2007 MONITORING REPORT FOR SEDIMENT REMEDIATION IN WARD COVE, ALASKA

Prepared for

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ACRONYMS AND ABBREVIATIONS

ANOVA	analysis of variance
AOC	area of concern
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CoC	chemical of concern
EPA	U.S. Environmental Protection Agency
KPC	Ketchikan Pulp Company
LMRP	long-term monitoring and reporting plan
MDS	multidimensional scaling
MLLW	mean lower low water
PCDD/F	polychlorinated dibenzo-*p*-dioxin and polychlorinated dibenzofuran
RAO	remedial action objective
RI/FS	remedial investigation and feasibility study
ROD	record of decision
SDI	Swartz' dominance index
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 Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 consent decree (November 2000), the Ward Cove remedial investigation and feasibility study (RI/FS) (Exponent 1999), the record of decision (ROD) for the Marine Operable Unit of Ward Cove (U.S. EPA 2000a), and the long-term monitoring and reporting plan for sediment remediation in Ward Cove (LMRP) (Exponent 2001), which was approved by the U.S. Environmental Protection Agency (EPA). The multiple lines of evidence used to evaluate sediment quality in the Ward Cove area of concern (AOC) indicate that the remedial action objectives (RAOs) have been achieved. The lines of evidence include quantitative and qualitative evaluations of temporal and spatial trends in toxicity responses, benthic macroinvertebrate community characteristics, and supporting measurements of chemicals of concern (CoCs) and conventional variables. These measurements have been conducted on AOC sediments since remedial efforts were implemented in 2000/2001.

BACKGROUND

The RI/FS was conducted in Ward Cove from 1996 to 1999. Of the approximately 250 acres of Ward Cove that were evaluated during the RI/FS, 80 acres were designated as an AOC where remedial action was warranted (Exponent 1999).

Sediment concentrations of persistent chemicals that are toxic or that have the potential to bioaccumulate in marine organisms (e.g., mercury, polychlorinated dibenzo-*p*-dioxin and polychlorinated dibenzofuran) were low and did not pose unacceptable risks to human health, fish, or wildlife (i.e., birds and mammals). However, potential risks to benthic macroinvertebrates were predicted from three CoCs (i.e., ammonia, 4-methlyphenol, and sulfide) based on results of sediment toxicity tests and synoptic measurements of those chemicals. These CoCs are natural degradation products of pulp mill by-products, are themselves non-persistent, and are readily oxidized in the natural environment. The cessation of pulp mill activities in May 1997, the non-persistent nature of the CoCs, the physical constraints of the site bathymetry and sediment characteristics, and the potential for natural recovery were all considered during remedy selection.

Remedial action within the AOC was performed between October 2000 and February 2001. Because the risks were limited to benthic macroinvertebrate communities and the CoCs were non-persistent, the remedy relied largely on monitored natural recovery and enhanced natural recovery. Enhanced natural recovery using thin layer placement (TLP) with 6–12 in. of clean sand was successfully implemented at approximately 27 acres within Ward Cove. Monitored natural recovery was the preferred alternative for the remainder of the 80-acre AOC.

Although three CoCs were identified in the RI/FS, only ammonia and 4-methylphenol were selected in the ROD for the long-term monitoring effort, and evaluations of both CoCs were specified as being based on bulk sediment chemical measurements (i.e., as they were in the RI/FS). Sulfide was not selected for the long-term monitoring effort in the ROD because dissolved sulfide (i.e., the form of sulfide most likely to be toxic to benthic macroinvertebrates) cannot be adequately characterized by bulk sediment chemistry measurements. In addition, it was not considered practical, efficient, or ecologically relevant in the ROD to monitor sulfide in pore water, given its high spatial and temporal variability.

REMEDIAL ACTION OBJECTIVES AND MONITORING STUDY DESIGN

EPA identified RAOs for Ward Cove in the ROD. Specifically, the response action was intended to achieve the following RAOs:

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

As stated in the ROD, monitoring data were evaluated using a weight-of-evidence approach to determine whether consistent and acceptable progress has been made toward achieving the RAOs, rather than strict triggers for additional actions. The weight-of-evidence approach is recommended by EPA for sediment quality assessments throughout the United States as a part of EPA's national sediment assessment programs, and is consistent with the most current methods of sediment assessment recommended by national experts.

In using a weight-of-evidence approach to evaluate if RAOs have been achieved, EPA considered all information relevant to whether benthic communities at a particular location are recovering as expected. A weight-of-evidence approach is also considered appropriate for this site because determining whether the benthic community is recovering at an acceptable rate is a more sophisticated analysis than would be captured by strict numerical trigger values, such as determining whether a thick cap has been breached.

The LMRP was designed to evaluate progress made in achieving the RAOs following completion of remedial activities in Ward Cove in 2001. The LMRP specified that monitoring would occur every three years in July until RAOs were achieved. The program was designed to evaluate three major indicators of sediment quality: 1) sediment chemistry, 2) sediment toxicity, and 3) benthic macroinvertebrate communities, with the central focus on toxicity and macroinvertebrate communities, which directly relate to the RAOs. Although site-specific sediment quality values were developed for ammonia and 4-methylphenol during the RI/FS to help determine the boundaries of the AOC (Exponent 1999), these values were used in the long-term monitoring effort only to help interpret the related biological results. These site-specific sediment quality values were not designed for use as RAOs, because ammonia and 4-methyphenol are non-persistent and readily oxidized in the natural environment.

To best represent the varying conditions in the 80-acre AOC, it 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). Each stratum had five to seven monitoring stations located within it. At most stations, single samples were collected for sediment toxicity and benthic community evaluations. Seven of the monitoring stations represented locations characterized for the RI/FS. Five replicate laboratory toxicity tests were conducted for four of these seven RI/FS locations to allow temporal comparisons of sediment toxicity responses to be made on a statistical basis. Two reference area strata were designated within the cove, based on water depth and distance from known sources of chemical contamination. Spatial comparisons were made by statistically comparing the mean conditions in each AOC stratum with the conditions found in its respective depth-specific reference area stratum.

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

- **Sediment Chemistry**—Each surface sediment sample (0–10 cm horizon) was analyzed for the two CoCs (i.e., ammonia and 4-methylphenol), to assist in the interpretation of the sediment toxicity and benthic community results. Sediment samples were also analyzed for selected conventional variables (i.e., grain size distribution, organic content, and total solids) to also assist in the interpretation of the biological results.
- **Sediment Toxicity**—The potential toxicity of each surface sediment sample was evaluated using the 10-day amphipod test based on *Eohaustorius estuarius.* This test is commonly used to evaluate sediment toxicity of marine and estuarine sediments, and has standardized and well-established test protocols. In addition, this test is consistent with the test used to characterize sediment toxicity in Ward Cove for the RI/FS (i.e., the 10-day amphipod test based on *Rhepoxynius abronius*). Although *R. abronius* was originally used in the RI/FS, it was necessary to change the test species in 2004 to *E. estuarius*, because of uncertainties involved with obtaining an adequate number of healthy *R. abronius* for testing. Because these amphipods have been documented to be sensitive to chemical toxicity and are directly exposed to sediment contaminants, they provide an environmentally conservative assessment of the changes in sediment toxicity following remediation in Ward Cove.
- **Benthic Communities**—The characteristics of benthic communities in various parts of Ward Cove were directly evaluated by collecting and enumerating the organisms found in surface sediment samples collected from the site. Benthic communities are commonly used to assess sediment quality because these organisms are relatively stationary and live in close association with the bottom sediments (U.S. EPA 1990). Sediments were sieved (>1.0 mm), retained material was transferred to appropriate containers and fixed

with buffered formalin, and organisms were transferred to the laboratory for taxonomic analysis. Sediment samples were sorted with a minimum accuracy of 95 percent and taxonomic identifications were made to the lowest taxonomic level practical by qualified taxonomic experts. Quantitative evaluations of individuals and major taxa included comparisons between the AOC strata (i.e., TLP and natural recovery strata) and reference areas with respect to a variety of benthic metrics based on abundance, richness, and Swartz' dominance index (SDI). Qualitative observations of key benthic macroinvertebrate taxa were also made to determine whether the communities were recolonizing the TLP and natural recovery areas consistent with the classical patterns identified for disturbed benthic habitats.

As described in the LMRP, the long-term monitoring strategy for the Ward Cove AOC implicitly recognized the limited degree of the risk posed by Ward Cove sediments (i.e., absence of bioaccumulative chemicals; absence of risks to humans, fish, and wildlife) and the inherent uncertainties in the rate of natural recovery. The LMRP adopted a flexible, adaptive risk management strategy to interpret the monitoring data and determine appropriate actions. The lines of evidence used to support this approach included the multiple measures of sediment quality, and both qualitative and quantitative interpretation methods.

The long-term monitoring approach used for Ward Cove is consistent with the recommendations of recent EPA guidance for addressing contaminated sediments at hazardous waste sites (U.S. EPA 2005), which was not available when the LMRP was prepared in 2001. The monitoring approach is consistent with the six-step process for developing and implementing a monitoring plan (U.S. EPA 2004; see Highlight 8-3 of U.S. EPA 2005). In addition, the monitoring approach is consistent with the remedy-specific monitoring approaches recommended by U.S. EPA (2005) for both monitored natural recovery and *in situ* capping or TLP. The monitoring data for Ward Cove were evaluated using a combination of physical, chemical, and biological endpoints. U.S. EPA (2005) also emphasizes the use of multiple lines of evidence for assessing natural recovery and achievement of RAOs. Finally, U.S. EPA (2005) suggests that EPA project managers use an adaptive management approach that involves re-evaluating site assumptions as new information is gathered.

MONITORING DATA INTERPRETATION

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 in the Ward Cove AOC:

- **Comparison of TLP and Natural Recovery Areas to Reference Areas—**Allows 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.

Based on the results of the 2004 monitoring event (Exponent 2005), EPA determined that monitoring at one of the four natural recovery areas identified in the ROD was no longer necessary. That area was the shallow natural recovery area with thin organic deposits (i.e., Stratum 2c). Additional monitoring of Stratum 2c was not considered necessary because the RAOs had been achieved—sediment toxicity was reduced and benthic recolonization was enhanced such that Stratum 2c now supports healthy benthic communities with multiple taxonomic groups. Stratum 2c is therefore not addressed in this 2007 monitoring report.

The progress toward recovery based on the 2007 monitoring data is summarized in the following table and in the text below:

Summary of Recovery Status for Various Biological Indicators in Ward Cove Based on 2007 Data[a]

	Stratum					
	Thin-Layer Placement			Natural Recovery		
Indicator	1	2a	3a	2b	3b	4
Sediment Toxicity	✓	✓	✓	✓	✓	✓
Benthic Community Metrics[b]	100%	100%	100%	33%[c]	100%	100%
Abundance						
Total abundance	✓	✓	✓	--	✓	✓
Taxa abundance						
Molluscs	✓	✓	✓	--	✓	✓
Polychaetes	✓	✓	✓	✓	✓	✓
Arthropods	✓	✓	✓	✓	✓	✓
Richness						
Total richness	✓	✓	✓	--	✓[d]	✓
Taxa richness						
Molluscs	✓	✓	✓	--	✓[d]	✓
Polychaetes	✓	✓	✓	--	✓[d]	✓
Arthropods	✓	✓	✓	✓	✓	✓
SDI	✓	✓	✓	--	✓[d]	✓

✓ = For sediment toxicity: Survival is greater than the 75 percent screening value specified in the LMRP.
For benthic metrics: Value is not significantly lower ($P>0.05$) than the respective mean reference value.

-- = Significantly lower ($P\leq0.05$) than the respective mean reference value.

[a] Sediment chemistry was analyzed, but not included in this table because it is not applicable to RAOs. Stratum 2c is not included in this table because results of the 2004 monitoring event showed that this area had achieved the RAOs (see above text for further explanation).

[b] Percentages indicate the number of benthic metrics that are not significantly lower ($P>0.05$) than their respective mean reference values (note that for Stratum 3b, uncertainty exists for some benthic metrics due to low statistical power).

[c] Recovery of benthic communities is progressing in this stratum (see text on p. xvii for explanation).

[d] Low statistical power for benthic comparisons.

Overall AOC

Sediment toxicity was not only reduced throughout the AOC in 2007, but exceeded the screening value of 75 percent (as specified in the LMRP) in all AOC strata, indicating that the RAO based on sediment toxicity has been achieved throughout the AOC. In 2004, mean amphipod survival in Stratum 2c also exceeded the screening value of 75 percent, indicating that the RAO based on sediment toxicity had been achieved in that stratum, which, as described previously, was considered recovered after the 2004 monitoring event. In addition, mean survival for all TLP and natural recovery strata was not significantly lower ($P>0.05$) than the reference values. Although statistical comparisons for Stratum 4 were affected by low statistical power, the fact that mean survival for that stratum was greater than the screening value of 75 percent indicates that the RAO based on sediment toxicity has been achieved.

In addition to the above information, specific temporal patterns for the six strata sampled in 2007 for sediment toxicity can be summarized as follows:

- Values of mean amphipod survival for all three TLP areas in 2007 were very high (i.e., 92–95 percent) and comparable to the values found in 2004 (i.e., 93–96 percent). In the natural recovery areas, values of mean amphipod survival in 2007 (i.e., 80–96 percent) generally were considerably higher than the values found in 2004 (i.e., 32–76 percent).
- For individual stations within the strata, amphipod survival exceeded the screening value of 75 percent at all 15 stations sampled in the TLP areas, which was consistent with the 2004 results. In the natural recovery areas, amphipod survival exceeded the minimum acceptable value at 14 of the 17 stations sampled in 2007, compared with only 7 of the 17 stations sampled in 2004.

Remedial efforts have successfully enhanced recolonization of surface sediment to support healthy marine benthic macroinvertebrate communities with multiple taxonomic groups throughout most of the AOC. As discussed above, the RAO for benthic communities was achieved in 2004 for Stratum 2c. Of the six strata sampled in 2007, community metrics were not significantly lower ($P>0.05$) than reference values in the three TLP areas and two natural recovery areas indicating that the RAO for benthic macroinvertebrate communities has been achieved in most parts of the AOC. Benthic metrics at the remaining natural recovery area (i.e., Stratum 2b) were significantly lower ($P\leq0.05$) than reference values for the following metrics: total abundance, total richness, polychaete richness, mollusc abundance, mollusc richness, and SDI. Stratum 2b is discussed in greater detail below.

In addition to the results described above for community metrics, a number of additional qualitative and quantitative benthic analyses were conducted on the 2007 data, including evaluations of the successional stages of key benthic species, temporal patterns in community characteristics, multivariate analysis of benthic communities, and taxa richness at individual stations. The results of those analyses are summarized below and show that, in general, diverse communities comprising multiple taxa now inhabit the three TLP areas and two of the three natural recovery areas (i.e., Strata 3b and 4). The results of the additional benthic analyses can be summarized as follows:

- Approximately 6,800 benthic macroinvertebrates from 130 taxa were sampled as part of the 2007 sampling event, compared to the approximately 4,500 individuals from 117 taxa that were sampled in 2004. The 2004 results for Stratum 2c were not included in these comparisons, because that stratum was not evaluated in 2007. These values represent increases of approximately 33 and 10 percent in the total numbers of individuals and taxa over the 3-year period between monitoring events.
- The number of polychaete taxa and the relative abundance of polychaetes declined in 2007 compared to 2004, whereas the number of mollusc taxa and the relative abundance of molluscs increased between the two sampling periods. This pattern continues the trend of an increasing representation of molluscs in the benthic communities that was first identified in 2004.
- The benthic communities in the TLP areas in 2007 continued to be characterized primarily by species commonly found in areas where organic enrichment is declining, as they were in 2004. These species include the polychaete *Prionospio steenstrupi* and the bivalves *Axinopsida serricata* and *Parvilucina tenuisculpta*. Although benthic communities in the three natural recovery areas were characterized primarily by species commonly found in organically enriched areas, the relative abundance of the polychaete *Capitella capitata* declined substantially, as the abundances of the polychaetes *Nephtys cornuta* and *Dorvillea annulata* increased. The decline in the abundances of *C. capitata* is notable, as this species complex is a classic indicator of organic enrichment throughout the world. Coupled with the decline in nematodes (i.e., another classic indicator of organic enrichment) that occurred between 1992 and 2004, the decline in *C. capitata* indicates that conditions in the natural recovery areas have been continually improving over time.
- If *C. capitata* and nematodes are removed from the benthic communities sampled in 1992, 2004, and 2007, mean total abundance in 2004 (95 individuals per station) is nearly identical to the value found in 1992 (100 individuals per station), and the value found in 2007 (250 individuals per station) is two and one-half times the 1992 value. These results indicate that total abundances of benthic communities (exclusive of species characteristic of high levels of organic enrichment) increased substantially between the 2004 and 2007 monitoring events.
- With respect to the number of benthic taxa that accounted for more than 5 percent of total abundance at any station in the AOC, there were only seven such taxa in 1992. In 2004, the number of these taxa increased relatively modestly to 11 taxa, but by 2007, the number increased substantially to 28 taxa. These results indicate that many more species were becoming numerically important at various stations throughout the AOC in 2007, which is an indication that conditions have improved in the AOC since 2004.

- Results of multivariate analyses of the benthic macroinvertebrate data collected in Ward Cove in 2007 showed that three distinct clusters or groups of stations were apparent, with the natural recovery areas clustering with the reference areas and the TLP areas clustering only with themselves. These results indicate that TLP in the cove has resulted in benthic communities that are different from the communities found in the natural recovery and reference areas. Given the other characteristics of these communities described in this report, it can be concluded that TLP in the cove has resulted in modifications of the communities such that they are now enhanced beyond the reference conditions. In addition, although the natural recovery areas have not shown the same degree of enhancement, they are now relatively similar to the reference conditions.

Stratum 2b

Although six benthic community metrics for Stratum 2b were found to be significantly lower ($P \leq 0.05$) than reference values, mean amphipod survival in this stratum in 2007 exceeded the minimum acceptable value of 75 percent specified in the LRMP, indicating that this stratum has fully recovered with respect to the RAO based on sediment toxicity. Additional lines of evidence based on sediment toxicity, sediment chemistry, and benthic community species composition also indicate that overall recovery of the stratum is occurring, including benthic community recovery. These lines of evidence are described in greater detail in the main body of this report, including the conclusions section.

The multiple lines of evidence for Stratum 2b indicate that this stratum has made substantial advances in overall recovery. For example, sediment toxicity conditions in Stratum 2b have fully recovered with respect to the RAO for sediment toxicity, and mean concentrations of both CoCs (i.e., ammonia and 4-methylphenol) and total organic carbon (TOC) declined by 20 to 50 percent between 2004 and 2007. The patterns observed for individual benthic macroinvertebrate taxa support the conclusion that benthic community recovery is progressing. That is, the polychaete *N. cornuta* (a Successional Stage III species) has become a dominant member of the benthic community in Stratum 2b (accounting for 41 percent of individuals in 2007 compared to less than 5 percent in 2004), whereas the relative abundance of the polychaete *C. capitata* (a Successional Stage I species) has declined substantially in that stratum, such that this species accounted for only 6 percent of individuals in 2007, compared to 93 percent of individuals in 2004.

The weight of evidence described above for Stratum 2b indicates that the RAO for sediment toxicity has been achieved, and that consistent and acceptable progress has been made towards achieving the RAO for healthy benthic communities comprising multiple taxa. Because the sediments in Stratum 2b are no longer toxic, benthic community recovery will continue in the future. In addition, the CoC and TOC concentrations in Stratum 2b will likely continue to decline, because the major source of organic loadings to Ward Cove has been removed, further indicating that benthic community recovery will continue in the future. Therefore, based on the benthic succession patterns described in the general literature as well as the degree of benthic community recovery that has already occurred in other parts of the Ward Cove AOC, there is a weight of evidence that benthic community recovery will continue to proceed in Stratum 2b.

From the standpoint of the overall Ward Cove AOC, Stratum 2b represents a relatively small area (i.e., approximately 12 percent of the AOC). Therefore, it is unlikely that the slower recovery observed in that stratum relative to the remainder of the AOC will have a substantial impact on organisms at higher trophic levels that prey on benthic macroinvertebrates, such as crabs and a number of demersal fish species. As noted in the ROD, a benefit of achieving the RAOs in the Ward Cove AOC is that a healthy benthic macroinvertebrate community will provide a diverse food source for organisms at higher trophic levels.

SUMMARY AND RECOMMENDATIONS

The RAOs have been achieved in Ward Cove. The results of the 2004 and 2007 monitoring events demonstrate that environmental conditions throughout the Ward Cove AOC have improved substantially since the RI/FS was conducted in 1996–1999. In addition, most conditions showed continual improvement between 2004 and 2007. The TLP has been 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 enhanced characteristics beyond those of the reference areas. In addition, recovery is proceeding in the natural recovery areas, such that all four areas surpassed sediment toxicity screening levels and three of the four areas have achieved healthy benthic communities with multiple taxonomic groups. The weight of evidence for the remaining natural recovery area (i.e., Stratum 2b) indicates that, in addition to surpassing sediment toxicity screening levels, substantial and acceptable progress has been made towards achieving a healthy benthic community. There are numerous reasons to predict that diversification of benthic communities in Stratum 2b will continue to proceed, because sediment toxicity in that area has achieved the RAO, concentrations of TOC and the two CoCs declined by 20 to 50 percent between 2004 and 2007, and the major source of CoCs to the AOC has been removed.

Based on the results of both the 2004 and 2007 monitoring events, it is concluded that TLP and natural recovery have been successful remediation tools for the Ward Cove AOC. Sediment toxicity has been reduced and benthic recolonization has been enhanced such that the overall AOC now supports healthy benthic communities with multiple taxonomic groups. The RAOs have been achieved and monitoring is no longer necessary.

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). This monitoring report has been prepared in compliance with the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) consent decree (November 2000), the Ward Cove remedial investigation and feasibility study (RI/FS) (Exponent 1999), the record of decision (ROD) for the Marine Operable Unit of Ward Cove (U.S. EPA 2000a), and the long-term monitoring and reporting plan for sediment remediation in Ward Cove (LMRP) (Exponent 2001), which was approved by the U.S. Environmental Protection Agency (EPA). The multiple lines of evidence used to evaluate sediment quality in the Ward Cove area of concern (AOC) indicate that the remedial action objectives (RAOs) have been achieved. The lines of evidence include quantitative and qualitative evaluations of temporal and spatial trends in toxicity responses, benthic macroinvertebrate community characteristics, and supporting measurements of chemicals of concern (CoCs) and conventional variables that have been conducted on AOC sediments since remedial efforts were implemented in 2000/2001.

The RI/FS was conducted in Ward Cove between 1996 and 1999. Of the approximately 250 acres of Ward Cove that were evaluated during the RI/FS, 80 acres were designated as an AOC where remedial action was warranted (Exponent 1999). The unique physical and chemical characteristics of Ward Cove were critical considerations in the selection of remedial actions. Sediment concentrations of persistent chemicals that are toxic or that have the potential to bioaccumulate in marine organisms (e.g., mercury, polychlorinated dibenzo-*p*-dioxin and polychlorinated dibenzofuran [PCDD/F]) were low and did not pose unacceptable risks to human health, fish, or wildlife (i.e., birds and mammals). However, potential risks to benthic macroinvertebrates were predicted from three CoCs (i.e., ammonia, 4-methlyphenol, and sulfide) based on results of sediment toxicity tests and synoptic measurements of those chemicals. These natural degradation products of pulp mill by-products are themselves non-persistent and are readily oxidized in the natural environment. The cessation of pulp mill activities in May 1997, the non-persistent nature of the CoCs, the physical constraints of the site bathymetry and sediment characteristics, and the potential for natural recovery were all considered during remedy selection.

Although three CoCs were identified in the RI/FS, only ammonia and 4-methylphenol were selected in the ROD for the long-term monitoring effort, and evaluations of both CoCs were specified as being based on bulk sediment chemical measurements (i.e., as they were in the RI/FS). Sulfide was not selected for the long-term monitoring effort in the ROD because dissolved sulfide (i.e., the form of sulfide most likely to be toxic to benthic macroinvertebrates) cannot be adequately characterized by bulk sediment chemistry measurements. In addition, it was not considered practical, efficient, or ecologically relevant in the ROD to monitor sulfide in pore water, given its high spatial and temporal variability.

Remedial action within the Ward Cove AOC was performed between October 2000 and February 2001. Three general categories of remedial action were specified in EPA's 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 2007 monitoring event, which is the second such study to be conducted since remediation occurred in 2000/2001. The initial monitoring event was conducted in July 2004 (Exponent 2005). Field sampling for the 2007 monitoring event was conducted in July 2007. The contents of this document include an initial overview of the monitoring objectives, monitoring approach, and program design for the overall monitoring program. The results of the 2007 monitoring event are then discussed, including all departures from the original design that occurred in 2007, a summary of the 2007 field sampling activities, and the results of the analysis and interpretation of the data collected during 2007. All data collected in 2007 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.

Based on the results of the 2004 monitoring event in Ward Cove, it was concluded that environmental conditions in many parts of the Ward Cove AOC had improved since the RI/FS was conducted in 1996–1999 (Exponent 2005). 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. In 2004, one of the four natural recovery areas (i.e., Stratum 2c) had shown improvements that were comparable to those found in the three TLP areas. Stratum 2c was therefore removed from the overall monitoring program in 2004 because recovery was considered sufficient. Because the RAOs had been achieved, Stratum 2c was not sampled in 2007. With the exception of Stratum 2c, all other monitoring areas evaluated in 2004 were evaluated in 2007 using identical field and laboratory methods, which facilitates direct comparison of results between the two monitoring events, as well as with the results of the RI/FS.

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 a 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 was intended to:

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

Although site-specific Ward Cove sediment quality values (WCSQVs) were developed for two CoCs (i.e., ammonia and 4-methylphenol) during the RI/FS (Exponent 1999), these values were used only to help interpret the related sediment toxicity results and were not designed for use as RAOs because these chemicals are non-persistent and readily oxidized in the natural environment.

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
- Evaluate CoC concentrations and their relationship to sediment toxicity and benthic community structure.

The information collected to satisfy the objectives described above were used to provide an assessment of how sediment toxicity and benthic communities in TLP and natural recovery areas were changing over time, as well as how similar the evolving communities were to those of reference areas at various points in time. This information was used to determine the degree to which sediment recovery was 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 were evaluated on sediment samples representing the surface (i.e., 0–10 cm horizon) of the sediments. Sediment chemistry and toxicity were assessed during the RI/FS and therefore these monitoring components were compared to pre-remedial conditions as well as to reference areas. Temporal trends in sediment chemistry, sediment toxicity, and benthic macroinvertebrate communities were evaluated from multiple monitoring events until RAOs were achieved. Benthic community measurements in 2004 were compared only qualitatively to reference area conditions, because these communities were not evaluated in the RI/FS. Analytical methods for chemistry and toxicity testing were the same as those used in the RI/FS (Exponent 1999).

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

- **Sediment chemistry—**Each surface sediment sample was analyzed for ammonia and 4-methylphenol. These analytes were identified as CoCs in the RI/FS and ROD and assisted in the interpretation of the biological data. Sediments were also 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 was evaluated using a standardized 10-day amphipod test (PSEP 1995; U.S. EPA 2000c). Although the test species was originally specified as the amphipod *R. abronius* in the LMRP, in 2004 it was necessary to change the test species to an alternative amphipod, *E. estuarius*, because of uncertainties involved with obtaining adequate numbers of healthy *R. abronius* for testing (Exponent 2005). *E. estuarius* was also the test species used in the 2007 monitoring event.
- **Benthic macroinvertebrate communities—**The characteristics of benthic macroinvertebrate communities in various parts of Ward Cove were evaluated directly by collecting and enumerating the organisms found in surface sediment samples collected from the site.

Sampling of the AOC in Ward Cove was specified to occur in July every third year after completion of the remedial activities (e.g., 2004 and 2007) 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 were 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 could be conducted. The mean values of monitoring variables (e.g., chemical concentrations, sediment toxicity responses, and benthic community characteristics) within each stratum was then compared statistically on both a temporal and spatial basis. The temporal evaluations involved comparisons of monitoring variables for each benthic stratum among different sampling periods, whereas the spatial evaluations involved 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 was made for the sediment toxicity responses, in which results at four representative stations (Stations 8, 9, 13, and 38) were 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 the WCSQVs for the CoCs and exceedances of the sediment quality standard for the *R. abronius* toxicity test. The four monitoring stations were positioned at the same locations used for the RI/FS. Similar comparisons were not made for benthic community variables because benthic communities were not evaluated in the RI/FS.

Qualitative observations of benthic community characteristics were made to assess whether the evolving communities were 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 were 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 were 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 depth 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 toxicity or exceedances of WCSQVs.

Based on the results of the 2004 monitoring event, several modifications to the overall monitoring design were made (Exponent 2005). As discussed previously, monitoring of Stratum 2c was discontinued because the RAOs had been achieved. In addition, Station 67 in Stratum 1 was moved to ensure that it was located within the actual TLP area of that stratum. Finally, the level of replication in each of the reference areas (i.e., Strata 5a and 5b) was increased from five to seven replicate samples for sediment chemistry, sediment toxicity, and benthic communities, to enhance the probability that the five replicates ultimately used for statistical comparisons with AOC strata met all reference area selection criteria. Those five replicates were selected from the total of seven replicates sampled in each reference area, and used for all statistical and non-statistical evaluations based on reference conditions.

3 METHODS USED DURING THE 2007 MONITORING EVENT

3.1 FIELD METHODS

Surface sediment samples (upper 10 cm) were collected in 2007 from 32 stations along the north shoreline of Ward Cove in the 80-acre AOC (Figure 2), following field procedures described in the field sampling plan (Appendix A of the LMRP) and the study modifications agreed to in the 2004 monitoring report (Exponent 2005). In addition, 14 surface sediment samples were collected from two reference areas outside the AOC, but within Ward Cove (i.e., seven samples from each reference area). Sampling was conducted in July 2007. Oversight was provided on July 9, 2007, by Karen Keeley, of EPA. Phillip Benning, Mike Kinney, Kit Keyes, and Barry Hogarty were KPC's representatives onboard the sampling vessel.

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 using a mesh of 1.0 mm. Retained material was transferred to appropriate containers, fixed with formalin, and transferred to the laboratory for taxonomic analysis.

Table 2 provides a summary of the general characteristics of each station sampled in Ward Cove in 2007.

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 LMRP. Differences in the analytical methods referenced in the LMRP 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 pipette 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 *E. estuarius* were consistent with those used in the RI/FS and those specified in the LMRP for *R. abronius*, which are based on PSEP (1995) and U.S. EPA (2000c). Although the test species was originally specified as the amphipod *R. abronius* in the LMRP, it was necessary to change the test species in 2004 to an alternative amphipod, *E. estuarius*, because of uncertainties involved with obtaining adequate numbers of healthy *R. abronius* for testing (Keeley 2004, pers. comm.). To maintain consistency between the monitoring periods and due to continued uncertainties with *R. abronius* availability, *E. estuarius* was the toxicity test species used for the 2007 study.

As specified in the LMRP, 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 2007 monitoring event were consistent with the methods specified in the LMRP 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 in 2007 to the sediment sampling strategy described in the field sampling plan (Appendix A of the LMRP):

- Due to an error in the navigational positioning system, Station 86 was located approximately 25–30 ft away from the location sampled in 2004.
- Because a permanent log boom (i.e., affixed to the shoreline with cables and anchors) and other floating structures (i.e., walkways and ramps), which provided access to vessels in the area, prevented access to reference area Station 96 (Stratum 5a), the replicate stations at this location were positioned in a line along the shoreline rather than in the pattern that was used in 2004. In all cases, the target water depth was maintained and station locations were moved less than 10 m laterally.
- As agreed upon by EPA and KPC in the 2004 monitoring report (Exponent 2005), *E. estuarius* continued to be used as the test organism for the sediment toxicity test.
- As agreed upon by EPA and KPC in the 2004 monitoring report (Exponent 2005), monitoring was no longer necessary for the shallow natural recovery area with thin organic deposits (Stratum 2c), because the RAOs had been achieved for this area.
- As agreed upon by EPA and KPC in the 2004 monitoring report (Exponent 2005), Station 67 was moved so that it is now located within the actual TLP area of Stratum 1.
- As agreed upon by EPA and KPC, laboratory taxonomic analyses were conducted only on the organisms retained on the 1.0-mm screen. No archive sample of benthic macroinvertebrates was collected from a 0.5-mm screen.
- As agreed upon by EPA and KPC in the 2004 monitoring report (Exponent 2005), seven replicate samples at each of the reference areas were analyzed for sediment chemistry, sediment toxicity, and benthic communities to enhance the probability that all five replicates used for statistical comparisons with AOC strata met all reference area selection criteria.
- Differences in the analytical methods referenced in the LMRP versus those used by the laboratory are summarized in Table B1-2 in Appendix B of this document. However, all of the same analytical methods were used for both the 2004 and 2007 monitoring events.

5 DATA ANALYSIS AND INTERPRETATION

Post-remediation monitoring data were evaluated using two primary types of statistically based analyses, each of which was 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 allowed decisions to be made regarding recovery in TLP and natural recovery areas. Evaluation of temporal trends allowed 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 made in a quantitative manner only between the 2007 and 2004 results, because benthic data were not collected in 1996–1997 during the RI/FS. However, qualitative comparisons of benthic data were made with the limited amount of data collected in Ward Cove in 1992 by EVS (1992).

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 taxononomic group (i.e., molluscs, polychaetes, arthropods)
- **Major taxa richness:** Number of taxa in each major taxonomic group (i.e., molluscs, polychaetes, arthropods).

Although several miscellaneous taxa (i.e., taxa other than the three major ones identified above) were found in some of the samples collected in 2004 and 2007, they were not included in the statistical analyses because of their low abundance and infrequent occurrence.

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 LMRP, they were included in the evaluation of the 2004 data (Exponent 2005) 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 and 2007 monitoring events. 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 2007 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 values of the benthic communities at all stations within each TLP and natural recovery area in 2007 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 2007 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 2007 in Ward Cove. Mean values for these CoCs and conventional analytes are provided in Tables 3 and 4. Data collected during the 2007 monitoring event are provided in Appendix A. A quality assurance review of laboratory procedures and results was conducted by Integral to ensure that the chemical analyses were consistent with the specifications of the test protocols and that the data are acceptable for use in the monitoring program. The complete quality assurance report of the data is provided in Appendix B. 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 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 2007 results with the results found in 2004 during the initial monitoring event and in 1996–1997 during the RI/FS at the seven stations that were sampled during multiple time periods (Table 5). In addition, comparisons among time periods were made between the mean values of the sediment conventional variables for the eight benthic strata.

6.1.1 Chemicals of Concern

6.1.1.1 Ammonia

Concentrations of ammonia at individual stations in the AOC ranged from 1.7 mg/kg at Station 67 in Stratum 1 to 230 mg/kg at Station 88 in Stratum 4 (Figure 4a). Mean concentrations of ammonia in the six benthic strata in the AOC ranged from 3.5 to 100 mg/kg (Table 3).

Exceedances of the WCSQV(1) for ammonia were found in two benthic strata: 3b and 4. Within the AOC, two exceedances were found in Stratum 3b (the moderately deep natural recovery area), and one exceedance was found in Stratum 4 (the deep natural recovery area). Two of the three 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., <15 mg/kg) in the three TLP areas (Strata 1, 2a, and 3a). All of the ammonia concentrations were less than the WCSQV(1).
- **Natural recovery areas:** Ammonia concentrations in the shallow natural recovery area (Stratum 2b) were less than 60 mg/kg. Concentrations in the moderately deep and deep natural recovery areas (Strata 3b and 4) were heterogeneous, ranging from 20 to 230 mg/kg, with three values exceeding the WCSQV(1).
- **Reference areas:** Ammonia concentrations at all stations in the shallow reference area (Stratum 5a) were less than 50 mg/kg, whereas concentrations in the moderately deep reference area (Stratum 5b) were heterogeneous, ranging from 35 to 84 mg/kg (Figure 4b). None of the ammonia concentrations in the references areas exceeded the WCSQV(1).

With respect to the seven stations sampled for temporal comparisons, the range of ammonia concentrations found in 2007 in the three TLP areas (i.e., 2.4–5.8 mg/kg) was similar to the range of values found in 2004 (i.e., 1.4–5.6 mg/kg), but was substantially lower than the values found in 1996–1997 (57–300 mg/kg) (Table 5). Ammonia concentrations in 2007 in the three natural recovery areas (i.e., 25–96 mg/kg) were somewhat lower than the values found in 2004 (i.e., 54–110 mg/kg) and considerably lower than the values found in 1996–1997 (i.e., 150–360 mg/kg).

With respect to temporal patterns in mean ammonia concentrations at the eight benthic strata (AOC and reference areas), values declined in all strata but Stratum 3a (Figure 5). The declines in mean ammonia concentrations ranged from 23 to 69 percent between 2004 and 2007. The greatest percentage declines were found for Strata 1 and 2a, both TLP strata. For Stratum 3a (also a TLP stratum), the mean concentration increased slightly from 4.9 mg/kg in 2004 to 5.7 mg/kg in 2007. On an absolute basis, the greatest declines in mean ammonia concentrations were observed in the three natural recovery areas.

In summary, ammonia concentrations in the Ward Cove AOC were generally low in all TLP areas. This pattern indicates that the TLP was successful in dramatically reducing the concentrations of this CoC. 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 study area between 1996–1997 and 2007, with the greatest declines found in the TLP areas.

6.1.1.2 4-Methylphenol

Concentrations of 4-methylphenol in the AOC ranged from 2.2 μg/kg at Station 66 in Stratum 1 to 25,000 μg/kg at Station 77 in Stratum 2b (Figure 4a). Mean concentrations of 4-methylphenol in the six benthic strata in the AOC ranged from 14 to 8,200 μg/kg (Table 3).

Exceedances of the WCSQV(1) for 4-methylphenol were found in three benthic strata: 2b, 3b, and 4. Four exceedances were found in Stratum 2b (the shallow natural recovery area), four exceedances were found in Stratum 3b (the moderately deep natural recovery area), and two exceedances were found in Stratum 4 (the deep natural recovery area). All eight of the WCSQV(1) exceedances in Strata 2b and 3b also exceeded the WCSQV(2).

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

- **TLP areas:** 4-Methylphenol concentrations were low (i.e., ≤50 μg/kg) at most stations in the three TLP areas (Strata 1, 2a, and 3a). The only exceptions were the value of 130 μg/kg found at Station 84 in Stratum 3a, and the value of 250 μg/kg found at Station 74 in Stratum 2a.
- **Natural recovery areas:** 4-Methylphenol concentrations in the deep natural recovery areas (Stratum 4) were moderate, ranging from 110 to 1,600 μg/kg. 4-Methylphenol concentrations at the majority of stations in the shallow and moderately deep natural recovery areas (Strata 2b and 3b) were elevated, ranging from 3,500 to 25,000 μg/kg at all but 4 of the 12 stations in those two areas.
- **Reference areas:** 4-Methyphenol concentrations at the shallow reference area (Stratum 5a) were generally low (Figure 4b), ranging from 29 to 79 μg/kg. By contrast, concentrations at the moderately deep reference area (Stratum 5b) were considerably higher, ranging from 250 to 550 μg/kg. None of the 4-methylphenol concentrations in the reference areas exceeded the WCSQV(1).

With respect to the seven stations sampled for temporal comparisons, the range of concentrations of 4-methylphenol found in 2007 (i.e., 8–20 μg/kg) in all three TLP areas were slightly greater than the range found in 2004 (i.e., 4–11 μg/kg), but were substantially lower than the values found in 1996–1997 (860–16,000 μg/kg) (Table 5). The range of concentrations of 4-methylphenol in the three natural recovery areas in 2007 (i.e., 110–14,000 μg/kg) was somewhat lower than the range found in 2004 (i.e., 520–18,000 μg/kg).

With respect to temporal patterns in mean 4-methylphenol concentrations at the eight benthic strata (AOC and reference areas), no consistent trend was found (Figure 6). Mean concentrations increased in four strata and decreased in four strata. The declines in mean 4-methylphenol concentrations ranged from 17 to 77 percent between 2004 and 2007, whereas the increases ranged from 5 to 100 percent between the two time periods.

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 in many, but not all, parts of the study area.

6.1.2 Conventional Analytes

6.1.2.1 Total Organic Carbon

TOC concentrations in the AOC ranged from 0.27 percent at Station 66 in Stratum 1 to 31 percent at Stations 76 and 77 in Stratum 2b (Figure 7a). Mean TOC concentrations in the six benthic strata in the AOC ranged from 0.9 to 18 percent (Table 4).

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

- **TLP areas:** TOC concentrations were less than 3 percent at all stations in the three TLP areas (Strata 1, 2a, and 3a).
- **Natural recovery areas:** TOC concentrations in the shallow natural recovery area (Stratum 2b) were heterogeneous, ranging from 5.3 to 31 percent. By contrast, TOC concentrations in the moderately deep and deep natural recovery areas (Strata 3b and 4) were relatively uniform and elevated, with ranges of 13–22 and 16–20 percent, respectively.
- **Reference areas:** TOC concentrations in both reference areas (Reference Strata 5a and 5b) were relatively uniform and elevated (Figure 7b), with ranges of 18–23 and 13–16 percent, respectively.

With respect to the seven stations sampled for temporal comparisons, the range of TOC concentrations found in 2007 at stations in the three TLP areas (i.e., 0.53–2.1 percent) were slightly greater than the range found in 2004 (i.e., 0.26–0.51 percent), but were substantially lower than the range found in 1996–1997 (24–38 percent) (Table 5). The range of TOC concentrations found in the natural recovery areas in 2007 (i.e., 16–22) was similar to the range found in 2004 (i.e., 18–29 percent), but lower than the range found in 1996–1997 (i.e., 22–34 percent).

With respect to temporal patterns in mean TOC concentrations at the eight benthic strata, values declined in all strata but Strata 3a and 3b (Figure 8). The declines in mean TOC concentrations ranged from 9 to 65 percent between 2004 and 2007. The greatest declines were found for Strata 1 and 2a, both TLP strata. For Stratum 3a (also a TLP stratum), the mean concentration increased slightly from 0.52 percent in 2004 to 1.3 percent in 2007. For Stratum 3b (a natural recovery stratum), the mean concentration increased slightly from 14 percent in 2004 to 17 percent in 2007.

In summary, TOC concentrations in the Ward Cove AOC were relatively 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 study area between 1996–1997 and 2007, with the greatest declines found in the TLP areas.

6.1.2.2 Percent Fines

Percent fines in the AOC ranged from 1.5 percent at Station 9 in Stratum 2a to 73 percent at Station 80 in Stratum 3b (Figure 7a). Mean values of percent fines in the six benthic strata in the AOC ranged from 3.0 to 63 percent (Table 4).

The patterns found for the various strata were as follows:

- **TLP areas:** Percent fines were relatively low (i.e., <10 percent) at all stations in the TLP areas (Strata 1, 2a, and 3a).
- **Natural recovery areas:** Percent fines in the shallow and moderately deep natural recovery areas (Strata 2b and 3b) were heterogeneous and moderate in magnitude, with ranges of 20–57 and 46–73 percent, respectively. Percent fines in the deep natural recovery areas (Stratum 4) were relatively uniform and moderate in magnitude (i.e., 59–67 percent).
- **Reference areas:** Percent fines throughout both reference areas (Strata 5a and 5b) were relatively uniform and moderate in magnitude (i.e., 36–52 and 53–56 percent, respectively) (Figure 7b).

With respect to the seven stations sampled for temporal comparisons, the range of percent fines found in 2007 in the three TLP areas (i.e., 1.5–6.2 percent) was slightly higher than the range of values found in 2004 (i.e., 1.4–3.5 percent), but substantially lower than the values found in 1996–1997 (31–70 percent) (Table 5). The range of percent fines found in 2007 in the natural recovery areas (i.e., 46–67 percent) was higher than the range found in 2004 (i.e., 30–45 percent), but similar to the range found in 1996–1997 (i.e., 46–77 percent).

With respect to temporal patterns in mean percent fines at the eight benthic strata, values increased in all strata but Strata 1, 2a, and 2b (Figure 9). The increases in mean percent fines ranged from 5 to 64 percent between 2004 and 2007. In general, most increases were found in the natural recovery strata. In summary, percent fines in the Ward Cove AOC were relatively 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 in most parts of the study area have increased between 2004 and 2007.

6.1.2.3 Total Solids

Concentrations of total solids in the AOC ranged from 13 percent at Station 80 in Stratum 3b to 84 percent at Station 67 in Stratum 1 (Figure 7a). Mean concentrations of total solids in the six benthic strata in the AOC ranged from 15 to 79 percent (Table 4).

The patterns found for the various strata were as follows:

- **TLP areas:** Concentrations of total solids were relatively high (i.e., >50 percent) at all stations in the TLP areas (Strata 1, 2a, and 3a).
- **Natural recovery areas:** Concentrations of total solids in the shallow natural recovery area (Stratum 2b) were heterogeneous, ranging from 18 to 44 percent. By contrast, concentrations of total solids in the moderately deep and deep natural recovery areas (Strata 3b and 4) were relatively uniform and low, with ranges of 13–18 and 15–17 percent, respectively.
- **Reference areas:** Concentrations of total solids at all stations in both reference areas (Strata 5a and 5b) were relatively uniform and low, with ranges of 17–19 and 16–24 percent, respectively (Figure 7b).

With respect to the seven stations sampled for temporal comparisons, the range of total solids concentrations found in 2007 in the three TLP areas (i.e., 68–79 percent) was slightly lower than the range found in 2004 (i.e., 76–81 percent), but substantially higher than the range found in 1996–1997 (14–20 percent) (Table 5). The range of total solids concentrations in 2007 in the natural recovery areas (i.e., 15–20 percent) was similar to the range found in 2004 (i.e., 15–19 percent), but slightly greater than the range found in 1996–1997 (i.e., 12–16 percent).

With respect to temporal patterns in mean total solids concentrations, no consistent patterns were found (Figure 10). Mean concentrations increased in four strata, decreased in two strata, and remained constant in two strata. Temporal changes in only one stratum exceeded 25 percent (i.e., a 32 percent decline in Stratum 3b). In summary, concentrations of total solids in the Ward Cove AOC were relatively 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 many, but not all, parts of the study area between 1996–1997 and 2007.

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 2007 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. In general, ammonia concentrations declined in most parts of the study area between 2004 and 2007, whereas 4-methylphenol concentrations showed no consistent trend. These results indicate that the TLP was successful in reducing the concentrations of these CoCs. 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 or freshly deposited material. From a temporal perspective, concentrations of both CoCs appear to have declined in most parts of the study area 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 study area, relative to pre-remediation conditions.

6.2 TOXICITY TESTING

As discussed previously, the potential toxicity of sediments collected in Ward Cove during July 2007 was evaluated using the 10-day amphipod test based on *Eohaustorius estuarius*. Data collected during the 2007 monitoring event is provided in Appendix A. A quality assurance review of laboratory procedures and results was conducted by Integral 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 B. 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 2007 is presented in Figure 11a. Percent survival in the AOC ranged from 50 percent at Station 88 in Stratum 4 to 100 percent at nine stations distributed across multiple benthic strata. Mean survival in all TLP and in all natural recovery strata exceeded the screening value of 75 percent (as specified in the LMRP). Therefore, all areas of the AOC have achieved the RAO based on sediment toxicity. Nevertheless, statistical comparisons with reference areas are discussed in this section to be consistent with the specifications of the LMRP.

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

- **TLP areas:** 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 percent observed at Station 72 in Stratum 2a and Station 93 in Stratum 3a.
- **Natural recovery areas:** Survival was 85 percent or greater at all but one station in the shallow natural recovery area (Stratum 2b). The only exception was the value of 70 percent found at Station 71. In the moderately deep natural recovery area (Stratum 3b), survival was very high (i.e., ≥90 percent) at all stations. Survival in the deep natural recovery area (Stratum 4) was very high (i.e., ≥90 percent) at three of the five stations. The two exceptions were the values of 50 and 65 percent observed at Stations 88 and 87, respectively. However, mean survival for Stratum 4 (i.e., 80 percent) exceeded the screening value of 75 percent (as specified in the LMRP).
- **Reference areas:** Survival in the shallow reference area (Stratum 5a) was very high (≥95 percent) at all stations (Figure 11b). In the moderately deep reference area (Stratum 5b), survival was 90 percent or greater at four of the five stations. Survival at one station was lower, with a value of 85 percent found at Station 95A (Figure 11b).

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 analysis of variance (ANOVA) followed by Dunnett's test. As described in Exponent (2005), the first five replicate samples collected at each of the two reference areas were the preferred samples to be used for statistical comparisons with results from the AOC, providing that they all satisfy the chemical and toxicity criteria for valid reference conditions. Because no exceedances of the WCSQV(1) were found at any of the preferred reference stations, the chemical criterion for acceptability was satisfied at all of those stations. In addition, because percent survival at all of the preferred reference stations exceeded the minimum acceptable reference value of 75 percent specified for the amphipod test in the RI/FS (Exponent 1999) and the LMRP, the toxicity criterion for acceptability was also satisfied at all of those stations. Therefore, the first five samples collected at each reference area (i.e., 95A–95E and 96A–96E) were considered suitable for use in statistical comparisons.

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 6 and 7 and Figure 12. All statistical methods were consistent with those specified in the LMRP. 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, ANOVA, and Dunnett's test. All details are included in Appendix C (Table C-1 and Figures C-1a–f). Analysis was conducted using S-Plus 2000.

As shown in Figure 12, mean amphipod survival in the six benthic strata of the Ward Cove AOC ranged from 80 percent in the deep natural recovery area (Stratum 4) to 96 percent in the moderately deep natural recovery area (Stratum 3b). Mean amphipod survival in the reference areas ranged from 93 to 98 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., 92–95 percent) and was not significantly lower (P>0.05) than the reference value. Mean amphipod survival in the moderately deep natural recovery area (Stratum 3b) was similarly very high (i.e., 96 percent), and was not significantly lower (P>0.05) than the reference value. Mean amphipod survival in the shallow and deep natural recovery areas (Strata 2b and 4, respectively) was relatively high (i.e., 88 and 80 percent, respectively), and was not significantly lower (P>0.05) than the reference value.

Although mean survival in the deep natural recovery area (Stratum 4) was 80 percent, it was not significantly lower (P>0.05) than the corresponding mean reference value of 93 percent. However, because the standard deviation for that stratum (22 percent) exceeded the screening 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 five 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 five values were distributed across a large range (i.e., 50 to 100 percent), with two values (i.e., 50 and 65 percent) being low and three values being very high (i.e., 90, 96, and 100 percent). However, because the value of mean survival for Stratum 4 (i.e., 80 percent) exceeded the screening value of 75 percent for the amphipod test (as specified in the LMRP), mean survival for Stratum 4 was acceptable despite the elevated standard deviation associated with it.

In summary, amphipod survival was very high (i.e., >90 percent) at most stations sampled in the three TLP areas and in the moderately deep natural recovery stratum (Stratum 3b). In addition, mean amphipod survival in all four areas was very high (i.e., 92–96 percent) and was not significantly lower (P>0.05) than the reference value. Therefore, these results indicate that all four of those areas have achieved the RAO based on sediment toxicity.

Although amphipod survival at many of the stations in the shallow and deep natural recovery areas (Strata 2b and 4) was very high (i.e., >90 percent), survival at three stations was relatively low (i.e., <70 percent). Although, mean survival in both of those areas was not significantly lower (P>0.05) than the reference value, the high variability in the station-specific results for the deep natural recovery area (Stratum 4) resulted in low statistical power to discriminate differences with the reference value. Nevertheless, because mean survival in that area exceeded the screening value of 75 percent (as specified in the LMRP), all of the natural recovery areas have achieved the RAO based on sediment toxicity.

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 and 2007. The sediments collected in 2004 and 2007 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–d).

The results of the temporal comparisons showed that mean amphipod survival in 2007 was very high at all four stations, ranging from 94 to 98 percent (Figure 13 and Table 8). All four values were substantially greater than the values found in 1996–1997, which ranged from 0 to 54 percent. The 2007 values were comparable to the 2004 values for Stations 8 and 9 in the moderately deep and shallow TLP areas, respectively. For Stations 13 and 38 in the deep and shallow natural recovery areas, respectively, the 2007 values were greater than the 2004 values, with the value at Station 13 increasing from 43 to 96 percent and the value at Station 38 increasing from 89 to 98 percent. Mean survival at all four stations exhibited a significant trend ($P \leq 0.05$), with values increasing between 1996 and 2007 (Table 8).

A statistical summary of trend evaluations of amphipod survival in Ward Cove between 2004 and 2007 is presented in Table 9 and the results of a statistical power evaluation of amphipod survival in Ward Cove between 2004 and 2007 is presented in Table 10. The 2007 values show a mean increase in survival in all of the natural recovery areas ranging from 12 to 54 percent over 2004 amphipod survival.

In addition to the four replicated stations described above, three additional historical stations were reoccupied in 2004 (Stations 5, 6, 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 eight 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 and 2007. The fact that the 1996–1997 stations were not reoccupied exactly in 2004 and 2007 adds a degree of uncertainty to the interpretation of these qualitative comparisons.

As shown in Figure 14, amphipod survival in 2007 was very high at the three stations (i.e., 95–100 percent), was greater than the historical values at all three reoccupied stations, and was greater than or equal to the results found in 2004. Survival values of 100 percent were found in both 2004 and 2007 at Station 5 in the very shallow TLP area (Stratum 1) and Station 48 in the moderately deep TLP area (Stratum 3a). The historical survival values for these three stations were 25–39 percent, 5 percent, and 5 percent, respectively, indicating that substantial increases in survival had occurred at all three stations in 2004 and 2007.

By contrast with the two stations described above (Stations 5 and 48), 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. However, survival at this location in 2007 was very high (i.e., 95 percent), indicating that conditions had improved considerably since 2004.

As shown in Figure 15, amphipod survival in 2007 was high (i.e., 85–100 percent) at all five historical stations located within 30 m of the 2004 stations, and were comparable to the values found in 2004. All of the survival values found in 2004 and 2007 were considerably higher than the lowest values found in 1996 or 1997.

In summary, the temporal trends of amphipod survival found at the 12 selected stations in the Ward Cove AOC indicate that survival had substantially increased in 2007 at all stations, compared to results found in 1996–1997. This pattern was evident in both statistical and qualitative comparisons. In addition, mean amphipod survival in all benthic strata in 2007 was comparable to or greater than amphipod survival in 2004.

6.2.3 Evaluation of Sulfide Concentrations in Pore Water

As noted in the QA/QC review for the sediment toxicity tests conducted in 2007 (Appendix B), 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 B, all porewater ammonia concentrations were below the no-effect levels for *Eohaustorius estuarius* specified by U.S. EPA (2000c). Although similar no-effect levels are not available for sulfide, it was concluded in Appendix B 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. Sulfide concentrations on Day 0 exceeded 60 mg/L only at the three stations where amphipod survival was less than the screening value of 75 percent. These stations include Stations 87 and 88 in the deep natural recovery area (Stratum 4) and Station 71 in the shallow natural recovery area. At Stations 87 and 71, porewater sulfide concentrations (i.e., 65 and 70 mg/L, respectively) and amphipod survival (i.e., 70 and 65 percent, respectively) were similar. However, at Station 88, porewater sulfide concentration (i.e., 184 mg/L) was considerably greater than the values found at the other two stations, and amphipod survival (i.e., 50 percent) was considerably lower. These results indicate that elevated porewater sulfide concentrations may have influenced the results of the toxicity tests at these three stations. This potential relationship was also found in the RI/FS (Exponent 1999) and during the 2004 monitoring event (Exponent 2005).

A number of uncertainties exist regarding application of the laboratory results for porewater sulfide 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 negative relationship found between amphipod survival and elevated porewater sulfide concentrations in this study suggest that sulfide should continue to be monitored in sediment pore water during toxicity testing.

6.2.4 Summary of Sediment Toxicity Evaluations

Overall, the results of the sediment toxicity evaluations conducted in 2007 indicate that conditions had improved substantially in both the TLP and natural recovery areas compared to pre-remediation conditions. Mean amphipod survival in all TLP and natural recovery areas exceeded the screening value of 75 percent (as specified in the LMRP), indicating that from the standpoint of sediment toxicity, all of these areas have achieved the RAOs based on sediment toxicity. The results of the statistical analysis showed that mean amphipod survival in all TLP and natural recovery areas was not significantly lower ($P>0.05$) than the reference value. However the comparison for the deep natural recovery area (Stratum 4) was affected by low statistical power, adding some degree of uncertainty to the results. Nevertheless, because mean survival in that area (i.e., 80 percent) exceeded the screening value of 75 percent (as specified in the LMRP), it achieved the RAO based on sediment toxicity.

From a temporal perspective, amphipod survival found at the 12 selected stations in the Ward Cove AOC indicated that survival had substantially increased in 2007 at all stations, compared to results found in 1996–1997. This pattern was found based on both statistical and qualitative comparisons.

6.3 BENTHIC MACROINVERTEBRATE COMMUNITIES

As specified in the LMRP, the benthic macroinvertebrate communities sampled in 2007 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 2007 monitoring event are provided in Appendix A. A quality assurance review of laboratory procedures and results was conducted by Integral 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 B.

Temporal patterns of the characteristics of benthic communities were evaluated qualitatively by comparing information collected in 1992 (EVS 1992) and 2004 with the results of the 2007 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.

6.3.1 Overview of Spatial Patterns

Approximately 6,800 benthic macroinvertebrates from 130 taxa were sampled as part of the 2007 sampling event. In 2004, approximately 4,500 individuals from 117 taxa were sampled. (Note: Stratum 2c has been removed from total number of organisms and number of taxa collected in 2004 for direct comparison to 2007.) Relative to the 2004 results (not including Stratum 2c, which was not sampled in 2007), the 2007 results represent increases of approximately 33 and 10 percent in the total numbers of individuals and taxa collected, respectively. Polychaetes accounted for the most taxa in 2007 (47), as they did in 2004 (69), but declined by 22 taxa between the two sampling periods. Molluscs accounted for 44 taxa in 2007, and represented an increase in 7 taxa compared to 37 taxa found in 2004. Finally, arthropods accounted for 26 taxa in 2007, and represented an increase of 11 taxa compared to 15 taxa in 2004. Polychaetes also exhibited the highest relative abundance in 2007, accounting for 61 percent of total abundance, compared to 76 percent in 2004. Molluscs accounted for 36 percent of total abundance in 2007, compared to 21 percent in 2004. Arthropods accounted for only 2.9 percent of total abundance in 2007, compared to 2.7 percent in 2004. Miscellaneous taxa accounted for less than 1 percent of total abundance in both 2007 and 2004.

In summary, the benthic communities of Ward Cove in 2007 were dominated by polychaetes and molluscs, with arthropods and miscellaneous taxa contributing relatively small numbers of individuals. This same general pattern was found in 2004. By contrast, the numbers of polychaete taxa and the relative abundance of polychaetes declined in 2007 compared to 2004, whereas the number of mollusc taxa and the relative abundance of molluscs increased between the two sampling periods. Although the numbers of arthropod taxa increased in 2007 compared to 2004, their relative abundance did not change substantially between the two sampling periods.

Figures 16a and 16b show the spatial distributions of total abundance, total richness, and Swartz' dominance index (SDI) values at the 32 stations sampled in the Ward Cove AOC and the 10 reference area stations sampled in 2007. Mean values of benthic invertebrate metrics in each benthic stratum are provided in Table 11. The general patterns of these three community metrics were as follows:

- **Total abundance:** This metric was >85 individuals/sample at all but one station in the three TLP areas (Strata 1, 2a, and 3a). Total abundance was only 35 individuals/sample at Station 8 in Stratum 3a. Total abundance was >85 individuals/sample at 10 of the 17 stations in the three natural recovery areas (Strata 2b, 3b, and 4). Total abundance was particularly low at Stations 70 and 77 in Stratum 2b, where only 16 and 0 individuals/sample were found, respectively. Total abundance differed between the two reference areas, with the shallow area (Reference Stratum 5a) having higher abundances (110–260 individuals/sample) than the moderately deep area (Reference Stratum 5b; 12–110 individuals/sample).
- **Taxa richness:** This metric was >10 taxa/sample at most stations located in the three TLP areas (Strata 1, 2a, and 3a). The exceptions were for Station 72 in Stratum 2a and Station 8 in Stratum 3a, where values of 5 and 4 taxa/sample were found, respectively. Taxa richness was <10 taxa/sample at most stations in the three natural recovery areas (Strata 2b, 3b, and 4). The exceptions were for Station 81 in Stratum 3b and Stations 86 and 88 in Stratum 4, where values of 11, 16, and 20 taxa/sample were found. The range of taxa richness in the shallow reference area (13–20 taxa/sample) was generally greater than the range found at the moderately deep reference area (2–18 taxa/sample).
- **SDI:** This index was relatively high (≥5) at 7 of the 15 stations located in the three TLP areas. By contrast, the SDI was relatively low (1–2) at all but one of the stations located in the three natural recovery areas. The SDI was also low at four of the five stations located in the moderately deep reference area (Stratum 5b). In the shallow reference area, the SDI was moderate (3–4) at four of the five stations.

In summary, all three community indices suggest that benthic macroinvertebrates are continuing to recolonize the three TLP areas. Communities in the remaining three natural recovery strata and the two reference areas are generally characteristic of organically enriched environments.

Figures 17a, 17b, 18a, and 18b show the spatial distributions of the abundances and taxa richness of major benthic taxa at the 32 stations sampled in the Ward Cove AOC and the 10 reference area stations in 2007. Mean values of total abundance and total richness of major benthic taxonomic groups in each benthic stratum are provided in Table 12.

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 most stations in both the natural recovery areas, as well as the reference areas. The polychaete assemblages in the moderately deep and deep natural recovery areas, as well as the moderately deep reference areas were dominated by a single species: *N. cornuta*. The assemblage in the shallow natural recovery area was also dominated by *N. cornuta*, as well as *D. annulata*. A noticeable overall pattern with respect to polychaetes was the decline in abundance of *C. capitata* and increase in abundance of *N. cornuta* between 2004 and 2007. In general, the polychaete assemblages in the three TLP areas included more polychaete taxa and more balanced distributions of those taxa, although *N. cornuta* was the most numerous taxon found in the shallow TLP area.
- **Mollusca:** Molluscs were characterized by relatively high abundances and numbers of taxa at most stations in the three TLP areas. The only exception was Station 72 in the shallow TLP area where no molluscs were found, and Station 8 in the moderately deep TLP area where only 2 molluscs were found. Consistent with the patterns found in 2004, the most abundant molluscan species in 2007 were the deposit feeding bivalves *Axinopsida serricata* and *Parvilucina tenuisculpta.*
- **Arthropoda:** Arthropods were generally rare at all stations sampled in Ward Cove. This pattern was also found in 2004.

In summary, benthic communities at the 42 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 than in the natural recovery areas. Benthic communities in the three natural recovery areas were generally dominated by one or two polychaete species. These results are consistent with those found in 2004, and suggest that recolonization is continuing to occur in the three TLP areas, 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 LMRP. The results of those comparisons are presented in Tables 13, 14, and C-3 (Figures C3a-h through C11a-h). Several of the determinations of not significantly lower (P>0.05) than reference values were affected by low statistical power (particularly for Stratum 3b), adding some degree of uncertainty to those results (Table 14). Benthic metrics that were significantly lower (P≤0.05) than reference values were found in only one stratum (i.e., Stratum 2b; the shallow natural recovery stratum). For this stratum, six benthic metrics were found to be significantly lower (P≤0.05) than the reference value: total abundance, mollusc abundance, total richness, polychaete richness, mollusc richness, and SDI. This represents an improvement over the results for 2004, for which benthic metrics were significantly lower (P≤0.05) than reference values in three benthic strata (i.e., Strata 1, 2a, and 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 in 1996, 1997, 2004, or 2007, including:

- The polychaete *Capitella capitata*
- The polychaete *Nephtys cornuta*
- The polychaete *Dorvillea annulata*
- The mollusc *Axinopsida serricata*
- The mollusc *Parvilucina tenuisculpta*
- The mollusc *Rochefortia tumida*.

Additional benthic species are identified in Table 15, 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 15, five to seven benthic species accounted for 5 percent or more of total abundance at all three TLP areas in 2007, compared to the three to five species found in 2004. 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. Those patterns are similar to the ones found in 2004. Consistent with the results found in 2004, the bivalves *A. serricata* and *P. tenuisculpta* accounted for 30 percent or more of total abundances for each TLP area in 2007. However, the abundances of *N. cornuta* in

Stratum 2a increased substantially in 2007, such that it was the most abundant species found in that stratum, accounting for 23 percent of total abundance. These results indicate that benthic communities in these strata are composed of relatively diverse species assemblages and that the number of taxa accounting for 5 percent or more of the total abundance in each stratum has increased since 2004.

By contrast with the three TLP strata described above, benthic communities in the three natural recovery areas were dominated by one or two polychaete species (i.e., *N. cornuta* and *D. annulata*), with only two additional taxa in Stratum 2b accounting for 5 percent or more of total abundance (i.e., *C. capitata* and *Dorvillea* spp.). In addition, the dominant species accounted for more than 70 percent of total abundance in each stratum. These results are generally consistent with those found in 2004, except that the abundance of *C. capitata* has declined substantially as the abundances of *N. cornuta* and *D. annulata* have increased. The species patterns observed in the three natural recovery areas in both 2004 and 2007 are 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 in 2007 were dominated by *C. capitata* and *D. annulata* (Stratum 5a) and *N. cornuta* (Stratum 5b), as these species accounted for 50 percent or more of total abundance in each stratum. These patterns were identical to those found in 2004, except that the three species accounted for 60 percent or more of total abundance during that monitoring event. In addition, two additional species (*P. tenuisculpta* and *R. tumida*) accounted for 5 percent or more of total abundance in Stratum 5a in 2007, whereas no additional species accounted for more than 5 percent of total abundance in either of the reference area strata in 2004. These patterns indicate that the benthic communities found in the two reference area strata in both 2004 and 2007 are characteristic of the communities found in relatively uncontaminated but organically enriched areas of Ward Cove. In addition, these patterns indicate that the communities became more diverse between 2004 and 2007.

The characteristics of the various benthic strata identified in Table 15 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. In addition, the successional stages identified by Rhoads et al. (1978) and Rhoads and Germano (1982, 1986) for the various benthic taxa were also considered, with Successional Stages I, II, and III representing the continuum from pioneering to equilibrium taxa.

The key characteristics of the various species for which information was available are as follows, with the species progressing from polychaetes to bivalves:

- ***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. 1976; 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. *C. capitata*, as a capitellid, is considered a Successional Stage I taxon (EVS 2001).
- ***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. *N. cornuta*, as a nephtyid, is considered a Successional Stage III taxon (EVS 2001).
- ***Dorvillea annulata:*** This polychaete is a facultative carnivore that can feed on plant material if necessary (Fauchald and Jumars 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. *D. annulata*, as a dorvilleid, is considered a Successional Stage I taxon (EVS 2001).
- ***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 (Fauchald and Jumars 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. *P. steenstrupi*, as a spionid, is considered a Successional Stage I taxon (EVS 2001).
- ***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. *A. serricata*, as a lucinid, is considered a Successional Stage III taxon (EVS 2001).

- ***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. *P. tenuisculpta*, as a lucinid, is considered a Successional Stage III taxon (EVS 2001).
- ***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.

In summary, the key characteristics of the benthic macroinvertebrate species discussed above generally indicate that benthic communities in the TLP areas continued to be characterized primarily by species commonly found in areas where organic enrichment is declining, as they were in 2004. These species include the polychaete *P. steenstrupi* and the bivalves *A. serricata* and *P. tenuisculpta*. In addition, the latter two bivalve species are considered Successional Stage III taxa. The only exception to this pattern was the relatively high abundance of *N. cornuta* found in Stratum 2a, although this species is also considered a Successional Stage III taxon.

By contrast with the TLP areas, communities in the three natural recovery areas were characterized primarily by species commonly found in organically enriched areas, including the polychaetes *N. cornuta, D. annulata,* and to a lesser extent, *C. capitata*. The latter two polychaete species are considered Successional Stage I taxa. These patterns were similar to those found in 2004, except that *C. capitata* was considerably more abundant during the earlier monitoring event. 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 *D. annulata*.

6.3.4 Comparisons of Benthic Macroinvertebrate Communities between 1992, 2004, and 2007

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 and 2007 monitoring events. 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.

In addition to the cove-wide comparisons described above, temporal comparisons were also made for major benthic metrics between 2004 and 2007. These additional comparisons were based on the mean values of the benthic metrics found in the various benthic strata during the two monitoring events.

EVS (1992) sampled five stations in the inner part of Ward Cove in January 1992 (Figure 19). 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 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 monitoring events conducted in 2004 and 2007. All abundance data collected during those two events 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 *C. 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 20 compares taxa richness of benthic macroinvertebrate communities sampled in Ward Cove in 1992, 2004, and 2007. The comparison shows that the mean number of taxa per station in 2007 (12) was slightly greater than the value found in 2004 (11), and was more than twice the value found in 1992 (5.0). The mean numbers of polychaete, mollusc, and arthropod taxa per station found in 2007 were comparable to the values found in 2004, with slight increases found for molluscs and arthropods and a slight decrease found for polychaetes. As for 2004, the largest increase in taxa richness in 2007 compared to 1992 occurred for molluscs, for which mean richness increased by a factor of nine. Mean richness of polychaete taxa increased by a factor of 1.6 between l992 and 2007, 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 2007, but remained relatively stable between 2004 and 2007.

Table 16 compares the abundances of major benthic macroinvertebrate taxa in communities sampled in Ward Cove in 1992, 2004, and 2007. 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 and almost two times the value found in 2007, 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 2004 (95 individuals per station) is nearly identical to the value found in 1992 (100 individuals per station), and the value found in 2007 (250 individuals per station) is two and one-half times the 1992 value. These results indicate that total abundances of benthic communities (exclusive of species characteristic of high levels of organic enrichment) increased substantially between the 2004 and 2007 monitoring events.

With respect to the individual taxa presented in Table 16, all three of the numerically dominant taxa found in 1992 were found in reduced abundances in 2004 and 2007. The most dramatic declines were found for *Schistomeringos japonica* and nematodes, which were absent from the 2004 and 2007 communities. In addition, the mean abundance of *C. capitata* in 2004 had declined to 40 percent of its 1992 abundance, and in 2007 this species had further declined to only 6.8 percent of its 1992 abundance. Because all three of these taxa are indicators of organic enrichment, their considerable declines in abundance in the 2004 and 2007 communities indicate that the effects of organic enrichment in the cove had declined markedly by 2004 and 2007.

In contrast to the decline in abundances of indicators of organic enrichment between 1992, 2004, and 2007, 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 and 2007. The most notable increases in abundances were found for molluscs, particularly *A. serricata*, *P. tenuisculpta*, and *R. tumida*, which were nearly absent from the cove in 1992, but increased to 4.6, 16, and 3.8 individuals per 0.1 m^2 in 2004 (respectively), and then further increased to 45, 25, and 16 individuals per 0.1 m^2 in 2007 . In addition, two polychaete species (*Nephtys cornuta* and *Dorvillea annulata*) were absent or present in relatively low numbers in 1992, but became the numerically dominant members of the benthic communities by 2007, with densities of 74 and 21 individuals per 0.1 m^2, respectively.

With respect to the number of benthic taxa that accounted for more than 5 percent of total abundance at any station, Table 16 shows that there were only seven such taxa in 1992. In 2004, the number of these taxa increased relatively modestly to 11 taxa, but by 2007, the number increased substantially to 28 taxa. These results indicate that many more species were becoming numerically important at various stations throughout the AOC in 2007, which is an indication of improving conditions in the AOC.

The results of trend and statistical power evaluations of benthic metrics for benthic communities between 2004 and 2007 are presented in Table 17 and shown in Figures 21, 22, and 23. A significant increase ($P \leq 0.05$) in total abundance of benthic macroinvertebrates was observed in Strata 2a and 3a in the TLP area, in Strata 3b and 4 in the natural recovery area, and in Stratum 5b in the reference area. No significant increases ($P > 0.05$) were found in any benthic strata for total richness and SDI (Table 17).

