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2010 Benthic Macroinvertebrate Analysis and Multi-Year Trend Assessment for the Macaulay Point Outfall

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REPORT

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Executive Summary

The Capital Regional District Environmental Protection Division (CRD-EP) (formerly the Scientific Programs Group) collects benthic invertebrates annually from a number of stations surrounding the Macaulay Point wastewater outfall in Greater Victoria, BC as part of the Macaulay and Clover Point Wastewater and Marine Environment Program (WMEP). Several benthic community metrics are calculated based on the results of taxonomic identifications of the benthic samples. The broad design and approach have remained sufficiently consistent over the last decade to facilitate a rigorous evaluation of trends over time and space. This report presents a detailed quantitative analysis of the 2010 monitoring event and a multi-year trend assessment to place results in the context of other data collected over more than a decade.

Objectives

The objectives of this study were to:

1) Confirm that the monitoring station groupings identified in previous assessments (*i.e.*, near-field, far-field, and mid-field distance-direction groups) remain valid;

2) Derive and summarize the main biological characteristics of the 2010 benthic community samples, including the following indices: taxa richness, polychaete abundance, total abundance, abundance of other major taxonomic groups, abundances of individual taxa, Infaunal Trophic Index, and the Swartz Dominance Index;

3) Conduct a spatial analysis of overall benthic community health using the benthic community indices, functional groups, dominance, multivariate analyses, *etc.*, consistent with methodologies applied in previous assessments;

4) Determine if the benthic community indices exhibit statistically significant differences between individual distance (and/or distance-plus-direction) groups and the Parry Bay reference stations;

5) Compare benthic community parameters to sediment chemistry variables including metals, polycyclic aromatic hydrocarbons (PAHs), particle size distribution, total organic carbon, and other substances of interest (SOIs);

6) Derive and summarize the main biological characteristics of the Macaulay Point benthic community samples (*e.g.*, total abundance, polychaete abundance, Swartz Dominance Index) of the historical benthic community (*i.e.*, 2000 to 2010) to facilitate evaluation of trends over time;

7) Evaluate strength, direction, and statistical significance of temporal trends in the main biological characteristics (*e.g.*, total abundance, polychaete abundance, Swartz Dominance Index);

8) Evaluate spatial trends in historical benthic community composition between the reference stations and the different distance-direction groups and distance groups; and

9) Summarize the above findings and methodologies to characterize the overall effects on the invertebrate community in the vicinity of the Macaulay Point outfall.

Results

At a broad level, the evaluation of 2010 benthic community data suggests that some spatial trends in 2010 were qualitatively similar to other recent years (*i.e.*, 2002 through 2009). The summary metrics (total abundance, ITI, SDI, *etc.*) yielded similar numbers to previous years across most of the site, and many patterns related to proximity to the outfall were reconfirmed in 2010. However, more detailed analysis of the 2010 data identified a number of deviations relative to other recent monitoring events.

The most significant of the differences relative to previous monitoring years included:

- **Flat spatial response for organism abundance** – In 2010, the outfall terminus station M0 exhibited a high total abundance due to the dominance of *Capitella capitata*, but stations close to the outfall had abundances that were not significantly different from the reference. Earlier in the 2000s decade, the increased abundance of TOC-tolerant species compensated for slightly lower abundances of some taxonomic groups (*e.g.*, bivalves, gastropods). In the last three years, however, and particularly in 2010, the increases in a few taxonomic groups have not been sufficient to outweigh the reductions of other taxa at some stations close to the outfall;

- **Altered pattern of impairment at M0** – The benthic communities at M0 have exhibited substantial interannual variability, and 2010 was no exception. In 2010, as in previous monitoring events, station M0 exhibited a modified benthic community relative to reference, with elevated total abundance but reduced richness and lower abundances of several major taxonomic groups. The results from 2010 are intermediate between data from 2009 and previous years, with a marginal improvement of community health compared with 2009, but greater impairment relative to most monitoring events conducted over the last decade;

- **Separation of M0 from near-field group** – Related to the findings above, the 2010 data confirmed the findings from 2008 and 2009 that M0 no longer groups strongly with the other near-field stations. In the last three years, the multivariate profiling of the benthic community, combined with the univariate assessments, strongly indicated that the biological assemblages sampled at M0 differed from those at near-field stations M1E, M1SE, and M2SE;

- **Broader richness response** – In most monitoring events conducted over the last decade, reduced richness relative to reference has been quite limited in spatial extent, generally limited to outfall and near-field stations. However, recent monitoring events have suggested a change in the distribution of reduced richness values, along with other metrics that measure biological diversity. The results from 2010 were similar to 2008 and exhibited a strong spatial trend of increasing richness with distance from the outfall;

- **Broader SDI response** – The spatial extent and magnitude of the decrease in normalized SDI was greater in 2008 and in 2009 than in previous sampling years, and this pattern was repeated in 2010. This is consistent with the recently observed pattern in richness, indicating alteration toward a less diverse benthic community at outfall monitoring stations;

- **Decrease of gastropod abundances** – While there was a slight recovery of gastropod abundances at all distance groups in 2009 after a period of decline, the numbers of gastropods decreased further in 2010, with the lowest numbers observed at the outfall, 100 m and 200 m stations. Gastropods appear to be a sensitive indicator of benthic community alteration;

- **Increase in localized major taxa abundances** – Capitellid polychaetes, crustaceans and miscellaneous taxa have all increased at the outfall in 2010; and
- **Shift in patterns for individual taxa** – At a broad level, the analysis of individual taxa in 2010 produced generally similar results to previous studies. However, at a more refined level of analysis, the number of taxa that exhibited net-positive responses was somewhat diminished in 2010. Although several taxa appear to benefit from modest increases in organic carbon content at intermediate (or mid-field) distances from the outfall, fewer taxa exhibited strong positive responses to outfall-related exposures.

As a result of the above findings, the revised multi-year trend assessment represents a departure from findings presented in earlier trend assessments (Golder 2005a,b, 2006, 2007a, 2008). The previous monitoring report (Golder 2007a) stated that “the consistency in taxonomic richness across the majority of the study area indicates that biodiversity is not significantly affected by Macaulay Point discharge beyond the IDZ (*i.e.*, 100 m) or outside the near-field region”. This conclusion requires revision in light of the data collected from the last three years. Based on the results from 2008-2010, the depression of richness now extends beyond the IDZ, and in some cases beyond the near-field stations. The results of the 2010 study clarify previous uncertainty from 2008 and 2009 and strongly suggest that the apparent changes in broad community composition reflect true changes in the biological assemblages.

In terms of overall environmental condition, the 2010 assessment indicates the following:

- **M0** – Benthic community data are indicative of a highly degraded benthic community. The reduced taxonomic richness (approximately 50% of reference), combined with sharp decreases in abundances of sensitive taxa (*e.g.*, bivalves and gastropods), and reduced summary metrics (SDI and ITI), are the main lines of evidence used to reach this conclusion. The assessment for M0 has changed in 2009 and 2010 relative to 2008 and previous years, when a conclusion of “moderately degraded benthic community” was rendered;
- **Near-field stations (not including M0)** – Similar to 2008 and 2009, community patterns are indicative of a moderately degraded benthic community. The reduced taxonomic richness (by approximately 55% relative to reference), combined with decreases in abundances of bivalves and gastropods, and reduced summary metrics (SDI and ITI), are the main lines of evidence used to reach this conclusion. The spatial pattern of these responses reconfirms the assignment of stations to the near-field group;
- **Mid-field stations** – The monitoring data collected for mid-field stations show a small negative response to the influence of the outfall. A general pattern of moderate biological alteration is evident in mid-field stations (more polychaetes, and fewer bivalves, crustaceans and gastropods), with significant declines in community health metrics compared with reference. Richness and ITI (standard) were reduced by 20% of the reference, whereas SDI was 75% of reference. In monitoring reports prior to 2008, the mid-field responses have been characterized as “neutral to slightly positive responses to outfall influence,” while the last assessment characterized the mid-field as “net neutral”. Therefore, the 2010 program reflects a change in the overall assessment of alteration; and
- **Far-field stations** – The 2010 data indicate a net neutral to positive response to the influence of the outfall, which is a minor change from the clearly net positive characterization that had been previously assigned to this grouping. The far-field stations exhibit summary biological metrics such as SDI and richness, that are slightly less than reference, whereas ITI (standard) is similar to reference. In addition, these stations contain abundances of major taxonomic groups that exceed the reference condition (*e.g.*, bivalves, amphipods and polychaetes).

The comparison of sediment chemistry to biological metrics (abundance, richness, *etc.*) indicated a number of statistically significant correlations. Although these significant correlations should not be interpreted as evidence of cause-effect for the substances of interest measured in sediment, the number and magnitude of significant correlations was elevated in 2010. The sediment chemistry parameters were strongly inter-correlated and were strongly associated with organic carbon content of sediment. Graphical assessment of substrate effects indicated that benthic community metrics generally follow a spatial distribution similar to that of TOC. The analysis suggests that enhancement of organic carbon and substrate type are important explanatory variables for describing variations in benthic communities, although these factors alone cannot fully explain the biological patterns observed in 2010.

The benthic community conditions at the reference location (Parry Bay) were evaluated over the period of record to assess the degree to which the above conclusions may have been influenced by regional changes in biological conditions (which would be observed at the reference stations). Indicators of biological variation (*i.e.*, richness and dominance indices) over the last three years were similar to earlier sampling events, whereas the total abundances of invertebrates (and major taxonomic groups such as bivalves, crustaceans, and gastropods) were higher in 2009 and 2010 than other recent monitoring events. As such, regional variations in reference conditions may have influenced some of the apparent trends at outfall monitoring stations (when expressed relative to reference) for some parameters, but not others. Furthermore, the changes in the spatial patterns within the outfall monitoring stations cannot be explained on the basis of regional trends.

Conclusion

Broad-scale changes in benthic communities in the vicinity of Macaulay Point (relative to reference) appear to be reconfirmed by the addition of 2010 data. Apparent changes to benthic community assemblages that were equivocal based on recent monitoring events were confirmed in the 2010 program. The last three rounds of monitoring have identified changes in the patterns of: major taxa abundances; sensitive indicator taxa (including gastropods, echinoderms, and bivalves); biological diversity metrics (including richness and SDI); and functional metrics such as the ITI and spatial patterns of individual taxa. Cumulatively, these findings suggest that an altered baseline condition exists; this should be taken into consideration in the development of a long-term monitoring program associated with the planned upgrade to secondary wastewater treatment. The 2011 program will be important for providing further characterization of the baseline condition,

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List of Acronyms

ANOVA	Analysis of Variance
AVS	Acid Volatile Sulphides
BSG	Benthic Services Group
C0	Clover Point Outfall Terminus Station
CI	Confidence Interval
CRD	Capital Regional District
CRD-EP	Capital Regional District Environmental Protection Division
DQO	Data Quality Objective
IDZ	Initial Dilution Zone
ITI	Infaunal Trophic Index
LWMP	Liquid Waste Management Program
MMAG	Marine Monitoring Advisory Group
NC	Not Calculated
NM	Not Measured
NMDS	Non-metric Multidimensional Scaling
NV	No Value
OC	Organic Carbon
P	Precision Metric
PA	Polychaete Abundance
PB	Parry Bay
PAH	Polycyclic Aromatic Hydrocarbon
PCA	Principal Components Analysis
QA/QC	Quality Assurance/Quality Control
REMP	Receiving Environment Monitoring Program
SD	Standard Deviation
SDI	Swartz Dominance Index
SOI	Substance of Interest
SPSS	Statistical Package for the Social Sciences
TA	Total Abundance
TOC	Total Organic Carbon
TR	Taxa Richness
WMEP	Wastewater and Marine Environment Program

1.0 INTRODUCTION

1.1 Background

The Capital Regional District Environmental Protection Division (CRD-EP) (formerly the Scientific Programs Group) collects benthic invertebrates annually from a number of stations surrounding the Macaulay Point wastewater outfall in Greater Victoria, BC as part of the Macaulay and Clover Point Wastewater and Marine Environment Program (WMEP) (Figure 1). Several benthic community metrics are calculated based on the results of taxonomic identifications of the benthic samples. Statistical analyses of these parameters, and the determination of any trends relative to previous years' data, are conducted. The monitoring design and investigation methods for the Macaulay Point outfall benthic community have been modified over time, in response to input and recommendations by the Marine Monitoring Advisory Group (MMAG), CRD-EP, and various consultants. However, the broad design and approach have remained sufficiently consistent over the last decade to facilitate a rigorous evaluation of trends over time and space.

The use of benthic invertebrates as indicators of potential environmental effects is extensive. Monitoring of benthic communities is conducted to evaluate effects to the invertebrates themselves (for intrinsic value and as bio-indicators of ecosystem responses) and also to evaluate potential effects of higher trophic level receptors that rely on invertebrates as a food source (Figure 2). Native populations of deep-sea benthic invertebrates have been used as indicators of potential effects related to the Macaulay Point wastewater discharge with varying frequency since the late 1970s. The benthic community data adjacent to the Macaulay Point outfall have been evaluated and summarized by a number of authors including Chapman *et al.* (1996), EVS (2000), Striplin (2001), Ecostat (2003), Paine (2004), and Golder (2005a,b, 2006, 2007a, 2008, 2009, 2011a). Analyses of overall benthic community health, including the summary biological metrics and analysis of spatial trends, are conducted annually. In addition to the annual benthic community assessments, formal statistical trend assessments are conducted at regular intervals to evaluate whether patterns are emerging in the annual monitoring; such assessments were last performed based on monitoring events up to and including 2007 (Golder 2008). This report summarizes the results of various analyses of the 2010 benthic invertebrate community data and provides a formal statistical trend assessment for the period of record from 2000 through 2010.

1.2 Study Objectives

The objectives of this study were to:

1) Confirm that the monitoring station groupings identified in previous assessments (*i.e.*, near-field, far-field, and mid-field distance-direction groups) remain valid;

2) Derive and summarize the main biological characteristics of the 2010 benthic community samples, including the following indices: taxa richness, polychaete abundance, total abundance, abundance of other major taxonomic groups, abundances of individual taxa, Infaunal Trophic Index, and the Swartz Dominance Index;

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8) Evaluate spatial trends in historical benthic community composition between the reference stations and the different distance-direction groups and distance groups; and

9) Summarize the above findings and methodologies to characterize the overall effects on the invertebrate community in the vicinity of the Macaulay Point outfall.

The methods used to accomplish the above tasks are described in Section 2 of this report. The study applied methodologies similar to previous years in order to allow for consistent and meaningful comparisons across years.

2.0 METHODS

The interpretative tools consisted of summary statistical metrics, graphical trend analyses, and formal statistical hypothesis tests. Where possible, the evaluation applied methodologies similar to previous years (*e.g.,* Paine 2004; Golder 2005a, 2006, 2007a, 2008, 2009, 2011a) to facilitate consistent and meaningful comparisons of summary statistics among years. Some methods have been customized in recent sampling years to incorporate the recommendations of the Marine Monitoring Advisory Group (MMAG). These recommendations relate primarily to the groupings and statistical manipulations of benthic community data. In order to provide consistency with previous reporting, while also incorporating the requested MMAG modifications, some of the analyses were reported two different ways to facilitate interpretation. For example, station groupings were evaluated using both a “distance-only” and a “distance-direction” basis, as was conducted for the 2007, 2008 and 2009 benthic data (Golder 2008, 2009, 2011a). The evaluations have also incorporated additional metrics in recent years, including the infaunal trophic index and spatial profiles of individual taxa. Methodological details, including sample collection, selection of indicator metrics and data analyses are described below.

2.1 Sample Collection

Benthic community samples were collected from 23 stations located within one kilometre of the Macaulay Point outfall terminus and at five (5) reference stations located approximately 10 km southwest of the Macaulay Point outfall, at Parry Bay (Figure 1). The sampling design was based on spatial gradients, with one outfall terminus station (M0), eight (8) stations positioned at approximately 100 m from the outfall, eight (8) at approximately 200 m from the outfall, four (4) at approximately 400 m from the outfall, and the remaining two (2) at approximately 800 m from the outfall (Figure 1). Sampling was conducted in 1994, 1997, and annually from 1999 through 2010. The broad sampling strategy and design has remained relatively consistent since 2000, with the only change being an increased sampling of reference stations, as indicated in Table 1. The sampling design has not changed since 2005, when two additional Parry Bay references were added.

Four replicate grabs were collected at each of twenty-seven (27) sampling stations, and five replicate grabs were collected from the outfall terminus (station M0). The taxonomists (Benthic Services Group) performed precision analysis on the sorting enumeration data using the following formula for precision (P):

$$P = \left[\frac{s/\sqrt{n}}{\bar{x}} \right] \times 100\%$$

Where: s = sample standard deviation; n = sample size; and $\bar{x}$ = sample arithmetic mean.

All five Macaulay Point outfall terminus (M0) replicates were enumerated to increase statistical power. At each remaining outfall monitoring station, three out of the four grab samples were randomly chosen for taxonomic analysis. For these stations, the remaining (fourth) benthic community replicate was analyzed only if the precision statistic (P) exceeded 20% for the first three replicates. This procedure was consistent with previous monitoring rounds. The fourth benthic community replicate was analyzed at seven (7) of the 22 remaining outfall monitoring stations in 2010.

Each grab sample was sieved to 1.0 mm, preserved in formalin solution and transported to the taxonomic laboratory (Gary Rosenthal, Benthic Services Group). Once a replicate was selected for analysis, benthic invertebrates were sorted, enumerated and identified to the lowest practicable taxonomic level using Puget Sound Protocols (PSAMP 2002). The same taxonomic methods have been applied, and the same taxonomic laboratory has been used for all years from 2002 through 2010 inclusive, making temporal comparisons of benthic community metrics more robust in recent years due to reduced variability in analytical methods.

2.2 Data Aggregation and Pre-Processing

Three consultants (Aquametrix, Biologica, and Benthic Services Group) have performed all of the taxonomic evaluations for the Macaulay Point monitoring program that have been conducted since 1992. Because details of taxonomic enumeration methods can influence the values of summary metrics (even within a single sampling event), an approach for standardization of taxonomy was implemented by CRD-EP in 2002. Ecostat (2003) documents several data consolidation steps that have been incorporated in the CRD-EP benthic taxonomy database to streamline and rationalize the long-term data and to promote consistency. The flow of data and associated data processing for the 2010 CRD-EP benthic community program included:

- Species coding summaries from previous years' work were supplied to the contracted benthic taxonomists (Benthic Services Group [BSG]) to assist with standardization of enumerations. BSG has conducted the annual CRD-EP outfall benthic taxonomy work since 2002 and are familiar with the coding conventions used in this project;
- Raw benthic taxonomy data from BSG were provided to Dr. Brenda Burd (Ecostat Research Ltd., Saanich, BC) for quality assurance review of species coding. Any species not observed previously in CRD studies were assigned a unique identifying code by Valerie Macdonald (Biologica Environmental Services, Victoria, BC);
- Prior to statistical analysis, fully coded benthic taxonomy data was further assessed by Ecostat Research Ltd. for quality assurance, reformatting, and other data consolidations, and to reconcile species identification with other local or regional studies; and
- Data from Ecostat Research Ltd. were incorporated into the CRD-EP database, from which taxonomy data were exported to Golder for processing and statistical analyses.

Other data processing steps conducted by Golder included:

- The raw benthic invertebrate community data for 2010 included separate counts for the number of adult specimens and juvenile individuals. Values were summed to equal the total number of individuals for each taxon. The main reason for not evaluating juvenile invertebrates separately was the sieve size used, which was too large to accurately provide information on recruitment of juveniles. Use of total invertebrate abundance counts also provides consistency with analyses from previous years' data; and

- The 2010 raw data were investigated for the presence of taxa that are difficult to enumerate (because they are very small and are not sampled with uniform efficiency using the mesh size applied). In past years, three such taxa (Nematoda [nematodes], Pandeidae [a hydrozoan], and *Bowerbankia gracilis* [a bryozoan]) were identified as "present" or "absent" but without reliable abundance counts. In 2010, nematodes were observed in several samples. One additional taxa, *Umbonula arctica* [a bryozoan], was identified in 2010 as "present". No *Bowerbankia gracilis* or Pandeidae individuals were observed in 2010. The presence of these taxa was considered in calculation of taxonomic richness; however, these taxa were not included in total abundance calculations, because of the lack of reliable quantitative counts.

2.3 Selection of Indicator Metrics

The indicator metrics applied to 2010 data include metrics that have been applied consistently throughout the last decade of Macaulay Point monitoring plus additional metrics that have been added to provide a more thorough assessment of responses (and to address the recommendations of the MMAG).

The CRD Core Area Liquid Waste Management Plan (LWMP) has implemented a Wastewater and Marine Environment Program (WMEP) for the Clover and Macaulay Point outfalls. Historically, the indicators used to evaluate benthic invertebrate community condition included the Swartz Dominance Index (SDI), taxonomic richness (TR), total abundance (TA), and polychaete abundance (PA). SDI, TR, TA, and PA have all been retained as indicator metrics in this assessment. The SDI metric has been interpreted with caution, as it is strongly influenced by the pattern of organic concentrations in the vicinity of the outfall, such that increases in abundances of opportunistic taxa result in reduced SDI values irrespective of the responses to other taxonomic groups. Following discussion with representatives of the MMAG, it was agreed that SDI analysis is appropriate provided that the subsequent interpretation clearly recognizes the role and limitations of the SDI metric. In this respect, the SDI is an indicator of benthic alteration but should not be interpreted as an indicator of degradation (negative ecological response) without other supporting lines of evidence. Similarly, the polychaete abundance metric must be evaluated carefully because the increases in abundances of polychaete can be positive, negative, or neutral, depending on the types and numbers of polychaetes observed and the consequent effects on other parts of the community.

Although the metrics listed above are useful, they do not provide all the information necessary to evaluate the effects and impacts of the Macaulay Point outfall on the receiving environment. Salas *et al.* (2006) recommends that interpretations of benthic monitoring programs include a suite of indices that provide complimentary information. These indices may include indicator species, indices based on ecological strategies, indicators based on species biomass and/or abundance, and other indicators. Therefore, in recent years, additional metrics have been used in the benthic community evaluation; these have relevance to the monitoring of effects of CRD outfall discharges and reflect the metric types recommended by Salas *et al.* (2006). These additional metrics were included in the evaluation of the 2010 data, and included the following:

- **Major taxa abundances** – Mean abundances of all species of major taxa (*e.g.*, polychaetes, amphipods, molluscs, echinoderms) were derived to provide additional information on biodiversity and taxonomic richness. These benthic metrics do not involve any *a priori* assumptions, but allow for assessment of patterns in subgroups of organisms that may not be revealed with other techniques. In past monitoring events (Golder 2005a,b, 2006, 2007a, 2008, 2009, 2011a), spatial trends in the composition of benthic communities have been observed at this level of organization (*e.g.*, increase in polychaetes and reduction in bivalves close to the outfall terminus). The assessment of major taxonomic groups is relevant to the assessment of potential degradation because net changes in abundances indicate net positive, negative, or neutral responses of the community to outfall exposure. Furthermore, by combining species into broader taxonomic groups, which are generally related to their functional roles in the ecosystem, variability is reduced and patterns more easily recognized;

- **Multivariate metrics** – Statistics that reduce the dimensionality of complex data sets while also describing the main sources of variation (Zar 1984) can be helpful in identifying differences among stations or groups of stations. Principal Components Analysis (PCA), non-metric multidimensional scaling (NMDS), and cluster analyses involving "boot strapping" techniques to test for significance between clusters (Nemec and Brinkhurst 1988a,b) are examples of such methods. These approaches produce qualitatively similar results when the associations between parameters or variables are robust (Chapman 1996). Although PCA and NMDS quantitative scores are not directly comparable among sampling years due to differences in the meaning of scores calculated in separate ordinations, the patterns of station groupings have been demonstrated to be useful in terms of simplifying complex chemical and biological data sets. The multivariate approach is complementary to the assessment of major taxonomic groups; the former reduces dimensionality based on mathematical similarity, whereas the latter reduces dimensionality based on taxonomic similarity;

- **Normalized/standardized metrics** – Where univariate metrics are applied, standardization to stations with similar habitat influences (but varying exposures to outfall discharges) is important to provide context to the absolute values of the metrics. Comparisons to reference stations of similar habitat/substrate are useful, as are analyses conducted relative to magnitude of exposure (*i.e.*, gradient analyses). The latter can be estimated as a function of distance from the outfall terminus, gradients based on distance and direction, or based on quantitative analyses of chemical concentrations in environmental media;

- **Abundances of individual taxa** – The spatial distributions of individual taxa provide an additional line of evidence in assessing overall outfall effects by exploring species-specific responses to outfall influences. This provides a finer resolution analysis that may reveal trends that are obscured by coarse level analyses. The individual taxa also convey the complexity of environmental responses to a stressor, in which some species exhibit clear positive responses, some exhibit clear negative responses, and some exhibit more complex patterns, depending on the nature of the sensitivity to the stressor and the degree of exposure experienced. A limitation to the assessment of individual taxa is that the variability is high (due to natural stochasticity of benthic abundances) and therefore meaningful assessments can only be conducted for taxa with sufficient total abundances. However, by classifying the patterns exhibited by individual taxa, general patterns can be identified and these are complementary to the assessments of other benthic metrics described above; and

- **The Infaunal Trophic Index (ITI)** – The distribution of dominant feeding groups of benthic fauna can be used to quantitatively model community response to organic material in the water column and/or substratum (Maurer *et al.* 1999; Word 1979). The ITI and its response to organic matter is based on the principle that with increasing organic carbon concentration the dominant feeding type changes from species that feed at the sediment-water interface to species that are predominantly deposit feeders.

