.71	
38	2b	Shallow	Natural recovery	1997	*Rhepoxynius abronius*	0	0	--	yes
				2004	*Eohaustorius estuarius*	89	8.2	0.092	

Note: ANOVA - analysis of variance
CV - coefficient of variation
TLP - thin layer placement

Percent survival was analyzed using ANOVA followed by Dunnett's test or Wilcoxon's non-parametric rank test. Significance was determined at a 0.05 overall level. Pairwise comparisons were one-sided to test only whether 2004 survival was significantly greater than survival in each earlier year.

Appendix C provides all statistical test results and supporting analyses. All analyses were conducted using S-Plus 2000.

Table 8. Statistical power evaluation of amphipod survival among different sampling periods in Ward Cove

Station	Benthic Stratum	Depth Category	Remediation Category	Year	Species	Percent Survival Mean	Percent Survival Std.Dev.	Percent Survival CV	Significantly Lower	Actual MDRD	Actual Power		MDRD for power levels 60%	MDRD for power levels 70%	MDRD for power levels 80%
8	3a	Moderate depth	TLP	1996	*Rhepoxynius abronius*	43	23	0.53	yes	-54%	100%		-15%	-17%	-19%
				2004	*Eohaustorius estuarius*	99	2.2	0.023							
9	2a	Shallow	TLP	1996	*Rhepoxynius abronius*	54	18	0.33	yes	-41%	100%		-18%	-21%	-24%
				2004	*Eohaustorius estuarius*	91	7.4	0.081							
13	4	Deep	Natural recovery	1996	*Rhepoxynius abronius*	36	11	0.30	no	-9%	6%	*	-51%	-57%	-64%
				1997	*Rhepoxynius abronius*	15	23	1.5	no	-54%	45%	*	-65%	-73%	-82%
				2004	*Eohaustorius estuarius*	43	31	0.71							
38	2b	Shallow	Natural recovery	1997	*Rhepoxynius abronius*	0	0	--	yes	comparison used non-parametric method,					
				2004	*Eohaustorius estuarius*	89	8.2	0.092		so no power evaluation was conducted					

Note:
* - qualitative interpretation recommended
CV - coefficient of variation
MDRD - minimum detectable relative difference, calculated relative to 2004; MDRD is the minimum detectable difference divided by the 2004 mean
TLP - thin layer placement

MDRD and power calculations were conducted for one-sided comparisons between 2004 survival and survival in each earlier year.

An adjusted alpha level of 0.025 = 0.05/2 was used to account for multiple comparisons for Station 13.

Arcsin square-root transform was used for calculations for Stations 8 and 13.

Table 9. Mean values of benthic metrics for benthic communities sampled in Ward Cove in July 2004

Benthic Stratum	Depth Category	Remediation Category	Total Abundance[a]	Total Richness[a]	SDI
AOC Strata					
1	Very shallow	TLP	180	22	3.8
2a	Shallow	TLP	50	14	5.8
2b	Shallow	Natural recovery	160	3.3	1.6
2c	Shallow	Natural recovery	81	27	11.4
3a	Moderate depth	TLP	66	20	7.5
3b	Moderate depth	Natural recovery	19	3.2	1.6
4	Deep	Natural recovery	17	4.8	1.6
Reference Area Strata					
5a	Shallow	--	330	22	3.6
5b	Moderate depth	--	27	5.4	1.8

Note: SDI - Swartz' dominance index
TLP - thin layer placement

[a] Per 0.06-m^2 sample.