A statistical summary of trend evaluations of total abundance and total richness of the major macroinvertebrate taxonomic groups between 2004 and 2007 is presented in Table 18 and shown in Figures 24 through 29. Significant increases ($P \leq 0.05$) in polychaete abundance were found in Strata 2a, 3a, 3b, 4, and 5b in 2007 (similar to the pattern described above for total abundance), but few increases were found for any of the other benthic metrics based on major taxonomic groups (Table 18). These results indicate that increases in total abundance were primarily due to increases in polychaete abundance. Several of the determinations of no significant increases ($P > 0.05$) were affected by low statistical power, adding some degree of uncertainty to those results (Table 18).

In summary, comparisons of benthic macroinvertebrate communities found throughout Ward Cove in 1992, 2004, and 2007 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 1992 and are less affected by taxa indicative of organic enrichment. Furthermore, these improvements continued in the 3 years between the two monitoring events. In addition, mean total abundance and mean taxa richness of benthic macroinvertebrates in five of the six AOC benthic strata increased relative to the mean values found in 2004, although not all of these increases were statistically significant ($P \leq 0.05$).

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), as was done for the 2004 data set (Exponent 2005). 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 eight benthic strata sampled in Ward Cove during the 2007 monitoring event.

Figure 30 shows the results of the classification analysis of the benthic macroinvertebrate data collected in 2007. Three clusters of benthic strata were apparent from the dendrogram and were identified as Benthic Groups A, B, and C. Benthic Group A included Reference Stratum 5b (the moderately deep reference area), whereas Benthic Group B included Reference Stratum 5a (the shallow reference area). The characteristics of each benthic group are described below:

- **Benthic Group A—**This group included Reference Stratum 5b and the moderately deep and deep natural recovery areas (i.e., Strata 3b and 4, respectively).
- **Benthic Group B—**This group included the three TLP areas.
- **Benthic Group C—**This group included Reference Stratum 5a and the shallow natural recovery areas (i.e., Stratum 2b).

The characteristics of the three benthic groups described above indicate that they were based on a combination of remedial category and depth. In addition, the groups indicate that the natural recovery areas are most similar to the reference areas, whereas the three TLP strata are relatively unique.

Figure 31 shows the MDS results for the benthic macroinvertebrate data collected during the 2007 monitoring event. The two dimensional plot exhibited an r^2 value of 0.67, indicating that it accounted for 67 percent of the variability in the data. Three groups of benthic strata were apparent on the MDS plot, and they matched the three benthic groups identified on the basis of the dendrogram presented in Figure 30. The group on the upper right side of the plot corresponded to Benthic Group A, as defined by the classification analysis, and included the moderately deep Reference Stratum 5b, as well as the moderately deep and deep natural recovery areas (Strata 3b and 4). The group on the upper left side of the plot corresponded to Benthic Group B, as defined by the classification analysis, and included the three TLP areas (Strata 1, 2a, and 3a). Finally, the group in the lower center of the plot corresponded to Benthic Group C, as defined by the classification analysis, and included the shallow Reference Stratum 5a and the shallow natural recovery area.

In summary, results of the multivariate analyses of the benthic macroinvertebrate data collected in Ward Cove in 2007 showed that three distinct clusters or groups of stations were apparent, with the natural recovery areas clustering with the reference areas and the TLP areas clustering only with themselves. These results indicate that TLP in the cove has resulted in benthic communities that are different from the communities found in the natural recovery and reference areas. Given the other characteristics of these communities described in this report, it can be concluded that TLP in the cove has resulted in modifications of the communities such that they are now enhanced beyond the reference conditions. In addition, although the natural recovery areas have not shown the same degree of enhancement, conditions in two of the three natural recovery areas are now relatively similar to the reference conditions.

6.3.6 Evaluation of Taxa Richness at Individual Stations

As discussed previously, taxa richness values for 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 32), the following patterns were found for taxa richness:

- **Total Taxa:** Richness values for all five stations in Stratum 1 and 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 in Stratum 2a, where only five taxa were found, compared to the minimum reference value of 13 taxa. Richness values for all seven stations in Stratum 2b were well below the minimum reference value, ranging from zero to seven taxa.
- **Molluscs:** Richness values for all five stations in Stratum 1 and 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 in Stratum 2a, where no mollusc taxa were found, compared to the minimum reference value of four taxa. Richness values at only one of seven stations in Stratum 2b was within the reference range. Richness values for the remaining six stations in Stratum 2b were below the minimum reference value (i.e., zero or two taxa).
- **Polychaetes:** Richness values for all five stations in Stratum 1 and 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 in Stratum 2a, where only five polychaete taxa were found, compared to the minimum reference value of six taxa. Richness values for all seven stations in Stratum 2b were below the minimum reference value, ranging from zero to four taxa.

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 and 2a generally comprise multiple taxonomic groups that, in most cases are comparable to or greater than 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 33), the following patterns were found for taxa richness:

- **Total Taxa:** Richness values for all six stations in Stratum 3a and four of the five stations in both Strata 3b and 4 were either within the reference range or exceeded the range. The only exceptions were found for Station 79 in Stratum 3b and Station 85 in Stratum 4, where only one taxon was found, compared to the minimum reference value of two taxa.
- **Molluscs:** Richness values for all stations in Strata 3a, 3b, and 4 were either within the reference range or exceeded the range.
- **Polychaetes:** Richness values for all stations in Strata 3a, 3b, and 4 were either within the reference range or exceeded the range.

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 Strata 3a, 3b, and 4 generally comprise multiple taxonomic groups that, in most cases, are comparable to or greater than the range of values found in the reference area.

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, 3a, 3b, and 4. By contrast, taxa richness at all or most stations in benthic communities in Stratum 2b was less than 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 2007 monitoring event indicate that TLP has resulted in the establishment of diverse communities that comprise multiple taxonomic groups. In general, the characteristics of these communities at most of the TLP stations are enhanced beyond those of the references areas. By contrast, most of the natural recovery areas comprise less diverse communities and lower numbers of taxa, but are generally comparable to the reference areas at a number of stations. The exception was the shallow natural recovery area (Stratum 2b), which generally did not exhibit the same level of improvement as the other two natural recovery areas.

Results of statistical comparisons of benthic community metrics between remediation strata and reference strata indicated that with the exception of six benthic metrics for the shallow natural recovery area with thick organic deposits (Stratum 2b), all of the metrics in the TLP and natural recovery areas were not significantly lower ($P>0.05$) than the values found in the reference areas. In most cases (i.e., 37 of 54), the benthic metrics at the AOC stations exceeded their respective reference values. However, several of the determinations of not significantly lower

(P>0.05) than reference values were affected by low statistical power, adding some degree of uncertainty to those results.

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 were characterized primarily by species commonly found in areas where organic enrichment is declining. By contrast, communities in the 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 2007 comprise more than twice as many 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 2007, including the polychaete *Schistomeringos japonica* and nematodes. The fourth taxon that was numerically dominant in 1992, the polychaete *Capitella capitata*, was present in 2007, but at only 6.8 percent of the density found in 1992. These patterns were comparable to those found in 2004, with the exception that densities of *C. capitata* had declined to only 40 percent of its 1992 value.

Multivariate analysis of the benthic community data collected in 2007 documented three distinct clusters of groups of benthic strata. Two groups included one or more natural recovery areas in conjunction with one of the two reference area strata. The third group comprised only three TLP strata. These results, in conjunction with other results described in this section, indicate that TLP in the cove resulted in modifications of the benthic communities such that they are now enhanced beyond the reference conditions. In addition, although the natural recovery areas have not shown the same degree of enhancement, they are now relatively similar to the reference conditions.

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 moderately deep and deep natural recovery areas. By contrast, taxa richness at all or most stations in benthic communities in the shallow natural recovery stratum (Stratum 2b) was less than the minimum reference value.

Although six benthic community metrics for Stratum 2b were found to be significantly lower ($P \leq 0.05$) than the reference values, mean amphipod survival in this stratum in 2007 exceeded the screening value of 75 percent specified in the LRMP, indicating that this stratum has fully recovered with respect to the RAO based on sediment toxicity. Additional lines of evidence based on sediment toxicity, sediment chemistry, and benthic community species composition also indicate that overall recovery of the stratum is occurring, including benthic community recovery. These lines of evidence are identified below:

- **Reductions in Sediment Toxicity between 1997 and 2007**
  - As discussed above, mean amphipod survival in 2007 exceeded the screening value of 75 percent (Table 6), indicating that recovery based on sediment toxicity is complete.
  - Mean amphipod survival in 2007 was not significantly lower ($P>0.05$) than the mean reference area value of 98 percent (Table 6).
  - Amphipod survival at six of the seven stations in the stratum in 2007 exceeded 75 percent by a margin greater than 10 percent (i.e., 85 to 100 percent); survival at one station (i.e., 70 percent) was only slightly below 75 percent (Figure 11a).
  - Mean amphipod survival increased from 76 to 88 percent between 2004 and 2007; although this increase was not significant ($P>0.05$) due to high variance in the 2004 data (Figure 12).
  - Amphipod survival at Station 38 in this stratum exhibited a significant ($P\leq0.05$) trend during the 10-year period between 1997 and 2007, with survival values of 0, 89, and 98 percent found during 1997, 2004, and 2007, respectively (Table 8).
- **Reductions in TOC Concentrations between 2004 and 2007**
  - Mean TOC concentrations declined by approximately 20 percent (i.e., 23 to 18 percent) between 2004 and 2007 (Table 4, Figure 8).
  - TOC concentrations at four of the seven stations in the stratum in 2007 were less than the values found in 2004 (Figure 7a).
- **Reductions in CoC Concentrations between 2004 and 2007**
  - Ammonia
    - Mean ammonia concentrations declined by approximately 50 percent (i.e., from 63 to 32 mg/kg) between 2004 and 2007 (Table 3, Figure 5).
    - Ammonia concentrations at six of the seven stations in the stratum in 2007 were less than the values found in 2004 (Figure 4a).
    - Ammonia concentrations at Station 38 in this stratum declined by over 85 percent (i.e., from 260 to 35 mg/kg) during the 10-year period between 1997 and 2007 (Table 5).
  - 4-Methylphenol
    - Mean 4-methylphenol concentrations declined by approximately 30 percent (i.e., from 12,000 to 8,200 µg/kg) between 2004 and 2007 (Table 3, Figure 6).
    - 4-Methylphenol concentrations at five of the seven stations in the stratum in 2007 were less than the values found in 2004 (Figure 4a).

  - o 4-Methylphenol concentrations at Station 38 in this stratum declined by approximately 40 percent (i.e., from 8,300 to 5,100 µg/kg) during the 10-year period between 1997 and 2007 (Table 5).

- **Changes in Benthic Community Taxonomic Composition between 1992 and 2007**
  - – The relative abundance of the polychaete *Capitella capitata* (i.e., the classic worldwide Successional Stage I species complex) declined from 93 to 6 percent between 2004 and 2007 (Table 15); typically this pattern indicates that recovery is in its early stage (e.g., Pearson and Rosenberg 1978).
  - – Four taxa each accounted for ≥5 percent of total abundance in 2007, whereas only *C. capitata* did in 2004 (Table 15).
  - – The four abundant benthic taxa in 2007 included one Successional Stage III taxon, and three Successional Stage I taxa (Table 15), indicating that recovery is occurring according to the patterns identified by Rhoads et al. (1978) and Rhoads and Germano (1982, 1986); the four taxa and their relative abundances and successional stages were:
    - o *Nephtys cornuta* (41 percent, Stage III)
    - o *Dorvillea annulata* (41 percent, Stage I)
    - o *C. capitata* (6 percent, Stage I)
    - o *Dorvillea* sp. (5 percent, Stage I).
  - – *N. cornuta* is also an abundant species in most other sampling areas in Ward Cove, and increased in abundance in five of those seven other areas between 2004 and 2007 (Table 15), as follows:
    - o TLP Stratum 2a: from 5 to 23 percent
    - o Natural Recovery Stratum 3b: from 87 to 94 percent
    - o Natural Recovery Stratum 4: from 51 to 71 percent
    - o Reference Area 5b: from 61 to 85 percent.
  - – Throughout Ward Cove, mean station densities of *C. capitata* have declined dramatically while densities of *N. cornuta* have increased during the 15-year period between 1992 and 2007, with values of 190, 76, and 13 individuals/m^2 for *C. capitata* and 9, 11, and 74 individuals/m^2 for *N. cornuta* found in 1992, 2004, and 2007, respectively (Table 16), thereby indicating the patterns observed in Stratum 2b are consistent with the overall patterns found throughout the cove.
  - – Weston (1990) found similar relative patterns for *C. capitata* and Nephtyidae juveniles (i.e., probably *N. cornuta* in most cases) in response to organic enrichment near a salmon farm in Puget Sound, with densities of *C. capitata* decreasing and densities of Nephtyidae generally increasing with increasing distances from the farm; at distances of 0, 45, 90, 150, and 450 m, the following densities (individuals/m^2) were found:

- *C. capitata:* 8,300, 6,000, 5,700, 5,100, and 960
- Nephtyidae: 0, 7, 280, 400, and 110.

The multiple lines of evidence provided above for Stratum 2b indicate that this stratum has made substantial advances in overall recovery. For example, sediment toxicity conditions in Stratum 2b have fully recovered with respect to the RAO for sediment toxicity, and mean concentrations of both CoCs (i.e., ammonia and 4-methylphenol) and TOC declined by 20 to 50 percent between 2004 and 2007. The patterns observed for individual benthic macroinvertebrate taxa support the conclusion that benthic community recovery is progressing. That is, the polychaete *N. cornuta* (a Successional Stage III species) has become a dominant member of the benthic community in Stratum 2b (accounting for 41 percent of individuals in 2007 compared to less than 5 percent in 2004), whereas the relative abundance of the polychaete *C. capitata* (a Successional Stage I species) has declined substantially in that stratum, such that this species accounted for only 6 percent of individuals in 2007, compared to 93 percent of individuals in 2004.

The weight of evidence described above for Stratum 2b indicates that the RAO for sediment toxicity has been achieved, and that consistent and acceptable progress has been made towards achieving the RAO of healthy benthic communities comprising multiple taxa. Because the sediments in Stratum 2b are no longer toxic, benthic community recovery will continue in the future. In addition, the CoC and TOC concentrations in Stratum 2b will likely continue to decline, because the major source of organic loadings to Ward Cove has been removed, further indicating that benthic community recovery will continue in the future. Therefore, based on the benthic succession patterns described in the general literature as well as the degree of benthic community recovery that has already occurred in other parts of the Ward Cove AOC, there is a weight of evidence that benthic community recovery will continue to proceed in Stratum 2b.

From the standpoint of the overall Ward Cove AOC, Stratum 2b represents a relatively small area (i.e., approximately 12 percent of the AOC). Therefore, it is unlikely that the slower recovery observed in that stratum relative to the remainder of the AOC will have a substantial impact on organisms at higher trophic levels that prey on benthic macroinvertebrates, such as crabs and a number of demersal fish species. As noted in the ROD, a benefit of achieving the RAOs in the Ward Cove AOC is that a healthy benthic macroinvertebrate community will provide a diverse food source for organisms at higher trophic levels.

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 enhanced characteristics beyond those of the reference areas. In addition, recovery is proceeding in the natural recovery areas, such that benthic communities in two of those areas have characteristics similar to the reference areas, and the community in the third area (i.e., Stratum 2b) is exhibiting characteristics that demonstrate that recovery is progressing.

7 EVALUATION OF REFERENCE AREAS

As discussed in the LMRP, 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. As specified in the LMRP, the adequacy of the reference areas was assessed after the first year of monitoring and the results of this evaluation were presented in the 2004 monitoring report (Exponent 2005). The adequacy of the reference areas was confirmed in 2007. In this section, information collected during the 2007 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 (2000b,c).

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 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.

Examination of the CoC results for the 2007 monitoring event showed that none of the ammonia or 4-methylphenol concentrations at individual reference stations exceeded their site-specific WCSQVs (Exponent 1999), and that concentrations at many stations had declined since 2004. For ammonia, the concentration ranges in the shallow (13–41 mg/kg) and moderately deep (35−84 mg/kg) reference areas were well below the ammonia WCSQV(1) of 110 mg/kg. For 4-methylphenol, the concentration ranges in the shallow (29–79 μg/kg) and moderately deep (250–550 μg/kg) reference areas were also well below the 4-methylphenol WCSQV(1) of 1,300 mg/kg. These results therefore confirm that CoC concentrations in the reference areas were not a concern.

Examination of the sediment toxicity results for the 2007 monitoring event showed that all of the amphipod survival values at individual stations exceeded the minimum acceptable value of 75 percent (Exponent 1999), and that the 2007 values were generally comparable to or considerably greater than the values found in 2004. Moreover, the ranges of amphipod survival in the shallow (95–100 percent) and moderately deep (85–100 percent) reference areas were well above the minimum acceptable value of 75 percent.

Although no reference area performance criteria were available for benthic community characteristics, comparisons of the 2004 monitoring data with the data collected in 2007 showed that mean taxa richness in the moderately deep reference area were generally comparable (i.e., 5.4 and 6.2 taxa per sample). However, mean taxa richness in the shallow reference area appeared to decline somewhat between 2004 and 2007 (i.e., 22 and 16 taxa per sample). Because there was no apparent cause for this slight reduction in taxa richness, it may have been the result of natural variability.

In summary, evaluation of the information on CoC concentrations, sediment toxicity results, and taxa richness of benthic communities found for the two reference areas in 2007 suggests that these areas continue to be valid reference areas for the various benthic strata in the Ward Cove AOC. That is, the characteristics of the sediments in both areas were considered representative of the large-scale background conditions that exist in the cove, concentrations of both CoCs were all below their respective site-specific WCSQVs, no sediment toxicity was observed, and benthic macroinvertebrate communities were considered reflective of the background conditions found in the cove, as they were in the 2004 monitoring report.

8 CONCLUSIONS AND RECOMMENDATIONS

Results of the 2004 and 2007 monitoring events in Ward Cove demonstrate that the RAOs have been achieved. Environmental conditions throughout the Ward Cove AOC have improved substantially since the RI/FS was conducted in 1996–1999. In addition, most conditions showed continual improvement between 2004 and 2007. The TLP has been 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 enhanced characteristics beyond those of the reference areas. In addition, recovery is proceeding in the natural recovery areas, such that all four areas have achieved the RAO for sediment toxicity and three of the four areas have achieved healthy benthic communities with multiple taxonomic groups. The weight of evidence for the remaining natural recovery area (i.e., Stratum 2b) indicates that, in addition to achieving the RAO for sediment toxicity, substantial and acceptable progress has been made towards achieving a healthy benthic community. There are numerous reasons to predict that diversification of benthic communities in Stratum 2b will continue to proceed, because sediment toxicity in that area has achieved the RAO, concentrations of TOC and the two CoCs declined by 20 to 50 percent between 2004 and 2007, and the major source of CoCs to the AOC has been removed.

Figures 34a and 34b provide summaries of the key variables monitored in the benthic strata of Ward Cove in 2007. The figures show that concentrations of the two CoCs are below WCSQVs in all three TLP areas. In addition, ammonia is below its WCSQV at 14 of the 17 stations located in the three natural recovery areas, and 4-methylphenol is below its WCSQV at 7 of the 17 stations located in the natural recovery areas. These patterns indicate that the TLP was successful in reducing the concentrations of these CoCs and that natural recovery was occurring in the 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 or freshly deposited material.

With respect to sediment toxicity in 2007, mean amphipod survival in all AOC strata exceeded the screening value of 75 percent (as specified in the LMRP), indicating that the RAO based on sediment toxicity has been achieved in all AOC strata. In 2004, mean amphipod survival in Stratum 2c also exceeded the screening value of 75 percent, indicating that the RAO based on sediment toxicity had been achieved in that stratum, which, as described previously, was considered recovered after the 2004 monitoring event. In addition, mean survival for all TLP and natural recovery strata was not significantly lower ($P \leq 0.05$) than the reference values. Although statistical comparisons for Stratum 4 were affected by low statistical power, the fact that mean survival for that stratum (i.e., 80 percent) was greater than the screening value of 75 percent indicates that the RAO based on sediment toxicity has been achieved.

In addition to the above information, specific temporal patterns for the six strata sampled in 2007 for sediment toxicity can be summarized as follows:

- Values of mean amphipod survival for all three TLP areas in 2007 were very high (i.e., 92–95 percent) and comparable to the values found in 2004 (i.e., 93–96 percent). In the natural recovery areas, values of mean amphipod survival in 2007 (i.e., 80–96 percent) generally were considerably higher than the values found in 2004 (i.e., 32–76 percent).
- For individual stations within the strata, amphipod survival exceeded the screening value of 75 percent at all 15 stations sampled in the TLP areas, which was consistent with the 2004 results. In the natural recovery areas, amphipod survival exceeded the minimum acceptable value at 14 of the 17 stations sampled in 2007, compared with only 7 of the 17 stations sampled in 2004.

Remedial efforts have successfully enhanced recolonization of surface sediment to support healthy marine benthic macroinvertebrate communities with multiple taxonomic groups throughout most of the AOC. As discussed above, the RAO for benthic communities was achieved in 2004 for Stratum 2c. Of the six strata sampled in 2007, community metrics were not significantly lower ($P > 0.05$) than reference values in all three TLP areas and two of the three natural recovery areas indicating that the RAO for benthic macroinvertebrate communities has been achieved in most parts of the AOC. Benthic metrics at only one of the three natural recovery areas (i.e., Stratum 2b) were significantly lower ($P \leq 0.05$) than reference values for the following metrics: total abundance, total richness, polychaete richness, mollusc abundance, mollusc richness, and SDI. Stratum 2b is discussed in greater detail below. Statistical comparisons for several benthic metrics for Stratum 3b were affected by low statistical power adding some degree of uncertainty to those results.

In addition to the results described above for community metrics, a number of additional qualitative and quantitative benthic analyses were conducted, including evaluations of the successional stages of key benthic species, temporal patterns in community characteristics, multivariate analysis of benthic communities, and taxa richness at individual stations. The results of those analyses are summarized below and show that, in general, diverse communities comprising multiple taxa now inhabit the three TLP areas and two of the three natural recovery areas (i.e., Strata 3b and 4). The results of the additional benthic analyses can be summarized as follows:

- Approximately 6,800 benthic macroinvertebrates from 130 taxa were sampled as part of the 2007 sampling event, compared to approximately 4,500 individuals from 117 taxa that were sampled in 2004. These values represent increases of approximately 33 and 10 percent in the total numbers of individuals and taxa over the 3-year period between monitoring events. The 2004 results for Stratum 2c were not included in these comparisons, because that stratum was not evaluated in 2007.

- The number of polychaete taxa and the relative abundance of polychaetes declined in 2007 compared to 2004, whereas the number of mollusc taxa and the relative abundance of molluscs increased between the two sampling periods (Figure 20). This pattern continues the trend of an increasing representation of molluscs in the benthic communities that was first identified in 2004.
- Statistical comparisons of the benthic metrics between remediated areas of the Ward Cove AOC and the reference areas in 2007 showed that benthic metrics at most stations were not significantly lower ($P>0.05$) than reference values, with most metrics being greater than their respective reference values (Table 13). However, several of the determinations of not significantly lower ($P>0.05$) than reference values were affected by low statistical power, adding some degree of uncertainty to those results.
- The benthic communities in the TLP areas in 2007 continued to be characterized primarily by species commonly found in areas where organic enrichment is declining, as they were in 2004 (Table 15). These species include the polychaete *Prionospio steenstrupi* and the bivalves *Axinopsida serricata* and *Parvilucina tenuisculpta*. Although benthic communities in the three natural recovery areas were characterized primarily by species commonly found in organically enriched areas, the relative abundance of the polychaete *Capitella capitata* declined substantially, as the abundances of the polychaetes *Nephtys cornuta* and *Dorvillea annulata* increased (Table 15). The decline in the abundances of *C. capitata* is notable, as this species complex is a classic indicator of organic enrichment throughout the world. Coupled with the decline in nematodes (i.e., another classic indicator of organic enrichment) that occurred between 1992 and 2004, the decline in *C. capitata* indicates that conditions in the natural recovery areas have been continually improving over time.
- If *C. capitata* and nematodes are removed from the benthic communities sampled in 1992, 2004, and 2007, mean total abundance in 2004 (95 individuals per station) is nearly identical to the value found in 1992 (100 individuals per station), and the value found in 2007 (250 individuals per station) is two and one-half times the 1992 value (Table 16). These results indicate that total abundances of benthic communities (exclusive of species characteristic of high levels of organic enrichment) increased substantially between the 2004 and 2007 monitoring events.
- With respect to the number of benthic taxa that accounted for more than 5 percent of total abundance at any station in the AOC), there were only seven such taxa in 1992 (Table 16). In 2004, the number of these taxa increased relatively modestly to 11 taxa, but by 2007, the number increased substantially to 28 taxa. These results indicate that many more species were becoming numerically important at various stations throughout the AOC in 2007, which is an indication that conditions have improved in the AOC since 2004.

- Results of multivariate analyses of the benthic macroinvertebrate data collected in Ward Cove in 2007 showed that three distinct clusters or groups of stations were apparent, with the natural recovery areas clustering with the reference areas and the TLP areas clustering only with themselves (Figures 30 and 31). These results indicate that TLP in the cove has resulted in benthic communities that are different from the communities found in the natural recovery and reference areas. Given the other characteristics of these communities described in this report, it can be concluded that TLP in the cove has resulted in modifications of the communities such that they are now enhanced beyond the reference conditions. In addition, although the natural recovery areas have not shown the same degree of enhancement, they are now relatively similar to the reference conditions.

Although six benthic community metrics for Stratum 2b were found to be significantly lower ($P \leq 0.05$) than the reference values, mean amphipod survival in this stratum in 2007 exceeded the screening value of 75 percent specified in the LRMP, indicating that this stratum has fully recovered with respect to the RAO based on sediment toxicity. Additional lines of evidence based on sediment toxicity, sediment chemistry, and benthic community species composition indicate that overall recovery of the stratum is occurring, including benthic community recovery. These lines of evidence are identified below:

- **Reductions in Sediment Toxicity between 1997 and 2007**
  - As discussed above, mean amphipod survival in 2007 exceeded the screening value of 75 percent (Table 6), indicating that recovery based on sediment toxicity is complete.
  - Mean amphipod survival in 2007 was not significantly lower ($P>0.05$) than the mean reference value of 98 percent (Table 6).
  - Amphipod survival at six of the seven stations in the stratum in 2007 exceeded 75 percent by a margin greater than 10 percent (i.e., 85 to 100 percent); survival at one station (i.e., 70 percent) was only slightly below 75 percent (Figure 11a).
  - Mean amphipod survival increased from 76 to 88 percent between 2004 and 2007; although this increase was not significant ($P>0.05$) due to high variance in the 2004 data (Figure 12).
  - Amphipod survival at Station 38 in this stratum exhibited a significant ($P \leq 0.05$) trend during the 10-year period between 1997 and 2007, with survival values of 0, 89, and 98 percent found during 1997, 2004, and 2007, respectively (Table 8).
- **Reductions in TOC Concentrations between 2004 and 2007**
  - Mean TOC concentrations declined by approximately 20 percent (i.e., 23 to 18 percent) between 2004 and 2007 (Table 4, Figure 8).

- TOC concentrations at five of the seven stations in the stratum in 2007 were less than the values found in 2004 (Figure 7a).

- **Reductions in CoC Concentrations between 2004 and 2007**
  - Ammonia
    - Mean ammonia concentrations declined by approximately 50 percent (i.e., from 63 to 32 mg/kg) between 2004 and 2007 (Table 3, Figure 5).
    - Ammonia concentrations at six of the seven stations in the stratum in 2007 were less than the values found in 2004 (Figure 4a).
    - Ammonia concentrations at Station 38 in this stratum declined by over 85 percent (i.e., from 260 to 35 mg/kg) during the 10-year period between 1997 and 2007 (Table 5).
  - 4-Methylphenol
    - Mean 4-methylphenol concentrations declined by approximately 30 percent (i.e., from 12,000 to 8,200 μg/kg) between 2004 and 2007 (Table 3, Figure 6).
    - 4-Methylphenol concentrations at four of the seven stations in the stratum in 2007 were less than the values found in 2004 (Figure 4a).
    - 4-Methylphenol concentrations at Station 38 in this stratum declined by approximately 40 percent (i.e., from 8,300 to 5,100 μg/kg) during the 10-year period between 1997 and 2007 (Table 5).

- **Changes in Benthic Community Taxonomic Composition between 1992 and 2007**
  - The relative abundance of the polychaete *Capitella capitata* (i.e., the classic worldwide Successional Stage I species complex) declined from 93 to 6 percent between 2004 and 2007 (Table 15); typically this pattern indicates that recovery is in its early stage (e.g., Pearson and Rosenberg 1978).
  - Four taxa each accounted for ≥5 percent of total abundance in 2007, whereas only *C. capitata* did in 2004 (Table 15).
  - The four abundant benthic taxa in 2007 included one Successional Stage III taxon, and three Successional Stage I taxa (Table 15), indicating that recovery is occurring according to the patterns identified by Rhoads et al. (1978) and Rhoads and Germano (1982, 1986); the four taxa and their relative abundances and successional stages were:
    - *Nephtys cornuta* (41 percent, Stage III)
    - *Dorvillea annulata* (41 percent, Stage I)
    - *C. capitata* (6 percent, Stage I)
    - *Dorvillea* sp. (5 percent, Stage I).

- *N. cornuta* is also an abundant species in most other sampling areas in Ward Cove, and increased in abundance in five of those seven other areas between 2004 and 2007 (Table 15), as follows:
  - TLP Stratum 2a: from 5 to 23 percent
  - Natural Recovery Stratum 3b: from 87 to 94 percent
  - Natural Recovery Stratum 4: from 51 to 71 percent
  - Reference Area 5b: from 61 to 85 percent.
- Throughout Ward Cove, mean station densities of *C. capitata* have declined dramatically while densities of *N. cornuta* have increased during the 15-year period between 1992 and 2007, with values of 190, 76, and 13 individuals/m^2 for *C. capitata* and 9, 11, and 74 individuals/m^2 for *N. cornuta* found in 1992, 2004, and 2007, respectively (Table 16), thereby indicating the patterns observed in Stratum 2b are consistent with the overall patterns found throughout the cove.
- Weston (1990) found similar relative patterns for *C. capitata* and Nephtyidae juveniles (i.e., probably *N. cornuta* in most cases) in response to organic enrichment near a salmon farm in Puget Sound, with densities of *C. capitata* decreasing and densities of Nephtyidae generally increasing with increasing distances from the farm; at distances of 0, 45, 90, 150, and 450 m, the following densities (individuals/m^2) were found:
  - *C. capitata:* 8,300, 6,000, 5,700, 5,100, and 960
  - Nephtyidae: 0, 7, 280, 400, and 110.

The multiple lines of evidence provided above indicate that Stratum 2b of the Ward Cove AOC has made substantial advances in overall recovery. For example, sediment toxicity conditions in Stratum 2b have fully recovered with respect to the RAO for sediment toxicity, and mean concentrations of both CoCs (i.e., ammonia and 4-methylphenol) and TOC declined by 20 to 50 percent between 2004 and 2007. The patterns observed for individual benthic macro-invertebrate taxa support the conclusion that benthic community recovery is progressing. That is, the polychaete *N. cornuta* (a Successional Stage III species) has become a dominant member of the benthic community in Stratum 2b (accounting for 41 percent of individuals in 2007 compared to less than 5 percent in 2004), whereas the relative abundance of the polychaete *C. capitata* (a Successional Stage I species) has declined substantially in that stratum, such that this species accounted for only 6 percent of individuals in 2007, compared to 93 percent of individuals in 2004.

The weight of evidence described above for Stratum 2b indicates that the RAO for sediment toxicity has been achieved, and that consistent and acceptable progress has been made towards achieving the RAO of healthy benthic communities comprising multiple taxa. Because the sediments in Stratum 2b are no longer toxic, benthic community recovery will continue in the future. In addition, the CoC and TOC concentrations in Stratum 2b will likely continue to decline, because the major source of organic loadings to Ward Cove has been removed, further indicating that benthic community recovery will continue in the future. Therefore, based on the benthic succession patterns described in the general literature as well as the degree of benthic community recovery that has already occurred in other parts of the Ward Cove AOC, there is a weight of evidence that benthic community recovery will continue to proceed in Stratum 2b.

From the standpoint of the overall Ward Cove AOC, Stratum 2b represents a relatively small area (i.e., approximately 12 percent of the AOC). Therefore, it is unlikely that the slower recovery observed in that stratum relative to the remainder of the AOC will have a substantial impact on organisms at higher trophic levels that prey on benthic macroinvertebrates, such as crabs and a number of demersal fish species. As noted in the ROD, a benefit of achieving the RAOs in the Ward Cove AOC is that a healthy benthic macroinvertebrate community will provide a diverse food source for organisms at higher trophic levels.

Based on the results of both the 2004 and 2007 monitoring events, it is concluded that TLP and natural recovery have been successful remediation tools for the Ward Cove AOC. Sediment toxicity has been reduced and benthic recolonization has been enhanced such that the AOC now supports healthy benthic communities with multiple taxonomic groups. The RAOs have been achieved and monitoring is no longer necessary.

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FIGURES

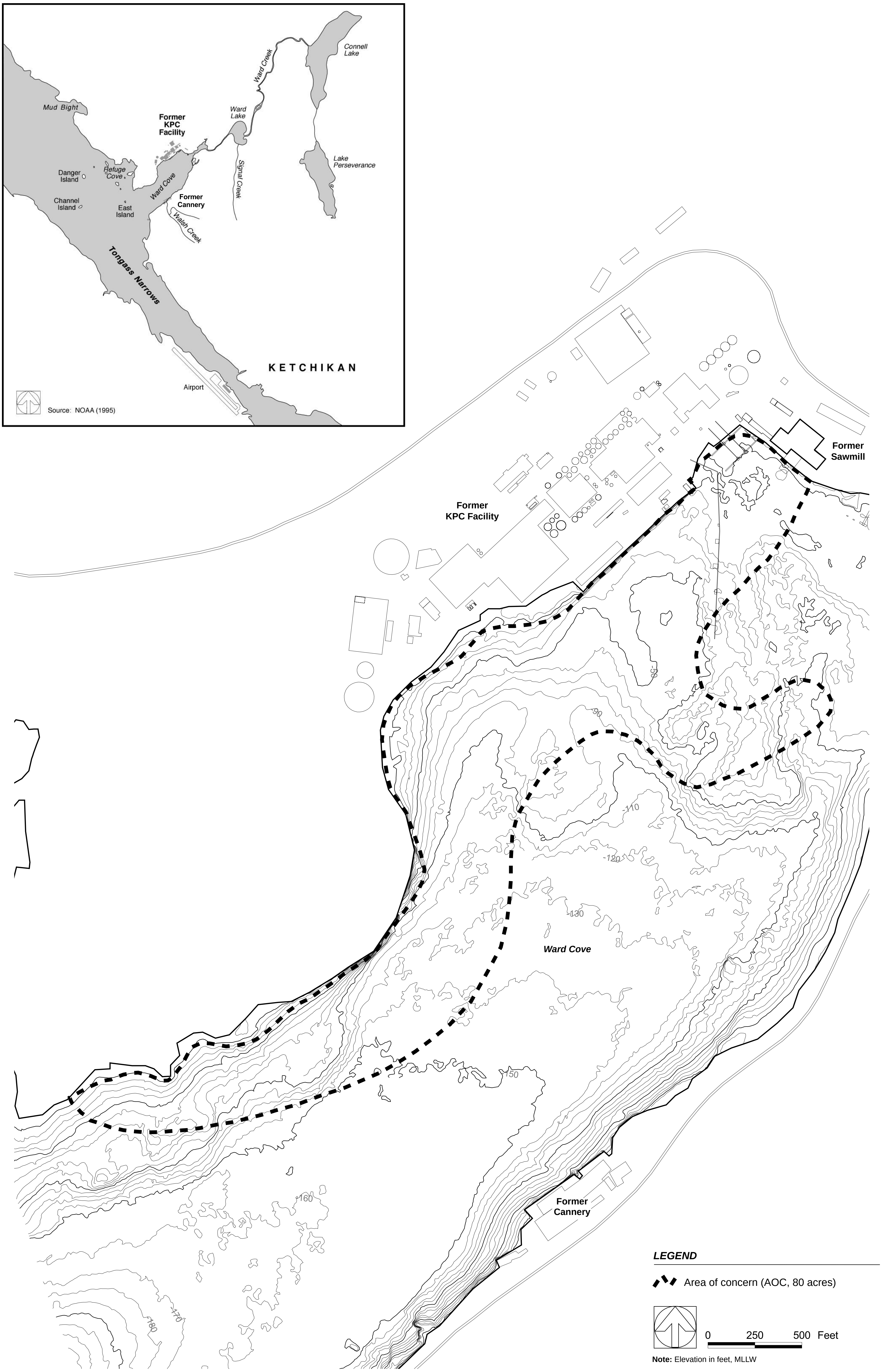


Figure 1. Location of Ward Cove and the area of concern within the cove

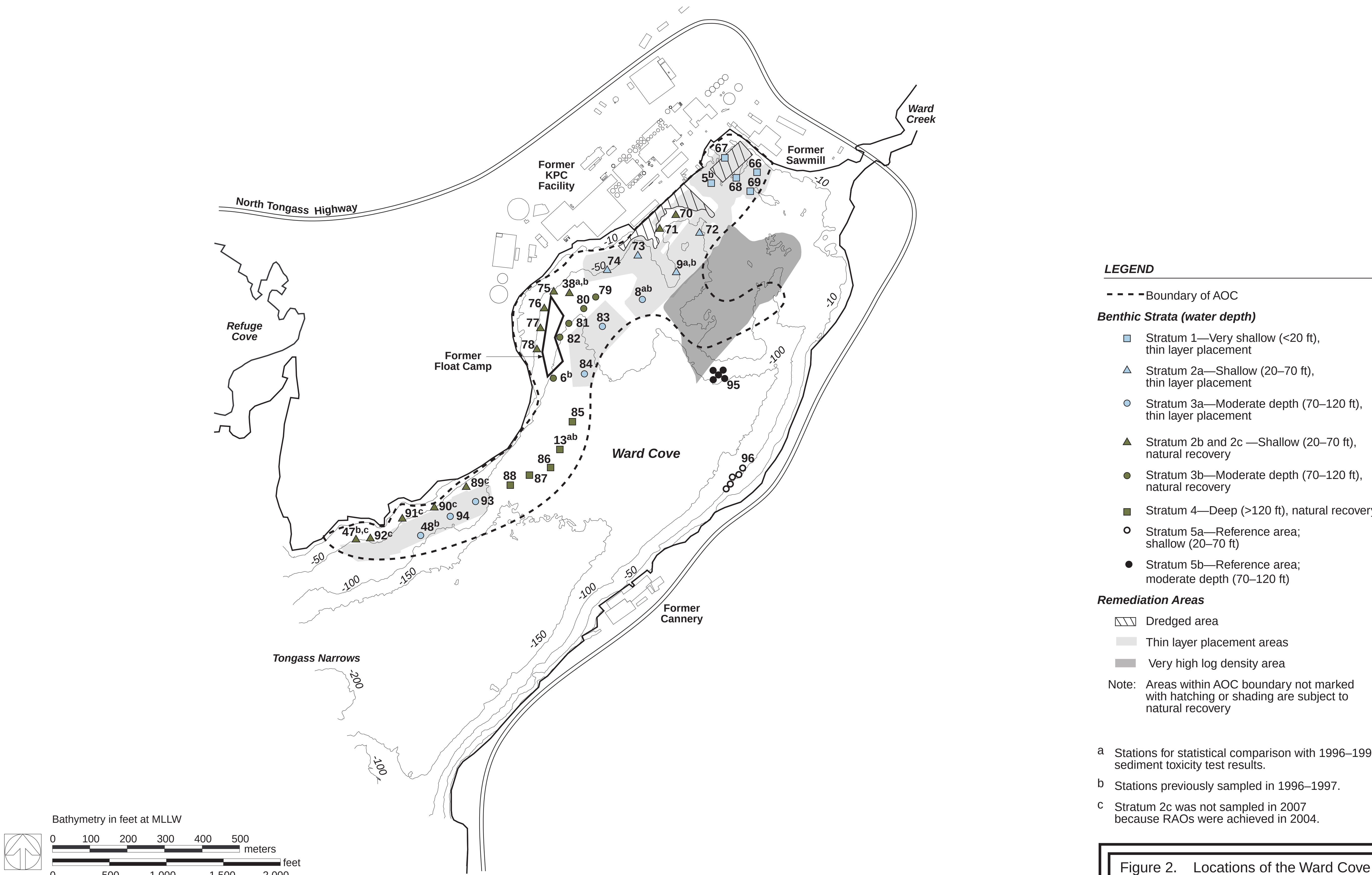


Figure 2. Locations of the Ward Cove AOC; areas of thin layer placement, dredging, and natural recovery; and stations sampled in July 2007

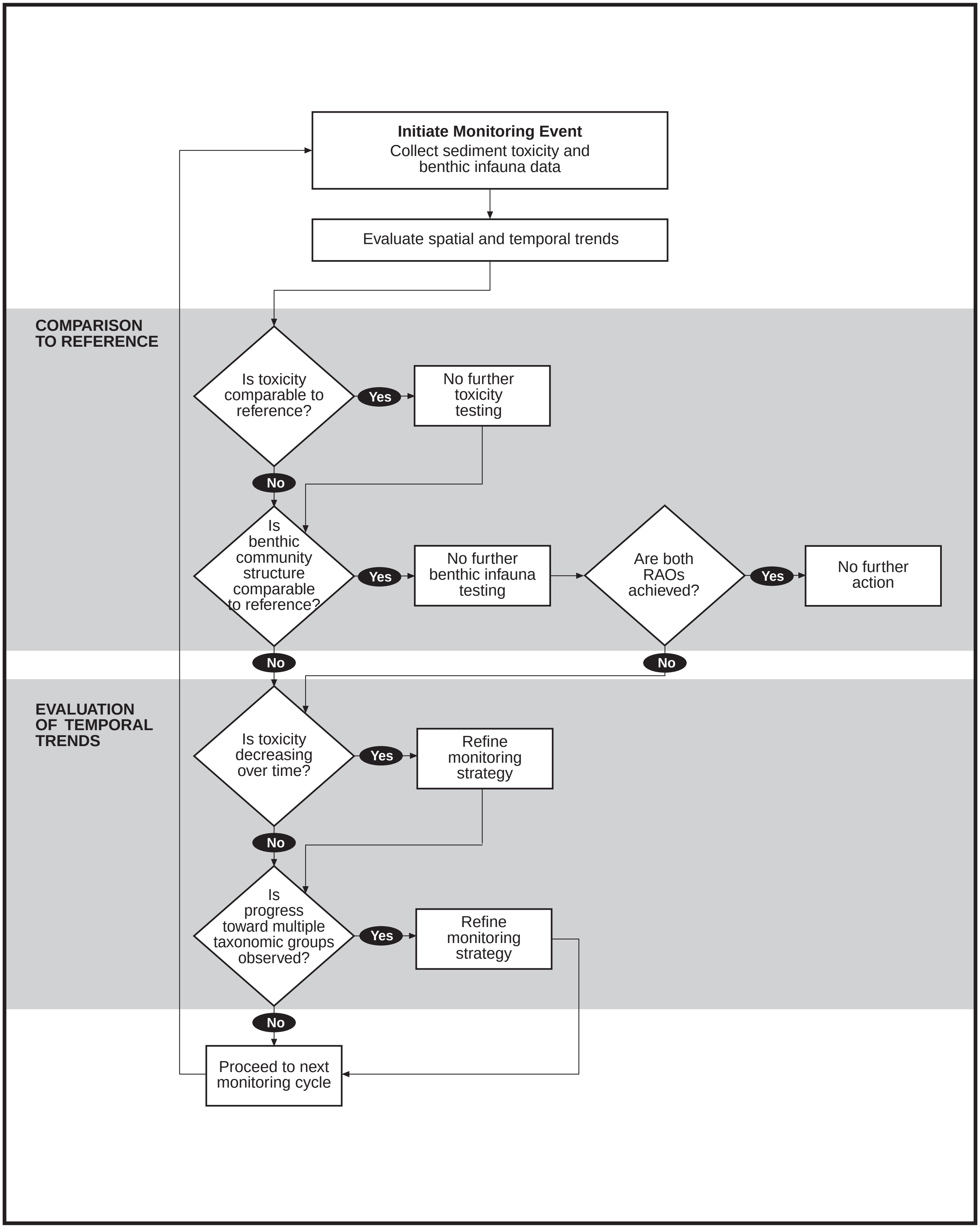


Figure 3. Overview of process for evaluating monitoring data

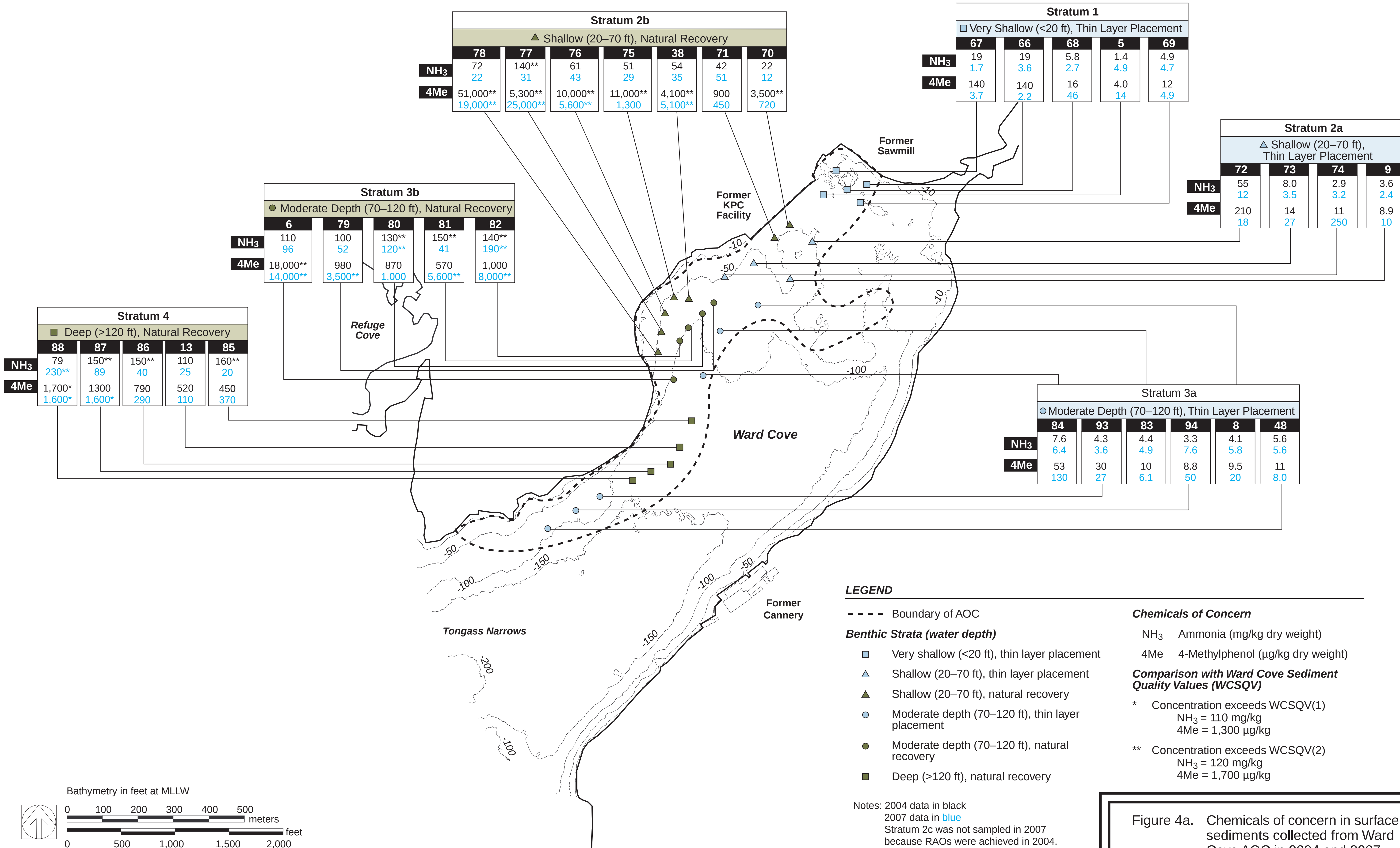
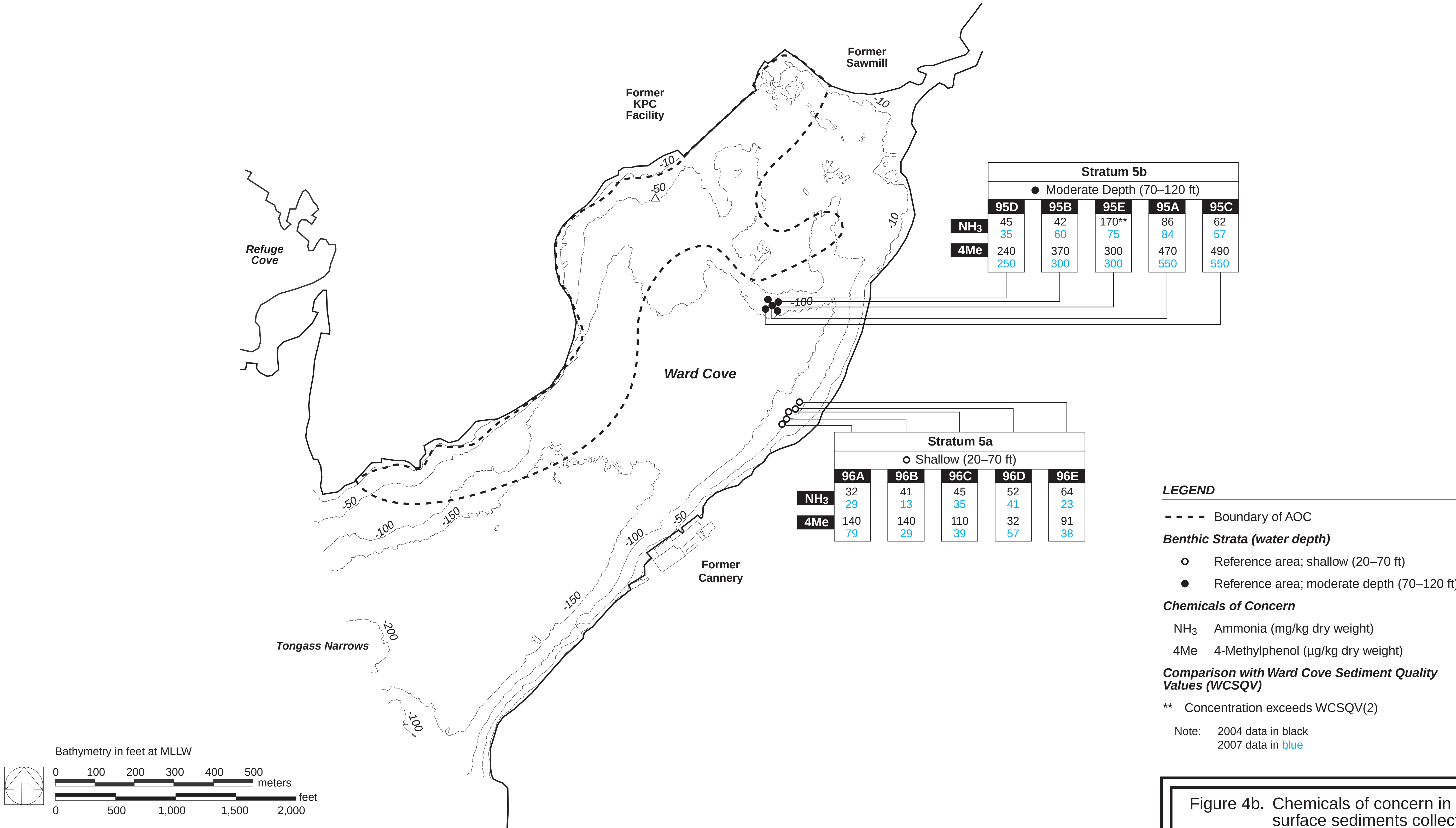


Figure 4a. Chemicals of concern in surface sediments collected from Ward Cove AOC in 2004 and 2007



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

	95D	95B	95E	95A	95C
NH_3 (2004)	45	42	170**	86	62
NH_3 (2007)	35	60	75	84	57
4Me (2004)	240	370	300	470	490
4Me (2007)	250	300	300	550	550

Stratum 5a – ○ Shallow (20–70 ft)

	96A	96B	96C	96D	96E
NH_3 (2004)	32	41	45	52	64
NH_3 (2007)	29	13	35	41	23
4Me (2004)	140	140	110	32	91
4Me (2007)	79	29	39	57	38

Figure 4b. Chemicals of concern in surface sediments collected from Ward Cove reference areas in 2004 and 2007

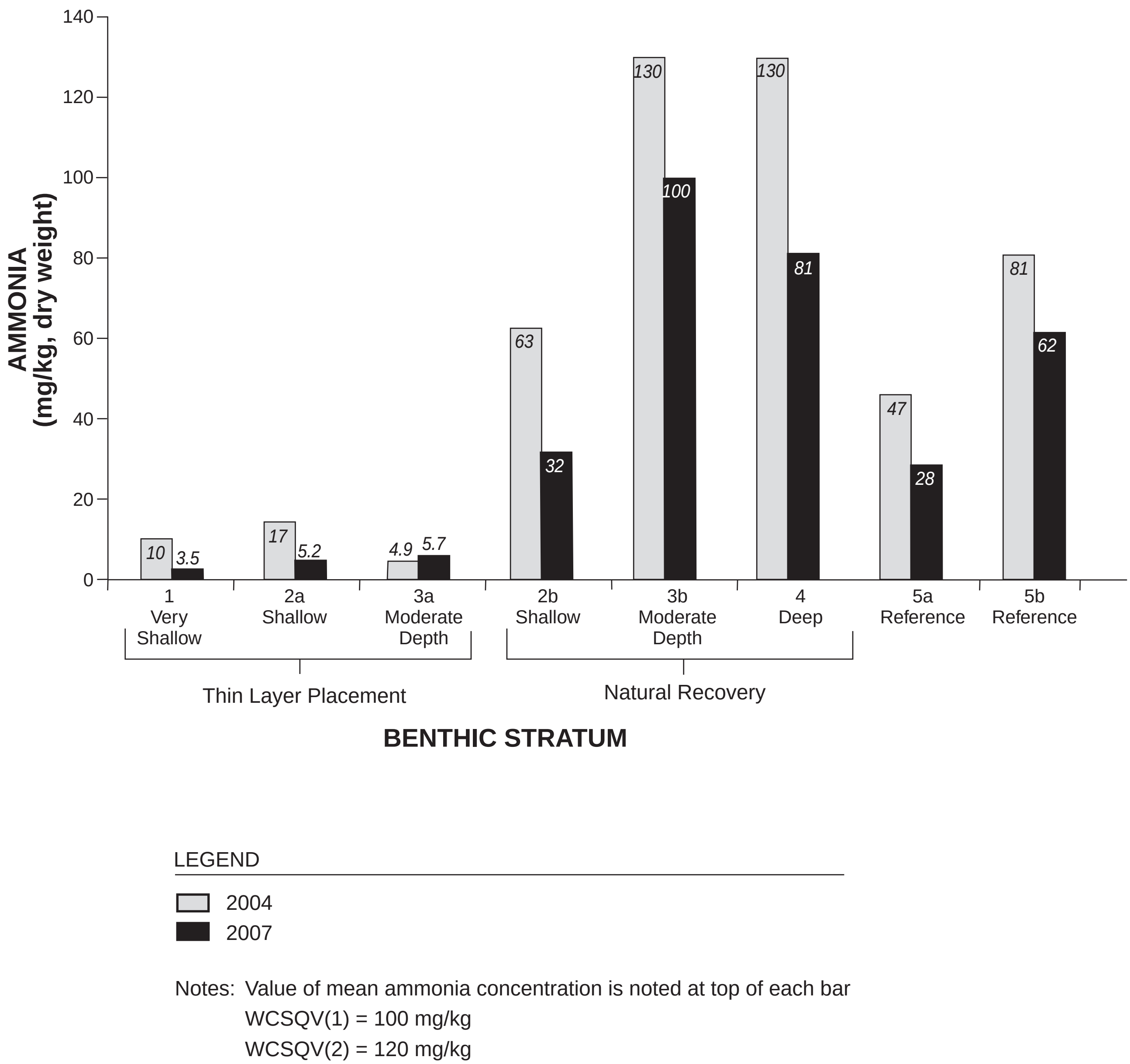


Figure 5. Comparisons of mean ammonia concentrations between Ward Cove benthic strata between 2004 and 2007

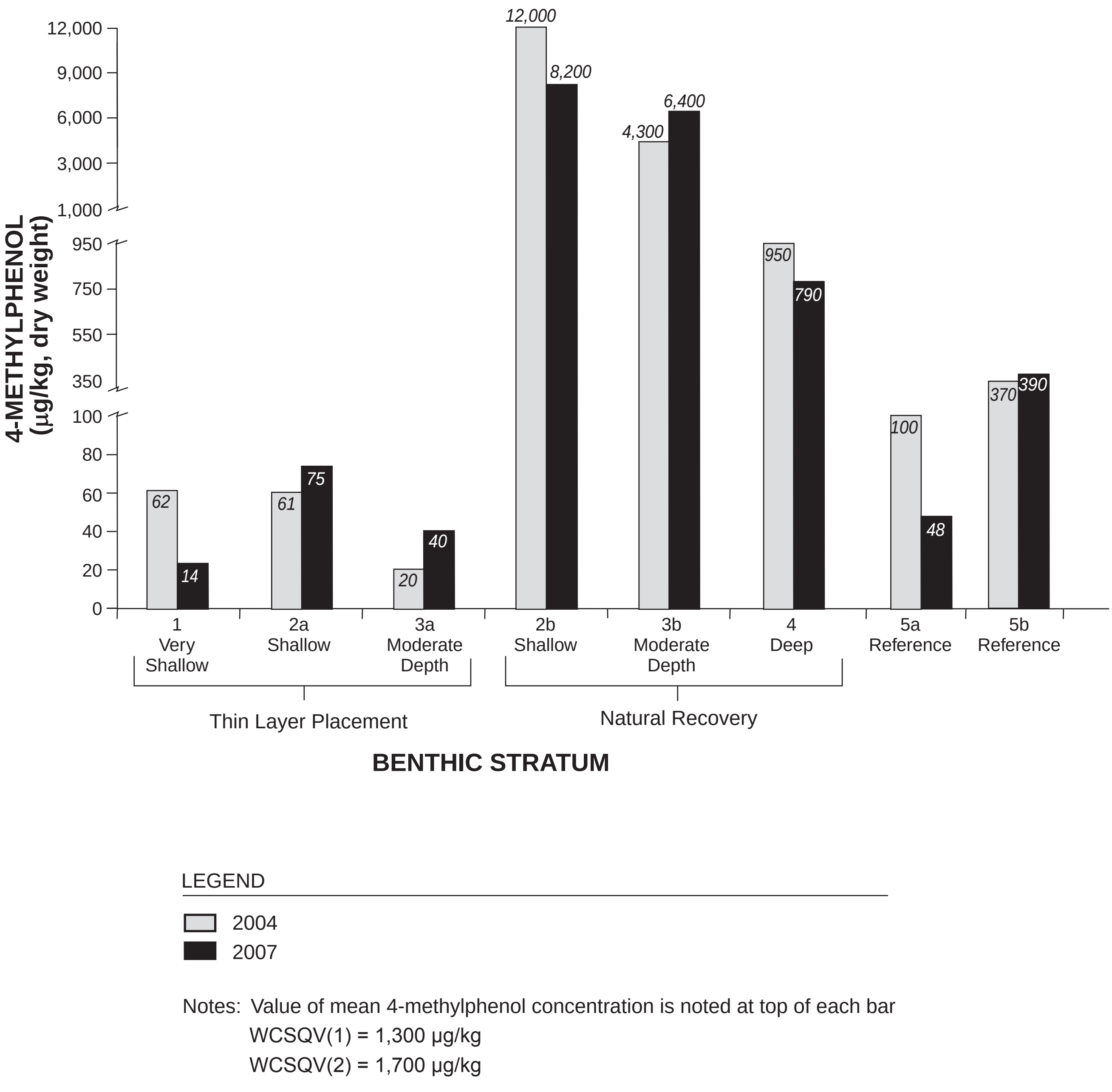
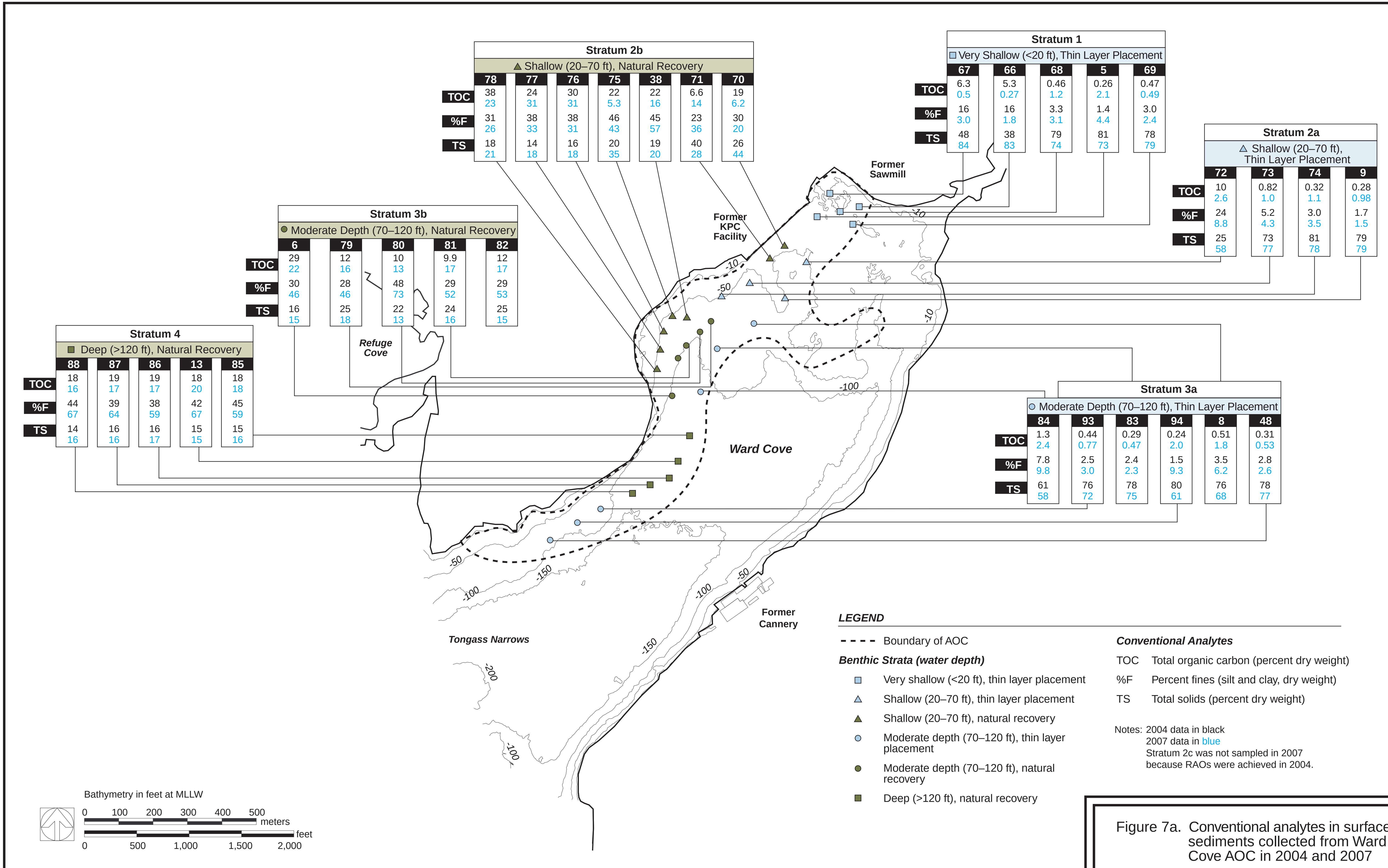


Figure 6. Comparisons of mean 4-methylphenol concentrations between Ward Cove benthic strata between 2004 and 2007



Stratum 2b — Shallow (20–70 ft), Natural Recovery (2004 / 2007)

	78	77	76	75	38	71	70
TOC	38 / 23	24 / 31	30 / 31	22 / 5.3	22 / 16	6.6 / 14	19 / 6.2
%F	31 / 26	38 / 33	38 / 31	46 / 43	45 / 57	23 / 36	30 / 20
TS	18 / 21	14 / 18	16 / 18	20 / 35	19 / 20	40 / 28	26 / 44

Stratum 1 — Very Shallow (<20 ft), Thin Layer Placement (2004 / 2007)

	67	66	68	5	69
TOC	6.3 / 0.5	5.3 / 0.27	0.46 / 1.2	0.26 / 2.1	0.47 / 0.49
%F	16 / 3.0	16 / 1.8	3.3 / 3.1	1.4 / 4.4	3.0 / 2.4
TS	48 / 84	38 / 83	79 / 74	81 / 73	78 / 79

Stratum 2a — Shallow (20–70 ft), Thin Layer Placement (2004 / 2007)

	72	73	74	9
TOC	10 / 2.6	0.82 / 1.0	0.32 / 1.1	0.28 / 0.98
%F	24 / 8.8	5.2 / 4.3	3.0 / 3.5	1.7 / 1.5
TS	25 / 58	73 / 77	81 / 78	79 / 79

Stratum 3b — Moderate Depth (70–120 ft), Natural Recovery (2004 / 2007)

	6	79	80	81	82
TOC	29 / 22	12 / 16	10 / 13	9.9 / 17	12 / 17
%F	30 / 46	28 / 46	48 / 73	29 / 52	29 / 53
TS	16 / 15	25 / 18	22 / 13	24 / 16	25 / 15

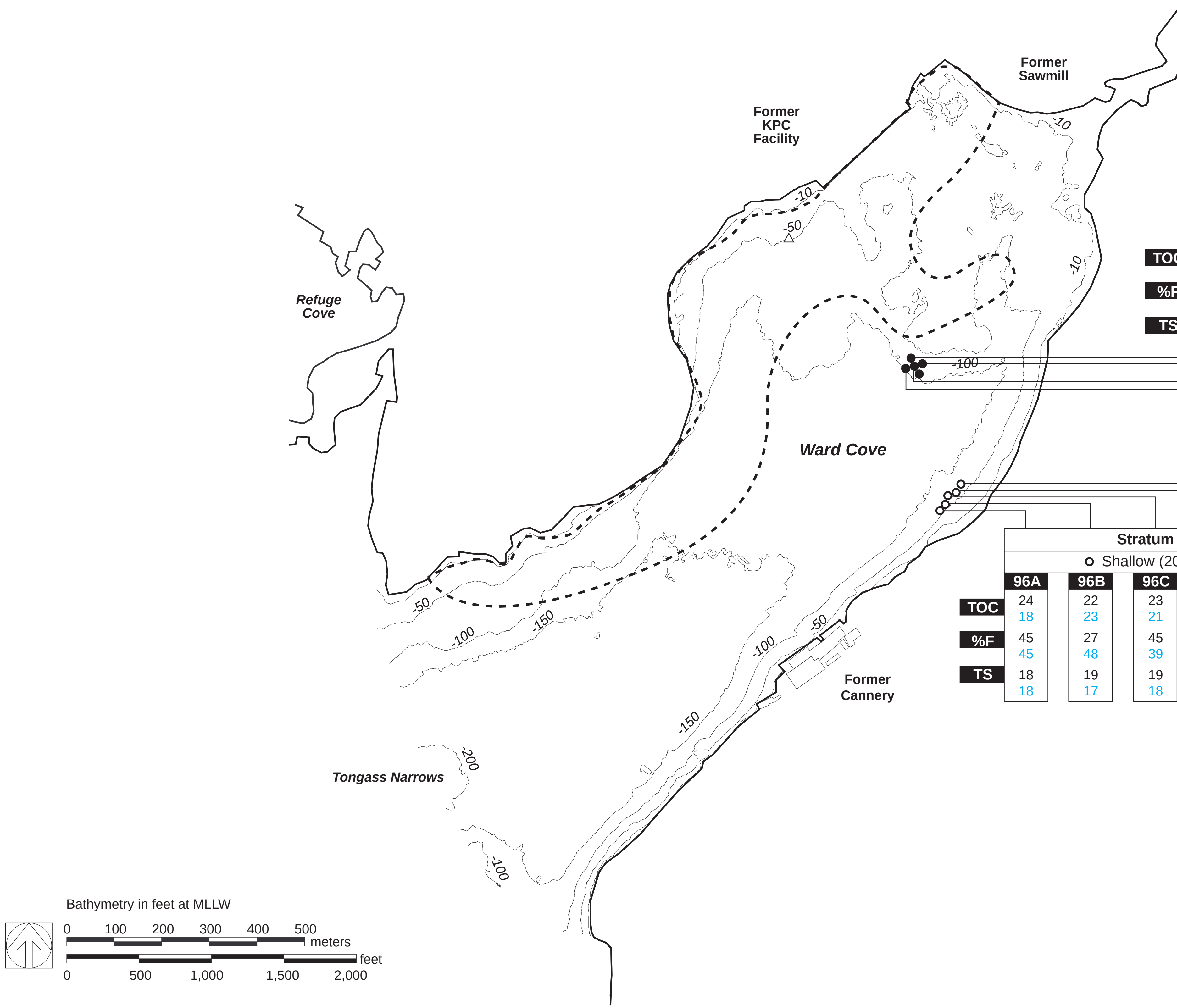
Stratum 4 — Deep (>120 ft), Natural Recovery (2004 / 2007)

	88	87	86	13	85
TOC	18 / 16	19 / 17	19 / 17	18 / 20	18 / 18
%F	44 / 67	39 / 64	38 / 59	42 / 67	45 / 59
TS	14 / 16	16 / 16	16 / 17	15 / 15	15 / 16

Stratum 3a — Moderate Depth (70–120 ft), Thin Layer Placement (2004 / 2007)

	84	93	83	94	8	48
TOC	1.3 / 2.4	0.44 / 0.77	0.29 / 0.47	0.24 / 2.0	0.51 / 1.8	0.31 / 0.53
%F	7.8 / 9.8	2.5 / 3.0	2.4 / 2.3	1.5 / 9.3	3.5 / 6.2	2.8 / 2.6
TS	61 / 58	76 / 72	78 / 75	80 / 61	76 / 68	78 / 77

Figure 7a. Conventional analytes in surface sediments collected from Ward Cove AOC in 2004 and 2007



Stratum 5b

● Moderate Depth (70–120 ft)

	95D	95B	95E	95A	95C
TOC	18 15	18 14	16 15	18 16	19 13
%F	48 53	29 55	52 53	39 55	45 56
TS	18 24	22 18	15 18	19 19	19 16

Stratum 5a

○ Shallow (20–70 ft)

	96A	96B	96C	96D	96E
TOC	24 18	22 23	23 21	26 23	25 21
%F	45 45	27 48	45 39	47 36	39 52
TS	18 18	19 17	19 18	15 19	18 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)

Note: 2004 data in black
2007 data in blue

Figure 7b. Conventional analytes in surface sediments collected from Ward Cove reference areas in 2004 and 2007