For all metrics, relative values rather than absolute values communicate the most information regarding biological responses associated with the outfall discharges. Scaling of station indicators to the reference conditions facilitates comparisons among sampling years and across spatial groups. Past assessment of the reference stations in Parry Bay has consistently indicated that the five reference stations are an appropriate baseline against which to compare outfall monitoring data, as the references have low concentrations of substances of concern but similar habitat and substrate conditions to the outfall receiving environment.

2.4 Analysis of 2010 Data

All statistical analyses were conducted using SPSS™ version 14.0 software, with the exception of the non-metric multidimensional scaling (NMDS), which was conducted using Systat™ version 11.0. Box-and-whisker plots (boxplots) were often used to portray distributions of benthic community metrics. A boxplot is a graph summarizing the distribution of a set of data values, and includes the following features:

- **Median** – The median is the 50th percentile value (*i.e.*, equal number of data points above and below the median) and is depicted as a solid black line through the box;
- **Interquartile range** – The upper and lower ends of the center box indicate the 75th and 25th percentiles of the data. In other words, the box contains half of the data points in the distribution (*i.e.*, the middle half, rather than the remaining half that is split between the upper and lower extremes); and
- **Outlying values** – Boxplot "whiskers" (*i.e.*, vertical lines) and outliers (extreme individual values in the data distribution) are indicated by symbols extending from the centre box. Whiskers extend out 1.5 times the interquartile range. Outliers and extreme cases (> 1.5 times away from the edge of the box) are marked with an open circle.

In addition to boxplots, descriptive statistics were calculated for each summary metric (*i.e.,* arithmetic mean, median, standard deviation, minimum, and maximum) for general use as part of the WMEP.

Spatial patterns in benthic parameters were assessed using two complementary approaches:

- **Linear distance from outfall** (*i.e.*, 100 m, 200 m, 400 m, 800 m) – The distance-based approach has been included in all recent monitoring reports, and has been repeated here to provide consistency and comparison with those reports. The monitoring program, including number and position of stations, has been relatively stable over the past decade, such that data aggregated over distance increments are comparable over time; and
- **Distance-direction from outfall** (*i.e.*, near-field, far-field, *etc.*) – Recent monitoring events (*e.g.*, Golder 2007a, 2008, 2009, 2011a) have indicated a pattern of exposure and biological response that is linked to direction from the outfall terminus M0; this pattern results from the southeast orientation of currents in the area. The distance-plus-direction approach allowed for the identification of geographical groupings that reflect factors other than distance from the outfall that may govern wastewater transport and associated benthic invertebrate habitat factors.

The distance-plus-direction approach is considered to be a better approach for assessment of biological patterns over space because it is more closely tied to the pattern of exposure related to the wastewater discharges. However, there are two limitations of this approach:

- The distance-plus-direction analysis was only applied in recent years, and therefore direct comparisons cannot be made to early years of the period or record; and
- The distance-plus-direction approach requires specification of groupings based on patterns of exposure and community assemblages. As these patterns are subject to variations over time, the groupings must be re-evaluated from time to time to assess whether the existing groupings remain valid. Where refinements to groupings are made over time, the direct comparability to previous analyses is slightly reduced.

For these reasons, CRD-EP has opted to retain both approaches.

Prior to 2009, the outfall terminus station (M0) was combined with near-field stations in order to increase sample size for the statistical tests. However, following inspection of the univariate and multivariate graphics in the 2008 assessment, M0 was identified as being qualitatively different from the near-field stations in terms of benthic community composition. As a result, it was recommended that M0 be handled as a separate treatment for statistical tests (*e.g.*, ANOVAs and pairwise contrasts), rather than combined with near-field stations. Therefore, based on these recommendations, M0 was plotted separately on all figures and treated as a distinct group for statistical analyses in the 2009 and 2010 assessments. Although separation of M0 from the near-field group results in a weakened statistical power through the use of a single station with five replicates, discrimination of M0 assists in the evaluation of finer-scale spatial trends near the outfall. The 2010 sampling data confirmed the importance of evaluating M0 as a distinct exposure unit along the gradient of wastewater influence.

2.4.1 Multivariate Assessment of Distance-Direction Groupings

In the previous statistical trend assessment (Golder 2008), Golder conducted a multivariate assessment using historical benthic community and sediment chemistry data. The purpose of that analysis was to confirm previously identified groups of stations with similar characteristics based on benthic community and sediment chemistry, and to investigate the potential presence of additional groupings. The analysis identified one additional station grouping, resulting in a total of five distinct station groupings:

- **Outfall** – Station M0;
- **Near-field** – Stations M1E, M1SE, and M2SE;
- **Mid-field** – Stations M1W, M1SW, M1S, M2E, M2NE, M4SE, and M4E;
- **Far-field** – Stations M1N, M1NE, M1NW, M2N, M2NW, M2S, M2SW, M2W, M4SW, M4W, M8W, and M8E; and
- **Reference** – All five Parry Bay stations (PB1 through PB5).

Figure 3 depicts the Macaulay Point sampling stations categorized by distance-direction groups. The distribution of the near-field, mid-field, and far-field groups match the direction of outfall exposure and community pattern, which is to the east and southeast of the outfall. This spatial distribution is also consistent with the general water circulation pattern caused by currents in the region. The figure demonstrates that the area of greatest influence in terms of biology and chemistry is similar in size to the area encompassed by the IDZ boundary (shown in dashed line in Figure 3); however, the orientation of the near-field station grouping is to the southeast.

Part of the multi-year trend assessment entails re-evaluation of the spatial patterns in benthic community and sediment chemistry parameters to determine whether the distance-direction groupings remain appropriate for characterizing the patterns of responses observed at the site. Should the spatial patterns change substantially over time, modifications to the statistical design used to evaluate the data could be warranted. Accordingly, non-metric multidimensional scaling (NMDS) was used to identify spatial patterns in benthic community and sediment chemistry parameters collected in recent years (2008-2010). NMDS is a non-parametric technique that starts by mapping out the relationships among all stations (cases) in the form of a Bray-Curtis dissimilarity matrix. Bray-Curtis distance is a measure of how dissimilar two stations are in a multivariate sense. NMDS then searches for a reduced-dimensional (ideally two-dimensional) representation of the stations that retains as much as possible the same pattern of distances among cases. The resulting dimensions are therefore distantly related to the original variables, but probably not linearly or even monotonically. NMDS has no parametric requirements, so it works with any data distribution type. Principal components analysis (PCA) was also considered as an alternate analytical tool; however, it was not used in this study because of the large number of missing values in the dataset (*i.e.*, the data quality objective [DQO] failures in 2008-2010). PC scores can only be plotted for station-years with data for all parameters used to derive the PCA.

Benthic community data collected between 2008 and 2010 (*i.e.*, abundance counts of major taxa groups) were reduced to one common unit of replication prior to conducting the multivariate analyses. The unit of replication was station-year (*i.e.*, one value per station per year). Reduction of biological data included average abundance calculations for each station-year (*i.e.*, averaging replicates at each station). The following taxa groups were included in the NMDS:

- Echinodermata;
- Bivalvia;
- Gastropoda;
- Amphipoda;
- Crustacea [not including amphipods];
- Polychaeta;
- Polychaeta Sedentaria [not including *Capitella capitata* complex];
- *Capitella capitata* complex; and
- Miscellaneous taxa.

Sediment data collected between 2008 and 2010 were used in the multivariate assessment. Substances of interest (SOI) were selected to reflect those identified in the recent sediment trend assessment (Golder 2011c). Parameters with DQO severe failures or non detected values in more than 50% of samples were not included in the analyses. The retained sediment chemistry parameters included:

- Metals/Inorganics: aluminum, antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel, phosphorus, selenium, silver and zinc;
- Organics: anthracene, benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[g,h,i]perylene, benzo[k]fluoranthene, chrysene, fluoranthene, fluorene, indeno[1,2,3-c,d]pyrene, naphthalene, phenanthrene, pyrene, 2 methylnaphthalene, and phenols;
- Total organic carbon (TOC); and
- Acid volatile sulphides (AVS).

Data reduction for sediment chemistry parameters was conducted by first averaging all laboratory replicates, and then averaging all field replicates for a given station-year. Concentrations reported as less than the analytical detection limit (DL) were converted to one-half the DL. All data were log-transformed prior to analysis.

Relationships between NMDS dimension scores and the individual parameters were analysed using Spearman rank correlations. NMDS ordination plots were used to visually confirm the validity of the distance-direction groupings identified in the previous trend assessment (Golder 2008).

2.4.2 Total Abundance and Polychaete Abundance

Total abundance (TA) was calculated as the sum of all individual organisms identified in a sample (excluding nematodes and *Umbonula arctica*). An abundance count was calculated for each sample replicate. Polychaete abundance (PA) was calculated in a similar manner, using only polychaete species. The abundance statistics were calculated at the replicate level, rather than the station level, because the number of benthic community replicates per station was not consistent across all stations (*i.e.*, three [3] at most stations, four [4] at a subset of stations in 2010, and five [5] at M0). Treatment of the data at the level of replicate (*i.e.*, average abundance per replicate) therefore avoided bias associated with use of uneven numbers of replicates among stations.

2.4.3 Taxonomic Richness

Taxonomic richness (TR) was calculated as total number of distinct individual species or taxa (including nematodes and *Umbonula arctica*, as applicable) observed in an individual replicate, identified to the lowest practical taxonomic level. The overall TR values for each station were derived by taking the mean of the individual replicate richness values. This procedure eliminates potential bias associated with use of uneven numbers of replicates among stations over space and time (*i.e.*, the probability of sampling rare taxa increases with increasing number of replicates).

2.4.4 Swartz Dominance Index

The Swartz Dominance Index (SDI) represents the minimum number of species/taxa that cumulatively accounts for 75 percent of the total abundance in an individual sample replicate. Linear interpolation was used to specify decimal fractions of the SDI value to maintain the precision of the index for low SDI values. For example, if the three most dominant taxa comprised 70% of abundance, and the four most dominant taxa comprised 80% of abundance, the SDI would be calculated to be 3.5. Mean values by station and by distance group, as well as percent relative to reference, were calculated as described above for abundance and richness metrics.

2.4.5 Infaunal Trophic Index

The Infaunal Trophic Index (ITI) is a numerical representation of the distribution of dominant feeding groups of benthic fauna that has been used to quantitatively model community response to organic material in the water column and/or substratum (Maurer *et al.* 1999). The ITI and its response to organic matter is based on the principle that with increasing organic carbon concentration the dominant feeding type changes from species that feed at the sediment-water interface to species that are predominantly deposit feeders.

A new approach to ITI classification was considered for the 2010 Macaulay Point data, as a result of the identification of a 2010 document titled "Taxonomic and Feeding Guild Classification for the Marine Benthic Macroinvertebrates of the Strait of Georgia, British Columbia" (Macdonald *et al*. 2010). This new ITI classification (ITI-regional) extends the standardization of taxa to include ecological attributes such as feeding mode, food type/source and life habit.

To facilitate comparisons across sampling years, the ITI system (ITI-standard) that has been used previously in CRD benthic assessments (*e.g.*, Golder 2007a, 2008, 2009) has been retained in the current assessment. Statistics for the ITI-regional classification have been evaluated alongside ITI-standard, to assess the potential differences between the two classifications.

Appendix A summarizes the methods of each ITI classification system and the results of the species classification, including results of a literature review conducted for two previously uncategorized species.

For both ITI classification systems, the sample-specific ITI value is calculated by first determining the total abundance of the taxa belonging to one of four ITI groups and combining them in the following formula:

$$ITI = 100 - \left[33\frac{1}{3}\left(\frac{0n_1 + 1n_2 + 2n_3 + 3n_4}{n_1 + n_2 + n_3 + n_4} \right) \right]$$

Where: n_1 through n_4 are the number of individuals found in feeding groups 1 through 4, respectively.

In assigning species to feeding groups, there is uncertainty associated with making assignments to discrete groups. Some species could logically be assigned to multiple feeding groups depending on the environment in which they are found. For example, some species may behave as suspension feeders in high turbidity environments, but behave as detritus feeders where fewer suspended solids are available. Predatory species were particularly difficult to classify because the origin of their diet is often strongly dependent on the availability and type of prey items. Because of the complexity of these relationships, we did not attempt to partition exposure among the four types of dietary sources; rather, the dominant source as determined from professional judgement was assigned. The assignment was designed to minimize error in the ITI calculation (*i.e.*, a species believed to exhibit feeding habits of Group I, II, and III in approximately equal amounts was assigned Group II to simulate the “average” feeding habit).

Values of the index range from 0 - 100 with low values indicative of potentially altered conditions. ITI values have been used by some investigators to classify areas of seabed into either ‘normal’ (values 100–60), ‘changed’ (60-30) or ‘degraded’ (30-0) (Bascom *et al.* 1979). However, as the metric is based upon feeding strategies rather than ecosystem function, it does not distinguish between alterations that are net-positive, neutral, or that negatively affect ecosystem function (*i.e.*, cause impairment). Furthermore, the metric cannot distinguish between ITI values driven by physical and habitat factors versus those influenced by sediment contamination. Because feeding categories are expected to be linked to concentrations of organic matter in the sediment bed, areas of elevated TOC are likely to exhibit reductions in ITI scores. Whether such alterations translate into ecological impairment is a function of the types and magnitudes of alterations observed.

2.4.6 Abundances of Major Taxonomic Groups

The subdivision of total abundance into major taxonomic groups required selection of categories that: (1) provided breakdown of taxa into groups with potentially differing responses to wastewater constituents; and (2) maintained sufficient organism counts across stations and groups to conduct statistical tests. Species were grouped into nine major taxonomic groups, and abundance counts for each taxon were calculated. The groupings were consistent with the taxonomic divisions evaluated in previous years of benthic monitoring and included:

- **Echinodermata** – Phylum that includes starfish, brittle stars, sea cucumbers, sea urchins, and sand dollars;
- **Bivalvia** – Class of organisms within the phylum Mollusca, consisting of shelled organisms comprised of two hinged valves, including mussels, oysters, scallops, and clams;
- **Gastropoda** – Class of organisms within the phylum Mollusca, consisting mostly of shelled organisms with a ventral foot, and including snails and slugs;
- **Amphipoda** – Order of organisms within the class Crustacea consisting of numerous small, shrimp-like crustaceans. Amphipods are considered the most efficient scavengers of sea bottoms and shorelines, where they probably clear up and recycle more organic near-shore debris than any other animal group (Schmitt 1968);
- **Crustacea** [not including amphipods] – Class of arthropods that includes water fleas, shrimps, copepods, barnacles, lobsters, and crabs. Amphipods were excluded from this category because they were considered as a separate group;
- **Polychaeta Errantia** – Class of annelid segmented worms; the Errantia are active and mobile polychaetes;
- **Polychaeta Sedentaria** [not including *Capitella capitata* complex] – Class of annelid segmented worms; the Sedentaria are immobile (sedentary), spending their entire lives burrowed in sediment;

- ***Capitella capitata* complex** – The *Capitella capitata* represents a species complex (Grassle and Grassle 1976) of over ten sibling species (Gamenick and Giere 1997). It is a widely-occurring, opportunist species complex that is particularly associated with organically enriched sediments (Pearson and Rosenberg 1978) where it can out compete other taxa; and
- **Miscellaneous** – Other combined taxa with generally low organism counts.

Mean values by station and by distance group, as well as percent relative to reference, were calculated for each of the nine major taxonomic groups. Previous monitoring studies at Macaulay Point have shown that these groups can reveal patterns in community assemblages over space and time.

2.4.7 Abundances of Individual Taxa

Due to the complex interrelationships between biotic assemblages and numerous physical, chemical, and biological processes, ascertaining the potential influence of wastewater discharges (and particularly individual wastewater constituents) on benthic communities is challenging. Moreover, the organic matter contributions from wastewater discharges create a modified environment in which the conditions are made more favourable to some organisms and less favourable to others. The assessment of whether the changes in food sources and benthic habitat are overall positive, negative, or neutral to the benthic community depends on the types of changes observed in various taxa, including the shapes of the trends in environmental response and the magnitudes of the trends. Some of the observed trends are broad and apply to numerous taxa, whereas others are highly species-specific, depending on the mode of feeding, the sensitivity to disturbance, and other factors. To supplement the analyses conducted using summary metrics and major taxonomic groups, the distribution patterns of individual taxa were evaluated. This provides a finer resolution analysis that may reveal trends that are obscured by broad level analyses.

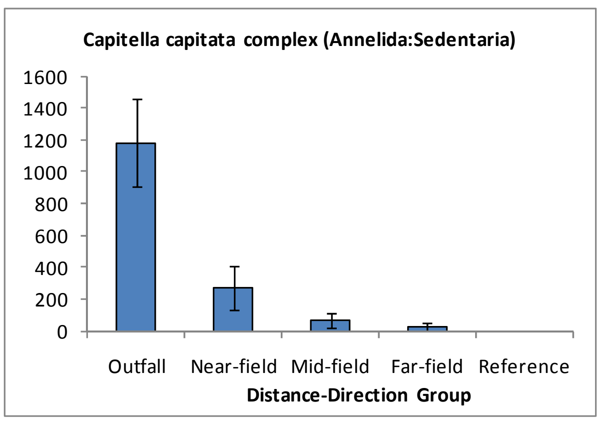
The assessment of individual taxa must recognize the following caveats and limitations:

- Trends in taxa abundances are influenced by organism preferences to organic carbon concentrations (and associated oxygen conditions) but are also strongly influenced by other factors such as sediment substrate type (*e.g.*, particle size distribution), water depth, and other oceanographic conditions. As such, an observed pattern for an individual taxon is not necessarily causally related to outfall effects;
- Benthic communities are inherently heterogeneous, and natural stochasticity of organism distributions can obscure (or exaggerate) trends in biotic distributions. The influence of variability on the spatial distributions of individual taxa is most pronounced when sample sizes are small;
- Changes in biotic assemblages over space or time are not necessarily indicative of ecological impairment. Assessment of a trend in abundances of an individual taxon does not take into consideration the functional role of the taxon in the ecosystem, nor does it account for compensatory effects of changes in other organism abundances, which may be positive, negative, or neutral depending of the type of alteration observed; and
- The characterization of the response to an individual taxon depends on the magnitude of exposure, and as such, can vary greatly depending on proximity to source. Whereas enhancement (or depression) of some taxa can occur in response to effluent discharges, the response can be reversed as the degree of exposure changes.

All of the above factors indicate that, in evaluating trends in abundances of individual taxa, care should be exercised not to draw strong conclusions from a single taxon or from a small number of taxa. Rather, the interpretation should consider the weight of evidence (cumulative and complementary findings) from all taxa. Our approach emphasized the identification of common spatial profiles shared by multiple taxa, and assignment to broad categories that suggest a functional response to proximity to the outfall.

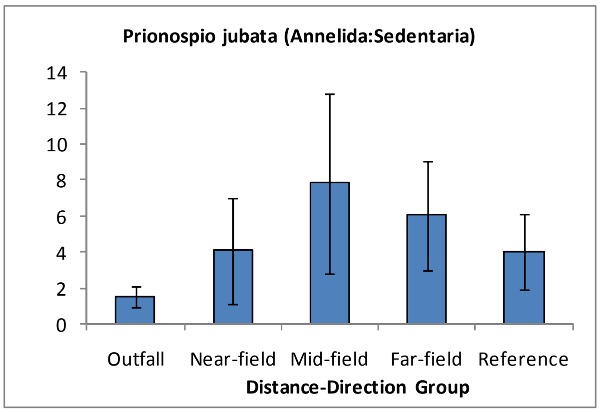
The approach used to assess individual taxa was similar to that of McElligott (2004) and previous benthic community monitoring (Golder 2007a, 2008, 2009, 2011a) and entailed plotting abundance as a function of a potential disturbance gradient. The assessment of individual taxa considered organisms with a total (study-wide) abundance of at least 100 organisms. The relationship between organism abundance and distance (or distance-plus-direction) from the outfall was plotted along a gradient, and each organism was placed into one of six categories (Figure 4) based on the nature of the distance gradient observed:

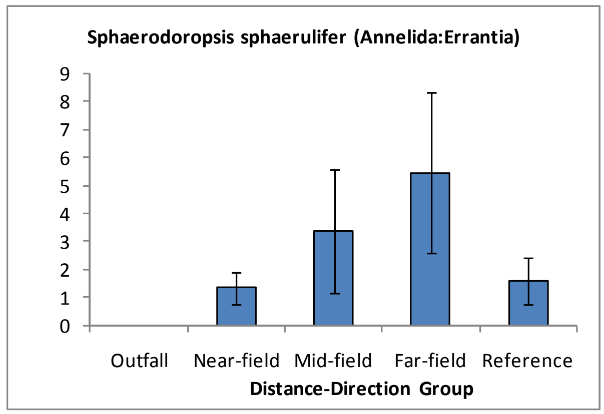
- **Pattern A** – Most abundant near the outfall terminus, with abundances generally declining with distance (or distance-plus-direction) from outfall, and less abundant at the reference location. This pattern is suggestive of organisms that thrive in and/or are opportunistic in the environment and substrate near the outfall. For these organisms, the benefits of wastewater influence substantially outweigh the potential negative influence of contaminants. As such, these organisms may displace organisms that are sensitive to outfall influences. Pattern A is well represented by abundances of *Capitella captitata* in the 2010 monitoring event;



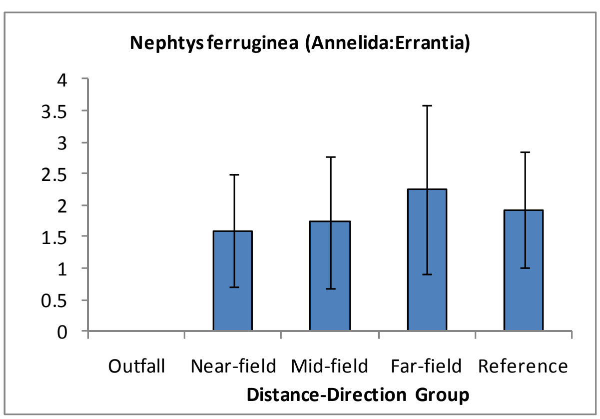
- **Pattern B** – Most abundant at intermediate distances from outfall terminus, with lower abundances (or absence) at outfall terminus and low abundances at the reference location. In 2010, Pattern B was partitioned into two sub-patterns, based on the observation of a distinct pattern caused by the M0 station assemblage:
  - Pattern B1 has similar abundances at the outfall and reference stations, but with enhanced abundances at intermediate distances from the outfall; and
  - Pattern B2 has very low abundance (or absence) near the outfall relative to reference, but enhanced abundance overall due to large numbers of taxa at intermediate distances.