Table 10. Mean values of total abundance and total richness of major benthic macroinvertebrate taxonomic groups collected in Ward Cove in July 2004

Benthic Stratum	Depth Category	Remediation Category	Abundance[a]			Richness[a]		
			Mollusca	Polychaeta	Arthropoda	Mollusca	Polychaeta	Arthropoda
AOC Strata								
1	Very shallow	TLP	93	84	1.8	7.6	13	1.4
2a	Shallow	TLP	32	16	2.0	5.5	6.5	1.3
2b	Shallow	Natural recovery	0.14	160	0.57	0.14	2.9	0.29
2c	Shallow	Natural recovery	23	48	8.8	4.2	19	3.6
3a	Moderate depth	TLP	34	27	1.5	6.7	11	1.5
3b	Moderate depth	Natural recovery	1.2	17	1.0	1.2	1.2	0.80
4	Deep	Natural recovery	1.0	14	2.2	1.0	2.2	1.6
Reference Area Strata								
5a	Shallow	--	15	300	7.2	5.2	15	2.4
5b	Moderate depth	--	7.4	18	1.2	2.2	2.4	0.80

Note: TLP - thin layer placement

[a] Per 0.06-m^2 sample.

Table 11. Results of statistical comparisons of benthic metrics between AOC and reference strata in Ward Cove in July 2004

	Benthic Stratum	Depth Category	Remediation Category	Mean	Std.Dev.	CV	Transform[a]	Significantly lower Dunnett's[b]	Significantly lower Wilcoxon[c]
Total Abundance[d]									
	1	Very shallow	TLP	180	110	0.64	$\log_{10}(+1)$	no	no
	2a	Shallow	TLP	50	52	1.0		no	no
	2b	Shallow	Natural recovery	160	360	2.2		no	no
	2c	Shallow	Natural recovery	81	47	0.57		no	no
ref	5a	Shallow	--	330	250	0.76			
	3a	Moderate depth	TLP	66	38	0.57	$\log_{10}(+1)$	no	no
	3b	Moderate depth	Natural recovery	19	7.6	0.40		no	no
	4	Deep	Natural recovery	17	12	0.66		no	no
ref	5b	Moderate depth	--	27	11	0.43			
Taxa Abundance[d]									
Polychaetes									
	1	Very shallow	TLP	84	59	0.71	$\log_{10}(+1)$	no	no
	2a	Shallow	TLP	16	11	0.73		no	yes
	2b	Shallow	Natural recovery	160	350	2.2		no	no
	2c	Shallow	Natural recovery	48	30	0.63		no	no
ref	5a	Shallow	--	300	240	0.80			
	3a	Moderate depth	TLP	27	11	0.40	sqrt	no	no
	3b	Moderate depth	Natural recovery	17	8.5	0.51		no	no
	4	Deep	Natural recovery	14	10	0.67		no	no
ref	5b	Moderate depth	--	18	6.7	0.37			
Arthropods									
	1	Very shallow	TLP	1.8	1.8	0.99	$\log_{10}(+1)$	yes	no
	2a	Shallow	TLP	2.0	0.82	0.41		no	no
	2b	Shallow	Natural recovery	0.57	1.1	2.0		yes	yes
	2c	Shallow	Natural recovery	8.8	7.5	0.86		no	no
ref	5a	Shallow	--	7.2	4.8	0.66			
	3a	Moderate depth	TLP	1.5	1.2	0.82	sqrt	no	no
	3b	Moderate depth	Natural recovery	1.0	1.0	1.0		no	no
	4	Deep	Natural recovery	2.2	1.3	0.59		no	no
ref	5b	Moderate depth	--	1.2	1.6	1.4			
Molluscs									
	1	Very shallow	TLP	93	78	0.84	$\log_{10}(+1)$	no	no
	2a	Shallow	TLP	32	43	1.4		no	no
	2b	Shallow	Natural recovery	0.14	0.38	2.6		yes	yes
	2c	Shallow	Natural recovery	23	15	0.64		no	no
ref	5a	Shallow	--	15	7.4	0.48			
	3a	Moderate depth	TLP	34	27	0.80	sqrt	no	no
	3b	Moderate depth	Natural recovery	1.2	0.84	0.70		no	no
	4a	Deep	Natural recovery	1.0	1.0	1.0		no	no
ref	5b	Moderate depth	--	7.4	6.7	0.90			

Table 11. (cont.)