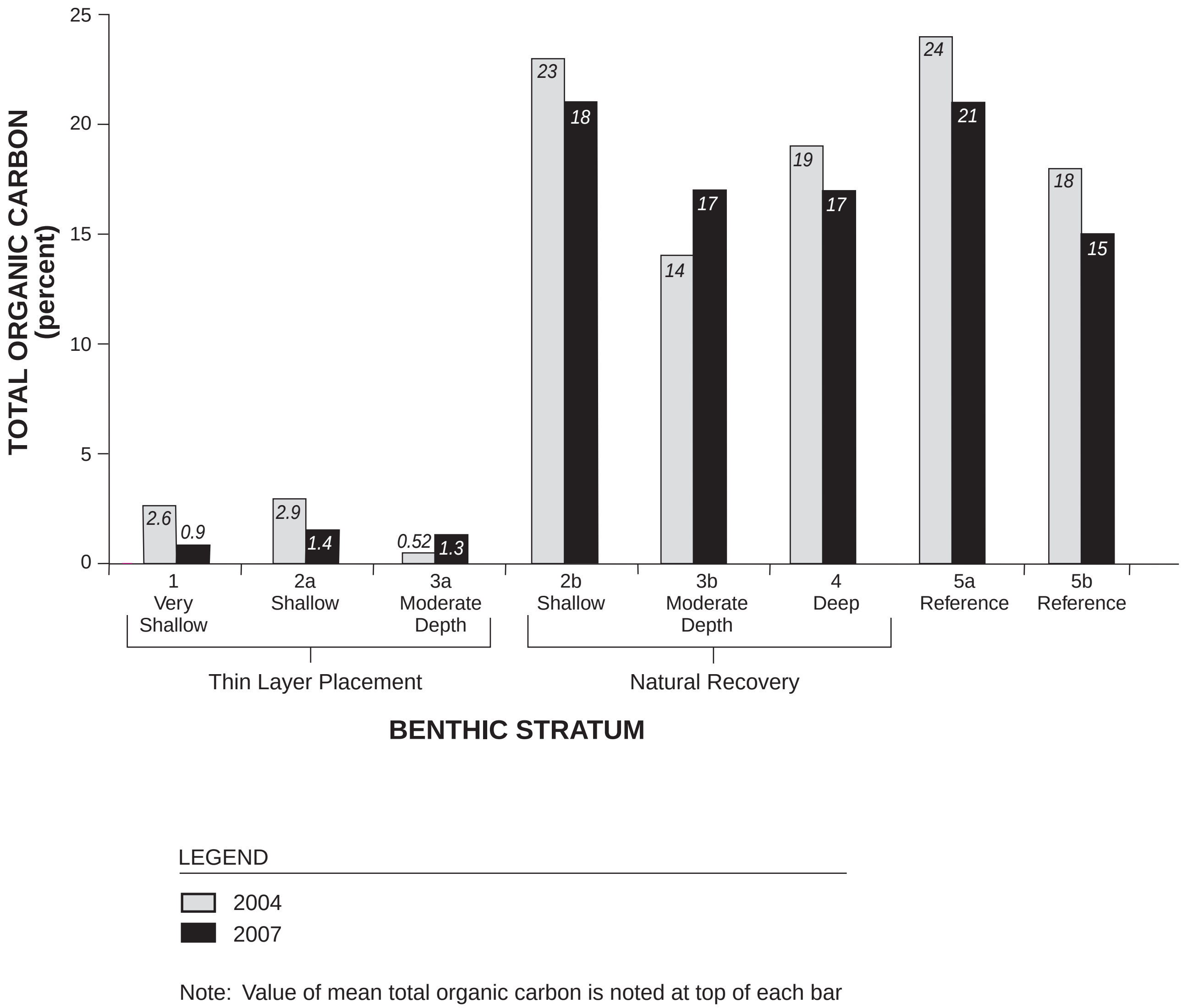


Figure 8. Comparisons of mean total organic carbon concentrations between Ward Cove benthic strata between 2004 and 2007

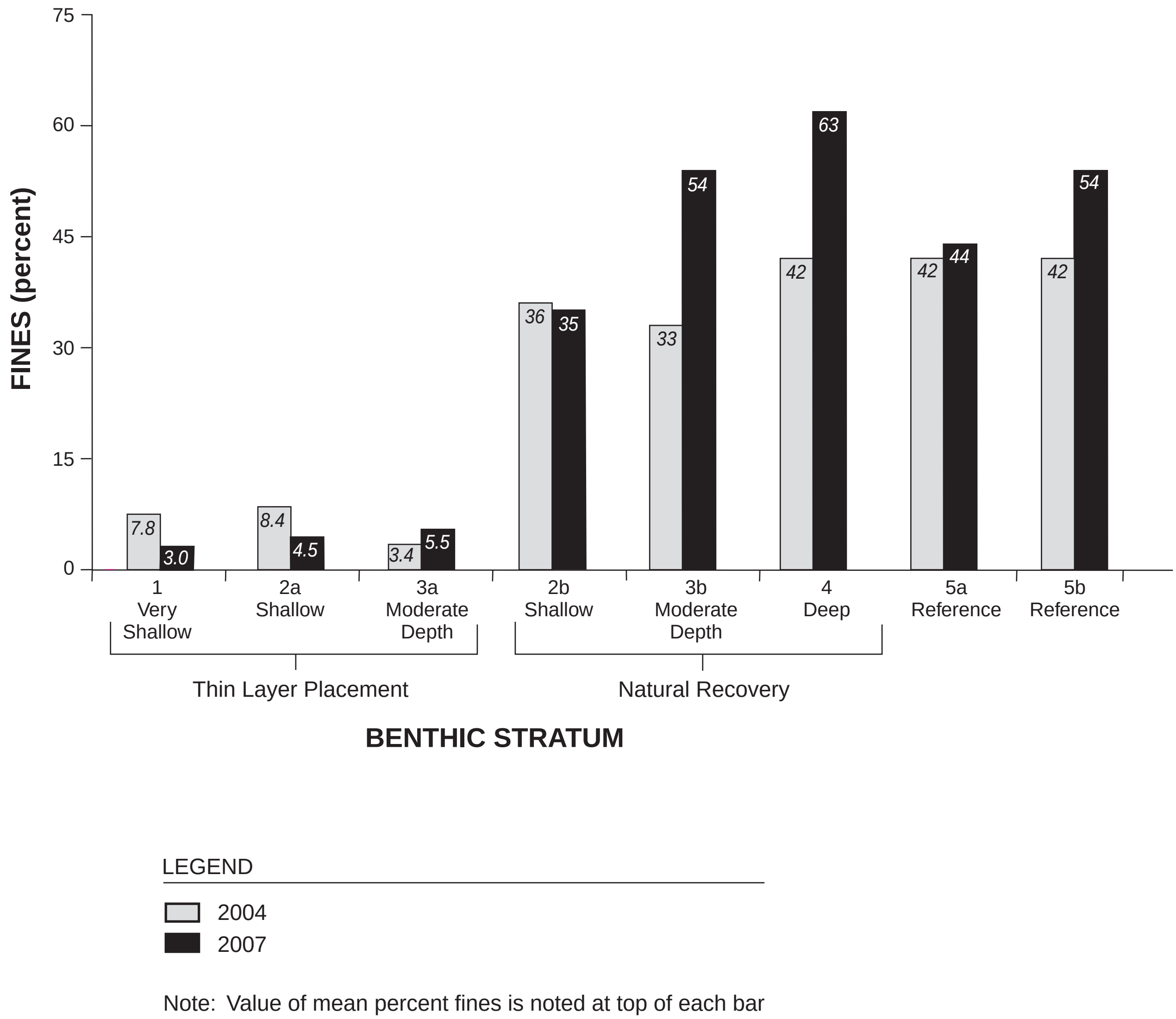


Figure 9. Comparisons of mean percent fines concentrations between Ward Cove benthic strata between 2004 and 2007

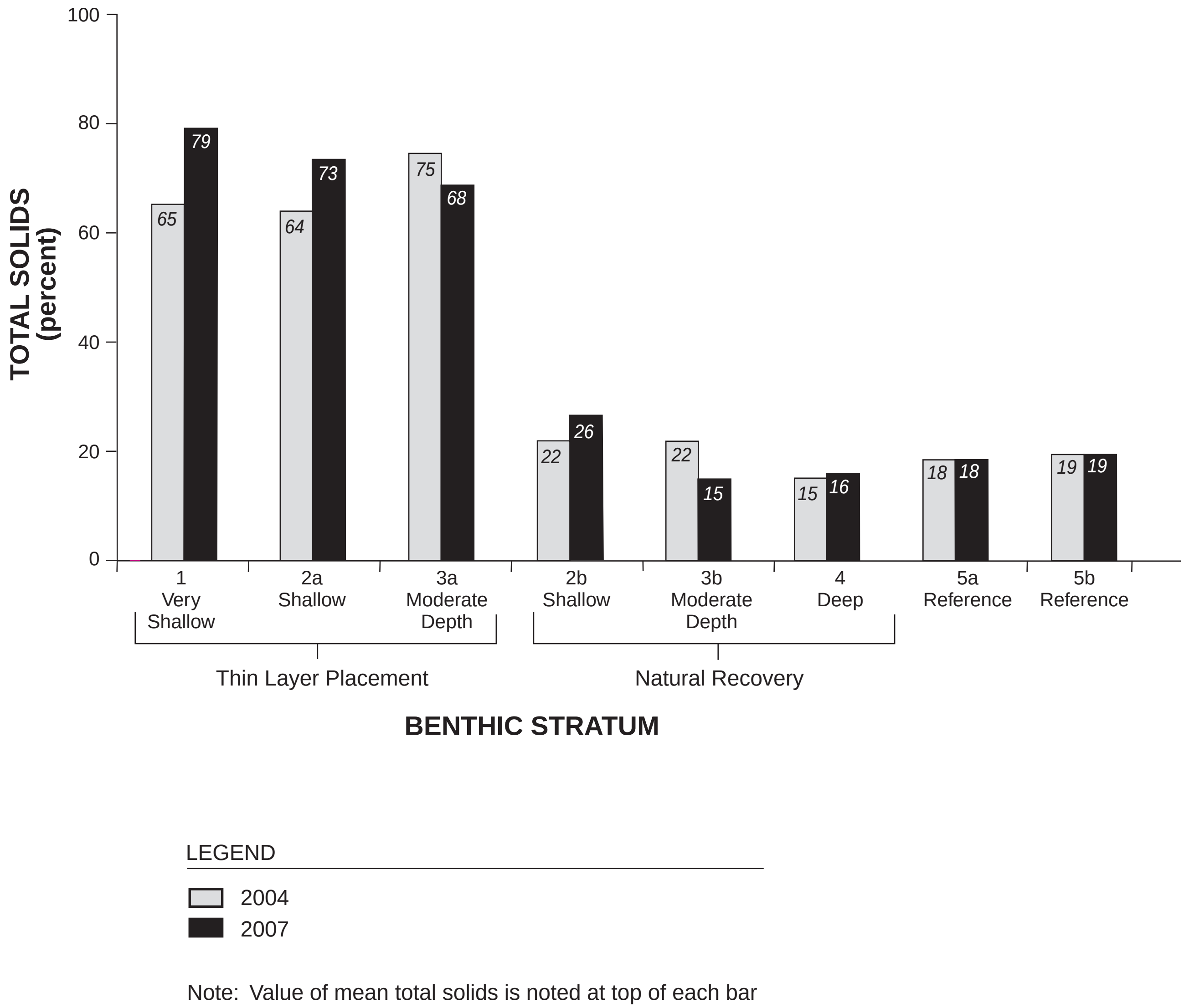


Figure 10. Comparisons of mean total solids concentrations between Ward Cove benthic strata between 2004 and 2007

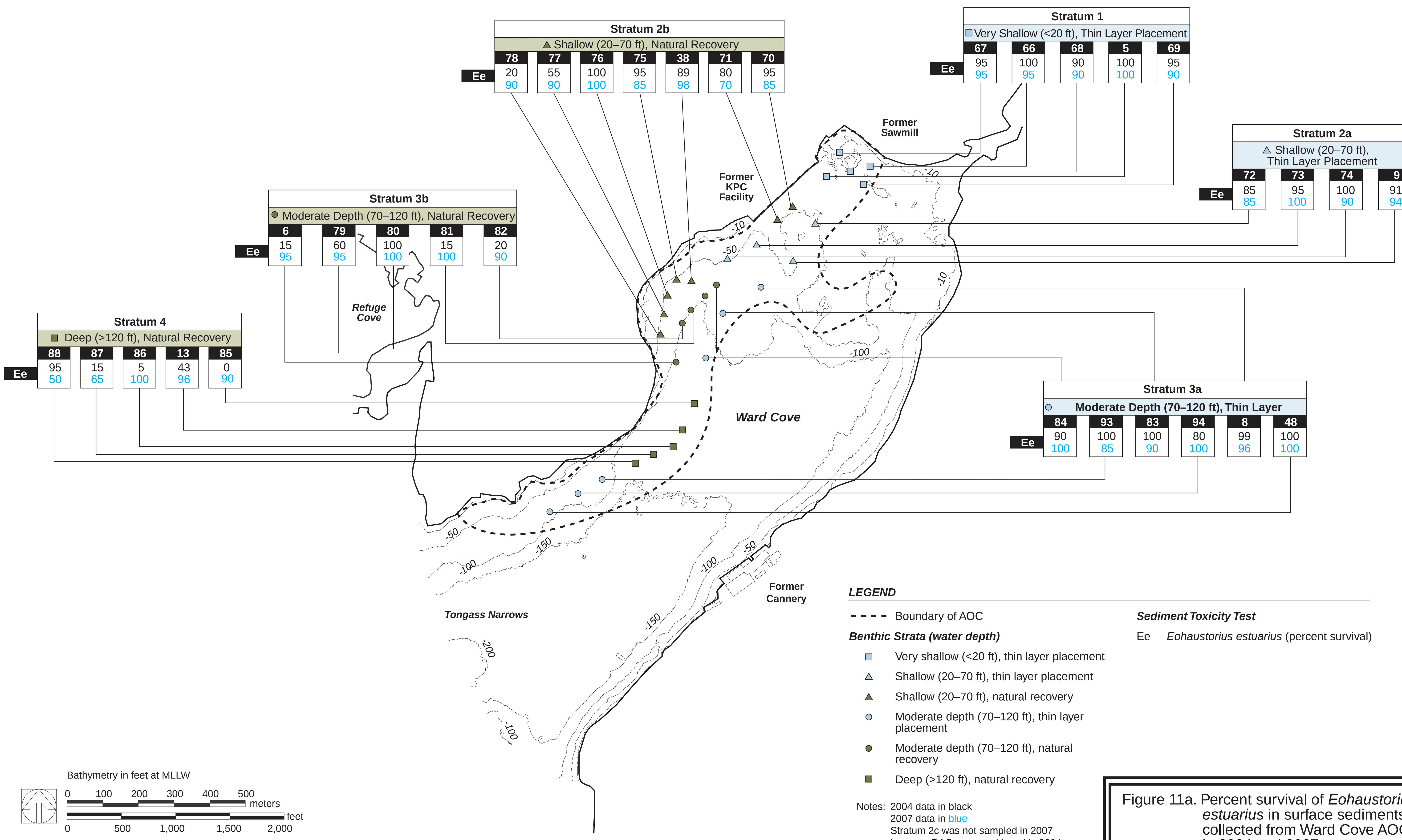


Figure 11a. Percent survival of *Eohaustorius estuarius* in surface sediments collected from Ward Cove AOC in 2004 and 2007

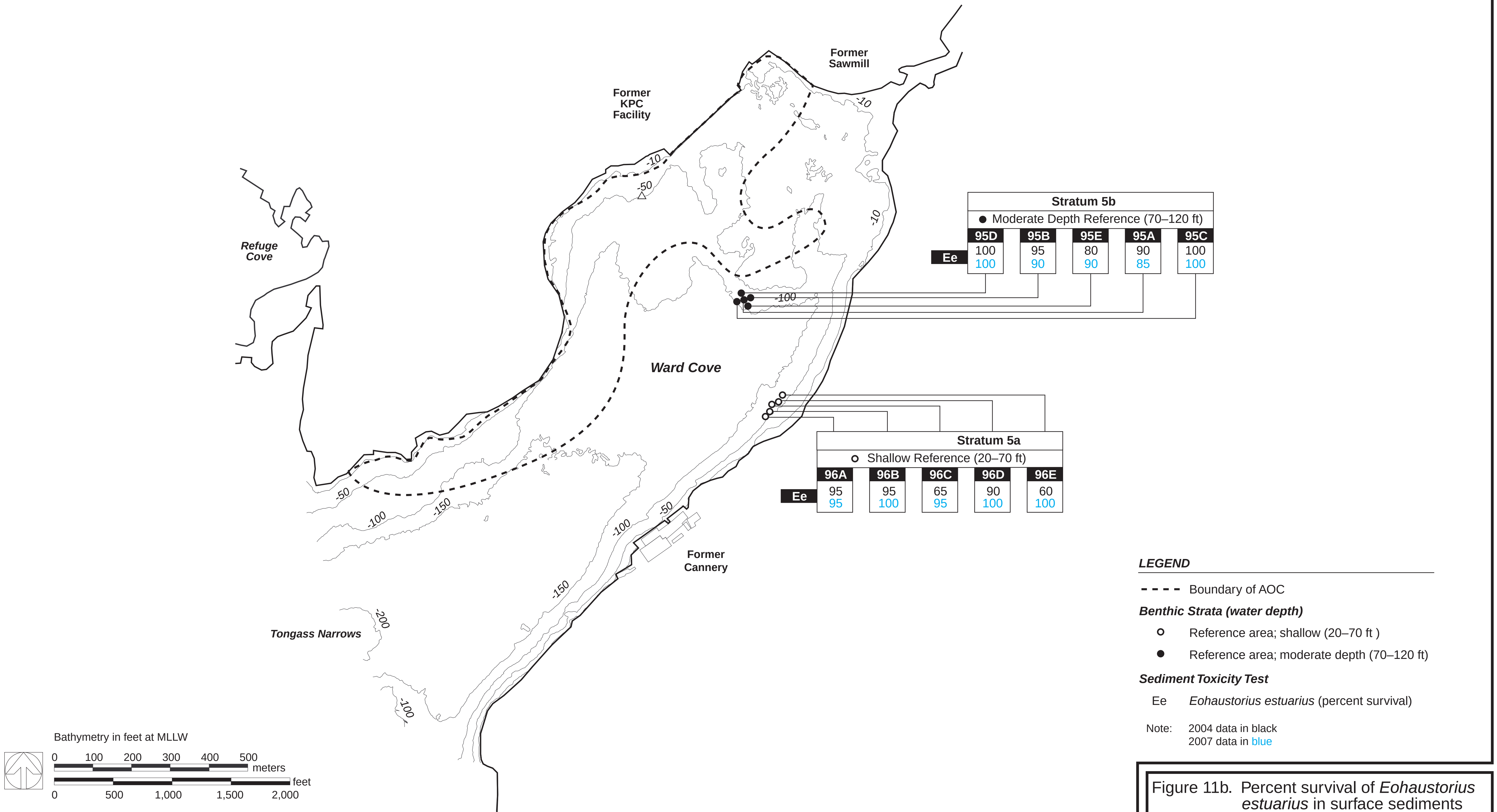


Figure 11b. Percent survival of *Eohaustorius estuarius* in surface sediments collected from Ward Cove reference areas in 2004 and 2007

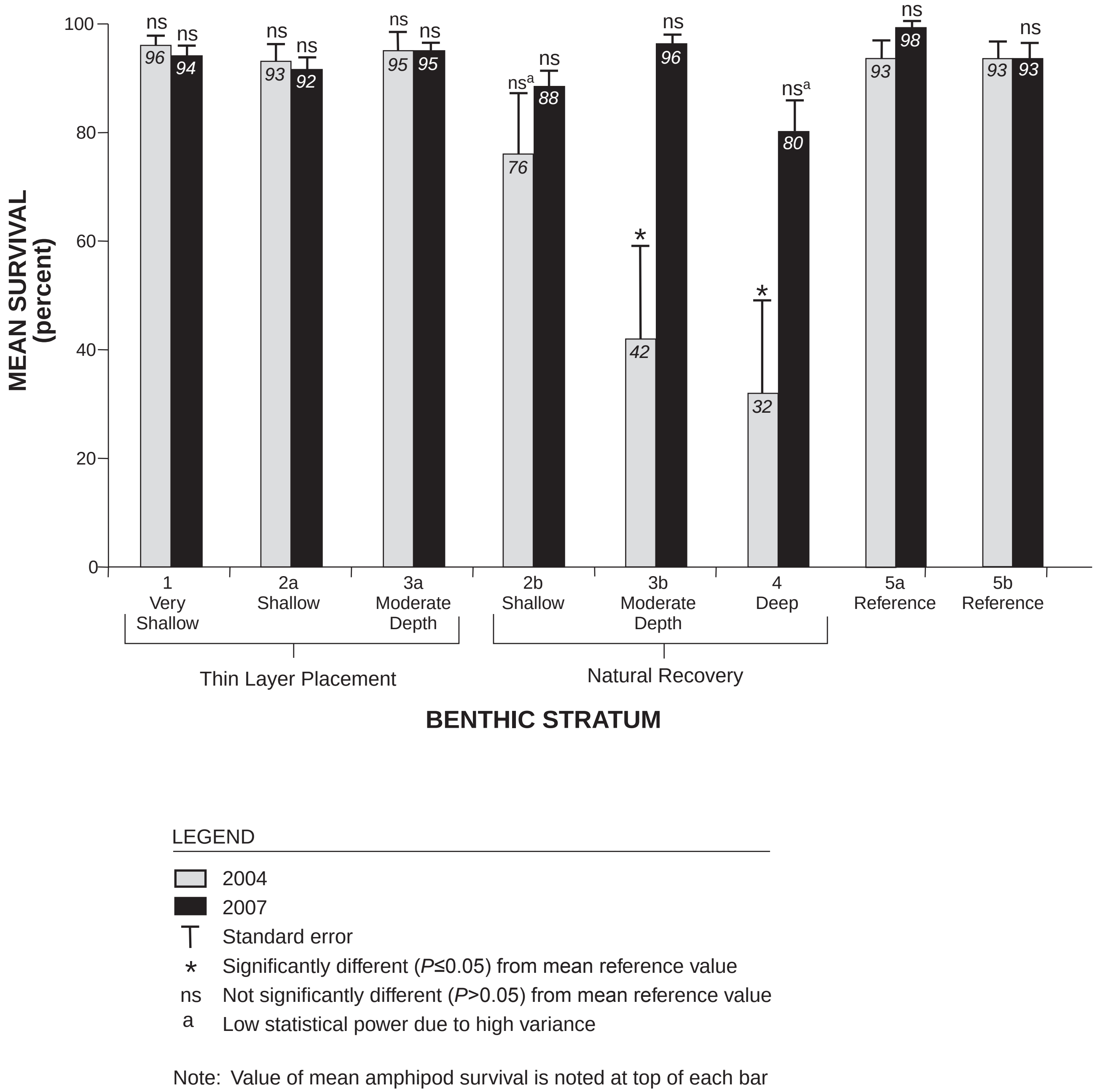
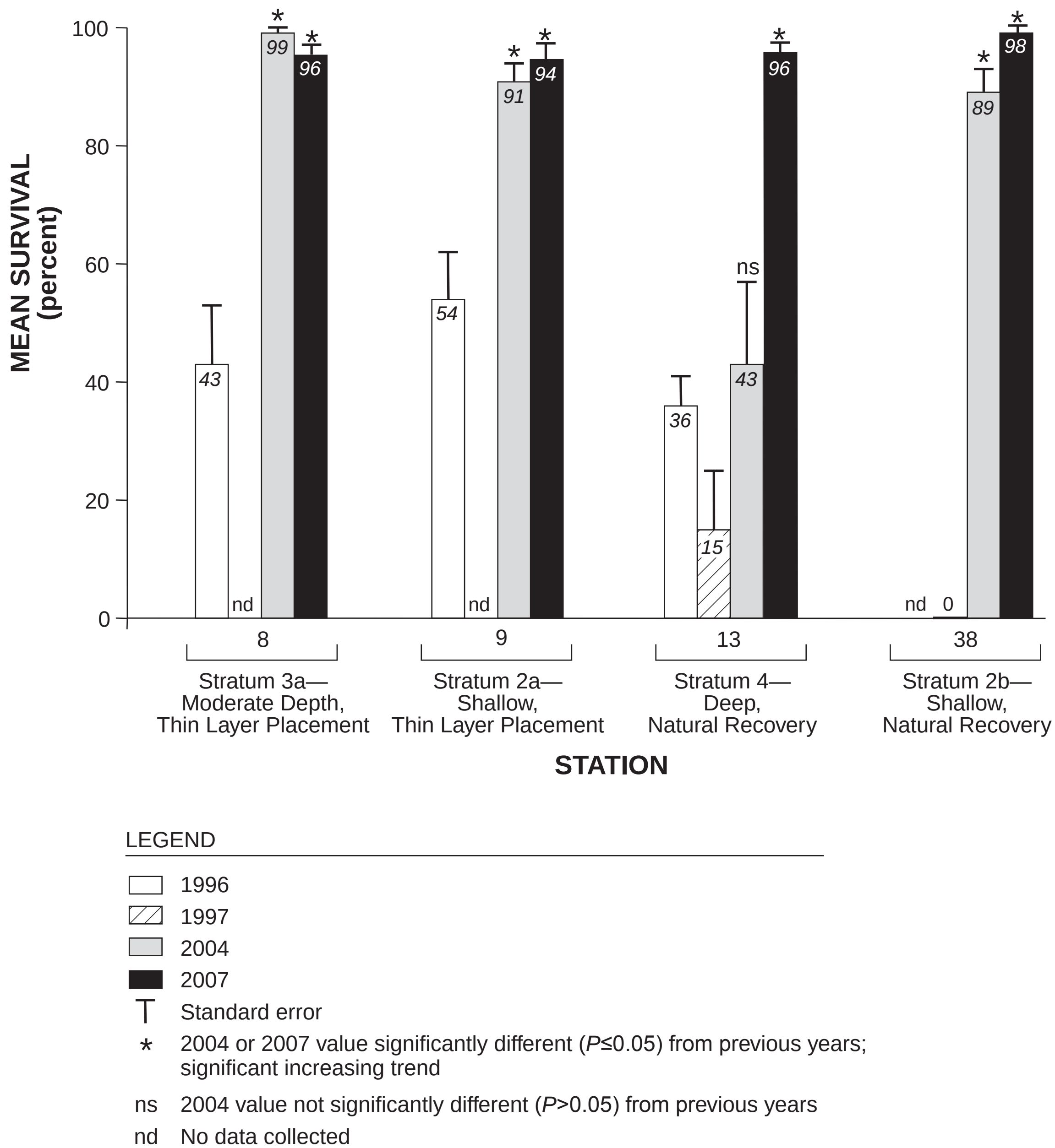
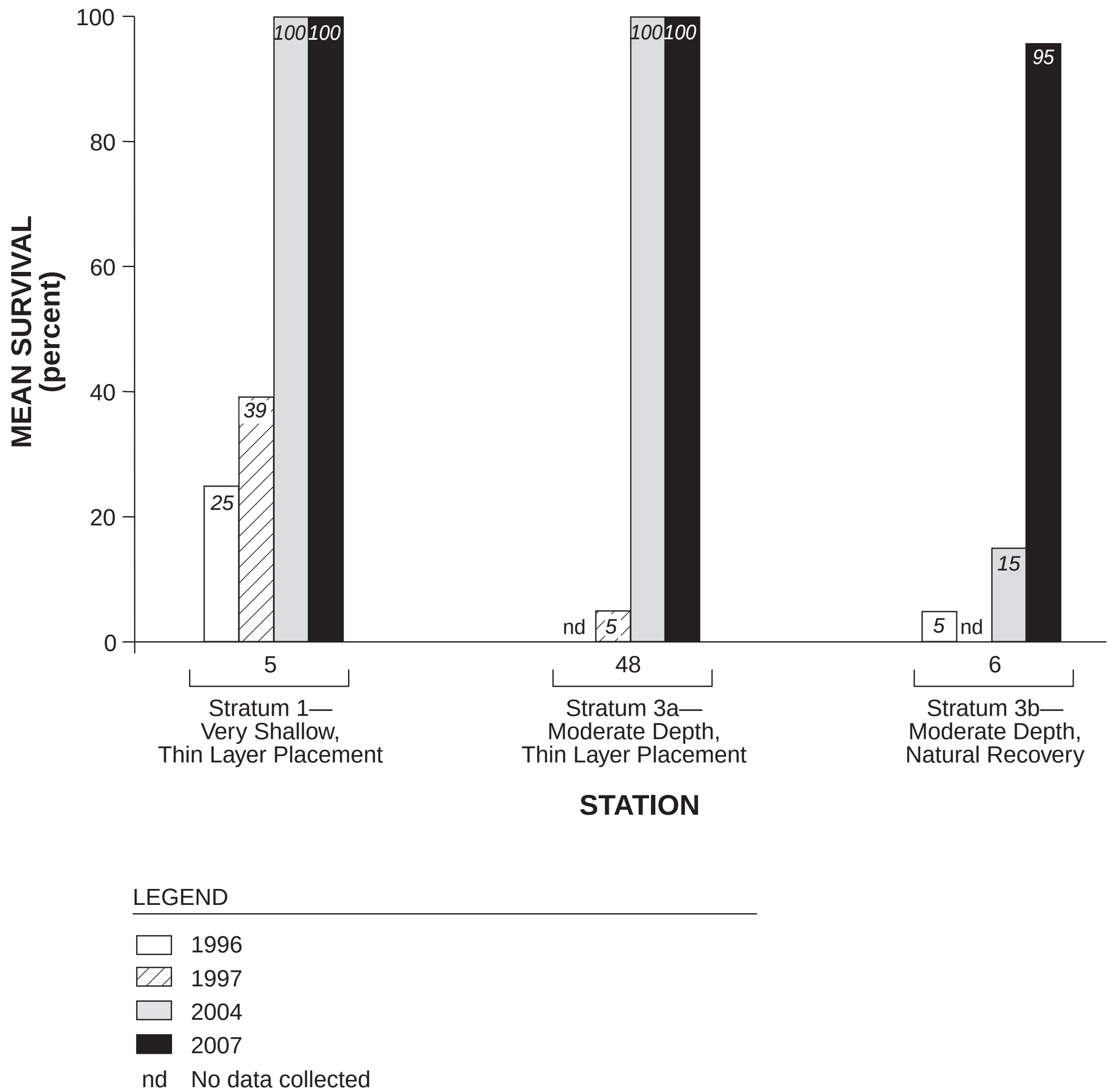


Figure 12. Statistical comparisons of mean amphipod survival between Ward Cove benthic strata between 2004 and 2007



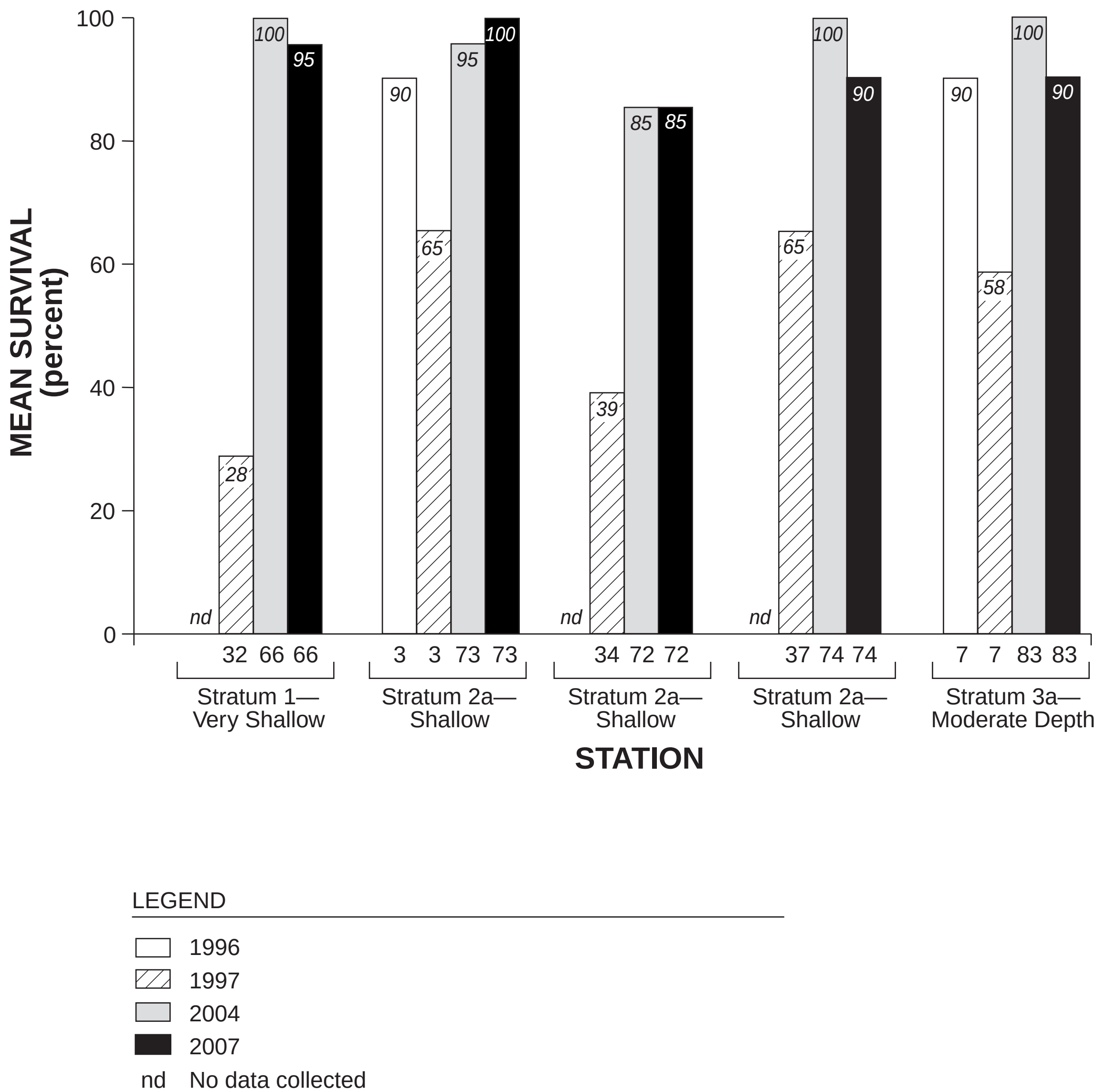
Note: Value of mean amphipod survival is noted at top of each bar

Figure 13. Statistical comparisons of mean amphipod survival between 1996, 1997, 2004, and 2007



Note: Amphipod toxicity tests in 1996 and 1997 were performed with five laboratory replicates, whereas tests in 2004 and 2007 were performed with one laboratory replicate.

Figure 14. Qualitative comparisons of mean amphipod survival between 1996, 1997, 2004, and 2007



Note: Amphipod toxicity tests in 1996 and 1997 were performed with five laboratory replicates, whereas tests in 2004 and 2007 were performed with one laboratory replicate.

Figure 15. Qualitative comparisons of mean amphipod survival between 1996, 1997, 2004, and 2007 stations estimated to be within 30 m of one another and located within thin layer placement strata

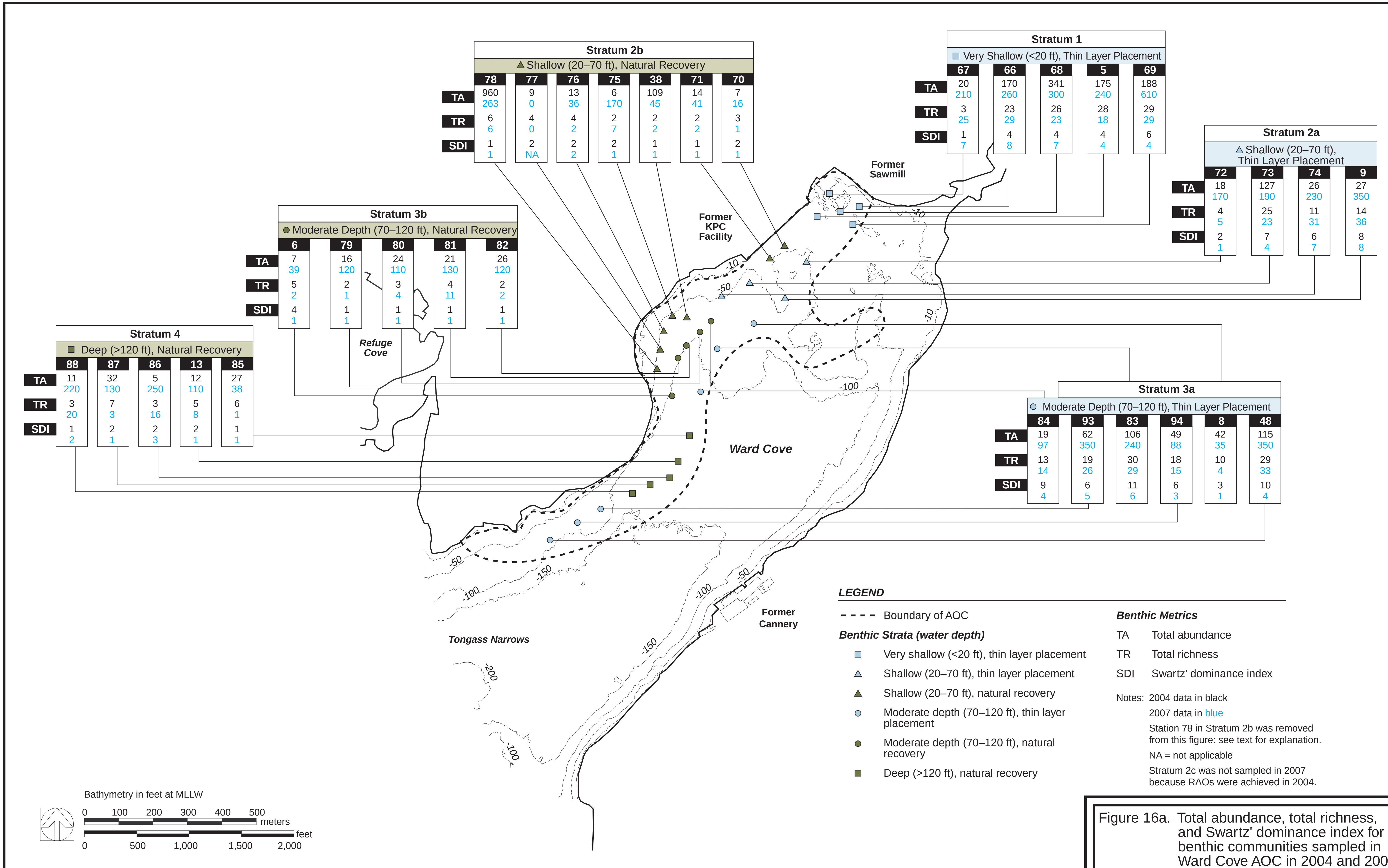
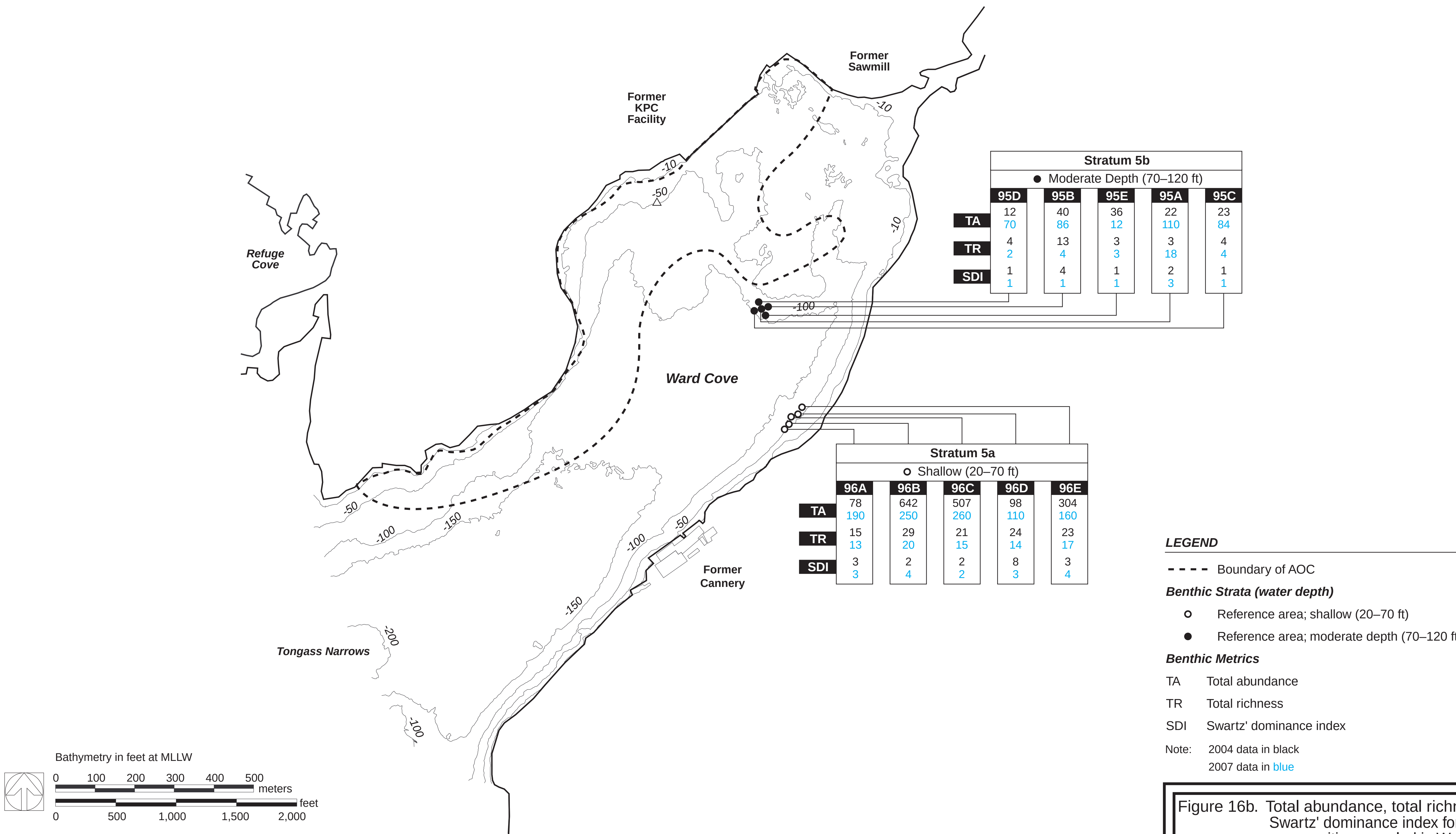


Figure 16a. Total abundance, total richness, and Swartz' dominance index for benthic communities sampled in Ward Cove AOC in 2004 and 2007



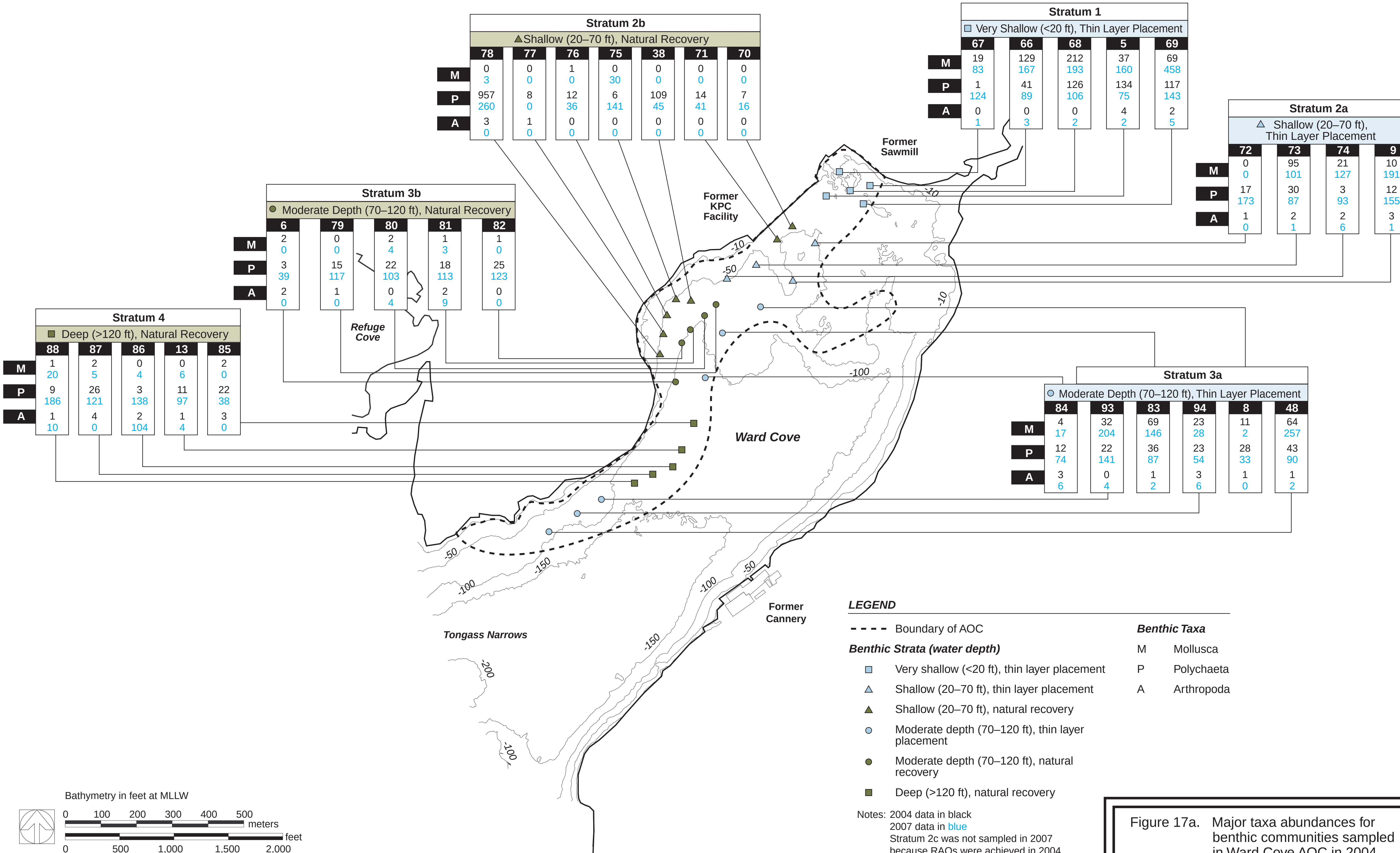
Stratum 5b — ● Moderate Depth (70–120 ft)

	95D	95B	95E	95A	95C
TA	12 70	40 86	36 12	22 110	23 84
TR	4 2	13 4	3 3	3 18	4 4
SDI	1 1	4 1	1 1	2 3	1 1

Stratum 5a — ○ Shallow (20–70 ft)

	96A	96B	96C	96D	96E
TA	78 190	642 250	507 260	98 110	304 160
TR	15 13	29 20	21 15	24 14	23 17
SDI	3 3	2 4	2 2	8 3	3 4

Figure 16b. Total abundance, total richness, and Swartz' dominance index for benthic communities sampled in Ward Cove reference areas in 2004 and 2007



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

	67	66	68	5	69
M (2004)	19	129	212	37	69
M (2007)	83	167	193	160	458
P (2004)	1	41	126	134	117
P (2007)	124	89	106	75	143
A (2004)	0	0	0	4	2
A (2007)	1	3	2	2	5

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

	72	73	74	9
M (2004)	0	95	21	10
M (2007)	0	101	127	191
P (2004)	17	30	3	12
P (2007)	173	87	93	155
A (2004)	1	2	2	3
A (2007)	0	1	6	1

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

	78	77	76	75	38	71	70
M (2004)	0	0	1	0	0	0	0
M (2007)	3	0	0	30	0	0	0
P (2004)	957	8	12	6	109	14	7
P (2007)	260	0	36	141	45	41	16
A (2004)	3	1	0	0	0	0	0
A (2007)	0	0	0	0	0	0	0

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

	84	93	83	94	8	48
M (2004)	4	32	69	23	11	64
M (2007)	17	204	146	28	2	257
P (2004)	12	22	36	23	28	43
P (2007)	74	141	87	54	33	90
A (2004)	3	0	1	3	1	1
A (2007)	6	4	2	6	0	2

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

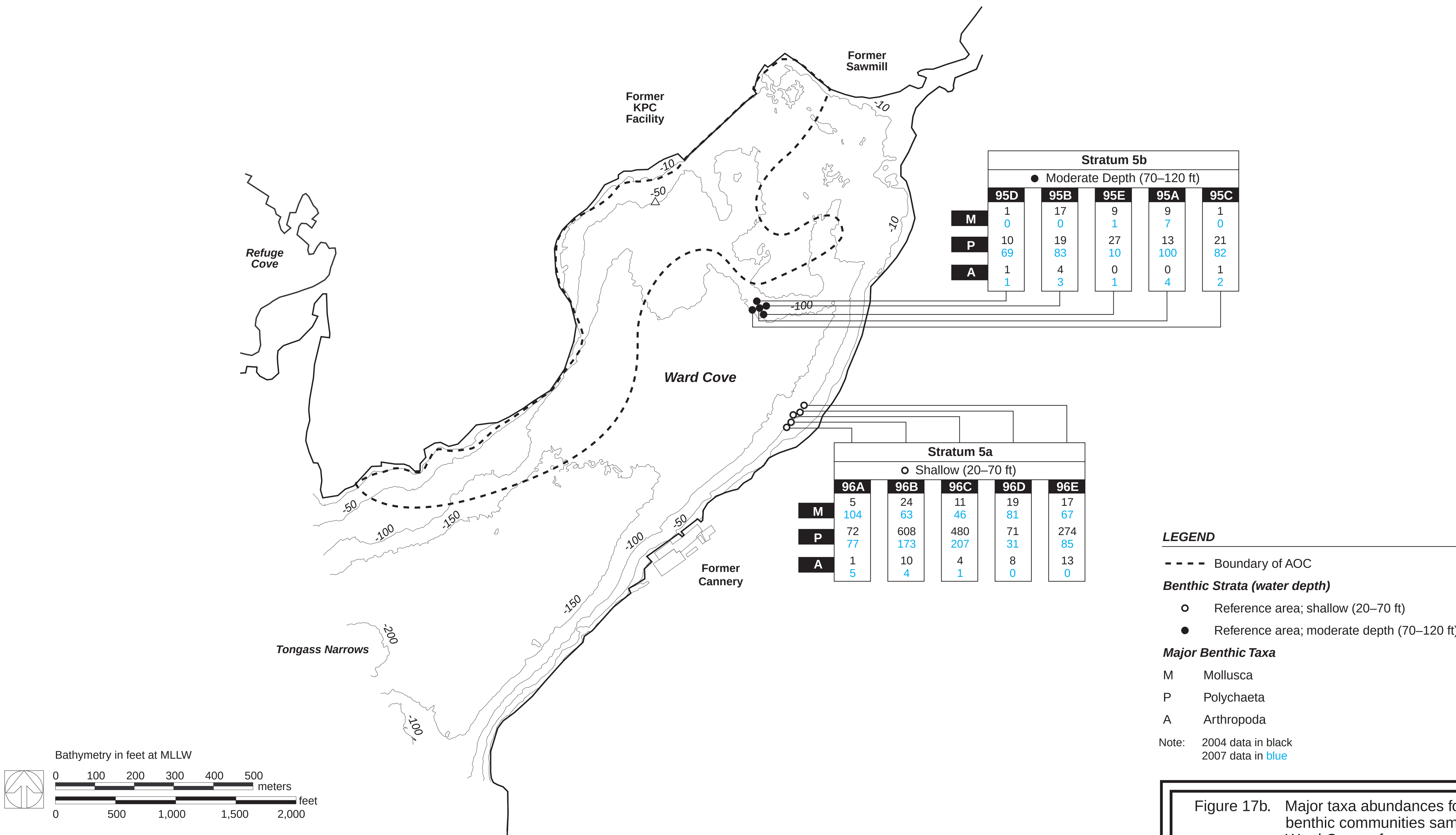
	6	79	80	81	82
M (2004)	2	0	2	1	1
M (2007)	0	0	4	3	0
P (2004)	3	15	22	18	25
P (2007)	39	117	103	113	123
A (2004)	2	1	0	2	0
A (2007)	0	0	4	9	0

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

	88	87	86	13	85
M (2004)	1	2	0	0	2
M (2007)	20	5	4	6	0
P (2004)	9	26	3	11	22
P (2007)	186	121	138	97	38
A (2004)	1	4	2	1	3
A (2007)	10	0	104	4	0

Notes: 2004 data in black
2007 data in blue
Stratum 2c was not sampled in 2007 because RAOs were achieved in 2004.

Figure 17a. Major taxa abundances for benthic communities sampled in Ward Cove AOC in 2004 and 2007



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

	95D	95B	95E	95A	95C
M	1 / 0	17 / 0	9 / 1	9 / 7	1 / 0
P	10 / 69	19 / 83	27 / 10	13 / 100	21 / 82
A	1 / 1	4 / 3	0 / 1	0 / 4	1 / 2

Stratum 5a — ○ Shallow (20–70 ft)

	96A	96B	96C	96D	96E
M	5 / 104	24 / 63	11 / 46	19 / 81	17 / 67
P	72 / 77	608 / 173	480 / 207	71 / 31	274 / 85
A	1 / 5	10 / 4	4 / 1	8 / 0	13 / 0

(first value: 2004 data, in black; second value: 2007 data, in blue)

Figure 17b. Major taxa abundances for benthic communities sampled in Ward Cove reference areas in 2004 and 2007

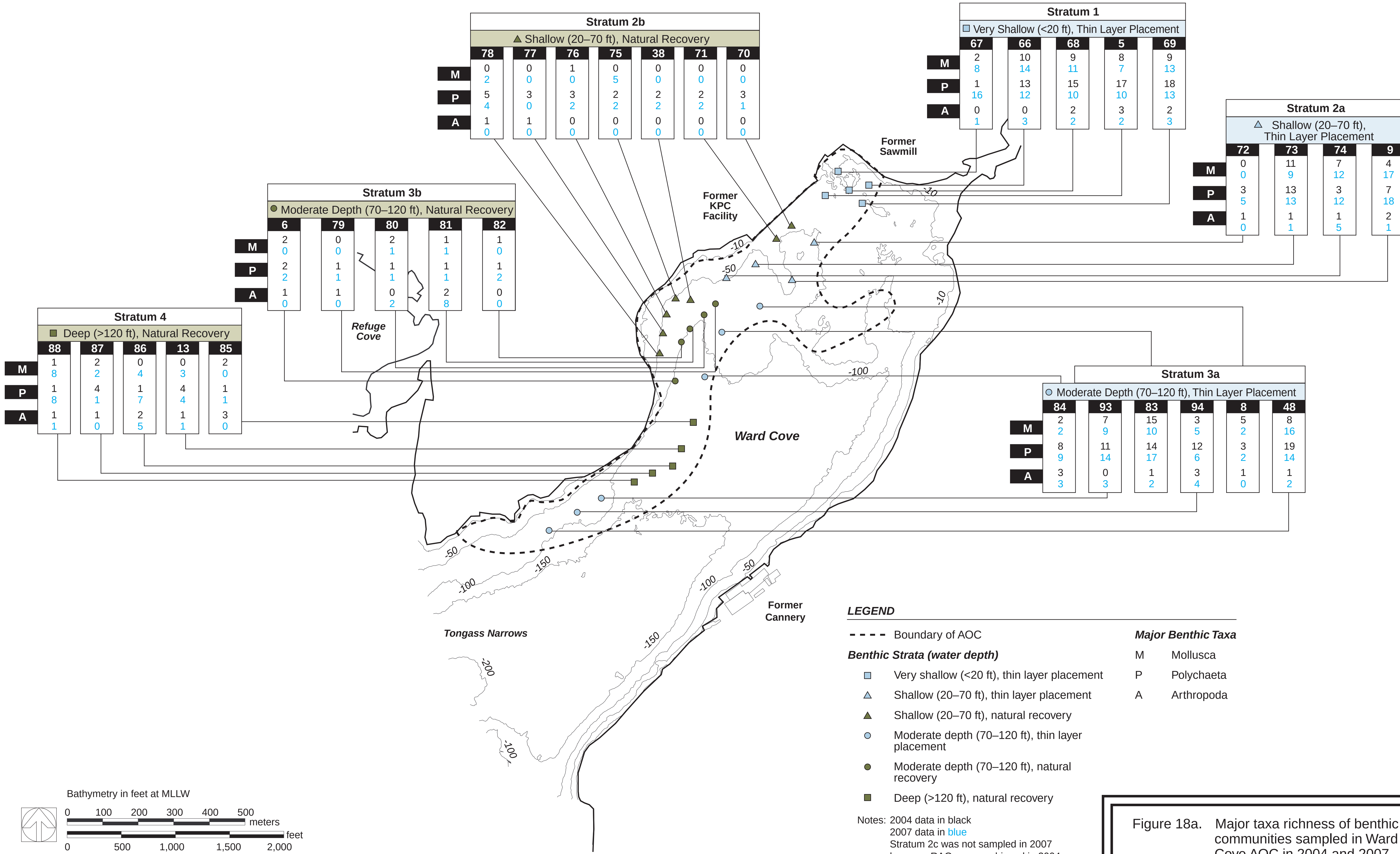


Figure 18a. Major taxa richness of benthic communities sampled in Ward Cove AOC in 2004 and 2007

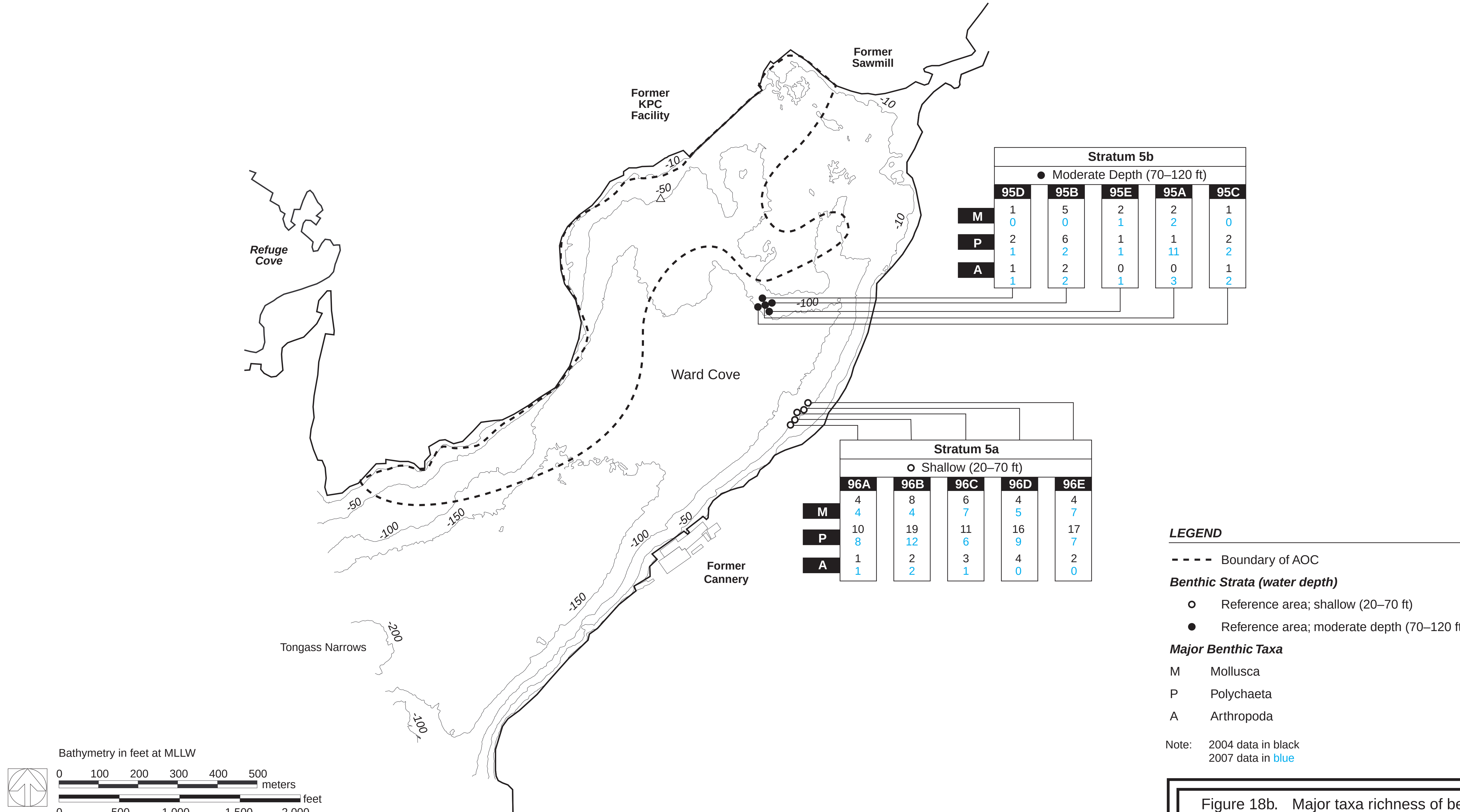


Figure 18b. Major taxa richness of benthic communities sampled in Ward Cove reference areas in 2004 and 2007

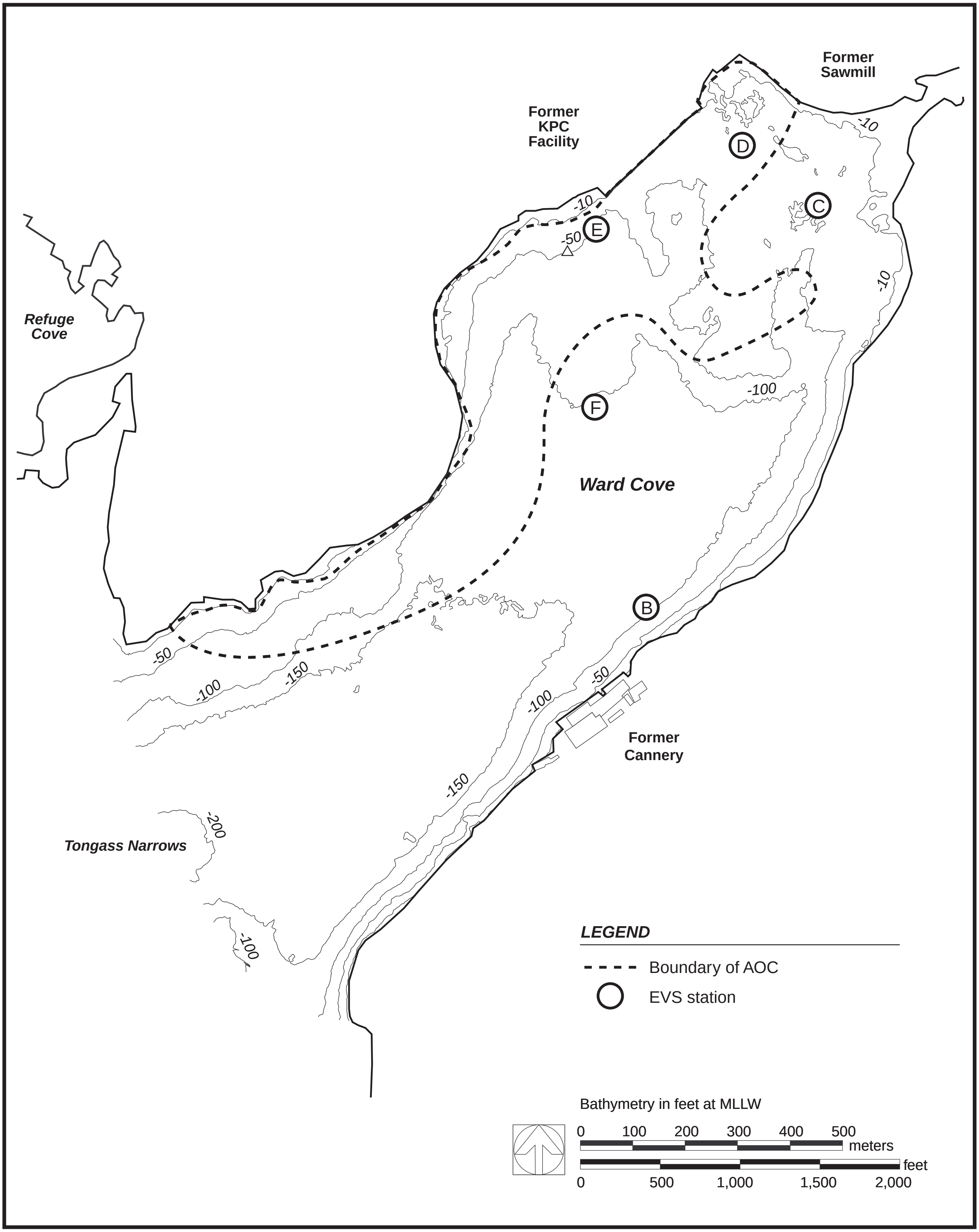
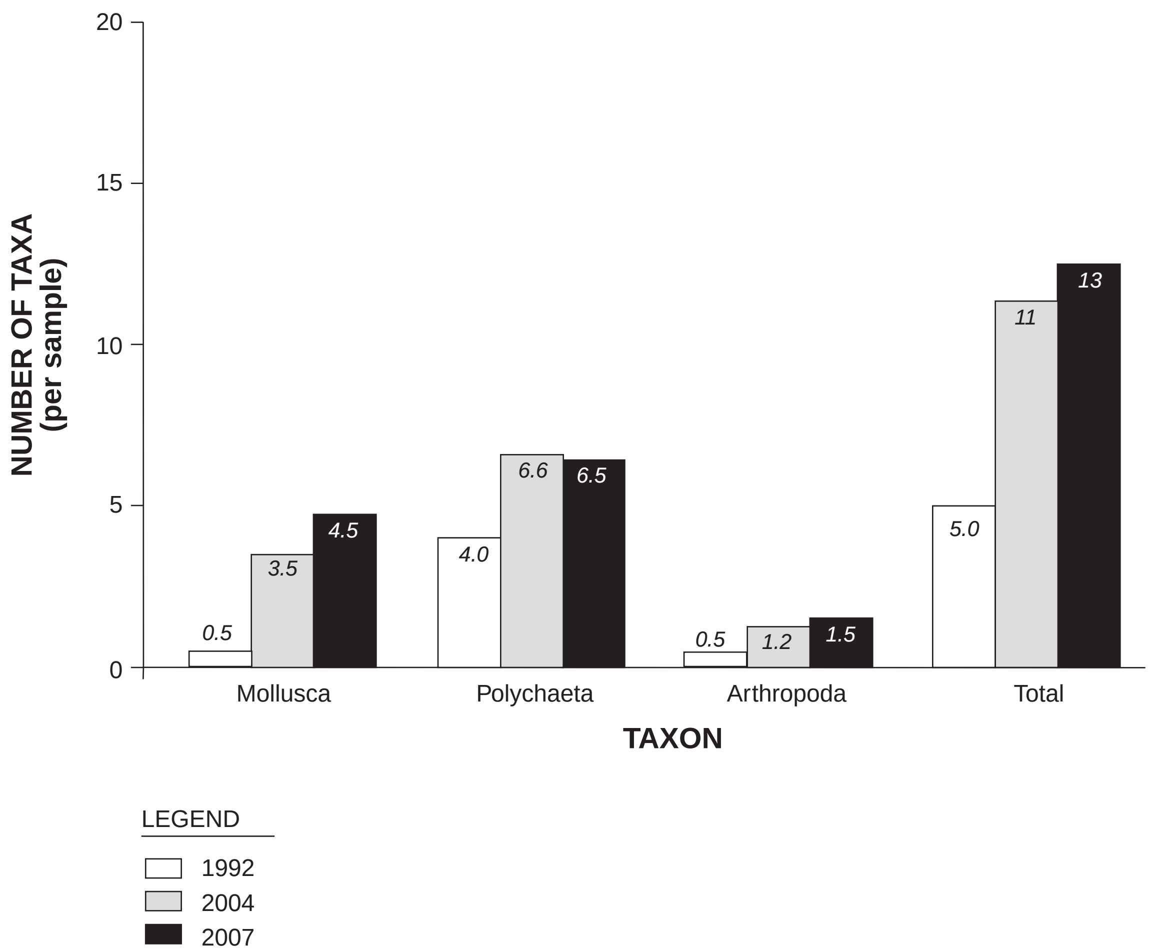


Figure 19. Approximate locations of stations sampled in Ward Cove for benthic macroinvertebrate communities in 1992 by EVS (1992)



Note: Stratum 2C removed from 2004 value.
The numbers presented above are mean values.