  These patterns are suggestive of species that exhibited positive responses to outfall exposures, but only at intermediate distances. Pattern B is also consistent with the phenomenon called hormesis, in which a contaminant exhibits the opposite effect in small concentrations as in large concentrations (*i.e.*, generally-favourable biological responses to low exposures to environmental stressors). The most plausible explanation for a hormetic response in outfall monitoring data is a response to enhanced organic matter production, which provides additional nutrients at moderate levels, but can lead to oxygen depletion and other adverse biochemical conditions at higher exposures. In order to be assigned to Pattern B, the categorization required that the overall response of the taxon be *net-positive* (*i.e.*, the positive responses at intermediate distances must be greater in magnitude and spatial scale relative to suppression [if any] observed at M0). Accordingly, Pattern A and Pattern B are the only two patterns for which the net response of a taxon to effluent is considered to be positive. Pattern B1 is well represented by abundances of the sedentary polychaete *Prionospio jubata* in the 2010 monitoring event. Pattern B2 is well represented by abundances of the mobile polychaete *Sphaerodoropsis sphaerulifer* in the 2010 monitoring event;

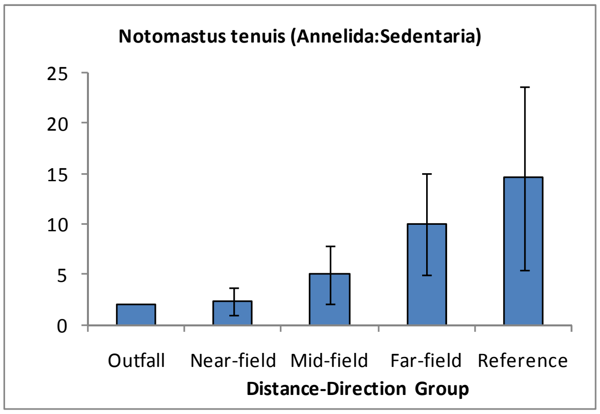




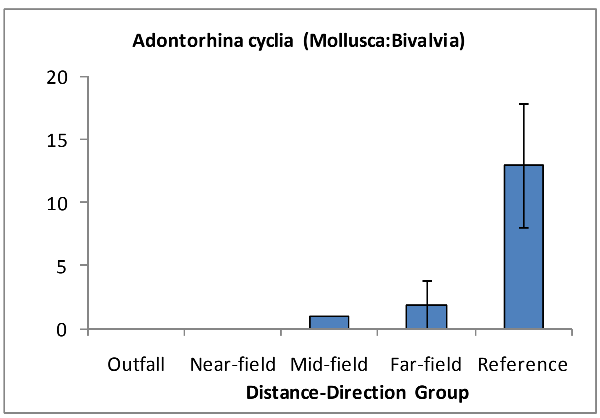
- **Pattern C** – Absence or low abundances at or near the outfall terminus, but similar abundances at most remaining outfall monitoring stations and the reference location. This pattern is suggestive of species that are poorly suited to the conditions immediately adjacent to the outfall, but that are relatively unaffected by reduced exposure to outfall-related conditions. For these species, there may be limiting factors (*e.g.*, biological oxygen demand, ammonia concentrations) that restrict the survival and reproduction of these taxa. Effects are observed only when environmental conditions fall outside the natural tolerance ranges of the organisms. Pattern C is well represented by abundances of the mobile polychaete *Nephtys ferruginea* in the 2010 monitoring event, as the distance groups beyond outfall station M0 do not indicate any statistically significant differences;



- **Pattern D** – Absent or uncommon near the outfall terminus, with generally increasing abundance with distance from outfall, and abundant at the reference location. This pattern is suggestive of species that are relatively poorly suited to environmental conditions near the outfall, and for which moderate exposure to outfall-related conditions may still result in adverse responses. Pattern D is well represented by abundances of the errant polychaete *Notomastus tenuis* in the 2010 monitoring event;



- **Pattern E** – Absent or uncommon at the outfall terminus and also uncommon at near and mid-field stations, but common at far-field stations and the reference location. This pattern is suggestive of species that are highly intolerant and sensitive to outfall-related exposures. Pattern E is well represented by abundances of the bivalve *Adontorhina cyclia* in the 2010 monitoring event; and



- **Pattern F** – Unclear or no linkage between abundance and proximity to outfall. This category includes all taxa for which abundance oscillates between high and low values with distance from the outfall. This could be indicative of natural variation obscuring a spatial response, or could be due to a combination of ecological processes that interact in a complex manner such that broad level trends are obscured.

In the above definitions, patterns may be defined based on distance only, or based on a combination of distance and direction. In each case, the “distance” may be interpreted as a measure of the degree of exposure to outfall related contamination.

Figure 4 depicts typical shapes of spatial patterns associated with each of the six response types. Although there were variations in the patterns exhibited, most taxa could be ascribed to one of the patterns A though E. Data were plotted and categorized based on both traditional distance groups (*i.e.*, 100 m, 200 m, *etc.*) and the distance-plus-direction groups (*i.e.*, outfall, near-field, mid-field, far-field, and reference).

The number of individual taxa that fall within each of the above categories provides insight regarding the type of benthic patterns observed, particularly in the context of environmental disturbance models (Pearson and Rosenberg 1978; Nilson and Rosenberg 2000) (Figure 5). However, because the assessment did not stratify samples on the basis of substrate type or other environmental factors, the empirical relationships observed as a function of distance from outfall do not necessarily imply cause-effect attributable to organic carbon contributions (or other outfall-related impacts).

2.4.8 Multivariate Methods

Non-metric multidimensional scaling (NMDS), as described in Section 2.4.1, was used to derive summary measures of the 2010 benthic invertebrate data. Station scores along the dimension axes provide a means of assessing the overall structure of the benthic community at a particular station, as well as identifying any spatial patterns among stations. Abundances of major taxa for sample replicates were used as the input variables into NMDS. Summary metrics, such as total abundance and richness, were not included in the NMDS as these parameters would be strongly inter-correlated with major taxa abundances.

Multivariate methods are helpful for distilling complex data sets down to a manageable number of variables. Choice of number of dimensions depends of several considerations, including statistical criteria (stress values, increased degree of variance with each added dimension) and qualitative factors (level of complexity that can be understood and graphically displayed). As the axes of a multivariate plot do not convey a specific biological significance, but rather have meaning through their association with the individual component variables, it is important to restrict the complexity to a level of detail that can be readily conceptualized. Furthermore, the quantitative output of a multivariate analysis cannot be directly compared to results from previous years. As such, the interpretation of NMDS depends strongly on the ability of the investigator to identify patterns and to compare them qualitatively to previous findings.

2.4.9 Spatial Patterns

Spatial patterns in the benthic community metrics were investigated to assess potential effects of the outfall on the benthic community. Distance gradients were assessed using non-parametric Spearman rank correlations of the station means for each metric.

Differences in the benthic community metrics were assessed between the individual distance groups (outfall, 100 m, 200 m, 400 m, and 800 m) and the reference area, and also between distance-plus-direction groups (outfall, near-field, mid-field, and far-field) and the reference area. These comparisons were made using one way analysis of variance (ANOVA) if the data met the assumptions of a normal distribution and homogeneity of variance. Tests for normality were conducted with the Shapiro-Wilk test. Homogeneity of variance was tested using Levene’s test. Where an ANOVA identified significant differences among treatments, *post hoc* comparisons between each group and the reference area were made using Dunnett’s test. Data transformations (*e.g.*, logarithmic transformation) were used where required to meet the assumptions of ANOVA. Where a data transformation was not sufficient to meet the above assumptions, a non-parametric version of the ANOVA called the Kruskal-Wallis test was used to identify differences among stations grouped by distance. *Post hoc* comparisons for the Kruskal-Wallis test were made using the Mann Whitney test, with a Bonferroni correction factor included to account for simultaneous multiple comparisons. Comparisons among distance and distance-direction groups were made using individual sample replicates.

2.4.10 Relationships between Biology Parameters and Sediment Variables

The potential effects of physical and chemical sediment parameters on benthic community parameters were assessed by identifying statistical relationships among these variables. Sediment data collected as part of the 2010 monitoring program were used in this assessment. Spearman rank correlations were computed to identify significant relationships. Station means (*i.e.*, means of individual replicate values) were used in this analysis for both the sediment substrate/chemistry and benthic community variables.

Prior to statistical analyses, sediment chemistry data were screened against data quality objectives (DQOs). Data were assessed with respect to three types of DQOs (Golder 2007b):

- **Precision** – Data precision, reflecting the degree of repeatability of measurements, was assessed with respect to the variability among laboratory and field replicate samples;
- **Bias** – Data bias, reflecting the consistent tendency, if any, of a measured value to deviate positively or negatively from a true value, was assessed with respect to the recovery of analytes in certified reference materials, matrix spike samples, and internal surrogate standards; and
- **Representativeness** – Data representativeness, reflecting how well data derived from a sampling program represent the actual state of the environment under study, was assessed with respect to the ratio of analyte concentrations in laboratory method blanks to associated samples.

When measures of precision, bias and/or representativeness fell outside the acceptable ranges defined by the CRD's DQOs, these were considered to be DQO 'failures'. The type(s) and severity of DQO failures were used to determine whether each reported value should be accepted, accepted with qualification, or rejected. A summary of the resulting DQO qualifiers that were applied to the 2010 sediment chemistry data is provided in Golder (2011b).

As part of a recent sediment trend assessment (Golder 2011c), sediment chemistry data from Macaulay Point were evaluated to identify substances of interest (SOIs) based on presence of significant trends (spatial and temporal) and exceedances of sediment quality guidelines. Substances identified as high priority (Categories A and B) were retained for the current assessment. Parameters with DQO severe failures or non detected values in more than 50% of samples were not included in the analyses. The retained 2010 sediment chemistry parameters included:

- **Metals** – aluminum, antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel, phosphorus, selenium, silver, and zinc;

- **Polycyclic aromatic hydrocarbons (PAHs**) – 2-methylnaphthalene, anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[g,h,i]perylene, benzo[k]fluoranthene, chrysene, fluoranthene, fluorene, indeno[1,2,3-c,d]pyrene, naphthalene, phenanthrene, and pyrene;
- **Phenolics** – total phenols; and
- **Conventionals** – Total organic carbon (TOC), acid volatile sulphides (AVS), and particle size parameters (percent fines, percent gravel).

1,4-dichlorobenzene was initially identified as a SOI; however, due to a high frequency of non-detected values (greater than 50% of samples), this parameter was not included in the statistical analyses.

For some substances, particularly organic parameters, the bioavailable concentration is better represented by the organic carbon (OC) normalized concentration rather than the dry weight concentration. To determine whether the correlation analyses would be influenced by the choice of concentration units, the correlations were repeated using OC-normalized sediment data for organic contaminants (*i.e.*, PAHs and phenolics). OC-normalized concentrations were calculated as follows:

$$\text{OC-normalized concentration (mg/kg OC)} = \frac{\text{Concentration in sediment (mg/kg dry weight)}}{\text{fraction TOC (kg OC/kg dry weight)}}$$

2.5 Multi-Year Trend Assessment

To the extent possible, the technical approach was designed to be consistent with previous trend reports (*e.g.*, Golder, 2005b; Golder, 2008) in order to facilitate the integration of new findings with those previously reported. Additional methods of data presentation and analysis have been considered where such analyses augment and are complementary to the approaches used in previous investigations.

2.5.1 Data Preparation

The first task entailed preparation of the benthic community data for statistical analyses. Considering the relative consistency of the sampling design in 2000-2007, and following consultation with the CRD-SP, it was determined during the previous trend assessment (Golder 2008) that the 2000 to 2007 period of record (with the exception of 2001) was best suited to a formal evaluation of trends. Data compiled by Golder during the previous trend assessment (Golder 2008) were used, and the three most recent years' of data (including monitoring data from 2008 to 2010) were appended to the Golder (2008) dataset.

Additional years of available data included 1994, 1997, 1999, and 2001. However, data from 2001 were not included in the statistical assessment due to differences in enumeration methods in this year. Data from 1994, 1997 and 1999 were also not included in the quantitative assessment due to differences in sampling designs; however, these data were included in time-trend plots for qualitative assessment.

The following benthic metrics were included in the trend assessment. A description of these parameters is provided in Section 2.4:

- Total abundance and total polychaete abundance;
- Total taxonomic richness;
- Abundances of major taxa (abundance counts of the nine major taxonomic groups);
- The infaunal trophic index[1] (ITI-standard); and
- The Swartz Dominance Index (SDI).

Benthic community data were reduced to one common unit of replication for subsequent analyses. The unit of replication was station-year (*i.e.*, one value per station per year). Reduction of benthic community data included calculating average benthic metrics for each station (*i.e.*, averaging individual replicates at each station).

Summary statistics, including means, medians, standard deviations, minima and maxima were computed for the 2000-2010 (excluding 2001) benthic data. Summary statistics were computed separately for the 2000-2010 (excluding 2001) and 2008-2010 time periods, and are categorized using both distance groups and distance-direction groups.

2.5.2 Analysis of Spatial Trends

Spatial trends in the Macaulay Point benthic community data were assessed relative to distance from outfall and among spatial groups of stations using methodologies similar to previous trend reports (Paine 1999, 2004; Golder 2005a, 2005b; Golder 2008).

Benthic data trends were conducted using the full period of record (2000-2010; excluding 2001), and also separately for the three most recent years' data alone (2008–2010). A comparison of the results of these two analyses was intended to evaluate whether recent spatial patterns are consistent with the broader historical trends. This analysis is complementary to the analysis of multivariate groupings of parameters in that both approaches evaluate the consistency of spatial patterns over time.

2.5.2.1 Spearman Rank Correlations

Distance gradients were assessed using non-parametric Spearman rank correlations of benthic parameters as a function of distance from the outfall. Spearman rank correlations were calculated for both the distance groups and the distance-direction groups.

[1] The infaunal trophic index (ITI-standard) was included in the trend assessment using data from 2006 through 2010; data prior to 2006 were not computed for this parameter.

2.5.2.2 Analysis of Variance

Differences in benthic community metrics between each distance group (outfall, 100 m, 200 m, 400 m, and 800 m) and the reference area were made using one-way analysis of variance (ANOVA) followed by *post hoc* multiple comparisons. Differences between distance-direction groups (outfall, mid-field, near-field and far-field) and the reference area were made using the same approach. Prior to conducting the analyses, data were tested for normality using the Kolmogorov Smirnov test and the Shapiro-Wilk tests (depending on the size of the data set), and for homogeneity of variance using Levene's test. Data that did not meet the assumptions of parametric analysis were assessed using nonparametric ANOVA (*i.e.*, Kruskal-Wallis tests) with multiple comparisons evaluated using the Mann-Whitney test. P-values for *post hoc* multiple comparisons were adjusted using a Bonferroni correction factor to account for potential false-positives resulting from simultaneous multiple comparisons.

2.5.3 Analysis of Temporal Trends

Temporal trends in benthic community metrics were assessed using methodologies similar to previous trend reports (Paine 1999, 2004; Golder 2005a, 2005b; Golder 2008). The formal quantitative analyses were conducted for the period of 2000 to 2010 (excluding 2001), whereas the qualitative assessment (*i.e.*, graphical analysis) also included the years 1994, 1997 and 1999.

For assessing temporal trends, benthic community metrics (with the exception of SDI and ITI) were normalized to the mean of the reference area stations (on a year by year basis); the normalized data were expressed as a "percent of reference" value for each year. Normalization to the reference area mean corrects for potential year-to-year fluctuations in abundances due to natural broad-scale processes, such as inter-annual variations in weather, food availability, *etc.*, and may normalize for some of the variability in taxonomic enumerations. The polychaete *Capitella capitata* complex was not present or present at very low numbers (*i.e.*, average abundance of <1) at reference stations in every year, therefore abundances could not be reference normalized and temporal trends were assessed using untransformed abundances[2].

2.5.3.1 Time Series Plots

Plots of the reference-normalized benthic community metrics (grouped by distance-direction and by distance) were used to qualitatively assess temporal trends. These temporal plots are used following each year of monitoring to discern broad trends. Because the 2010 program included a formal statistical trend assessment, the graphical evaluation was included as a complementary technique for evaluating trends over the last decade.

2.5.3.2 Spearman Rank Correlations

Temporal trends were assessed quantitatively using Spearman rank correlations between reference-normalized benthic community metrics and time (year). Temporal trends were assessed using multiple combinations of spatial groupings, including:

[2] The lack of any temporal variability in *Capitella capitata* complex abundance at reference stations eliminates the need to reference-normalize this metric.

- All stations excluding reference, to assess local trends (*i.e.*, at all stations potentially influenced by the outfall);
- Each distance group treated separately (*i.e.*, outfall, 100 m, 200 m, 400 m, 800 m, and reference groups), to assess variation in temporal trends as a function of linear distance from the outfall;
- Each distance-direction grouping including the outfall, near-field, mid-field, far-field, and reference station groupings, to assess variation in temporal trends as a function of influence of the outfall; and
- Each individual station, to test for overall spatial homogeneity of temporal trends[3].

2.5.3.3 Homogeneity of Trends

Rank correlations were compared among stations using a modified version of the van Belle test for homogeneity of trends, as outlined in Paine (2004). Spearman rank correlations were calculated for each parameter as a function of time, for each station separately. The correlation coefficients were then transformed into standard normal deviates (Z-scores). These Z-scores were used to calculate a chi-square statistic for each benthic community parameter, effectively summarizing in a single value the variability in Z-scores among stations for a particular parameter. The calculated chi square statistics were compared to critical values to determine if the distribution of Z-scores was significantly different from what would be expected if the trends were homogeneous among all stations. In other words, a statistically significant result for a particular parameter (test chi-square value greater than critical chi-square value) provides evidence that temporal trends for that parameter were not the same at all stations.

Separate van Belle test statistics were calculated once for all monitoring stations combined (including reference) and once for all stations except references. A comparison of the results of these two analyses was intended to assess the extent to which any significant heterogeneity identified by the van Belle tests was due to:

- Differences between reference stations and the other distance groups (*i.e.*, potentially indicating regional-scale variability in trends); or
- Differences among the non-reference distance groups (*i.e.*, potentially indicating local scale variability in trends with distance from the outfall).

[3] Individual station trends were calculated using raw benthic data (not reference-normalized) to allow for evaluation of homogeneity of trends among stations.

3.0 RESULTS

3.1 Multivariate Assessment of Distance-Direction Groupings

3.1.1 Benthic Community Metrics

Non-metric multidimensional scaling (NMDS) was conducted using the most recent three years (2008-2010) of benthic community data (*i.e.*, abundance counts of major taxa groups). Two dimensions were derived that accounted for 92.5% of the variance in the original nine variables. Spearman rank correlations between the benthic metrics and the NMDS dimensions (Benthic Dim 1 and Benthic Dim 2) are presented in Table 2. Benthic Dim 1 was significantly positively correlated with abundance counts of the polychaete *Capitella capitata* complex, and significantly negatively correlated with abundance counts of bivalves, miscellaneous taxa, gastropods, non-amphipod crustaceans and echinoderms. Benthic Dim 2 was significantly positively correlated with abundance counts of mobile polychaetes, amphipods, miscellaneous taxa, non-amphipod crustaceans and echinoderms.

Figure 6 presents an ordination plot of Benthic Dim 1 and Benthic Dim 2. As expected, the Benthic Dim 1 scores reflect some spatial trends in the combined biological metrics, with stations close to the outfall tending to have higher values (indicating more capitellids, but fewer bivalves, gastropods, crustaceans, echinoderms, and miscellaneous taxa), and stations far from the outfall (particularly reference stations) exhibiting negative values. Along the Dim 2 axis, most stations and station groups exhibited similar distributions in the ordination, with the exception of M0 (outfall terminus station). The latter exhibited high Dim 2 scores, reflecting higher abundances of some taxa (particularly amphipods) relative to other near-field stations.

3.1.2 Sediment Chemistry

Non-metric multidimensional scaling (NMDS) was conducted using the most recent three years (2008-2010) of sediment chemistry parameters. Two dimensions were derived from the sediment chemistry data (30 individual parameters), which together accounted for 98% of the variance. Spearman rank correlations between the sediment chemistry parameters and the NMDS dimensions (Chemistry Dim 1 and Chemistry Dim 2) are presented in Table 3. Chemistry Dim 1 was significantly positively correlated to all parameters except aluminum; therefore this dimension is a good representation of sediment chemistry concentrations in general. Nearly all parameters exhibited a strong statistical association with Dim 1 (*i.e.*, $|r_s| > 0.6$).

Chemistry Dim 2 indicated a weaker pattern associated with a subset of the parameters, and was significantly positively correlated with ten (10) of the thirty (30) chemistry parameters (arsenic, aluminum, cadmium, chromium, copper, lead, nickel, phosphorus, silver, and zinc). The strengths of the correlations were weaker, within only chromium exhibiting a strong (*i.e.*, $|r_s| > 0.6$) statistical association with Dim 2. Antimony, selenium and mercury were the only metals that were not significantly correlated with Chemistry Dim 2. In contrast, no PAHs were significantly correlated with Chemistry Dim 2. Figure 7 presents an ordination plot of Chemistry Dim 1 and Chemistry Dim 2. The plot shows a general pattern in which the stations most influenced by the outfall (particularly M0) tend to have positive values on the Chemistry Dim 1 axis, and stations far from the outfall exhibit negative values.

3.1.3 Spatial Patterns

The ordination plots of the NMDS dimensions resulting from the most recent three years (2008-2010) of data were used to qualitatively (visually) assess the consistency of distance-direction groupings over time. Figure 6 and Figure 7 were compared with figures created using the same parameters in the last trend assessment (Golder 2008), to determine if the patterns were similar and to determine if any stations warranted a formal change of grouping.

For both time periods (2005-2007 and 2008-2010), the benthic dimensions exhibited clearer spatial patterns with distance/direction from the outfall relative to the sediment chemistry dimensions. In general, patterns between the NMDS dimensions were similar between the two time periods, and support the previously defined distance-direction groups.

The reference stations generally remain to one side of the ordination plots, reflecting a systematic difference of reference stations with respect to both benthic community and sediment chemistry. However, overlap with far-field stations is visible in both of the plots, indicating the natural variability and illustrating that many far-field stations resemble Parry Bay reference stations in terms of benthic community and sediment chemistry attributes.

Based on the multivariate assessment of Macaulay Point benthic community and sediment chemistry data, no individual monitoring stations were considered to warrant a change of grouping. The following five groups defined in Golder (2008) have been maintained for the current study:

- Outfall: M0;
- Near-field: M1E, M1SE and M2SE;
- Mid-field: M1W, M1SW, M1S, M2E, M2NE, M4SE and M4E;
- Far-field: M1N, M1NE, M1NW, M2N, M2NW, M2S, M2SW, M2W, M4SW, M4W, M8W and M8E; and
- Reference: Parry Bay stations (PB1 – PB5).

The maintenance of a consistent distance-direction grouping system has a number of advantages, including:

- Consistency allows for direct comparisons of univariate metrics among sampling programs; and
- Confirmation of previous patterns provides evidence that these broad patterns reflect underlying spatial trends, rather than merely sampling variation.

3.2 2010 Benthic Metrics

Summary statistics for 2010 benthic community metrics are presented in Table 4. Results are presented by individual stations (*e.g.*, M0, M8E) and also by distance group, including distance from outfall (*e.g.*, 100 m, 200 m) and the distance-plus-direction groupings (*i.e.*, near-field, mid-field and far-field). Correlations with distance from the outfall are presented in Table 5.

Figure 8 presents the spatial distributions of the benthic community metrics (*e.g.*, total richness and abundance of each major taxonomic group). Each parameter is plotted as a function of distance-direction group (left panels) and distance group (right panels), and using box plots (top panels) and means ± 95% confidence intervals (bottom panels). The box plots communicate the distribution of the data, whereas the means and 95% confidence intervals (CIs) represent a range within which the true mean is likely to fall. The 95% CIs are influenced by both the variability of the data (*i.e.*, standard deviation) and the sample size (*n*), so that a dataset with high variability and/or a small sample size will have wider 95% CIs than a dataset with low variability and/or a large sample size.

The data for each benthic community metric were tested for normality and homogeneity of variance prior to running ANOVA comparisons. Abundance of mobile (errant) polychaetes met the assumptions of ANOVA for the traditional distance-based groups, whereas abundance of non-amphipod Crustacea, ITI (Regional) and Benthic Dimension 2 met the assumptions of ANOVA for the distance-plus-direction categories. The two species abundance parameters required log transformations to meet these assumptions. *Post hoc* comparisons for parametric analyses were conducted using Dunnett's test.

The non-parametric Kruskal-Wallis test was used to identify significant differences between stations grouped by distance (and distance-direction) from the outfall for all of the remaining metrics. *Post hoc* comparisons with the reference station were made using the non-parametric Mann-Whitney test with a Bonferroni adjustment for multiple comparisons.

3.2.1 Total Abundance and Polychaete Abundance

Total abundance in individual replicates ranged from 152 individuals at a Station M8E replicate to 2,342 individuals at an outfall (Station M0) replicate (Table 4). The mean abundance at reference stations was 438 individuals. Ten (10) of the twenty-three (23) outfall monitoring stations exhibited mean abundances below this reference level; station averages for these locations ranged from 42% to 98% of the reference mean). The remaining individual station averages ranged from 101% to 410% of reference. A statistically significant difference was identified between the outfall and the reference area ($p < 0.01$), indicating that total abundance was greater at the outfall relative to reference (Table 5 and Table 6; Figure 8a). No other statistically significant differences in total abundance were identified between the reference area and either of the distance or distance-plus-direction groups. The correlations between total abundance and each of the distances from the outfall (and all distance-direction groups) were not significant.

The pattern of total abundance in the current assessment (2010 data) is similar to the pattern from the 2008 data, in that abundances at near-field stations are considerably lower than at station M0, and not significantly different from reference. Therefore, the general profile in total abundance observed in 2010 is not unique. However, in most sampling events over the last decade, the near-field total abundance has been higher than observed in 2010. For example, in last year's assessment (2009 monitoring data), total abundance at near-field stations was similar to that of M0 and was significantly greater than at the reference stations.