	Benthic Stratum	Depth Category	Remediation Category	Mean	Std.Dev.	CV	Transform[a]	Significantly lower Dunnett's[b]	Significantly lower Wilcoxon[c]
Total Richness[d]									
	1	Very shallow	TLP	22	11	0.49	sqrt	no	no
	2a	Shallow	TLP	14	8.7	0.65		no	no
	2b	Shallow	Natural recovery	3.3	1.5	0.46		yes	yes
	2c	Shallow	Natural recovery	27	8.9	0.33		no	no
ref	5a	Shallow	--	22	5.1	0.23			
	3a	Moderate depth	TLP	20	8.2	0.41	$\log_{10}(+1)$	no	no
	3b	Moderate depth	Natural recovery	3.2	1.3	0.41		no	no
	4	Deep	Natural recovery	4.8	1.8	0.37		no	no
ref	5b	Moderate depth	--	5.4	4.3	0.79			
Taxa Richness[d]									
Polychaetes									
	1	Very shallow	TLP	13	6.9	0.54	sqrt	no	no
	2a	Shallow	TLP	6.5	4.7	0.73		yes	no
	2b	Shallow	Natural recovery	2.9	1.1	0.37		yes	yes
	2c	Shallow	Natural recovery	19	5.7	0.31		no	no
ref	5a	Shallow	--	15	3.9	0.27			
	3a	Moderate depth	TLP	11	5.4	0.49	$\log_{10}(+1)$	no	no
	3b	Moderate depth	Natural recovery	1.2	0.45	0.37		no	no
	4	Deep	Natural recovery	2.2	1.6	0.75		no	no
ref	5b	Moderate depth	--	2.4	2.1	0.86			
Arthropods									
	1	Very shallow	TLP	1.4	1.3	0.96	sqrt	no	no
	2a	Shallow	TLP	1.3	0.50	0.40		no	no
	2b	Shallow	Natural recovery	0.29	0.49	1.7		yes	yes
	2c	Shallow	Natural recovery	3.6	2.6	0.72		no	no
ref	5a	Shallow	--	2.4	1.1	0.48			
	3a	Moderate depth	TLP	1.5	1.2	0.82	$\log_{10}(+1)$	no	no
	3b	Moderate depth	Natural recovery	0.80	0.84	1.0		no	no
	4	Deep	Natural recovery	1.6	0.89	0.56		no	no
ref	5b	Moderate depth	--	0.80	0.84	1.0			
Molluscs									
	1	Very shallow	TLP	7.6	3.2	0.42	sqrt	no	no
	2a	Shallow	TLP	5.5	4.7	0.85		no	no
	2b	Shallow	Natural recovery	0.14	0.38	2.6		yes	yes
	2c	Shallow	Natural recovery	4.2	1.3	0.31		no	no
ref	5a	Shallow	--	5.2	1.8	0.34			
	3a	Moderate depth	TLP	6.7	4.7	0.70	$\log_{10}(+1)$	no	no
	3b	Moderate depth	Natural recovery	1.2	0.8	0.70		no	no
	4	Deep	Natural recovery	1.0	1.0	1.0		no	no
ref	5b	Moderate depth	--	2.2	1.6	0.75			

Table 11. (cont.)

	Benthic Stratum	Depth Category	Remediation Category	Mean	Std.Dev.	CV	Transform[a]	Significantly lower Dunnett's[b]	Significantly lower Wilcoxon[c]
Swartz' Dominance Index									
	1	Very shallow	TLP	3.8	1.8	0.47	sqrt	no	no
	2a	Shallow	TLP	5.8	2.6	0.46		no	no
	2b	Shallow	Natural recovery	1.6	0.53	0.34		no	yes
	2c	Shallow	Natural recovery	11	1.7	0.15		no	no
ref	5a	Shallow	--	3.6	2.5	0.70			
	3a	Moderate depth	TLP	7.5	3.0	0.40	$\log_{10}(+1)$	no	no
	3b	Moderate depth	Natural recovery	1.6	1.3	0.84		no	no
	4	Deep	Natural recovery	1.6	0.55	0.34		no	no
ref	5b	Moderate depth	--	1.8	1.3	0.72			