Figure 20. Comparison of taxa richness throughout Ward Cove in 1992 (EVS 1992), 2004, and 2007

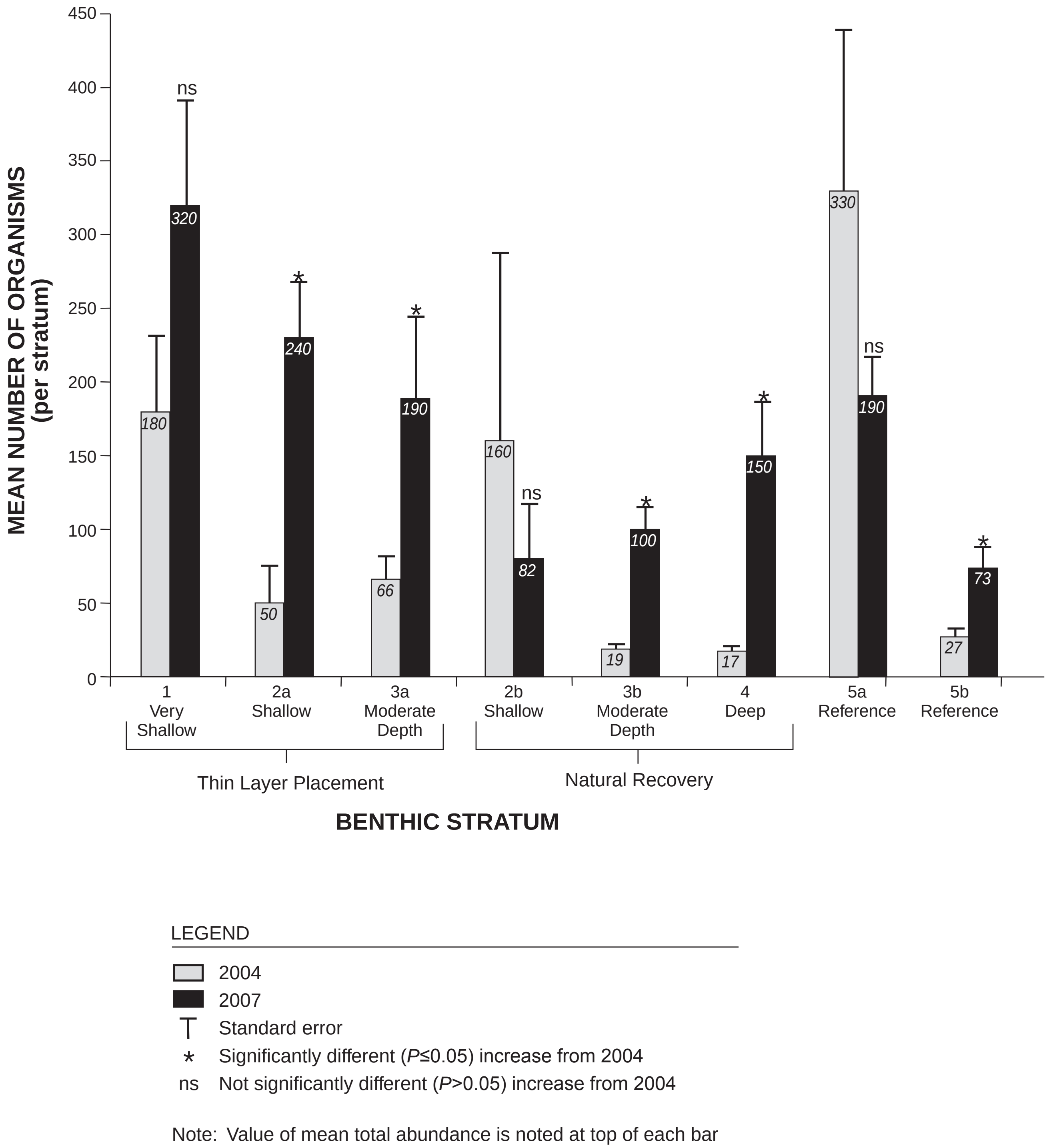


Figure 21. Statistical comparisons of mean total abundance between Ward Cove benthic strata between 2004 and 2007

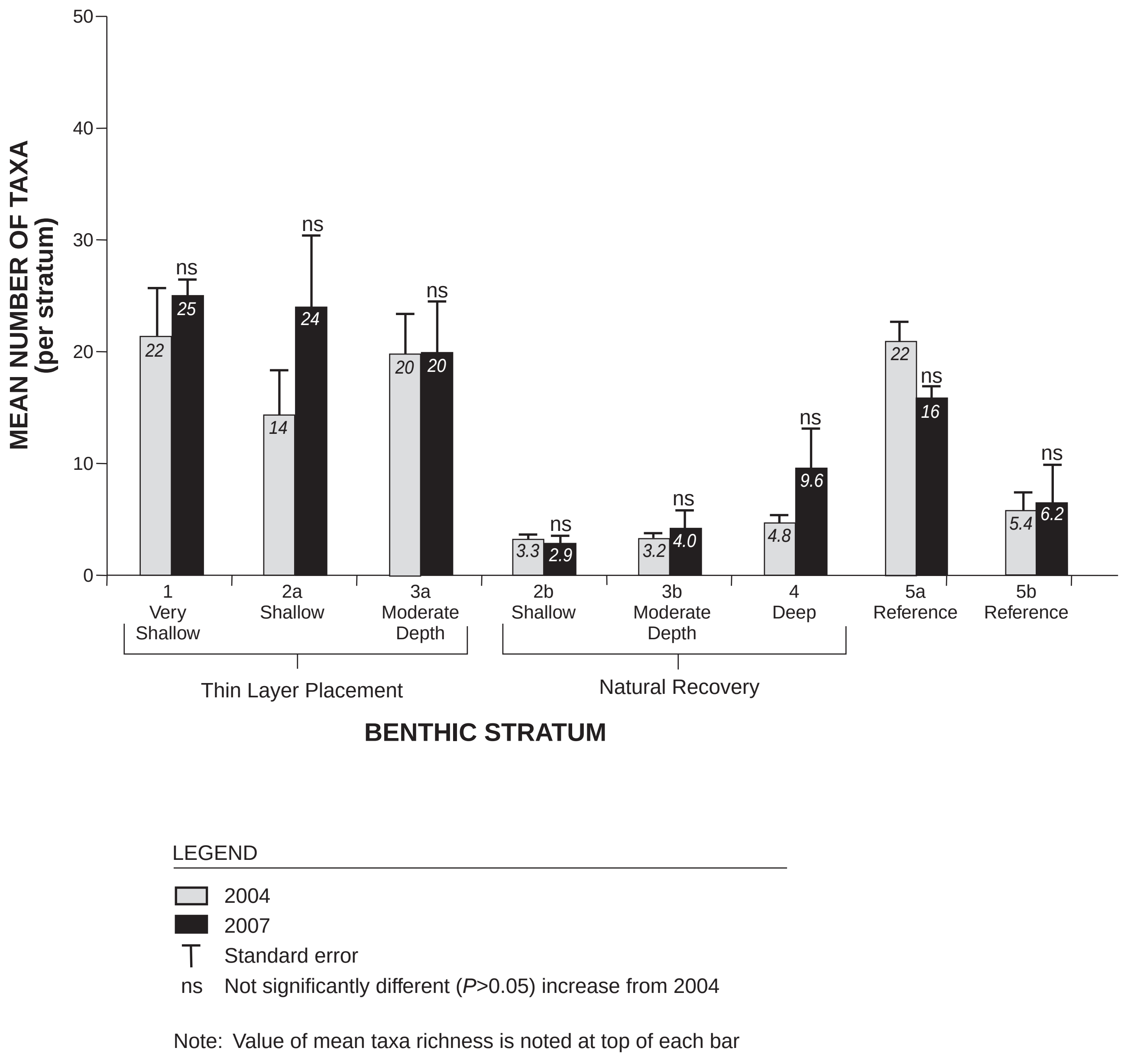


Figure 22. Statistical comparisons of mean taxa richness between Ward Cove benthic strata between 2004 and 2007

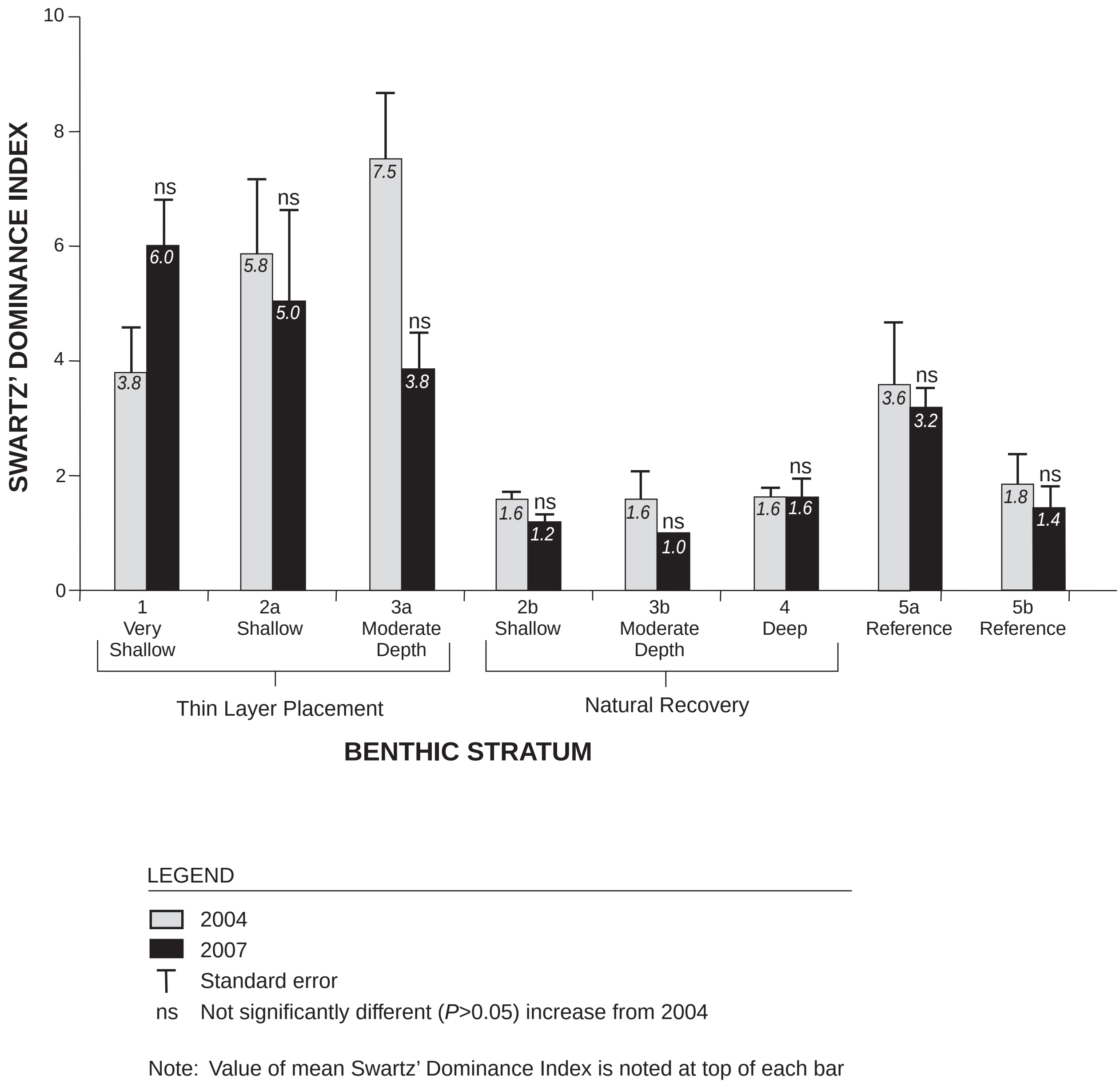


Figure 23. Statistical comparisons of mean Swartz' dominance index between Ward Cove benthic strata between 2004 and 2007

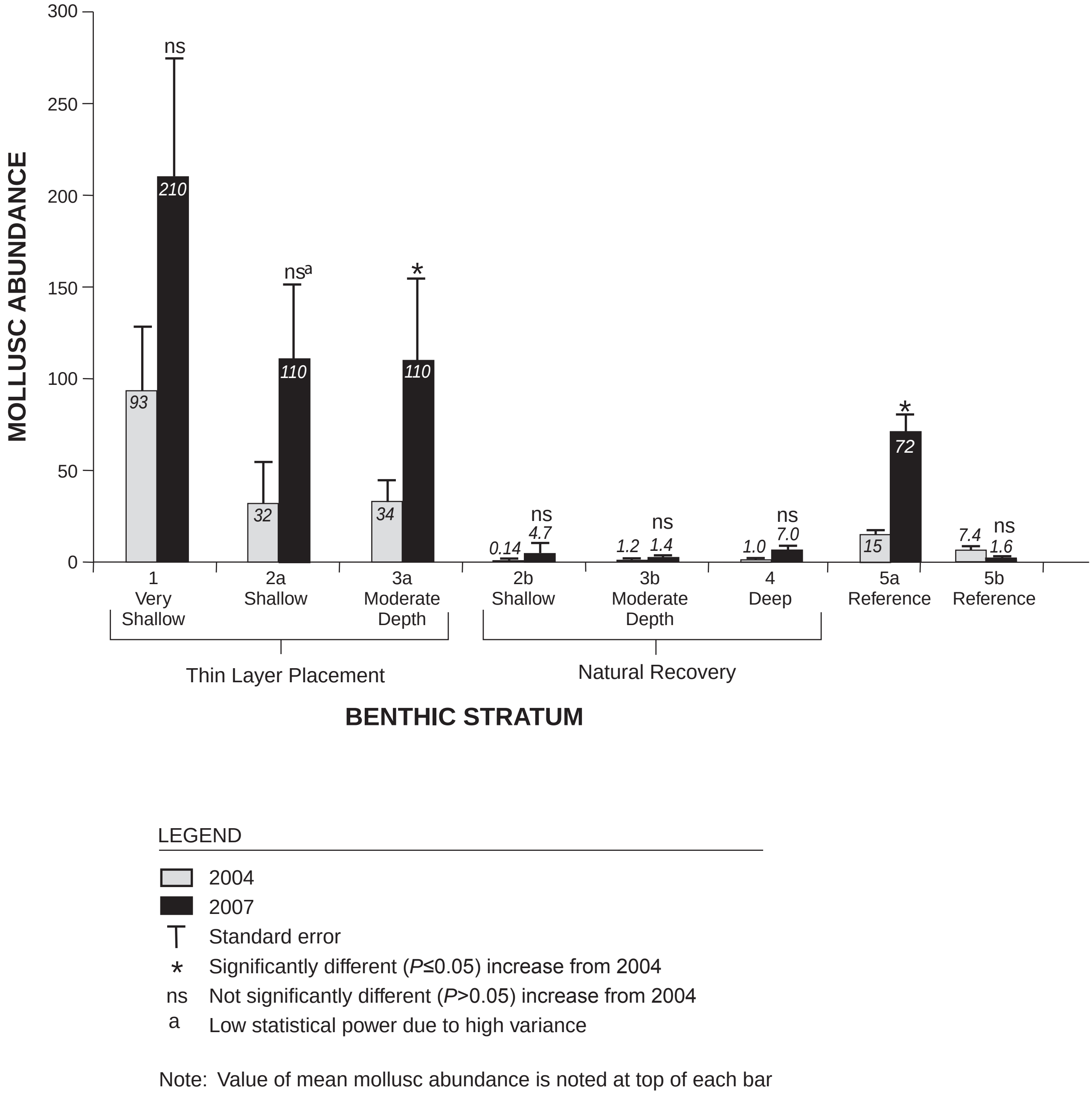


Figure 24. Statistical comparisons of mean mollusc abundance between Ward Cove benthic strata between 2004 and 2007

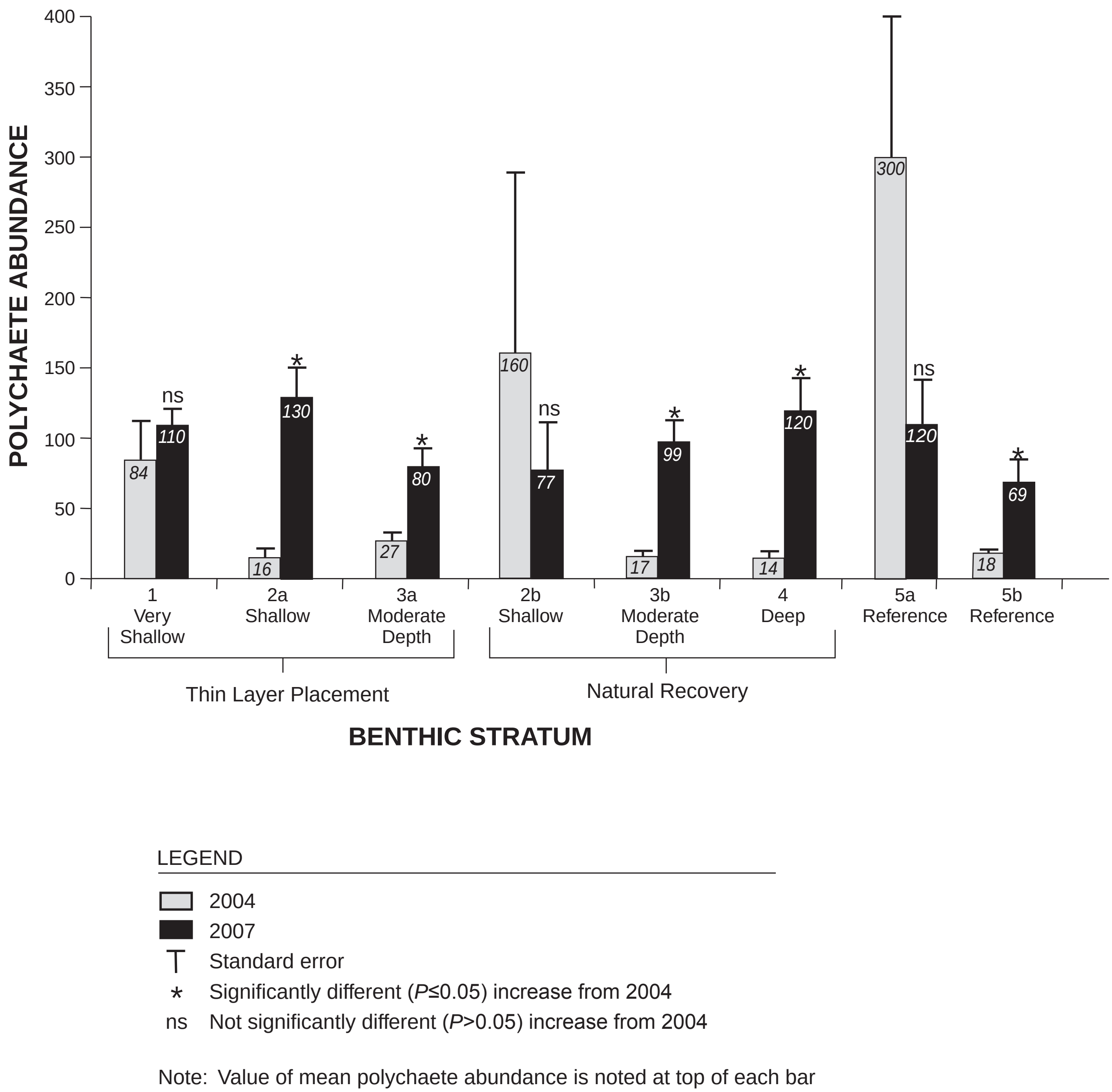


Figure 25. Statistical comparisons of mean polychaete abundance between Ward Cove benthic strata between 2004 and 2007

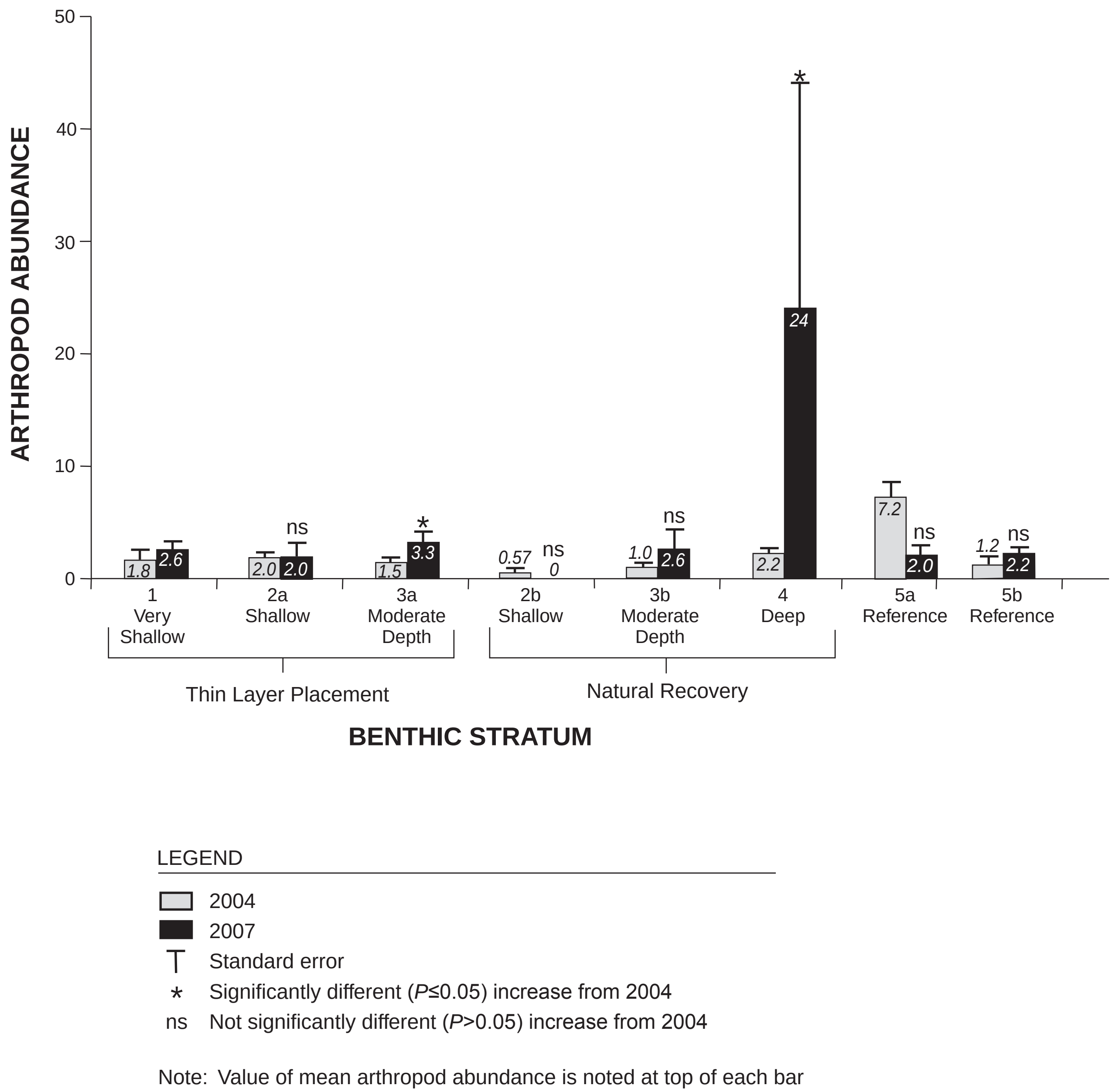
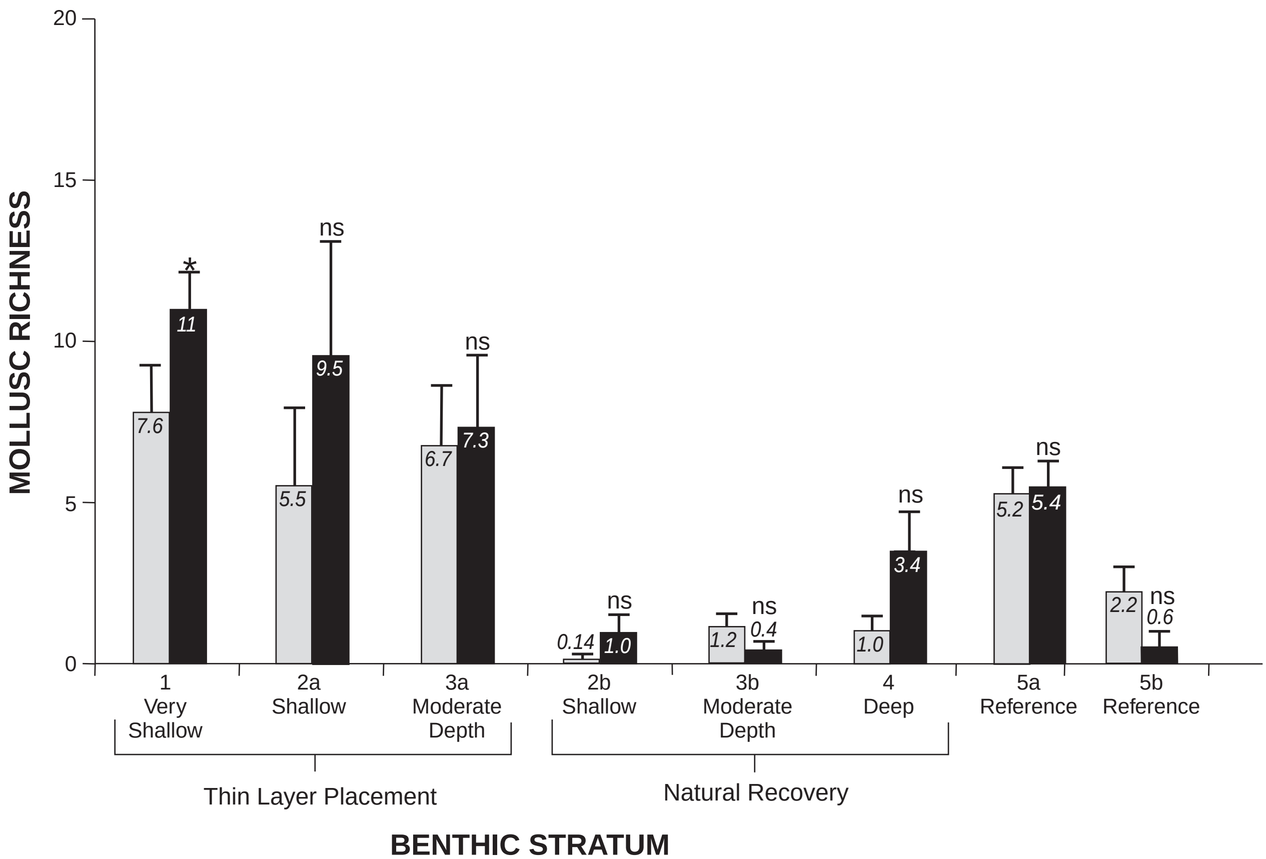


Figure 26. Statistical comparisons of mean arthropod abundance between Ward Cove benthic strata between 2004 and 2007



LEGEND

- 2004
- 2007
- Standard error
- * Significantly different ($P \leq 0.05$) increase from 2004
- ns Not significantly different ($P > 0.05$) increase from 2004

Note: Value of mean mollusc richness is noted at top of each bar

Figure 27. Statistical comparisons of mean mollusc richness between Ward Cove benthic strata between 2004 and 2007

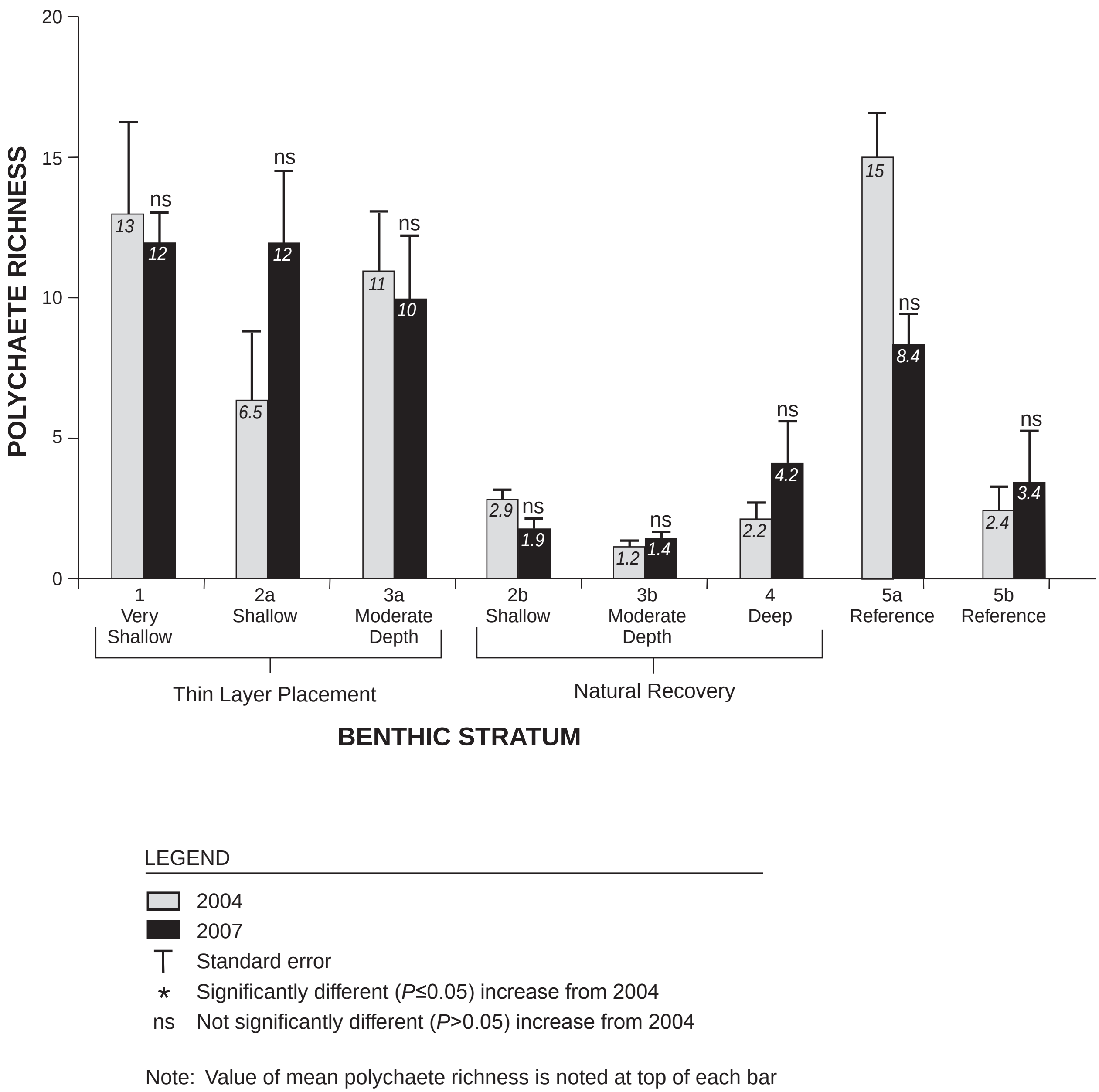


Figure 28. Statistical comparisons of mean polychaete richness between Ward Cove benthic strata between 2004 and 2007

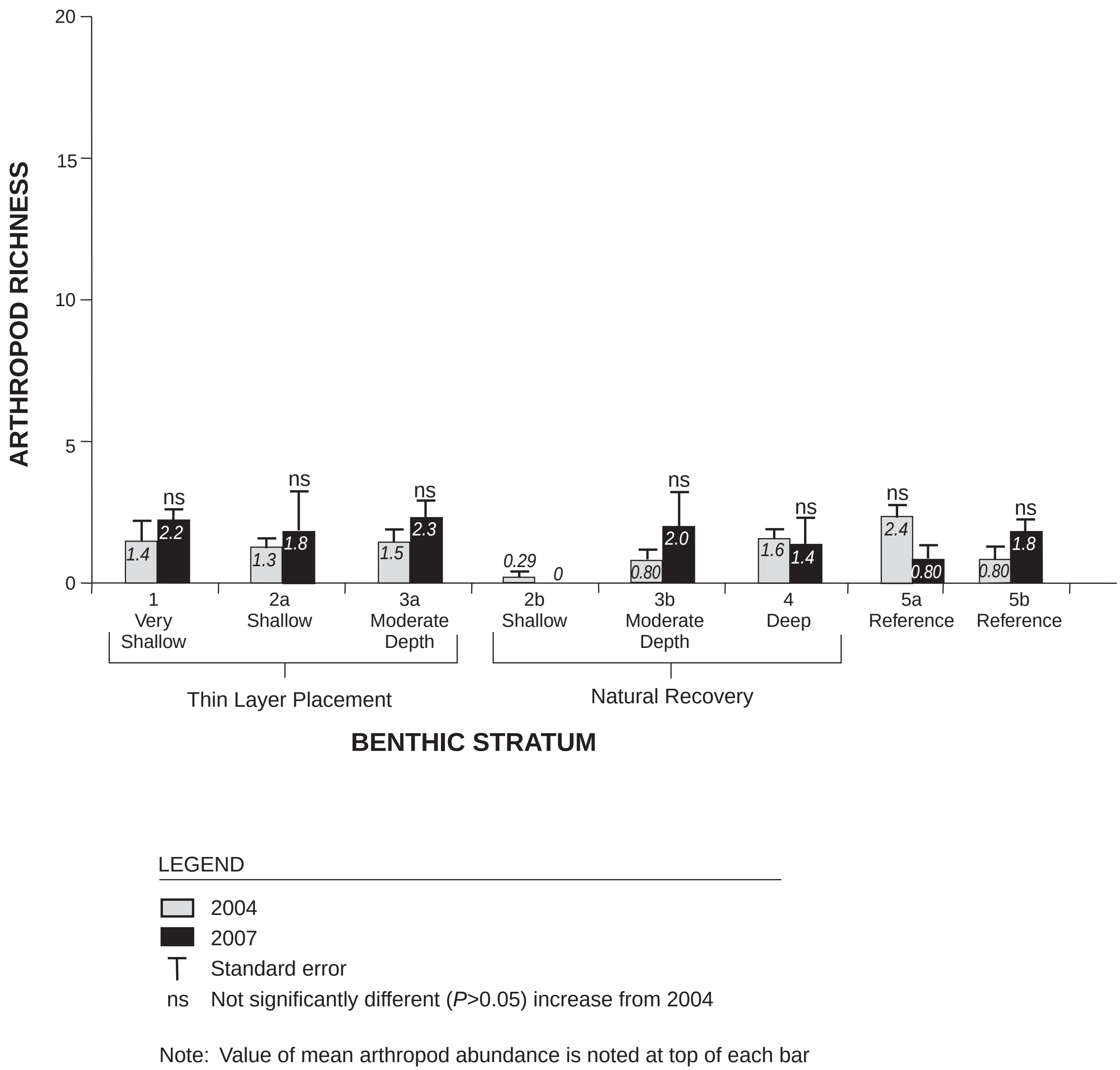


Figure 29. Statistical comparisons of mean arthropod richness between Ward Cove benthic strata between 2004 and 2007

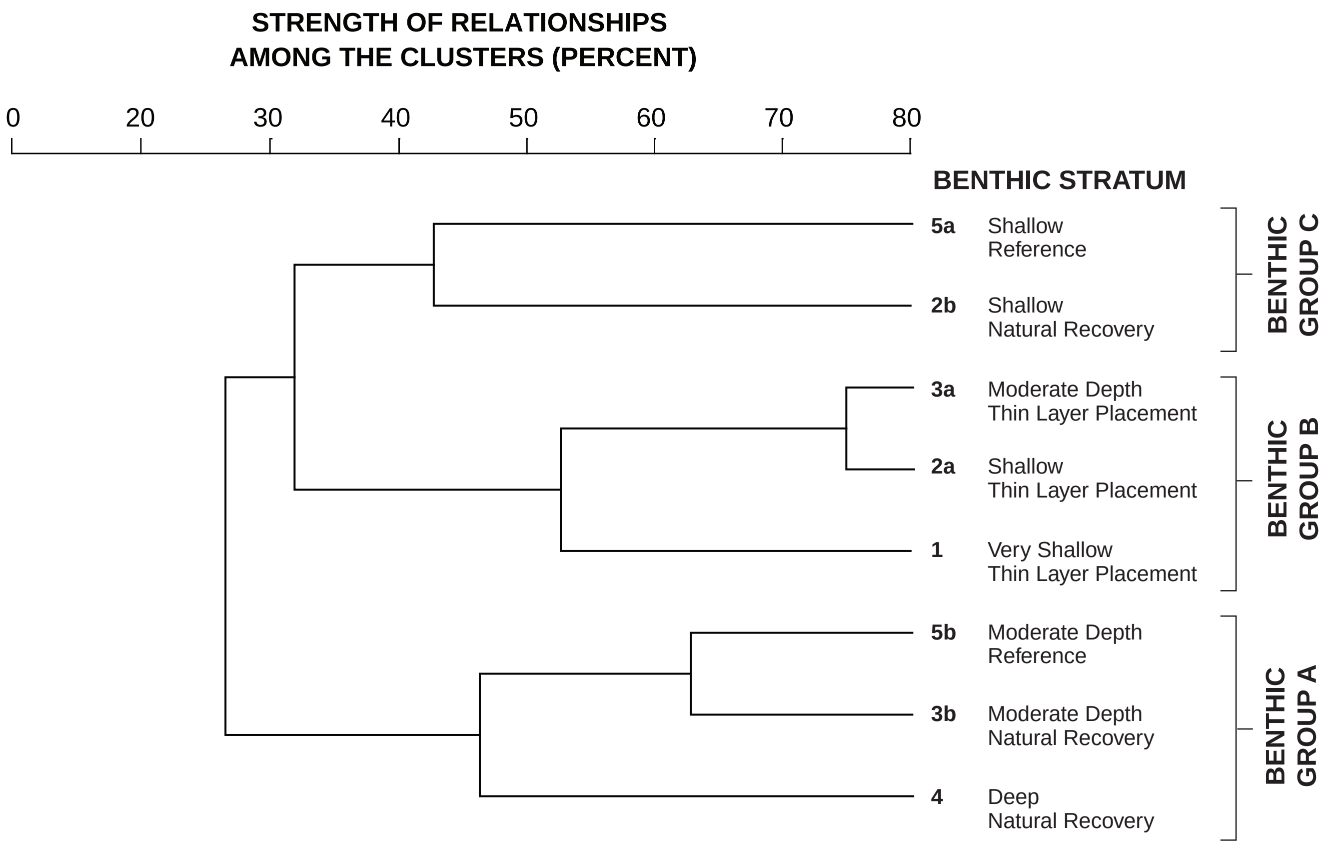
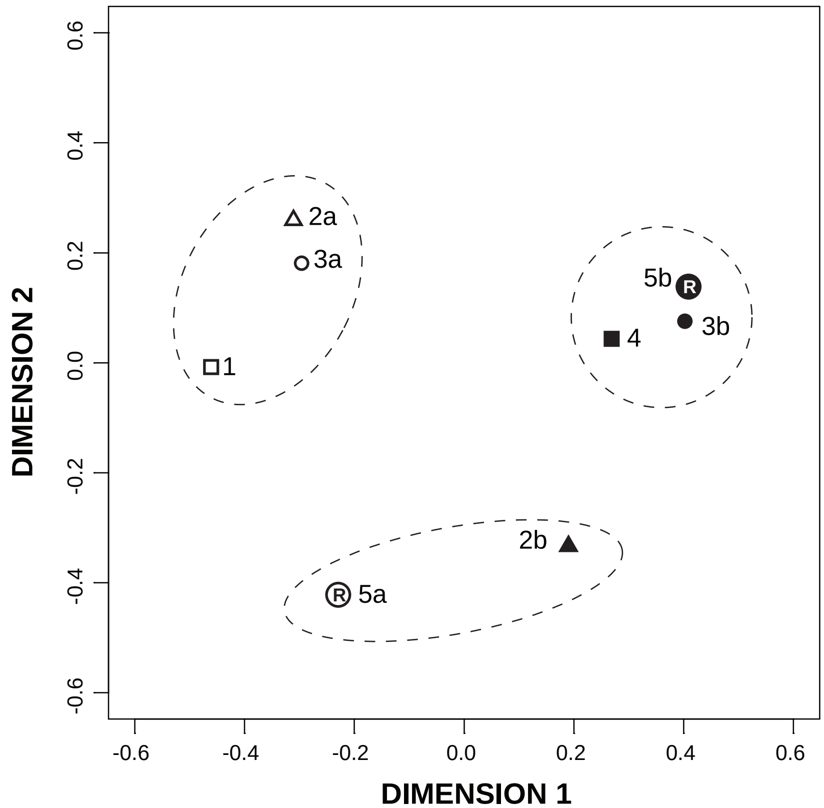


Figure 30. Results of classification analysis of benthic macroinvertebrate communities in various benthic strata of Ward Cove in July 2007



LEGEND

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
- Ⓡ Reference (20–70 ft), shallow
- 🅡 Reference (70–120 ft), moderate depth

Figure 31. Results of multidimensional scaling analysis of benthic macroinvertebrate communities in various benthic strata of Ward Cove in July 2007

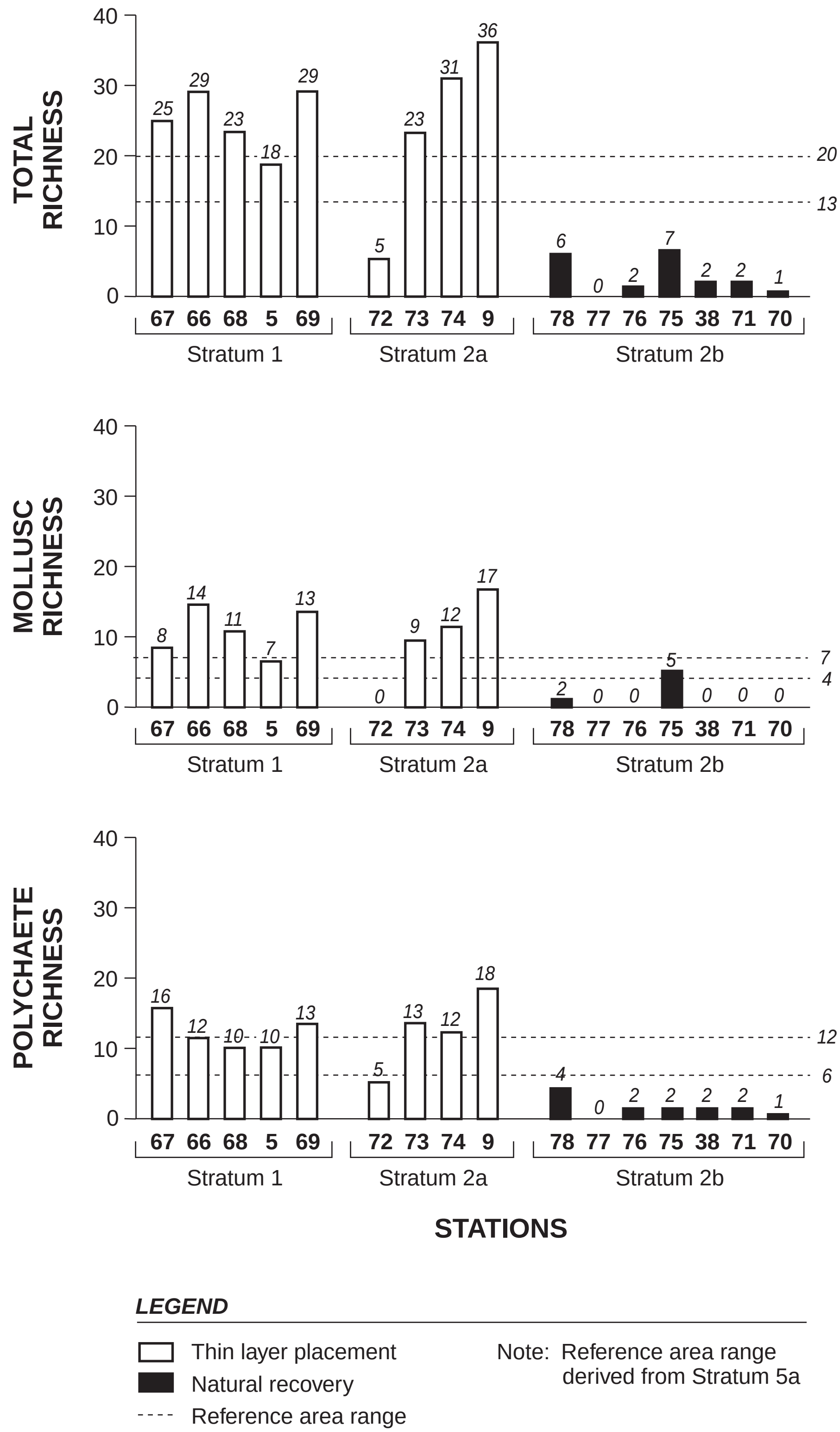


Figure 32. Overview of taxa richness of benthic macroinvertebrate communities in very shallow and shallow depth strata in Ward Cove AOC in July 2007

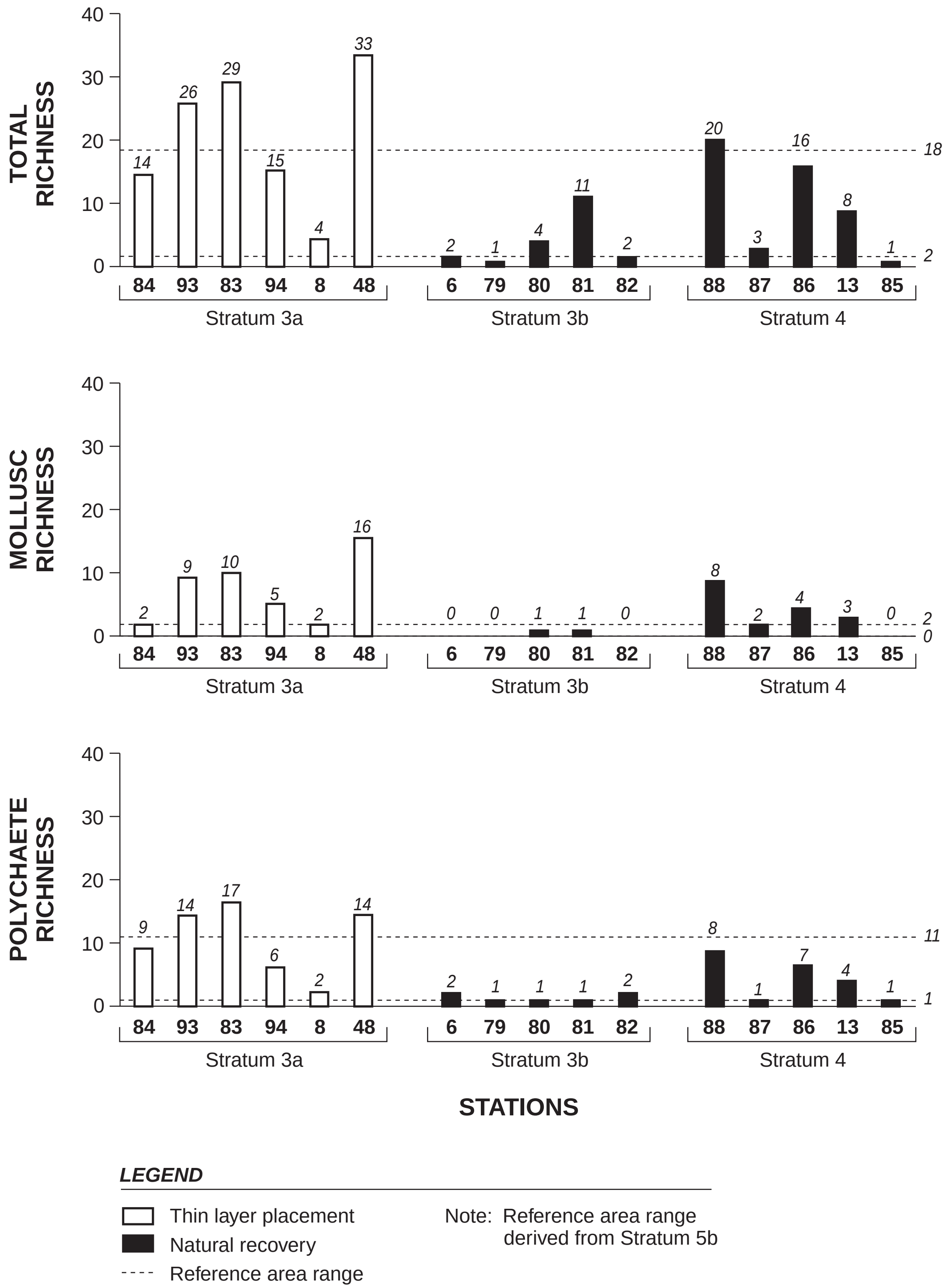


Figure 33. Overview of taxa richness of benthic macroinvertebrate communities in moderate depth and deep strata in Ward Cove AOC in July 2007

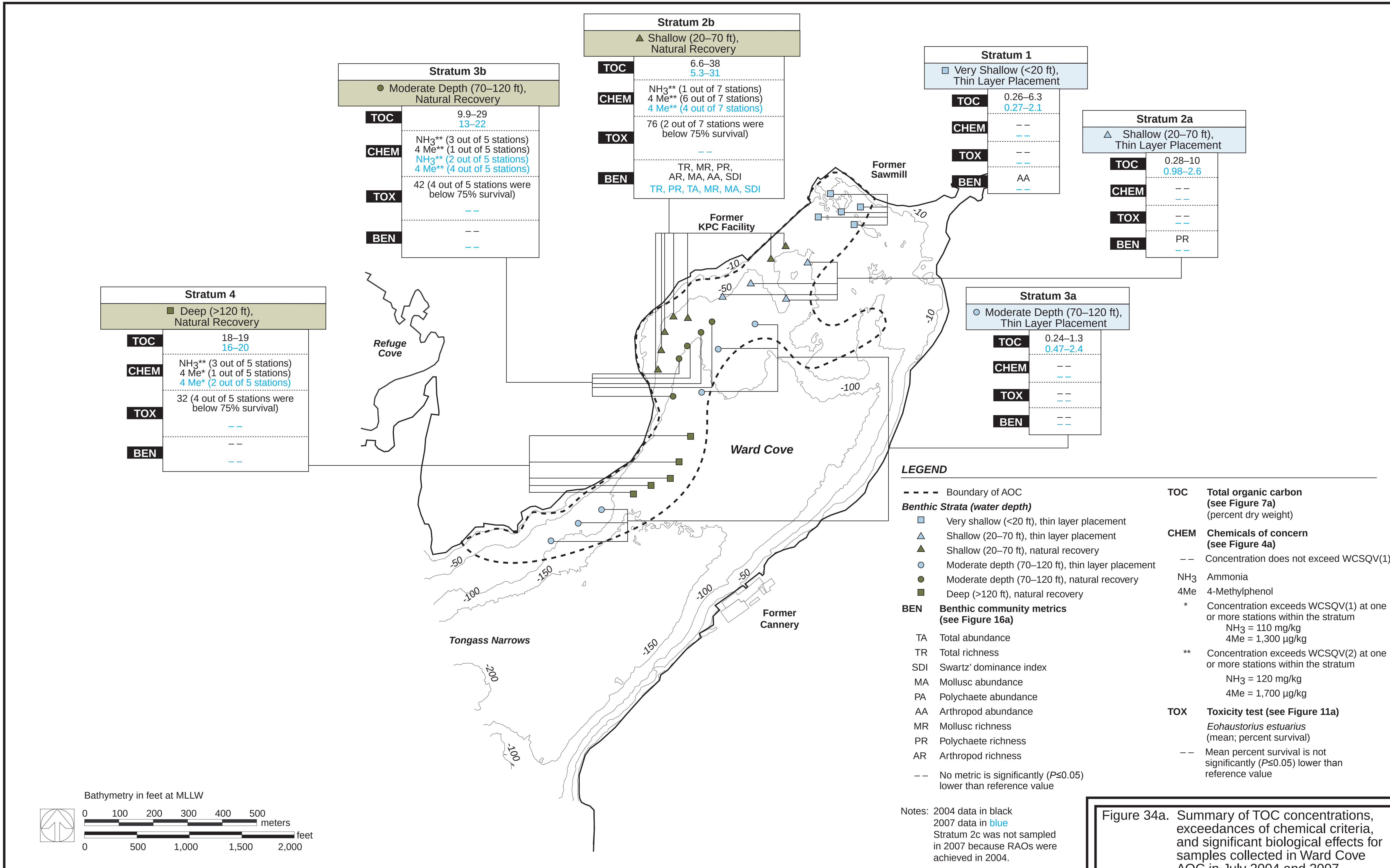


Figure 34a. Summary of TOC concentrations, exceedances of chemical criteria, and significant biological effects for samples collected in Ward Cove AOC in July 2004 and 2007

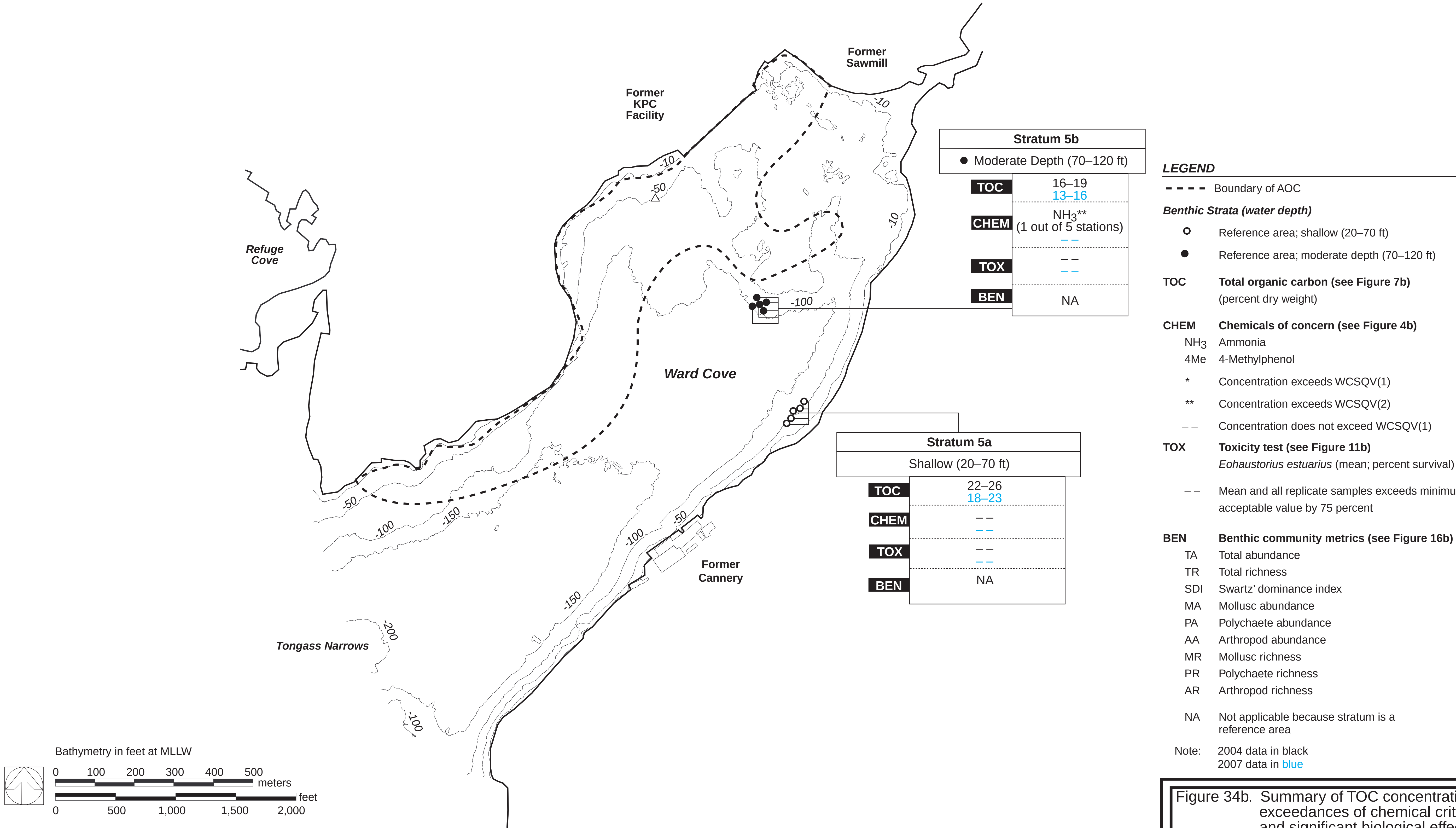


Figure 34b. Summary of TOC concentrations, exceedances of chemical criteria, and significant biological effects for samples collected in Ward Cove reference areas in July 2004 and 2007

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)
AOC Strata				
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)
3a	Moderate depth (70–120)	TLP	8, 48, 83, 84, 93, 94	8 (5), 48 (1), 83 (1), 84 (1), 93 (1), 94 (1)
2b	Shallow (20–70)	Natural recovery	38, 70, 71, 75, 76, 77, 78	38 (5), 70 (1), 71 (1), 75 (1), 76 (1), 77 (1), 78 (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)
Reference Area Strata				
5a	Shallow (20–70)	Reference	96 (7 field replicates)[a]	96 (7 field replicates, 1 laboratory replicate each)[a]
5b	Moderate depth (70–120)	Reference	95 (7 field replicates)[a]	95 (7 field replicates, 1 laboratory replicate each)[a]

Notes: As agreed upon by the U.S. Environmental Protection Agency (EPA) and Ketchikan Pulp Company (KPC) in the 2004 monitoring report (Exponent 2005), Stratum 2c was removed from 2007 monitoring, because RAOs were achieved for this area in 2004.

AOC = area of concern
MLLW = mean lower low water
TLP = thin layer placement

[a] As agreed upon by EPA and KPC in the 2004 monitoring report (Exponent 2005), seven field replicates were collected at the reference areas; however, only five replicates were used for statistical comparisons.

Table 2. Station Locations, Water Depths, and General Sample Characteristics for Surface Sediments Sampled in Ward Cove in July 2007

Station	Sample Collection Date	Location[a] Longitude	Location[a] Latitude	Penetration (cm)	Water Depth (m)	Tide (above MLLW)	Adjusted Water Depth (m)	General Sediment Characteristics[b]
AOC Stratum 1 – TLP								
5	7/10/2007	-131.724696788	55.407002926	16	7	2.124	4	Very dark gray with dark gray-brown surface (<1mm) color; coarse grain sand with some silt; worms and bivalves; shell fragments; strong reducing odor
66	7/10/2007	-131.722882502	55.407143662	11	6	3.125	3	Very dark gray with lighter gray surface (<1mm) color; silty, fine grain sand with some coarser pebbles/gravel; little moisture; worms and bivalve; little wood debris (bark) with large piece of bark removed; shell fragments; normal odor
67	7/9/2007	-131.724371746	55.407637941	18	6	1.863	4	Very dark gray with brown (surface, <1mm) color; medium to coarse grain sand with some silt; 20 percent moisture; large red worm; strong reducing odor
68[c]	7/10/2007	-131.723629224	55.407118510	15	6	3.427	3	Dark gray color; medium to coarse grain silty sand; 10-20 percent moisture; worms and bivalves; large pieces of bark and wood; shell fragments; slight reducing odor
69	7/10/2007	-131.723048648	55.406780902	17	6	3.434	2	Dark gray with gray-brown surface (<1mm) color; fine grain silty sand with some coarser pebbles/gravel; little moisture; lots of worms, crab, brittle star; shell fragments; slight reducing odor
AOC Stratum 2a – TLP								
9	7/10/2007	-131.726281067	55.404912749	17	16	1.731	15	Very dark gray-brown with gray surface (<1mm) color; mixed fine, medium, and coarse grain sand; small bivalves; shell fragments; normal odor

Table 2. Station Locations, Water Depths, and General Sample Characteristics for Surface Sediments Sampled in Ward Cove in July 2007

Station	Sample Collection Date	Location[a] Longitude	Latitude	Penetration (cm)	Water Depth (m)	Tide (above MLLW)	Adjusted Water Depth (m)	General Sediment Characteristics[b]
72	7/10/2007	-131.725242369	55.405844911	19	20	2.466	17	Black color; fine grain sandy silt sediment with some medium grain sand and a little gravel; 20 percent moisture; worms; wood debris (bark and wood chips); shell fragments; strong reducing odor
73	7/9/2007	-131.727880645	55.405329513	12	18	1.363	17	Very dark gray with gray-brown, green (olive) surface color; coarse grain sand with silt; 10 percent moisture; worms, bivalves, brittle star; wood debris; lots of shell fragments; normal odor
74	7/14/2007	-131.729178744	55.405007220	17	13	-0.253	13	Dark gray with dark gray-brown surface color; fine to coarse grain sand with some silt; 10 percent moisture; few worms, brittle star, bivalves; little wood debris; shell fragments; normal odor
AOC Stratum 3a – TLP								
8	7/10/2007	-131.727739250	55.404265815	17	28	1.662	26	Dark gray with gray-brown surface (<1mm) color; mixed fine and coarse grain sand with some silt; 20 percent moisture; worms and bivalves; shell fragments; faint sulfide odor
48	7/11/2007	-131.737345479	55.398768345	14	30	3.587	27	Dark gray with gray-brown surface color; fine grain silt with a little sand; 15 percent moisture; worms, brittle star, bivalves; very little wood debris; shell fragments; normal odor
83	7/10/2007	-131.729440658	55.403642252	16	27	1.37	25	Very dark gray with gray-brown surface (<1mm) color; mixed fine and coarse grain sand with some fine grain sediment; lots of worms, small bivalves, brittle star; organic debris (sticks and stems); shell fragments; normal odor

Table 2. Station Locations, Water Depths, and General Sample Characteristics for Surface Sediments Sampled in Ward Cove in July 2007

Station	Sample Collection Date	Location[a] Longitude	Location[a] Latitude	Penetration (cm)	Water Depth (m)	Tide (above MLLW)	Adjusted Water Depth (m)	General Sediment Characteristics[b]
84	7/10-11/2007	-131.730377063	55.402735963	17	38	2.894	36	Very dark gray with gray-brown surface (<1mm) color; silt with mixed medium to fine grain sand; lots of worms; wood debris (chips and other organic material) and large pieces of bark; shell fragments; sheen on surface of composite; reducing odor
93	7/11/2007	-131.734980287	55.399544918	16	28	2.921	25	Very dark gray with dark gray-brown surface color; silty fine grain sand mixed with medium to coarse grain sand; few small pebbles; brittle star, lots of worms lots of small bivalves, large hermit crab, jellyfish (removed); very little wood debris and few small sticks; shell fragments; normal odor
94	7/11/2007	-131.736081029	55.399204324	17	35	3.541	32	Very dark gray color; silty medium to coarse grain sand with some fine grain sand; lots of small shrimp, worms, bivalves, large piece of bull kelp (approx. 3 ft); large piece of bark; faint reducing odor
AOC Stratum 2b – Natural Recovery								
38	7/14/2007	-131.730777679	55.404472686	17	28	3.925	24	Very dark gray color; silt with some fine grain sand; 70-80 percent moisture; 20-30 percent fresh wood debris (chips); other wood debris (leaves, stems); white fibers on surface; reducing odor
70	7/11/2007	-131.726222341	55.406274989	19	15	1.44	14	Black color; silt with fine grain sand layer at 3-5cm; 50 percent moisture; wood debris (chips and fine wood particles); very few shell fragments; strong reducing odor

Table 2. Station Locations, Water Depths, and General Sample Characteristics for Surface Sediments Sampled in Ward Cove in July 2007

Station	Sample Collection Date	Location[a] Longitude	Latitude	Penetration (cm)	Water Depth (m)	Tide (above MLLW)	Adjusted Water Depth (m)	General Sediment Characteristics[b]
71	7/11/2007	-131.726904493	55.405943202	19	16	1.421	14	Black color; fine grain sandy silt with some coarse grain sand; 50 percent moisture content; lots of wood debris (bark) (60 percent); bivalve; shell fragments; white fibers on surface; slight reducing odor
75	7/7/2007	-131.731442776	55.404527830	16	16	4.138	12	Black color; very fine, moist, silt sediment; some fine to medium grain sand at 6-10 cm; white fibers on surface; wood debris (bark); little sheen in benthic sieve; strong reducing odor
76	7/7/2007	-131.731858720	55.404121657	17	23	1.746	21	Black to very dark gray with brown (surface, <1mm) color; silty sediment; shell fragments; wood debris (bark); reducing odor; piece of trash bag removed from grab
77	7/12/2007	-131.732058486	55.403658620	16	22	3.792	18	Very dark gray color; silt with fine to medium grain sand; few worms, jelly fish; lots of wood debris (75-80 percent wood chips); lots of shell fragments (mussels, barnacles); sheen observed on surface of composite; reducing odor
78	7/12/2007	-131.732218710	55.403153951	14	23	2.946	20	Very dark gray color; silt with very little fine grain sand; few worms; lots of wood debris (80 percent wood chips); lots of shell fragments; reducing odor
AOC Stratum 3b – Natural Recovery								
6	7/12/2007	-131.731694198	55.402660064	17	35	3.911	31	Very dark gray color; silt; 50 percent moisture; lots of worms; very fine wood debris and pieces of bark; shell fragments; strong reducing odor

Table 2. Station Locations, Water Depths, and General Sample Characteristics for Surface Sediments Sampled in Ward Cove in July 2007

Station	Sample Collection Date	Location[a] Longitude	Latitude	Penetration (cm)	Water Depth (m)	Tide (above MLLW)	Adjusted Water Depth (m)	General Sediment Characteristics[b]
79	7/14/2007	-131.729684381	55.404358653	18	32	4.003	28	Very dark gray with gray-brown surface (<1 mm) color; silt with little fine grain sand; 80 percent moisture; worms, piece of can (removed); alder leaves; white fibers on surface; reducing odor
80	7/12/2007	-131.730207242	55.404097212	19	31	2.227	29	Black color; silt with very small amount of fine grain sand; 80 percent moisture; worms, jelly fish; pine needles; few white fibers on surface; shell fragments; reducing odor
81	7/14/2007	-131.730850312	55.403746171	18	33	2.685	30	Very dark gray color; silt with fine to medium grain sand; 70-80 percent moisture; worms, sea anemone; very little wood debris and pieces of bark; shell fragments; slight reducing odor
82	7/14/2007	-131.731235978	55.403423084	19	36	4.365	31	Very dark gray with gray-green (olive) surface color; silt with little very fine grain sand; 80 percent moisture; worms; shell fragments; very strong reducing odor
AOC Stratum 4 – Natural Recovery								
13	7/11/2007	-131.731394816	55.400726318	18	45	3.197	41	Very dark gray with gray-brown, green (olive) surface color; silt; 80 percent moisture; worm, sea squirt, small crab; lots of small, decomposing wood debris mixed with larger pieces of bark; shell fragments; strong reducing odor
85	7/12/2007	-131.730835209	55.401376924	19	43	3.328	39	Very dark gray color; silt with little clay; 80 percent moisture; jelly fish; fine wood debris (bark); lots of shell fragments; white fibers on surface; very slight reducing odor

Table 2. Station Locations, Water Depths, and General Sample Characteristics for Surface Sediments Sampled in Ward Cove in July 2007

Station	Sample Collection Date	Location[a] Longitude	Latitude	Penetration (cm)	Water Depth (m)	Tide (above MLLW)	Adjusted Water Depth (m)	General Sediment Characteristics[b]
86	7/8/2007	-131.731928313	55.400494557	18	47	3.138	44	Very dark gray to black color; very fine grain sand, silt ; 50 percent moisture; *C. capitata* , small crab, snails; wood debris; vegetation (removed); shell fragments; white fibers on surface; sheen observed on surface of composite; strong reducing odor
87	7/14/2007	-131.732693514	55.400134560	18	45	1.818	43	Very dark gray with thin olive green-gray surface (<1mm) color; silt with very little fine grain sand; 80 percent moisture; worms, several different snail shells; some wood debris (wood chips); shell fragments; white fibers on surface
88	7/14/2007	-131.733602173	55.399935929	17	44	0.692	43	Very dark gray with thin olive green-gray surface (<1mm) color; silt with very little fine grain sand; 70 percent moisture; brittle star, worms, small bivalves; some wood debris (bark); strong reducing odor
Reference Area								
95A	7/13/2007	-131.725207424	55.402387775	17	30	3.689	26	Very dark gray color; silty sediment with a little fine grain sand and few shale fragments; 40-50 percent moisture; tube worms, tunicate; 30-40 percent wood debris (small pieces bark); reducing odor
95B	7/13/2007	-131.725097300	55.402399882	17	31	4.103	27	Very dark gray color; silty sediment with a little fine grain sand; 40-50 percent moisture; 30-40 percent wood debris (small pieces bark); reducing odor
95C	7/13/2007	-131.725178652	55.402393942	19	31	4.15	27	Very dark gray color; silty sediment with a little fine grain sand; 50 percent moisture; 20 percent wood debris (small pieces bark); reducing odor

Table 2. Station Locations, Water Depths, and General Sample Characteristics for Surface Sediments Sampled in Ward Cove in July 2007

Station	Sample Collection Date	Location[a] Longitude	Location[a] Latitude	Penetration (cm)	Water Depth (m)	Tide (above MLLW)	Adjusted Water Depth (m)	General Sediment Characteristics[b]
95D	7/13/2007	-131.725124546	55.402356545	18	32	3.701	28	Very dark gray color; silty sediment with a little fine grain sand; 50 percent moisture; 20 percent wood debris (small pieces bark); reducing odor
95E	7/13/2007	-131.725169558	55.402378873	18	33	2.727	30	Very dark gray color; silty sediment with a little fine grain sand; 50 percent moisture; 20 percent wood debris (small pieces bark); reducing odor
95F	7/13/2007	-131.725178896	55.402360175	19	34	1.501	32	Very dark gray color; silty sediment with a little fine grain sand; 70 percent moisture; few worms; 20 percent wood debris (small pieces bark) and some larger bark; reducing odor
95G	7/13/2007	-131.725149939	55.402342674	18	34	1.059	33	Very dark gray color; silty sediment with a little fine grain sand; 70 percent moisture; few worms; 20 percent wood debris (small pieces bark) and some larger bark; reducing odor
96A	7/12/2007	-131.723649196	55.400078948	10	0	2.022	-2	Very dark gray color; silty sediment; lots of worms, bivalve; wood debris; lots of shell fragments; sheen; reducing odor
96B	7/12/2007	-131.723610074	55.400118484	13	17	1.239	16	Very dark gray color; silty sediment; lots of worms, bivalve; wood debris; lots of shell fragments; sheen; reducing odor
96C	7/12/2007	-131.723593179	55.400172375	13	17	1.312	16	Very dark gray color; silty sediment; lots of worms, bivalves, large red worm, large clam; wood debris; lots of shell fragments; sheen; reducing odor
96D	7/12/2007	-131.723570188	55.400158708	15	17	1.861	15	Very dark gray color; silty sediment; lots of worms, bivalve; more wood debris; lots of shell fragments; sheen; reducing odor
96E	7/13/2007	-131.723396626	55.400230037	18	0	0.807	-1	Very dark gray color; silty sediment; large worm tubes, few worms; lots of wood debris (70 percent); shell fragments; sheen; reducing odor

Table 2. Station Locations, Water Depths, and General Sample Characteristics for Surface Sediments Sampled in Ward Cove in July 2007

Station	Sample Collection Date	Location[a] Longitude	Latitude	Penetration (cm)	Water Depth (m)	Tide (above MLLW)	Adjusted Water Depth (m)	General Sediment Characteristics[b]
96F	7/13/2007	-131.723428839	55.400290945	11	23	1.87	21	Very dark gray color; silty sediment; large worm tubes, few worms, large red worm; lots of wood debris (70 percent); shell fragments; sheen; reducing odor
96G	7/13/2007	-131.723501170	55.400313738	17	23	2.678	20	Very dark gray color; silty sediment; lots of worms, bivalve; wood debris; lots of shell fragments; sheen; reducing odor

Notes:

Samples collected from 0–10 cm.

MLLW = mean lower low water

TLP = thin layer placement

[a] Data were collected in WGS 84 (datum and spheroid).

[b] Wood debris refers to small wood chips and bark (unless otherwise noted).

[c] Difficult to find TLP material at this station; repositioned sampling vessel several times between successful grabs.

Table 3. Mean Values of Chemicals of Concern in Surface Sediments Collected in 2004 vs. 2007 in Each Benthic Stratum in Ward Cove

			Mean Concentrations			
			Ammonia (mg/kg dry)		4-Methylphenol (µg/kg dry)[a]	
Benthic Stratum	Depth Category	Remediation Category	2004	2007	2004	2007
AOC Strata						
1	Very shallow	TLP	10	3.5	62	14
2a	Shallow	TLP	17	5.2	61	75
3a	Moderate depth	TLP	4.9	5.7	20	40
2b	Shallow	Natural recovery	63	32	12,000	8,200
3b	Moderate depth	Natural recovery	130	100	4,300	6,400
4	Deep	Natural recovery	130	81	950	790
Reference Area Strata						
5a	Shallow	--	47	28	100	48
5b	Moderate depth	--	81	62	370	390

Notes:
AOC = area of concern
TLP = thin layer placement

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

Table 4. Mean Values of Conventional Analytes in Surface Sediments Collected in 2004 vs. 2007 in Each Benthic Stratum in Ward Cove

			Mean Percentages					
			Total Organic Carbon (percent)		Percent Fines (percent)		Total Solids (percent)	
Benthic Stratum	Depth Category	Remediation Category	2004	2007	2004	2007	2004	2007
AOC Strata								
1	Very shallow	TLP	2.6	0.9	7.8	3.0	65	79
2a	Shallow	TLP	2.9	1.4	8.4	4.5	64	73
3a	Moderate depth	TLP	0.52	1.3	3.4	5.5	75	68
2b	Shallow	Natural recovery	23	18	36	35	22	26
3b	Moderate depth	Natural recovery	14	17	33	54	22	15
4	Deep	Natural recovery	19	17	42	63	15	16
Reference Area Strata								
5a	Shallow	--	24	21	42	44	18	18
5b	Moderate depth	--	18	15	42	54	19	19

Notes:
AOC = area of concern
TLP = thin layer placement

Table 5. Comparison of Chemicals of Concern and Conventional Analytes in Surface Sediments Collected in 1996, 1997, 2004, and 2007 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
				2007	4.9	14	2.1	4.4	73
2a	Shallow	TLP	9	1996	82	1,400	27	56	18
				2004	3.6	8.9	0.28	1.7	79
				2007	2.4	10	0.98	1.5	79
3a	Moderate	TLP	8	1996	100	1,400	24	66	18
				2004	4.1	9.5	0.51	3.5	76
				2007	5.8	20	1.8	6.2	68
			48	1997	300	1,100	25	70	14
				2004[c]	5.6	11	0.31	2.8	78
				2007	5.6	8.0	0.53	2.6	77
2b	Shallow	Natural recovery	38	1997	260	8,300	34	46	14
				2004[c]	54	4,100	22	45	19
				2007	35	5,100	16	57	20
3b	Moderate	Natural recovery	6	1996	360	8,300	33	50	12
				2004	110	18,000	29	30	16
				2007	96	14,000	22	46	15
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
				2007	25	110	20	67	15

Notes:
AOC = area of concern
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 6. Summary of Statistical Comparisons of Amphipod (*Eohaustorius estuarius)* Survival for Ward Cove in 2007

Benthic Stratum	Depth Category	Remediation Category	Percent Survival Mean	Standard Deviation	CV	Lower Than Reference[a]	High Variance[b]
AOC Strata							
1	Very shallow	TLP	94	4.2	0.04	no	no
2a	Shallow	TLP	92	6.3	0.07	no	no
3a	Moderate depth	TLP	95	6.3	0.07	no	no
2b	Shallow	Natural recovery	88	9.9	0.11	no	no
3b	Moderate depth	Natural recovery	96	4.2	0.04	no	no
4	Deep	Natural recovery	80	22	0.27	no	yes
Reference Area Strata							
5a	Shallow	--	98	2.7	0.03		
5b	Moderate depth	--	93	6.7	0.07		

Notes:
ANOVA = analysis of variance
AOC = area of concern
CV = coefficient of variation
TLP = thin layer placement
Appendix C provides all statistical test results and supporting analyses. All analyses were conducted using S-Plus 2000.

[a] Overall ANOVA for comparison to reference 5b was not significant ($P = 0.294$), so individual comparisons were not made. Comparisons to reference 5a were done using a one-tailed nonparametric Wilcoxon test with Bonferroni adjustment (P-value is compared to comparison-wise alpha of 0.05/3 = 0.0167).

[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). However, survival in all the toxicity tests was >75 percent.