Whereas the mean total abundance at near-field stations was lower in 2010 than in 2009, the most conspicuous difference between these two sampling events was the higher total abundance at Station M0 in 2010 (1,799 individuals), which was approximately 2.5 times greater than the total abundance at the outfall station in 2009 (693 individuals). The contrasting patterns observed in the last few years illustrate the high variability in total abundance that has been observed in the benthic community monitoring program. In general, the pattern of total abundance exhibits a decreasing trend with increased distance from the outfall. However, in any individual sampling year, deviations from this broad trend can be observed. In 2008, some near-field stations were atypically low in abundance, whereas in 2009 the outfall station M0 was atypically low (*i.e.*, M0 usually has the highest abundance, but was similar to near-field stations in 2009). In 2010, the total mean abundance at M0 (1,799 individuals) was high in comparison to the previous two assessments, which had a combined average total abundance of approximately 700 individuals.

Total polychaete abundance ranged from 74 individuals at a Station M8E replicate to 1,603 individuals at a outfall station (M0) replicate (Table 4). Mean polychaete abundance was greater than the reference area mean for all outfall monitoring stations, with the exception of the two 800 metre stations (M8E and M8W), which had station averages that were 75% and 81% of the reference mean, respectively. The remaining twenty-one (21) stations had station averages that ranged from 108% to 1082% of the reference mean. Statistically significant differences were identified between each of the outfall, 100 m, 200 m, 400 m and 800 m distance groups relative to the reference area ($p < 0.05$), indicating that total polychaete abundance was greater than the reference stations for each of these distance groups, with the exception of the 800 m group, which had lower abundance counts (Table 5; Figure 8b). Significant differences were also observed between each of the distance-plus-direction groups and the reference area ($p < 0.01$) (Table 6; Figure 8b). Polychaete abundance was greatest near the outfall, particularly at the outfall terminus (M0) and to the south east of the outfall (*i.e.*, M1SE and M2SE).

The correlation between distance from the outfall and polychaete abundance was statistically significant ($p < 0.01$) and negative, indicating that this metric decreases with distance from the outfall (Table 5). Polychaete abundance significantly ($p < 0.01$) decreased with distance-direction from the outfall as well (Table 6).

3.2.2 Taxonomic Richness

Taxonomic richness ranged from a minimum of 25 taxa in a replicate at Station M0 and at Station M1SE to a maximum of 96 taxa at a Station M4W replicate (Table 4). Mean taxonomic richness was equal to or greater than the reference area mean at only two (M2N and M4W) of the 23 Macaulay Point outfall monitoring stations, compared to eight (8) stations in both 2009 and 2008, seven (7) stations in 2007 and fifteen (15) stations in 2006. Station averages ranged from 44% to 115% of reference richness. The majority of stations exhibited richness values that were within 25% of reference, with six exceptions (M0, M1E, M1S, M1SE, M1SW, M2SE) near the zone of greatest outfall influence. In the previous assessment, a similar pattern was observed although the majority of stations were within 10% of reference. Statistically significant differences ($p < 0.05$) were identified between each of the outfall, 100 m, 200 m and 800 m distance groups relative to the reference area indicating that taxonomic richness was less than the reference stations for each of these distance groups (Table 5; Figure 8c). The correlation between distance from the outfall and taxonomic richness was statistically significant and positive ($r_s = 0.61$; Table 5). Statistically significant differences ($p < 0.05$) were also identified between each of the outfall and distance-direction groups and the reference area (Table 6; Figure 8c). The correlation between distance-direction groups and taxonomic richness was also statistically significant and positive ($r_s = 0.69$; Table 6).

Figure 9 depicts the spatial distribution of taxonomic richness (TR) across the study area in 2010; station group means and data distributions are depicted in Figure 8c. As with previous monitoring events, the mean taxonomic richness at the outfall (36 at M0 in 2010) was lower than the mean reference station value (68 in 2010). However, the 2010 sampling results differ from most other sampling events in that the outfall station M0 did not exhibit the lowest mean taxonomic richness, which was instead observed at Station M1SE (30 in 2010). Accordingly, the spatial extent of the reduced richness is greater in 2010 than has been observed in other recent sampling events. As shown in Figure 9, the five lowest mean richness values (30 at M1SE, 36 at M0, 40 at M1E, 42 at M2SE, 43 at M1SW) were all observed near the outfall and generally in the direction of the current (*i.e.*, near-field stations). The occurrence of reduced richness in the area of greatest outfall influence is suggestive of an adverse response due to wastewater-related effects. The degree to which richness was reduced at M0 was less in 2010 than in 2009 (53% and 39% of reference, respectively). Historically, the richness at M0 has been variable, with some years exhibiting richness similar to reference, and other years exhibiting richness reduced by more than a factor of 2. The 2010 monitoring event falls somewhere in between the two extremes, which is an improvement on the observations of 2009 when richness fell at the lower end of the historically observed range for M0.

At far-field stations, relative richness was similar to previous years of monitoring with values ranging from 93% to 105% of reference. Overall, the data suggest a moderate degree of reduction in species richness near the outfall terminus and at other near-field stations (oriented generally to the southeast of the diffuser).

3.2.3 Swartz Dominance Index

The Swartz Dominance Index (SDI) ranged from 0.9 taxa at a Station M1SE replicate to 29 taxa at a Station M2N replicate (Table 4). Mean SDI was lower than the reference area mean for the majority of stations (18 out of 23 stations), with values below reference ranging from 6% to 87% of reference. The remaining five stations with SDI values above reference ranged from 106% to 154% of reference (M1N, M2N, M2NE, M4E and M8E). Statistically significant differences were identified for each of the outfall, 100 m and 200 m distance groups relative to the reference area ($p < 0.05$), indicating that the SDI was lower at these stations relative to the reference stations (Table 5; Figure 8d). The outfall, near-field, mid-field and far-field distance groups were also identified to have statistically significantly lower SDI values compared with the reference group ($p < 0.05$) (Table 6; Figure 8d).

The correlation between SDI and distance from the outfall was significant and positive ($r_s = 0.62$), indicating that SDI increased with increasing distance from the outfall (Table 5). The correlation between SDI and distance-direction groups was also significant and positive ($r_s = 0.59$; Table 6).

The spatial patterns in SDI were stronger in the last three monitoring events (2008-2010) relative to previous years. Figure 8d illustrates the systematic increase in SDI with distance from the outfall exposure source. The previous monitoring study (Golder 2011a) indicated that the 2009 and 2008 datasets both showed an increased effect size (*i.e.*, the most affected groups are 3- to 4-fold lower than reference, compared to a two-fold difference in 2007). This increase in effect size is still apparent, with the most affected groups approximately 5-fold lower than reference. The last three years of data also suggest an increased spatial zone of influence in comparison to 2007 and previous years. In 2007, large reductions in SDI (relative to reference) were observed only at M0 and near-field stations. In contrast, the 2008-2010 data indicate reductions in SDI across all distance-plus-direction groups.

Overall, the SDI data reconfirm the general trend of decreasing SDI with increased outfall exposure (*i.e.*, south-east of the outfall, following the direction of prevailing currents). This spatial pattern is consistent with the distribution of enhanced polychaete abundance and reduced taxonomic richness described above. In the most recent years (2008-2010), the pattern of SDI was clearer and more pronounced than in previous monitoring events.

3.2.4 Infaunal Trophic Index

The Infaunal Trophic Index (ITI) was calculated using two methods, as described in Appendix A. Results are presented for both methods. ITI-standard is comparable to the ITI classifications designated in previous monitoring studies (*e.g.*, Golder 2006, 2007a, 2008, 2009, 2011a); ITI-regional is based on a 2010 study (Macdonald *et al*. 2010), and extends the standardization of taxa to include ecological attributes such as feeding mode, food type/source and life habit.

ITI-standard ranged from a minimum of 9 in a replicate at Station M1SE to a maximum of 63 at a Station M8E replicate. ITI-regional ranged from a minimum of 4 at a Station M1SE replicate to 58 at a Station M8W replicate (Table 4). The mean ITI-standard values were lower than the reference area mean for 14 out of 23 outfall monitoring stations, with values ranging from 22% to 99% of reference. The nine stations with mean ITI-standard values greater than reference ranged from 100% to 106% of reference. The mean ITI-regional values were lower than the reference area mean for all but one of the 23 outfall monitoring stations, with values ranging from 12% to 96% of reference. Only Station M8W had a mean ITI-regional value above the reference area mean (115% above reference; Table 4). Statistically significant differences in ITI-standard were identified between each of the outfall and 100 m distance groups in comparison with the reference area ($p < 0.05$); significant differences in ITI-regional were identified between each of the outfall, 100 m, 200 m and 400 m distance groups in comparison with the reference area ($p < 0.05$). These results indicate that the ITI-standard and ITI-regional values were lower at these distance groups relative to the reference area (Table 5; Figure 8e and Figure 8f).

The correlations with distance from the outfall and both ITI-standard and ITI-regional were significant and positive, indicating that ITI scores increased with increasing distance from the outfall (Table 5). The correlation between distance from the outfall and ITI-regional was stronger than the correlation between ITI-standard and distance from the outfall ($r_s = 0.60$ and 0.70, respectively).

When distance-direction groups were compared, significant differences in ITI-standard were identified for each of the outfall, near-field and mid-field groups in comparison with the reference area; significant differences in ITI-regional were identified for each of the outfall, near-field, mid-field and far-field groups in comparison with the reference area (Table 6; Figure 8e and Figure 8f). A significant difference in ITI-standard values was not identified between the far-field distance-direction group and the reference area.

Both the ITI-standard and ITI-regional metrics were significantly positively correlated with distance-direction, indicating that ITI scored increased with increasing distance-direction from the outfall (Table 6; Figure 8f). Both correlation coefficients indicated a stronger relationship between the ITI metrics and distance-direction in comparison with the correlations with distance alone.

An increase in ITI scores with increasing distance from the outfall is consistent with that expected for an area with elevated organic matter adjacent to a point source discharge (Maurer *et al.* 1999). The change in dominance of organisms from those feeding on suspended materials to those that feed on deposited materials is indicative of increases in the amount of sedimentary particulate organic material. The largest reductions in the ITI metrics (relative to reference) were observed at the outfall and in the near-field group (*i.e.*, M1SE, and M2SE) that are in the region of greatest influence of the outfall discharge (*i.e.*, south and east of the outfall, following the direction of prevailing currents).

Bascom *et al.* (1979) established ranges of ITI values inferred to represent environmental quality conditions, including 'normal' (values >60), 'changed' (60 – 30) or 'degraded' (<30). Using these criteria for the ITI-standard metric, Stations M0, M1SE, and M2SE would be considered "degraded"; the remaining twenty outfall monitoring stations and the five reference area stations would be considered "changed". Using these criteria for the ITI-regional metric, eight of the outfall monitoring stations (M0, M1E, M1SE, M2SE, M1W, M1SW, M2N and M4SE) would be considered "degraded"; the remaining fifteen outfall monitoring stations and the five reference area stations would be considered "changed".

In Golder (2009), recommendations were made for the site-specific interpretation of ITI, specifically that the ITI narrative considers the Parry Bay reference condition. Values within 20% of the mean reference condition may be defined as 'normal', reductions of 20 – 49% relative to reference would be considered 'changed', and reductions of 50% or more would be considered 'degraded'. These thresholds are considered more relevant because they avoid mischaracterization of reference sediments as 'changed', and align with effect sizes that are commonly applied in ecological risk assessments to rank magnitudes of response. The resulting classifications using ITI-standard are:

- Normal – All 400 m stations, all 800 m stations, all 200 m stations with the exception of M2SE, M1N, M1NE, M1NW, M1S;
- Changed – M1E, M1SW, M1W; and
- Degraded – M0, M1SE and M2SE.

The resulting classifications using ITI-regional are:

- Normal –M1N, M1NE, M2NW, M2S, M2SW, M2W, M4E, M4SW, M4W, M8W;
- Changed – M1NW, M1S, M2E, M2N, M2NE, M4SE, M8E; and
- Degraded – M0, M1E, M1SE M1SW, M1W and M2SE.

The magnitude of effects relative to reference was greater in 2010 in comparison with previous years, particularly at station M0, where ITI-standard averaged only 16% of reference. In 2009, ITI-standard was 19% of reference at M0, whereas in 2008, ITI values in M0 replicates were similar to those at the other near-field stations (at approximately 30 to 40% of reference). The very low ITI-standard scores observed at station M0 in 2010 and 2009 is attributable to the high relative abundance of the polychaete *Capitella capitata* complex (a group IV deposit feeder), which contributed greater than 60% of total abundance at this station. The spatial extent of ITI response in 2010 was similar to previous years, with significant reductions observed in near-field and mid-field stations, and levels at far-field resembling those at the reference stations.

3.2.5 Abundances of Major Taxonomic Groups

Mean values and percent of reference values for each of the nine major taxonomic groups are presented in Table 7 including separate statistics for individual stations, for groups of stations at common distances (*i.e.*, 100 m, 200 m, 400 m, 800 m, and reference stations) and for distance-direction groups. Correlations with distance and distance-direction from the outfall, and comparisons among each of these groups are presented in Tables 5 and 6. Box and whisker plots and 95% confidence interval plots (subdivided by distance and distance-direction from the outfall) are depicted in Figures 8g through 8o. Figure 10 provides cumulative abundance data for the major taxonomic groups, organized by distance and distance-direction group means.

- **Echinodermata** – Mean abundance of echinoderms was low in all Macaulay Point outfall monitoring stations and reference stations (Table 7). A statistically significant difference was identified between each of outfall and distance groups and the reference area, with the exception of the 400 m distance group (Table 5; Figure 8g). The correlation between echinoderm abundance and distance from the outfall was significant and positive (r_s = 0.54; Table 5), indicating that echinoderm abundances increased with distance from outfall. A statistically significant difference was identified between each of the outfall, near-field, and far-field distance-direction groups and the reference area. The correlation between echinoderm abundance and distance-plus-direction groups was significant (r_s = 0.31; Table 6). The results from 2010 differ from the previous monitoring event in that there were no significant differences observed between distance groups and the reference in 2009. However, in terms of broad spatial patterns, echinoderms still conform to Pattern D (absent or uncommon near the outfall terminus, with generally increasing abundance with distance from outfall) indicating that echinoderms are relatively poorly suited to environmental conditions near the outfall;

- **Bivalvia** – A statistically significant difference was identified between the outfall and the reference area; the correlation between bivalve abundance and distance from the outfall was significant and positive (r_s = 0.29; Table 5), though weak. When analyzed in terms of distance-plus-direction groups, bivalve abundance was statistically significantly lower in each of the outfall, near-field and mid-field groups, and significantly higher in the far-field group, relative to the reference area (Table 6; Figure 8h). The correlation between abundance and distance-direction group was significant and positive (r_s = 0.65; Table 6), indicating that bivalve abundances increased with distance-direction from outfall. The analysis of bivalve abundances in previous sampling years has suggested that bivalves tend to be less abundant at near-field locations relative to reference, supporting the 2010 results. In terms of broad spatial patterns, bivalves conform to Pattern C (distance-based) or Pattern D (distance-direction) because bivalves are not abundant near M0, but are present in higher numbers at greater distances. This indicates that bivalves do not respond well to the maximum exposure to wastewater discharges, but can accommodate moderate levels of exposure;

- **Gastropoda** – Mean gastropod abundance was lower at the outfall station in comparison with the other monitoring stations (Figure 8i). Statistically significant differences were identified between each of the outfall and distance groups and the reference area with the exception of the 800m group (Table 5; Figure 8i). The correlation between gastropod abundance and distance from the outfall was significant (r_s = 0.69; Table 5). When analyzed by distance-direction, gastropod abundance was statistically significantly lower at the outfall and all distance-direction groups relative to the reference area and the correlation between abundance and distance-plus-direction group was significant and positive

(r_s = 0.72; Table 6). In terms of broad spatial patterns, gastropods conform to Pattern D (absence or low abundances near outfall terminus M0, but increase in abundance with distance from the outfall) indicating that gastropods are poorly suited to the environmental conditions near the outfall. This differs from the observations of 2008 and 2009 data which were indicative of Pattern C, and suggest a shift in the spatial pattern of echinoderm abundances;

- **Crustacea (Amphipoda)** – A statistically significant difference was identified between the each of the outfall and the 200 m distance group, and the reference area, and the correlation between amphipod abundance and distance from the outfall was significant and negative but weak in strength (r_s = -0.24; Table 5). In 2009, the highest mean abundance of amphipods occurred at stations south and east of the outfall (Stations M1SE, M2E, M1E and M1S). Conversely, in 2010, the mean abundance of amphipods at Stations M1E, M1S, and M1SE were the lowest of the outfall monitoring stations, ranging from 56% to 76% of reference. The correlation between amphipod abundance and distance-direction was not significant. In terms of broad spatial patterns, amphipods appear to fall into Pattern A (most abundant near the outfall terminus, with abundances generally declining with distance [or distance-direction] from outfall) in 2010. However, the atypically low amphipod counts at several near-field stations in 2010 weakened the strength of this Pattern A response. In 2009, amphipods were considered to fall into Pattern B, and in 2008, amphipods did not exhibit any clear pattern with distance from the outfall (Pattern F). Patterns in amphipod abundance have varied from year to year, with no clear dominant pattern emerging;

- **Crustacea (Other)** – Mean abundances of other crustaceans were variable, but were below the reference area mean for the majority of stations (Table 7). Stations M0 and M8W were the only stations with a mean abundance of other crustaceans greater than the reference area mean, at 287% and 152% of reference, respectively. All other station averages ranged from 7% to 72% of reference. A statistically significant difference was identified between each of the outfall, 100 m, 200 m and 400 m station groups and the reference area stations (Table 5), with the reference stations exhibiting greater mean abundance for all groups except the outfall. The correlation between abundance of other crustaceans and distance from the outfall was significant and positive; however, the correlation coefficient (r_s = 0.37; Table 5), indicates a weak association. The graphical pattern of the 2010 data suggests that the outfall (M0) contained substantially more crustaceans than at all other distance and distance-plus-direction groups (Figure 8k). This pattern is in agreement with the findings of 2007 and 2008, and suggests that the low relative abundance observed at M0 in 2009 was an anomaly. Statistically significant differences were identified between each of the outfall and distance-direction groups relative to the reference area, and the correlation between abundance of other crustaceans and distance-plus-direction groups was positive and significant (r_s = 0.50; Table 6);

- **Polychaeta Errantia** – Mean abundances of mobile polychaetes were greater than the reference area mean for the vast majority of stations (Table 7). Stations M1SE and M8E were the only stations with a mean abundance of mobile polychaetes lower than the reference area mean, at 87% and 98% of reference respectively. The abundances of mobile polychaetes were significantly higher in each of the outfall, 100 m, 200 m and 400 m distance groups relative to reference. The correlation between abundance of mobile polychaetes and distance from outfall was significant and negative (r_s = -0.39; Table 5, Figure 8l). The correlation between mobile polychaete abundance and distance-direction was also significant and negative (r_s = -0.38; Table 6). Both of the mid-field and far-field distance groups differed significantly from the reference area, but no significant difference was identified between the outfall or the near-field group and the reference area (Table 6; Figure 8l). In 2010, mobile polychaetes were most abundant at the outfall monitoring stations, with lower abundances at the reference area and 800 m stations. This distribution is indicative of “Pattern A” (positive influence of the outfall, with lower abundances at far-field stations and at the reference location). In 2009, mobile polychaetes exhibited a “Pattern B” distribution and in 2008, a “Pattern A” designation was assigned. Although the patterns have changed slightly from year to year, the spatial distributions are indicative of an overall net-positive effect of outfall discharges on mobile polychaetes;

- **Polychaeta Sedentaria (Other)** – Mean abundance of non-capitellid sedentary polychaetes was greater than the reference area mean for the majority of stations (Table 7). Stations M0, M1S, M1SE, M1SW, M8E and M8W were the only stations with a mean abundance of other sedentary polychaetes less than the reference area mean, with relative abundance ranging from 48% to 86% of reference. Although the outfall had fewer sedentary polychaetes than the reference area the difference was not significant; statistically significant differences were identified between each of the 200 m and 800 m distance groups in comparison with reference (Table 5; Figure 8m). The reduced abundances at M0 observed in 2010 and 2009 are not typical of other monitoring events in the last decade, as abundances of sedentary polychaetes have historically been close to reference or somewhat higher than reference. The correlation between abundance of other sedentary polychaetes and distance from the outfall was not significant. Abundance in the far-field distance-direction group was statistically significantly higher than the reference area, however the correlation between abundance and distance-direction groups was not statistically significant (Table 6). In terms of broad spatial patterns, sedentary polychaetes appear to fall into either Pattern B2 or Pattern C in 2010, because abundances were lower in some near-field stations, but reach a maximum in mid-field and far-field stations. In 2009, a Pattern B response was identified (net-positive), and in 2008, a Pattern A response was observed. Therefore, the last few years have exhibited a gradual change in spatial profile of sedentary polychaete abundances, with weakening of the previously observed net-positive response profile;

- **Polychaeta sedentaria (*Capitella capitata* complex)** – *Capitella* individuals were not identified in any of the five reference stations or in Stations M2N, M4SW, or M8W, and as a result, percent of reference could not be calculated (Table 7). As expected, the highest mean *Capitella* individuals were observed at the outfall station and in stations included in the near-field group (*i.e.*, M1E, M1SE and M2SE) that are in the region of greatest influence of the outfall discharge (*i.e.*, south and east of the outfall, following the direction of prevailing currents). This spatial pattern is consistent with the distribution of enhanced polychaete abundance and marginally reduced taxonomic richness described above. A strong and significant negative correlation (r_s = -0.76; Table 5) was observed between *Capitella* abundance and distance from the outfall, indicating that abundance counts of this taxon decreased with increasing distance from the outfall (Figure 8n). All distance-direction groups were significantly different from the reference area, and the correlation between *Capitella* abundance and distance-direction was strong and negative (r_s = -0.86; Table 6). Similar to previous years, *Capitella* clearly conform to Pattern A (most abundant near the outfall terminus, with abundances declining with distance [or distance-direction] from outfall); and

- **Miscellaneous taxa** – Mean abundance of miscellaneous taxa was less than the reference area mean at 21 of the 23 outfall monitoring stations, which ranged from 2% to 60% of reference. Mean abundance of miscellaneous taxa at Stations M0 and M8W were greater than the reference area mean, with abundances of 681% and 157% of reference, respectively. The outfall station was identified as having a significantly greater abundance of miscellaneous taxa relative to reference (Table 5; Figure 8o), but the correlation between abundance of miscellaneous taxa and distance from the outfall was significant and positive but weak in magnitude (r_s = 0.32; Table 5). Abundances of miscellaneous taxa were significantly lower in all of the distance groups and distance-direction groups relative to reference area. The correlation between abundance of miscellaneous taxa and distance-direction was significant and positive but weak in magnitude (r_s = 0.33; Table 6). The relatively high abundances at Station M0 suggest that the outfall terminus may provide habitat for specialized organisms that are suited to organically-enhanced sediments and the substrate/habitat conditions found at M0. Apart from this localized phenomenon, there are few strong trends in the abundances of miscellaneous taxa.

3.2.6 Multivariate Profiling

Non-metric multidimensional scaling (NMDS) was performed using the nine major taxonomic groups discussed above. The objectives of this exercise were to:

- Assess the spatial distribution of recently added reference stations (PB4 and PB5, introduced in 2005) in comparison to the other reference stations (PB1 through PB3); and
- Investigate the spatial distribution of monitoring stations based on the 2010 benthic data.

These results differ from those discussed in Section 3.1 in that the latter were based on three combined years of monitoring data, whereas the former are specific to the 2010 monitoring event. Two dimensions were derived from the 2010 benthic community data, which together accounted for 93% of the variance in the original nine variables. NMDS dimension 1 (Benthic Dim 1) was strongly negatively correlated with the polychaete *Capitella capitata* complex (r_s = -0.95) and negatively correlated with mobile polychaetes (r_s = -0.39) (Table 8). In addition, Benthic Dim 1 was significantly positively correlated with echinoderms (r_s = 0.44), bivalves (r_s = 0.55), gastropods (r_s = 0.78), non-amphipod crustaceans (r_s = 0.60), and miscellaneous taxa (r_s = 0.50) (Table 8). Therefore, Benthic Dim1 can be considered a general measure of the abundance of several major taxa, in particular the sedentary polychaete *Capitella capitata* complex; as Benthic Dim1 scores increase, abundances of capitellids decrease and the abundances of non-polychaete taxa (*e.g.*, bivalves, gastropods and amphipods) increase. NMDS dimension 2 (Benthic Dim 2) exhibited a strongly significant negative correlation with abundances of miscellaneous taxa (r_s = -0.73) and non-amphipod crustaceans (r_s = -0.71), and was also significantly negatively correlated to amphipod crustaceans (r_s = -0.56) (Table 8).