Note:
ANOVA - analysis of variance
AOC - area of concern
CV - coefficient of variation
MANOVA - multivariate analysis of variance
TLP - thin layer placement

Total abundance, total richness, and Swartz' dominance index were analyzed using ANOVA followed by Dunnett's test. Taxa abundance and richness were analyzed using an overall MANOVA, followed by individual ANOVAs and Dunnett's test. For all comparisons, a non-parametric analysis was also conducted. Significance was determined at 0.05 overall level for each set of comparisons. Pairwise comparisons were one-sided to test only whether values in each AOC stratum were significantly lower than reference values.

Appendix C provides all statistical test results and supporting analyses. All analyses were conducted using S-Plus 2000.

[a] $\log_{10}(+1)$ indicates the $\log_{10}$ of the value plus 1 was used. Sqrt indicates the square-root of the value was used.

[b] Dunnett's one-sided multiple comparison tests were conducted following an overall ANOVA indicating differences. ($P \leq 0.05$)

[c] Wilcoxon's non-parametric rank test.

[d] Per 0.06-m^2 sample.

Table 12. Statistical power evaluation of the benthic invertebrate community in Ward Cove in 2004

	Benthic Stratum	Depth Category	Remediation Category	Mean	Standard Deviation	CV	Transform	Dunnett's[a]	Wilcoxon[b]	Actual MDRD	Actual Power		MDRD for power levels 60%	70%	80%
Total Abundance															
	1	Very shallow	TLP	180	110	0.64	$\log_{10}(+1)$	no	no	-11%	9%	*	-29%	-32%	-36%
	2a	Shallow	TLP	50	52	1.0		no	no	-34%	81%		-27%	-30%	-34%
	2b	Shallow	Natural recovery	160	360	2.2		no	no	-39%	67%		-37%	-41%	-45%
	2c	Shallow	Natural recovery	81	47	0.57		no	no	-23%	55%	*	-24%	-27%	-30%
ref	5a	Shallow	--	330	250	0.76									
	3a	Moderate depth	TLP	66	38	0.57	$\log_{10}(+1)$	no	no	>Reference			--	--	--
	3b	Moderate depth	Natural recovery	19	7.6	0.40		no	no	-10%	16%	*	-22%	-25%	-28%
	4	Deep	Natural recovery	17	12	0.66		no	no	-16%	22%	*	-27%	-30%	-34%
ref	5b	Moderate depth	--	27	11	0.43									
Taxa Abundance															
Polychaetes															
	1	Very shallow	TLP	84	59	0.71	$\log_{10}(+1)$	no	no	-49%	40%	*	-61%	-68%	-75%
	2a	Shallow	TLP	16	11	0.73		no	yes	-77%	91%		-54%	-59%	-66%
	2b	Shallow	Natural recovery	160	350	2.2		no	no	-50%	24%	*	-81%	-90%	-100%
	2c	Shallow	Natural recovery	48	30	0.63		no	no	-58%	67%		-54%	-60%	-67%
ref	5a	Shallow	--	300	240	0.80									
	3a	Moderate depth	TLP	27	11	0.40	sqrt	no	no	>Reference			--	--	--
	3b	Moderate depth	Natural recovery	17	8.5	0.51		no	no	-7%	4%	*	-39%	-43%	-48%
	4	Deep	Natural recovery	14	10	0.67		no	no	-15%	10%	*	-40%	-45%	-50%
ref	5b	Moderate depth	--	18	6.7	0.37									
Arthropods															
	1	Very shallow	TLP	1.8	1.8	0.99	$\log_{10}(+1)$	yes	no	-59%	55%	*	-63%	-69%	-77%
	2a	Shallow	TLP	2.0	0.82	0.41		no	no	-45%	53%	*	-48%	-53%	-59%
	2b	Shallow	Natural recovery	0.57	1.1	2.0		yes	yes	-85%	96%		-53%	-58%	-65%
	2c	Shallow	Natural recovery	8.8	7.5	0.86		no	no	>Reference			--	--	--
ref	5a	Shallow	--	7.2	4.8	0.66									
	3a	Moderate depth	TLP	1.5	1.2	0.82	sqrt	no	no	>Reference			--	--	--
	3b	Moderate depth	Natural recovery	1.0	1.0	1.0		no	no	-4%	2%	*	-147%	-164%	-183%
	4	Deep	Natural recovery	2.2	1.3	0.59		no	no	79%	0%	*	-126%	-140%	-157%
ref	5b	Moderate depth	--	1.2	1.6	1.37									