Table 7. Statistical Power Evaluation of Amphipod (*Eohaustorius estuarius)* Survival in Ward Cove in 2007

Benthic Stratum	Depth Category	Remediation Category	N	Percent Survival Mean	Percent Survival Std.Dev.	Percent Survival CV	Transform	Significantly Lower Than Reference	Relative Difference	MDRD for power levels[a] 60%	MDRD for power levels[a] 70%	MDRD for power levels[a] 80%
AOC Strata												
1	Very shallow	TLP	5	94	4.2	0.04	no	no	4.1%	7.9%	8.4%	9.0%
2a	Shallow	TLP	4	92	6.3	0.07	no	no	5.9%	11%	11%	12%
3a	Moderate depth	TLP	6	95	6.3	0.07	asin sqrt	no	-2.3%			
2b	Shallow	Natural recovery	7	88	9.9	0.11	no	no	9.9%	17%	18%	20%
3b	Moderate depth	Natural recovery	5	96	4.2	0.04	asin sqrt	no	-3.2%			
4	Deep	Natural recovery	5	80	22	0.27	asin sqrt	no	14%	32%	34%	37%
Reference Area Strata												
5a	Shallow	--	5	98	2.7	0.03	no					
5b	Moderate depth	--	5	93	6.7	0.07	asin sqrt					

Notes:

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

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

[a]MDRD and power calculations were conducted for one-sided comparisons between each AOC stratum and the reference area stratum. Power analysis was not performed when the mean survival in the test sediment exceeded the mean survival in the reference sediment. For the comparisons to reference 5a, power is for one-sided t-test with Bonferroni adjustment (alpha = 0.05/3 = 0.0167). Because the test performed was a nonparametric Wilcoxon test, these MDRDs represent upper bounds for the actual MDRD expected using a Wilcoxon test when normal assumptions are not met. For the comparisons to reference 5b, power is for one-sided t-test with pooled variance from transformed ANOVA and Bonferroni adjustment (alpha = 0.05/3 = 0.0167).

Table 8. Comparison of Amphipod Survival among Different Sampling Periods in Ward Cove[a]

Station	Benthic Stratum	Depth Category	Remediation Category	Year	Species	Percent Survival Mean	Standard Deviation	CV	Significant Trend[b]
AOC Strata									
8	3a	Moderate depth	TLP	1996	*Rhepoxynius abronius*	43	23	0.53	
				2004	*Eohaustorius estuarius*	99	2.2	0.02	yes
				2007	*Eohaustorius estuarius*	96	4.2	0.04	
9	2a	Shallow	TLP	1996	*Rhepoxynius abronius*	54	18	0.33	
				2004	*Eohaustorius estuarius*	91	7.4	0.08	yes
				2007	*Eohaustorius estuarius*	94	6.5	0.07	
13	4	Deep	Natural recovery	1996	*Rhepoxynius abronius*	36	11	0.30	
				1997	*Rhepoxynius abronius*	15	23	1.5	yes
				2004	*Eohaustorius estuarius*	43	31	0.71	
				2007	*Eohaustorius estuarius*	96	4.2	0.04	
38	2b	Shallow	Natural recovery	1997	*Rhepoxynius abronius*	0	0	--	
				2004	*Eohaustorius estuarius*	89	8.2	0.09	yes
				2007	*Eohaustorius estuarius*	98	2.7	0.03	

Notes:
AOC = area of concern
CV = coefficient of variation
TLP = thin layer placement
Appendix C provides all statistical test results and supporting analyses. All analyses were conducted using S-Plus 2000.

[a] Not all stations were sampled every year.

[b] For increasing means, trends were assessed using linear regression with "Year" as the independent variable and replicate observations for the dependent variable. The trend was considered statistically significant when the F-test for the regression was significant ($P < 0.05$).

Table 9. Statistical Summary of Trend Evaluations of *Eohaustorius estuarius* Survival for Ward Cove in 2004 vs. 2007

Benthic Stratum	Depth Category	Remediation Category	Increase in Percent Survival 2004 - 2007: Mean	Std. Dev.	CV	Normality[a]: Pass?	*P*-value	Increase from 2004?: Absolute Increase?	Test[b]	Significant?	*P*-value
AOC Strata											
1	Very shallow	TLP	-2.0	2.7	-1.4	no	0.01	no			
2a	Shallow	TLP	-0.5	6.7	-13	yes	0.33	no			
3a	Moderate depth	TLP	0.3	12.9	39	yes	0.87	yes	t-test	no	0.48
2b	Shallow	Natural recovery	12.0	30.3	2.5	no	0.04	yes	Wilcoxon	no	0.43
3b	Moderate depth	Natural recovery	54.0	36.0	0.67	yes	0.30	yes	t-test	yes	0.01
4	Deep	Natural recovery	48.6	56.2	1.2	yes	0.15	yes	t-test	no	0.06
Reference Area Strata											
5a	Shallow	Reference	17.0	17.2	1.0	yes	0.42	yes	t-test	yes	0.05
5b	Moderate depth	Reference	3.6E-16	6.1	1.7E+16	yes	0.15	yes	t-test	no	0.50

Notes:
AOC = area of concern
CV = coefficient of variation
n/a = not applicable or cannot be calculated
TLP = thin layer placement

[a] Normality was evaluated using the Shapiro-Wilk's goodness-of-fit test. Significance level of 0.05 was used.

[b] Statistical tests were performed only if the mean increase in survival was greater than zero. If data were approximately normal, a one-tailed paired *t*-test was used for each stratum. If the data were not approximately normal, a nonparametric one-tailed paired Wilcoxon test was used. Comparison-wise alpha is 0.05.

Table 10. Statistical Power Evaluation of *Eohaustorius estuarius* Survival for Ward Cove in 2004 vs. 2007

			Increase in Percent			Increase From 2004?				MDD[a]		
Benthic Stratum	Depth Category	Remediation Category	Mean	Std. Dev.	CV	Absolute Increase?	Test[b]	Significant?	*P*-value	60%	70%	80%
AOC Strata												
1	Very shallow	TLP	-2.0	2.7	-1.4	no						
2a	Shallow	TLP	-0.50	6.7	-13	no						
3a	Moderate depth	TLP	0.33	13	39	yes	*t*-test	no	0.48	12	14	15
2b	Shallow	Natural recovery	12	30	2.5	yes	Wilcoxon	no	0.43	25	29	33
3b	Moderate depth	Natural recovery	54	36	0.67	yes	*t*-test	yes	0.01			
4	Deep	Natural recovery	49	56	1.2	yes	*t*-test	no	0.06	60	68	77
Reference Area Strata												
5a	Shallow	Reference	17	17	1.01	yes	*t*-test	yes	0.05			
5b	Moderate depth	Reference	0	6.1	n/a	yes	*t*-test	no	0.50			

Notes:
AOC = area of concern
CV = coefficient of variation
TLP = thin layer placement
MDD = minimum detectable difference in original units; the absolute difference in means that is detectable at the given power level.
n/a = not applicable. CV cannot be calculated when the mean is zero.

[a] Power is calculated for stations with increased survival in 2007, based on a paired *t*-test with comparison-wise alpha of 0.05. Power analysis was not performed (i.e., no result is displayed) when the mean difference was less than zero, or if the result was significant.

Table 11. Mean Values of Benthic Metrics for Benthic Communities Sampled in 2004 vs. 2007 in Each Benthic Stratum in Ward Cove

Benthic Stratum	Depth Category	Remediation Category	Total Abundance[a] 2004	Total Abundance[a] 2007	Total Richness[a] 2004	Total Richness[a] 2007	SDI 2004	SDI 2007
AOC Strata								
1	Very shallow	TLP	180	322	22	25	3.8	6.0
2a	Shallow	TLP	50	235	14	24	5.8	5.0
3a	Moderate depth	TLP	66	193	20	20	7.5	3.8
2b	Shallow	Natural recovery	160	82	3.3	2.9	1.6	1.2
3b	Moderate depth	Natural recovery	19	103	3.2	4.0	1.6	1.0
4	Deep	Natural recovery	17	148	4.8	9.6	1.6	1.6
Reference Area Strata								
5a	Shallow	--	330	330	22	16	3.6	3.2
5b	Moderate depth	--	27	73	5.4	6.2	1.8	1.4

Notes:

AOC = area of concern

SDI = Swartz' dominance index

TLP = thin layer placement

[a] Per 0.06-m^2 sample.

Table 12. Mean Values of Total Abundance and Total Richness of Major Benthic Macroinvertebrate Taxonomic Groups Collected in Ward Cove in July 2004 and 2007

			Abundance[a]						Richness[a]					
			Mollusca		Polychaeta		Arthropoda		Mollusca		Polychaeta		Arthropoda	
Benthic Stratum	Depth Category	Remediation Category	2004	2007	2004	2007	2004	2007	2004	2007	2004	2007	2004	2007
AOC Strata														
1	Very shallow	TLP	93	212	84	107	1.8	2.6	7.6	11	13	12	1.4	2.2
2a	Shallow	TLP	32	106	16	140	2.0	2.3	5.5	9.7	6.5	12	1.3	2.0
3a	Moderate	TLP	34	109	27	80	1.5	3.3	6.7	7.3	11	10	1.5	2.3
2b	Shallow	Natural recovery	0.14	4.7	160	77	0.57	0	0.14	1.0	2.9	1.9	0.29	0
3b	Moderate	Natural recovery	1.2	1.4	17	99	1.0	2.6	1.2	0.4	1.2	1.4	0.80	2.0
4	Deep	Natural recovery	1.0	7.0	14	116	2.2	24	1.0	3.4	2.2	4.2	1.6	1.4
Reference Area Strata														
5a	Shallow	--	15	72	300	115	7.2	2.0	5.2	5.4	15	8	2.4	0.8
5b	Moderate	--	7.4	1.6	18	69	1.2	2.2	2.2	0.6	2.4	3.4	0.80	1.8

Notes:
AOC = area of concern
TLP = thin layer placement

[a] Per 0.06-m^2 sample.

Table 13. Results of Statistical Comparisons of Benthic Metrics between AOC and Reference Strata in Ward Cove in July 2007

	Benthic Stratum	Depth Category	Remediation Category	Mean	Std. Dev.	CV	Transform[a]	Significantly lower: Group Comparison[b]	Significantly lower: Single Comparison[c]
Total Abundance[d]									
	1	Very shallow	TLP	322	162	0.50	SQRT		
	2a	Shallow	TLP	235	79	0.34			
	2b	Shallow	Natural recovery	82	97	1.2		yes	yes
ref	5a	Shallow	--	191	61	0.32			
	3a	Moderate depth	TLP	193	139	0.72	n/a		
	3b	Moderate depth	Natural recovery	103	36	0.35			
	4	Deep	Natural recovery	148	86	0.58			
ref	5b	Moderate depth	--	73	38	0.52			
Taxa Abundance[d]									
Molluscs									
	1	Very shallow	TLP	212	143	0.68	Rankit		
	2a	Shallow	TLP	105	79	0.8			
	2b	Shallow	Natural recovery	4.7	11	2.4		no	yes
ref	5a	Shallow	--	72	22	0.30			
	3a	Moderate depth	TLP	109	108	0.99	n/a		
	3b	Moderate depth	Natural recovery	1.4	1.9	1.4		n/a[e]	n/a[e]
	4a	Deep	Natural recovery	7.0	7.6	1.1			
ref	5b	Moderate depth	--	1.6	3.0	1.9			
Polychaetes									
	1	Very shallow	TLP	107	27	0.25	Rankit	no	no
	2a	Shallow	TLP	127	43	0.34			
	2b	Shallow	Natural recovery	77	92	1.2		no	no
ref	5a	Shallow	--	115	73	0.64			
	3a	Moderate depth	TLP	80	37	0.46	n/a		
	3b	Moderate depth	Natural recovery	99	34	0.35			
	4	Deep	Natural recovery	116	54	0.47			
ref	5b	Moderate depth	--	69	35	0.50			

Table 13. Results of Statistical Comparisons of Benthic Metrics between AOC and Reference Strata in Ward Cove in July 2007

	Benthic Stratum	Depth Category	Remediation Category	Mean	Std. Dev.	CV	Transform[a]	Significantly lower: Group Comparison[b]	Significantly lower: Single Comparison[c]
Arthropods									
	1	Very shallow	TLP	2.6	1.5	0.58	Rankit		
	2a	Shallow	TLP	2.0	2.7	1.4			
	2b	Shallow	Natural recovery	0	0	n/a		no	n/a
ref	5a	Shallow	--	2.0	2.3	1.2			
	3a	Moderate depth	TLP	3.3	2.4	0.73	n/a		
	3b	Moderate depth	Natural recovery	2.6	4.0	1.5			
	4	Deep	Natural recovery	24	45	1.9			
ref	5b	Moderate depth	--	2.2	1.3	0.59			
Total Richness[d]									
	1	Very shallow	TLP	25	4.6	0.19	Rankit		
	2a	Shallow	TLP	24	14	0.57			
	2b	Shallow	Natural recovery	2.9	2.6	0.91		yes	yes
ref	5a	Shallow	--	16	2.8	0.18			
	3a	Moderate depth	TLP	20	11	0.54	Log10 + 1		
	3b	Moderate depth	Natural recovery	4.0	4.1	1.0		no	no
	4	Deep	Natural recovery	9.6	8.2	0.85			
ref	5b	Moderate depth	--	6.2	6.6	1.1			
Taxa Richness[d]									
Molluscs									
	1	Very shallow	TLP	11	3.0	0.29	Rankit		
	2a	Shallow	TLP	9.5	7.1	0.75			
	2b	Shallow	Natural recovery	1.0	1.9	1.9		no	yes
ref	5a	Shallow	--	5.4	1.5	0.28			
	3a	Moderate depth	TLP	7.3	5.4	0.74	Rankit		
	3b	Moderate depth	Natural recovery	0.40	0.55	1.4		no	no
	4	Deep	Natural recovery	3.4	3.0	0.87			
ref	5b	Moderate depth	--	0.60	0.89	1.5			

Table 13. Results of Statistical Comparisons of Benthic Metrics between AOC and Reference Strata in Ward Cove in July 2007

	Benthic Stratum	Depth Category	Remediation Category	Mean	Std. Dev.	CV	Transform[a]	Significantly lower: Group Comparison[b]	Significantly lower: Single Comparison[c]
Polychaetes									
	1	Very shallow	TLP	12	2.5	0.20	Rankit		
	2a	Shallow	TLP	12	5.4	0.45			
	2b	Shallow	Natural recovery	1.9	1.2	0.65		yes	yes
ref	5a	Shallow	--	8.4	2.3	0.27			
	3a	Moderate depth	TLP	10	5.7	0.55	Rankit		
	3b	Moderate depth	Natural recovery	1.4	0.55	0.39		no	no
	4	Deep	Natural recovery	4.2	3.3	0.78			
ref	5b	Moderate depth	--	3.4	4.3	1.3			
Arthropods									
	1	Very shallow	TLP	2.2	0.84	0.38	Rankit		
	2a	Shallow	TLP	1.8	2.2	1.3			
	2b	Shallow	Natural recovery	0	0	n/a		no	n/a
ref	5a	Shallow	--	0.8	0.84	1.0			
	3a	Moderate depth	TLP	2.3	1.4	0.59	Rankit		
	3b	Moderate depth	Natural recovery	2.0	3.5	1.7			
	4	Deep	Natural recovery	1.4	2.07	1.5		no	no
ref	5b	Moderate depth	--	1.8	0.84	0.46			
Swartz' Dominance Index									
	1	Very shallow	TLP	6.0	1.9	0.31	Rankit		
	2a	Shallow	TLP	5.0	3.2	0.63			
	2b	Shallow	Natural recovery	1.2	0.41	0.35		no	yes
ref	5a	Shallow	--	3.2	0.84	0.26			
	3a	Moderate depth	TLP	3.8	1.7	0.45	Rankit		
	3b	Moderate depth	Natural recovery	1.0	0	0		no	no
	4	Deep	Natural recovery	1.6	0.89	0.56			
ref	5b	Moderate depth	--	1.2	0.45	0.37			

Notes:
ANOVA = analysis of variance
AOC = area of concern
CV = coefficient of variation
MANOVA = multivariate analysis of variance

Table 13. Results of Statistical Comparisons of Benthic Metrics between AOC and Reference Strata in Ward Cove in July 2007

Benthic Stratum	Depth Category	Remediation Category	Mean	Std. Dev.	CV	Transform[a]	Significantly lower: Group Comparison[b]	Significantly lower: Single Comparison[c]

TLP = thin layer placement

n/a = not applicable; could not be calculated or no test was run.

Total abundance, total richness, and Swartz' dominance index were analyzed using ANOVA followed by Dunnett's test if the ANOVA was significant ($P<0.05$). Taxa abundance and richness were analyzed using an overall MANOVA, followed by individual ANOVAs and Dunnett's tests if the MANOVA and ANOVAs were significant ($P<0.05$). For all cases where site values were less than reference, a simple two-sample comparison was also used. This was either a parametric t-test or a non-parametric Wilcoxon test, depending on the distribution. 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] Transformation required to achieve normality, based on results of Shapiro-Wilk's test ($P<0.05$). $\text{Log}_{10}(+1)$ indicates the $\log_{10}$ of the value plus 1 was used. SQRT indicates the square-root of the value was used. Rankit indicates rankit transformation.

[b] Results displayed only for cases with station mean worse than reference. Result is from MANOVA, ANOVA, or Dunnett's one-sided multiple comparison tests (see Table C-3 for details).

[c] One-sided *t*-test or Wilcoxon test, depending on distributions. Tests were not run for stations with means better than reference.

[d] Per 0.06-m^2 sample. No abundance results were compared to Benthic Stratum 5b because only one site value was less than reference, mollusc abundance at Stratum 3b.

[e] Comparison was not made because this was the only abundance result lower than Benthic Stratum 5b.

Table 14. Statistical Power Evaluation for Benthic Invertebrate Community Comparsons in Ward Cove in 2007

	Benthic Stratum	Depth Category	Remediation Category	Mean	Std. Dev.	CV	Transform[a]	Significantly lower: Group Comparison[b]	Significantly lower: Single Comparison[c]	Observed Relative Difference	MDRD for Power Levels[d]: 60%	70%	80%
Total Abundance[e]													
	1	Very shallow	TLP	322	162	0.50	SQRT						
	2a	Shallow	TLP	235	79	0.34							
	2b	Shallow	Natural recovery	82	97	1.2		yes	yes	57.2%			
ref	5a	Shallow	--	191	61	0.32							
	3a	Moderate depth	TLP	193	139	0.72	n/a						
	3b	Moderate depth	Natural recovery	103	36	0.35							
	4	Deep	Natural recovery	148	86	0.58							
ref	5b	Moderate depth	--	73	38	0.52							
Taxa Abundance[e]													
Molluscs													
	1	Very shallow	TLP	212	143	0.68	Rankit						
	2a	Shallow	TLP	105	79	0.8							
	2b	Shallow	Natural recovery	4.7	11	2.4		no	yes	93.5%			
ref	5a	Shallow	--	72	22	0.30							
	3a	Moderate depth	TLP	109	108	0.99	n/a						
	3b	Moderate depth	Natural recovery	1.4	1.9	1.4		n/a[f]	n/a[f]				
	4a	Deep	Natural recovery	7.0	7.6	1.1							
ref	5b	Moderate depth	--	1.6	3.0	1.9							
Polychaetes													
	1	Very shallow	TLP	107	27	0.25	Rankit	no	no	6.3%	86%	94%	105%
	2a	Shallow	TLP	127	43	0.34							
	2b	Shallow	Natural recovery	77	92	1.2		no	no	32.8%	108%	119%	133%
ref	5a	Shallow	--	115	73	0.64							
	3a	Moderate depth	TLP	80	37	0.46	n/a						
	3b	Moderate depth	Natural recovery	99	34	0.35							
	4	Deep	Natural recovery	116	54	0.47							
ref	5b	Moderate depth	--	69	35	0.50							
Arthropods													
	1	Very shallow	TLP	2.6	1.5	0.58	Rankit						
	2a	Shallow	TLP	2.0	2.7	1.4							
	2b	Shallow	Natural recovery	0	0	n/a		no	n/a	100%	108%	119%	133%
ref	5a	Shallow	--	2.0	2.3	1.2							
	3a	Moderate depth	TLP	3.3	2.4	0.73	n/a						
	3b	Moderate depth	Natural recovery	2.6	4.0	1.5							
	4	Deep	Natural recovery	24	45	1.9							
ref	5b	Moderate depth	--	2.2	1.3	0.59							

Table 14. Statistical Power Evaluation for Benthic Invertebrate Community Comparsons in Ward Cove in 2007

Benthic Stratum	Depth Category	Remediation Category	Mean	Std. Dev.	CV	Transform[a]	Significantly lower: Group Comparison[b]	Significantly lower: Single Comparison[c]	Observed Relative Difference	MDRD for Power Levels[d]: 60%	70%	80%
Total Richness[e]												
1	Very shallow	TLP	25	4.6	0.19	Rankit						
2a	Shallow	TLP	24	14	0.57							
2b	Shallow	Natural recovery	2.9	2.6	0.91		yes	yes	81.9%			
ref 5a	Shallow	--	16	2.8	0.18							
3a	Moderate depth	TLP	20	11	0.54	$Log_{10} + 1$						
3b	Moderate depth	Natural recovery	4.0	4.1	1.0		no	no	35%	159%	175%	194%
4	Deep	Natural recovery	9.6	8.2	0.85							
ref 5b	Moderate depth	--	6.2	6.6	1.1							
Taxa Richness[e]												
Molluscs												
1	Very shallow	TLP	11	3.0	0.29	Rankit						
2a	Shallow	TLP	9.5	7.1	0.75							
2b	Shallow	Natural recovery	1.0	1.9	1.9		no	yes	81%			
ref 5a	Shallow	--	5.4	1.5	0.28							
3a	Moderate depth	TLP	7.3	5.4	0.74	Rankit						
3b	Moderate depth	Natural recovery	0.40	0.55	1.4		no	no	33%	221%	243%	270%
4	Deep	Natural recovery	3.4	3.0	0.87							
ref 5b	Moderate depth	--	0.60	0.89	1.5							
Polychaetes												
1	Very shallow	TLP	12	2.5	0.20	Rankit						
2a	Shallow	TLP	12	5.4	0.45							
2b	Shallow	Natural recovery	1.9	1.2	0.65		yes	yes	77.9%			
ref 5a	Shallow	--	8.4	2.3	0.27							
3a	Moderate depth	TLP	10	5.7	0.55	Rankit						
3b	Moderate depth	Natural recovery	1.4	0.55	0.39		no	no	59%	160%	177%	196%
4	Deep	Natural recovery	4.2	3.3	0.78							
ref 5b	Moderate depth	--	3.4	4.3	1.3							
Arthropods												
1	Very shallow	TLP	2.2	0.84	0.38	Rankit						
2a	Shallow	TLP	1.8	2.2	1.3							
2b	Shallow	Natural recovery	0	0	n/a		no	n/a[g]	100%	96%	106%	118%
ref 5a	Shallow	--	0.8	0.84	1.0							
3a	Moderate depth	TLP	2.3	1.4	0.59	Rankit						
3b	Moderate depth	Natural recovery	2.0	3.5	1.7							
4	Deep	Natural recovery	1.4	2.07	1.5		no	no	22%	157%	173%	192%
ref 5b	Moderate depth	--	1.8	0.84	0.46							

Table 14. Statistical Power Evaluation for Benthic Invertebrate Community Comparsons in Ward Cove in 2007

	Benthic Stratum	Depth Category	Remediation Category	Mean	Std. Dev.	CV	Transform[a]	Significantly lower		Observed Relative Difference	MDRD for Power Levels[d]		
								Group Comparison[b]	Single Comparison[c]		60%	70%	80%
Swartz' Dominance Index													
	1	Very shallow	TLP	6.0	1.9	0.31	Rankit						
	2a	Shallow	TLP	5.0	3.2	0.63							
	2b	Shallow	Natural recovery	1.2	0.41	0.35		no	yes	64%			
ref	5a	Shallow	--	3.2	0.84	0.26							
	3a	Moderate depth	TLP	3.8	1.7	0.45	Rankit						
	3b	Moderate depth	Natural recovery	1.0	0	0		no	no	17%	47%	52%	58%
	4	Deep	Natural recovery	1.6	0.89	0.56							
ref	5b	Moderate depth	--	1.2	0.45	0.37							

Notes:

ANOVA = analysis of variance

AOC = area of concern

CV = coefficient of variation

MANOVA = multivariate analysis of variance

MDRD = minimum detectable relative difference calculated relative to reference; MDRD is the minimum detectable difference divided by the reference mean

TLP = thin layer placement

n/a = not applicable; Could not be calculated or no test was run.

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

[a] Transformation required to achieve normality, based on results of Shapiro-Wilk's test (P <0.05). $Log_{10}(+1)$ indicates the log_{10} of the value plus 1 was used. SQRT indicates the square-root of the value was used. Rankit indicates rankit transformation.

[b] Results displayed only for cases with station mean worse than reference. Result is from MANOVA, ANOVA, or Dunnett's one-sided multiple comparison tests (see Table C-3 for details).

[c] One-sided *t* -test or Wilcoxon test, depending on distributions. Tests were not run for stations with means better than reference.

[d] Per 0.06-m^2 sample. No abundance results were compared to Station 5b because only one site value was less than reference, mollusc abundance at Station 3b.

[e] Comparison was not made because this was the only abundance result lower than Reference 5b.

[f] MDRD power calculations were conducted for one-sided comparisons between each AOC stratum and reference area stratum based on *t* -test comparisons. Power was not calculated for tests that were not performed or for tests that were significant (because power was sufficient to detect the observed difference). 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 multiple comparisons. These MDRDs represent upper bounds for the actual MDRD expected using a Wilcoxon test when normal assumptions are not met.

[g] Although single test was not conducted due to zero variance, power was estimated using variance pooled across all stations.

Table 15. Summary of Species that Accounted for ≥5 Percent of Total Abundance in Each Benthic Stratum of Ward Cove in 2004 and 2007

Stratum	Depth Category	Remediation Category	Species	Relative Abundance (percent) 2004	Relative Abundance (percent) 2007
AOC Strata					
1	Very shallow	TLP	*Parvilucina tenuisculpta* (M)	--	22
			Axinopsida serricata (M)	34	20
			Rochefortia tumida (M)	7.9	15
			Prionospio steenstrupi (P)	--	8.0
			Glycinde picta (P)	--	5.0
			Leitoscoloplos pugettensis (P)	--	5.0
			Lumbrineridae (P)	--	5.0
			Owenia fusiformis (P)	15	--
			Dorvillea annulata (P)	11	--
			Lumbrineris californiensis (P)	5.0	--
2a	Shallow	TLP	*Nephtys cornuta* (P)	5.0	23
			Parvilucina tenuisculpta (M)	17	24
			Axinopsida serricata (M)	23	13
			Galathowenia oculata (P)	--	6.0
			Spio spp. (P)	--	5.0
			Acteocina eximea (M)	6.6	--
			Tellina modesta (M)	5.1	--
			Capitella capitata complex (P)	5.1	--
3a	Moderate	TLP	*Parvilucina tenuisculpta* (M)	11	33
			Axinopsida serricata (M)	25	16
			Nephtys cornuta (P)	11	7.0
			Galathowenia oculata (P)	--	6.0
			Leitoscoloplos pugettensis (P)	5.0	5.0
			Spio spp. (P)	--	5.0
2b	Shallow	Natural recovery	*Dorvillea annulata* (P)	--	41
			Nephtys cornuta (P)	--	41
			Capitella capitata complex (P)	93	6.0
			Dorvillea spp. (P)	--	5.0
3b	Moderate	Natural recovery	*Nephtys cornuta* (P)	87	94
4	Deep	Natural recovery	*Nephtys cornuta* (P)	51	71
			Limnoria lignorum (A)	--	10
			Capitella capitata complex (P)	26	--
			Pinnotheridae indet. (A)	7.0	--
Reference Area Strata					
5a	Shallow	Natural recovery	*Capitella capitata* complex (P)	65	26
			Dorvillea annulata (P)	14	25
			Parvilucina tenuisculpta (M)	--	16
			Rochefortia tumida (M)	--	15
			Parvilucina tenuisculpta (M)	7.0	--
			Gastropteron pacificum (M)	5.0	--
5b	Moderate	Natural recovery	*Nephtys cornuta* (P)	61	85
			Parvaplustrum spp.	14	--

Notes:
A = Arthropoda
AOC = area of concern
M = Mollusca
P = Polychaeta
TLP = thin layer placement

[a] Major taxonomic groups denoted in parentheses

Table 16. Comparison of Major Benthic Macroinvertebrate Taxa between Communities Sampled in Ward Cove in 1992, 2004, and 2007[a,b]

Taxon	Mean Number Captured (per 0.1 m^2)		
	1992[c]	2004[d]	2007[d,e]
Molluscs			
Parvilucina tenuisculpta	0.4[f]	4.6	45
Axinopsida serricata	0.1[f]	16	25
Rochefortia tumida	1.2	3.8	16
Tellina modesta	--	2.0	2.5
Astyris gausapata	--	--	2.3
Pandora filosa	--	--	1.2
Macoma inquinata	--	--	0.6
Gastropteron pacificum	--	--	<0.1
Acteocina eximea	--	1.1	--
Parvaplustrum spp.	--	1.0	--
Polychaetes			
Nephtys cornuta	8.9	11	74
Dorvillea annulata	--	12	21
Capitella capitata complex	190	76	13
Leitoscoloplos pugettensis	--	--	7.1
Lumbrineridae	--	--	6.1
Prionospio steenstrupi	--	--	5.0
Galathowenia oculata	--	--	5.0
Spio spp.	--	--	4.3
Glycinde picta	--	--	4.1
Dorvillea spp.	--	--	2.0
Lumbrineris californiensis	--	2.0	1.8
Decamastus spp.	--	--	1.8
Pholoides asperus	--	--	1.6
Owenia fusiformis	--	4.6	0.8
Paraprionospio pinnata	--	--	0.6
Eudistylia catharinae	--	--	0.5
Schistomeringos japonica	73	--	--
Arthropoda			
Limnoria lignorum	--	--	3.1
Corophium spp.	--	--	0.7
Monoculodes spp.	--	--	0.3
Nematodes	180	--	--
Total Abundance	470	180	270
Modified Total Abundance[g]	100	95	250

Notes:
-- = 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) using a 0.1 m^2 van Veen; sampling in 2004 was conducted at 47 stations (1 sample per station) as part of the present study using a 0.6 m^2 van Veen; sampling in 2007 was conducted at 42 stations (1 sample per station) as part of the present study using a 0.6 m^2 van Veen.
[c] *A. serricata*, *P. tenuisculpta*, and *R. tumida* were all collected in a singe replicate grab sample from one station.
[d] Excludes data from Stratum 2c (which was removed from further study after the 2004 monitoring event).
[e] Stratum 2c was not sampled in 2007 because RAOs were achieved in 2004.
[f] Data provided in EVS (1992) as one significant figure.
[g] *Capitella capitata* and nematodes removed.

Table 17. Trend and Statistical Power Evaluations of Benthic Metrics for Benthic Communities Sampled in 2004 vs. 2007

Benthic Stratum	Depth Category	Remediation Category	Increase 2004 - 2007 Mean	Std. Dev.	CV	Assumption Normality[a] Pass?	P-value	Increase from 2004? Absolute Increase?	Test[b]	Significant?	P-value	MDD for Specified Power[c] 60%	70%	80%
Total Abundance														
AOC Strata														
1	Very shallow	TLP	143	174	1.2	yes	0.59	no	t-test	no	0.069	187	210	239
2a	Shallow	TLP	185	107	0.58	yes	0.97	yes	t-test	yes	0.021			
3a	Moderate depth	TLP	127	115	0.90	yes	0.69	yes	t-test	yes	0.021			
2b	Shallow	Natural recovery	-78	282	-3.6	no	0.0023	no						
3b	Moderate depth	Natural recovery	84	30	0.36	no	0.027	yes	Wilcoxon	yes	0.031			
4	Deep	Natural recovery	131	95	0.72	yes	0.53	yes	t-test	yes	0.018			
Reference Area Strata														
5a	Shallow	Reference	-135	202	-1.5	yes	0.91	no						
5b	Moderate depth	Reference	47	43	0.92	yes	0.32	yes	t-test	yes	0.036			
Total Richness														
AOC Strata														
1	Very shallow	TLP	3.0	12	4.0	yes	0.67	no	t-test	no	0.30	13	15	17
2a	Shallow	TLP	10.3	13	1.2	yes	0.15	no	t-test	no	0.10	16	18	21
3a	Moderate depth	TLP	0.33	4.7	14	yes	0.99	no	t-test	no	0.43	4.4	5.0	5.7
2b	Shallow	Natural recovery	-0.43	2.8	-6.6	yes	0.25	no						
3b	Moderate depth	Natural recovery	0.80	3.8	4.7	yes	0.38	no	t-test	no	0.33	4.0	4.6	5.2
4	Deep	Natural recovery	4.8	9.9	2.1	yes	0.37	no	t-test	no	0.17	11	12	14
Reference Area Strata														
5a	Shallow	Reference	-6.6	3.1	-0.47	yes	0.60	no						
5b	Moderate depth	Reference	0.8	8.8	11	yes	0.31	no	t-test	no	0.42	9.4	11	12
SDI														
AOC Strata														
1	Very shallow	TLP	2.2	3.2	1.5	yes	0.86	no	t-test	no	0.099	3.4	3.9	4.4
2a	Shallow	TLP	-0.8	1.7	-2.28	yes	0.85	no						
3a	Moderate depth	TLP	-3.7	2.0	-0.54	yes	0.56	no						
2b	Shallow	Natural recovery	-0.3	0.52	-1.5	no	0.0014	no						
3b	Moderate depth	Natural recovery	-0.6	1.3	-2.2	no	0.00013	no						
4	Deep	Natural recovery	0.0	1.0	NA	yes	0.12	no						
Reference Area Strata														
5a	Shallow	Reference	-0.4	2.7	-6.8	yes	0.12	no						
5b	Moderate depth	Reference	-0.4	1.5	-3.8	no	0.044	no						

Notes:
AOC = area of concern
CV = coefficient of variation
MDD = minimum detectable difference; the absolute difference in means that is detectable at the given power level
TLP = thin layer placement

[a] Normality was evaluated using the Shapiro-Wilk's goodness-of-fit test. Significance level of 0.05 was used.

[b] Statistical tests were performed (and results displayed) only if there was increase in 2007. If data were approximately normal, a paired *t*-test was used for each stratum. If the data were not approximately normal, a nonparametric Wilcoxon test was used. One-tailed comparison-wise alpha is 0.05.

[c] Power is estimated (and result displayed) only for stations with increase over 2004.

Table 18. Trend and Statistical Power Evaluations of Benthic Metrics for Benthic Communities Sampled in 2004 vs. 2007

			Increase 2004 - 2007			Assumption Normality[a]		Increase from 2004?				MDD for Specified Power[c]		
Benthic Stratum	Depth Category	Remediation Category	Mean	Std. Dev.	CV	Pass?	*P*-value	Absolute Increase?	Test[b]	Significant?	*P*-value	60%	70%	80%
Total Abundance - Polychaetes														
AOC Strata														
1	Very shallow	TLP	24	69	2.9	yes	0.95	yes	t-test	no	0.24	74	84	95
2a	Shallow	TLP	112	46	0.41	yes	0.55	yes	t-test	yes	0.008			
3a	Moderate	TLP	53	38	0.73	yes	0.61	yes	t-test	yes	0.010			
2b	Shallow	Natural recovery	-82	278	-3.4	no	0.0012	no						
3b	Moderate	Natural recovery	82	27	0.33	yes	0.058	yes	t-test	yes	0.0012			
4	Deep	Natural recovery	102	60	0.59	yes	0.93	yes	t-test	yes	0.0096			
Reference Area Strata														
5a	Shallow	Reference	-186	178	-0.96	yes	0.77	no						
5b	Moderate	Reference	51	40	0.78	yes	0.068	yes	t-test	yes	0.023			
Total Abundance - Arthropods														
AOC Strata														
1	Very shallow	TLP	0.8	2.3	2.9	yes	0.33	yes	t-test	no	0.24	2.5	2.8	3.1
2a	Shallow	TLP	0.0	2.7	n/a	yes	0.062	no						
3a	Moderate	TLP	1.8	1.8	1.0	yes	0.57	yes	t-test	yes	0.029			
2b	Shallow	Natural recovery	-0.6	1.1	-2.0	no	0.00037	no						
3b	Moderate	Natural recovery	1.6	3.8	2.4	yes	0.43	yes	t-test	no	0.20	4.1	4.6	5.2
4	Deep	Natural recovery	21	45	2.1	no	0.0029	yes	Wilcoxon	no	0.25	49	55	62
Reference Area Strata														
5a	Shallow	Reference	-5.2	6.3	-1.2	yes	0.96	no						
5b	Moderate	Reference	1.0	1.9	1.9	yes	0.45	yes	t-test	no	0.15	2.0	2.3	2.6
Total Abundance - Molluscs														
AOC Strata														
1	Very shallow	TLP	119	159	1.3	yes	0.16	yes	t-test	no	0.085	171	192	219
2a	Shallow	TLP	73	87	1.2	yes	0.34	yes	t-test	no	0.095	114	127	144
3a	Moderate	TLP	75	88	1.2	yes	0.16	yes	t-test	yes	0.046			
2b	Shallow	Natural recovery	4.6	11	2.5	no	0.000046	yes	Wilcoxon	no	0.25	9	11	12
3b	Moderate	Natural recovery	0.2	1.8	8.9	yes	0.38	yes	t-test	no	0.41	1.9	2.2	2.5
4	Deep	Natural recovery	6.0	7.8	1.3	yes	0.29	yes	t-test	no	0.081	8.4	9.5	11

Table 18. Trend and Statistical Power Evaluations of Benthic Metrics for Benthic Communities Sampled in 2004 vs. 2007

			Increase 2004 - 2007			Assumption Normality[a]		Increase from 2004?				MDD for Specified Power[c]		
Benthic Stratum	Depth Category	Remediation Category	Mean	Std. Dev.	CV	Pass?	*P*-value	Absolute Increase?	Test[b]	Significant?	*P*-value	60%	70%	80%
Reference Area Strata														
5a	Shallow	Reference	57	26	0.45	yes	0.28	yes	t-test	yes	0.0039			
5b	Moderate	Reference	-5.8	6.9	-1.2	yes	0.075	no						
Total Richness - Polychaetes														
AOC Strata														
1	Very shallow	TLP	-0.60	9.0	-15	no	0.03	no						
2a	Shallow	TLP	5.5	5.3	0.97	yes	0.41	yes	t-test	no	0.065	7.0	7.8	8.9
3a	Moderate	TLP	-0.83	3.9	-4.7	yes	0.26	no						
2b	Shallow	Natural recovery	-1.0	1.2	-1.2	yes	0.14	no						
3b	Moderate	Natural recovery	0.20	0.45	2.2	no	0.0001	yes	Wilcoxon	no	0.21	0	0.5	0.6
4	Deep	Natural recovery	2.0	4.3	2.2	yes	0.33	yes	t-test	no	0.18	4.6	5.2	5.9
Reference Area Strata														
5a	Shallow	Reference	-6.2	2.9	-0.48	yes	0.85	no						
5b	Moderate	Reference	1.0	5.3	5.3	yes	0.10	yes	t-test	no	0.35	5.7	6.4	7.3
Total Richness - Arthropods														
AOC Strata														
1	Very shallow	TLP	0.80	1.5	1.9	yes	0.78	yes	t-test	no	0.15	1.6	1.8	2.0
2a	Shallow	TLP	0.50	2.4	4.8	yes	0.051	yes	t-test	no	0.35	3.1	3.5	4.0
3a	Moderate	TLP	0.83	1.3	1.6	yes	0.51	yes	t-test	no	0.093	1.2	1.4	1.6
2b	Shallow	Natural recovery	-0.29	0.49	-1.7	no	0.0003	no						
3b	Moderate	Natural recovery	1.2	2.9	2.5	yes	0.14	yes	t-test	no	0.21	3.2	3.6	4.1
4	Deep	Natural recovery	-0.20	2.2	-11	yes	0.75	no						
Reference Area Strata														
5a	Shallow	Reference	-1.6	1.7	-1.0	yes	0.31	no						
5b	Moderate	Reference	1.0	1.2	1.2	yes	0.15	yes	t-test	no	0.071	1.3	1.5	1.7

Table 18. Trend and Statistical Power Evaluations of Benthic Metrics for Benthic Communities Sampled in 2004 vs. 2007

			Increase 2004 - 2007			Assumption Normality[a]		Increase from 2004?				MDD for Specified Power[c]		
Benthic Stratum	Depth Category	Remediation Category	Mean	Std. Dev.	CV	Pass?	*P*-value	Absolute Increase?	Test[b]	Significant?	*P*-value	60%	70%	80%
Total Richness - Molluscs														
AOC Strata														
1	Very shallow	TLP	3.0	2.6	0.88	yes	0.68	yes	t-test	yes	0.032			
2a	Shallow	TLP	4.0	6.7	1.7	yes	0.57	yes	t-test	no	0.16	8.8	10	11
3a	Moderate	TLP	0.7	4.5	6.8	yes	0.79	yes	t-test	no	0.37	4.2	4.8	5.4
2b	Shallow	Natural recovery	0.9	2.0	2.4	no	0.016	yes	Wilcoxon	no	0.25	1.7	1.9	2.2
3b	Moderate	Natural recovery	-0.8	0.8	-1.0	yes	0.31	no						
4	Deep	Natural recovery	2.4	3.5	1.5	yes	0.94	yes	t-test	no	0.10	3.8	4.2	4.8
Reference Area Strata														
5a	Shallow	Reference	0.2	2.6	13	yes	0.38	yes	t-test	no	0.44	2.8	3.1	3.6
5b	Moderate	Reference	-1.6	1.9	-1.2	no	0.018	no						

Notes:

AOC = area of concern

CV = coefficient of variation

MDD = minimum detectable difference; the absolute difference in means that is detectable at the given power level

TLP = thin layer placement

[a] Normality was evaluated using the Shapiro-Wilk's goodness-of-fit test. Significance level of 0.05 was used.

[b] Statistical tests were only performed if there was increase in 2007. If data were approximately normal, a one-tailed paired *t*-test was used for each stratum. If the data were not approximately normal, a one-tailed nonparametric Wilcoxon test was used. Alpha = 0.05.

[c] Power is estimated only for stations with increase over 2004 that was not statistically significant, based on a paired *t*-test. When the assumptions of the paired *t*-test are not met, the displayed MDD represents an upper bound of the MDD for the Wilcoxon test.

APPENDIX A

DATA COLLECTED DURING THE 2007 SAMPLING EVENT

Table A-1. Chemicals of Concern in Surface Sediments Collected in Ward Cove in July 2007

Benthic Stratum	Depth Category (ft MLLW)	Remediation Category	Station	Date	Field Replicate	Sample Number	Ammonia (mg/kg dry)	4-Methylphenol (µg/kg dry)[a]
AOC Strata								
1	Very shallow (<20)	TLP	5	7/10/2007		SD0026	4.9	14
			66	7/10/2007		SD0019	3.6	2.2
			67	7/9/2007		SD0015	1.7	3.7
			68	7/10/2007		SD0021	2.7	46
			69	7/10/2007		SD0020	4.7	4.9
2a	Shallow (20–70)	TLP	9	7/10/2007		SD0023	2.4	10
			72	7/10/2007		SD0022	12	18
			73	7/9/2007		SD0018	3.5	27
			74	7/14/2007	1	SD0054	3.1	330
					2	SD0055	3.4	160
3a	Moderate depth	TLP	8	7/10/2007		SD0025	5.8	20
			48	7/11/2007		SD0030	5.6	8.0
			83	7/10/2007		SD0024	4.9	6.1
			84	7/11/2007		SD0027	6.4	130
			93	7/11/2007		SD0028	3.6	27
			94	7/11/2007		SD0029	7.6	50
2b	Shallow (20–70)	Natural recovery	38	7/14/2007		SD0061	35	5,100
			70	7/11/2007		SD0033	12	720
			71	7/11/2007		SD0032	51	450
			75	7/7/2007		SD0005	29	1,300
			76	7/7/2007		SD0004	43	5,600
			77	7/12/2007		SD0038	31	25,000
			78	7/12/2007		SD0039	22	19,000
3b	Moderate depth	Natural recovery	6	7/12/2007		SD0037	96	14,000
			79	7/14/2007		SD0059	52	3,500
			80	7/12/2007	1	SD0034	120	860
					2	SD0035	130	1,200
			81	7/14/2007		SD0058	41	5,600
			82	7/14/2007		SD0060	190	8,000
4	Deep (>120)	Natural recovery	13	7/11/2007		SD0031	25	110
			85	7/12/2007		SD0036	20	370
			86	7/8/2007		SD0008	40	290

Table A-1. Chemicals of Concern in Surface Sediments Collected in Ward Cove in July 2007

Benthic Stratum	Depth Category (ft MLLW)	Remediation Category	Station	Date	Field Replicate	Sample Number	Ammonia (mg/kg dry)	4-Methylphenol (µg/kg dry)[a]
			87	7/14/2007		SD0057	89	1,600
			88	7/14/2007		SD0056	230	1,600
Reference Area Strata								
5a	Shallow (20–70)	--	96A	7/12/2007		SD0040	29	79
			96B	7/12/2007		SD0041	13	29
			96C	7/12/2007		SD0042	35	39
			96D	7/12/2007		SD0043	41	57
			96E	7/13/2007		SD0044	23	38
5b	Moderate depth	--	95A	7/13/2007		SD0047	84	550
			95B	7/13/2007		SD0048	60	300
			95C	7/13/2007		SD0049	57	550
			95D	7/13/2007		SD0050	35	250
			95E	7/13/2007		SD0051	75	300

Notes:
TLP = thin layer placement
MLLW = mean lower low water

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

Table A-2. Conventional Analytes in Surface Sediments Collected in Ward Cove in July 2007

Benthic Stratum	Depth Category (ft MLLW)	Remediation Category	Station	Sampling Date	Sample Number	Field Replicate	Total Organic Carbon (percent)	Percent Fines (percent)	Total Solids (percent)
AOC Strata									
1	Very shallow (<20)	TLP	5	7/10/2007	SD0026		2.1	4.4	73
			66	7/10/2007	SD0019		0.27	1.8	83
			67	7/9/2007	SD0015		0.50	3.0	84
			68	7/10/2007	SD0021		1.2	3.1	74
			69	7/10/2007	SD0020		0.49	2.4	79
2a	Shallow (20–70)	TLP	9	7/10/2007	SD0023		0.98	1.5	79
			72	7/10/2007	SD0022		2.6	8.8	58
			73	7/9/2007	SD0018		1.0	4.3	77
			74	7/14/2007	SD0054	1	1.1	3.5	77
					SD0055	2	1.0	3.4	80
3a	Moderate depth (70–120)	TLP	8	7/10/2007	SD0025		1.8	6.2	68
			48	7/11/2007	SD0030		0.53	2.6	77
			83	7/10/2007	SD0024		0.47	2.3	75
			84	7/11/2007	SD0027		2.4	9.8	58
			93	7/11/2007	SD0028		0.77	3.0	72
			94	7/11/2007	SD0029		2.0	9.3	61
2b	Shallow	Natural recovery	38	7/14/2007	SD0061		16	57	20
			70	7/11/2007	SD0033		6.2	20	44
			71	7/11/2007	SD0032		14	36	28
			75	7/7/2007	SD0005		5.3	43	35
			76	7/7/2007	SD0004		31	31	18
			77	7/12/2007	SD0038		31	33	18
			78	7/12/2007	SD0039		23	26	21
3b	Moderate depth (70–120)	Natural recovery	6	7/12/2007	SD0037		22	46	15
			79	7/14/2007	SD0059		16	46	18
			80	7/12/2007	SD0034	1	13	73	13
					SD0035	2	13	72	13
			81	7/14/2007	SD0058		17	52	16
			82	7/14/2007	SD0060		17	53	15
4	Deep (>120)	Natural recovery	13	7/11/2007	SD0031		20	67	15
			85	7/12/2007	SD0036		18	59	16
			86	7/8/2007	SD0008		17	59	17

Table A-2. Conventional Analytes in Surface Sediments Collected in Ward Cove in July 2007

Benthic Stratum	Depth Category (ft MLLW)	Remediation Category	Station	Sampling Date	Sample Number	Field Replicate	Total Organic Carbon (percent)	Percent Fines (percent)	Total Solids (percent)
			87	7/14/2007	SD0057		17	64	16
			88	7/14/2007	SD0056		16	67	16
Reference Area Strata									
5a	Shallow	--	96A	7/12/2007	SD0040		18	45	18
	(20–70)		96B	7/12/2007	SD0041		23	48	17
			96C	7/12/2007	SD0042		21	39	18
			96D	7/12/2007	SD0043		23	36	19
			96E	7/13/2007	SD0044		21	52	18
5b	Moderate depth	--	95A	7/13/2007	SD0047		16	55	19
	(70–120)		95B	7/13/2007	SD0048		14	55	18
			95C	7/13/2007	SD0049		13	56	16
			95D	7/13/2007	SD0050		15	53	24
			95E	7/13/2007	SD0051		15	53	18

Notes:
TLP = thin layer placement
MLLW = mean lower low water

Table A-3. Original Data for Amphipod (*Eohaustorius estuarius*) Sediment Toxicity Test Conducted for Ward Cove in July 2007

Station	Benthic Strata	Depth Category	Remediation Category	Sample Number	Sampling Date	Replicate	Number of Survivors	Survival (percent)	Total Emergence	Reburial (percent)
AOC Strata										
5	1	Very shallow	TLP	SD0026	7/10/2007	1	20	100	3	100
66	1	Very shallow	TLP	SD0019	7/10/2007	1	19	95	8	100
67	1	Very shallow	TLP	SD0015	7/9/2007	1	19	95	7	100
68	1	Very shallow	TLP	SD0021	7/10/2007	1	18	90	6	100
69	1	Very shallow	TLP	SD0020	7/10/2007	1	18	90	2	100
9	2a	Shallow	TLP	SD0023	7/10/2007	1	17	85	3	100
9	2a	Shallow	TLP	SD0023	7/10/2007	2	18	90	8	100
9	2a	Shallow	TLP	SD0023	7/10/2007	3	20	100	3	100
9	2a	Shallow	TLP	SD0023	7/10/2007	4	20	100	1	100
9	2a	Shallow	TLP	SD0023	7/10/2007	5	19	95	1	100
72	2a	Shallow	TLP	SD0022	7/10/2007	1	17	85	2	100
73	2a	Shallow	TLP	SD0018	7/9/2007	1	20	100	5	100
74	2a	Shallow	TLP	SD0054	7/14/2007	1	18	90	8	100
8	3a	Moderate depth	TLP	SD0025	7/10/2007	1	19	95	0	100
8	3a	Moderate depth	TLP	SD0025	7/10/2007	2	20	100	0	100
8	3a	Moderate depth	TLP	SD0025	7/10/2007	3	20	100	0	100
8	3a	Moderate depth	TLP	SD0025	7/10/2007	4	18	90	5	100
8	3a	Moderate depth	TLP	SD0025	7/10/2007	5	19	95	2	100
48	3a	Moderate depth	TLP	SD0030	7/11/2007	1	20	100	5	100
83	3a	Moderate depth	TLP	SD0024	7/10/2007	1	18	90	0	100
84	3a	Moderate depth	TLP	SD0027	7/11/2007	1	20	100	1	100
93	3a	Moderate depth	TLP	SD0028	7/11/2007	1	17	85	1	100
94	3a	Moderate depth	TLP	SD0029	7/11/2007	1	20	100	0	100
38	2b	Shallow	Natural recovery	SD0061	7/14/2007	1	19	95	10	100
38	2b	Shallow	Natural recovery	SD0061	7/14/2007	2	20	100	2	100
38	2b	Shallow	Natural recovery	SD0061	7/14/2007	3	19	95	2	100
38	2b	Shallow	Natural recovery	SD0061	7/14/2007	4	20	100	4	100
38	2b	Shallow	Natural recovery	SD0061	7/14/2007	5	20	100	9	100
70	2b	Shallow	Natural recovery	SD0033	7/11/2007	1	17	85	19	100
71	2b	Shallow	Natural recovery	SD0032	7/11/2007	1	14	70	13	100
75	2b	Shallow	Natural recovery	SD0005	7/7/2007	1	17	85	4	100
76	2b	Shallow	Natural recovery	SD0004	7/7/2007	1	20	100	17	100
77	2b	Shallow	Natural recovery	SD0038	7/12/2007	1	18	90	12	100
78	2b	Shallow	Natural recovery	SD0039	7/12/2007	1	18	90	3	100
6	3b	Moderate depth	Natural recovery	SD0037	7/12/2007	1	19	95	4	100

Table A-3. Original Data for Amphipod (*Eohaustorius estuarius*) Sediment Toxicity Test Conducted for Ward Cove in July 2007

Station	Benthic Strata	Depth Category	Remediation Category	Sample Number	Sampling Date	Replicate	Number of Survivors	Survival (percent)	Total Emergence	Reburial (percent)
79	3b	Moderate depth	Natural recovery	SD0059	7/14/2007	1	19	95	2	100
80	3b	Moderate depth	Natural recovery	SD0034	7/12/2007	1	20	100	1	100
81	3b	Moderate depth	Natural recovery	SD0058	7/14/2007	1	20	100	0	100
82	3b	Moderate depth	Natural recovery	SD0060	7/14/2007	1	18	90	5	100
13	4	Deep	Natural recovery	SD0031	7/11/2007	1	20	100	0	100
13	4	Deep	Natural recovery	SD0031	7/11/2007	2	19	95	0	100
13	4	Deep	Natural recovery	SD0031	7/11/2007	3	18	90	0	100
13	4	Deep	Natural recovery	SD0031	7/11/2007	4	20	100	2	89
13	4	Deep	Natural recovery	SD0031	7/11/2007	5	19	95	2	100
85	4	Deep	Natural recovery	SD0036	7/12/2007	1	18	90	6	0
86	4	Deep	Natural recovery	SD0008	7/8/2007	1	20	100	0	100
87	4	Deep	Natural recovery	SD0057	7/14/2007	1	13	65	0	100
88	4	Deep	Natural recovery	SD0056	7/14/2007	1	10	50	1	100
Reference Area Strata										
96A	5a	Shallow	--	SD0040	7/12/2007	1	19	95	1	100
96B	5a	Shallow	--	SD0041	7/12/2007	1	20	100	2	100
96C	5a	Shallow	--	SD0042	7/12/2007	1	19	95	2	100
96D	5a	Shallow	--	SD0043	7/12/2007	1	20	100	0	100
96E	5a	Shallow	--	SD0044	7/13/2007	1	20	100	4	100
95A	5b	Moderate depth	--	SD0047	7/13/2007	1	17	85	8	100
95B	5b	Moderate depth	--	SD0048	7/13/2007	1	18	90	1	100
95C	5b	Moderate depth	--	SD0049	7/13/2007	1	20	100	2	100
95D	5b	Moderate depth	--	SD0050	7/13/2007	1	20	100	1	100
95E	5b	Moderate depth	--	SD0051	7/13/2007	1	18	90	3	100

Notes:

TLP = thin layer placement

[a] Twenty individuals per replicate were used.

Table A-4. Summary of Benthic Metrics for Benthic Macroinvertebrate Communities Sampled in Ward Cove in July 2007

Benthic Stratum	Depth Category	Remediation Category	Station	Sample	Total Abundance[a]	Total Richness[a]	SDI
AOC Strata							
1	Very shallow	TLP	5	BI0024	236	18	4
			66	BI0017	259	29	8
			67	BI0014	208	25	7
			68	BI0019	301	23	7
			69	BI0018	606	29	4
				Mean	322	24.8	6.0
				SD	162	4.6	1.9
				SE	72.6	2.1	0.84
2a	Shallow	TLP	9	BI0021	347	36	8
			72	BI0020	173	5	1
			73	BI0016	189	23	4
			74	BI0051	229	31	7
				Mean	234.5	23.8	5.0
				SD	78.6	13.6	3.2
				SE	39.3	6.8	1.6
3a	Moderate depth	TLP	8	BI0023	35	4	1
			48	BI0028	351	33	4
			83	BI0022	235	29	6
			84	BI0025	97	14	4
			93	BI0028	349	26	5
			94	BI0029	88	15	3
				Mean	192.5	20.2	3.8
				SD	138.8	11.0	1.7
				SE	56.6	4.5	0.7
2b	Shallow	Natural recovery	38	BI0057	45	2	1
			70	BI0031	16	1	1
			71	BI0030	41	2	1
			75	BI0005	171	7	1
			76	BI0004	36	2	2
			77	BI0035	0	0	NA
			78	BI0036	263	6	1
				Mean	82	2.9	1.2
				SD	97	2.6	0.41
				SE	37	0.99	0.17
3b	Moderate depth	Natural recovery	6	BI0034	39	2	1
			79	BI0055	117	1	1
			80	BI0032	111	4	1
			81	BI0054	126	11	1
			82	BI0056	123	2	1
				Mean	103.2	4.0	1.0
				SD	36.3	4.1	0.0
				SE	16.3	1.82	0.0

Table A-4. Summary of Benthic Metrics for Benthic Macroinvertebrate Communities Sampled in Ward Cove in July 2007

Benthic Stratum	Depth Category	Remediation Category	Station	Sample	Total Abundance[a]	Total Richness[a]	SDI
4	Deep	Natural recovery	13	BI0029	107	8	1
			85	BI0033	38	1	1
			86	BI0008	246	16	3
			87	BI0053	126	3	1
			88	BI0052	223	20	2
				Mean	148.0	9.6	1.6
				SD	85.9	8.2	0.89
				SE	38.4	3.67	0.40
Reference Area Strata							
5a	Shallow	--	96A	BI0037	186	13	3
			96B	BI0038	245	20	4
			96C	BI0039	256	15	2
			96D	BI0040	112	14	3
			96E	BI0041	155	17	4
				Mean	191	15.8	3.2
				SD	61	2.8	0.84
				SE	27	1.2	0.37
5b	Moderate depth	--	95A	BI0044	114	18	3
			95B	BI0045	86	4	1
			95C	BI0046	84	4	1
			95D	BI0047	70	2	1
			95E	BI0048	12	3	1
				Mean	73.2	6.2	1.4
				SD	37.8	6.6	0.89
				SE	16.9	3.0	0.40

Notes:
SD = standard deviation
SDI = Swartz' dominance index
SE = standard error
TLP = thin layer placement
NA = not applicable

[a] Per 0.06-m^2 sample.

Table A-5. Summary of Major Taxa Abundance for Benthic Macroinvertebrate Communities Sampled in Ward Cove in July 2007

Benthic Stratum	Depth Category	Remediation Category	Station	Sample	Abundance[a] Mollusca	Polychaeta	Arthropoda
AOC Strata							
1	Very shallow	Thin capping	5	BI0024	160	75	2
			66	BI0017	167	89	3
			67	BI0014	83	124	1
			68	BI0019	193	106	2
			69	BI0018	458	143	5
				Mean	212	107	2.6
				SD	143	27	1.5
				SE	64	12	0.7
2a	Shallow	Thin capping	9	BI0021	191	155	1
			72	BI0020	0	173	0
			73	BI0016	101	87	1
			74	BI0051	127	93	6
				Mean	105	127	2.0
				SD	79	43	2.7
				SE	40	22	1.4
3a	Moderate	Thin capping	8	BI0023	2	33	0
			48	BI0028	257	90	2
			83	BI0022	146	87	2
			84	BI0025	17	74	6
			93	BI0028	204	141	4
			94	BI0029	28	54	6
				Mean	109	80	3.3
				SD	108	37	2.4
				SE	44	15	0.99
2b	Shallow	Natural recovery	38	BI0057	0	45	0
			70	BI0031	0	16	0
			71	BI0030	0	41	0
			75	BI0005	30	141	0
			76	BI0004	0	36	0
			77	BI0035	0	0	0
			78	BI0036	3	260	0
				Mean	4.7	77	0
				SD	11	92	0
				SE	4.2	35	0
3b	Moderate	Natural recovery	6	BI0034	0	39	0
			79	BI0055	0	117	0
			80	BI0032	4	103	4
			81	BI0054	3	113	9
			82	BI0056	0	123	0
				Mean	1.4	99	2.6
				SD	1.9	34	4.0
				SE	0.87	15	1.8

Table A-5. Summary of Major Taxa Abundance for Benthic Macroinvertebrate Communities Sampled in Ward Cove in July 2007

Benthic Stratum	Depth Category	Remediation Category	Station	Sample	Abundance[a] Mollusca	Abundance[a] Polychaeta	Abundance[a] Arthropoda
4	Deep	Natural recovery	13	BI0029	6	97	4
			85	BI0033	0	38	0
			86	BI0008	4	138	104
			87	BI0053	5	121	0
			88	BI0052	20	186	10
				Mean	7.0	116	24
				SD	7.6	54	45
				SE	3.4	24	20
Reference Area Strata							
5a	Shallow	--	96A	BI0037	104	77	5
			96B	BI0038	63	173	4
			96C	BI0039	46	207	1
			96D	BI0040	81	31	0
			96E	BI0041	67	85	0
				Mean	72	115	2.0
				SD	22	73	2.3
				SE	9.7	33	1.0
5b	Moderate	--	95A	BI0044	7	100	4
			95B	BI0045	0	83	3
			95C	BI0046	0	82	2
			95D	BI0047	0	69	1
			95E	BI0048	1	10	1
				Mean	1.6	69	2.2
				SD	3.0	35	1.3
				SE	1.4	16	0.58

Notes:
SD = standard deviation
SE = standard error
TLP = thin layer placement

[a] Per 0.06-m^2 sample.

Table A-6. Summary of Taxa Richness for Major Taxa for Benthic Macroinvertebrate Communities Sampled in Ward Cove in July 2007

Benthic Stratum	Depth Category	Remediation Category	Station	Sample	Richness[a] Mollusca	Richness[a] Polychaeta	Richness[a] Arthropoda
AOC Strata							
1	Very	Thin capping	5	BI0024	7	10	2
			66	BI0017	14	12	3
			67	BI0014	8	16	1
			68	BI0019	11	10	2
			69	BI0018	13	13	3
				Mean	11	12	2.2
				SD	3.0	2.5	0.8
				SE	1.4	1.1	0.37
2a	Shallow	Thin capping	9	BI0021	17	18	1
			72	BI0020	0	5	0
			73	BI0016	9	13	1
			74	BI0051	12	12	5
				Mean	9.5	12	1.8
				SD	7.1	5.4	2.2
				SE	3.6	2.7	1.1
3a	Moderate	Thin capping	8	BI0023	2	2	0
			48	BI0028	16	14	2
			83	BI0022	10	17	2
			84	BI0025	2	9	3
			93	BI0028	9	14	3
			94	BI0029	5	6	4
				Mean	7.3	10	2.3
				SD	5.4	5.7	1.4
				SE	2.2	2.3	0.56
2b	Shallow	Natural recovery	38	BI0057	0	2	0
			70	BI0031	0	1	0
			71	BI0030	0	2	0
			75	BI0005	5	2	0
			76	BI0004	0	2	0
			77	BI0035	0	0	0
			78	BI0036	2	4	0
				Mean	1.0	1.9	0.0
				SD	1.9	1.2	0.0
				SE	0.72	0.46	0.0
3b	Moderate	Natural recovery	6	BI0034	0	2	0
			79	BI0055	0	1	0
			80	BI0032	1	1	2
			81	BI0054	1	1	8
			82	BI0056	0	2	0
				Mean	0.40	1.4	2.0
				SD	0.55	0.55	3.5
				SE	0.24	0.24	1.5

Table A-6. Summary of Taxa Richness for Major Taxa for Benthic Macroinvertebrate Communities Sampled in Ward Cove in July 2007

Benthic Stratum	Depth Category	Remediation Category	Station	Sample	Richness[a] Mollusca	Richness[a] Polychaeta	Richness[a] Arthropoda
4	Deep	Natural recovery	13	BI0029	3	4	1
			85	BI0033	0	1	0
			86	BI0008	4	7	5
			87	BI0053	2	1	0
			88	BI0052	8	8	1
				Mean	3.4	4.2	1.4
				SD	3.0	3.3	2.1
				SE	1.3	1.5	0.93
Reference Area Strata							
5a	Shallow	--	96A	BI0037	4	8	1
			96B	BI0038	4	12	2
			96C	BI0039	7	6	1
			96D	BI0040	5	9	0
			96E	BI0041	7	7	0
				Mean	5.4	8.4	0.80
				SD	1.5	2.3	0.84
				SE	0.68	1.0	0.37
5b	Moderate	--	95A	BI0044	2	11	3
			95B	BI0045	0	2	2
			95C	BI0046	0	2	2
			95D	BI0047	0	1	1
			95E	BI0048	1	1	1
				Mean	0.60	3.4	1.8
				SD	0.89	4.3	0.84
				SE	0.40	1.9	0.37

Notes:
SD = standard deviation
SE = standard error
TLP = thin layer placement

[a] Per 0.06-m^2 sample.