A plot of Benthic Dim1 against Benthic Dim2, categorized by the distance-direction groups, is presented in Figure 11. Clear separation among the distance-direction groups is visible in multivariate space, with minimal overlap occurring among groups. Similar to the 2008 and 2009 results, station M0 exhibits a clear separation from the near-field stations, suggesting that the biological assemblages are distinct from near-field stations in spite of similar levels of organic enhancement. The degree of separation between far-field and reference stations is low, indicating that some of the stations removed from the directional influence of the predominant currents (*i.e.*, outfall exposure) closely resemble the reference stations in term of benthic composition.

A spatial gradient is apparent along Dim 1, with near-field stations falling on the left and far-field and reference stations occupying the right portion of the plot. The spatial trend in Dim 1 scores is associated with the relative abundances of the polychaete *Capitella capitata* and non-polychaete taxa (especially gastropods), which exhibit significant monotonic increases (gastropods) and decreases (*Capitella*) with distance from the outfall.

Additional variability among distance-direction groups is apparent along Dim 2. In general, Dim 2 scores are highest for the near-field, mid-field and far-field groups and lowest at M0 stations. Dim 2 was significantly associated with abundances of crustaceans (both amphipods and other Crustacea) and miscellaneous taxa. These individual taxa groups all exhibited a similar spatial pattern (Figure 8), with high abundances near the outfall terminus, declining with distance [or distance-direction] from the Macaulay Point outfall.

Statistical comparisons of benthic community structure were conducted using Benthic Dim 1 and Dim 2 scores as the parameters of interest and station grouping (both distance groupings and distance-direction groupings) as the treatment (Tables 5 and 6). NMDS scores were not normally distributed within the traditional distance groups. Benthic Dim 1 scores were also not normally distributed within the distance-direction groups but Benthic Dim 2 scores were normally distributed. Non-parametric methods (*i.e.*, Kruskal-Wallis test and Mann-Whitney multiple comparisons) were used for station grouping comparisons of non-normal parameters, whereas normally distributed parameters were analyzed using parametric methods (*i.e.*, ANOVA and Dunnett's *post hoc* test):

- **Distance-based Groups** – Significant differences ($p < 0.05$) were identified between each of the outfall and all distance groups relative to the reference stations for Benthic Dim 1 (Table 5). Figure 12 (top right panel) shows that Dim1 scores are lowest at M0 and increase with distance from the outfall, a reversal of the pattern displayed by the polychaete *Capitella capitata*, which was strongly negatively correlated to Dim 1. Dim 1 scores were significantly positively correlated with distance from the outfall ($r_s = 0.77$). Dim 2 scores were significantly different ($p < 0.01$) at the outfall and 100 m distance groups compared to reference stations; Dim 2 scores at the outfall terminus (M0) were significantly lower than those at the reference stations, with significantly higher values present at 100 m stations. The spatial distribution of Benthic Dim 2 scores follows Pattern C which exhibits a low abundance in the vicinity of the outfall but rapidly plateaus to reference levels in the near-field; and

- **Distance-direction Groups** – Significant differences ($p < 0.01$) in Benthic Dim1 scores were identified between each of the outfall, near-field, mid-field and far-field groups in comparison with the reference area. Figure 12 (top left panel) shows that Dim1 scores were lower at the near-field stations compared with the outfall stations, but outfall stations were lower than mid-field stations, with a pronounced increase from mid-field to far-field to reference (in that order). Dim 1 scores were strongly and significantly positively correlated with distance-direction from the outfall ($r_s = 0.90$). Dim 2 scores were significantly lower at outfall stations and significantly higher at mid-field stations relative to reference; the correlation between Benthic Dim 2 scores and distance-direction was not significant.

3.2.7 Assessment of Individual Taxa

As documented in Sections 3.2.5 and 3.2.6, the spatial response to outfall-related exposure varies significantly depending on the taxonomic group. In this section, the benthic enumerations were investigated in more detail to identify spatial trends taxa identified to lowest practical taxonomic level.

In the 2010 data, fifty-eight (58) individual taxa were identified as having a study area wide abundance of greater than 100 organisms. The distribution patterns of these individual taxa are summarized in Table 9, and distance and distance-direction-based plots for commonly observed taxa are presented in Appendix B. Individual taxa were classified into one of six distributional patterns (Figure 4), consistent with the evaluation of 2007, 2008 and 2009 data.

3.2.7.1 General Interpretation of Patterns

From the distribution of taxa among the seven distributional patterns described in Section 2.4.7, it is evident that proximity to the wastewater outfall terminus does not correspond to uniform changes to abundances of invertebrates. Instead, the spatial response is highly species-specific. The observed benthic trends depend on the life-history and preferences of the organisms, the magnitude of the outfall-related disturbance, the sensitivity of the organisms in question, and other confounding factors (natural disturbances, substrate type, *etc.*). Although some taxa appear to respond positively to conditions at or adjacent to the outfall (which include greater exposure to wastewater influence and associated organic matter), other taxa respond adversely (*i.e.*, cannot survive and/or are out-competed), and some taxa exhibit more complex responses.

Section 2.4.7 summarizes the narrative interpretations for each of the seven distributional patterns. Each pattern conveys a different interpretation with respect to whether the response is net positive (beneficial) or net negative (degraded) relative to background, and responses may also depend on the proximity to the contamination source. For example, Pattern C is indicative of a response that is impaired near the outfall, and neutral for remaining outfall monitoring stations. A summary of the net environmental response typical for each pattern and distance group is tabulated below:

Pattern	Outfall/Near-Field	Mid-Field	Far-Field	Net Response
A	⬆	⬆	⇧	⬆
B1	• / ⇩	⇧ / ⬆	⇧ / ⬆	⇧
B2	⇩ / ⬇	• / ⇧	⇧ / ⬆	• /⇧
C	⬇	•	•	⇩
D	⬇	⇩	• / ⇩	⇩ /⬇
E	⬇	⬇	⇩ / ⬇	⬇
F	•	•	•	•

Symbols represent pattern of abundance by station-group (normalized to reference):
⬆ pronounced increase; ⬇ pronounced decrease; ⇧ moderate increase; ⇩ moderate decrease; • no clear trend identified

Three of the patterns (A, B1, B2) are net positive (beneficial), because they result in overall increased abundance of an organism across the study area. Three patterns (C, D, E) are considered net negative (adverse), although the adverse responses of pattern C are spatially localized. The sixth pattern (F) is considered net neutral.

3.2.7.2 Distance-Based Groups

By comparing the numbers of taxa that correspond to each type of spatial trend (Appendix B), some inferences regarding the influence of the wastewater discharge can be made. When data are categorized based on distance from the outfall, Pattern A (11 species) is one of the most readily identifiable patterns, representing the taxa that respond most favourably to wastewater exposures.

Patterns B1 (6 species) and B2 (12 species) collectively form the most common spatial pattern, and follows a "hump-shaped" pattern consistent with the model of organic carbon enhancement discussed by Pearson and Rosenberg (1978) and Nilsson and Rosenberg (2000). As depicted in Figure 5, the disturbance-gradient model predicts that at high levels of disturbance, reductions in species abundance are common. However, at low to intermediate levels of disturbance, particularly in the case of enhanced organic carbon loadings, there are often increases in benthic abundance. In the context of the Macaulay Point wastewater discharges, such an intermediate level of disturbance is found where the benefits of organic carbon contributions (*e.g.*, increased food supply) outweigh the potential negative aspects (*e.g.*, contaminant responses or modification of substrate). The site-specific data suggest that for many taxa, net positive effects are observed at intermediate distances from the outfall, but not at stations immediately adjacent to the outfall terminus.

Patterns C, D, and E represent indications of adverse responses of taxa to outfall influence. Pattern E (4 species) represents the taxa that appear most poorly suited to the influence of the discharges. Pattern D (11 taxa) also provides a profile suggestive of organism sensitivity to proximity to wastewater influence; for these taxa the abundances increase as exposures to wastewater discharges decrease. This pattern may be due to factors associated with wastewater discharge, although other factors such as substrate type may also be important. Pattern C (9 taxa) provides a profile suggestive of localized alterations only; outside the near-field area the pattern suggests no response (negative or positive) to distance-related factors (whether outfall-related or not).

The distance-based analysis indicate 29 taxa that respond net positively to proximity to outfall, and 24 taxa that respond net negatively. Of the negative responses, 15 of 24 of the affected species were affected over a large spatial range; the remaining taxa (Pattern C) were affected only within 200 metres of the outfall M0. More than half of the positive responses (18 of 29) reflected the response of taxa to a moderate enhancement of organic matter, in which increases in organism abundance occurred at intermediate distance stations. The remaining positive responses reflected a more pronounced positive response to organic matter enhancement, with elevated abundance near the outfall and decreasing abundance with distance from the outfall. Five additional taxa showed an unclear pattern or no linkage between abundance and proximity to the outfall.

3.2.7.3 Distance-Plus-Direction Based Groups

When data are categorized based on distance-direction groups, Pattern D (14 taxa) represents the most common spatial pattern, indicating that these taxa are negatively influenced by the outfall. The distance-plus-direction groups showed a higher number of strong negative effects (Pattern E; 8 taxa) relative to the distance only groups (4 taxa). An additional 8 taxa responded negatively within close proximity to the outfall (Pattern C). Of the net positive spatial trends, Pattern A (10 taxa) represents the most common when data are categorized based on distance-plus-direction groups, which is similar to observations of distance only groups (11 taxa). The number of species that are represented by Pattern B1 are similar when grouped by distance (6 taxa) and distance-direction (5 taxa), however the positive influence of outfall exposure at intermediate distance is not as evident when data is categorized based on distance-direction groups, owing largely to the decrease in taxa exhibiting Pattern B2 (8 taxa) compared with distance groups (12 taxa).

The distance-direction analysis indicates 23 taxa that respond net positively to proximity to the outfall, and 30 taxa that respond net negatively. Of the negative responses, most of the affected species (22 of 30) are affected over a large spatial range; the eight remaining taxa (Pattern C) were affected only in the near-field area. Five (5) taxa showed an unclear pattern or no linkage between abundance and proximity to the outfall.

3.2.7.4 Summary

Overall, the analyses of individual taxa in 2010 are similar to those identified in recent years and suggest a pattern of moderate biological alteration, with the nature of disturbance depending on the proximity to the outfall terminus and on the tolerance and feeding preferences of the individual taxa. Most species exhibit significant spatial trends, largely dependent on their tolerance to the organic carbon and modified substrate caused by deposition of sediment particles. The numbers of net positive and net negative responses were approximately equal, such that a reduction in the abundance of any given species is generally compensated by an increase in another species.

The ratio of net positive to net negative responses was similar among 2010, 2009 and 2008 sampling events when the patterns were evaluated using distance-based analyses. Specifically the ratios of positive to negative responses were: 24:22 in 2008; 28:26 in 2009; and, 29:24 in the 2010 sampling event. However, the ratios differed somewhat when the patterns were evaluated using distance-direction analyses. The ratios of positive to negative patterns were: 22:26 in 2008; 27:22 in 2009; and, 23:30 in the 2010 monitoring event.

Also the ratios between positive to negative responses have remained relatively stable over time, the 2010 data indicated some changes to the general "hump-shaped" Pattern B relative to previous sampling events. Specifically, whereas the peak abundances at mid-field stations have been maintained, the abundances at M0 were often very low. Pattern B2 reflects this response in which the net response over the entire study area is positive, but such occurs in spite of localized impairment close to the outfall. The B2 profile is less desirable than B1 in terms of overall benthic health, and as such the 2010 benthic community data reflect a deterioration relative to the 2009 sampling data.

Observation of benthic alteration does not equate with ecological degradation; the ecological consequences of changes depend on the types and magnitude of changes and their relevance to ecological function in the benthic community. The individual taxa collectively suggest the following:

- M0 and Near-field – For many organisms, abundances are very low at M0, and often the abundances are also lower at other nearby stations. The combination of patterns for individual taxa indicates a moderate to high level of benthic impairment (*i.e.*, at the Stage 0/1 boundary on Figure 5). This marks a change from several previous monitoring events, wherein the near-field responses were categorized by a typical Stage 1 profile rather than Stage 0/1. In the 2010 data set, the benefits of supplementation of some species are offset by the loss of others, resulting in reduced taxonomic richness, reduced representation of some major taxonomic groups, and adverse responses to some species. Although some taxa are enhanced in the near vicinity of the outfall, particularly capitellids, other taxa are adversely affected. In 2010, the response at M0 was more pronounced than has been observed in several other recent monitoring events, with a high total abundance owing to an increase in the abundance of *Capitella capitata* complex;
- Mid-field – Several organisms indicate positive responses to outfall exposure; however there are an approximately equal number that indicate negative responses. This marks a change from several recent monitoring events that indicated a net-positive response for mid-field stations. On balance, the mid-field zone in 2010 exhibited either a neutral or a slightly net-negative biological response to the outfall (Figure 10). The total abundances are similar to reference, with representation of all major taxonomic groups; however there is a small shift in the composition of the community, with fewer bivalves, crustaceans and gastropods, and greater numbers of opportunistic taxa, such as the capitellid polychaetes; and

- Far-field – At distance from the outfall, the combination of biological responses translates to a neutral or net-positive response because some of the taxa are either enhanced in these areas or similar to reference. In these areas, enhancement of organism abundances does not come at the expense of reduced taxonomic richness (Figure 10).

The exact causal factors responsible for the reductions in abundances of some common taxa at the outfall terminus (as indicated by Patterns C, D, and E) are not known. However, the effect on sensitive species is sufficiently large in the near-field region that a moderate effect on taxonomic richness is observed. The magnitude of this response has fluctuated among annual monitoring events, although the response size observed at the outfall in 2009, and to a lesser extent 2010, is greater than observed in other recent monitoring events. The localized depression in richness is the last two years is larger in magnitude than in any other monitoring event in the last decade.

3.2.8 Relationships between Biology Parameters and Sediment Variables

Sediment chemistry data are summarized in Table 10. Table 11 presents the results of rank correlations between 2010 biological metrics and sediment variables. For organic parameters (*i.e.*, PAHs), correlations were repeated with organic carbon (OC) normalized concentrations, to take into account spatial variations in TOC. Rank correlations provide a measure of statistical association, but do not provide evidence of cause-effect relationships.

3.2.8.1 Substances of Interest

Results of the correlation analysis included:

- Similar to the previous few years of monitoring data, total abundance of organisms did not correlate well with the sediment SOIs. None of the SOIs exhibited significant correlations with total abundance in 2010, matching the 2009 results. In 2007 and 2008, only one parameter was found to correlate with total abundance (arsenic in 2008 and manganese in 2007);
- Total richness was significantly negatively correlated with all of the metals (except aluminum, chromium and nickel), total phenols, and 12 of 13 of the individual PAHs. Significant correlations were generally moderate in strength (r_s values ranging from -0.43 to -0.73). Among the SOIs, the strongest negative correlations were observed for the priority metals antimony (r_s = -0.73), cadmium (r_s = -0.68), mercury (r_s = -0.73) and silver (r_s = -0.68). In 2008 and 2009, significant negative correlations were observed for several metals and for most or all of the PAHs;
- The number of significant correlations of both the standard and regional Infaunal Trophic Index (ITI) results was similar to those for total richness. ITI (both standard and regional versions of the metric) was significantly negatively correlated with 11 of 13 metals, total phenols, and 12 of 13 of the individual PAHs. In all cases with significant correlations, the regional ITI was more strongly correlated with the sediment SOIs. The Swartz Dominance Index (SDI) was significantly negatively correlated to 8 of 13 metals, total phenols, and 3 of 13 PAHs, with significant correlation coefficients ranging from -0.38 to -0.63. The magnitude of the correlations observed between ITI (standard) and SDI and the SOIs are similar in 2010 to those observed in the previous year;

- Several significant positive correlations were observed between polychaete abundances (total polychaetes, mobile polychaetes and *Capitella capitata* complex) and SOIs. Significant correlations for at least one of the polychaete parameters were observed for all SOIs with the exception of aluminum and chromium. The strongest correlations were observed for *Capitella capitella* complex (23 SOIs with $r_s > 0.6$). No significant correlations were observed between the non-capitellid sedentary polychaetes and SOIs in 2010, which was also observed in the previous assessment;

- Significant negative correlations were observed between bivalve abundances and most of the metals (10 of 13) and PAHs (12 of 13) with r_s values ranging from -0.40 (nickel) to -0.74 (selenium). These results are similar to those observed in 2009 but differ from 2008, when only a few metals exhibited significant correlations and most of the individual PAHs did not exhibit significant correlations. Correlations between bivalve abundance and SOIs for the 2008 data were mostly negative; however, fewer correlations were significant, indicating an increase in the magnitude of the relationship between these parameters in the last two monitoring events;

- Some negative correlations were observed between abundances of echinoderms, gastropods, and non-amphipod crustaceans and the concentrations of SOIs in sediment. For echinoderms, significant correlations were identified for four of the metals (r_s of -0.50 to -0.73), total phenols, and three PAHs (r_s of -0.39 to -0.53). Gastropods exhibited significant negative correlations with all SOIs (r_s of -0.55 to 0.92), with the exception of aluminum, chromium, and 2-methylnapthelene. This differs considerably from 2009 when only lead (r_s = -0.49) and phenol (r_s = -0.45) were significantly correlated with gastropod abundance. Non-amphipod crustaceans were negatively correlated to all metals (r_s of -0.41 to -0.68) except aluminum and chromium, and 9 of 13 PAHs (r_s of -0.39 to -0.77). In 2009, non amphipod crustaceans were negatively correlated to antimony (r_s of -0.54) and 2 methylnaphthalene (r_s = -0.43) only. Thus the number and magnitude of significant correlations for these groups was generally higher than those observed in 2009;

- The magnitudes of correlations were similar for many of the SOI groups (*i.e.*, among PAHs and among several metals including arsenic, cadmium, copper, mercury and zinc). This indicates high covariation in the spatial distributions of the contaminants. Due to this covariation, it is difficult, if not impossible, to discern the potential causal agent(s) responsible for the changes in the biological trends using only a simple empirical correlation analysis. Furthermore, the correlations of most biological metrics with TOC and particle size parameters were very strong (discussed further in the following section), such that the influence of physical and habitat factors cannot be distinguished from possible SOI effects on the benthic communities;

- OC-normalized PAH concentrations in sediment generally exhibited weaker correlations with biological parameters than the dry weight concentrations, and the frequency of significant correlations was reduced when data were OC-normalized. The absolute magnitudes of the decreases in correlation strength were relatively small, indicating that differences in sediment OC content have some influence on the correlation results but only partially explain the relationships observed using dry-weight sediment concentrations; and

- In general, correlation results are similar to those in recent sampling years. In 2010, the strongest positive correlations were observed between the capitellid polychaetes and SOI concentrations in sediment and the strongest negative correlations were observed between ITI and SOI concentrations.

3.2.8.2 Substrate Effects (TOC and Particle Size)

Statistical (*i.e.*, Spearman rank correlations and ANOVA comparisons) and graphical analyses were used to explore the effect of substrate type (*i.e.*, organic carbon content and particle size) on the spatial distribution of the benthic community parameters.

Total organic carbon (TOC) was positively correlated to total polychaete abundance (r_s = 0.68), mobile polychaetes (r_s = 0.49) and *Capitella capitata* abundance (r_s = 0.77), and negatively correlated to ITI (r_s of -0.61 and -0.80 for standard and regional, respectively) and richness (r_s = -0.64) metrics (Table 11). Abundances of bivalves, echinoderms, gastropods, non-amphipod crustaceans and miscellaneous taxa were also negatively correlated to TOC. These broad findings are similar to the previous investigation; however, more significant correlations were observed in 2010 relative to previous years, and SDI was not significantly correlated to TOC (statistical significance was marginal for SDI). As in 2008 and 2009, total abundance did not correlate strongly with TOC, mainly because the major components of abundance exhibited trends in opposite directions (which cancelled each other out). This is observed in Figure 10, which shows that the distribution of total abundance changes between near-field and far-field stations, whereas the total numbers of organisms remain similar.

As with previous investigations, TOC concentrations were generally higher near the outfall (M0 and near-field) and lowest at the reference stations (Figure 13). Figure 14 illustrates the distribution of TOC among individual stations. At 2.5%, the TOC concentration at station M0 in 2010 was slightly higher than that observed in 2009 (2.0%) and equal to the TOC observed in 2008, but was elevated in comparison to far-field and reference stations. The highest individual TOC concentrations were measured at stations M2W (9.4%), followed by M1SW and M2NE (3.8%). In the previous assessment, TOC was an order of magnitude lower at station M2W (0.97% in 2009), and was also lower at stations M1SW and M2NE (1.7% and 2.0%, respectively). This demonstrates the small-scale variability in TOC concentrations over space and time. Significant differences relative to reference were identified for each of the 100 m and 200 m distance groups, and for each of the mid-field and far-field distance-direction groups (Table 5 and Table 6). These findings are consistent with the historically-observed trend in organic enhancement with distance and direction from the outfall. In 2010, polychaete abundance mirrored the spatial trend in TOC with decreasing abundances with increasing distance from outfall and distance-direction group (Figure 13). Although this pattern was not as strong as was observed in 2009, it has been consistently observed, and is believed to represent the strong adaptation of polychaetes to sediments that have been influenced by an increased food supply. ITI (standard and regional) followed an inverse trend to TOC, increasing with increasing distance (and distance-direction) from the outfall. These results confirm the importance of organic matter to polychaete abundance and ITI values across the study area. However, Figure 13 shows that the responses in the outfall and near-field zones cannot be explained on the basis of TOC alone. For example, TOC concentrations were greater at the near-field stations relative to M0, yet station M0 showed the greatest impairment in terms of low ITI (standard) values and richness compared to the other near-field stations. This observation suggests that TOC is not the only controlling factor and that other physical, biological, or chemical factors associated with wastewater releases are influencing the benthic community assemblages.

Figure 15 illustrates the distribution of percent gravel relative to individual stations. The highest gravel contents were observed at the outfall terminus station (M0; 19%) and at the near-field station M1SE (10%). Gravel content at the two remaining near-field stations M1E and M2SE was 3.2% and 4.4%, respectively. Percent gravel was positively correlated with polychaete abundance (r_s = 0.46) and *Capitella capitata* abundance

(r_s = 0.52), and negatively correlated to ITI (standard and regional) and richness metrics (Table 11). Percent gravel is also negatively correlated to abundances of bivalves, gastropods, non-amphipod crustaceans and miscellaneous taxa. This relationship is driven by the presence of elevated gravel content both at the outfall terminus and in the direction of the wastewater influence (Figure 15). This pattern has also been observed in previous monitoring events, and although the physical process by which gravel content is elevated adjacent to M0 is poorly understood, the data have repeatedly indicated correlation between gravel content and distance-direction from outfall. Significant differences with reference were identified in percent gravel for the 100 m distance group and for each of the near-field and mid-field distance-direction groups (Table 5 and Table 6). No significant differences were identified among the distance groups or the distance-direction groups for percent fines.

Taxonomic richness was lower at the outfall, and in some near-field stations, relative to those at distance from the outfall (Figure 8c, Figure 9, Figure 13). Although the magnitude of the difference is not large at most stations, the region of decreased richness is coincident with sediment that contains elevated TOC and/or elevated gravel content. When compared to far-field and reference, it appears from Figure 13 that there is a moderate reduction in richness combined with no distinct change in abundance within the near-field area, concordant with the interface between Stage 1 and Stage 2 of the organic enrichment model of Nilsson and Rosenberg (2000; Figure 5). At the outfall, further reduction in richness combined with a marked increase in total abundance was observed in 2010. Accordingly, the area of greatest wastewater exposure (M0) matches the characteristics of Stage 1 of Nilsson and Rosenberg's (2000) model, which is indicative of a larger magnitude of biological disruption than Stage 2.

Figure 10 illustrates the cumulative abundance of each major taxa across distance groups and distance-direction groups. When compared to the organic enrichment model of Nilsson and Rosenberg (2000) (Figure 5), there are some indications of Stage 1 and Stage 2 conditions in near-field and outfall sediments that are indicative of pronounced environmental disturbance. The impacts were most pronounced at station M0 in 2010, with a considerable increase in the relative abundance of most taxonomic groups, particularly the polychaete *Capitella capitata*, relative to reference. The trends observed in 2010 were similar to those seen in 2008, but were more pronounced due to the greater abundance of capitellid polychaetes at the outfall. The observations at the outfall in 2010 are characteristic of Stage 1 conditions, where there was higher total abundance associated with the presence of thriving opportunistic species, but fewer species overall, and elimination of some sensitive taxa. Although, not as pronounced as at the outfall, there is evidence of modest impairment (Stage 2) in the near-field zone, with no change in overall abundance, but a relative increase in the abundance of the opportunistic *Capitella capitata*.

In stations beyond the near-field, the data generally indicate negligible to low net impairment of the benthic community. The TOC concentrations and percent gravel are slightly elevated relative to reference, but significant influence on benthic community metrics is not apparent. Figure 10 and Figure 13 indicate that in mid-field and far-field areas, overall abundances and major taxa abundances are similar to reference conditions. Taxonomic richness and ITI gradually increase with distance from the outfall. Overall, the mid-field and far-field distance groups show signs of increased community health as a result of decreased influence of the environmental disturbance, which is characteristic of late Stage 2 to Stage 3 of the organic enhancement model.