Table 12. (cont.)

	Benthic Stratum	Depth Category	Remediation Category	Mean	Standard Deviation	CV	Transform	Dunnett's[a]	Wilcoxon[b]	Actual MDRD	Actual Power		MDRD for power levels 60%	70%	80%
Molluscs															
	1	Very shallow	TLP	93	78	0.84	$\log_{10}(+1)$	no	no	>Reference			--	--	--
	2a	Shallow	TLP	32	43	1.4		no	no	>Reference			--	--	--
	2b	Shallow	Natural recovery	0.14	0.38	2.6		yes	yes	-96%	100%		-32%	-35%	-40%
	2c	Shallow	Natural recovery	23	15	0.64		no	no	>Reference			--	--	--
ref	5a	Shallow	--	15	7.4	0.48									
	3a	Moderate depth	TLP	34	27	0.80	sqrt	no	no	>Reference			--	--	--
	3b	Moderate depth	Natural recovery	1.2	0.84	0.70		no	no	-60%	52%	*	-66%	-73%	-82%
	4a	Deep	Natural recovery	1.0	1.0	1.0		no	no	-68%	60%		-68%	-76%	-85%
ref	5b	Moderate depth	--	7.4	6.7	0.90									
Total Richness															
	1	Very shallow	TLP	22	11	0.49	sqrt	no	no	-3%	2%	*	-59%	-66%	-73%
	2a	Shallow	TLP	14	8.7	0.65		no	no	-40%	33%	*	-55%	-61%	-68%
	2b	Shallow	Natural recovery	3.3	1.5	0.46		yes	yes	-85%	100%		-26%	-29%	-32%
	2c	Shallow	Natural recovery	27	8.9	0.33		no	no	>Reference			--	--	--
ref	5a	Shallow	--	22	5.1	0.23									
	3a	Moderate depth	TLP	20	8.2	0.41	$\log_{10}(+1)$	no	no	>Reference			--	--	--
	3b	Moderate depth	Natural recovery	3.2	1.3	0.41		no	no	-41%	15%	*	-88%	-98%	-110%
	4	Deep	Natural recovery	4.8	1.8	0.37		no	no	-11%	3%	*	-91%	-102%	-114%
ref	5b	Moderate depth	--	5.4	4.3	0.79									
Taxa Richness															
Polychaetes															
	1	Very shallow	TLP	13	6.9	0.54	sqrt	no	no	-11%	6%	*	-43%	-47%	-53%
	2a	Shallow	TLP	6.5	4.7	0.73		yes	no	-36%	68%		-33%	-37%	-41%
	2b	Shallow	Natural recovery	2.9	1.1	0.37		yes	yes	-56%	100%		-17%	-19%	-21%
	2c	Shallow	Natural recovery	19	5.7	0.31		no	no	>Reference			--	--	--
ref	5a	Shallow	--	15	3.9	0.27									
	3a	Moderate depth	TLP	11	5.4	0.49	$\log_{10}(+1)$	no	no	>Reference			--	--	--
	3b	Moderate depth	Natural recovery	1.2	0.45	0.37		no	no	-26%	22%	*	-45%	-51%	-57%
	4	Deep	Natural recovery	2.2	1.6	0.75		no	no	-4%	2%	*	-59%	-66%	-74%
ref	5b	Moderate depth	--	2.4	2.1	0.86									

Table 12. (cont.)