Table A-7. Abundances (per 0.06-m^2 sample) of Benthic Macroinvertebrate Taxa Collected at Ward Cove AOC and Reference Areas in July 2007

					Stratum 1					Stratum 2a				Stratum 3a						Stratum 2b						
					Very Shallow, TLP (<20 ft)					Shallow, TLP (20-70 ft)				Moderate Depth, TLP (70-120 ft)						Shallow, Natural Recovery (20-70 ft)						
					Station Number					Station Number				Station Number						Station Number						
Phylum	Class	Order	Family	Genus/species	5	66	67	68	69	9	72	73	74	8	48	83	84	93	94	38	70	71	75	76	77	78
Mollusca	Gastropoda	Neotaenioglossa	Rissoidae	*Alvania compacta*					1	1			3													
			Capulidae	*Trichotropis cancellata*																						
		Neogastropoda	Columbellidae	*Astyris gausapata*						3		3	2		2	7	11	3								
			Nassariidae	*Nassarius mendicus*					1	2			3													
			Conidae	*Kurtzia arteaga*					2																	
				Oenopota fidicula														1								
				Oenopota harpa		1	2								1	1										
				Oenopota turricula									1													
		Heterostropha	Pyramidellidae	*Turbonilla* spp.		2		1	3	1					1											
		Cephalaspidea	Cylichnidae	*Acteocina eximia*						2		1			4	1		1					3			
				Cylichna attonsa											1											
			Aglajidae	*Aglaja ocelligera*																						
				Melanochlamys diomedea												1										
			Gastropteridae	*Gastropteron pacificum*																						
		Nudibranchia	Onchidorididae	*Onchidoris* spp.																						
	Bivalvia	Mytiloida	Mytilidae	*Acila castrensis*																						
				Mytilus spp.	1																		1			
				Solamen columianum						4					1			5								
		Veneroida	Lucinidae	*Parvilucina tenuisculpta*	48	44	31	65	163	102		62	62		144	107		117	17				4			
			Thyasiridae	*Axinopsida serricata*	17	51	12	63	177	52		28	42	1	86	22	6	67	7							
				Thyasira flexuosa						1					4	1		6								
			Lasaeidae	*Rochefortia tumida*	87	11	25	34	92			3			1											2
			Cardiidae	*Clinocardium nuttalli*		10		2	1																	
				Lucinoma annulatum														2								
			Veneridae	*Compsomyax subdiaphana*						5		1	1		4											
				Nutricola lordi						6																
				Protothaca staminea		3	1	6	4	1		1														
				Saxidomus gigantea		3	2	3	2																	
			Tellinidae	*Macoma carlottensis*									3	1	2	2			2							1
				Macoma elimata		1																				
				Macoma golikovi	5	1	8	5	2				1													
				Macoma inquinata																			15			
				Macoma nasuta	1	9	2	4	3			1	2		1											
				Macoma spp.		3																				
				Tellina modesta	1	27		9	7	2		1	5		3	2							7			
		Myoida	Hiatellidae	*Hiatella arctica*																						
			Myidae	*Mya arenaria*						1					1											
		Pholadomyoida	Pandoridae	*Pandora filosa*						2			2		1											
			Lyonsiidae	*Lyonsia californica*		1		1		5						2		2								
		Neritoida	Neritidae	*Margarites helicinus*															1							
				Margarites pupillus															1							
		Solemyoida	Solemyidae	*Solemya reidi*																						
		Nuculoida	Yoldiidae	*Yoldia hyperborea*						1																
				Yoldia seminuda																						
Annelida	Polychaeta	Orbiniida	Orbiniidae	*Leitoscoloplos pugettensis*	10	18	9	20	26	10		20	11		7	24	11	10	2							
		Canalipalpata	Spionidae	*Paraprionospio pinnata*							1															
				Prionospio multibranchiata																						

Table A-7. Abundances (per 0.06-m^2 sample) of Benthic Macroinvertebrate Taxa Collected at Ward Cove AOC and Reference Areas in July 2007

					Stratum 1					Stratum 2a				Stratum 3a						Stratum 2b						
					Very Shallow, TLP (<20 ft) Station Number					Shallow, TLP (20-70 ft) Station Number				Moderate Depth, TLP (70-120 ft) Station Number						Shallow, Natural Recovery (20-70 ft) Station Number						
Phylum	Class	Order	Family	Genus/species	5	66	67	68	69	9	72	73	74	8	48	83	84	93	94	38	70	71	75	76	77	78
				Prionospio spp.																						
				Prionospio steenstrupi	25	11	47	18	22			3			1											
				Spio spp.		2			3	13		3	30		16	10		26								
				Spiochaetopterus pottsi						15			5		6	4	2	6								
				Spiophanes berkeleyorum												2										
				Polydora spp.									2													
		Capitellida	Capitellidae	*Capitella capitata* complex			3												46	4			2	26		
				Decamastus spp.											11	10		24								
				Mediomastus spp.		1				4																
			Maldanidae			1	1	7		10		1	4			2										
		Opheliida	Opheliidae	*Armandia brevis*			2		1																	
		Phyllodocida	Phyllodocidae	*Eteone* spp.			1			1			1		3	1	1									2
			Polynoidae																							
			Pholoidae	*Pholoe* spp.	2										1											
				Pholoides asperus														1								
			Hesionidae	*Ophiodromus pugettensis*			1																			
				Podarkeopsis glabrus																						
			Nereididae	*Platynereis bicanaliculata*																						
			Glyceridae	*Glycera americana*	1	2		2	4	5		1		1		1		2								
				Glycera nana	1	5	2	5	1	2		1			4	2	1	2								
			Goniadidae	*Glycinde picta*	10	23	11	17	17	4	1	1			3	3	1	1								
			Nephtyidae	*Nephtys cornuta*			1		1		169	33	16	32	3		46		3	41	16	40	139			
				Nephtys ferruginea	2	4		2	3	13		9	5		7	10		9								
				Nephtys spp.			2									1										
		Eunicida	Lumbrineridae		6	9	5	19	42	23	1	10	8		5	10	7	5	1			1				
				Lumbrineris californiensis		8		15	20	3																
				Scoletoma luti																						
			Dorvilleidae	*Dorvillea annulata*	15		19												1					10		227
				Dorvillea spp.																						30
		Oweniida	Oweniidae	*Galathowenia oculata*						40		3	9		22			51								
				Owenia fusiformis			15		1	3			1					1								
		Terebellida	Pectinariidae	*Pectinaria californiensis*						1		1					2									
				Pectinaria granulata			2					1	1													
			Ampharetidae							3																
				Amphicteis scaphobranchiata														1								
				Amphicteis spp.												2										
			Terebellidae	*Polycirrus* sp. complex							1						3									1
			Sabellidae	*Eudistylia catharinae*																						
		Canalipalpata	Flabelligeridae													1										
			Magelonidae	*Magelona longicornis*						2						1										
		Aciculata	Nereididae	*Nereis procera*	3											3										
				Nereis spp.		5	3	1	2	3					1				1							
		Sabellida	Sabellidae															2								
		Phyllodocida	Syllidae	*Typosyllis heterochaeta*																						
Arthropoda	Malacostraca	Cumacea	Diastylidae	*Diastylis alaskensis*		1	1	1	2				1				1	1								
				Leptostylis spp.									1													
		Tanaidacea	Leptocheliidae	*Leptochelia dubia*											1											

Table A-7. Abundances (per 0.06-m^2 sample) of Benthic Macroinvertebrate Taxa Collected at Ward Cove AOC and Reference Areas in July 2007

					Stratum 1					Stratum 2a				Stratum 3a						Stratum 2b						
					Very Shallow, TLP (<20 ft) Station Number					Shallow, TLP (20-70 ft) Station Number				Moderate Depth, TLP (70-120 ft) Station Number						Shallow, Natural Recovery (20-70 ft) Station Number						
Phylum	Class	Order	Family	Genus/species	5	66	67	68	69	9	72	73	74	8	48	83	84	93	94	38	70	71	75	76	77	78
		Isopoda	Limnoriidae	*Limnoria lignorum*																						
		Amphipoda	Oedicerotidae	*Oedicerotidae*		1																				
				Monoculodes spp.									1			1										
				Westwoodilla caecula									2		1											
			Phoxocephalidae	*Foxiphalus similis*																						
			Lysianassidae	*Orchomene* spp.													1									
			Amphitoidae	*Amphithoe* spp.																						
			Aoridae	*Aoroides* spp.															2							
			Corophiidae	*Corophium* spp.																						
			Podoceridae	*Dyopedos articus*																						
			Lysianassidae																							
			Melitidae	*Maera desdichada*															1							
			Opisidae	*Opisa tridentata*														2								
			Gammaridea	*Deflexilodes enigmaticus*								1														
				Peramphithoe spp.															1							
		Decapoda	Crangonidae	*Crangonidae*		1		1	2				1													
			Paguridae	*Pagurus armatus*														1								
			Majidae						1																	
			Pinnotheridae													1										
				Pinnixa spp.	1												4									
			Hippolytidae																2							
		Cumacea	Leuconidae							1																
	Ostracoda	Myodocopida	Philomedidae	*Euphilomedes producta*																						
Echinodermata	Ophiuroidea	Ophiurida																								
			Amphiuridae										1													
				Amphipholis spp.																						
	Stelleroidea	Ophiurida	Ophiuridae	*Ophiura luetkeni*																						
				Ophiura spp.																						
Nemertea	Anopla	Heteronemertea	Lineidae	*Micrura* spp.											2											
				Zygeupolia spp.																						
		Paleonemertea	Tubulanidae	*Tubulanus* spp.																						
				Tubulanus polymorphus									2													
	Enopla	Hoplonemertea	Emplectonematidae	*Paranemertes californica*																						
Chordata	Ascidiacea	Pleurogona	Styelidae	*Styela gibbsii*																						
Porifera	Demospongiae																									
Cnidaria	Anthozoa	Actiniaria	Metridiidae	*Metridium senile*																						
				*Total Number of Organisms** *(* per replicate)*	236	259	208	301	606	347	173	189	229	35	351	235	97	349	88	45	16	41	171	36	0	263

Note:
[a] Extra reference station counts are not included in the calculation of total number of organisms

Table A-7. Abundances (per 0.06-m^2 sample) of Benthic Macroinvertebrate Taxa Collected at Ward Cove AOC and Reference Areas in July 2007

					Stratum 3b Moderate Depth, Natural Recovery (70-120 ft) Station Number					Stratum 4 Deep, Natural Recovery (>120 ft) Station Number					Stratum 5a[a] Reference--Shallow (20-70 ft) Station Number							Stratum 5b[a] Reference--Moderate Depth (70-120 ft) Station Number						
Phylum	Class	Order	Family	Genus/species	6	79	80	81	82	13	85	86	87	88	96A	96B	96C	96D	96E	96F	96G	95A	95B	95C	95D	95E	95F	95G
Mollusca	Gastropoda	Neotaenioglossa	Rissoidae	*Alvania compacta*				3																				
			Capulidae	*Trichotropis cancellata*													1											
		Neogastropoda	Columbellidae	*Astyris gausapata*			4			4			4	12								5					3	8
			Nassariidae	*Nassarius mendicus*																								
			Conidae	*Kurtzia arteaga*																								
				Oenopota fidicula																								
				Oenopota harpa																								
				Oenopota turricula																								
		Heterostropha	Pyramidellidae	*Turbonilla* spp.																								
		Cephalaspidea	Cylichnidae	*Acteocina eximia*																								
				Cylichna attonsa																								
			Aglajidae	*Aglaja ocelligera*						1		1		1														
				Melanochlamys diomedea																								
			Gastropteridae	*Gastropteron pacificum*																	1					1	1	
		Nudibranchia	Onchidorididae	*Onchidoris* spp.															1									
	Bivalvia	Mytiloida	Mytilidae	*Acila castrensis*										1														
				Mytilus spp.																								
				Solamen columianum																								
		Veneroida	Lucinidae	*Parvilucina tenuisculpta*									1	1	41	42	35	38		39	48							
			Thyasiridae	*Axinopsida serricata*						1		1		1	3			1		2	3							
				Thyasira flexuosa																								
			Lasaeidae	*Rochefortia tumida*								1			59	11	3	38	32	7	36							
			Cardiidae	*Clinocardium nuttalli*																								
				Lucinoma annulatum											1													
			Veneridae	*Compsomyax subdiaphana*																								
				Nutricola lordi																								
				Protothaca staminea																								
				Saxidomus gigantea															1		1							
			Tellinidae	*Macoma carlottensis*										2						1								
				Macoma elimata																								
				Macoma golikovi												1	1											
				Macoma inquinata																								
				Macoma nasuta												9	1		1		1							
				Macoma spp.													4	3	3									
				Tellina modesta																								
		Myoida	Hiatellidae	*Hiatella arctica*								1					1		4			2						
			Myidae	*Mya arenaria*														1										
		Pholadomyoida	Pandoridae	*Pandora filosa*															25									
			Lyonsiidae	*Lyonsia californica*																								
		Neritoida	Neritidae	*Margarites helicinus*																								
				Margarites pupillus																								
		Solemyoida	Solemyidae	*Solemya reidi*										1														
		Nuculoida	Yoldiidae	*Yoldia hyperborea*																								
				Yoldia seminuda										1														
Annelida	Polychaeta	Orbiniida	Orbiniidae	*Leitoscoloplos pugettensis*																4	1							
		Canalipalpata	Spionidae	*Paraprionospio pinnata*										3								3	6	1			5	2
				Prionospio multibranchiata															1	2								

Table A-7. Abundances (per 0.06-m^2 sample) of Benthic Macroinvertebrate Taxa Collected at Ward Cove AOC and Reference Areas in July 2007

					Stratum 3b Moderate Depth, Natural Recovery (70-120 ft) Station Number					Stratum 4 Deep, Natural Recovery (>120 ft) Station Number					Stratum 5a[a] Reference--Shallow (20-70 ft) Station Number							Stratum 5b[a] Reference--Moderate Depth (70-120 ft) Station Number						
Phylum	Class	Order	Family	Genus/species	6	79	80	81	82	13	85	86	87	88	96A	96B	96C	96D	96E	96F	96G	95A	95B	95C	95D	95E	95F	95G
				Prionospio spp.																2								
				Prionospio steenstrupi																5								
				Spio spp.												1		2	2	1	1							
				Spiochaetopterus pottsi												1					1							
				Spiophanes berkeleyorum																								
				Polydora spp.																								
		Capitellida	Capitellidae	*Capitella capitata* complex					2							28	179	6	36	7								
				Decamastus spp.																								
				Mediomastus spp.																		1						
			Maldanidae																									
		Opheliida	Opheliidae	*Armandia brevis*																								
		Phyllodocida	Phyllodocidae	*Eteone* spp.						1		1		1		6		1		1	2							
			Polynoidae																	1	1							
			Pholoidae	*Pholoe* spp.												3		1	1									
				Pholoides asperus						1		24			1	6			5		2	2						
			Hesionidae	*Ophiodromus pugettensis*											3					6	3	1						
				Podarkeopsis glabrus														1										
			Nereididae	*Platynereis bicanaliculata*																1	1							
			Glyceridae	*Glycera americana*																1	1							
				Glycera nana								1		2	1													
			Goniadidae	*Glycinde picta*											2	6	2		1	1	1							
			Nephtyidae	*Nephtys cornuta*	30	117	103	113	121	94	38	108	121	167	2	1	1			5		74	77	81	69	10	105	81
				Nephtys ferruginea						1																		
				Nephtys spp.																								
		Eunicida	Lumbrineridae											1							4							1
				Lumbrineris californiensis																								
				Scoletoma luti																		1						
			Dorvilleidae	*Dorvillea annulata*	9							1		1	59	105	21	14	39	11	11	2						
				Dorvillea spp.											5	13	2											
		Oweniida	Oweniidae	*Galathowenia oculata*																								
				Owenia fusiformis																								
		Terebellida	Pectinariidae	*Pectinaria californiensis*										1							1							
				Pectinaria granulata														2										
			Ampharetidae																									
				Amphicteis scaphobranchiata																								
				Amphicteis spp.																								
			Terebellidae	*Polycirrus* sp. complex								2		10	4	1	2	3		5	4	1						
			Sabellidae	*Eudistylia catharinae*																		12						
		Canalipalpata	Flabelligeridae									1																
			Magelonidae	*Magelona longicornis*																								
		Aciculata	Nereididae	*Nereis procera*																								
				Nereis spp.												2		1										
		Sabellida	Sabellidae																			2						
		Phyllodocida	Syllidae	*Typosyllis heterochaeta*																		1						
Arthropoda	Malacostraca	Cumacea	Diastylidae	*Diastylis alaskensis*			1	1																1				
				Leptostylis spp.																								
		Tanaidacea	Leptocheliidae	*Leptochelia dubia*																								

Table A-7. Abundances (per 0.06-m^2 sample) of Benthic Macroinvertebrate Taxa Collected at Ward Cove AOC and Reference Areas in July 2007

					Stratum 3b Moderate Depth, Natural Recovery (70-120 ft) Station Number					Stratum 4 Deep, Natural Recovery (>120 ft) Station Number					Stratum 5a[a] Reference--Shallow (20-70 ft) Station Number							Stratum 5b[a] Reference--Moderate Depth (70-120 ft) Station Number						
Phylum	Class	Order	Family	Genus/species	6	79	80	81	82	13	85	86	87	88	96A	96B	96C	96D	96E	96F	96G	95A	95B	95C	95D	95E	95F	95G
		Isopoda	Limnoriidae	*Limnoria lignorum*				1				76					1						1					
		Amphipoda	Oedicerotidae	*Oedicerotidae*																			2					
				Monoculodes spp.			3	1																		1		
				Westwoodilla caecula				2													1						1	
			Phoxocephalidae	*Foxiphalus similis*								1								2	3							
			Lysianassidae	*Orchomene* spp.																				1	1			
			Amphitoidae	*Amphithoe* spp.												1												
			Aoridae	*Aoroides* spp.																								
			Corophiidae	*Corophium* spp.								17																
			Podoceridae	*Dyopedos articus*																		1						
			Lysianassidae					1																				
			Melitidae	*Maera desdichada*																								
			Opisidae	*Opisa tridentata*																								
			Gammaridea	*Deflexilodes enigmaticus*																								
				Peramphithoe spp.																								
		Decapoda	Crangonidae	*Crangonidae*				1																				
			Paguridae	*Pagurus armatus*																								
			Majidae																									
			Pinnotheridae																									
				Pinnixa spp.				1		4		9		10	5	3				2	3	2						
			Hippolytidae					1														1						
		Cumacea	Leuconidae																									
	Ostracoda	Myodocopida	Philomedidae	*Euphilomedes producta*								1																
Echinodermata	Ophiuroidea	Ophiurida												3														
			Amphiuridae																									
				Amphipholis spp.															1									
	Stelleroidea	Ophiurida	Ophiuridae	*Ophiura luetkeni*										2														
				Ophiura spp.										2														
Nemertea	Anopla	Heteronemertea	Lineidae	*Micrura* spp.													2		1		2							
				Zygeupolia spp.												4												
		Paleonemertea	Tubulanidae	*Tubulanus* spp.																	1							
				Tubulanus polymorphus																								
	Enopla	Hoplonemertea	Emplectonematidae	*Paranemertes californica*												1			1									
Chordata	Ascidiacea	Pleurogona	Styelidae	*Styela gibbsii*																		3						
Porifera	Demospongiae																					P						
Cnidaria	Anthozoa	Actiniaria	Metridiidae	*Metridium senile*				1																				
				*Total Number of Organisms** *(* per replicate)*	39	117	111	126	123	107	38	246	126	223	186	245	256	112	155	106	134	114	86	84	70	12	115	92

Note:
[a] Extra reference station counts are not included in the calculation of total number of organisms

Table A-7. Abundances (per 0.06-m^2 sample) of Benthic Macroinvertebrate Taxa Collected at Ward Cove AOC and Reference Areas in July 2007

Phylum	Class	Order	Family	Genus/species	TOTAL # Organisms
Mollusca	Gastropoda	Neotaenioglossa	Rissoidae	*Alvania compacta*	8
			Capulidae	*Trichotropis cancellata*	1
		Neogastropoda	Columbellidae	*Astyris gausapata*	60
			Nassariidae	*Nassarius mendicus*	6
			Conidae	*Kurtzia arteaga*	2
				Oenopota fidicula	1
				Oenopota harpa	5
				Oenopota turricula	1
		Heterostropha	Pyramidellidae	*Turbonilla* spp.	8
		Cephalaspidea	Cylichnidae	*Acteocina eximia*	12
				Cylichna attonsa	1
			Aglajidae	*Aglaja ocelligera*	3
				Melanochlamys diomedea	1
			Gastropteridae	*Gastropteron pacificum*	1
		Nudibranchia	Onchidorididae	*Onchidoris* spp.	1
	Bivalvia	Mytiloida	Mytilidae	*Acila castrensis*	1
				Mytilus spp.	2
				Solamen columianum	10
		Veneroida	Lucinidae	*Parvilucina tenuisculpta*	1124
			Thyasiridae	*Axinopsida serricata*	638
				Thyasira flexuosa	12
			Lasaeidae	*Rochefortia tumida*	399
			Cardiidae	*Clinocardium nuttalli*	13
				Lucinoma annulatum	3
			Veneridae	*Compsomyax subdiaphana*	11
				Nutricola lordi	6
				Protothaca staminea	16
				Saxidomus gigantea	11
			Tellinidae	*Macoma carlottensis*	13
				Macoma elimata	1
				Macoma golikovi	24
				Macoma inquinata	15
				Macoma nasuta	34
				Macoma spp.	13
				Tellina modesta	64
		Myoida	Hiatellidae	*Hiatella arctica*	8
			Myidae	*Mya arenaria*	3
		Pholadomyoida	Pandoridae	*Pandora filosa*	30
			Lyonsiidae	*Lyonsia californica*	11
		Neritoida	Neritidae	*Margarites helicinus*	1
				Margarites pupillus	1
		Solemyoida	Solemyidae	*Solemya reidi*	1
		Nuculoida	Yoldiidae	*Yoldia hyperborea*	1
				Yoldia seminuda	1
Annelida	Polychaeta	Orbiniida	Orbiniidae	*Leitoscoloplos pugettensis*	178
		Canalipalpata	Spionidae	*Paraprionospio pinnata*	14
				Prionospio multibranchiata	1

Table A-7. Abundances (per 0.06-m^2 sample) of Benthic Macroinvertebrate Taxa Collected at Ward Cove AOC and Reference Areas in July 2007

Phylum	Class	Order	Family	Genus/species	TOTAL # Organisms
				Prionospio spp.	0
				Prionospio steenstrupi	127
				Spio spp.	108
				Spiochaetopterus pottsi	39
				Spiophanes berkeleyorum	2
				Polydora spp.	2
		Capitellida	Capitellidae	*Capitella capitata* complex	332
				Decamastus spp.	45
				Mediomastus spp.	6
			Maldanidae		26
		Opheliida	Opheliidae	*Armandia brevis*	3
		Phyllodocida	Phyllodocidae	*Eteone* spp.	20
			Polynoidae		0
			Pholoidae	*Pholoe* spp.	8
				Pholoides asperus	40
			Hesionidae	*Ophiodromus pugettensis*	5
				Podarkeopsis glabrus	1
			Nereididae	*Platynereis bicanaliculata*	0
			Glyceridae	*Glycera americana*	19
				Glycera nana	30
			Goniadidae	*Glycinde picta*	103
			Nephtyidae	*Nephtys cornuta*	1867
				Nephtys ferruginea	65
				Nephtys spp.	3
		Eunicida	Lumbrineridae		153
				Lumbrineris californiensis	46
				Scoletoma luti	1
			Dorvilleidae	*Dorvillea annulata*	523
				Dorvillea spp.	50
		Oweniida	Oweniidae	*Galathowenia oculata*	125
				Owenia fusiformis	21
		Terebellida	Pectinariidae	*Pectinaria californiensis*	5
				Pectinaria granulata	6
			Ampharetidae		3
				Amphicteis scaphobranchiata	1
				Amphicteis spp.	2
			Terebellidae	*Polycirrus* sp. complex	28
			Sabellidae	*Eudistylia catharinae*	12
		Canalipalpata	Flabelligeridae		2
			Magelonidae	*Magelona longicornis*	3
		Aciculata	Nereididae	*Nereis procera*	6
				Nereis spp.	19
		Sabellida	Sabellidae		4
		Phyllodocida	Syllidae	*Typosyllis heterochaeta*	1
Arthropoda	Malacostraca	Cumacea	Diastylidae	*Diastylis alaskensis*	11
				Leptostylis spp.	1
		Tanaidacea	Leptocheliidae	*Leptochelia dubia*	1

Table A-7. Abundances (per 0.06-m^2 sample) of Benthic Macroinvertebrate Taxa Collected at Ward Cove AOC and Reference Areas in July 2007

Phylum	Class	Order	Family	Genus/species	TOTAL # Organisms
		Isopoda	Limnoriidae	*Limnoria lignorum*	79
		Amphipoda	Oedicerotidae	*Oedicerotidae*	3
				Monoculodes spp.	7
				Westwoodilla caecula	5
			Phoxocephalidae	*Foxiphalus similis*	1
			Lysianassidae	*Orchomene* spp.	3
			Amphitoidae	*Amphithoe* spp.	1
			Aoridae	*Aoroides* spp.	2
			Corophiidae	*Corophium* spp.	17
			Podoceridae	*Dyopedos articus*	1
			Lysianassidae		1
			Melitidae	*Maera desdichada*	1
			Opisidae	*Opisa tridentata*	2
			Gammaridea	*Deflexilodes enigmaticus*	
				Peramphithoe spp.	1
		Decapoda	Crangonidae	*Crangonidae*	6
			Paguridae	*Pagurus armatus*	1
			Majidae		1
			Pinnotheridae		1
				Pinnixa spp.	39
			Hippolytidae		4
		Cumacea	Leuconidae		1
	Ostracoda	Myodocopida	Philomedidae	*Euphilomedes producta*	1
Echinodermata	Ophiuroidea	Ophiurida			3
			Amphiuridae		1
				Amphipholis spp.	1
	Stelleroidea	Ophiurida	Ophiuridae	*Ophiura luetkeni*	2
				Ophiura spp.	2
Nemertea	Anopla	Heteronemertea	Lineidae	*Micrura* spp.	5
				Zygeupolia spp.	4
		Paleonemertea	Tubulanidae	*Tubulanus* spp.	0
				Tubulanus polymorphus	2
	Enopla	Hoplonemertea	Emplectonematidae	*Paranemertes californica*	2
Chordata	Ascidiacea	Pleurogona	Styelidae	*Styela gibbsii*	3
Porifera	Demospongiae				Present
Cnidaria	Anthozoa	Actiniaria	Metridiidae	*Metridium senile*	1

	Total # Orgs
*Total Number of Organisms**	6,851
(per replicate)*	

Note:
[a] Extra reference station counts are not included in the calculation of total number of organisms

APPENDIX B

QUALITY ASSURANCE REPORTS FOR DATA COLLECTED DURING THE 2007 SAMPLING EVENT

APPENDIX B1
QUALITY ASSURANCE REPORT FOR CHEMISTRY DATA

On behalf of Ketchikan Pulp Company, Integral Consulting Inc. (Integral) conducted the second phase of sampling and analysis for the long-term monitoring program at the area of concern in the Marine Operable Unit of Ward Cove, Ketchikan, Alaska. This report describes the results of a quality assurance review of results for chemical analyses conducted on marine sediment samples and an equipment rinsate blank collected July 7 through 14, 2007.

PURPOSE

The data quality review was conducted to verify that laboratory quality assurance and quality control (QA/QC) procedures were completed and documented as required and that the quality of the data is sufficiently high to support its use in meeting the monitoring objectives discussed in the monitoring plan (Exponent 2001). The remainder of this data quality report includes a summary of samples and analyses for the sampling program; descriptions of data validation procedures; and descriptions of QA/QC procedures and data quality for the environmental samples.

SAMPLE AND ANALYSES SUMMARY

Forty-eight marine sediment samples and one equipment rinsate blank (Sample BL0001) were collected and submitted for chemical and conventional analyses. Of the 44 marine sediment samples, 32 samples and 2 field duplicates (i.e., Sample SD0034 is a duplicate of Sample SD0035 and Sample SD0054 is a duplicate of Sample SD0055) were collected throughout benthic strata of the AOC, and 14 marine sediment samples were collected from reference locations. Additional samples were collected and placed into archived storage at −20°C at the laboratory. These archived samples were not analyzed and are not addressed in this report. Details regarding sample locations and field sampling procedures are described in the *Long-Term Monitoring and Reporting Plan for Sediment Remediation in Ward Cove* (Exponent 2001, Appendix A).

All chemical and conventional analyses were completed by Columbia Analytical Services, Inc. (CAS), in Kelso, Washington. CAS analyzed the samples in three sample delivery groups (SDGs) as follows: K0706082, K0706084, and K0706105. A summary of the samples collected, corresponding laboratory sample numbers, and the analyses completed is presented in Table B1-1. The chemical and conventional analyses were completed in accordance with methods indicated in the quality assurance project plan (QAPP) (Exponent 2001, Appendix B) and or the equivalent methods that were used in the first phase monitoring efforts of 2004 (Exponent 2005, Appendix B). Differences in the analytical methods referenced in the QAPP versus those used by the laboratory are summarized in Table B1-2. The equivalent analytical methods that were used in 2004 were also used in 2007 to maintain consistency between the monitoring periods. The use of the alternative methods does not affect the overall quality of the data reported.

All samples were analyzed for total solids, total organic carbon (TOC), grain size, ammonia as nitrogen, and 4-methylphenol. The compounds 3-methylphenol and 4-methylphenol cannot be separated by the chromatographic column used for their analysis because these compounds co-elute in this analysis. Therefore, 3- & 4-methylphenol were quantified by the laboratory as a single peak that represents the sum of the two compounds, but quantification was completed by the laboratory using only 4-methylphenol as a reference standard. The sum is expected to represent the concentration of 4-methylphenol exclusively, because 3-methylphenol was previously found to be absent (i.e., less than 20 μg/kg dry weight) at the site (ENSR 1995).

DATA QUALIFICATION SUMMARY

No data required qualification as estimated (*J*), restated as undetected (*U*), or rejected (*R*) as unusable for this investigation.

DATA EVALUATION PROCESS

The data were validated in accordance with the QAPP (Exponent 2001, Appendix B) and guidance specified by the *USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review* (U.S. EPA 1999) for the analyses completed for 3- & 4-methylphenol. The U.S. Environmental Protection Agency has not prepared national functional guidelines for validation of ammonia as nitrogen, TOC, grain size distribution, and total solids. For these analyses, data were validated following the general evaluation procedures specified in the *USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review* (U.S. EPA 2004) and in the context of method-specific quality control requirements and laboratory-established control limits (as are applicable to the analytical method). Procedures specified in the national functional guidelines (U.S. EPA 1999, 2004) for assessing holding times, instrument calibration, accuracy, and precision were used to determine whether data required qualification. The criteria used to assess the adequacy of applicable validation control measurements are summarized in Table B1-3.

In accordance with the QAPP, this data set was subjected to a Level 3 (U.S. EPA 1996) validation, which included evaluation of the following (as are applicable to the analyses completed):

- Case narratives discussing analytical problems (if any) and procedures
- Sample chain-of-custody documentation to verify completeness of the data set

- Sample preparation logs or laboratory summary result forms to verify that analytical holding times were met
- Results for instrument tuning for initial and continuing calibration results to assess instrument performance
- Results for method blanks and the equipment rinsate blank to determine whether an analyte reported as detected in any sample was the result of possible contamination at the laboratory or contamination during field sampling, respectively
- Results for internal standards to ensure that instrument performance was stable during the analysis of the samples
- Results for surrogate compound, laboratory control sample/laboratory control sample duplicate (LCS/LCSD), and matrix spike/matrix spike duplicate (MS/MSD) recoveries to assess analytical accuracy
- Results for duplicate or triplicate sample, LCSD, and MSD analyses, as applicable, to assess analytical precision
- Instrument printouts (e.g., chromatograms, mass spectra, and quantification reports) to assess validity of analyte identification as either detected or undetected and to verify quantification of sample results
- Laboratory summaries of analytical results

Laboratory QA/QC results were reviewed, but transcriptions and calculations were not verified during this quality assurance review.

DATA QUALITY EVALUATION

Chemistry and conventional data from 46 sediment samples, 2 sediment field homogenization splits, and 1 equipment rinsate blank were evaluated to assess data quality. The laboratory analyzed the samples in three SDGs consisting of 5 samples in SDG K0706082, 15 samples in SDG K0706084, and 29 samples in SDG K0706105.

The quality of the data collected from the AOC was generally very good. No data required qualification as estimated (*J*), restated as undetected (*U*), or rejected (*R*) as unusable for this investigation. Chemical analyses were 100 percent complete. All of the data are of sufficiently high quality for use of their intended purposes. Quality control results are described below.

Chain-of-Custody and Sample Holding Times

Chain-of-custody was maintained for all samples analyzed. All holding time constraints and sample preservation requirements specified in the QAPP (Exponent 2001, Appendix B and Table B1-3) and the applicable analytical methods were met for all samples and all analyses.

Instrument Performance

The performance of the analytical instruments was acceptable. No changes in instrument performance that would have resulted in the degradation of data quality were indicated during any analysis sequence. Mass spectrometer tuning checks were required for 3- & 4-methylphenol analyses completed by gas chromatography/mass spectrometry (GC/MS). Mass spectrometer tuning checks were completed as required by the analytical method and the results of all spectrometer tuning checks met method-specific (U.S. EPA 2007) criteria and functional guideline data validation requirements (U.S. EPA 1999).

Initial calibration and continuing calibration verification was completed as required for the analysis of 3- & 4-methylphenol, ammonia as nitrogen, and TOC. Instrument calibrations were acceptable in all cases and met the functional guidelines data validation requirements (U.S. EPA 1999, 2004) and the laboratory-established control limits for ammonia as nitrogen and TOC (see Table B1-3).

Method Blank Analyses

Laboratory blanks (i.e., method blanks, initial and continuing calibration blanks, and instrument blanks) are analyzed to check for contamination during sample preparation and analysis. An equipment rinsate blank was collected to determine the effectiveness of equipment decontamination procedures in the field. The results of laboratory and field blanks are summarized below.

A method blank was prepared and analyzed with each sample batch for the analysis of 3- & 4-methylphenol, ammonia as nitrogen, and TOC, as required by the analytical methods. None of these analytes was detected in any of the applicable method blanks.

Initial and continuing calibration blanks are required for the analysis of ammonia as nitrogen and TOC analyses, as specified in the analytical methods. All initial and continuing calibration blank results were below the method detection limit (MDL) for ammonia as nitrogen and TOC analyses. Initial and continuing calibration blanks were analyzed at the required frequency specified by the analytical methods and the laboratory standard operating procedures.

One equipment rinse blank (Sample BL0001) was collected to determine the effectiveness of equipment decontamination procedures completed in the field. No target analytes (i.e., 3- & 4-methylphenol and ammonia as nitrogen) were detected in the equipment rinsate blank, indicating the decontamination procedures were sufficient to prevent measurable cross contamination during sample collection.

Accuracy

The accuracy (i.e., bias) of the analytical results is reflected by the performance of applicable internal standards and the recoveries of applicable surrogate compounds, matrix spikes, and LCSs. Results for these quality control procedures are described below.

Internal Standard Performance

An internal standard is added to all samples for the analysis of 3- & 4-methylphenol to assess whether GC/MS sensitivity and response is stable during the analytical sequence. The method-specific criteria and the functional guideline (U.S. EPA 1999) requirements (see Table B1-3) for retention time and area count were met for all internal standards.

Surrogate Compound Recoveries

A surrogate compound is used to monitor the efficiency of sample extraction and analysis procedures on a sample-specific basis. The surrogate compound phenol-d6 was added to all field and quality control samples prior to extraction for the analysis of 3- & 4-methylphenol. The recoveries for this surrogate compound were acceptable and were within the laboratory-established control limits of 17–101 percent for solid samples and 25–118 percent for water samples (see Table B1-3).

Matrix Spike Recoveries

Matrix spikes are added to field samples to determine the analytical accuracy for samples from the study site. Matrix spike samples are required at a frequency of one per batch for all analyses except for grain size distribution and total solids. MS/MSD recoveries for 3- & 4-methylphenol (i.e., K0706082—45 and 53 percent; K0706084—45 and 53 percent; and K0706105—64 and 46 percent, and 120 and 114 percent) met laboratory-established control limits, except for one matrix spike in SDG K0706105 with 120 percent recovery. The exceedance was only 1 percent above the laboratory's upper control limit. One matrix spike in SDG K0706082 (45 percent), one matrix spike in SDG K0706084 (45 percent), and one MSD (46 percent recovery) in SDG K0706105 did not meet the QAPP-specified lower control limit of 50 percent. These slight control limit exceedances for MS/MSD results do not warrant qualification of the data, as other MS/MSD and LCS/ LCSD recoveries within the SDGs demonstrated that a consistent bias did not exist for the data sets.

Matrix spike recoveries for ammonia as nitrogen (i.e., K0706082—97 percent; K0706084—99 percent; and K0706105—87 and 95 percent) and TOC (i.e., K0706082—92 percent;

K0706084—95 percent; and K0706105—92 and 90 percent) met laboratory-established control limits and the QAPP-specified control limits for all applicable analyses (see Table B1-3).

Laboratory Control Sample Recoveries

LCSs provide a control for the entire analytical system, including sample preparation as well as instrument analysis. An LCS must be included with every sample batch for all analyses except grain size distribution and total solids. LCSs were analyzed as required in all cases.

LCS and LCSD recoveries met laboratory-established control limits (see Table B1-1) for 3- & 4-methylphenol (i.e., K0706082—53 and 54 percent; K0706084—53 and 54 percent; and K0706105—45 and 45 percent, and 47 and 51 percent), ammonia as nitrogen (i.e., K0706082—107 percent; K0706084—107 percent; K0706105—103 and 103 percent), and TOC (i.e., K0706082—99 and 94 percent; K0706084—99 and 89 percent; and K0706105—90 and 99 percent, and 94 and 92 percent). The LCS and LCSD recoveries met the QAPP-specified control limits (see Table B1-1) for all applicable analyses, except for 3- & 4-methylphenol in SDG K0706105. Three LCS recoveries (45, 45, and 47 percent) were slightly below the QAPP-specified lower control limit of 50 percent. These slight control limit exceedances for LCS/LCSD results do not warrant qualification of the data, as other MS/MSD and LCS/LCSD recoveries within the SDG demonstrated that a consistent bias does not exist for the data set.

Precision

Laboratory duplicate samples are used to determine the precision (expressed as a relative percent difference [RPD] or a relative standard deviation [RSD]) of analyses for ammonia as nitrogen, TOC, total solids, and grain size. The results for laboratory replicate sample analyses for ammonia as nitrogen (i.e., K0706082—20 RPD; K0706084—21 RPD; and K0706105—2 and 11 RPD), TOC (i.e., K0706082—<1 RSD; K0706084—13 RSD; and K0706105—<1 and 4 RSD), solids (i.e., K0706082—3 RPD and 3 RSD; K0706084—<1 RPD and <1 RSD); and K0706105—2 RPD, 2 RPD, <1 RSD, and 1 RSD) and grain size distribution (i.e., K0706082—0.3 to 2.8 RSD; K0706084—0.3 to 2.8 RSD; and K0706105—<1 to 1.6 RSD) met project-specified control limits and laboratory-established control limits (see Table B1-1) and required frequency for applicable analyses.

MSDs and LCSDs were prepared at the laboratory to monitor the precision of the analysis of 3- & 4-methylphenol and were analyzed with every sample batch. The precision of these MSDs (i.e., K0706082—14 RPD; K0706084—14 RPD; and K0706105—32 and 3 RPD) and LCSDs (i.e., K0706082—2 RPD; K0706084—2 RPD; and K0706105—7, 1, and 7 RPD) met the project-specified control limits and laboratory-established control limits (see Table B1-1) and required frequency for applicable analyses.

Identification and Quantification of Analytes

Identification requirements for organic and inorganic analyses are provided in each method description. Quantification of analyte concentrations involves calculation of concentrations with respect to standards; correction for sample weights or volumes, dilutions, and moisture content in the samples; and determination and correct calculation of MDLs and method reporting limits (MRLs) for each analyte in each sample type and dilution level (if completed). Verification of analyte quantification and identification were the responsibility of the laboratory.

Method Detection Limits and Method Reporting Limits

The MDLs and MRLs provided by the laboratory met project method quality objectives specified in the QAPP (Exponent 2001, Appendix B) in most cases. MDLs and MRLs varied with moisture content of the samples. Dilutions were necessary for many of the samples analyzed for 3- & 4-methylphenol due to relatively high concentrations of this target analyte in the samples.

Field Quality Control Samples

Results were reported for two sets of field duplicates (Samples SD0034 and SD0035 constitute one set of field duplicates and Samples SD0054 and SD0055 constitute the second set). The field duplicates represent homogenization split samples. They provide information regarding variability in field processing techniques in the area in which they were collected. Field duplicate results were used to evaluate the variability in the sample matrix and were not used solely to qualify sample results. Field replicate results were evaluated using the procedures specified in functional guidelines (U.S. EPA 2004), with RPDs calculated for results detected at greater than 5 times the MRL and a control limit of ±35 RPD. The results for the first set of field duplicates (Samples SD0034 and SD0035) were within ±35 RPD for all analyses greater than 5 times the MRL, except for the very coarse sand fraction (109 RPD). The elevated RPD for the very coarse sand fraction appears to be an anomaly and does not adversely impact the quality of the data (less than 3 percent of the sample is this size fraction). The results for the second set of field duplicates (Samples SD0054 and SD0055) were within ±35 RPD for all analyses greater than 5 times the MRL, except for 3- & 4-methylphenol (69 RPD). The elevated RPD for 3- & 4-methylphenol could be attributed to this sample comprising coarser grained material (i.e., 28 percent gravel, 70 percent sand, and 3 percent fines on average) and exhibiting greater heterogeneity.

The complete set of results for the field duplicate samples is provided in Table B1-4.

Completeness of Data Set

Completeness is calculated by comparing the total number of acceptable data (non-rejected data) to the total number of data points generated. Completeness for the 2007 Ward Cove data is 100%, which meets the QAPP completeness objective of 100%.

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TABLES

Table B1-1. Summary of Samples and Analyses Completed[a]

Benthic Stratum	Depth Category (ft MLLW)	Remediation Category	Station	Date Sampled	Field Duplicate	Sample Number	Data Package	Laboratory Sample ID	3- & 4-Methylphenol by 8270C by GC/MS	Total organic carbon by PSEP (1986)	Ammonia-nitrogen by 350.1	Total solids (dry weight as percent of wet weight or volume) by 160.3M	Clay by PSEP (1986)	Silt by PSEP (1986)	Very Fine Sand (phi class 3.00+ to 4.00) by PSEP (1986)	Fine Sand (phi class 2.00+ to 3.00) by PSEP (1986)	Medium Sand (phi class 1.00+ to 2.00) by PSEP (1986)	Coarse Sand (phi class 0.00+ to 1.00) by PSEP (1986)	Very Coarse Sand (phi class –1.00+ to 0.00) by PSEP (1986)	Gravel (phi class ≤1.0) by PSEP (1986)	Total (sum of eight size fractions)
AOC Strata																					
1	Very	TLP	5	7/10/2007		SD0026	K0706084	K0706084-008	X	X	X	X	X	X	X	X	X	X	X	X	X
	shallow		66	7/10/2007		SD0019	K0706084	K0706084-001	X	X	X	X	X	X	X	X	X	X	X	X	X
			67	7/9/2007		SD0015	K0706082	K0706082-014	X	X	X	X	X	X	X	X	X	X	X	X	X
			68	7/10/2007		SD0021	K0706084	K0706084-003	X	X	X	X	X	X	X	X	X	X	X	X	X
			69	7/10/2007		SD0020	K0706084	K0706084-002	X	X	X	X	X	X	X	X	X	X	X	X	X
2a	Shallow	TLP	9	7/10/2007		SD0023	K0706084	K0706084-005	X	X	X	X	X	X	X	X	X	X	X	X	X
	(20–70)		72	7/10/2007		SD0022	K0706084	K0706084-004	X	X	X	X	X	X	X	X	X	X	X	X	X
			73	7/9/2007		SD0018	K0706082	K0706082-017	X	X	X	X	X	X	X	X	X	X	X	X	X
			74	7/14/2007	1	SD0054	K0706105	K0706105-021	X	X	X	X	X	X	X	X	X	X	X	X	X
					2	SD0055	K0706105	K0706105-022	X	X	X	X	X	X	X	X	X	X	X	X	X
3a	Moderate	TLP	8	7/10/2007		SD0025	K0706084	K0706084-007	X	X	X	X	X	X	X	X	X	X	X	X	X
	depth		48	7/11/2007		SD0030	K0706084	K0706084-012	X	X	X	X	X	X	X	X	X	X	X	X	X
			83	7/10/2007		SD0024	K0706084	K0706084-006	X	X	X	X	X	X	X	X	X	X	X	X	X
			84	7/11/2007		SD0027	K0706084	K0706084-009	X	X	X	X	X	X	X	X	X	X	X	X	X
			93	7/11/2007		SD0028	K0706084	K0706084-010	X	X	X	X	X	X	X	X	X	X	X	X	X
			94	7/11/2007		SD0029	K0706084	K0706084-011	X	X	X	X	X	X	X	X	X	X	X	X	X
2b	Shallow	Natural	38	7/14/2007		SD0061															
	(20–70)	recovery					K0706105	K0706105-027	X	X	X	X	X	X	X	X	X	X	X	X	X
			70	7/11/2007		SD0033	K0706084	K0706084-015	X	X	X	X	X	X	X	X	X	X	X	X	X
			71	7/11/2007		SD0032	K0706084	K0706084-014	X	X	X	X	X	X	X	X	X	X	X	X	X
			75	7/7/2007		SD0005	K0706082	K0706082-005	X	X	X	X	X	X	X	X	X	X	X	X	X
			76	7/7/2007		SD0004	K0706082	K0706082-004	X	X	X	X	X	X	X	X	X	X	X	X	X
			77	7/12/2007		SD0038	K0706105	K0706105-005	X	X	X	X	X	X	X	X	X	X	X	X	X
			78	7/12/2007		SD0039	K0706105	K0706105-006	X	X	X	X	X	X	X	X	X	X	X	X	X
3b	Moderate	Natural	6	7/12/2007		SD0037															
	depth	recovery					K0706105	K0706105-004	X	X	X	X	X	X	X	X	X	X	X	X	X
	(70–120)		79	7/14/2007		SD0059	K0706105	K0706105-025	X	X	X	X	X	X	X	X	X	X	X	X	X
			80	7/12/2007	1	SD0034	K0706105	K0706105-001	X	X	X	X	X	X	X	X	X	X	X	X	X
					2	SD0035	K0706105	K0706105-002	X	X	X	X	X	X	X	X	X	X	X	X	X
			81	7/14/2007		SD0058	K0706105	K0706105-029	X	X	X	X	X	X	X	X	X	X	X	X	X
			82	7/14/2007		SD0060	K0706105	K0706105-026	X	X	X	X	X	X	X	X	X	X	X	X	X

Table B1-1. Summary of Samples and Analyses Completed[a]

Benthic Stratum	Depth Category (ft MLLW)	Remediation Category	Station	Date Sampled	Field Duplicate	Sample Number	Data Package	Laboratory Sample ID	3- & 4-Methylphenol by 8270C by GC/MS	Total organic carbon by PSEP (1986)	Ammonia-nitrogen by 350.1	Total solids (dry weight as percent of wet weight or volume) by 160.3M	Clay by PSEP (1986)	Silt by PSEP (1986)	Very Fine Sand (phi class 3.00+ to 4.00) by PSEP (1986)	Fine Sand (phi class 2.00+ to 3.00) by PSEP (1986)	Medium Sand (phi class 1.00+ to 2.00) by PSEP (1986)	Coarse Sand (phi class 0.00+ to 1.00) by PSEP (1986)	Very Coarse Sand (phi class –1.00+ to 0.00) by PSEP (1986)	Gravel (phi class ≤1.0) by PSEP (1986)	Total (sum of eight size fractions)
4	Deep (>120)	Natural recovery	13	7/11/2007		SD0031	K0706084	K0706084-013	X	X	X	X	X	X	X	X	X	X	X	X	X
			85	7/12/2007		SD0036	K0706105	K0706105-003	X	X	X	X	X	X	X	X	X	X	X	X	X
			86	7/8/2007		SD0008	K0706082	K0706082-008	X	X	X	X	X	X	X	X	X	X	X	X	X
			87	7/14/2007		SD0057	K0706105	K0706105-024	X	X	X	X	X	X	X	X	X	X	X	X	X
			88	7/14/2007		SD0056	K0706105	K0706105-023	X	X	X	X	X	X	X	X	X	X	X	X	X
Reference Area Strata																					
5a	Shallow (20–70)	--	96A	7/12/2007		SD0040	K0706105	K0706105-007	X	X	X	X	X	X	X	X	X	X	X	X	X
			96B	7/12/2007		SD0041	K0706105	K0706105-008	X	X	X	X	X	X	X	X	X	X	X	X	X
			96C	7/12/2007		SD0042	K0706105	K0706105-009	X	X	X	X	X	X	X	X	X	X	X	X	X
			96D	7/12/2007		SD0043	K0706105	K0706105-010	X	X	X	X	X	X	X	X	X	X	X	X	X
			96E	7/13/2007		SD0044	K0706105	K0706105-011	X	X	X	X	X	X	X	X	X	X	X	X	X
			96F	7/13/2007		SD0045	K0706105	K0706105-012	X	X	X	X	X	X	X	X	X	X	X	X	X
			96G	7/13/2007		SD0046	K0706105	K0706105-013	X	X	X	X	X	X	X	X	X	X	X	X	X
5b	Moderate depth (70–120)	--	95A	7/13/2007		SD0047	K0706105	K0706105-014	X	X	X	X	X	X	X	X	X	X	X	X	X
			95B	7/13/2007		SD0048	K0706105	K0706105-015	X	X	X	X	X	X	X	X	X	X	X	X	X
			95C	7/13/2007		SD0049	K0706105	K0706105-016	X	X	X	X	X	X	X	X	X	X	X	X	X
			95D	7/13/2007		SD0050	K0706105	K0706105-017	X	X	X	X	X	X	X	X	X	X	X	X	X
			95E	7/13/2007		SD0051	K0706105	K0706105-018	X	X	X	X	X	X	X	X	X	X	X	X	X
			95F	7/13/2007		SD0052	K0706105	K0706105-019	X	X	X	X	X	X	X	X	X	X	X	X	X
			95G	7/13/2007		SD0053	K0706105	K0706105-020	X	X	X	X	X	X	X	X	X	X	X	X	X

Notes:
AOC = area of concern
GC/MS = gas chromatography/mass spectrometry (operated in the full scan mode)
GC/MS-SIM = gas chromatography/mass spectrometry (operated in the selected ion monitoring [SIM] mode)
MLLW = mean lower low water
PSEP = Puget Sound Estuary Program
TLP = thin layer placement

[a] All samples and analyses completed were subjected to data validation.

Table B1-2. Summary of Analytical Methods

Target Analyte	Method Referenced in QAPP	Method Referenced by Laboratory
4-Methylphenol	GC/MS-SIM by SW-846 Method 8270C (U.S. EPA 2004)	GC/MS by SW-846 Method 8270C (U.S. EPA 2004) (solids)[a]
		GC/MS-SIM by SW-846 Method 8270C (U.S. EPA 2004) (water)
Ammonia	EPA 350.3M (solids)	Plumb (1981)[b]
	NA (water)	EPA Method 350.1 (water) (U.S. EPA 1983)
Total organic carbon	Standard Method 5310B (Franson 1992)	PSEP (1986)[c]
Grain size	PSEP	PSEP (1986)
Total solids	PSEP	EPA Method 160.3 M (U.S. EPA 1983)[d]

Notes:
EPA = U.S. Environmental Protection Agency
GC/MS = gas chromatography/mass spectrometry
NA = not applicable
PSEP = Puget Sound Estuary Program
SIM = selected ion monitoring

[a] Analysis for 4-methylphenol in sediment samples using SW-846 Method 8270C (U.S. EPA 2004) by GC/MS operated in the full scan mode was considered appropriate because of elevated concentrations of 4-methylphenol. Use of GC/MS operated in the SIM mode is appropriate to achieve low detection limits or for obtaining results for very low concentrations in samples. For these reasons, the analyses completed using GC/MS operated in the full scan mode are considered acceptable.

[b] Analyses for ammonia in sediment samples were completed by extraction with potassium chloride using the method specified by Plumb (1981). The digestate is diluted with ammonia-free water and analysis completed using automated phenate colorimetric detection. This procedure developed by Plumb was prepared for EPA and is appropriate for the analysis of ammonia in sediment samples. The use of EPA Method 350.3M is for the determination of ammonia in water samples using potentiometric ion selective detection and is not appropriate for sediment samples.

[c] Analyses for TOC in sediment samples using standard method 5310B (Franson 1992) is completed by combusting the sample at an "optimum" temperature of 900°C and using infrared detection. For this current work, the analytical procedure specified by PSEP (i.e., combustion of the sample at 950 ±10°C and using thermal conductivity detection) was used. While it is not currently known whether the use of these two methods yields "comparable" results, the use of the PSEP method yielded accurate and precise data (as indicated by acceptable recoveries of matrix spikes and laboratory control samples, analysis of laboratory duplicate samples, and analysis of field duplicate samples).

[d] Analyses for total solids in sediment samples using EPA Method 160.3M was completed by constant drying of the sediment samples at 103–105°C to a constant weight and is equivalent to the temperature specified by the PSEP method.

Table B1-3. Summary of Data Validation Criteria

Validation Evaluation	4-Methylphenol	Ammonia	Total organic carbon	Grain size	Total solids
Holding times	Store at 4°C, 14 days to completed extraction[a] as per QAPP, or freeze (–20°C) for 1 year (PSEP 1997)	Store at 4°C (do not freeze); complete extraction in 7 days from date of collection as per QAPP	Store at 4°C or freeze; complete analysis in 28 days (if stored at 4°C) or 180 days (if frozen) from date of collection as per QAPP	Store at 4°C (do not freeze); complete analysis in 28 days from date of collection as per QAPP	Store at 4°C; complete analysis in 180 days from date of collection as per QAPP
Instrument tuning	Ion abundance values must meet criteria specified in functional guidelines (U.S. EPA 1999)	NA	NA	NA	NA
Initial calibration	RRF is ≥0.050 and RSD of RRFs is ≤30, as per functional guidelines (U.S. EPA 1999)	Correlation coefficient of multiple point curve is >0.995 as per laboratory criteria	Correlation coefficient of multiple point curve is >0.995 as per laboratory criteria	NA	NA
Continuing calibration	RRF is ≥0.050 and percent difference of RRF is ≤25, as per functional guidelines (U.S. EPA 1999)	90–110 percent recovery as per laboratory-established control limit	90–110 percent recovery as per laboratory-established control limit	NA	NA
Method blanks	5 times rule, as per functional guidelines (U.S. EPA 1999)	5 times rule, as per functional guidelines (U.S. EPA 2004)	5 times rule, as per functional guidelines (U.S. EPA 2004)	NA	NA
Field blanks	5 times rule, as per functional guidelines (U.S. EPA 1999)	5 times rule, as per functional guidelines (U.S. EPA 2004)	5 times rule, as per functional guidelines (U.S. EPA 2004)	NA	NA
Accuracy					
Internal standards performance	Area counts cannot vary by more than a factor of two from the associated calibration standard (i.e., –50 percent < internal standard area < +100 percent) and retention times of all internal standards are within ±30 seconds from the associated 12-hour calibration standard as per functional guidelines (U.S. EPA 1999)	NA	NA	NA	NA
Surrogate compound recoveries	17–101 (solids) and 25–118 (water) percent recovery as per laboratory-established control limits	NA	NA	NA	NA
Matrix spike sample recoveries	50–150 percent as per QAPP and 10–119 percent as per laboratory-established control limits	75–125 as per QAPP and laboratory-established control limits	75–125 as per QAPP and laboratory-established control limits	NA	NA
Laboratory control sample recoveries	50–150 percent as per QAPP and 24–94 percent for solids and 30–116 percent for water as per laboratory-established control limits	75–125 as per QAPP and 90–110 percent as per laboratory-established control limits	75–125 as per QAPP and 85–115 percent as per laboratory-established control limits	NA	NA
Precision					
Laboratory duplicate sample analyses	±50 percent as per QAPP and ±40 percent difference for solids as per laboratory-established control limits for MS/MSD and LCS/LCSDs and ±30 percent difference for water as per laboratory-established control limits for LCS/LCSD	±35 percent difference per QAPP and ±20 percent difference as per laboratory-established control limits	±35 percent difference as per QAPP and ±20 percent difference as per laboratory-established control limits	NA	±35 percent difference as per QAPP and ±20 percent difference as per laboratory-established control limits
Laboratory triplicate sample analyses	NA	NA	RSD of ≤35	RSD of ≤35	NA
Field duplicate (i.e., co-located) sample analyses	NA	NA	NA	NA	NA

Notes:
LCS/LCSD = laboratory control sample/laboratory control sample duplicate
MS/MSD = matrix spike/matrix spike duplicate
NA = not applicable
QAPP = quality assurance project plan
RRF = relative response factor
RSD = relative standard deviation

[a] Extracts must be analyzed within 40 days of extraction.

Table B1-4. Summary of Field Duplicate RPDs

		Result			Result		
Target Analyte	MRL	SD0034	SD0035	RPD	SD0054	SD0055	RPD
4-Methylphenol	2.9 mg/kg	860	1,200	33	330	160	69
Ammonia as nitrogen	0.6 mg/kg	116	129	11	3.1	3.4	9
Total organic carbon	0.02%	13	13	0	1.1	1.0	10
Clay	0.1%	31.8	30.9	3	1.5	1.3	14
Very fine silt	0.1%	4.9	5.2	6	0.47	0.44	7
Fine silt	0.1%	10.4	11.1	7	0.28	0.46	NA
Medium silt	0.1%	19.9	18.0	10	0.65	0.56	15
Coarse silt	0.1%	6.1	5.5	10	0.48	0.63	NA
Very fine sand	0.1%	7.7	8.2	6	2.2	2.1	5
Fine sand	0.1%	6.2	6.0	3	16	16	0
Medium sand	0.1%	4.9	5.0	2	28	26	7
Coarse sand	0.1%	3.6	3.0	18	14	15	7
Very coarse sand	0.1%	0.77	2.6	109	11	10	10
Gravel	0.1%	0.25	0	NA	28	28	0
Total grain size	NA	96.7	95.7	1.0	103	103	0
Total solids	0.1%	13	13	0	77	80	4

Notes:
MRL = method reporting limit
NA = not applicable; when listed under RPD, the RPD does not apply when the parameter is detected at a concentration of less than 5 times the MRL.
RPD = relative percent difference

APPENDIX B2
QUALITY ASSURANCE REPORT FOR SEDIMENT TOXICITY DATA

INTRODUCTION

This report documents the results of the quality assurance and quality control (QA/QC) review of the data generated from the 10-day amphipod (i.e., *Eohaustorius estuarius*) toxicity test performed on 46 sediment samples collected from Ward Cove near Ketchikan, Alaska. These tests were conducted by Northwestern Aquatic Sciences (NAS) in Newport, Oregon. Integral conducted the quality assurance review to ensure that the toxicity testing was consistent with the specifications in the statement of work and that the data are acceptable for meeting the monitoring objectives discussed in the monitoring plan (Exponent 2001).

The quality assurance review consisted of an evaluation of the following major elements for the toxicity test:

- **Field Methods**—Were the major specifications of the field sampling procedures followed, as described in the field sampling and analysis plan (Exponent 2001, Appendix A)?
- **Laboratory System and Testing Methods**—Were the major specifications of the laboratory testing procedures followed, as described in the laboratory's statement of work? Were the specified methods (i.e., PSEP 1995 and U.S. EPA 2000) followed and were any modifications adequately justified and documented?
- **Sediment Holding Time**—Was each sediment sample analyzed within the specified holding time after collection?
- **Water Quality Conditions**—Were water quality conditions monitored adequately during testing and were the measured conditions within the specified ranges for each test chamber?
- **Negative Control Responses**—Were the responses in the negative controls (i.e., clean sediment) within specified limits?
- **Positive Control Responses**—Did the positive controls (i.e., reference toxicant) indicate that the test organisms were suitably responsive for testing?

The methods used to conduct the 10-day sediment toxicity test using *E. estuarius* were consistent with PSEP (1995) and U.S. EPA (2000), with one major exception: At four of the sampling stations, five replicate samples were tested as specified in the test protocols, but at the remaining stations, only a single replicate sample was tested. Throughout this report, the term "replicate" refers to subsamples of homogenized sediment collected at the stations. The following section of this report presents the results of the QA/QC evaluation for the sediment toxicity test. QA/QC considerations are then summarized, and conclusions are presented in the final section.

QUALITY ASSURANCE AND QUALITY CONTROL EVALUATION

Field Methods

From July 6 through 14, 2007, surface sediment (0–10 cm) samples were collected from Ward Cove near Ketchikan, Alaska. At each station, surface sediment was collected using a 0.06-m^2 van Veen grab sampler. A single, homogenized surface sediment sample to a sediment depth of 10 cm was collected for the amphipod survival test and for the chemical analyses to ensure that the toxicity test and the chemical analyses were related as closely as possible. Depending upon the amount of wood debris encountered during sampling at any given station, a single full grab sample or multiple partial grab samples were composited into a single sediment sample.

Sediment sampling was conducted according to the procedures and plans described in the field sampling and analysis plan (Exponent 2001, Appendix A).

Laboratory System

Water from Yaquina Bay, Oregon, was used for the toxicity testing program. The water was filtered to ≤0.40 μm, salinity was adjusted with MilliQ® deionized water, and the water was aerated prior to use. The laboratory performed the toxicity test in one batch. Sediments were stored at 4°C in the dark until used. All testing was conducted in accordance with the requirements defined in the U.S. Environmental Protection Agency Good Laboratory Practice regulations as revised August 17, 1989 (40 CFR 792).

Amphipod Survival Test

This toxicity test measured amphipod survival using the amphipod *E. estuarius* following a 10-day exposure to the test sediments.

Test Organism and Acclimation

The *E. estuarius* test organisms used in these toxicity tests were obtained from lower Yaquina Bay, Oregon. The test organisms were maintained in the laboratory in the same sediments that the laboratory used for the negative control. Adult amphipods were gradually acclimated to the test water temperature and salinity for 4 days prior to testing. Pretest survival of test organisms was not documented. However, only healthy, adult organisms of similar size and life history stage were used for the toxicity test.

Test Methods

Overall, the recommended protocols were followed closely during testing. All biological testing followed the protocols specified for *Eohaustorius estuarius* in U.S. EPA (2000), was generally in compliance with the PSEP (1995) guidelines for tests based on *Rhepoxynius abronius*, and was as consistent as possible with the methods used by NAS for testing Ward Cove sediments in 1996 and 1997 using *R. abronius*. As mentioned above, a single replicate sample at each station was tested with the exception of four sampling locations at which five replicate samples were tested.

Samples were collected and stored properly. The toxicity test was initiated on July 30, 2004. The test initiation date is within the specified 14-day holding time. All organisms used in the test were from the same source (see discussion above).

For each toxicity test replicate, 20 amphipods were exposed to a 2-cm layer of bedded test sediment in a 1-L chamber filled with clean seawater. Any amphipods that did not bury within 5–10 minutes were removed and replaced, unless the amphipods were repeatedly burrowing into the sediment and immediately emerging in an apparent avoidance response to the test sediment.

On Day 10, the surviving amphipods in all test chambers were carefully sieved through a ≤0.5mm screen and counted. Percent survival was calculated according to how many of the 20 individuals added to each chamber at the beginning of the test survived. The survivors were then exposed to negative control sediment, and the number that failed to rebury was determined. Percent nonreburial was determined relative to the number of survivors in each test chamber.

Water Quality Measurements

Water quality monitoring was conducted during the amphipod test. Measurements of the overlying water in one replicate for each station were taken just prior to the introduction of the test organisms into the other test replicate chambers, and then at the same time each day until the conclusion of the test. This monitoring consisted of the following measurements:

- Temperature was measured in the overlying water of each water quality replicate daily and in each test replicate on Days 0 and 10. The daily mean test temperature should be 15±1°C (mean temperature was 15.2±0.2°C). Temperatures measured during the testing period ranged from 14.5 to 16.1°C, which is slightly outside the recommended range of 14–16°C. The time-weighted average measured temperature at the end of the test should be within 1°C of the selected test temperature (i.e., 15°C). This temperature requirement was met during testing.

- Dissolved oxygen was measured in the overlying water of each water quality replicate daily and in each test replicate on Days 0 and 10. Dissolved oxygen concentrations should be greater than or equal to 60 percent saturation throughout the study in all control and test water quality replicates. The lowest dissolved oxygen concentration was 7.3 mg/L. The dissolved oxygen levels ranged from 7.3 to 8.8 mg/L (mean dissolved oxygen was 8.0±0.3 mg/L). Dissolved oxygen levels were within acceptable limits throughout the test. However, dissolved oxygen measurements were accidentally omitted in one test chamber on Day 2 (Lab #154) and in another test chamber (Lab #22) on Day 10.
- Values of pH were measured in the overlying water of each water quality replicate daily and in each test replicate on Days 0 and 10. Values for pH ranged from 7.6 to 8.7 (mean pH was 8.2 ±0.2), which is within the recommended range of 7–9 pH units.
- Salinity was measured in the overlying water of each water quality replicate daily and in each test replicate on Days 0 and 10. Salinity levels ranged from 25 to 31 ppt, which is slightly outside the recommended range of 27–29 ppt (mean salinity was 28.3±0.8 ppt). However, the salinity exceedances were minor ranging from 0.5 to 1.5 ppt above the recommended salinity range. These exceedances were not consistent for any specific replicate. Salinity was also measured in the pore water from sacrificial beakers on Day 0 and Day 5, and from a test replicate on Day 10 (after test organisms were removed). The salinity in the pore water prior ranged from 25 to 31 ppt (mean pore water salinity was 28.2±1.2 ppt).
- Total ammonia was measured in the overlying water of each test replicate on Days 0 and 10. Total ammonia levels in the overlying water ranged from <0.1 to 5.1 mg/L. Un-ionized ammonia was also measured in the overlying water on Days 0 and 10. Un-ionized ammonia levels in the overlying water on Day 0 ranged from <0.003 to 0.336 mg/L. Total ammonia and un-ionized ammonia were also measured in the pore water from sacrificial beakers on Day 0 and Day 5, and from a test replicate on Day 10 (after test organisms were removed). Total ammonia concentrations in the pore water ranged from 0.5 to 29.4 mg/L and un-ionized ammonia in the pore water ranged from 0.001 to 0.386 mg/L. The total and un-ionized ammonia concentrations were lower than the no-effect concentrations of 60 and 0.8 mg/L identified for *Eohaustorius estuarius* by U.S. EPA (2000). It therefore is unlikely that porewater ammonia concentrations affected the toxicity results.
- Total dissolved sulfides were measured in the overlying water of each test replicate on Days 0 and 10. Sulfide levels ranged from <0.1 to 0.2 mg/L. Total dissolved sulfides were also measured in the pore water from sacrificial beakers on Day 0 and Day 5, and from a test replicate on Day 10 (after test organisms were removed). Total dissolved sulfide levels in the pore water ranged from <0.5 to 184 mg/L, which indicates that elevated porewater concentrations of total sulfide were present in some

samples and their potential influence on the toxicity results should be considered during data analysis and interpretation.

Controls

A negative control consisting of sediment collected from the *E. estuarius* collection site in lower Yaquina Bay, Oregon, was used in these toxicity tests. Mean survival for the control sediment was 95 percent. Mean survival for sediment collected from the two reference areas were 93 and 98 percent, respectively. These results suggest that the test organisms were sufficiently healthy for testing.

A positive control was tested using cadmium chloride as the reference toxicant. The positive control exhibited a 96-hour LC50 value of 3.58 mg Cd/L, which is within the testing laboratory's control chart warning limits for this test (i.e., 1.65–5.63 mg Cd/L). The observed LC50 value suggests that the test organisms were suitably sensitive for testing.

SUMMARY OF QUALITY ASSURANCE AND QUALITY CONTROL CONSIDERATIONS

Mean survival in the negative control was 95 percent. For the testing to be considered acceptable, a minimum mean survival of 90 percent must occur in the negative controls. These results meet the performance standards set for the amphipod survival test (U.S. EPA 2000).

During the testing period, there were some inconsistencies with the specifications provided in the statement of work:

- Pretest survival of test organisms was not documented.
- Several salinity measurements exceeded the protocol-specified range of 28.0±1.0 ppt (minimum – 25 ppt; maximum – 31 ppt). However, the mean salinity for the testing period was 28.3±0.8 ppt. Both the initial salinity of sediments and effects of evaporation contributed to salinity variation. Adjustments were made by the laboratory during the test (i.e., deionized water was added to the affected test replicates) to attempt to counter evaporation effects. It is not anticipated that the deviation affected the results.
- Dissolved oxygen measurements were accidentally omitted in one test chamber on Day 2 and in another test chamber on Day 10. It is not anticipated that the deviation affected the results.
- Test temperature exceeded the protocol-specified range of 15±1°C in one test chamber on Day 9 by 0.1°C. It is not anticipated that the deviation affected the results.

The deviations did not appear to have an affect on test results. Therefore, the data are determined to be acceptable for use in the Ward Cove monitoring program. Because elevated porewater concentrations of sulfide were found for some samples, their potential influence on the toxicity results should be considered during data analysis and interpretation.

REFERENCES

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Exponent. 2001. Long-term monitoring and reporting plan for sediment remediation in Ward Cove. Prepared for Ketchikan Pulp Company, Ketchikan, AK. Exponent, Bellevue, WA.

PSEP. 1995. Recommended guidelines for conducting laboratory bioassays on Puget Sound sediments. U.S. Environmental Protection Agency Region 10, Office of Puget Sound, Puget Sound Estuary Program, Seattle, WA.

U.S. EPA. 2000. Methods for measuring the toxicity of sediment-associated contaminants with estuarine and marine amphipods. EPA/600/R-99/025. U.S. Environmental Protection Agency, Office of Research and Development, Duluth, MN.

APPENDIX B3
QUALITY ASSURANCE REPORT FOR
BENTHIC MACROINVERTEBRATE DATA

INTRODUCTION

This report documents the results of the quality assurance and quality control (QA/QC) review of the data generated on benthic macroinvertebrate communities that were collected from Ward Cove near Ketchikan, Alaska. These evaluations were conducted by Benthic Services Group in Seattle, Washington. Integral conducted the quality assurance review to ensure that the evaluation of the benthic macroinvertebrate community data are consistent with the specifications of the statement of work and that the data are acceptable for meeting the monitoring objectives discussed in the monitoring plan (Exponent 2001).

The quality assurance review consisted of an evaluation of the following major elements of the benthic macroinvertebrate evaluations:

- **Field Methods**—Were the major specifications of the field sampling procedures followed, as described in the field sampling and analysis plan (Exponent 2001, Appendix A)?
- **Laboratory System and Testing Methods**—Were the major specifications of the laboratory testing procedures followed, as described in the laboratory's statement of work? Were the specified methods (i.e., U.S. EPA 1987) followed and were any modifications adequately justified and documented?
- **Sorting Efficiency**—Was each sample sorted with an efficiency of 95 percent?
- **Taxonomic Accuracy**—Were taxonomic identifications conducted by experienced taxonomists using the appropriate literature and a reference collection?

The methods used to conduct the benthic macroinvertebrate evaluations were consistent with U.S. EPA (1987). The following section of this report presents the results of the QA/QC evaluation of the data for the benthic macroinvertebrate communities. QA/QC considerations are then summarized, and conclusions are presented in the final section.

QUALITY ASSURANCE AND QUALITY CONTROL EVALUATION

Field Methods

From July 6 through 14, 2007, surface sediment (0–10 cm) samples were collected from Ward Cove near Ketchikan, Alaska. At each station, surface sediment was collected using a 0.06-m^2

van Veen grab sampler. One grab sample was collected at each station. All of the sediment (to a maximum depth of 20 cm) and overlying water collected in each grab sample was sieved (1.0-mm) to isolate benthic organisms. Retained material from each grab sample was transferred to an appropriate sample container and preserved in the field with 10 percent formalin. The standard biological stain (rose bengal) was added to the samples in the field to facilitate the sorting process. The 1.0-mm fraction was sent to the taxonomic laboratory for evaluation of benthic macroinvertebrate communities.

Homogenized sediments collected from separate grab samples from the same station locations were used for chemical analyses and toxicity testing to ensure that the chemical analyses, toxicity test, and benthic macroinvertebrate community data were related as closely as possible.

Sediment sampling was conducted according to the procedures and plans described in the field sampling and analysis plan (Exponent 2001, Appendix A).

Laboratory Methods

Overall, the recommended protocols were followed closely during testing. All biological testing followed the protocols specified in U.S. EPA (1987). As mentioned above, a single grab sample at each station was evaluated for benthic macroinvertebrate communities. The analytical methods for the benthic macroinvertebrate samples were based on the specifications presented in the field sampling and analysis plan (Exponent 2001, Appendix A) and the laboratory statement of work. The laboratory methods are discussed in the following sections.

Sample Handling

Samples received by the laboratory remained in the 10 percent formalin solution for a minimum of 24 hours, to allow proper fixation. After fixation, the samples were washed (i.e., rescreened) with a sieve with a mesh opening of 0.5 mm, and preserved in a 70 percent solution of ethanol. Washed samples were stored in an upright position at a cool temperature and away from direct sunlight. Samples were stored in a secure place, where containers were not susceptible to breakage, and samples were checked periodically to ensure that adequate levels of preservative were maintained.

The laboratory inadvertently sorted two samples that were not a part of the study (Samples BI0011 and BI0015). These samples were not included in the final data set.

Sorting

All samples were sorted 100 percent; no subsampling occurred. Each sample was sorted by only one person. Each sample was sorted carefully in the laboratory by pouring the material over a 0.5-mm sieve (half the mesh size of the field sieve). Use of a smaller sieve than that used in the field ensured retention of smaller organisms and fragments. Small fractions of a sample were placed in a petri dish under a 10-power magnification dissecting microscope. The petri dish was scanned systematically and all animals and fragments were removed using forceps. Each petri dish was sorted at least twice to ensure removal of all animals. Organisms representing major taxonomic groups including Polychaeta, Arthropoda, Mollusca, and miscellaneous taxa were sorted and enumerated into separate, labeled vials containing 70 percent ethanol. Sample identification information was completed on the sample sort sheet.

Taxonomic Identifications and Counts

After sorting was completed, organisms were identified to the lowest taxonomic level possible, with the target being species level. Vials and jars were distributed to the taxonomists designated by the laboratory for each group of organisms. All taxonomic identifications were made by qualified taxonomists:

- **Mr. Gary Rosenthal—**Mr. Rosenthal is Principal of Benthic Services Group and served as Project Manager and lead taxonomist for this project. He is an environmental scientist and project manager with more than 19 years of experience specializing in the assessment of benthic community impacts and polychaete taxonomy. Mr. Rosenthal has extensive experience as principal investigator leading field surveys and implementing biological, sediment chemistry, and water quality sampling protocols. Mr. Rosenthal has managed benthic laboratories for EHI and EVS consultants and provides polychaete taxonomic services for benthic community studies. He has supported numerous investigations conducted in Canada, Alaska, the Pacific Northwest, and the Gulf of Mexico on the effects of pollutants and organic enrichment on intertidal and subtidal marine communities. His responsibilities include project management, training and supervision of laboratory support staff, coordination of sample processing, taxonomic identification and QA/QC, and project-wide quality assurance and control compliance.
- **Mr. Howard Jones—**Mr. Jones has extensive experience providing polychaete identifications and external QA/QC reviews. He has performed taxonomic identifications for more than 20 years and is well versed in the taxa found in the Ward Cove study area. Mr. Jones provided polychaete identifications for this project.
- **Ms. Pam Sparks—**Ms. Sparks has 19 years of experience as a taxonomist specializing in marine arthropods. She has identified marine arthropods from Mexico, the Pacific Northwest, Canada, and Alaska. Ms. Sparks provided arthropod identifications for this project.
- **Mr. Jeff Cordell—**Mr. Cordell is a taxonomic professional with more than 20 years of experience specializing in the identification of marine and freshwater arthropods. Mr. Cordell provided arthropod QA/QC review for this project.

- **Ms. Susan Weeks—**Ms. Weeks is the owner of OIKOS, a small, woman-owned enterprise providing taxonomic expertise in the identification of marine molluscs. Ms. Weeks has more than 18 years of experience identifying marine molluscs from the Pacific Northwest, Canada, and Alaska. Ms. Weeks provided mollusc identifications for this project.
- **Mr. Alan Fukiyama—**Mr. Fukiyama has more than 19 years of experience as a marine mollusc taxonomist. He has experience identifying molluscs from the Pacific Northwest, Canada, and Alaska. Mr. Fukiyama provided mollusc QA/QC review for this project.

All specimens were enumerated. For incomplete specimens, only the anterior or posterior end was enumerated, depending upon the taxon. All identifications were made using 15-power dissecting microscopes. At least two pieces of literature were used for each species identification (see Table B3-1). Each species identification was conferred on between taxonomic experts. If any rare or questionable specimens are encountered during a project, it is standard procedure for the taxonomic laboratory to compare them with reference collection samples or, if necessary, to submit them for additional peer review. No such specimens were encountered in this project. Enumeration data were entered into a Microsoft® Excel spreadsheet.

Table B3-1. Taxonomic references used to identify benthic invertebrates collected from Ward Cove in July 2004

Major Taxonomic Group	Reference
Mollusca	Abbott, R.T. 1974. American Seashells. Van Nostrand Reinhold Company. 663 pp.
	Bernard, F.R. 1970. A distributional checklist of the marine molluscs of British Columbia: based on faunistic surveys since 1950. Syesis 3:75–94.
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	Coan, E.V. 1977. Preliminary review of the Northwest American Carditidae. Veliger 19(4):375–386.
	Foighil, D.O., and A. Gibson. 1984. The morphology, reproduction and ecoiogy of the commensal bivalve *Scintillona bellerophon* spec. nov. (Galeornrnatacea). Veliger 27(1):72–80.
	Foster, N.R. 1991. Intertidal bivalves: A guide to the common marine bivalves of Alaska. University of Alaska Press. 152 pp.
	Keen, M.A., and E. Coan. 1974. Marine molluscan genera of western North America: An illustrated key. Stanford University Press. 208 pp.
	Kozloff, E.N. 1987. Marine invertebrates of the Pacific Northwest. University of Washington Press. 511 pp.
	McLean, J.H. 1978. Marine shells of Southern California. Natural History Museum of Los Angeles County. 104 pp.
	Oldroyd, I.S. 1924. The Marine shells of the west coast of North America. Vol. 1. Stanford University. 247 pp.
	Turgeon, D.D. 1988. Common and scientific names of aquatic invertebrates of the United States and Canada: Mollusks. American Fisheries Society. 277 pp.
Polychaeta	Banse, K. 1979. Sabellidae (Polychaeta) principally from the northeast Pacific Ocean. J. Fish. Res. Bd. Can. 36(8):869–882.
	Berkeley, E., and C. Berkeley. 1938. Notes on polychaeta from the coast of western Canada. 2. Syllidae. Ann. Mag. Nat. Hist. (ser. 11) 1:33–49.
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Table B3-1. (cont.)

Major Taxonomic Group	Reference
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Table B3-1. (cont.)

Major Taxonomic Group	Reference
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Table B3-1. (cont.)