3.3 Trends in Benthic Community Parameters

3.3.1 Summary Statistics

Table 12 presents the summary statistics for the selected benthic community metrics by distance and by distance-direction from the outfall, over the relevant period of record. The computed summary statistics included means, medians, standard deviations, minima, maxima and percent of reference.

3.3.2 Spatial Trends

3.3.2.1 Spearman Rank Correlations

Distance gradients, assessed using Spearman rank correlations between each benthic community metric and distance from the outfall, are presented in Table 13. Gradients based on the distance-direction groupings were also assessed using Spearman rank correlations and are presented in Table 14. Significant correlations ($p < 0.05$) are bolded and coded based on the strength of the correlations (weak correlations are underlined ($|r_s| < 0.4$), moderate strength correlations ($0.4 < |r_s| < 0.6$) are shaded and strong correlations ($|r_s| > 0.6$) are in white text on a black background. Spearman rank correlations were calculated for all years combined (2000-2010), for recent years only (2008-2010) and for each individual year. Reference stations were included in the calculations.

3.3.2.1.1 Total Abundance and Polychaete Abundance

Both total abundance and polychaete abundance metrics exhibited significant negative correlations with distance from the outfall for all years (2000-2010 [excluding 2001]), recent years (2008-2010), and individual years up to 2005 (Table 13). After 2005, total abundance has not exhibited a significant negative relationship with distance from the outfall during each individual year. However, the negative correlation of polychaete abundance with distance appears to have become stronger in the last five years (r_s > -0.72 from 2006-2010). Correlations between polychaete abundance and distance were stronger than those for total abundance, and were stronger in 2008-2010 (r_s = -0.73) than in 2000-2010 (r_s = -0.57). The highest correlation was observed between polychaete abundance and distance in the year 2009, with a correlation coefficient (r_s) of -0.79.

Correlations between total abundance and distance-direction were weaker than for distance alone, with an r_s of -0.23 for 2000-2010, compared to an r_s = -0.36 for distance alone. From 2003 to 2010, correlations between total abundance and distance-direction were not statistically significant, with the exception of weak correlations in 2005 and 2009 (Table 14). Polychaete abundance, however, was generally more strongly correlated to distance-direction than to distance alone. Strong negative correlations between polychaete abundance and distance-direction (r_s > 0.6) were observed in all individual years with the exception of 2004.

Overall, the above trends indicate a change in the benthic community over the last five years, with increased numbers of polychaetes observed at stations near the outfall. These increases have not been accompanied by similar increases in other taxa, however. As the correlations for polychaete abundance have strengthened, the correlations for total abundance have weakened, indicating a change to a near-field community that is more dominated by polychaetes, and with reduced diversity.

3.3.2.1.2 Richness and SDI

Total taxa richness was positively correlated to distance from the outfall for all years combined (2000-2010); however, the strength of the relationship was very weak (r_s = 0.27). From 2000 to 2006, the year 2000 was the only individual year that exhibited a significant correlation between richness and distance. Significant correlations existed between richness and distance for each individual year from 2007 to 2010, with moderate to strong correlations (r_s of 0.41 to 0.64). Swartz Dominance Index (SDI) was positively correlated with distance from the outfall, with a moderate strength correlation coefficient for all years combined (r_s = 0.58) and moderate-to-strong correlations in each individual year.

Relationships between richness distance-direction from the outfall were generally stronger than those for distance alone, although the correlation coefficient for all years combined was the same (r_s = 0.27) (Table 14). The number of significant correlations between richness and distance-direction for combined years and individual years was the same as that for richness and distance. There were fewer and generally weaker statistically significant correlations between SDI and distance-direction compared with SDI and distance, with an all years combined correlation coefficient of 0.45.

Overall, the above trends are suggestive of a change in the near-field benthic community, with movement toward a community that has lower taxonomic richness (a measure of genetic and functional diversity) and increased dominance by fewer species. Whereas the middle part of the last decade indicated relatively constant richness values across most of the study area, recent years of sampling have documented a change in richness gradients.

3.3.2.1.3 Abundances of Major Taxa

No significant correlations were observed between bivalve abundances and distance from the outfall, with the exception of one weak correlation (r_s = 0.38) in 2009 (Table 13). Similarly, there had been no significant correlations between gastropod abundances and distance in individual years until 2010, which exhibited a strong positive correlation (r_s = 0.77). Echinoderm abundance was positively correlated to distance in all years combined (r_s = 0.30) and recent years (r_s = 0.58). The correlation coefficient for recent years (2008-2010) has increased since the last trend assessment (r_s = 0.34 for 2005-2007) due to the moderate to strong significant and positive correlations in the last three years. Amphipods exhibited a weak negative correlation with distance from the outfall for all years (r_s = -0.21) and moderate negative correlations in 4 of 10 individual years (r_s ranging from -0.42 to -0.59). The abundances of non-amphipod crustaceans exhibited a weak positive correlation with distance (r_s = 0.21 for all years) and only two moderate significant correlations in individual years. Miscellaneous taxa abundances were also weakly significantly correlated to distance in all years combined (r_s = 0.15), but were not correlated in recent years. Abundances of polychaete sub-groups (*i.e.*, mobile polychaetes, sedentary polychaetes and *Capitella capitata* complex) were negatively correlated with distance from the outfall, although only capitellid polychaetes exhibited a strong correlation (r_s = -0.74). Among the three polychaete groups, capitellid polychaetes showed the strongest relationship with distance, with r_s values greater than 0.6 in all time periods. Correlations between the other two polychaete groups and distance from the outfall were weak for all years combined and in recent years, with some moderate strength correlations identified in individual years.

Relationships between the abundances of gastropods and non-amphipod crustaceans and distance-direction were similar to those for distance alone. Bivalves, however, showed a much stronger correlation with distance-direction, with moderate-to-strong positive correlations observed in all time periods (r_s ranging from

0.41 to 0.62). Echinoderm abundances exhibited no significant correlations with distance-direction in any of the individual years, although it showed a weak correlation in the 2008-2010 time period (r_s = 0.35). Relationships between polychaete groups and distance-direction were also generally stronger than for distance alone, with the strongest negative correlations observed between *Capitella* sp. and distance-direction (r_s ranging from -0.82 to -0.92 in individual years). Correlations between amphipods and distance-direction were generally slightly stronger than those for distance alone.

Overall, the above findings are indicative of relatively consistent negative correlations for taxa that are well suited to organic enhancement (such as many species of polychaetes and amphipods) but also a strengthening of the positive correlations for numerous groups of taxa. In recent years, and particularly in 2010, the spatial trends for bivalves, gastropods, non-amphipod crustaceans, and miscellaneous taxa have become more apparent. As the positive correlations for the latter organisms mean reduced abundances at stations near the outfall, these correlations are indicative of a potential impairment to the functional status of these communities.

3.3.2.2 Analysis of Variance

Prior to conducting the analysis of variance comparing distance groups (and distance-direction groups) to reference, all parameters were tested for normality (within distance and distance-direction groups) and homogeneity of variance between groups (the assumptions for ANOVA). The analysis of variance was conducted once for all years of data and once for only the three most recent years, to investigate whether trends have remained consistent in recent years. For distance groupings, none of the benthic parameters met the assumptions of ANOVA for all years combined (2000-2010) or recent years (2008-2010). For the distance-direction groupings, the logarithmic transformations of sedentary polychaete abundances were found to be normally distributed. When only recent years (2008-2010) were assessed for normality, total richness and the abundances of sedentary polychaetes and non-amphipod crustaceans (log transformed) met the assumptions for parametric analyses. All remaining parameters were analysed using non-parametric methods (*i.e.*, Kruskal-Wallis test with Mann-Whitney *post hoc* comparisons).

Results of the ANOVA (or Kruskal-Wallis) and *post hoc* multiple comparisons are presented in Tables 15 and 16. Figure 16 illustrates means and 95% CIs by distance group and by distance-direction group for each parameter.

3.3.2.2.1 Distance Groups versus Reference Stations

Most benthic community parameters exhibited significant differences among distance groups ($p < 0.05$) with the exception of bivalves and amphipods in recent years (2008-2010) (Table 15).

Post hoc comparisons for all years of data revealed that total abundance, total polychaete abundance and abundances of amphipods, crustaceans (non-amphipod), mobile polychaetes and *Capitella capitata* complex were significantly higher at all distance groups compared to reference group, with the exception of total abundance, amphipod abundance and crustacean (non-amphipod) abundance at 800 m stations, which was not significantly different from reference. A decrease in abundance from the outfall to the reference stations is apparent for all of these parameters (Figure 16). Abundances of other sedentary polychaetes were significantly higher in 100 m, 200 m and 400 m distance groups compared to the reference area, but no significant differences were observed between each of the outfall and 800 m groups and the reference area. The lack of statistical significance is likely due to the lower sample sizes and higher variability in these groups, particularly at the outfall and 800 m stations, as is evident in Figure 16.

Total richness was significantly lower at the outfall than at the reference stations, whereas richness was significantly higher at the 400 m stations compared to the reference. Figure 16 shows that average richness increases from the outfall to 800 m and then decreases slightly (to the level of the 100 m and 200 m stations) at the reference area. The results of *post hoc* comparisons also indicate that ITI (standard) and SDI values are lower at each of the outfall, 100 m and 200 m stations than at the reference stations. Figure 16 illustrates this trend, showing increasing ITI (standard) and SDI values with distance from the outfall.

Echinoderm abundance was significantly lower than reference at the outfall, 100 m and 200 m stations. Average echinoderm abundance increases from the outfall to reference, although the average abundance at the 800 m stations is slightly higher than reference (Figure 16). Bivalve and gastropod abundances both exhibited significant differences among distance groups; however only bivalve abundance at the outfall was significantly different from the reference. Figure 16 suggests a negative influence of outfall exposure to both bivalves and gastropods, but only within close proximity to the outfall.

Non-amphipod crustaceans were found to be significantly less abundant at each of the 100 m, 200 m, and 400 m distances compared to the reference stations, and significantly more abundant at the outfall compared to the reference stations. Figure 16 shows an elevated (and variable) average abundance of non-amphipod crustaceans at the outfall with a large decrease at the 100 m stations and a gradual increase from 200 m toward the reference. Abundances of miscellaneous taxa were significantly higher at the outfall compared to the reference, and significantly lower at the 100 m and 200 m stations compared to the reference area. Miscellaneous taxa display a spatial pattern similar to that of the non-amphipod crustaceans, with high and variable abundances at the outfall and slightly lower abundances at the intermediate distances compared to the reference (Figure 16). Crustaceans (amphipod and other) and miscellaneous taxa at the outfall vary dramatically from year to year (Figure 16), whereas lower but more consistent abundances are observed at the other distance groups.

Results for multiple comparisons among distance groups and the reference were similar for tests conducted using the recent data only; however, fewer significant differences were identified for some distance groups (*e.g.*, outfall and 800 m in particular). The reduction in statistical significance in recent years is likely attributable to the smaller sample sizes (especially for the outfall, with only 3 values from 2008 to 2010). Using recent data only, total abundance, bivalve and amphipod abundances were not significantly different between each of the distance groups and the reference area (Table 15). The negative influence of outfall exposure is more apparent in gastropod abundances from recent years with significantly lower averages at the outfall and 100 m stations.

3.3.2.2.2 Differences Among Distance-Direction Groups

All benthic community parameters exhibited significant differences ($p < 0.001$) among distance-direction groups in all years combined (2000-2010), and all but amphipods were significantly different for recent years only (2008-2010) (Table 16). *Post hoc* comparisons were conducted between each of outfall, near-field, mid-field and far-field versus the reference stations using all years of data (2000--2010) and once for recent years only (2008-2010).

Total abundances, polychaete abundances, and abundances of mobile polychaetes and *Capitella capitata* complex were significantly higher ($p < 0.05$) at near-field, mid-field and far-field stations relative to reference stations (Table 16). Other sedentary polychaetes were also more abundant at near-field, mid-field and far-field groups relative to reference, but were not significantly more abundant at the outfall stations. Amphipod abundances were significantly greater than reference stations at all distance-direction group stations except the near-field stations. These results are similar to those observed for the distance-only based analysis; however, Figure 16 generally shows a clearer separation between individual distance-direction groups than for the traditional distance groups.

Total richness was significantly lower ($p < 0.001$) at the outfall and near-field stations relative to reference stations (Table 16). These results are similar to those observed for the distance groups; however, a clearer separation is evident between the near-field and other distance-direction groups (Figure 16). The SDI was significantly lower at each of the outfall and distance-direction groups relative to reference. Figure 16 shows differing spatial patterns between the distance and distance-direction groupings, with the distance-direction plot displaying a clearer separation between higher SDI values in the mid-field, far-field, and reference areas. The steady increase of SDI with distance observed in the distance-based plot is likely a result of a smoothing artefact, in which stations in the 100 m and 200 m distance groups include stations that are qualitatively different. ITI (standard) values were significantly lower at each of the outfall and distance-direction groups relative to reference, which is similar to the observations for distance groups (Figure 16).

Echinoderm, bivalve and gastropod abundances exhibited a clearer spatial separation among distance-direction groups relative to the distance-only analysis (Figure 16), resulting in more statistically significant differences for the distance-direction groups (Table 16). Echinoderms were significantly less abundant at the outfall, near-field and far-field stations compared to reference stations. Bivalve abundances were significantly lower at the outfall, near-field and mid-field stations relative to reference stations, and significantly higher at far-field stations compared to reference. Gastropod abundances were significantly lower at near-field stations relative to reference stations, but there were no significant differences between any of the other distance-direction groups and the reference stations.

When grouped into distance-direction categories, non-amphipod crustaceans and miscellaneous taxa showed similar spatial patterns to those of the distance-only groupings. Miscellaneous taxa and non-amphipod crustacean abundances were statistically higher at the outfall and lower at each of the near-field, mid-field and far-field groups than at the reference stations other distance direction groups (Table 16).

Statistical comparisons among distance-direction groups using only recent data (2008-2010) yielded similar results to those using all years. Statistically significant *p*-values were generally higher (*i.e.*, lower significance) and fewer for the recent years due to reduced sample size (*i.e.*, only 3 years of data vs. 10 years). Amphipod abundances were not significantly different among distance-direction groups when only recent data was analyzed and only the outfall was statistically different to the reference for total abundances (Table 16).

3.3.3 Temporal Trends

3.3.3.1 Temporal Plots

Plots of the reference-normalized distance-group means over time for the benthic parameters are presented in Figure 17. Data from 1994, 1997 and 1999 were included in these plots; however, these were not included in the quantitative assessments provided above due to inconsistency in sampling plans (*i.e.*, number and location of stations, splitting of samples) relative to 2000-2010 data. Data from 2001 are also presented in the temporal trend graphs but were not included in the quantitative analyses, as these data were strongly influenced by the higher level of effort applied during taxonomic enumerations in this year[4]. Following 2001, the same benthic taxonomist has been contracted and methods have been standardized (*e.g.*, samples are no longer split) resulting in elimination of numerous sources of analytical variability. Some observations from the graphs include:

- In general, there is a greater temporal variability at the outfall than at any of the other distance and distance-direction groups. This is most evident for total abundance, polychaete abundance, crustaceans, miscellaneous taxa and *Capitella capitata* complex;
- The abundances of some taxa are more variable from 1994 to 1999 than in later years (*e.g.*, errant polychaetes, echinoderms, and miscellaneous taxa). At least part of this variability may be explained by the reduction in sources of analytical variability in recent sampling year;
- In the last decade, total abundance of organisms has exceeded reference levels for all distance groups and distance-direction groups. However, over the last decade, the degree to which the exposed stations exceed reference abundances has decreased. In the early 2000s, the magnitude of the difference was approximately a factor of two (for all groups except M0), but in recent years the difference has become small;
- Over the period of record, total abundance levels have been generally higher at outfall terminus compared to the remaining distances; however, a reduced relative abundance at the outfall is apparent from 2006-2009 compared to earlier years. This difference is due primarily to a general reduction in polychaete abundances, which have decreased over the last decade. However a marked increase in polychaete abundance at the outfall from 2009 to 2010 has resulted in an increase in total abundance at M0 in 2010;
- Abundance counts for echinoderms and gastropods appear to vary in a random manner over the period of record. However, the counts of these organisms in 2010 (relative to reference) are among the lowest observed over the period of record, and counts were particularly low at stations near the outfall;
- Average values for SDI and ITI (standard) are also variable, although the average outfall values are consistently lower than the rest of the distance groups and values tend to increase with distance from the outfall;
- Taxonomic richness appears to gradually decline from 2002-2010, with the outfall and near-field averages consistently lower than the rest of the distance group averages. Whereas richness at mid-field and far-field stations was greater than reference for the time period of 2002-2005, we have observed a steady decline in richness since that time, such that richness at mid-field and far-field stations is now similar to reference, but not greater;
- Small decreases in abundances of polychaetes (particularly errant species) are apparent over the last decade. *Capitella capitata* abundances have also tended to decrease with time for most of the distance groups although the pattern is more variable at the outfall. The highest *Capitella* abundances are consistently found at M0, as expected of this opportunistic species, whereas the spatial distribution of errant and non-capitellid sedentary polychaetes varies from year to year. The 2010 data mark a minor departure from recent trends in that abundances of all polychaete types at M0 increased relative to the previous year (2009);

[4] A different taxonomist was used in 2001.

- Bivalve abundances varied randomly prior to 2002, but have generally declined at all distance groups from 2002 to 2010, with the lowest abundances consistently present near the outfall (M0 and near-field stations);
- No clear temporal trends are apparent in crustacean abundance. Whereas the average abundances of most distance groups do not appear to change dramatically relative to each other, the outfall averages are extremely variable. The 2010 data indicate a return to elevated crustacean abundances at the outfall (similar to the pattern observed approximately one decade ago); however, it is unknown whether this reflects a meaningful change to the benthic community composition or merely a transient response; and
- The average abundances of miscellaneous taxa do not appear to change dramatically from 2002 to 2010 for all distance groups with the exception of the outfall, which varies substantially over time.

3.3.3.2 Spearman Rank Correlations

Temporal trends, assessed using Spearman rank correlations between each benthic community metric and year, are presented in Table 17. Significant trends are bolded and coded based on the strength of the relationship.

Significant negative trends (*i.e.*, a decrease over time) were identified for total abundance, total richness, and the abundances of echinoderms, bivalves, gastropods, crustaceans, mobile polychaetes and miscellaneous taxa, when all stations were analyzed together, although all of these relationships were quite weak, with correlation coefficients (r_s) ranging from -0.17 to -0.40 (Table 17).

When correlation coefficients were calculated for individual distance groups, stronger trends were identified for most parameters, with the strongest temporal trends occurring at the outfall (Table 17). Five strong negative temporal trends ($p < 0.05$) were identified at the outfall for total abundance, and abundances of echinoderms, bivalves, gastropods and amphipods (r_s ranging from -0.69 to -0.93). A few moderate strength significant negative trends were also observed in the 100 m distance group (total abundance, echinoderms, and gastropods), in the 200 m distance group (total abundance, total richness and echinoderms) and in the 800 m distance group (mobile polychaetes). No significant temporal trends were identified at the 400 m stations. Interestingly, there was a moderate strength positive temporal trend (*i.e.*, an increase over time) of gastropod abundance observed at reference stations.

When stations were subdivided into distance-direction groups, temporal trends were qualitatively similar to those in the distance groups, with the strongest trends appearing at near-field stations (Table 17). The observed increases in statistical significance is likely attributable to higher sample size in the near-field group (n = 30) in comparison to the outfall (n = 10) and the reduction in spatial variability within groups for some parameters. More significant correlations were identified in the near-field groups than at the outfall alone.

Results were generally similar to those from the 2007 multi-year trend assessment, including the presence of significant negative trends for total abundances, the abundances of gastropods and the strongest trends at the outfall. Some notable differences in results included:

- In the 2007 trend assessment, there were no significant temporal trends for total richness, whereas total richness was negatively significantly correlated at 100 m and 200 m from the outfall and at all distance-direction groupings in the current trend assessment. This change reflects the more pronounced decreases in richness that have been observed at near-field stations in recent years. Whereas in the middle part of the last decade, richness reductions were observed only at the outfall terminus, in the last few years the richness reductions have also been observed at several other stations within a few hundred metres of M0;

- In the current assessment there was an increase in the number of significant negative correlations (*e.g.*, echinoderms, bivalves and amphipods) at the outfall monitoring stations, compared with the 2007 trend assessment. As negative correlations indicate a decrease in biological metric over time, this is indicative of a potential worsening of environmental condition; and
- In the 2007 trend assessment, strong negative temporal trends were identified for polychaete abundances and *Capitella capitata* complex at the outfall and the near-field group, whereas negative trends were generally weaker or non-significant in the current assessment. This is likely due to the increases in *Capitella capitata* observed in recent years. There was also a general decrease in the strength of the negative temporal trends observed in mobile polychaetes in the current trend assessment compared with 2007. The changes indicate a potential trend toward benthic communities that are more dominated by polychaete taxa.

3.3.3.3 Homogeneity of Trends

The results of the van Belle test for benthic community parameters at Macaulay Point stations are presented in Table 18. Separate van Belle test statistics were calculated once for all monitoring stations combined (including reference) and once for all stations excluding references. A comparison of the results of these two analyses was intended to assess the extent to which any significant heterogeneity identified by the van Belle tests was due to:

- Differences between reference stations and the other distance groups (*i.e.*, potentially indicating regional-scale variability in trends); or
- Differences among the non-reference distance groups (*i.e.*, potentially indicating local scale variability in trends with distance from the outfall).

A significant test statistic was identified when all stations were included for total richness and abundance of gastropods. This result indicates that for these two benthic community metrics, trends over time differed significantly among at least two individual stations. When reference stations were excluded from the analysis, only gastropod abundance indicated a significant difference in temporal trends among the outfall monitoring stations.

3.3.3.4 Regional Patterns

The localized benthic community health declines observed at some stations in recent years are not concurrent with results from other monitoring components for the Macaulay Point wastewater discharges, including sediment chemistry or wastewater chemistry. As such, the declines could partly be attributable to factors other than the outfall, such as climate shifts, carbonate cycle shifts, dissolved oxygen profiles, or pH shifts. To explore the potential influence of broad scale (regional) factors in influencing the benthic communities, the patterns of variation in the reference station assemblages over time were explored.

Potential Significance of Reference Alterations

Regional changes in benthic communities over time could influence the trend assessment:

- If additional variation in benthic communities is introduced by factors unrelated to the outfall discharges, such variation may obscure or confound the assessment of the wastewater influence.
- If the reference station communities are changing substantially over time, comparisons of outfall monitoring stations to reference conditions would be more difficult to interpret in the temporal trend assessments. Assessment of time trends requires the assumption that physical and oceanographic factors influencing the reference conditions affect the outfall monitoring stations in similar ways.

Other jurisdictions in the Georgia Basin and Puget Sound have observed changes in background benthic invertebrate communities in recent years. For example:

- The Washington Department of Ecology (2011) observed increases in incidence and spatial extent of adversely affected benthos in the last decade, with deterioration in the mid to outer portions of the bays (Elliott Bay and Commencement Bay) at distance from point sources of contamination.
- Ecostat Research Ltd. (2011) has documented recent declines in benthic community parameters in the Strait of Georgia. Although a conclusive explanation was not provided, further research is exploring regional carbonate budgets and shifts in dissolved oxygen and pH.

Recent research has investigated potential causes for natural shifts in biological assemblages over time. Glover *et al* (2010) evaluated evidence for these inter-annual to decadal-scale changes in biologically driven, sedimented, deep-sea ecosystems, and concluded have evidence for a linkage to climate change was apparent in some, but not all, communities. The changes result not from direct influence of temperature, but rather from changes in water quality parameters that are linked to temperature. Vaquer-Suner and Duarte (2011) observed that drops in dissolved oxygen content (hypoxia), along with other related environmental factors such as presence of sulphide, hypercapnia, increased carbon dioxide, and low pH (acidification of ocean waters) can adversely affect marine life.

The CSAS (2011) has evaluated biological changes in the Strait of Georgia, and has documented decreased abundance of zooplankton concurrent with warming of the waters and lowering of the concentration of oxygen in the deep water. BC Environment (2012) has also considered the potential influence of climate change on background benthic community conditions in the Georgia Basin, concluding that:

> *Impacts related to climate changes that will drive benthic communities in this reserve include increased ocean temperature, decreased pH, altered coastal hydrology (rainfall and peak hydrograph patterns) and increased sedimentation due to sea level rise and increased storm activity. Temperature, pH and sedimentation rates directly influence benthic community structure while coastal hydrology and storm activity influences primary productivity patterns which, through food webs, will influence benthic communities. The benthic species response to these changes is not well understood, though the changing environmental conditions will favour those species that can adapt to higher sedimentation rates, lower pH, and greater variability in food availability.*

Nichols (2003) also evaluated benthos in central Puget Sound over a long term monitoring program, and observed that measures of species composition (*e.g*., similarity, diversity) indicated a subtle, gradual change in the community over time. However, no specific environmental factors were observed that would explain these changes, partly due to lack of understanding of possible linkages between climate regime shifts and fluctuations in local biological populations.