	Benthic Stratum	Depth Category	Remediation Category	Mean	Standard Deviation	CV	Transform	Dunnett's[a]	Wilcoxon[b]	Actual MDRD	Actual Power		MDRD for power levels 60%	70%	80%
Arthropods															
	1	Very shallow	TLP	1.4	1.3	0.96	sqrt	no	no	-40%	22%	*	-68%	-76%	-84%
	2a	Shallow	TLP	1.3	0.50	0.40		no	no	-27%	43%	*	-33%	-36%	-40%
	2b	Shallow	Natural recovery	0.29	0.49	1.7		yes	yes	-81%	100%		-41%	-46%	-51%
	2c	Shallow	Natural recovery	3.6	2.6	0.72		no	no	>Reference			--	--	--
ref	5a	Shallow	--	2.4	1.1	0.48									
	3a	Moderate depth	TLP	1.5	1.2	0.82	$\log_{10}(+1)$	no	no	>Reference			--	--	--
	3b	Moderate depth	Natural recovery	0.80	0.84	1.0		no	no	>Reference			--	--	--
	4	Deep	Natural recovery	1.6	0.89	0.56		no	no	>Reference			--	--	--
ref	5b	Moderate depth	--	0.80	0.84	1.0									
Molluscs															
	1	Very shallow	TLP	7.6	3.2	0.42	sqrt	no	no	>Reference			--	--	--
	2a	Shallow	TLP	5.5	4.7	0.85		no	no	-12%	3%	*	-81%	-90%	-100%
	2b	Shallow	Natural recovery	0.14	0.38	2.6		yes	yes	-94%	100%		-24%	-27%	-30%
	2c	Shallow	Natural recovery	4.2	1.3	0.31		no	no	-10%	11%	*	-26%	-28%	-32%
ref	5a	Shallow	--	5.2	1.8	0.34									
	3a	Moderate depth	TLP	6.7	4.7	0.70	$\log_{10}(+1)$	no	no	>Reference			--	--	--
	3b	Moderate depth	Natural recovery	1.2	0.84	0.70		no	no	-32%	20%	*	-58%	-64%	-72%
	4	Deep	Natural recovery	1.0	1.0	1.0		no	no	-46%	32%	*	-66%	-74%	-83%
ref	5b	Moderate depth	--	2.2	1.6	0.75									
Swartz' Dominance Index															
	1	Very shallow	TLP	3.8	1.8	0.47	sqrt	no	no	>Reference			--	--	--
	2a	Shallow	TLP	5.8	2.6	0.46		no	no	>Reference			--	--	--
	2b	Shallow	Natural recovery	1.6	0.53	0.34		no	yes	-32%	46%	*	-37%	-42%	-46%
	2c	Shallow	Natural recovery	11	1.7	0.15		no	no	>Reference			--	--	--
ref	5a	Shallow	--	3.6	2.5	0.70									
	3a	Moderate depth	TLP	7.5	3.0	0.40	$\log_{10}(+1)$	no	no	>Reference			--	--	--
	3b	Moderate depth	Natural recovery	1.6	1.3	0.84		no	no	-8%	3%	*	-64%	-71%	-80%
	4	Deep	Natural recovery	1.6	0.55	0.34		no	no	-2%	2%	*	-51%	-57%	-64%
ref	5b	Moderate depth	--	1.8	1.3	0.72									

Table 12. (cont.)

Note:

*	-	qualitative interpretation recommended
ANOVA	-	analysis of variance
AOC	-	area of concern
CV	-	coefficient of variation
MDRD	-	minimum detectable relative difference, calculated relative to reference; MDRD is the minimum detectable difference divided by the reference mean
TLP	-	thin layer placement

MDRD and power calculations were conducted for one-sided comparisons between each AOC stratum and reference area stratum based on transformed data. An adjusted alpha level, 0.0125 = 0.05/4 for comparison to 5a and 0.0167 = 0.05/3 for comparison to 5b, was used to account for mul tiple comparisons.