Major Taxonomic Group	Reference
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QA/QC Procedures

Re-sorting is the examination of a sample that has been sorted once and is considered free of organisms. Ten percent of the sorted samples were re-sorted for QA/QC purposes. Five samples were re-sorted (representing 10 percent of the samples) as stipulated in the QA/QC procedures for this project. If any benthic macroinvertebrates were found during the re-sorting process, it would be noted on the sample sort sheet and added to the replicate-specific vials or jars for the taxonomy.

Re-sorting was conducted by an individual other than the one who sorted the original sample. A partial re-sorting of selected samples ensured that any gross sorting errors were detected. For this study, a sample passed if the number of organisms found during the QA/QC check did not represent more than 5 percent of the total number of organisms found in the entire sample. If the number of organisms found was greater than five percent of the total number, the entire sample would have been re-sorted. Sorting efficiency for all of the QA/QC samples ranged from 98 to 100 percent. Therefore, all of the QA/QC re-sorted samples satisfied the 95 percent sorting efficiency criterion specified for this project.

Taxonomic Accuracy

As stated previously, taxonomic identifications were made by qualified taxonomists. As a check on the identifications, 5 percent of the samples were sent out for re-identification by a qualified regional expert. Specific results included the following:

- **Polychaeta—**The polychaete taxonomic QA/QC was in excellent agreement with the initial identifications. No differences were found in counts or taxa.
- **Arthropoda—**The arthropod taxonomic QA/QC was in very good agreement with the initial identifications. No differences were found in counts or taxa. (Note: Only two arthropods (*Themisto pacifica*) were found in the sample collected at Station 77. *T. pacifica* were not included in the data set because they are considered to be water-column organisms.) (Note: *Peramphithoe* spp. was misspelled in the original data sheets. The correct spelling was incorporated into the final data set.)
- **Mollusca—**The mollusc taxonomic QA/QC was in excellent agreement with the initial identifications. No differences were found in counts or taxa.
- **Miscellaneous Taxa—**The miscellaneous taxa QA/QC was in excellent agreement with the initial identifications. For the sample collected at Station 88, one juvenile *Amphiuridae* and two juvenile *Amphiodia* spp. were moved to *Ophiurida*. This change was incorporated into the final data set.

Based on the review of taxonomic accuracy, it was concluded that the taxonomic identifications were made with acceptable accuracy.

SUMMARY OF QUALITY ASSURANCE AND QUALITY CONTROL CONSIDERATIONS

Based on the sampling and analyses methods, sorting efficiency, and taxonomic accuracy, all of the results of the benthic macroinvertebrate evaluations are determined to be acceptable for use in the Ward Cove monitoring program.

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APPENDIX C

DETAILS OF STATISTICAL ANALYSES

Table C-1. Statistical Summary of Evaluations of *Eohaustorius estuarius* Survival for Ward Cove in 2007

			Percent Survival			Observed Data				Arcsine Square-root					Significant Differences from Reference[c]		
						Normality[a]		Variance[b]		Normality[a]		of Variance[b]					High
Benthic Stratum	Depth Category	Remediation Category	Mean	Std. Dev.	CV	Pass?	*P*-value	Pass?	*P*-value	Pass?	*P*-value	Pass?	*P*-value	Test[e]	Pass?	*P*-value	Variance[d]
AOC Strata																	
1	Very shallow	TLP	94	4.2	0.04	yes	0.31	yes	0.43	yes	0.10	yes	0.91	Wilcoxon	no	0.073	no
2a	Shallow	TLP	92	6.3	0.07	yes	0.99	yes	0.14	yes	0.51	yes	0.53	Wilcoxon	no	0.062	no
2b	Shallow	Natural recovery	88	9.9	0.11	yes	0.45	no	0.03	yes	0.73	yes	0.43	Wilcoxon	no	0.028	no
Ref 5a	Shallow	--	98	2.7	0.03	no[e]	0.01			no	0.00647						
3a	Moderate depth	TLP	95	6.3	0.07	yes	0.08	yes	0.88	yes	0.09	yes	0.86	ANOVA on transformed data	no	0.29	no
3b	Moderate depth	Natural recovery	96	4.2	0.04	yes	0.31	yes	0.38	yes	0.16	yes	0.61		no	0.29	no
4	Deep	Natural recovery	80	22	0.27	yes	0.32	no	0.04	yes	0.82	yes	0.35		no	0.29	yes
Ref 5b	Moderate depth	--	93	6.7	0.07	yes	0.20			yes	0.06						

Notes:
ANOVA = analysis of variance
AOC = area of concern
CV = coefficient of variation
TLP = thin layer placement

[a] Normality was evaluated using the Shapiro-Wilk's goodness-of-fit test. Significance level of 0.05 was used.

[b] Homogeneity of variance was evaluated using the ratio of variances *F*-test. Each stratum was compared to the appropriate reference (hence no result for reference rows). Significance level of 0.05 was used.

[c] A Bonferroni adjustment (comparison-wise alpha of 0.05/3 = 0.0167) was used for one-tailed comparisons between each of the three shallow stations and reference are Stratum 5a. Overall ANOVA for comparison to reference area Stratum 5b was not significant ($P = 0.294$).

[d] High variance strata are those not significantly different from reference conditions ($P > 0.05$) and with a standard deviation >15 percent of the mean (CV>0.15).

[e] Reference area Stratum 5a is non-normal because there are only two distinct values. The nonparametric Wilcoxon test was used for stations compared to reference area Stratum 5a.

Figure C-1a. Stratum 1

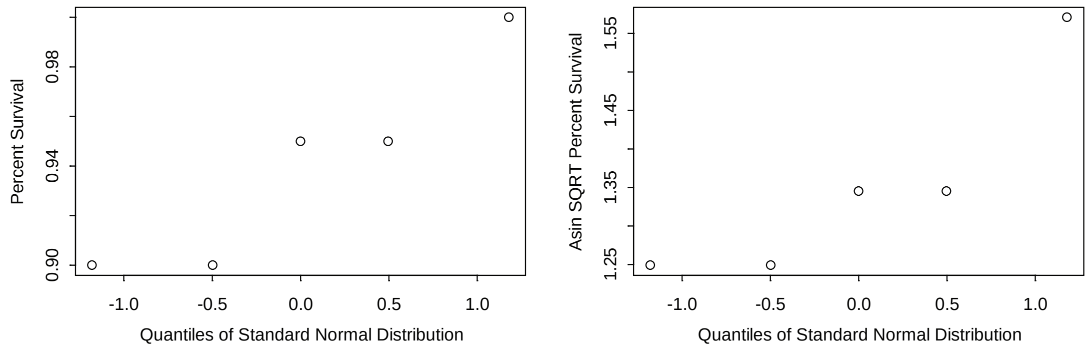


Figure C-1b. Stratum 2a

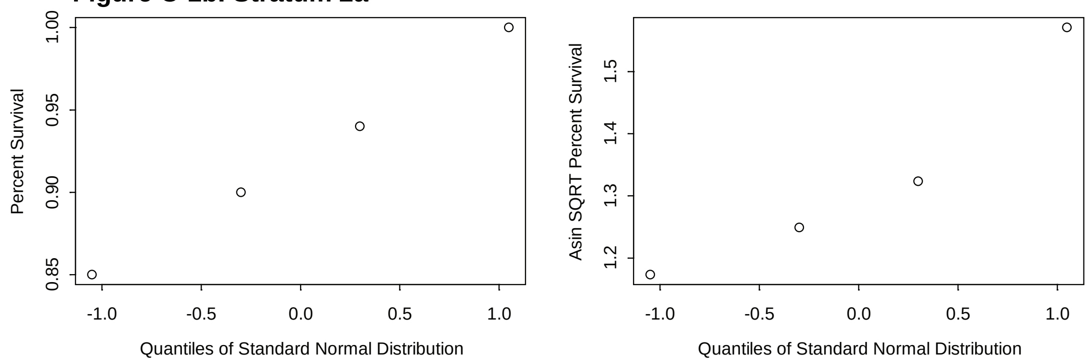


Figure C-1c. Stratum 2b

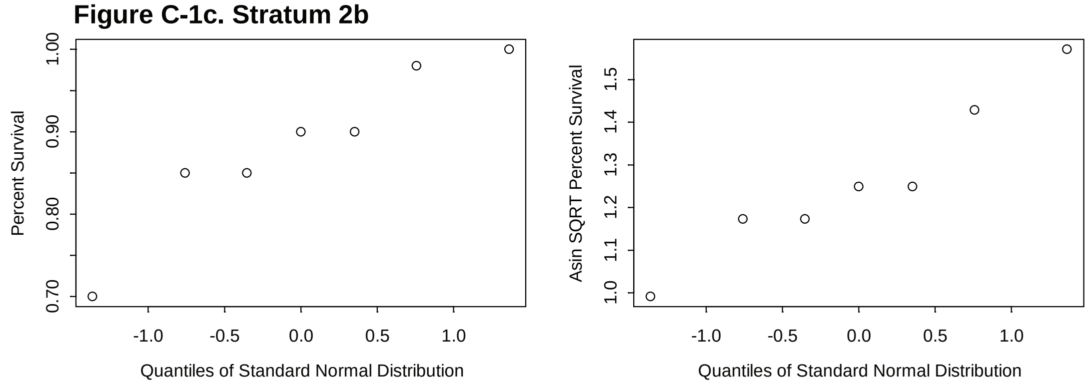


Figure C-1d. Stratum 3a

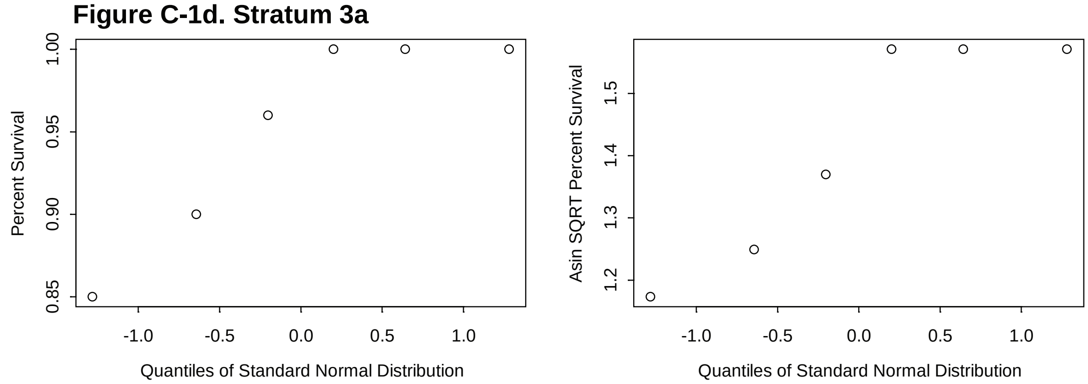


Figure C-1e. Stratum 3b

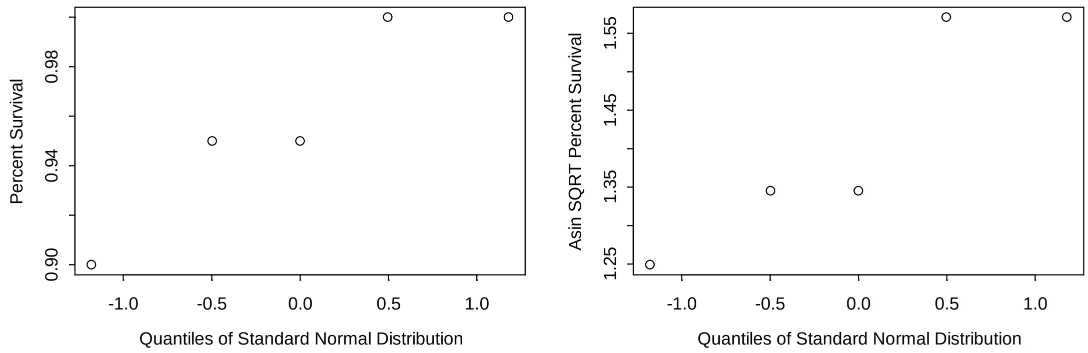


Figure C-1f. Stratum 4

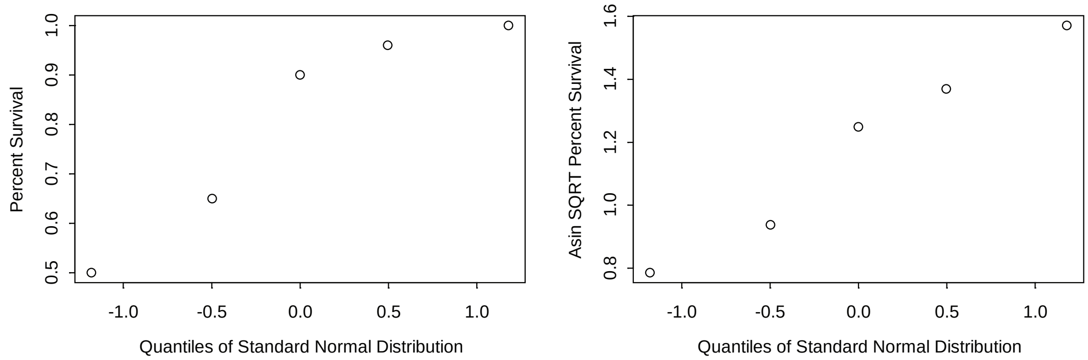


Table C-2. Comparison of Amphipod Survival among Different Sampling Periods in Ward Cove

						Percent Survival			Observed Data				Arcsine Square-root					Regression[d]		
									Normality[a]		Variance[b]		Normality[a]		Variance[b]					
Station	Benthic Stratum	Depth Category	Remediation Category	Year	Species	Mean	Std. Dev.	CV	Pass?	*P*-value	Pass?	*P*-value	Pass?	*P*-value	Pass?	*P*-value	Transform	R^2	Increasing Trend	*P*-value
8	3a	Moderate	TLP	1996	*Rhepoxynius abronius*	43	23	0.53												
				2004	*Eohaustorius estuarius*	99	2.2	0.02	yes	0.32	no	0.001	no	0.02			Rankit	0.59	yes	0.001
				2007	*Eohaustorius estuarius*	96	4.2	0.04												
9	2a	Shallow	TLP	1996	*Rhepoxynius abronius*	54	18	0.33												
				2004	*Eohaustorius estuarius*	91	7.4	0.08	yes	0.13	yes	0.08					no	0.72	yes	0.0001
				2007	*Eohaustorius estuarius*	94	6.5	0.07												
13	4	Deep	Natural recovery	1996	*Rhepoxynius abronius*	36	11	0.30												
				1997	*Rhepoxynius abronius*	15	23	1.5	no	0.02			yes	0.07	yes	0.063	arcsin	0.52	yes	0.0003
				2004	*Eohaustorius estuarius*	43	31	0.71												
				2007	*Eohaustorius estuarius*	96	4.2	0.04												
38	2b	Shallow	Natural recovery	1997	*Rhepoxynius abronius*	0	0	n/a												
				2004	*Eohaustorius estuarius*	89	8.2	0.09	no	0.005			yes	0.07	n/a		Rankit[c]	0.85	yes	0.000001
				2007	*Eohaustorius estuarius*	98	2.7	0.03												

Notes:

n/a = result could not be calculated due to zero variance.

CV = coefficient of variation

TLP = thin layer placement

[a] Normality was evaluated using the Shapiro-Wilk's goodness-of-fit test on residuals from the linear regression. Significance level of 0.05 was used.

[b] Homogeneity of variance was evaluated using the ratio of variances *F*-test. Largest variance was compared to smallest variance. Significance level of 0.05 was used. Test was not run (and no result is displayed) if data were not approximately normal.

[c] Station 38 in 1997 had zero variance; statistical comparison of variances cannot be made. Rankit transformation was used.

[d] Trends were evaluated using simple linear regression after appropriate transformation to meet the assumptions of the test. Significance level of 0.05 was used. Slope and intercept values are not presented because regressions were performed on transformed data.

Figure C-2a. Station 8

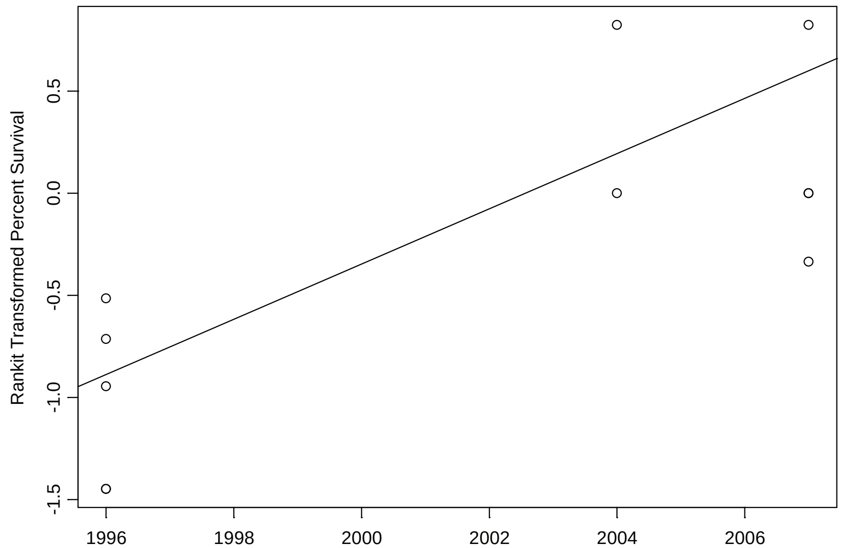


Figure C-2b. Station 9

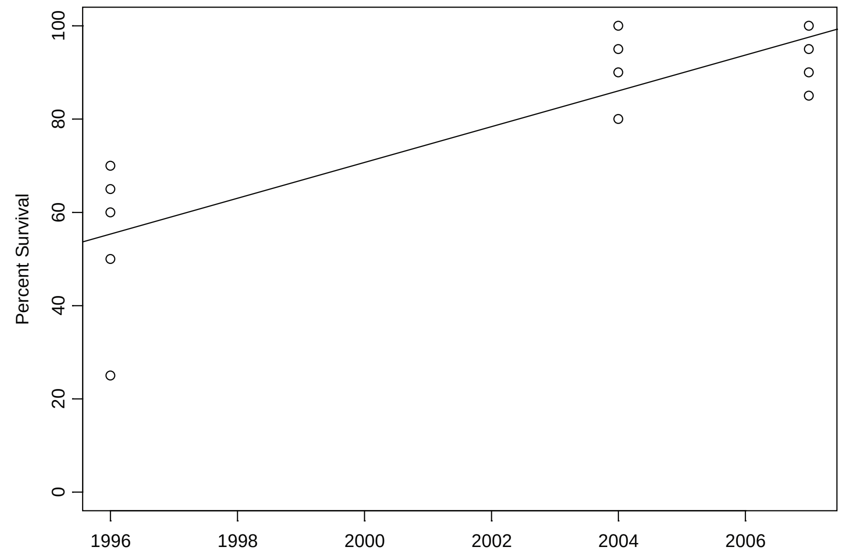


Figure C-2c. Station 13

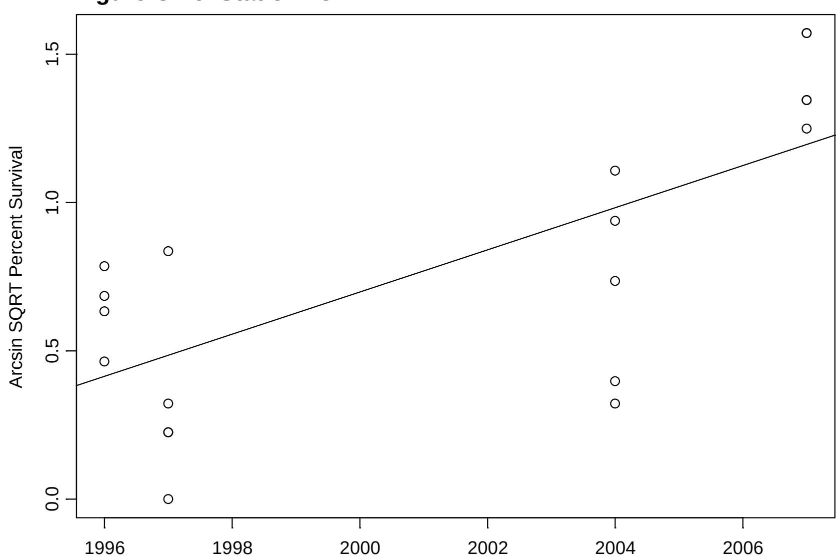


Figure C-2d. Station 38

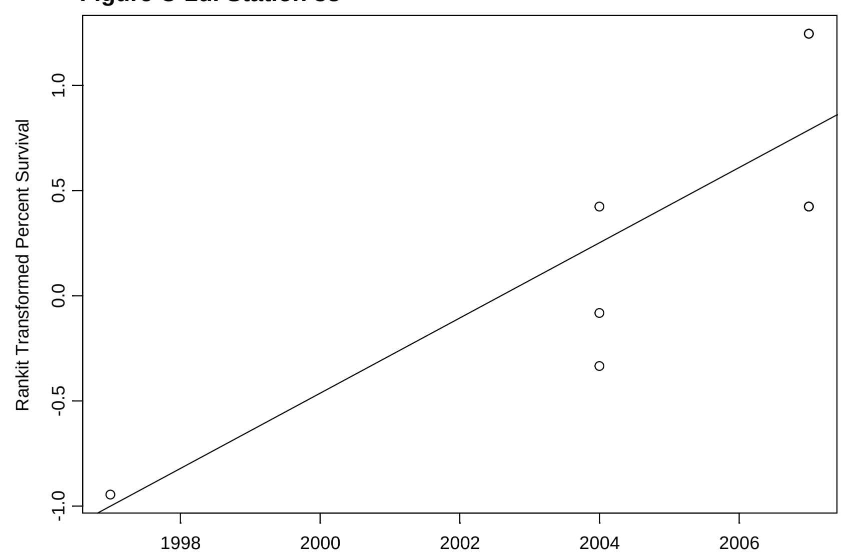


Table C-3. Statistical Summary of Comparisons of Benthic metrics between AOC and Reference Strata in Ward Cove in July 2007

						Observed Data				Log_{10}(+1) Transform				Square-Root Transform				Transformed								
Benthic		Remediation				Normality[a]		Homo.of Var.[b]		Normality[a]		Homo.of Var.[b]		Normality[a]		Homo.of Var.[b]										
Stratum	Depth Category	Category	Mean	Std.Dev.	CV	Pass?	*P*-value	Pass?	*P*-value	Pass?	*P*-value	Pass?	*P*-value	Pass?	*P*-value	Pass?	*P*-value	Mean	Std.Dev.	MANOVA[d]	ANOVA[d]	Dunnett's[e]		Single Comparison[f]		
Total Abundance																										
1	Very shallow	TLP	322.20	162.24	0.50	no	0.026			yes	0.16	yes	0.69	yes	0.066	yes	0.28	17.58	4.08		0.003					
2a	Shallow	TLP	234.50	78.61	0.34	yes	0.26			yes	0.46	yes	0.91	yes	0.35	yes	0.84	15.17	2.45							
2b	Shallow	Natural recovery	81.71	97.41	1.19	no	0.033			yes	0.27	no	0.01	yes	0.59	yes	0.11	7.49	5.47			yes	0.025	*t*-test	yes	0.020
ref 5a	Shallow	--	190.80	60.63	0.32	yes	0.65			yes	0.62			yes	0.66			13.66	2.26							
3a	Moderate depth	TLP	192.50	138.76	0.72																					
3b	Moderate depth	Natural recovery	103.20	36.35	0.35																					
4	Deep	Natural recovery	148.00	85.87	0.58																					
ref 5b	Moderate depth	--	73.20	37.75	0.52																					
Taxa Abundance																										
Molluscs																										
1	Very shallow	TLP	212.20	143.39	0.68	yes	0.088			yes	0.61			yes	0.30			1.06	0.63	0.052						
2a	Shallow	TLP	104.75	79.42	0.76	yes	0.85			no	0.02			yes	0.24			0.27	0.94							
2b	Shallow	Natural recovery	4.71	11.21	2.38	no	0.000022			no	0.00061			no	0.00032			-0.87	0.31					Wilcoxon	yes	0.0021
ref 5a	Shallow	--	72.20	21.72	0.30	yes	0.91			yes	0.98			yes	0.97			0.05	0.28							
3a	Moderate depth	TLP	109.00	108.42	0.99																					
3b	Moderate depth	Natural recovery	1.40	1.95	1.39																					
4a	Deep	Natural recovery	7.00	7.62	1.09																					
ref 5b	Moderate depth	--	1.60	3.05	1.91																					
Polychaetes																										
1	Very shallow	TLP	107.40	27.08	0.25	yes	0.94			yes	0.95	yes	0.061	yes	0.95	yes	0.079	0.15	0.42	0.052				*t*-test	no	0.42
2a	Shallow	TLP	127.00	43.42	0.34	yes	0.23			yes	0.21	yes	0.24	yes	0.22	yes	0.35	0.46	0.55							
2b	Shallow	Natural recovery	77.00	92.41	1.20	no	0.032			yes	0.28	yes	0.11	yes	0.71	yes	0.47	-0.47	1.28					Wilcoxon	no	0.17
ref 5a	Shallow	--	114.60	72.85	0.64	yes	0.56			yes	0.62			yes	0.69			0.14	1.07							
3a	Moderate depth	TLP	79.83	36.85	0.46																					
3b	Moderate depth	Natural recovery	99.00	34.32	0.35																					
4	Deep	Natural recovery	116.00	54.44	0.47																					
ref 5b	Moderate depth	--	68.80	34.67	0.50																					
Arthropods																										
1	Very shallow	TLP	2.60	1.52	0.58	yes	0.49	yes	0.42	yes	0.85	yes	0.18	yes	0.79	yes	0.133	0.67	0.40	0.052						
2a	Shallow	TLP	2.00	2.71	1.35	yes	0.06	yes	0.76	yes	0.47	yes	0.97	yes	0.59	yes	0.970	0.39	1.09							
2b	Shallow	Natural recovery	0.00	0.00	n/a		n/a		n/a		n/a		n/a		n/a		n/a	-0.70	0.00							
ref 5a	Shallow	--	2.00	2.35	1.17	yes	0.15			yes	0.20			yes	0.22			0.20	0.92							
3a	Moderate depth	TLP	3.33	2.42	0.73																					
3b	Moderate depth	Natural recovery	2.60	3.97	1.53																					
4	Deep	Natural recovery	23.60	45.13	1.91																					
ref 5b	Moderate depth	--	2.20	1.30	0.59																					
Total Richness																										
1	Very shallow	TLP	24.80	4.60	0.19	yes	0.44	yes	0.35	yes	0.36	yes	0.75	yes	0.40	yes	0.541	0.74	0.35		0.0002					
2a	Shallow	TLP	23.75	13.60	0.57	yes	0.56	no	0.010	yes	0.12	no	0.0081	yes	0.28	no	0.010	0.81	1.11							
2b	Shallow	Natural recovery	2.86	2.61	0.91	yes	0.11	yes	0.85	yes	0.50	no	0.012	yes	0.33	yes	0.086	-1.0	0.52			yes	0.013	*t*-test	yes	0.0000045
ref 5a	Shallow	--	15.80	2.77	0.18	yes	0.66			yes	0.80			yes	0.73			0.02	0.23							
3a	Moderate depth	TLP	20.17	10.98	0.54	yes	0.67			yes	0.20	yes	0.97	yes	0.49			1.25	0.31		0.031					
3b	Moderate depth	Natural recovery	4.00	4.06	1.02	no	0.045			yes	0.46	yes	0.95	yes	0.17			0.61	0.30			no	0.53	Wilcoxon	no	0.20
4	Deep	Natural recovery	9.60	8.20	0.85	yes	0.55			yes	0.64	yes	0.54	yes	0.68			0.88	0.43							
ref 5b	Moderate depth	--	6.20	6.65	1.07	no	0.0044			yes	0.10			no	0.021			0.75	0.31							

Table C-3. Statistical Summary of Comparisons of Benthic metrics between AOC and Reference Strata in Ward Cove in July 2007

Benthic Stratum	Depth Category	Remediation Category	Mean	Std.Dev.	CV	Observed Data: Normality[a] Pass?	Observed Data: Normality[a] *P*-value	Observed Data: Homo.of Var.[b] Pass?	Observed Data: Homo.of Var.[b] *P*-value	Log_{10}(+1) Transform: Normality[a] Pass?	Log_{10}(+1) Transform: Normality[a] *P*-value	Log_{10}(+1) Transform: Homo.of Var.[b] Pass?	Log_{10}(+1) Transform: Homo.of Var.[b] *P*-value	Square-Root Transform: Normality[a] Pass?	Square-Root Transform: Normality[a] *P*-value	Square-Root Transform: Homo.of Var.[b] Pass?	Square-Root Transform: Homo.of Var.[b] *P*-value	Transformed Mean	Transformed Std.Dev.	MANOVA[d]	ANOVA[d]	Dunnett's[e]		Single Comparison[f]		
Taxa Richness																										
Molluscs																										
1	Very shallow	TLP	10.60	3.05	0.29	yes	0.55			yes	0.49			yes	0.52			0.82	0.48	0.032	0.001					
2a	Shallow	TLP	9.50	7.14	0.75	yes	0.84			yes	0.092			yes	0.22			0.61	1.23							
2b	Shallow	Natural recovery	1.00	1.91	1.91	no	0.0006			no	0.0011			no	0.0011			-0.83	0.40			no	0.056	Wilcoxon	yes	0.0070
ref 5a	Shallow	--	5.40	1.52	0.28	yes	0.086			yes	0.10			yes	0.096			-0.04	0.27							
3a	Moderate depth	TLP	7.33	5.43	0.74	yes	0.46			yes	0.39			yes	0.51			0.94	0.69	0.038	0.001					
3b	Moderate depth	Natural recovery	0.40	0.55	1.37	no	0.0065			no	0.0065			no	0.0065			-0.67	0.39			no	0.66	Wilcoxon	no	0.45
4	Deep	Natural recovery	3.40	2.97	0.87	yes	0.78			yes	0.76			yes	0.77			0.26	0.73							
ref 5b	Moderate depth	--	0.60	0.89	1.49	no	0.046			no	0.046			no	0.037			-0.58	0.53							
Polychaetes																										
1	Very shallow	TLP	12.20	2.49	0.20	yes	0.38	yes	0.88									0.74	0.49	0.032	0.00009					
2a	Shallow	TLP	12.00	5.35	0.45	yes	0.80	yes	0.14									0.80	0.94							
2b	Shallow	Natural recovery	1.86	1.21	0.65	yes	0.24	yes	0.16									-1.04	0.47			yes	0.005	*t*-test	yes	0.000037
ref 5a	Shallow	--	8.40	2.30	0.27	yes	0.69											0.08	0.34							
3a	Moderate depth	TLP	10.33	5.68	0.55	yes	0.68			yes	0.25			yes	0.47			0.91	0.72	0.038	0.012					
3b	Moderate depth	Natural recovery	1.40	0.55	0.39	no	0.0065			no	0.0065			no	0.0065			-0.62	0.46			no	0.39	Wilcoxon	no	0.24
4	Deep	Natural recovery	4.20	3.27	0.78	yes	0.26			yes	0.16			yes	0.20			-0.11	0.78							
ref 5b	Moderate depth	--	3.40	4.28	1.26	no	0.0025			no	0.037			no	0.015			-0.24	0.78							
Arthropods																										
1	Very shallow	TLP	2.20	0.84	0.38	yes	0.31	yes	1.000									0.87	0.43	0.032	0.0020					
2a	Shallow	TLP	1.75	2.22	1.27	yes	0.10	yes	0.090									0.42	1.08							
2b	Shallow	Natural recovery	0.00	0.00	n/a		n/a		n/a									-0.70	0.00			no	0.082	n/a		n/a
ref 5a	Shallow	--	0.80	0.84	1.05	yes	0.31											-0.03	0.65							
3a	Moderate depth	TLP	2.33	1.37	0.59	yes	0.55			yes	0.055			no	0.035			0.36	0.78	0.038	0.67					
3b	Moderate depth	Natural recovery	2.00	3.46	1.73	no	0.010			no	0.046			no	0.046			-0.20	1.30							
4	Deep	Natural recovery	1.40	2.07	1.48	no	0.023			yes	0.22			yes	0.29			-0.25	1.01					Wilcoxon	no	0.14
ref 5b	Moderate depth	--	1.80	0.84	0.46	yes	0.31			yes	0.28			yes	0.30			0.13	0.45							
Swartz' Dominance Index																										
1	Very shallow	TLP	6.0	1.9	0.31	yes	0.11			yes	0.071			yes	0.086			0.66	0.44		0.67					
2a	Shallow	TLP	5.0	3.2	0.63	yes	0.65			yes	0.35			yes	0.48			0.31	1.00							
2b	Shallow	Natural recovery	1.2	0.4	0.35	no	0.000021			no	0.000021			no	0.000021			-0.54	1.10					Wilcoxon	yes	0.003
ref 5a	Shallow	--	3.2	0.8	0.26	yes	0.31			yes	0.28			yes	0.29			-0.06	0.29							
3a	Moderate depth	TLP	3.8	1.7	0.45	yes	0.83			yes	0.23			yes	0.41			0.93	0.81		0.32					
3b	Moderate depth	Natural recovery	1.0	0.0	0.00		n/a				n/a				n/a			-0.49	0.00					Wilcoxon	no	0.21
4	Deep	Natural recovery	1.6	0.9	0.56	no	0.046			no	0.048			no	0.049			-0.10	0.55							
ref 5b	Moderate depth	--	1.2	0.4	0.37	no	0.00013			no	0.00013			no	0.00013			-0.27	0.50							

Notes:

AOC = area of concern
ANOVA = analysis of variance
CV = coefficient of variation
MANOVA = multivariate analysis of variance
n/a = result cannot be calculated due to zero mean or variance.
SDI = Swartz' dominance index
TLP = thin layer placement

If reference area Stratum result is less than all station results, no statistical analysis was run. The only abundance result that is less than reference area Stratum 5b abundance is for mollusc abundance at Stratum 3b, so no statistical tests comparing abundances to reference area Stratum 5b were run.

If data were approximately normal with or without a transformation, total abundance, total richness, and SDI were analyzed using ANOVA followed by Dunnett's test. Otherwise, nonparametric rankit transformation was used prior to testing.
Taxa abundances and richnesses were analyzed using an overall MANOVA, followed by individual ANOVA and Dunnett's test. For all comparisons, a nonparametric analysis was also conducted. Significance was determined at a 0.05 overall level for each set of comparisons. Pairwise comparisons were one-sided to test whether site stations are significantly lower than reference.

Conclusions and *P*-values are reported for normality, homogeneity of variance, ANOVA, and Dunnett's and simple two-sample comparisons. However, only those tests that were necessary were run.

[a] Normality was evaluated using the Shapiro-Wilk's goodness-of-fit test. Significance level of 0.05 was used. No result is displayed if sites are greater than reference.

[b] If data were approximately normal, homogeneity of variance was evaluated using the ratio of variances *F*-test comparing each stratum to reference. Significance level of 0.05 was used. No result is displayed for reference rows, or for all rows if any stations were not normal.

[c] Transformation was used only if all strata met assumptions. Otherwise, Rankit nonparametric tests were used. For taxa abundance and richness, a single transformation for all taxa was used in order to run the MANOVA.

[d] For the three taxa abundances and for the three taxa richnesses, a single MANOVA was run. If the results were significant, ANOVAs were run for the individual taxa. If the result was not significant, no ANOVA was run (i.e., no result displayed). For the other endpoints, only ANOVAs were run. Significance indicates at least one stratum is different from reference, but not necessarily lower.

[e] Dunnett's one-sided multiple comparison tests were conducted following significant MANOVAs and ANOVAs. 'Yes' indicates the site station was significantly lower than reference at an overall 0.05 level. Results are not displayed for site stations with absolute performance greater than reference.

[f] Single comparisons are conducted for stations with absolute performance lower than reference. If data for both stations being compared are approximately normal, a *t*-test was used. If not, Wilcoxon's nonparametric rank test was conducted pairwise for each stratum comparison with reference. 'Yes' indicates the site station was significantly lower than reference at an overall 0.05 level, corrected for multiple comparisons (alpha = 0.05/number of comparisons).

Figure C-3a Stratum 1

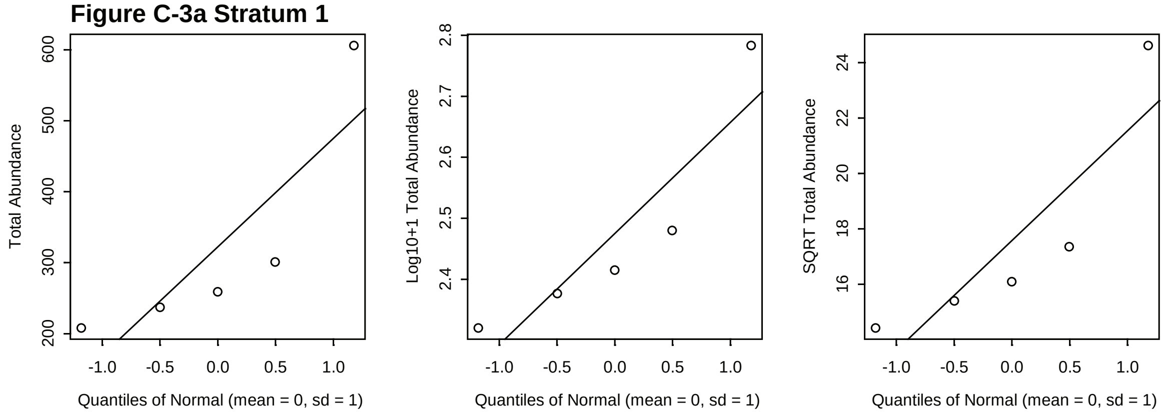


Figure C-3b Stratum 2a

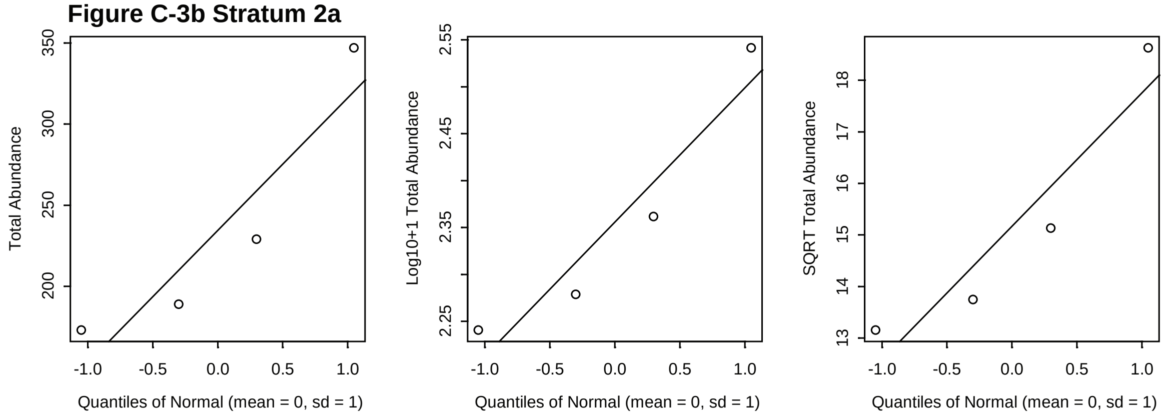


Figure C-3c Stratum 2b

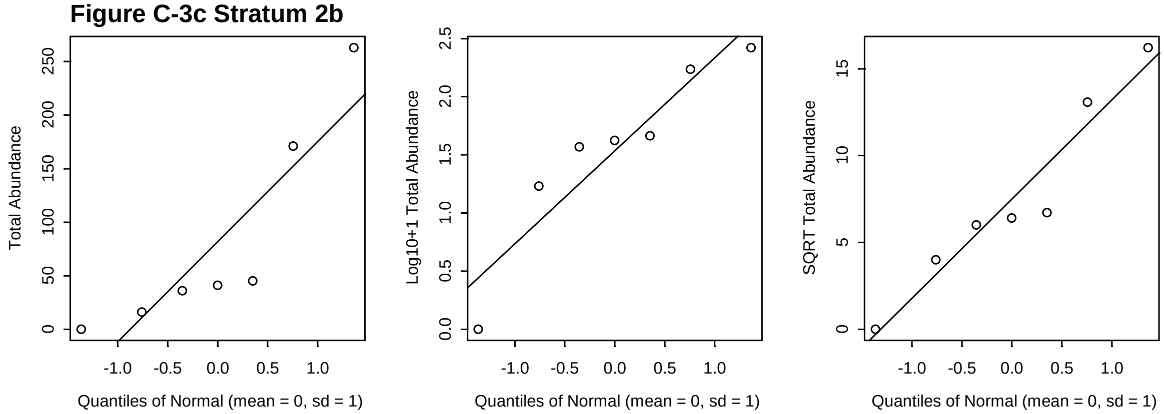


Figure C-3d Stratum 3a

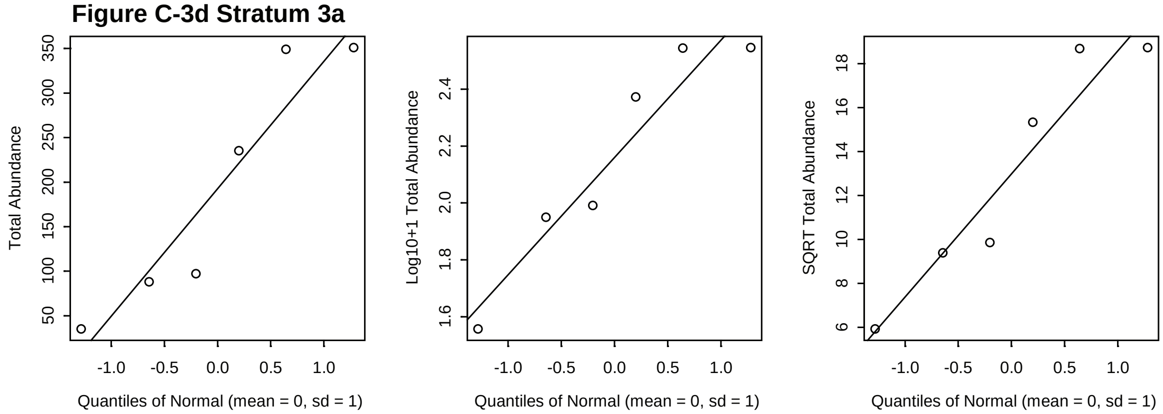


Figure C-3e Stratum 3b

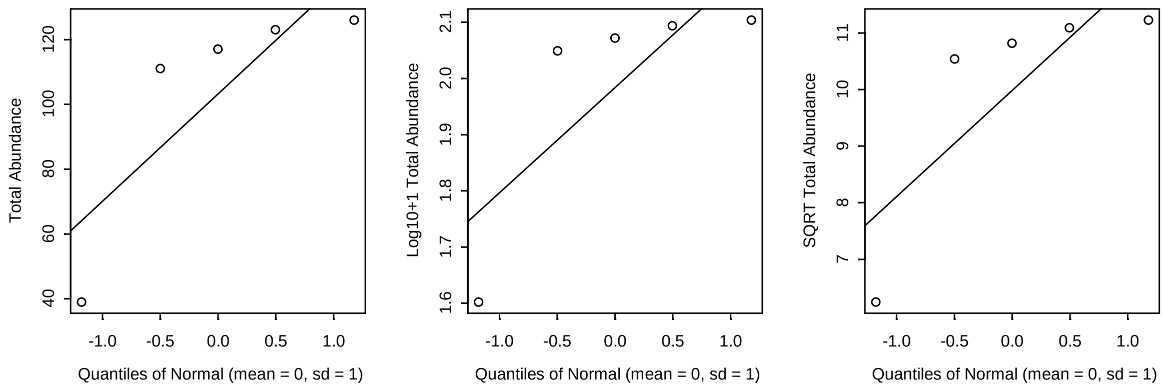


Figure C-3f Stratum 4

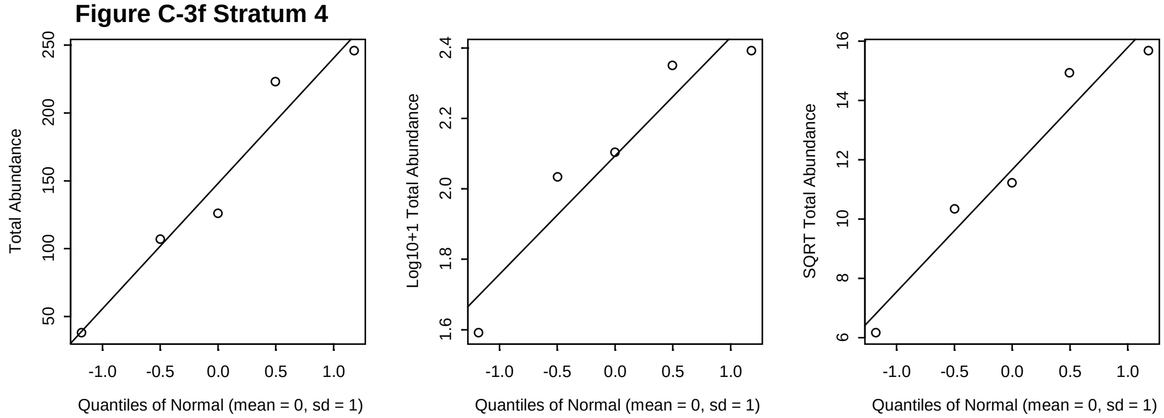


Figure C-3g Stratum 5a

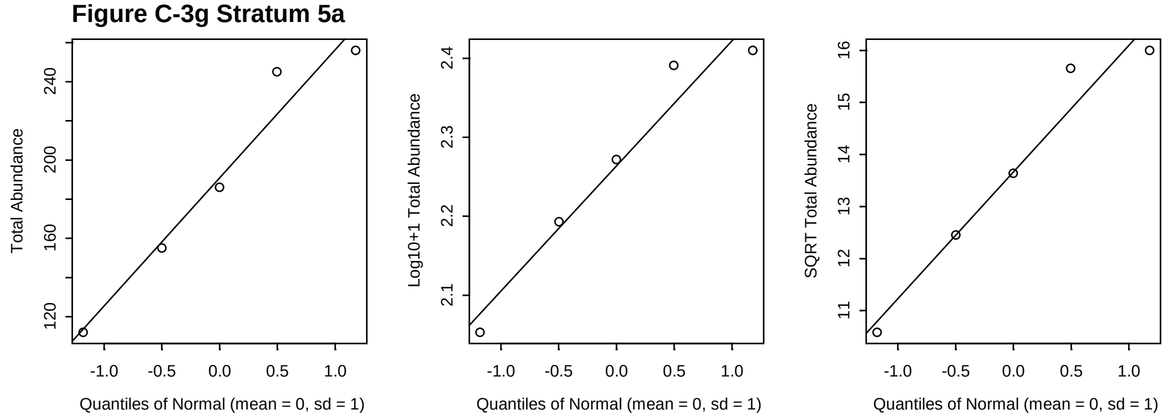


Figure C-3h Stratum 5b

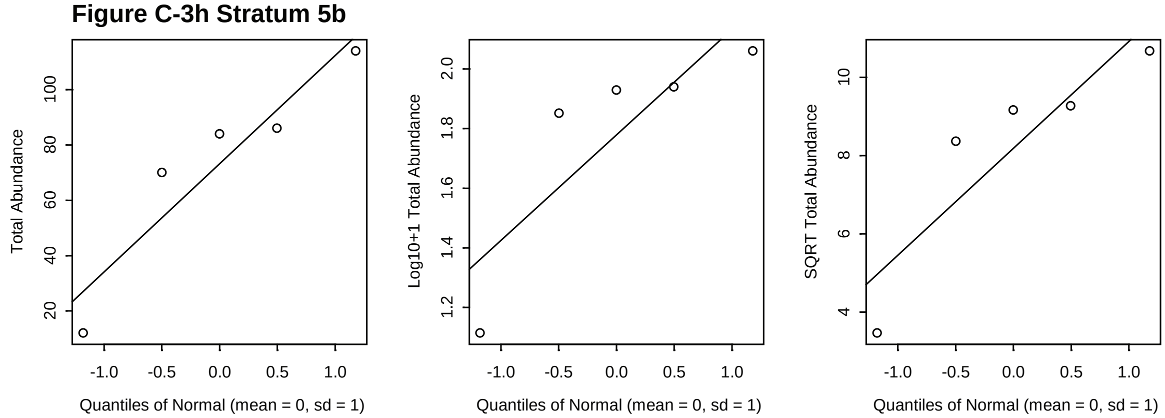


Figure C-4a Stratum 1

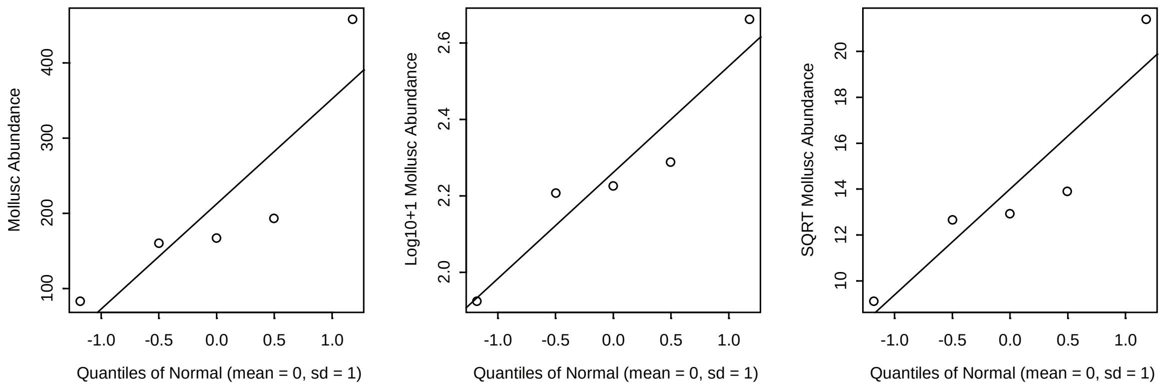


Figure C-4b Stratum 2a

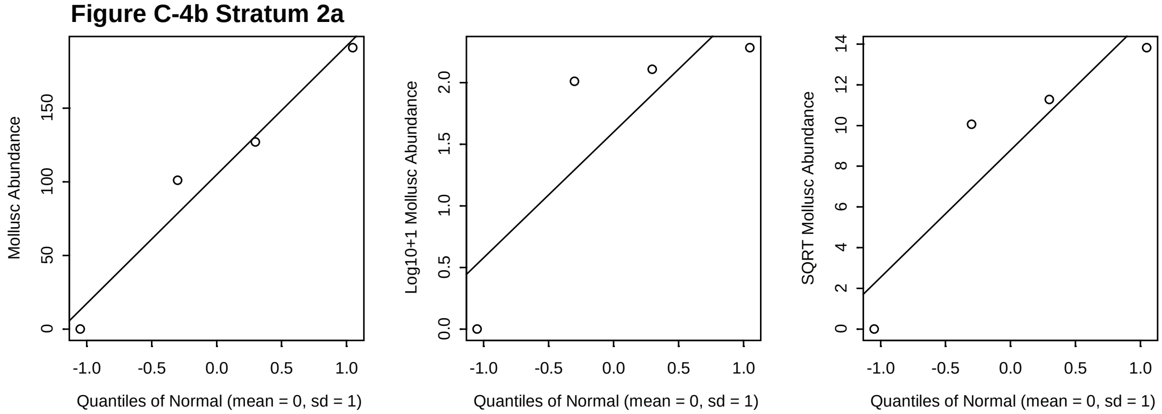


Figure C-4c Stratum 2b

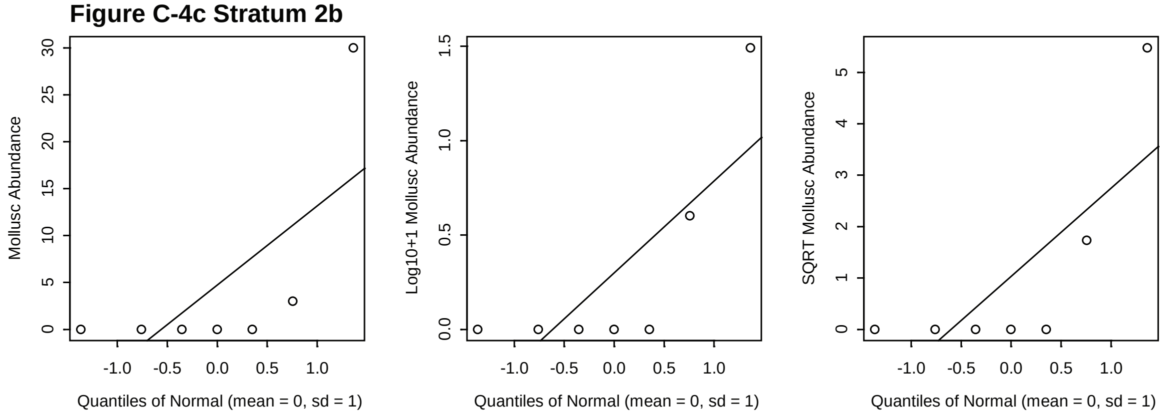


Figure C-4d Stratum 3a

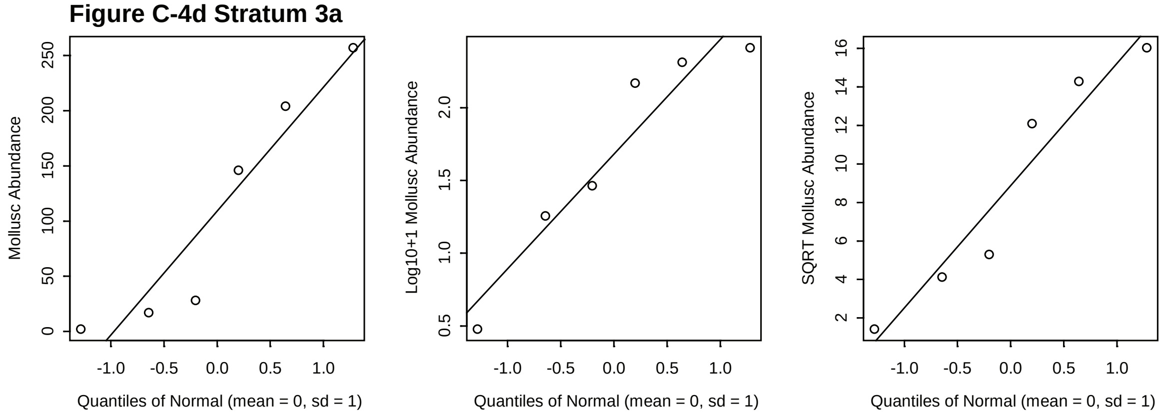


Figure C-4e Stratum 3b

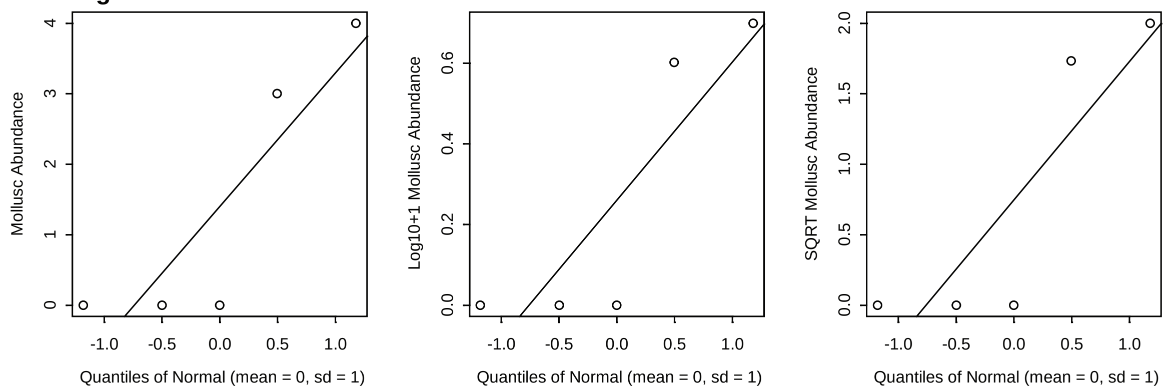


Figure C-4f Stratum 4

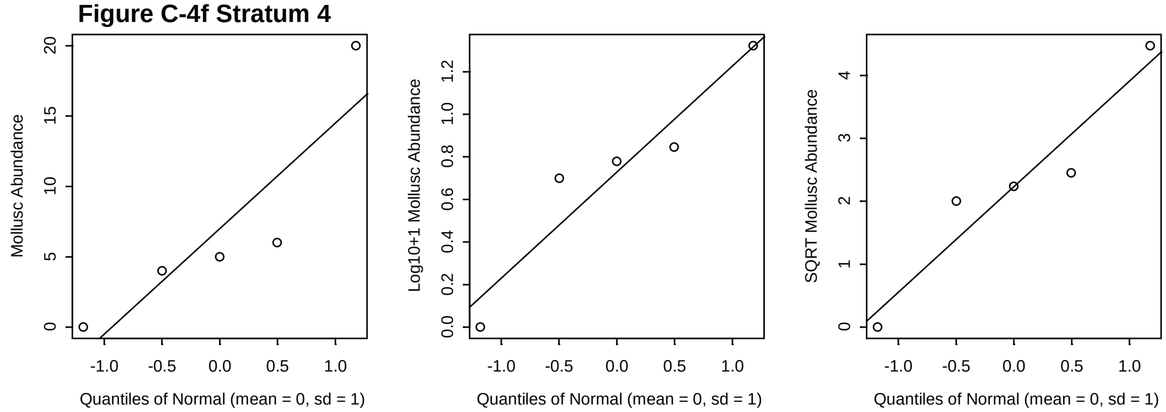


Figure C-4g Stratum 5a

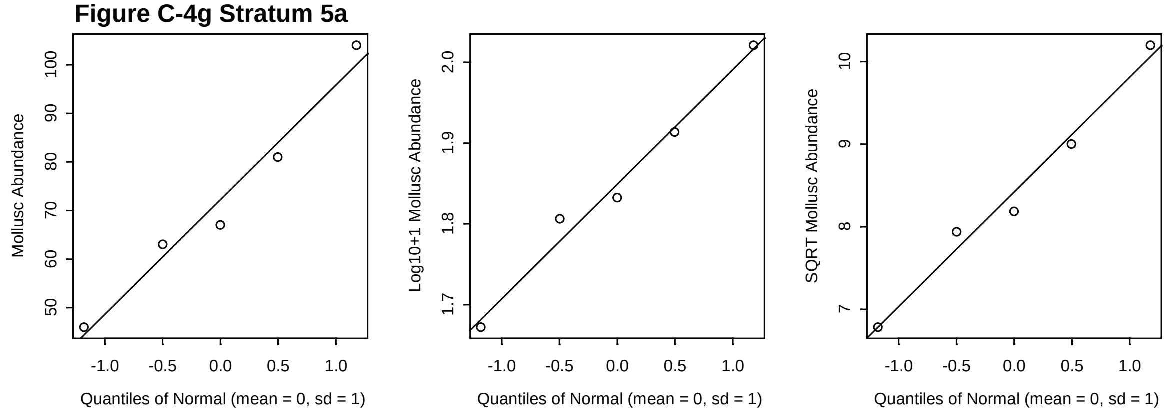


Figure C-4h Stratum 5b

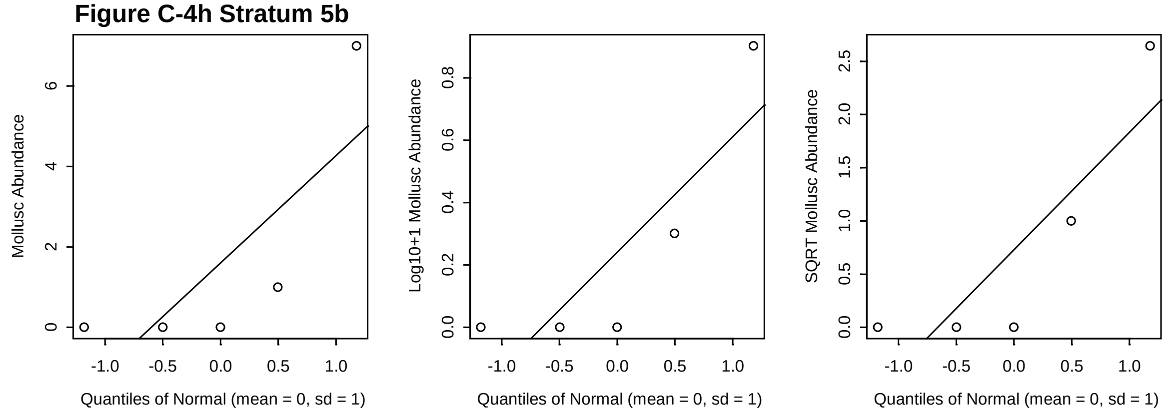


Figure C-5a Stratum 1

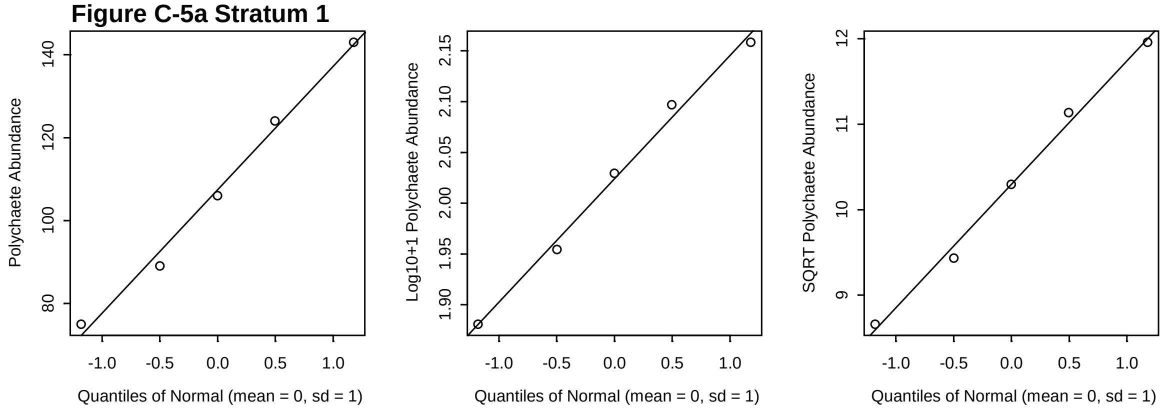


Figure C-5b Stratum 2a

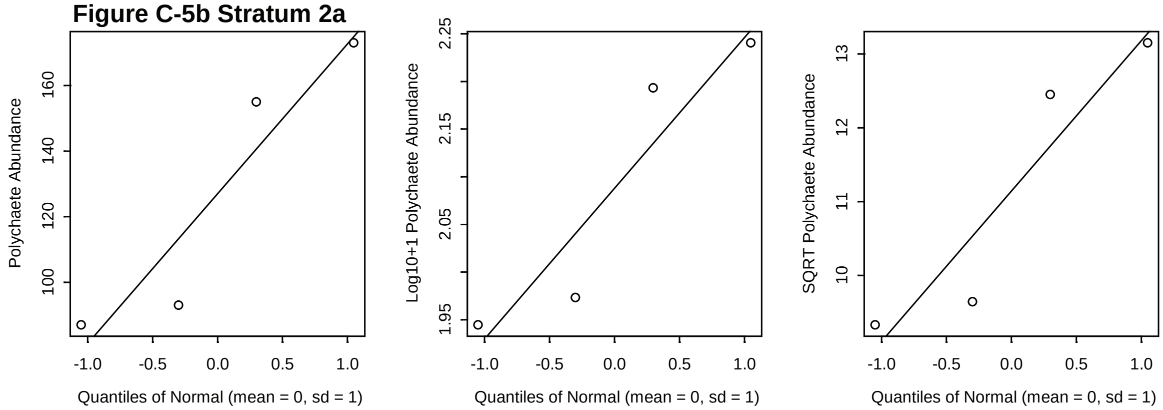


Figure C-5c Stratum 2b

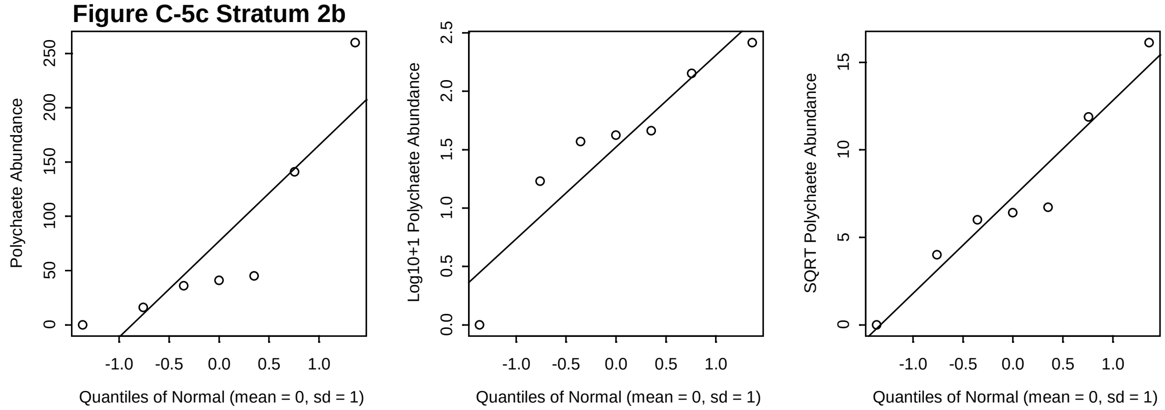


Figure C-5d Stratum 3a

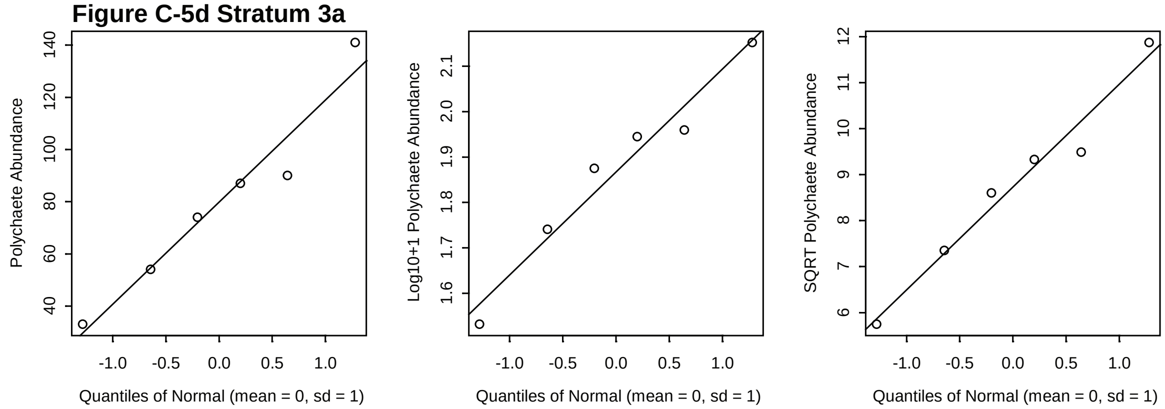


Figure C-5e Stratum 3b

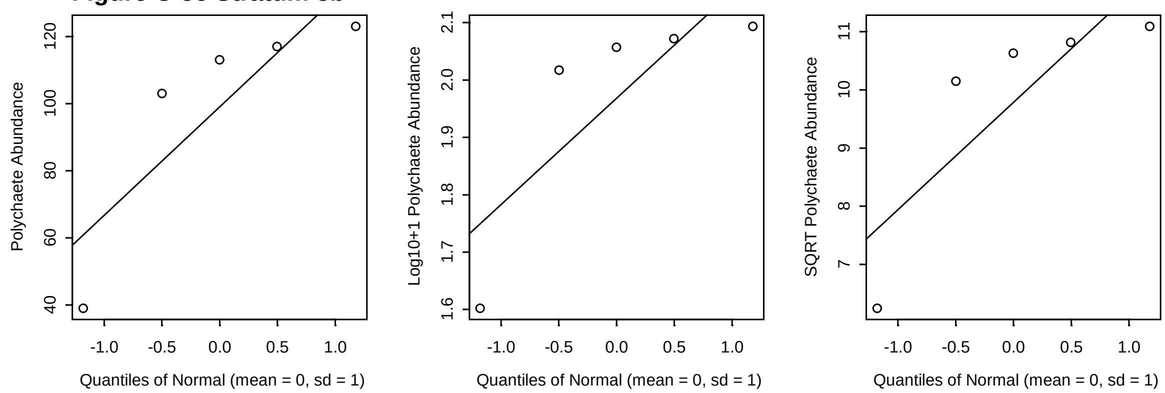


Figure C-5f Stratum 4

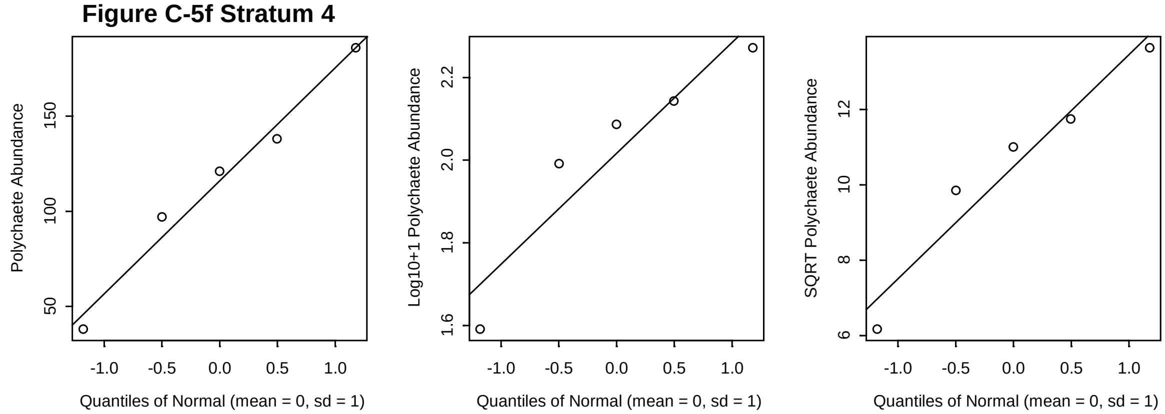


Figure C-5g Stratum 5a

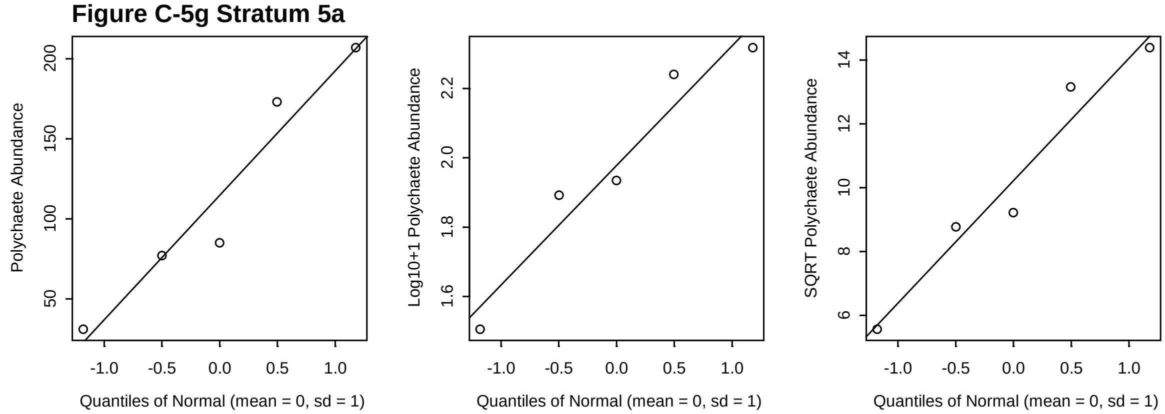


Figure C-5h Stratum 5b

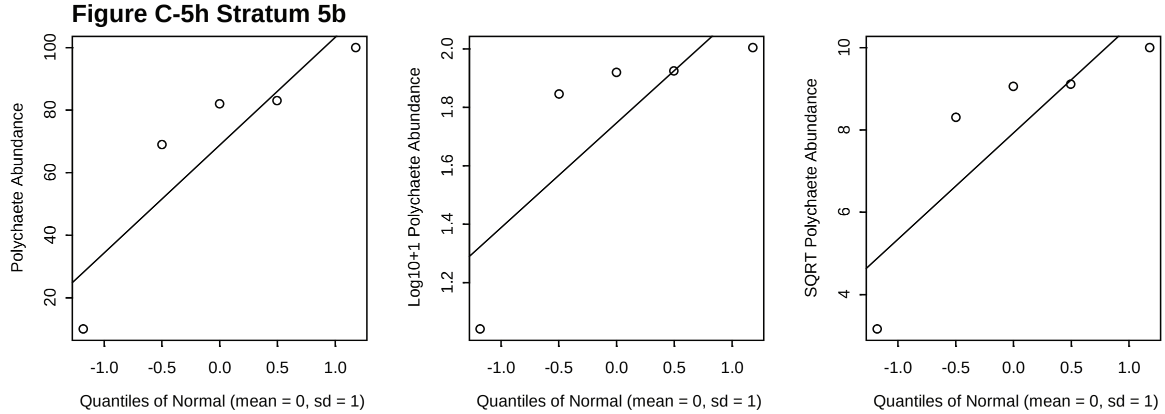


Figure C-6a Stratum 1

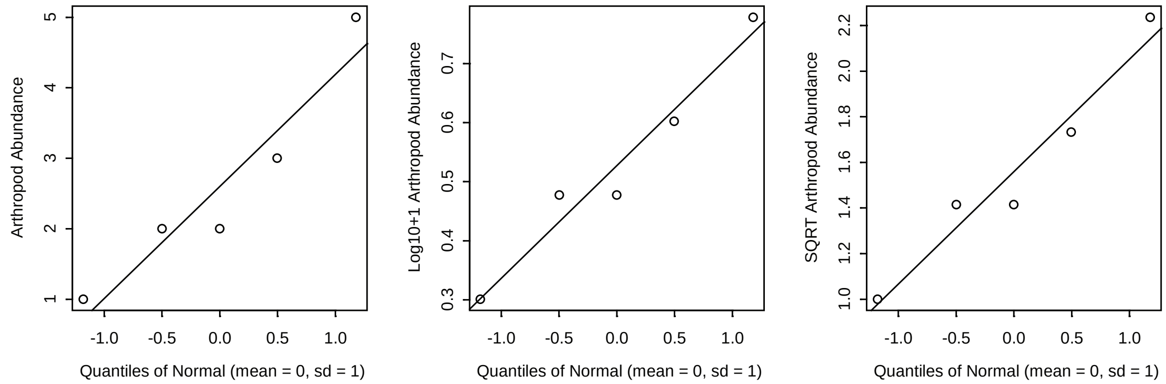


Figure C-6b Stratum 2a

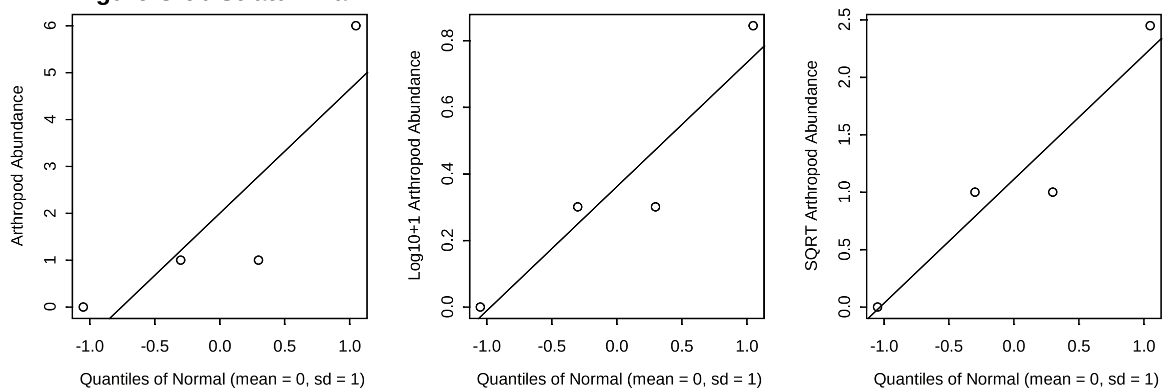


Figure C-6c Stratum 2b

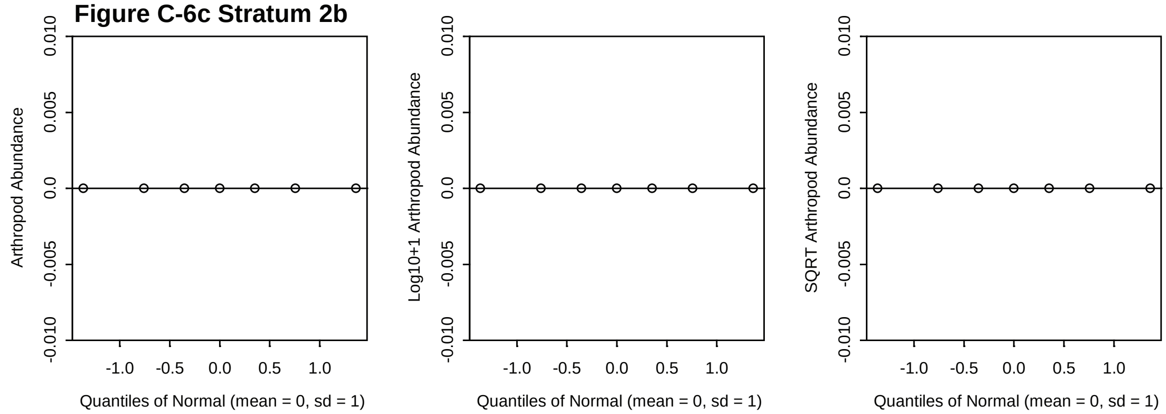
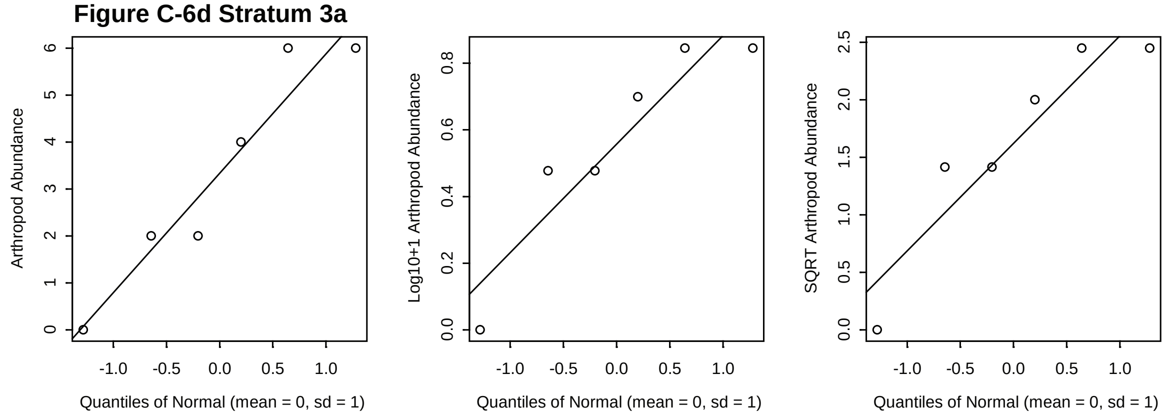