Evidence for Regional Alteration in Victoria Bight

Figure 19 depicts the long-term temporal trends in benthic metrics related to the variation of organisms found in reference site (Parry Bay) samples (*i.e*., richness and dominance indices). Recent monitoring years have remained within the historical range of values for these metrics, with no strong indications of a declining trend. The Swartz Dominance Index values over the last 5 years were slightly lower than the long term average, but the magnitude of the change is small and could simply represent interannual variation. Furthermore, the taxa richness values in recent years fall in the middle of the historical data distribution.

Figure 20 depicts the long-term temporal trends in benthic metrics related to the abundances of major organism types (plus cumulative abundance of taxa). In 2009 and 2010, the pattern of total abundances at Parry Bay stations different from other studies conducted in the last decade, and returned to a pattern more consistent with the earlier part of the record (1994-2000). Some differences in these patterns include:

- Increased total abundance; and
- Increased numbers of non-amphipod crustaceans, bivalves, and gastropods.

Because the reference communities contained higher number of certain taxa, there was potential for reduced values of reference-normalized abundances at outfall monitoring stations. However, it is unlikely that these differences would explain the localized benthic community health declines observed in recent sampling years, for several reasons:

- Changes to the regional benthic communities from climate change or other environmental factors would be expect to influence all stations, not a small subset of stations;
- The magnitude of change to reference conditions in the last two years was small in percentage terms; and
- Declines in benthic community parameters were observed for metrics that have remained stable at reference sites over the monitoring period.

In conclusion, while we cannot entirely discount the potential effect of regional-scale changes in benthic communities over time, such changes do not appear to have occurred to a degree that would significantly influence the interpretation of results from the Macaulay Point benthic monitoring program.

4.0 DISCUSSION

4.1 2010 Benthic Community

The evaluation of 2010 benthic community data suggests that broad spatial trends in 2010 were qualitatively similar to other recent years (*i.e.*, 2002 through 2009). The summary metrics (total abundance, ITI, SDI, *etc.*) yielded similar numbers to previous years across most of the site, and many patterns related to proximity to the outfall were reconfirmed in 2010. However, more detailed analysis of the 2010 data identified a number of deviations relative to other recent monitoring events.

The most significant of the differences relative to previous monitoring years included:

- **Flat spatial response for organism abundance** – As has been observed in most other recent years, the total organism abundance at the M0 station was significantly elevated relative to other outfall monitoring stations. However, unlike previous monitoring events, the pattern of organism abundance was very weak for other distance and distance-direction groups. Whereas most other monitoring events have yielded a clear spatial trend of declining total abundance with distance from the outfall, the spatial pattern in 2010 was weaker than all other monitoring events in the 2000s decade. In 2010, M0 exhibited a high total abundance due to the dominance of *Capitella capitata*, but stations close to the outfall had abundances that were not significantly different from the reference. Earlier in the 2000s decade, the increased abundance of TOC-tolerant species compensated for slightly lower abundances of some taxonomic groups (*e.g.*, bivalves, gastropods). In the last three years, however, and particularly in 2010, the increases in a few taxonomic groups have not been sufficient to outweigh the reductions of other taxa at some stations close to the outfall;
- **Altered pattern of impairment at M0** – The benthic communities at M0 have exhibited substantial interannual variability, and 2010 was no exception. In 2010, as in previous monitoring events, station M0 exhibited a modified benthic community, with elevated total abundance but reduced richness and lower abundances of several major taxonomic groups. The increased abundance in 2010 relative to 2009 is attributed in large part to the contribution of *Capitella*, but also to increased abundances of crustaceans and miscellaneous taxa (Figure 10). In 2009, total abundance was similar to other outfall monitoring stations (no enhancement as with previous years), and the composition of the community was less diverse than in 2010. The combination of low abundances for most taxa and the dominance of the *Capitella* group had resulted in increased impairment of benthic community health in 2009, as indicated by metrics such as richness, SDI, and ITI. In 2010, the community health metrics had marginally increased at the outfall, which may be a result of increased abundances of capitellids, crustaceans and miscellaneous taxa. In years previous to 2009, most taxonomic groups were reasonably well represented at M0, with suppression of only some specific taxa that were less suited to conditions of organic enrichment. The results from 2010 are intermediate between data from 2009 and previous years, with a marginal improvement of community health compared with 2009, but greater impairment relative to most monitoring events conducted over the last decade;
- **Separation of M0 from near-field group** – Related to the findings above, the 2010 data confirmed the findings from 2008 and 2009 that M0 no longer groups strongly with the other near-field stations. In the last three years, the multivariate profiling of the benthic community, combined with the univariate assessments, strongly indicated that the biological assemblages sampled at M0 differed from those at near-field stations

M1E, M1SE, and M2SE. The pattern observed in the last three years contrasts with earlier investigations which indicated greater correspondence of M0 with other near-field stations. The separation is not explainable on the basis of only organic carbon or particle size differences. It is possible that concentrations of substances of concern are responsible for the observed pattern, but the constituent(s) influencing biology are difficult to discern given the high inter-correlations among substances of concern;

- **Broader richness response** – In most monitoring events conducted over the last decade, reduced richness relative to reference has been quite limited in spatial extent, generally limited to outfall and near-field stations. However, recent monitoring events have suggested a change in the distribution of reduced richness values, along with other metrics that measure biological diversity. In 2008, some of the mid-field stations exhibited lower richness values, and raised an important question as to whether the atypical richness response observed in 2008 would be repeated. The 2009 data exhibited a weaker richness response than was observed in 2008, but not a complete return to the pattern observed earlier in the decade. The data from 2010 was similar to 2008 and exhibited a strong spatial trend of increasing richness with distance from the outfall. The previous monitoring report (Golder 2007a) stated that "the consistency in taxonomic richness across the majority of the study area indicates that biodiversity is not significantly affected by Macaulay Point discharge beyond the IDZ (*i.e.*, 100 m) or outside the near-field region". This conclusion requires revision in light of the data collected from the last three years. Based on the results from 2008-2010, the depression of richness now extends beyond the IDZ, and in some cases beyond the near-field stations;

- **Broader SDI response** – The spatial extent and magnitude of the decrease in normalized SDI was greater in 2008 and in 2009 than in previous sampling years, and this pattern was repeated in 2010. This is consistent with the pattern in richness, indicating alteration toward a less diverse benthic community at outfall monitoring stations;

- **Decrease of gastropod abundances** – While there was a slight recovery of gastropod abundances at all distance groups in 2009 after a period of decline, the numbers of gastropods decreased further in 2010, with the lowest numbers observed at the outfall, 100 m and 200 m stations. Gastropods appear to be a sensitive indicator of benthic community alteration; and

- **Increase in localized major taxa abundances** – Capitellid polychaetes, crustaceans and miscellaneous taxa have all increased at the outfall in 2010 (Figure 17). These taxa, although variable in abundance between years, tend to be among the more tolerant taxa to organic enhancement, and their increased abundance in 2010 may reflect their ability to outcompete more sensitive taxa in conditions of organic enhancement.

As a result of the above findings, the revised multi-year trend assessment represents a departure from findings presented in earlier trend assessments (Golder 2005a,b, 2006, 2007a, 2008). The 2009 results were equivocal with respect to whether the changes observed in 2008 represent stochastic temporal variations, or alternatively were indicative of a change in broad environmental condition in the Macaulay Point receiving environment. The results of the 2010 study suggest that the apparent changes in broad community composition reflect true changes in the biological assemblages.

At a broad level, the analysis of individual taxa in 2010 produced generally similar results to last year's assessment (Golder 2011a), with common taxa displaying different spatial patterns, each dependent on a number of factors, including the preferences of organisms for increased concentrations of organic carbon in sediment and the particle size distributions of sediment. However, at a more refined level of analysis, the number of taxa that exhibited net-positive responses was somewhat diminished in 2010. Although several taxa appear to benefit from modest increases in organic carbon content at intermediate (or mid-field) distances from the outfall, fewer taxa exhibited strong positive responses to outfall-related exposures.

In terms of overall environmental condition, the 2010 assessment indicates the following:

- **M0** – Benthic community data are indicative of a highly degraded benthic community. The reduced taxonomic richness (approximately 50% of reference), combined with sharp decreases in abundances of sensitive taxa (*e.g.*, bivalves and gastropods), and reduced summary metrics (SDI and ITI), are the main lines of evidence used to reach this conclusion. The assessment for M0 has changed in 2009 and 2010 relative to 2008 and previous years, when a conclusion of "moderately degraded benthic community" was rendered. The difference is attributable to the lower richness, very low SDI, and low ITI value. In 2010, total abundance at M0 was enhanced relative to reference, because of a significant increase in *Capitella capitata*, and other taxa that are well-suited to the higher TOC environment. However, these opportunistic species increased at the outfall at the expense of other taxa, which resulted in a reduction in species richness and other community health metrics (*e.g.*, SDI, ITI). The elevated gravel content at station M0 observed in 2009 and 2010 (19%) may also contribute to the observed reduction in richness and abundance of some taxa;

- **Near-field stations (not including M0)** – Similar to 2008 and 2009, community patterns are indicative of a moderately degraded benthic community. The reduced taxonomic richness (by approximately 55% relative to reference), combined with decreases in abundances of bivalves and gastropods, and reduced summary metrics (SDI and ITI), are the main lines of evidence used to reach this conclusion. The spatial pattern of these responses reconfirms the assignment of stations to the near-field group. In particular, the M2SE station grouped well with other near-field stations, confirming that the direction of outfall influence is predominantly to the southeast. The results from the past three years of monitoring have resulted in a reassignment of the level of alteration, as the reduced richness and responses to several major taxonomic groups indicate an increased degree of impairment relative to earlier years of sampling;

- **Mid-field stations** – The monitoring data collected for mid-field stations show a small negative response to the influence of the outfall. A general pattern of moderate biological alteration is evident in mid-field stations (more polychaetes, and fewer bivalves, crustaceans and gastropods), with significant declines in community health metrics compared with reference. Richness and ITI (standard) were reduced by 20% of the reference, whereas SDI was 75% of reference. In monitoring reports prior to 2008, the mid-field responses have been characterized as "neutral to slightly positive responses to outfall influence," while the last assessment characterized the mid-field as "net neutral". Therefore, the 2010 program reflects a change in the overall assessment of alteration. The enhancement of abundances and richness previously observed at mid-field stations were not observed in 2010, and instead a slight impairment of richness and other community health metrics led to the change of the characterization in 2010; and

- **Far-field stations** – The 2010 data indicate a net neutral to positive response to the influence of the outfall, which is a minor change from the clearly net positive characterization that had been previously assigned to this grouping. The far-field stations exhibit summary biological metrics such as SDI and richness that are slightly less than reference, whereas ITI (standard) is similar to reference. In addition, these stations contain abundances of major taxonomic groups that exceed the reference condition (*e.g.*, bivalves, amphipods and polychaetes). In these areas, the degree of exposure to outfall contamination is sufficiently limited to minimize any adverse effects, whereas a slight fertilization effect likely enhances the abundances of several taxa. The net effect in 2010 was that the functional status of far-field stations is considered equivalent to reference, but not enhanced as in previous monitoring events. The improvement in sediment quality with distance from M0 is most apparent from the abundances of bivalves. Whereas bivalve abundances are significantly reduced at near-field and far-field stations (and may be a sensitive indicator of outfall-related response), the bivalve abundances in the far-field areas are greater than reference. In summary, the far-field areas exhibit all the benefits of slightly increased TOC concentrations, without appreciable negative effects.

The comparison of sediment chemistry to biological metrics (abundance, richness, *etc.*) indicated a number of statistically significant correlations. Although these significant correlations should not be interpreted as evidence of cause-effect for the substances of interest measured in sediment, the number and magnitude of significant correlations was elevated in 2010. The sediment chemistry parameters were strongly inter-correlated and were strongly associated with organic carbon content of sediment. Graphical assessment of substrate effects indicated that benthic community metrics generally follow a spatial distribution similar to that of TOC. The analysis suggests that enhancement of organic carbon and substrate type are important explanatory variables for describing variations in benthic communities, although these factors alone cannot fully explain the biological patterns observed in 2010.

4.2 Investigation of Distance-plus-Direction Groupings

A previous trend assessment (Golder 2005b) identified three groups of stations (near field, far-field, and reference) based on multivariate analyses of Macaulay Point benthic community and sediment chemistry data collected from 2000 to 2004. In the most recent trend assessment (Golder 2008), these groupings were re-assessed using additional data (2000 to 2007, with omission of 2001), resulting in the identification of an additional “mid-field” group. The current trend assessment of benthic community data generally support the assignments of stations into these revised groupings, and therefore the groupings from Golder (2008) were carried forward in this multi-year trend assessment.

One problem with the application of distance-plus-direction groupings was the requirement that M0 be lumped with near-field stations in the conduct of statistical tests. In most previous years (prior to 2008), this was not problematic because M0 exhibited biological and chemical attributes similar to near-field stations, such that aggregation of the stations was logical. In the last three years, however, the stations near the outfall differed significantly in terms of biological composition, such that aggregation mixed stations of different type. Therefore, in 2009, a decision was made to partition the near-field group into M0 and remaining near-field stations. This distinction was made previously in the use of graphical methods that distinguished between M0 and other near-field stations. However, the statistics applied for 2009 and 2010 also distinguished between these stations. Although this procedure introduces some inconsistently in the details of the statistical processing among sampling years, the differences in M0 assemblages observed in recent years are considered sufficient to warrant the change.

The apparent separation of the outfall, near-field, mid-field and far-field stations from Golder (2008) reconfirms that the benthic community at Macaulay Point monitoring stations exhibits a spatial pattern that is related to both distance and direction from the outfall. Based on the current assessment, the direction of outfall influence appears to be the east and south-east, confirming the findings of previous investigations. Figure 11 shows that although there are groups that partly overlap, they are generally distinct from each other. This provides further confirmation that the station assignments used in the groupings are reasonable.

The application of the distance-plus-direction groupings to the data sets from recent years assisted in the interpretation of spatial trends. In many cases, spatial trends were strengthened or clarified through the incorporation of a direction-based component. This was particularly important in the 2010 analysis because stations located south and east of M0 (within 200 metres) exhibited assemblages that were quite distinct from stations to the west and north. For example, station M2SE (200 metres southeast) exhibited a biological profile indicative of outfall influence (*e.g.*, low bivalve abundance and high capitellid abundance), whereas all 100 m stations north and west of the outfall were relatively unaffected. Trends in benthic metrics such as SDI, ITI, and richness would have been obscured had only spatial zones been used to define groups. For evaluating patterns within a single year, the distance-plus-direction groupings are considered to be superior for investigating outfall-related influences. The distance-only comparisons have significant value for assessing temporal trends (as the study design has remained very stable over a decade of monitoring), but should be interpreted with caution when examining spatial trends.

4.3 Multiple Year Trend Assessment

This investigation is an update of previous benthic community trend analyses (Golder 2008). Broad-scale changes in benthic communities in the vicinity of Macaulay Point (relative to reference) appear to be reconfirmed by the addition of 2010 data, as seen in the graphic reference-normalized plots. Apparent changes to benthic community assemblages that were equivocal based on recent monitoring events were confirmed in the 2010 program. Some points that emerged from the analysis are as follows:

- Spatial correlations appear similar in recent years than in past years, with the exception of total abundance, which shows a stronger trend with distance in earlier years (2000 to 2005), and total richness and echinoderm abundance, which showed stronger trends with distance in recent years (2007 to 2010);
- In general, distance-direction groups yielded stronger spatial correlations for polychaetes, bivalves and ITI (standard) and the traditional distance groups produced stronger spatial correlation with total abundance and SDI;
- Weakly significant negative temporal trends were identified for echinoderms, bivalves, gastropods, crustaceans and mobile polychaetes. These trends were driven, for the most part, by strong reductions in abundance over time at the outfall;
- In the previous trend assessment (Golder 2008), weak negative temporal trends were observed for total polychaetes and *Capitella capitata* complex. These correlations are not significant in the current trend assessment owing to the increasing abundance of *Capitella capitata* at the outfall station in the last two years (Figure 17);
- There is a weak, significant negative temporal trend for taxonomic richness, which was not observed in the last trend assessment, owing to the decreasing richness observed in the last four years (Figure 18); and
- In 2010 amphipods, miscellaneous taxa and *Capitella capitata* increased substantially at the outfall relative to the reference.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Overall, the 2010 benthic monitoring program adjacent Macaulay Point provided useful data to inform the assessment of spatial and temporal trends in the receiving environment. The ability of the monitoring program to evaluate biological characteristics related to both distance and direction is a major strength of the existing program.

The main factor affecting the future design of the monitoring program is the decision to advance treatment from preliminary to secondary treatment. CRD (2010) presents draft conceptual changes of the program as part of a new receiving environment monitoring program (REMP) linked to the treatment upgrades. In light of these developments, it is useful to summarize recommendations that may influence the finalization of the REMP, while also recognizing that other changes are forthcoming for reasons unrelated to the historical role of the Macaulay Point monitoring program.

The main study recommendations are:

- **Continued Baseline** – Although changes to the frequency and sampling design details may be implemented per CRD (2010), it is recommended that at least one more annual sampling program be conducted in 2011 per the existing design. The reason is that the last three years have revealed some changes in biological assemblages relative to the mid 2000s, and therefore a confirmatory program would provide improved characterization of the baseline condition of the benthic community. Specifically, in the context of future monitoring, it will be important to select a temporal range deemed to represent a baseline for future changes in effluent treatment systems; it appears that the monitoring data from 2008 onward provide a basis for the current baseline condition, although the 2011 program will be important for refining uncertainty in the baseline characterization;

- **Station Groupings** – The modified distance-direction based analyses again proved to be an improvement over previous methods in terms of monitoring temporal and spatial trends benthic community parameters. The groupings reduce the incidence of false negatives in spatial trend assessments relative to distance-only methods (*i.e.*, more effective discriminator of underlying spatial trends due to improved statistical power and improved signal-to-noise ratio). We therefore recommend that interpretations of spatial trends be based preferentially on the distance-direction grouping. The expansion of richness reductions and other biological alterations to the southeast of M0 increases the importance of station groupings on the interpretation of trends. We recommend continuing with the preparation of distance-based analyses for making comparisons among successive years of monitoring; however, their value for spatial profiling is not as great as for temporal profiling;

- **Continue Increase Replication for Near-Field Stations** – The last three years of monitoring have revealed the importance of near-field station responses in terms of evaluating spatial trends. These sampling events revealed some responses that were different than previous monitoring events, such that the importance of 100 m and 200 m stations located to the south and east of M0 has increased over time. Rather than modify the sampling design in 2011, which would result in loss of consistency with previous programs, we recommend increasing replication for these stations, which will improve precision without introducing bias. Increased replication would reduce the potential influence of stochasticity and would provide a more robust data set for future analysis. As such, we recommend that all four (4) replicates (rather than minimum of three) be applied to stations M1SE, M2SE, M1E, M1W, M1SW and M1S[5] in the next sampling event; and

- **Use of ITI-regional** – The statistical evaluations conducted using ITI-standard and ITI-regional indicated that the latter were able to detect more statistically significant trends. Although this was based on only one year of analysis, it is possible that the improved consistency and regional relevance of the ITI classifications provided by Macdonald *et al.* (2010) make them more appropriate as a monitoring tool. An optional task would be to revaluate historical benthic community data from recent years to assess the impact of revising the ITI-standard assignments to ITI-regional assignments.

[5] In 2010, 4 replicates were analysed at each of these stations except station M1SE, for which only 3 replicates were analysed. Therefore, the proposed change would result in only a minor increase in scope for the 2011 program if variation in the benthic community samples is similar to 2010.

6.0 CLOSURE

We trust that this report is sufficient for your present needs. Should you have any questions or concerns, please do not hesitate to contact the undersigned at 604-296-4200.

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Table 1: Macaulay Point Benthic Monitoring Stations Sampled Between 1994 and 2010

Station	Sampling Year													
	1994	1997	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
M0	●	●	●	●	●	●	●	●	●	●	●	●	●	●
M1E	●	●	●	●	●	●	●	●	●	●	●	●	●	●
M1N				●	●	●	●	●	●	●	●	●	●	●
M1NE	●	●	●	●	●	●	●	●	●	●	●	●	●	●
M1NW				●	●	●	●	●	●	●	●	●	●	●
M1S				●	●	●	●	●	●	●	●	●	●	●
M1SE	●	●	●	●	●	●	●	●	●	●	●	●	●	●
M1SW	●	●	●	●	●	●	●	●	●	●	●	●	●	●
M1W	●	●	●	●	●	●	●	●	●	●	●	●	●	●
M2E	●	●	●	●	●	●	●	●	●	●	●	●	●	●
M2N				●	●	●	●	●	●	●	●	●	●	●
M2NE	●	●	●	●	●	●	●	●	●	●	●	●	●	●
M2NW	●	●		●	●	●	●	●	●	●	●	●	●	●
M2S				●	●	●	●	●	●	●	●	●	●	●
M2SE	●	●	●	●	●	●	●	●	●	●	●	●	●	●
M2SW	●	●	●	●	●	●	●	●	●	●	●	●	●	●
M2W	●	●	●	●	●	●	●	●	●	●	●	●	●	●
M4E	●	●	●	●	●	●	●	●	●	●	●	●	●	●
M4N	●	●												
M4S	●	●												
M4SE	●	●	●	●	●	●	●	●	●	●	●	●	●	●
M4SW	●	●		●	●	●	●	●	●	●	●	●	●	●
M4W	●	●		●	●	●	●	●	●	●	●	●	●	●
M8E	●	●		●	●	●	●	●	●	●	●	●	●	●
M8W	●	●		●	●	●	●	●	●	●	●	●	●	●
PB1	●	●	●	●	●	●	●	●	●	●	●	●	●	●
PB2			●	●	●	●	●	●	●	●	●	●	●	●
PB3			●	●	●	●	●	●	●	●	●	●	●	●
PB4									●	●	●	●	●	●
PB5									●	●	●	●	●	●

PB = Parry Bay reference station; ● indicates benthic community structure data (taxonomy) collected.

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2010 Benthic Report Tables for CRD gsl.xlsx [Table 1]

Table 2: Spearman Rank Correlations (r_s) between NMDS Dimensions and Abundances of Major Taxanomic Groups (2008 to 2010)

Taxanomic Group	Rank correlation with:	
	Benthic Dim 1	Benthic Dim 2
Capitella capitata complex	**0.961****	0.008
Polychaeta Errantia	0.192	**0.287****
Polychaeta Sedentaria	0.177	-0.159
Amphipoda	-0.062	**0.439****
Bivalvia	**-0.429****	0.091
Miscelaneous Taxa	**-0.432****	**0.630****
Gastropoda	**-0.439****	0.043
Crustacea (non-amphipod)	**-0.506****	**0.820****
Echinodermata	**-0.523****	**0.291****

Statistical Significance (2-tailed): ** = p < 0.01; * = p < 0.05; significant results in **boldface**.

Table 3: Spearman Rank Correlations (r_s) between NMDS Dimensions and Sediment Chemistry Parameters (2008-2010)

Sediment Chemistry Parameter	Rank correlation with:	
	Chemistry Dim 1	Chemistry Dim 2
AVS	**0.952****	0.037
cadmium	**0.928****	**0.240***
copper	**0.910****	**0.290****
antimony	**0.894****	0.063
TOC	**0.885****	0.032
lead	**0.884****	**0.261***
anthracene	**0.873****	0.011
fluoranthene	**0.866****	-0.013
benzo[b]fluoranthene	**0.862****	-0.021
pyrene	**0.857****	0.046
chrysene	**0.836****	0.016
mercury	**0.836****	-0.089
benzo[g,h,i]perylene	**0.835****	-0.045
zinc	**0.830****	**0.389****
benzo[a]pyrene	**0.830****	-0.023
phenanthrene	**0.830****	-0.029
benzo[k]fluoranthene	**0.830****	-0.008
benz[a]anthracene	**0.828****	0.024
silver	**0.826****	**0.335***
selenium	**0.821****	0.231
fluorene	**0.802****	-0.084
naphthalene	**0.783****	-0.095
indeno[1,2,3-c,d]pyrene	**0.728****	-0.030
phosphorus	**0.688****	**0.562****
arsenic	**0.652****	**0.242***
phenols	**0.614****	0.134
nickel	**0.526****	**0.552****
2-methylnaphthalene	**0.470****	-0.127
chromium	**0.215***	**0.757****
aluminum	0.007	**0.573****

Statistical Significance (2-tailed): ** = p < 0.01; * = p < 0.05; significant results in **boldface**.