Power levels were very low or zero for AOC strata with values higher than reference values because comparisons were one-sided to test only whether values for AOC strata were lower than reference values.

[a] Dunnett's one-sided multiple comparison tests were conducted following an overall ANOVA indicating significant differences ($P \leq 0.05$).

[b] Wilcoxon's non-parametric rank test.

Table 13. Summary of species that accounted for ≥5 percent of total abundance in each benthic stratum of Ward Cove in July 2004

Stratum	Depth Category	Remediation Category	Relative Abundance (percent)	Species[a]
AOC Stations				
1	Very shallow	TLP	35	*Axinopsida serricata* (B)
			15	*Owenia fusiformis* (P)
			11	*Dorvillea annulata* (P)
			7.9	*Rochefortia tumida* (B)
2a	Shallow	TLP	23	*Axinopsida serricata* (B)
			17	*Parvilucina tenuisculpta* (B)
			6.6	*Acteocina eximea* (G)
			5.1	*Tellina modesta* (B)
			5.1	*Capitella capitata* (P)
2b	Shallow	Natural recovery	93	*Capitella capitata* (P)
2c	Shallow	Natural recovery	20	*Parvilucina tenuisculpta* (B)
			10	*Lumbrineris californiensis* (P)
			6.2	*Dorvillea annulata* (P)
			5.9	*Prionospio steenstrupi* (P)
3a	Moderate depth	TLP	24	*Axinopsida serricata* (B)
			10	*Parvilucina tenuisculpta* (B)
			10	*Nephtys cornuta* (P)
3b	Moderate depth	Natural recovery	85	*Nephtys cornuta* (P)
4	Deep	Natural recovery	51	*Nephtys cornuta* (P)
			26	*Capitella capitata* (P)
Reference Area Stations				
5a	Shallow	--	65	*Capitella capitata* (P)
			14	*Dorvillea annulata* (P)
5b	Moderate depth	--	61	*Nephtys cornuta* (P)
			14	*Parvaplustrum* spp. (G)

Note: AOC - area of concern
TLP - thin layer placement

[a] Major taxonomic groups denoted in parentheses:
G - Gastropoda
B - Bivalvia
P - Polychaeta

Table 14. Comparison of major benthic macroinvertebrate taxa between communities sampled in Ward Cove in 1992 and 2004[a,b]

	Mean Number Captured (per 0.1 m^2)	
Taxon	1992[c]	2004
Molluscs		
Axinopsida serricata	0.1[d]	17
Parvilucina tenuisculpta	0.4[d]	7.5
Rochefortia tumida	1.2	4.1
Tellina modesta	--	2.0
Acteocina eximea	--	1.1
Parvaplustrum spp.	--	1.0
Polychaetes		
Capitella capitata	190	76
Dorvillea annulata	--	13
Nephtys cornuta	8.9	13
Owenia fusiformis	--	11
Lumbrineris californiensis	--	3.5
Prionospio steenstrupi	--	2.1
Schistomeringos japonica	73	--
Nematodes	180	--
Total Abundance	**470**	**180**
Modified Total Abundance[e]	**100**	**104**

Note: -- - taxon not found

[a] Major taxa were defined as those that accounted for more than 5 percent of the total abundance at any station.

[b] Sampling in 1992 was conducted at 5 stations (3 replicate samples per station) by EVS (1992); sampling in 2004 was conducted at 47 stations (1 sample per station) as part of the present study.

[c] *A. serricata*, *P. tenuisculpta*, and *R. tumida* were all collected in a single replicate grab sample from one station.

[d] Data provided in EVS (1992) as one significant figure.

[e] *Capitella capitata* and nematodes removed.