Figure C-6d Stratum 3a



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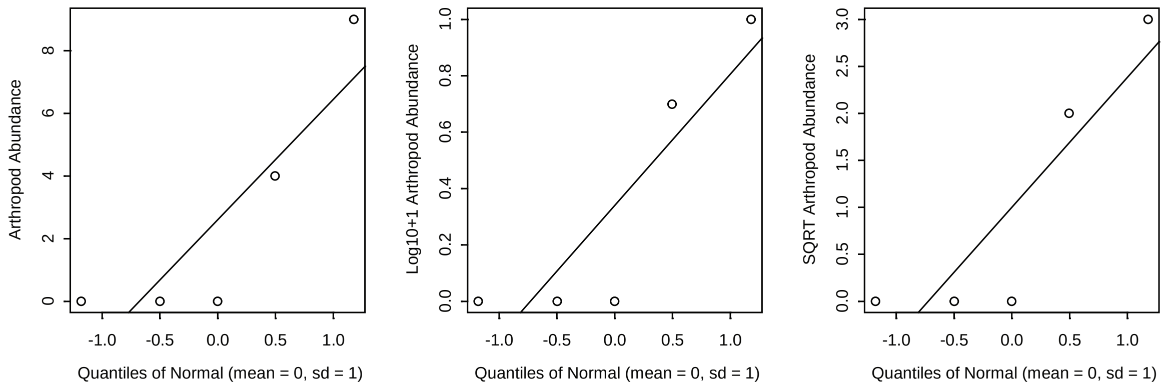


Figure C-6f Stratum 4

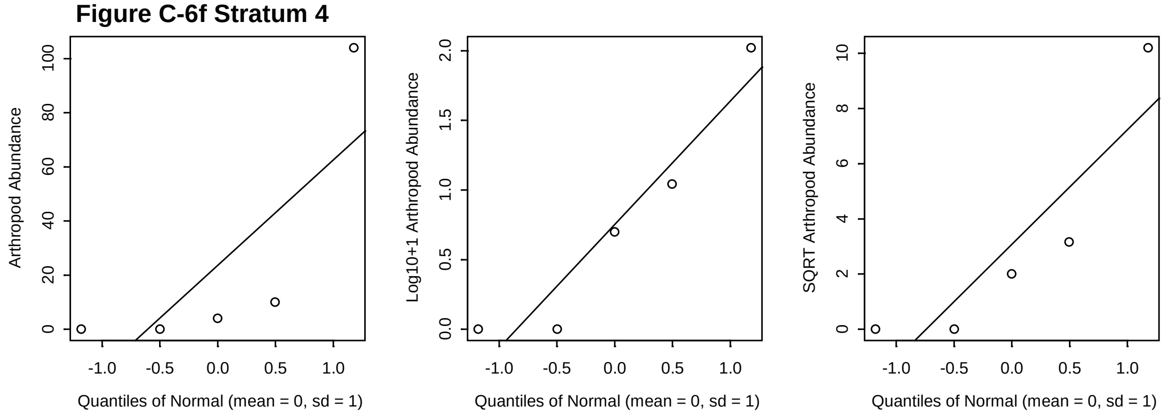
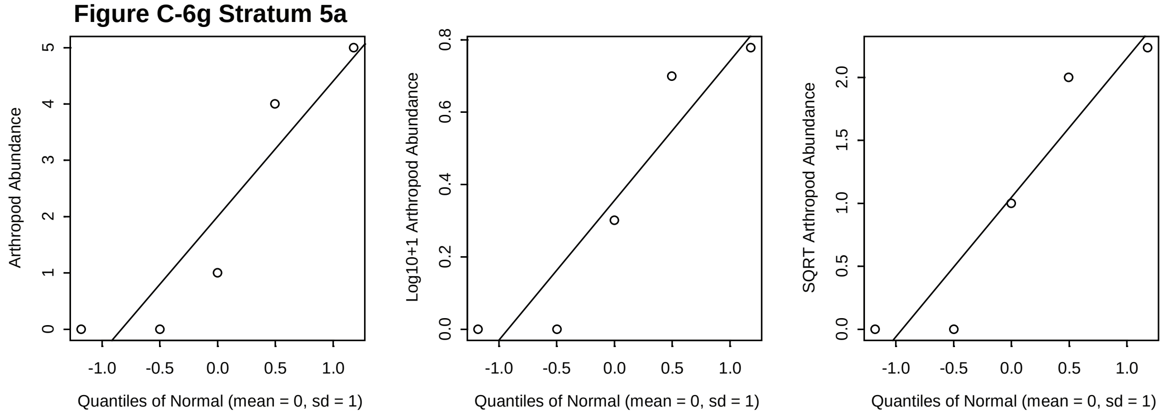


Figure C-6g Stratum 5a



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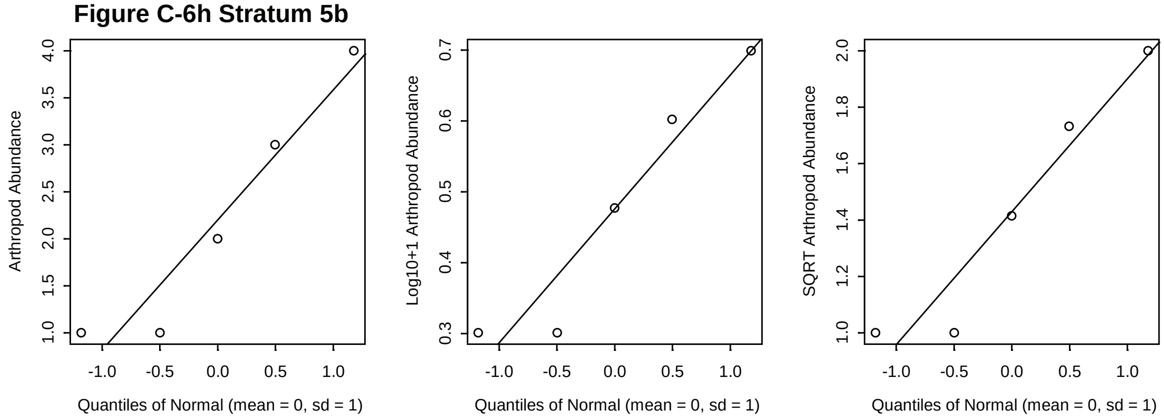


Figure C-7a Stratum 1

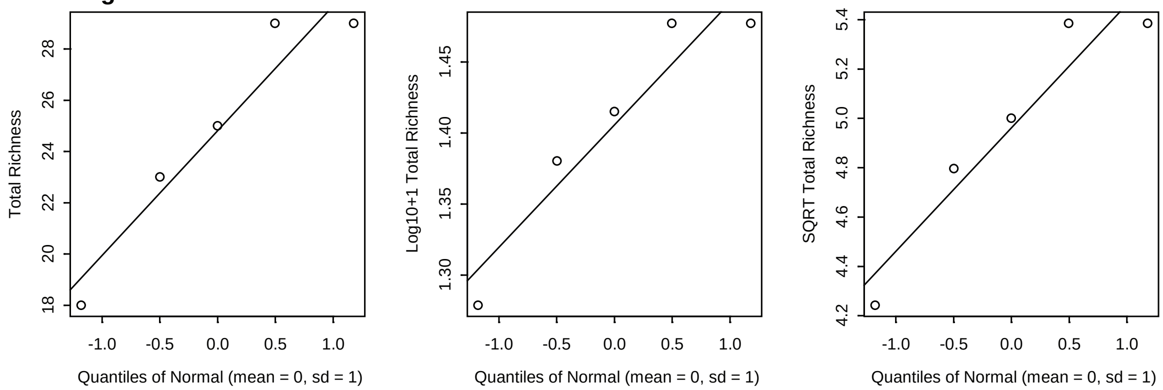


Figure C-7b Stratum 2a

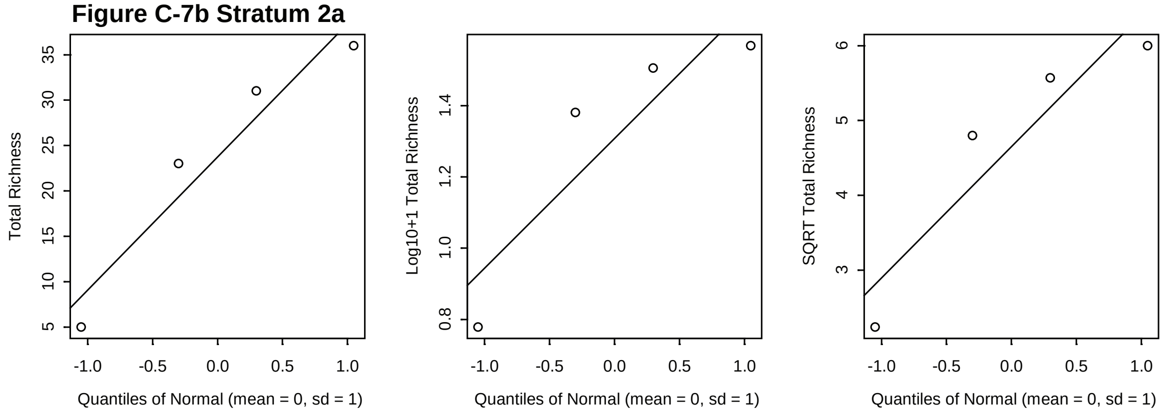


Figure C-7c Stratum 2b

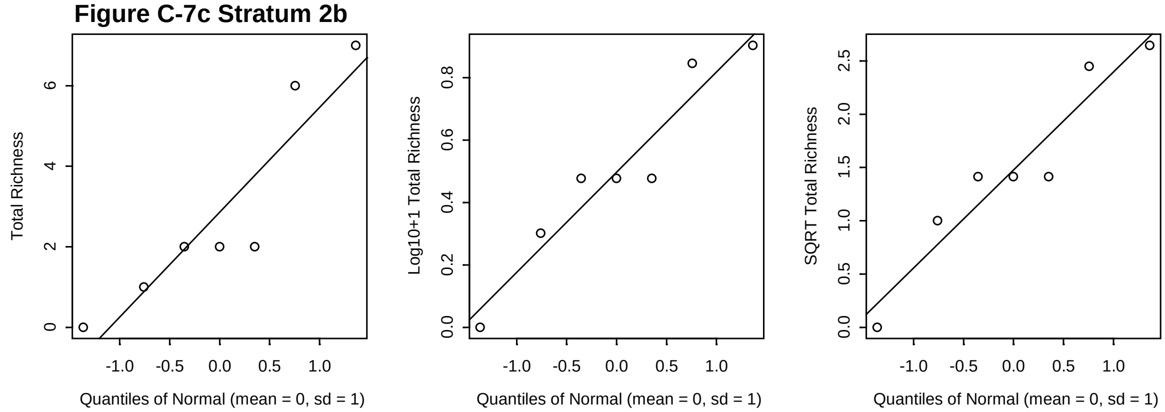
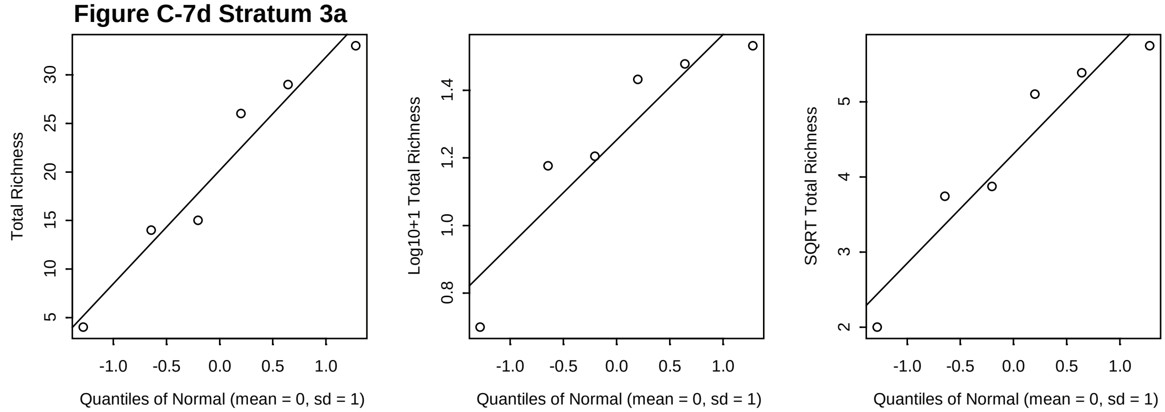


Figure C-7d Stratum 3a



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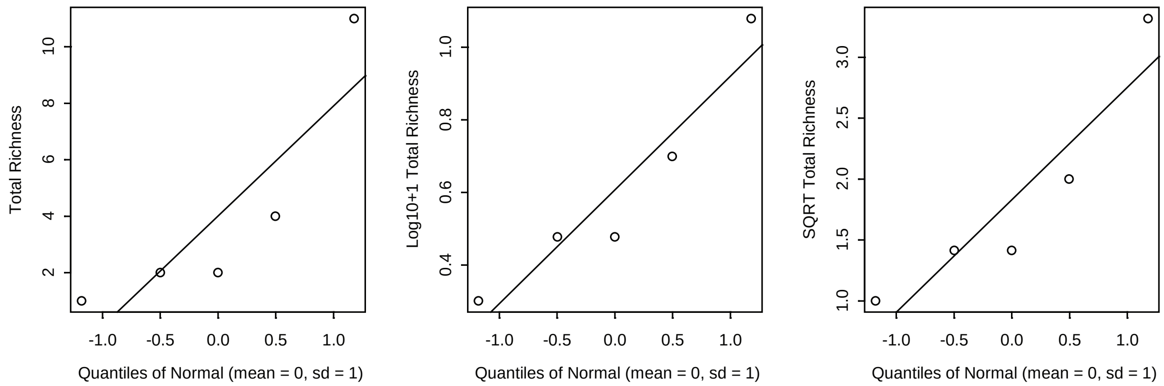


Figure C-7f Stratum 4

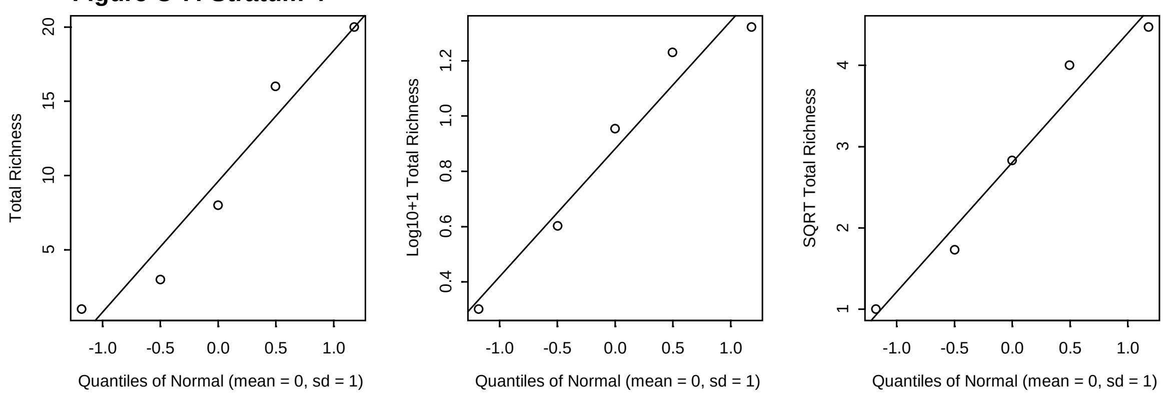


Figure C-7g Stratum 5a

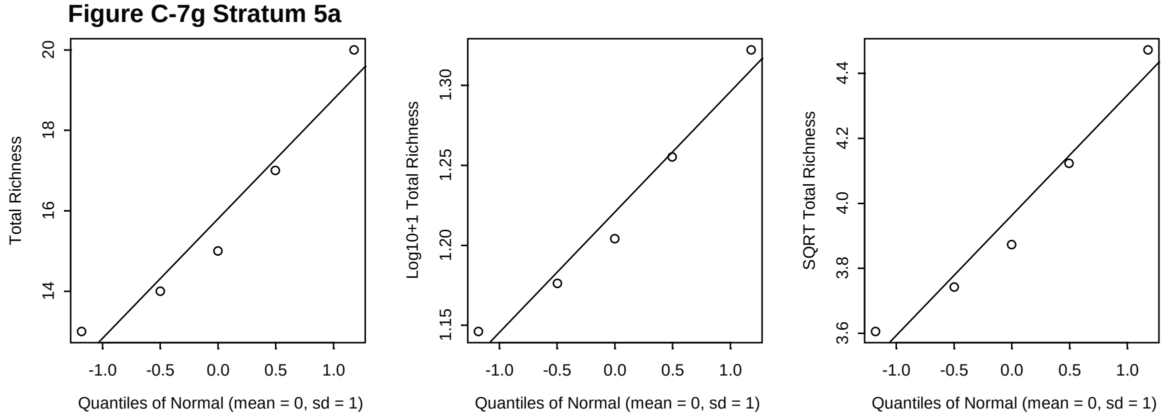


Figure C-7h Stratum 5b

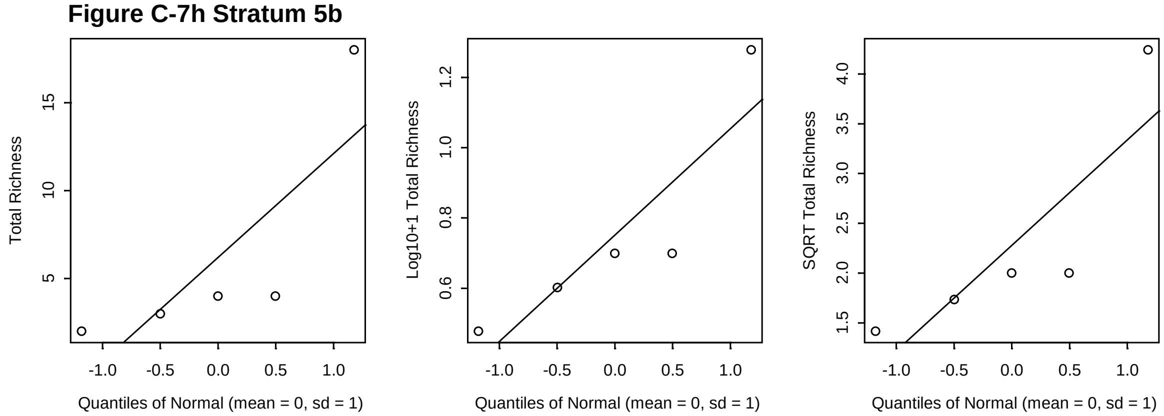


Figure C-8a Stratum 1

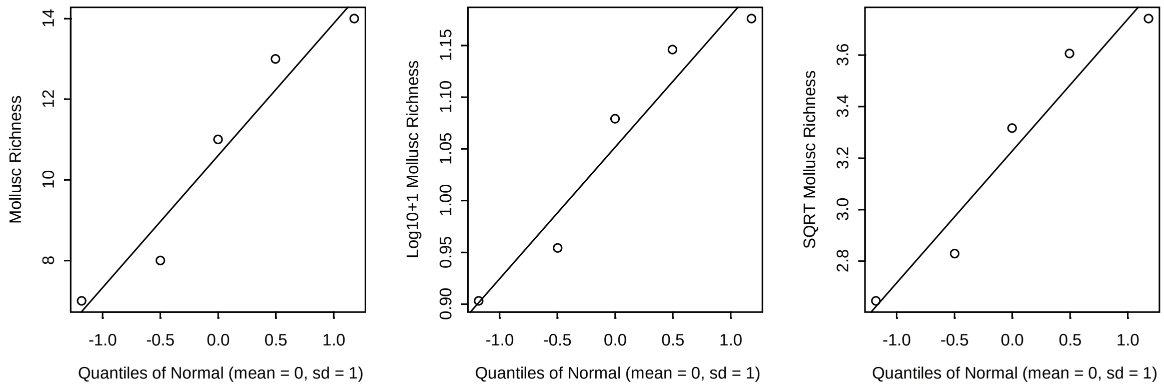


Figure C-8b Stratum 2a

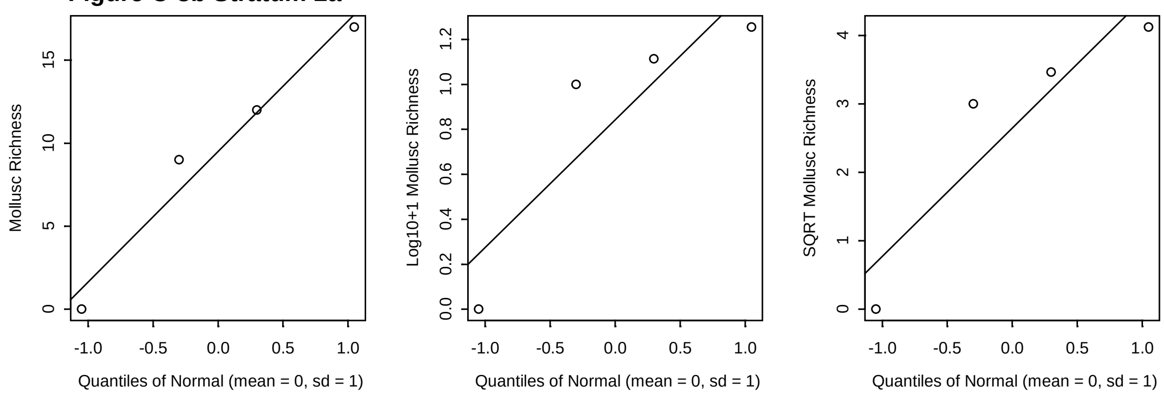


Figure C-8c Stratum 2b

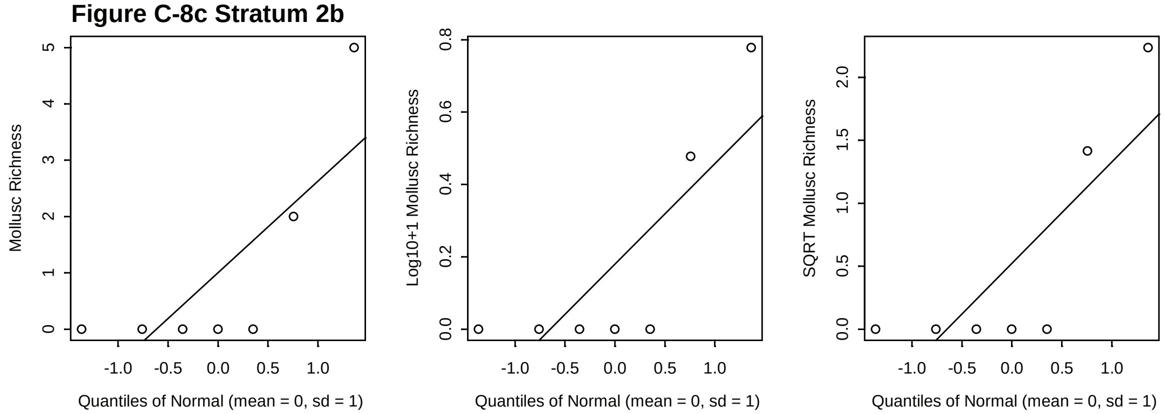


Figure C-8d Stratum 3a

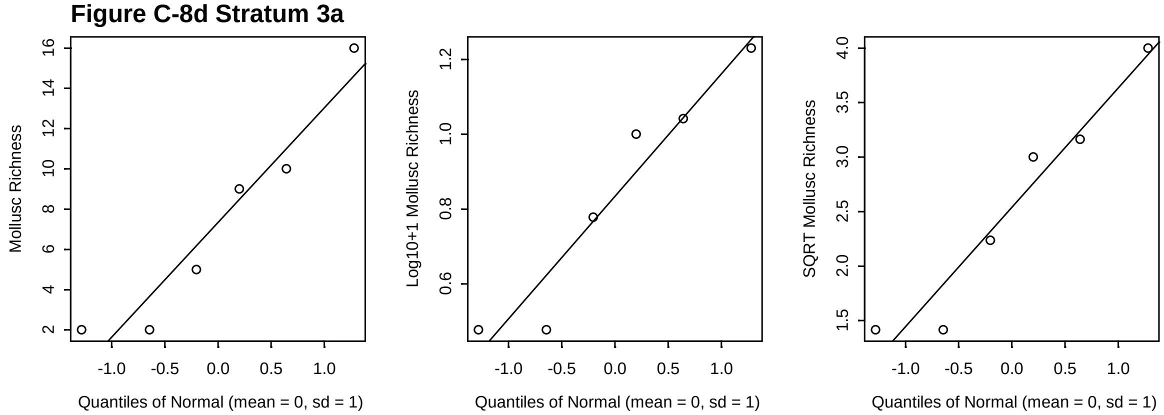


Figure C-8e Stratum 3b

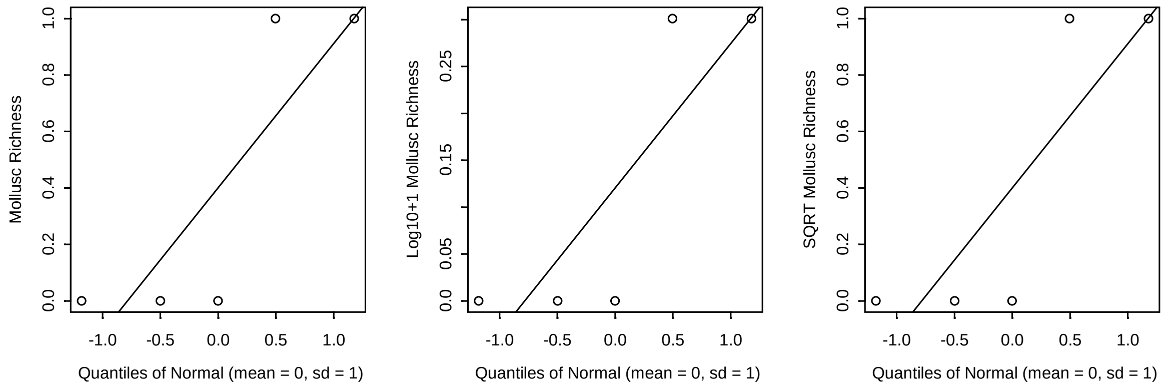


Figure C-8f Stratum 4

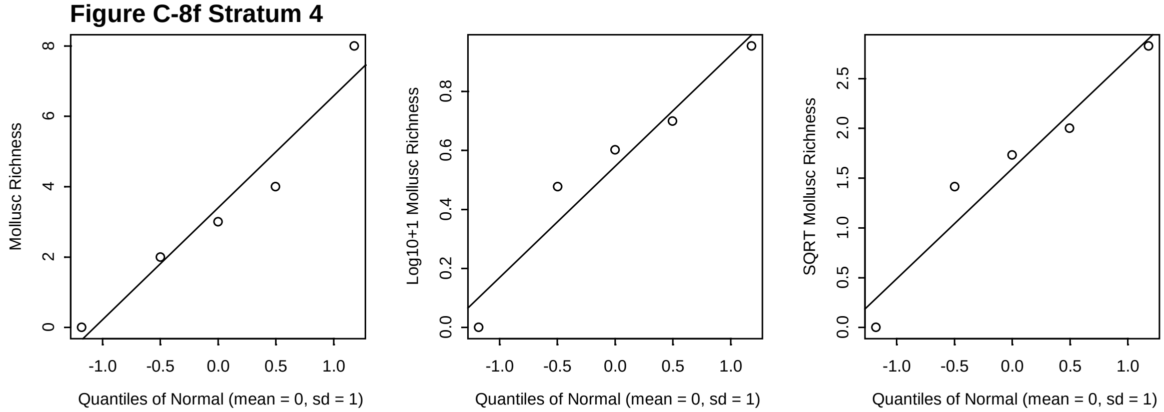


Figure C-8g Stratum 5a

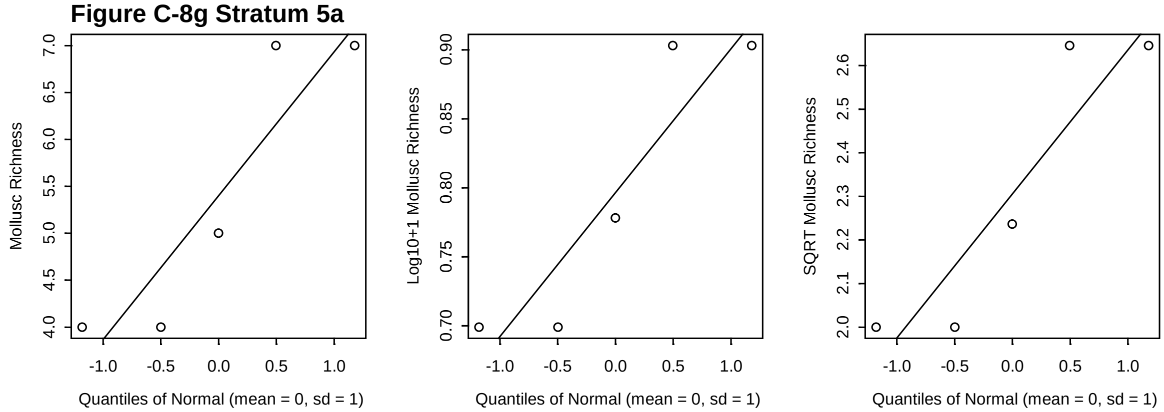


Figure C-8h Stratum 5b

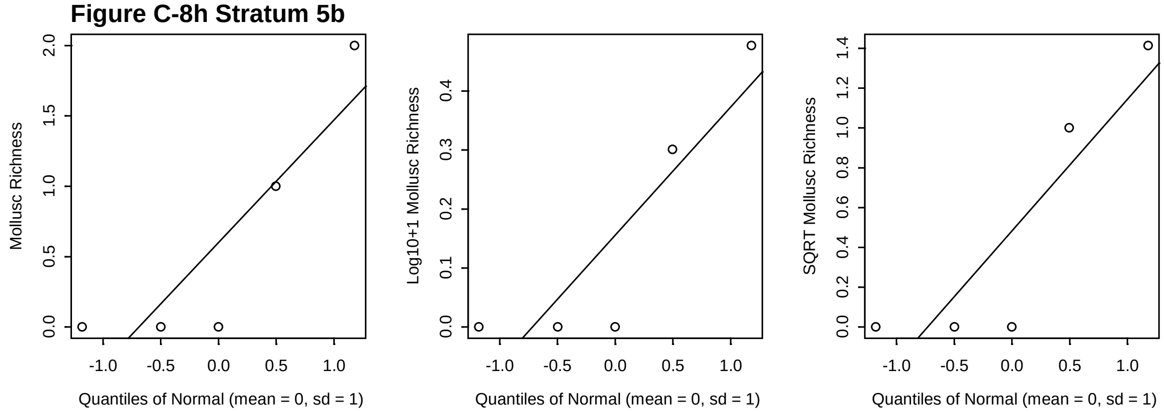


Figure C-9a Stratum 1

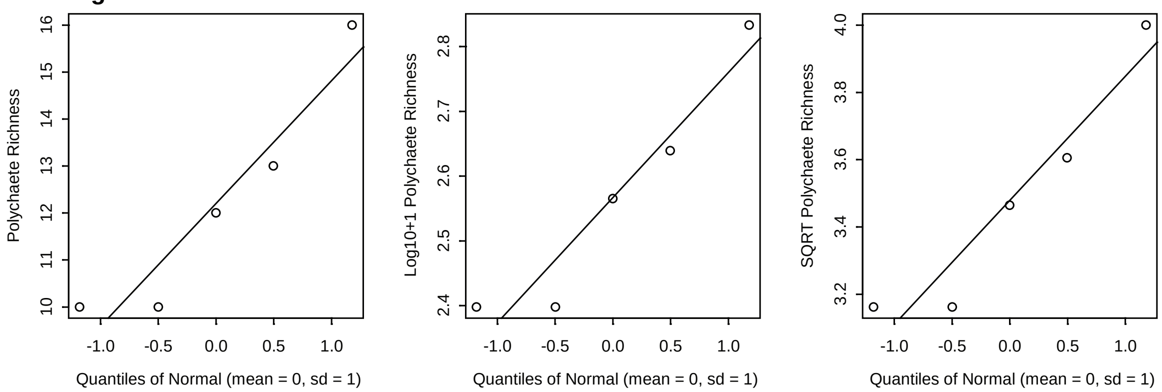


Figure C-9b Stratum 2a

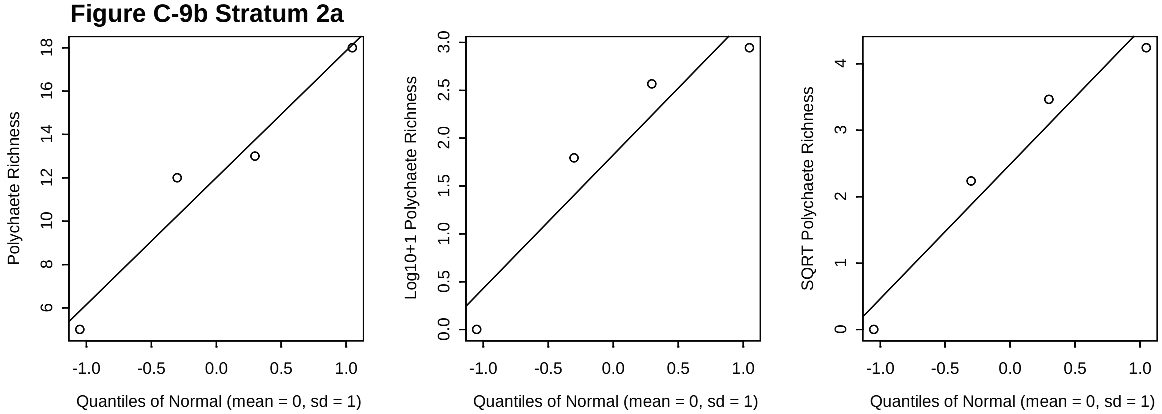


Figure C-9c Stratum 2b

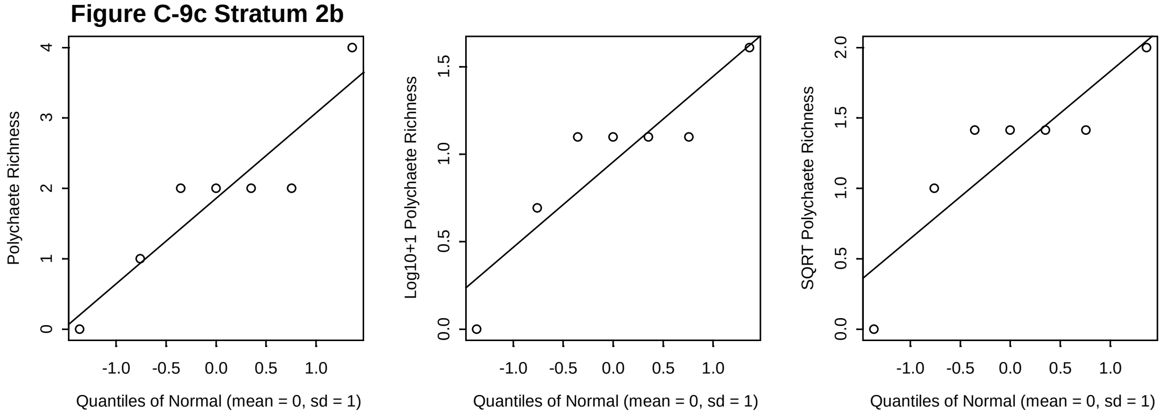


Figure C-9d Stratum 3a

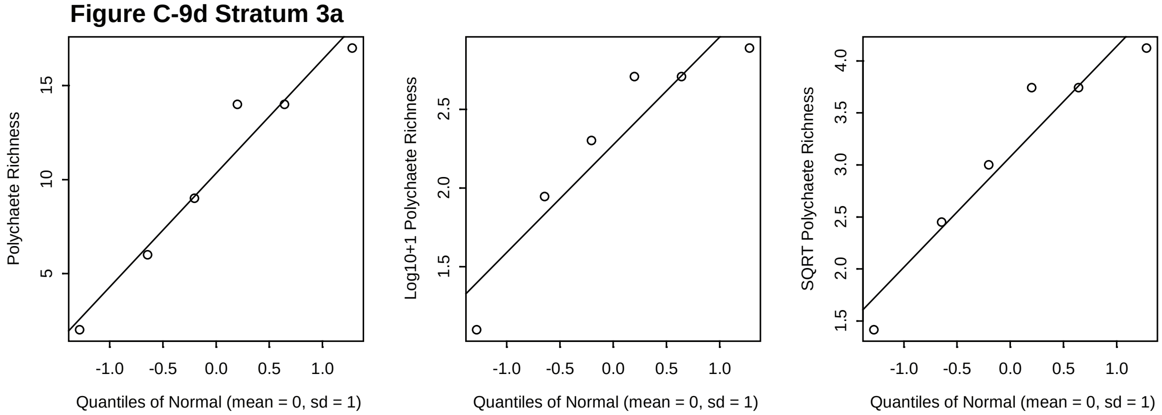


Figure C-9e Stratum 3b

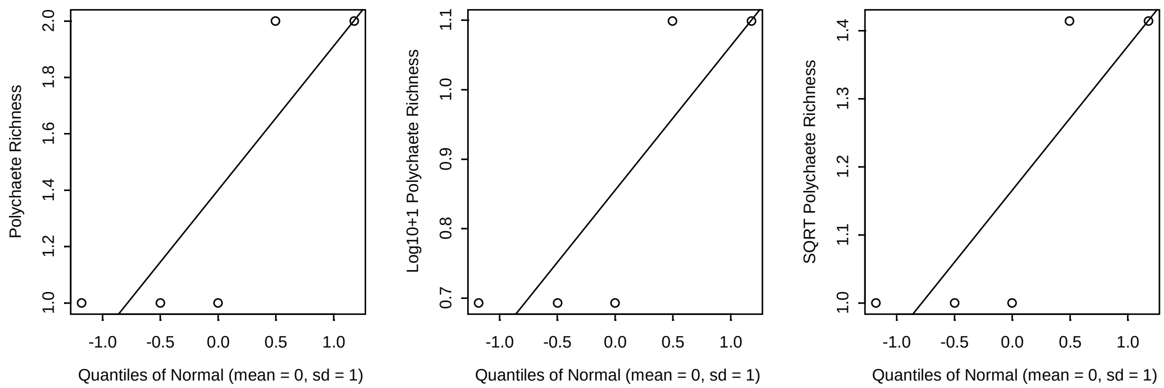


Figure C-9f Stratum 4

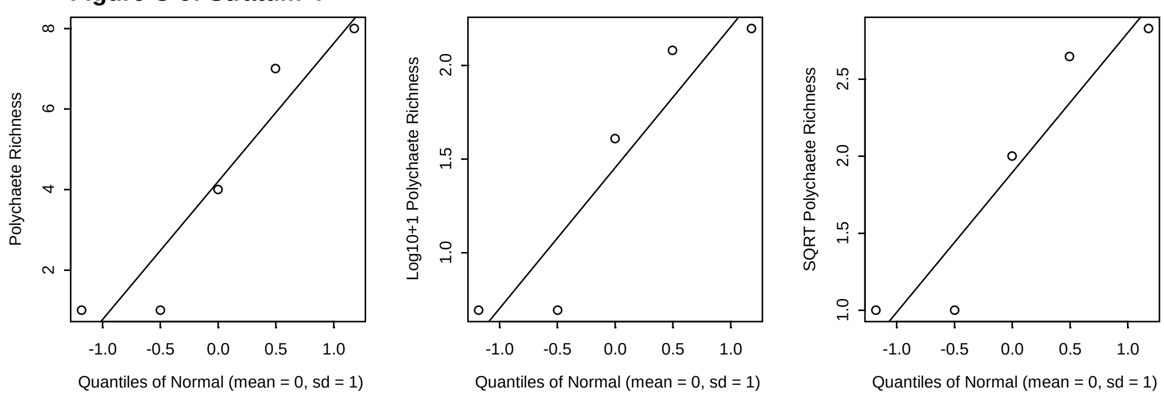


Figure C-9g Stratum 5a

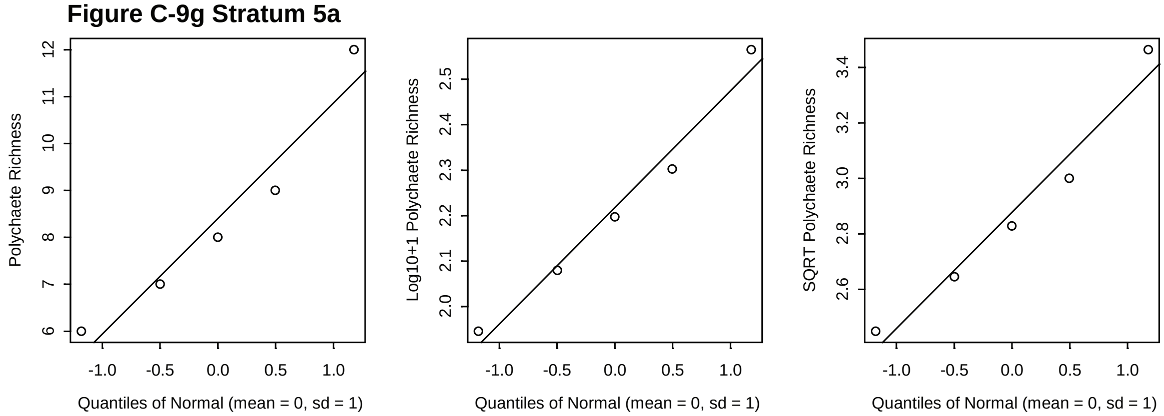


Figure C-9h Stratum 5b

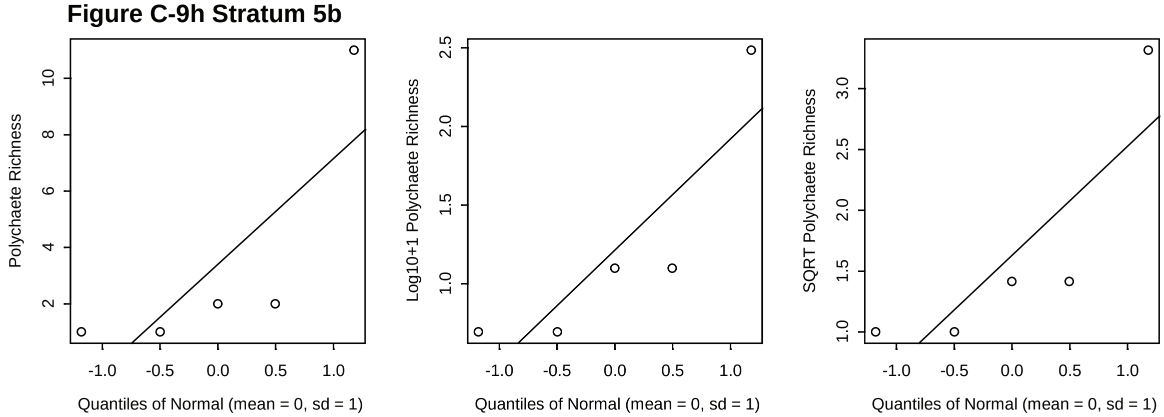


Figure C-10a Stratum 1

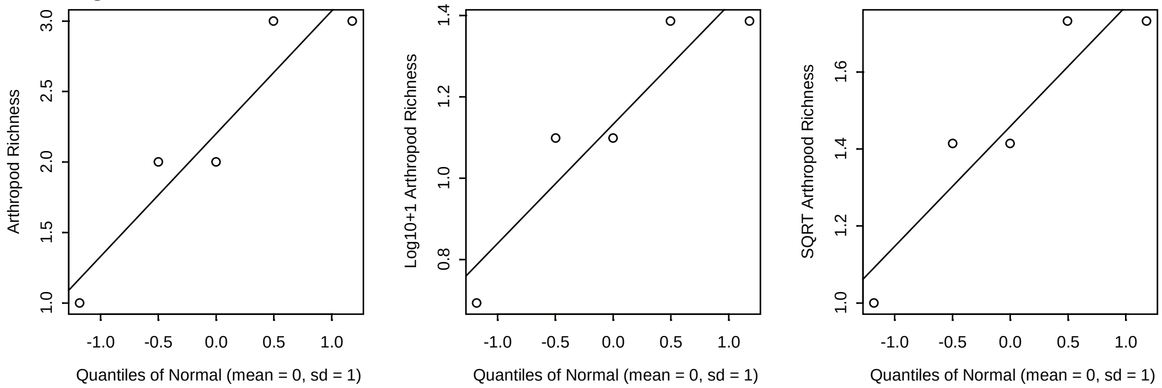


Figure C-10b Stratum 2a

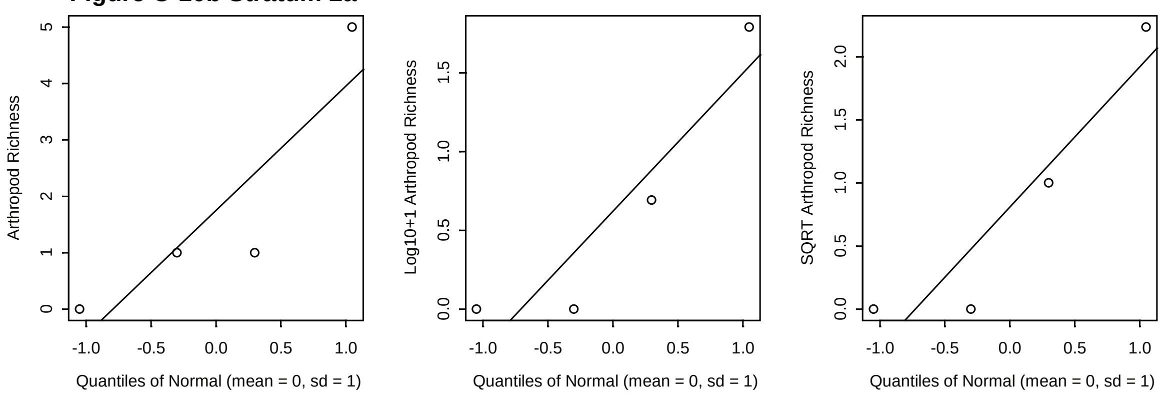


Figure C-10c Stratum 2b

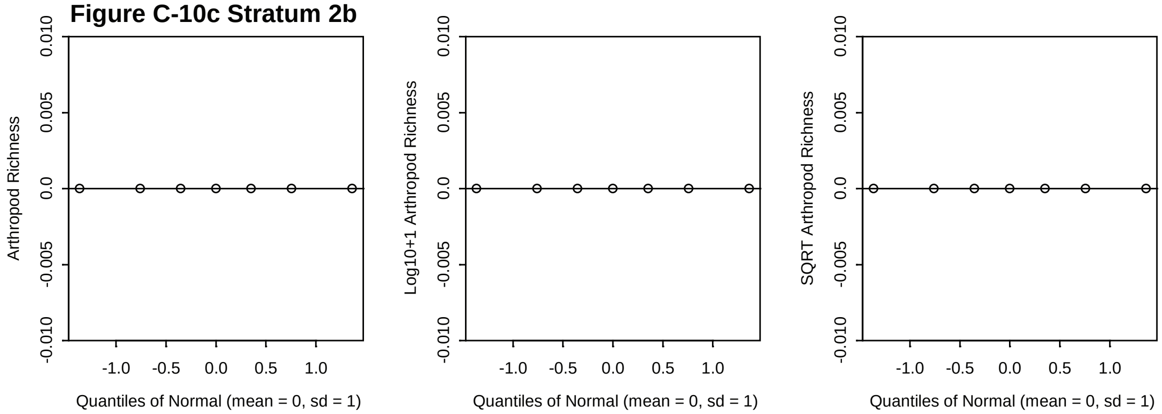
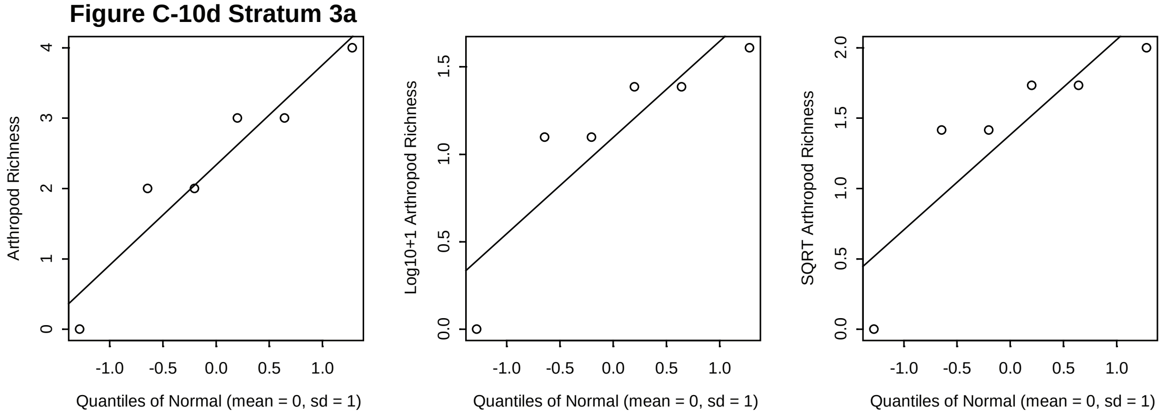


Figure C-10d Stratum 3a



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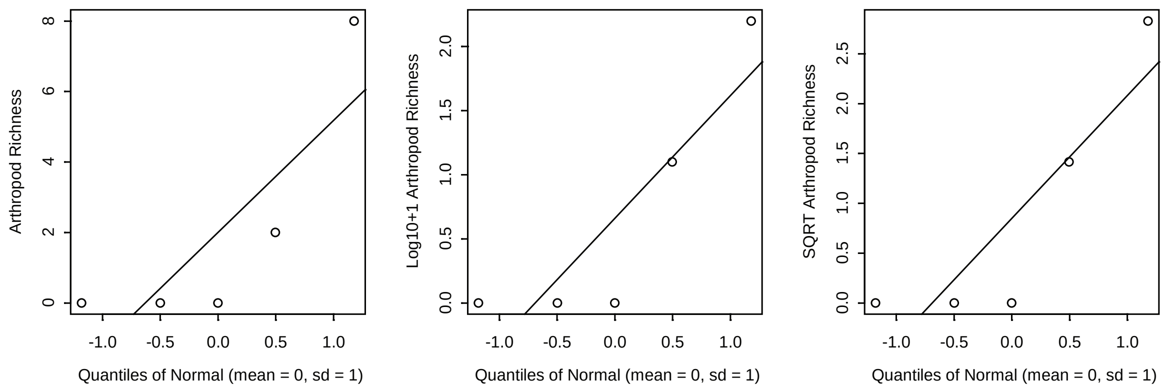

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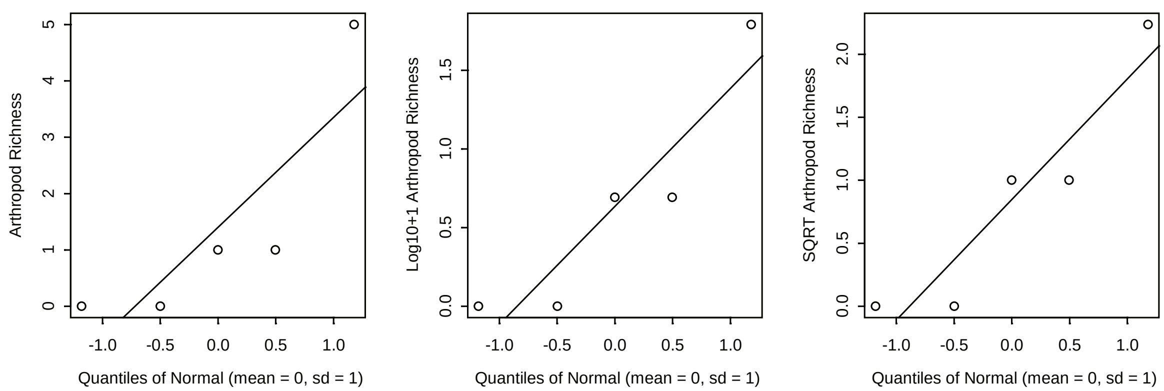
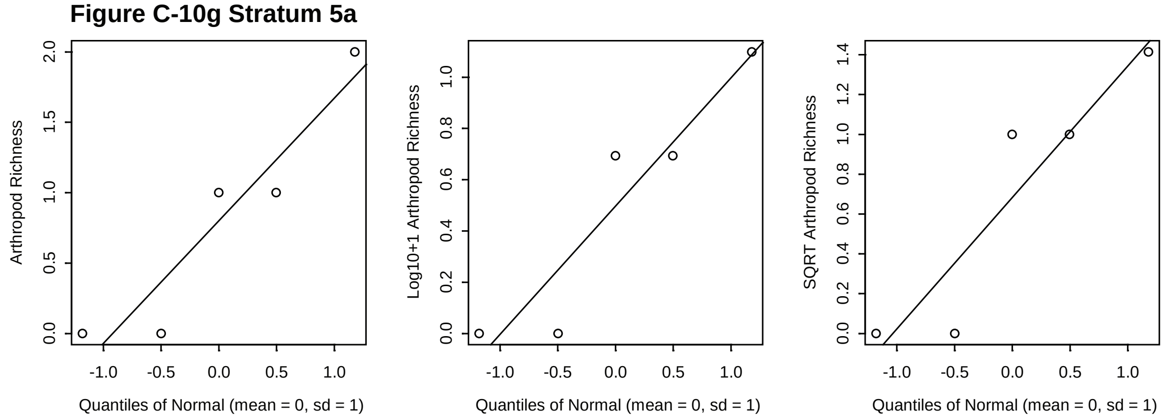


Figure C-10g Stratum 5a



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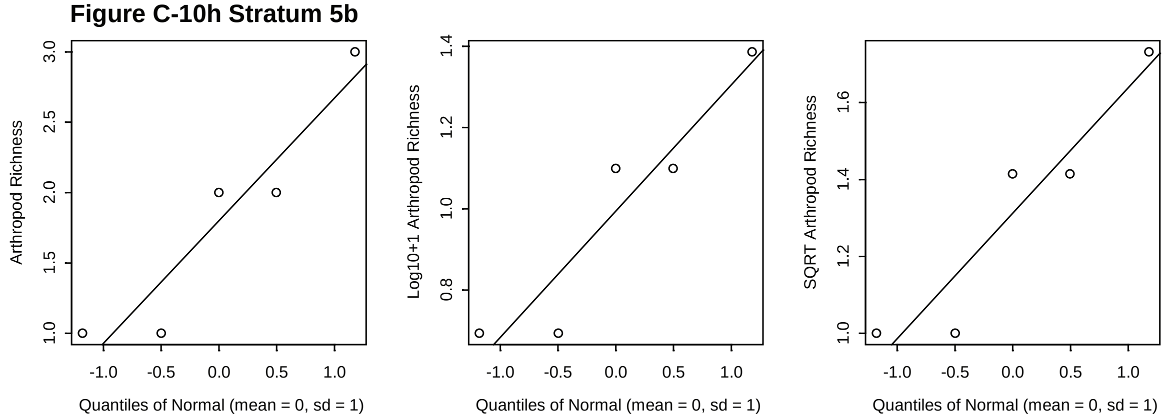


Figure C-11a Stratum 1

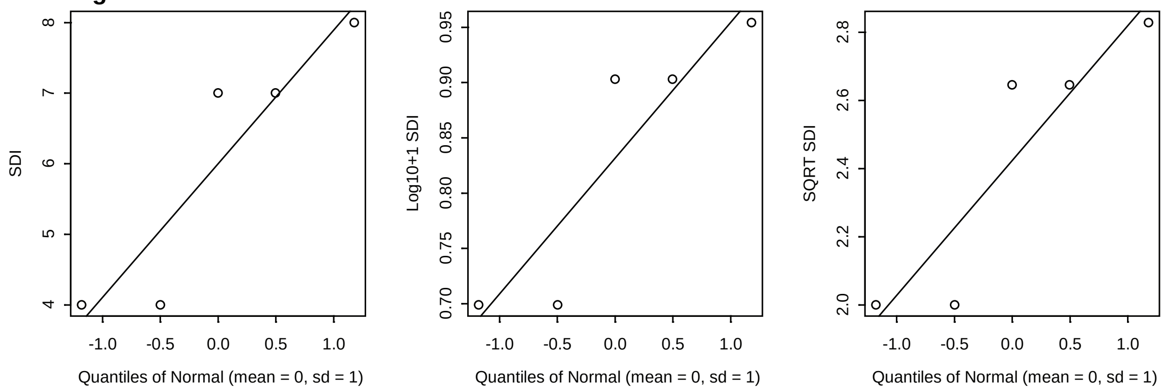


Figure C-11b Stratum 2a

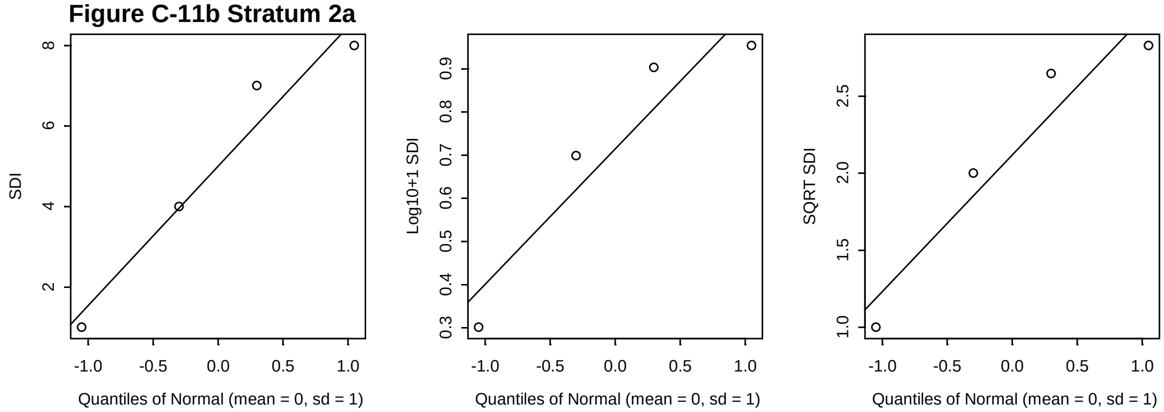


Figure C-11c Stratum 2b

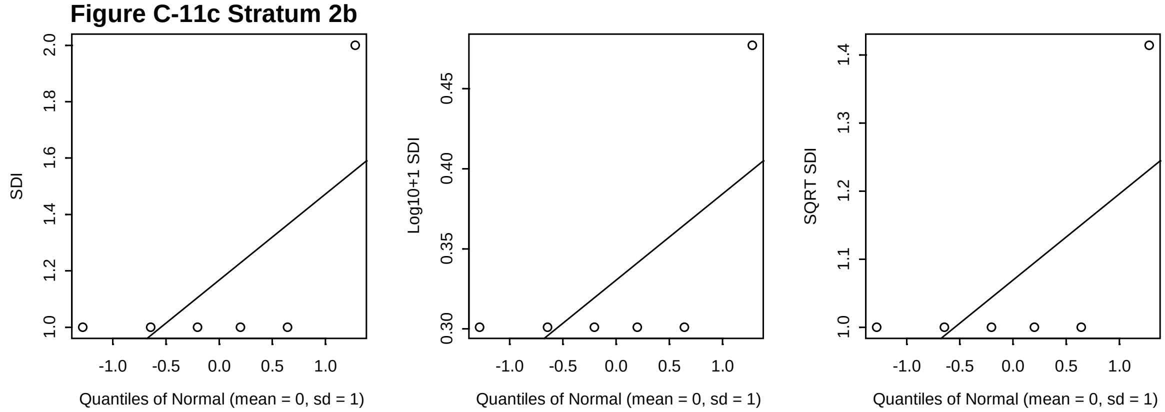
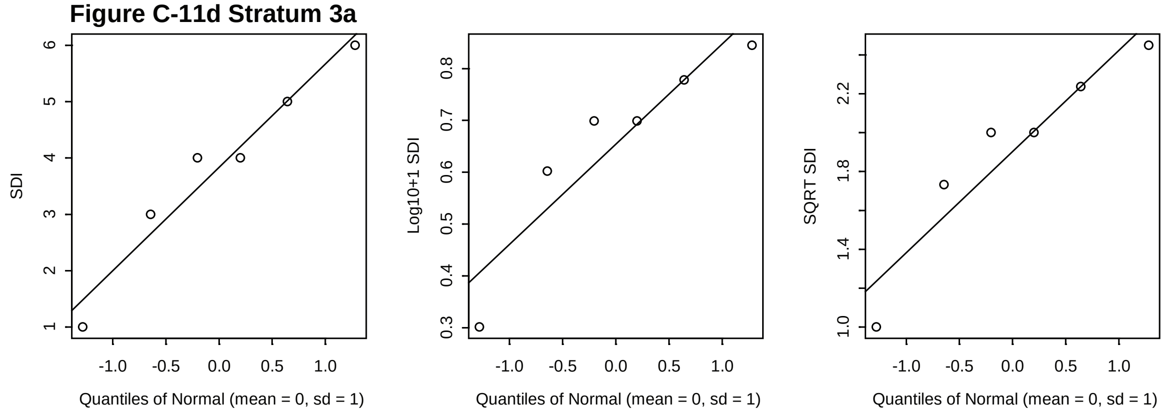


Figure C-11d Stratum 3a



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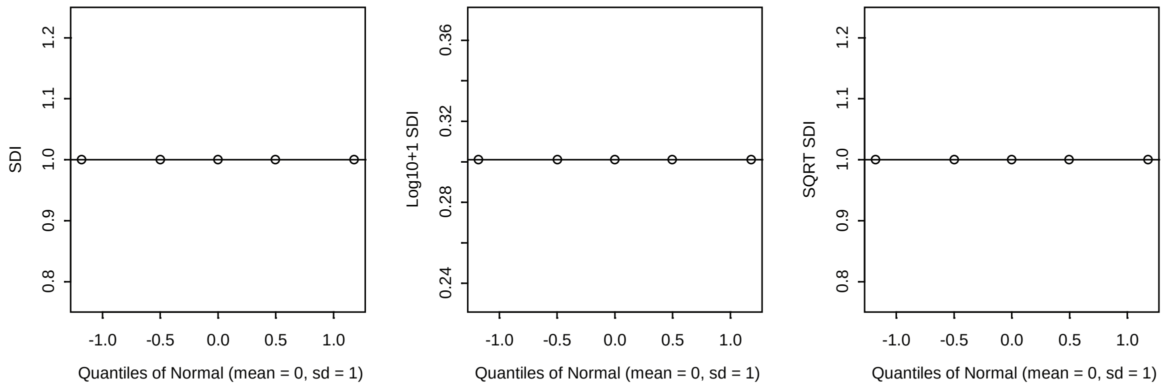

Figure C-11f Stratum 4

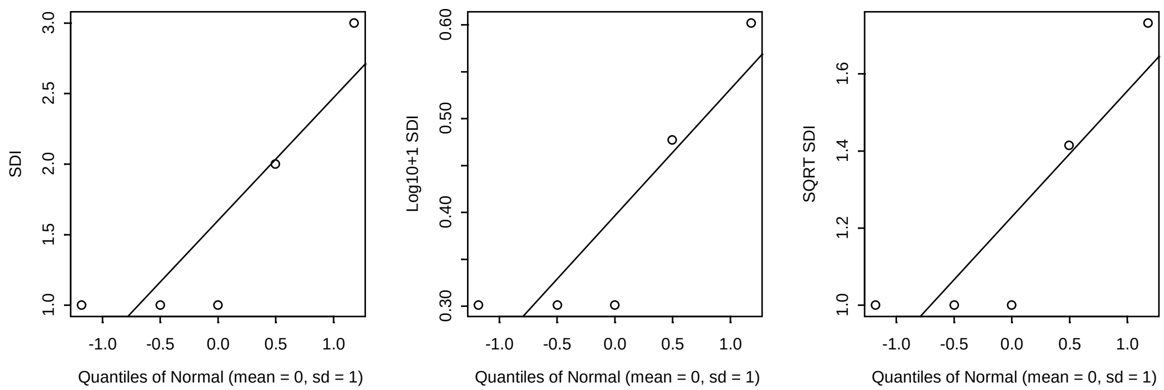

Figure C-11g Stratum 5a

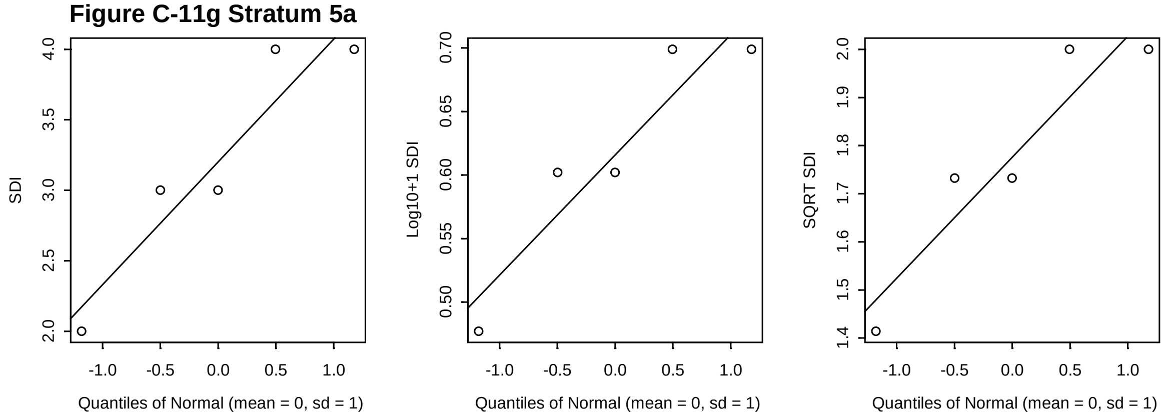

Figure C-11h Stratum 5b