Table 4: Summary Statistics for Macaulay Point 2010 Benthic Community Metrics

Station	Total Abundance						Polychaete Abundance						Taxonomic Richness					
	mean	median	SD	minimum	maximum	% reference	mean	median	SD	minimum	maximum	% reference	mean	median	SD	minimum	maximum	% reference
M0	1799	1576	425	1441	2342	410%	1311	1251	267	1011	1603	1082%	36.4	41.0	8.38	25	44	53%
M1E	306	320	53.3	233	349	70%	261	273	44.1	200	298	215%	39.5	38.0	5.45	35	47	58%
M1N	330	349	61.3	261	379	75%	144	145	25.0	118	168	119%	64.7	66.0	2.31	62	66	95%
M1NE	605	612	59.8	542	661	138%	264	262	11.6	253	276	218%	62.3	63.0	2.08	60	64	91%
M1NW	718	716	114	605	833	164%	176	159	31.5	156	212	145%	67.3	64.0	9.45	60	78	98%
M1S	399	366	117	298	565	91%	235	228	61.6	167	316	194%	49.5	49.5	11.0	40	59	72%
M1SE	481	464	48.2	443	535	110%	444	422	40.4	420	491	367%	30.0	32.0	4.36	25	33	44%
M1SW	341	313	75.5	286	451	78%	236	227	46.0	194	295	194%	43.3	40.5	5.85	40	52	63%
M1W	443	413	104	353	591	101%	309	300	60.4	246	391	255%	52.3	51.5	8.30	43	63	76%
100 metre stations	441	393	151	233	833	101%	259	251	90.2	118	491	213%	50.4	51.0	13.4	25	78	74%
M2E	383	395	110	246	497	87%	230	218	65.9	174	309	190%	52.0	52.5	7.16	44	59	76%
M2N	327	311	36.4	302	369	75%	163	165	17.1	145	179	134%	72.0	69.0	5.20	69	78	105%
M2NE	344	358	30.2	309	364	78%	214	245	56.9	148	248	176%	62.3	68.0	10.7	50	69	91%
M2NW	625	659	67.2	548	669	143%	199	203	24.2	173	221	164%	54.3	55.0	2.08	52	56	79%
M2S	520	572	98.3	407	582	119%	211	229	39.2	166	238	174%	63.7	66.0	4.93	58	67	93%
M2SE	557	577	112	403	670	127%	497	532	105	343	581	410%	41.8	43.5	11.0	27	53	61%
M2SW	623	662	69.0	543	663	142%	239	253	35.7	198	265	197%	60.3	62.0	2.89	57	62	88%
M2W	614	625	86.6	522	694	140%	257	257	36	221	293	212%	57.7	62.0	9.29	47	64	84%
200 metre stations	497	533	140	246	694	113%	260	234	118	145	581	214%	57.2	57.5	11.0	27	78	84%
M4E	397	456	139	190	487	91%	188	198	75.9	94	260	155%	68.3	73.0	13.8	48	79	100%
M4SE	443	465	84.7	349	514	101%	300	306	33.9	264	331	248%	64.3	63.0	6.11	59	71	94%
M4SW	428	420	15.3	419	446	98%	130	130	0.577	130	131	108%	61.0	61.0	1.00	60	62	89%
M4W	663	622	71.3	621	745	151%	211	195	42.9	179	260	174%	78.7	71.0	15.0	69	96	115%
400 metre stations	476	458	136	190	745	109%	206	195	75.6	94	331	170%	68.1	69.0	11.7	48	96	100%
M8E	185	167	44.8	152	236	42%	91.3	86	20.5	74	114	75%	57.0	55.0	5.29	53	63	83%
M8W	603	624	76.7	518	667	138%	98	92	14.9	87	115	81%	63.7	63.0	1.15	63	65	93%
800 metre stations	394	377	236	152	667	90%	94.7	89.5	16.5	74	115	78%	60.3	63.0	5.01	53	65	88%
PB1	409	363	104	335	528	93%	130	121	18.6	117	151	107%	65.7	65.0	4.04	62	70	96%
PB2	408	422	73.6	328	473	93%	115	113	13.1	103	129	95%	74.3	73.0	5.13	70	80	109%
PB3	405	425	46.9	351	438	92%	139	133	12.7	131	154	115%	68.3	66.0	5.86	64	75	100%
PB4	541	524	50.1	501	597	123%	107	106	7.02	100	114	88%	65.7	64.0	2.89	64	69	96%
PB5	431	442	72.7	353	497	98%	115	116	4.04	111	119	95%	68.0	69.0	2.65	65	70	99%
Reference stations	438	438	81.5	328	597	100%	121	117	15.9	100	154	100%	68.4	69.0	4.90	62	80	100%
Near-field stations	445	443	135	233	670	101%	397	420	128	200	581	327%	37.7	36.0	8.64	25	53	55%
Mid-field stations	393	375	97.3	190	591	90%	243	247	66.7	94	391	201%	55.4	55.0	11.9	40	79	81%
Far-field stations	520	560	170	152	833	119%	182	176	61.0	74	293	150%	63.6	63.0	8.45	47	96	93%

Notes:

Near-field includes: M1E, M1SE and M2SE.

Mid-field includes: M1W, M1SW, M1S, M2E, M2NE, M4SE and M4E.

Far-field indludes: M1N, M1NE, M1NW, M2N, M2NW, M2S, M2SW, M2W, M4SW, M4W, M8W and M8E.

Reference includes: PB1 to PB5.

Table 4: Summary Statistics for Macaulay Point 2010 Benthic Community Metrics (continued)

Station	Swartz Dominance Index						ITI Group (Standard)						ITI Group (Regional)					
	mean	median	SD	minimum	maximum	% reference	mean	median	SD	minimum	maximum	% reference	mean	median	SD	minimum	maximum	% reference
M0	1.62	1.59	0.249	1.29	1.97	10%	16.4	16.4	3.07	12.6	21.1	29%	13.9	13.9	4.06	9.22	20.2	28%
M1E	6.03	6.09	1.65	4.43	7.5	38%	37.9	39.0	5.03	31.1	42.4	67%	13.1	13.2	1.44	11.5	14.7	27%
M1N	18.6	19.3	1.32	17.1	19.4	116%	57.9	59.2	2.78	54.7	59.8	103%	41.6	41.6	3.45	38.1	45.0	84%
M1NE	10.9	12.0	1.95	8.64	12.1	68%	56.5	56.7	0.43	56.0	56.8	100%	42.8	43.1	1.20	41.5	43.8	87%
M1NW	6.88	5.83	2.16	5.43	9.37	43%	49.2	50.0	1.37	47.7	50.1	87%	37.9	37.2	2.42	35.9	40.6	77%
M1S	7.81	6.78	2.22	6.55	11.1	49%	47.1	46.2	2.47	45.3	50.6	84%	32.4	31.5	4.13	28.7	37.7	66%
M1SE	0.962	0.978	0.046	0.910	0.998	6%	12.2	11.9	3.18	9.22	15.5	22%	5.88	6.65	1.93	3.69	7.30	12%
M1SW	7.28	6.05	2.69	5.73	11.3	46%	36.4	35.6	4.41	31.8	42.4	65%	23.0	24.6	3.53	17.7	25.0	47%
M1W	7.85	7.88	0.43	7.31	8.35	49%	42.9	42.9	4.62	37.3	48.6	76%	24.4	24.0	2.36	22.4	27.2	50%
100 metre stations	8.14	7.35	4.70	0.910	19.4	51%	42.3	44.2	13.3	9.22	59.8	75%	27.0	26.4	12.5	3.69	45.0	55%
M2E	11.7	12.0	0.931	10.4	12.5	74%	47.0	48.3	3.62	41.6	49.6	83%	31.0	32.4	5.41	23.6	35.5	63%
M2N	24.5	23.9	4.10	20.8	28.9	154%	55.4	56.0	1.25	54.0	56.3	98%	28.1	27.4	2.41	26.1	30.8	57%
M2NE	16.9	17.8	5.45	11.1	21.9	106%	49.8	48.2	3.43	47.4	53.7	88%	31.5	29.9	4.84	27.6	36.9	64%
M2NW	7.10	7.02	1.07	6.08	8.21	45%	57.2	57.5	1.74	55.3	58.7	101%	45.5	46.0	0.98	44.4	46.2	93%
M2S	11.4	11.3	0.712	10.75	12.2	72%	59.8	59.3	0.92	59.1	60.8	106%	43.8	42.9	1.70	42.7	45.7	89%
M2SE	2.87	3.17	1.36	0.955	4.17	18%	19.1	19.8	4.68	12.9	24.0	34%	7.78	7.72	2.14	5.60	10.1	16%
M2SW	7.67	7.85	0.580	7.02	8.14	48%	56.8	56.1	2.34	54.8	59.4	101%	43.1	43.6	1.10	41.9	43.9	88%
M2W	8.14	7.98	0.852	7.38	9.06	51%	55.6	54.6	2.28	54.0	58.2	99%	40.0	39.2	1.61	39.0	41.9	81%
200 metre stations	11.0	9.72	6.73	0.955	28.9	69%	48.8	54.3	13.8	12.9	60.8	87%	32.7	36.2	12.8	5.60	46.2	66%
M4E	18.0	18.2	3.46	13.6	22.0	113%	56.7	56.6	1.96	54.6	59.3	101%	41.3	41.0	2.99	37.9	45.2	84%
M4SE	13.9	13.6	1.60	12.4	15.6	87%	49.7	49.8	1.00	48.7	50.6	88%	26.9	26.0	3.09	24.4	30.4	55%
M4SW	11.6	12.8	2.59	8.64	13.4	73%	59.5	59.0	2.26	57.6	62.0	106%	47.5	47.8	1.27	46.1	48.6	96%
M4W	12.6	11.2	3.16	10.4	16.2	79%	58.0	57.6	1.60	56.6	59.8	103%	45.1	44.9	1.82	43.4	47.0	92%
400 metre stations	14.3	13.6	3.65	8.64	22.0	90%	56.1	57.0	4.08	48.7	62.0	99%	40.3	43.4	8.27	24.4	48.6	82%
M8E	22.7	21.6	1.99	21.5	25.0	142%	55.8	53.8	6.14	50.9	62.7	99%	39.1	39.9	2.58	36.2	41.2	79%
M8W	8.62	8.35	1.57	7.2	10.3	54%	59.8	59.6	2.40	57.5	62.3	106%	56.5	57.0	1.63	54.7	57.9	115%
800 metre stations	15.7	15.9	7.88	7.2	25.0	98%	57.8	58.6	4.71	50.9	62.7	103%	47.8	48.0	9.74	36.2	57.9	97%
PB1	17.6	16.7	1.93	16.4	19.9	110%	54.6	53.3	2.91	52.6	57.9	97%	49.5	49.0	1.07	48.8	50.8	101%
PB2	18.2	19.3	2.97	14.8	20.4	114%	57.4	58.6	2.63	54.3	59.1	102%	51.2	52.6	2.68	48.1	52.9	104%
PB3	16.7	16.9	2.30	14.4	19.0	105%	52.4	52.5	2.37	50.1	54.8	93%	42.6	43.0	3.52	39.0	46.0	87%
PB4	12.2	12.4	0.863	11.3	13.0	77%	59.6	59.9	1.51	58.0	61.0	106%	53.8	53.9	0.66	53.1	54.3	109%
PB5	15.0	16.5	3.63	10.9	17.7	94%	57.7	57.6	1.39	56.3	59.1	102%	48.9	49.4	3.60	45.1	52.3	99%
Reference stations	16.0	16.5	3.08	10.9	20.4	100%	56.3	57.6	3.23	50.1	61.0	100%	49.2	49.4	4.41	39.0	54.3	100%
Near-field stations	3.50	3.19	2.45	0.910	7.5	22%	24.0	20.7	12.0	9.22	42.4	43%	9.20	9.07	3.60	3.69	14.7	19%
Mid-field stations	11.7	11.2	4.87	5.73	22.0	73%	46.9	48.3	6.81	31.8	59.3	83%	30.1	29.1	6.87	17.7	45.2	61%
Far-field stations	12.6	10.6	6.17	5.43	28.9	79%	56.8	57.1	3.48	47.7	62.7	101%	42.6	43.0	6.67	26.1	57.9	87%

Table 5: Macaulay Point 2010 Benthic Community Metrics - Correlations with Distance from the Outfall and Statistical Comparisons to Reference

Metric	Spearman Rank Correlation (r_s) with Distance from Outfall [1]	P-values (by Distance Group) for Comparisons to Reference Stations [1,2]				
		Outfall	100m	200m	400m	800m
Total Abundance	-0.129	**0.005**	1.00	0.837	1.00	1.00
Polychaete Abundance	**-0.671****	**0.005**	**<0.001**	**<0.001**	**0.005**	**0.045**
Taxonomic Richness	**0.609****	**0.005**	**<0.001**	**0.002**	1.00	**0.019**
Swartz Dominance Index (SDI)	**0.623****	**0.005**	**<0.001**	**0.012**	0.800	1.00
Infaunal Trophic Index (ITI) - Standard	**0.603****	**0.005**	**<0.001**	0.309	1.00	1.00
Infaunal Trophic Index (ITI) - Regional	**0.699****	**0.005**	**<0.001**	**<0.001**	**0.005**	1.00
Echinodermata	**0.542****	**0.009**	**<0.001**	**<0.001**	1.00	**0.023**
Bivalvia	**0.293****	**0.005**	0.264	1.00	1.00	1.00
Gastropoda	**0.691****	**0.005**	**<0.001**	**<0.001**	**0.001**	0.161
Crustacea (Amphipoda)	**-0.240***	**0.005**	1.00	**0.038**	1.00	1.00
Crustacea (Other)	**0.370****	**0.017**	**<0.001**	**<0.001**	**<0.001**	1.00
Polycheata Errantia	**-0.389****	**0.006**	**<0.001**	**<0.001**	**<0.001**	0.878
Polycheata Sedentaria (Other)	0.062	0.063	1.00	**0.034**	0.127	**0.007**
Capitella capitata complex	**-0.760****	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.110
Miscellaneous Taxa	**0.321****	**0.005**	**<0.001**	**<0.001**	**0.019**	1.00
Benthic Dim 1	**0.774****	**0.005**	**<0.001**	**<0.001**	**<0.001**	**0.025**
Benthic Dim 2	-0.078	**0.005**	**0.004**	0.598	0.264	1.00
Total Organic Carbon (TOC)	**-0.670****	-	-	-	-	-
Percent Gravel	**-0.599****	-	-	-	-	-
Percent Fines	0.221	-	-	-	-	-

[1] Statistical significance (2-tailed): ** = $p < 0.01$; * = $p < 0.05$. Significant results shown in **boldface**.

[2] P-values shown include Bonferroni adjustments for multiple comparisons where applicable.

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2010 Benthic Report Tables for CRD gsl.xlsx [Table 5]

Table 6: Macaulay Point 2010 Benthic Community Metrics - Correlations with Distance-Direction from the Outfall and Statistical Comparisons to Reference

Metric	Spearman Rank Correlation (r_s) with Distance-Direction from Outfall [1]	P-values (by Distance-Direction Group) for Comparisons to Reference Stations [1,2]			
		Outfall	Near-field	Mid-field	Far-field
Total Abundance	-0.004	**0.004**	1.00	0.561	0.155
Polychaete Abundance	**-0.758****	**0.004**	**<0.001**	**<0.001**	**0.002**
Taxonomic Richness	**0.691****	**0.004**	**<0.001**	**0.002**	**0.010**
Swartz Dominance Index (SDI)	**0.586****	**0.004**	**<0.001**	**0.018**	**0.044**
Infaunal Trophic Index (ITI) - Standard	**0.762****	**0.004**	**<0.001**	**<0.001**	1.00
Infaunal Trophic Index (ITI) - Regional	**0.864****	**<0.001**	**<0.001**	**<0.001**	**0.002**
Echinodermata	**0.312****	**0.008**	**<0.001**	0.211	**<0.001**
Bivalvia	**0.649****	**0.004**	**<0.001**	**0.003**	**0.018**
Gastropoda	**0.724****	**0.004**	**<0.001**	**<0.001**	**<0.001**
Crustacea (Amphipoda)	-0.114	**0.004**	1.00	0.383	0.058
Crustacea (Other)	**0.502****	**0.004**	**<0.001**	**<0.001**	**<0.001**
Polycheata Errantia	**-0.377****	0.082	0.406	**<0.001**	**<0.001**
Polycheata Sedentaria (Other)	0.199	0.051	1.00	1.00	**0.048**
Capitella capitata complex	**-0.856****	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Miscellaneous Taxa	**0.326****	**0.004**	**<0.001**	**<0.001**	**0.001**
Benthic Dim 1	**0.895****	**0.004**	**<0.001**	**<0.001**	**<0.001**
Benthic Dim 2	-0.086	**<0.001**	0.138	**0.010**	0.233
Total Organic Carbon (TOC)	**-0.779****	-	-	-	-
Percent Gravel	**-0.698****	-	-	-	-
Percent Fines	0.338	-	-	-	-

[1] Statistical significance (2-tailed): ** = $p < 0.01$; * = $p < 0.05$. Significant results shown in **boldface**.

[2] P-values shown include Bonferroni adjustments for multiple comparisons where applicable.

Near-field includes: M1E, M1SE and M2SE.

Mid-field includes: M1W, M1SW, M1S, M2E, M2NE, M4SE and M4E.

Far-field indludes: M1N, M1NE, M1NW, M2N, M2NW, M2S, M2SW, M2W, M4SW, M4W, M8W and M8E.

Reference includes: PB1 to PB5.

Table 7: Mean Values and Percent of Reference for Macaulay Point 2010 Abundance of Major Taxanomic Groups

Station	Echinodermata		Bivalvia		Gastropoda		Crustacea (Amphipoda)		Crustacea (Other)	
	Mean	% Reference	Mean	% Reference	Mean	% Reference	Mean	% Reference	Mean	% Reference
M0	0.00	0%	19.2	14%	1.80	4%	95.8	435%	259	287%
M1E	0.75	19%	13.3	9%	6.75	15%	12.3	56%	6.00	7%
M1N	0.33	8%	99.0	71%	7.67	17%	38.3	174%	34.3	38%
M1NE	0.00	0%	251	180%	23.0	51%	28.0	127%	32.7	36%
M1NW	0.33	8%	447	320%	16.3	36%	37.7	171%	33.7	37%
M1S	0.75	19%	129	92%	5.00	11%	16.5	75%	11.0	12%
M1SE	0.00	0%	3.67	3%	2.67	6%	16.7	76%	13.0	14%
M1SW	0.75	19%	52.3	37%	2.50	6%	37.3	169%	10.5	12%
M1W	0.25	6%	78.0	56%	3.00	7%	33.5	152%	15.0	17%
100 metre stations	0.43	11%	125	89%	7.79	17%	27.1	123%	18.3	20%
M2E	2.25	57%	68.8	49%	5.25	12%	44.5	202%	27.5	31%
M2N	1.00	25%	67.3	48%	15.7	35%	38.0	173%	35.7	40%
M2NE	3.33	85%	73.0	52%	3.00	7%	23.3	106%	22.0	24%
M2NW	0.33	8%	346	248%	13.7	30%	24.3	111%	34.3	38%
M2S	1.00	25%	231	165%	6.33	14%	36.0	164%	30.0	33%
M2SE	0.50	13%	12.0	9%	3.25	7%	28.8	131%	11.8	13%
M2SW	0.67	17%	317	227%	9.7	22%	28.0	127%	19.3	21%
M2W	0.00	0%	269	192%	13.0	29%	37.0	168%	37.3	41%
200 metre stations	1.15	29%	163	116%	8.38	19%	32.8	149%	26.7	30%
M4E	7.75	197%	112	80%	18.3	41%	39.5	180%	26.0	29%
M4SE	7.67	195%	61.7	44%	30.3	68%	27.0	123%	9.00	10%
M4SW	1.00	25%	220	158%	9.33	21%	17.3	79%	43.7	48%
M4W	1.00	25%	329	235%	13.0	29%	33.0	150%	65.3	72%
400 metre stations	4.62	117%	175	125%	17.8	40%	30.0	136%	35.2	39%
M8E	0.33	8%	29.3	21%	21.3	48%	20.7	94%	17.3	19%
M8W	1.00	25%	291	208%	27.0	60%	22.7	103%	137	152%
800 metre stations	0.67	17%	160	115%	24.2	54%	21.7	98%	77.2	86%
PB1	3.00	76%	102	73%	60.3	134%	20.3	92%	73.7	82%
PB2	6.33	161%	120	86%	53.3	119%	21.0	95%	80.3	89%
PB3	5.33	136%	112	80%	53.0	118%	26.3	120%	60.7	67%
PB4	3.00	76%	187	134%	28.3	63%	24.3	111%	161	179%
PB5	2.00	51%	179	128%	29.3	65%	18.0	82%	74.7	83%
Reference stations	3.93	100%	140	100%	44.9	100%	22.0	100%	90.1	100%
Near-field stations	0.45	12%	10.2	7%	4.36	10%	19.5	88%	10.0	11%
Mid-field stations	3.08	78%	83.2	60%	9.08	20%	32.2	146%	17.4	19%
Far-field stations	0.58	15%	242	173%	14.7	33%	30.1	137%	43.4	48%

NC = Not calculated; the mean abundance at reference stations was equal to zero and therefore the % Reference could not be calculated.

Near-field includes: M1E, M1SE and M2SE.

Mid-field includes: M1W, M1SW, M1S, M2E, M2NE, M4SE and M4E.

Far-field indludes: M1N, M1NE, M1NW, M2N, M2NW, M2S, M2SW, M2W, M4SW, M4W, M8W and M8E.

Reference includes: PB1 to PB5.

Table 7: Mean Values and Percent of Reference for Macaulay Point 2010 Abundance of Major Taxanomic Groups (continued)

Station	Polychaeta Errantia		Polychaeta Sedentaria (Other)		Polychaeta Sedentaria (Capitella)		Miscellaneous Taxa	
	Mean	% Reference	Mean	% Reference	Mean	% Reference	Mean	% Reference
M0	64.2	212%	63.6	70%	1183	NC	113	681%
M1E	57.8	191%	97.3	107%	106	NC	5.50	33%
M1N	42.0	139%	97.3	107%	4.33	NC	6.33	38%
M1NE	78.0	258%	146	161%	39.7	NC	6.67	40%
M1NW	51.3	170%	116	128%	8.00	NC	7.00	42%
M1S	84.3	278%	78.5	86%	72.0	NC	1.50	9%
M1SE	26.3	87%	43.7	48%	374	NC	0.33	2%
M1SW	60.3	199%	59.3	65%	116	NC	2.00	12%
M1W	84.5	279%	109	120%	116	NC	3.75	23%
100 metre stations	62.1	205%	92.4	102%	104	NC	4.00	24%
M2E	83.0	274%	98.5	108%	48.3	NC	5.00	30%
M2N	48.0	159%	115	126%	0.00	NC	6.67	40%
M2NE	90.3	298%	98.7	109%	24.7	NC	5.33	32%
M2NW	58.3	193%	109	120%	32.0	NC	7.33	44%
M2S	71.0	235%	121	133%	19.0	NC	4.67	28%
M2SE	48.8	161%	91.3	100%	357	NC	3.25	20%
M2SW	72.3	239%	116	128%	50.3	NC	9.33	56%
M2W	77.0	254%	121	133%	59.0	NC	0.67	4%
200 metre stations	68.4	226%	108	118%	83.7	NC	5.19	31%
M4E	71.3	235%	105	115%	11.3	NC	6.25	38%
M4SE	79.7	263%	161	177%	60.0	NC	6.67	40%
M4SW	39.7	131%	90.7	100%	0.00	NC	6.33	38%
M4W	66.7	220%	134	147%	11.0	NC	10.0	60%
400 metre stations	64.8	214%	121	133%	19.8	NC	7.23	44%
M8E	29.7	98%	60.3	66%	1.33	NC	4.67	28%
M8W	41.3	137%	56.7	62%	0.00	NC	26.0	157%
800 metre stations	35.5	117%	58.5	64%	0.67	NC	15.33	93%
PB1	35.0	116%	94.7	104%	0.00	NC	19.7	119%
PB2	34.3	113%	80.7	89%	0.00	NC	11.67	71%
PB3	33.3	110%	106	117%	0.00	NC	8.33	50%
PB4	28.3	94%	78.3	86%	0.00	NC	30.3	183%
PB5	20.3	67%	95.0	104%	0.00	NC	12.67	77%
Reference stations	30.3	100%	90.9	100%	0.00	NC	16.53	100%
Near-field stations	45.9	152%	80.5	88%	270	NC	3.27	20%
Mid-field stations	78.6	260%	99.2	109%	65.6	NC	4.23	26%
Far-field stations	56.3	186%	107	118%	18.7	NC	7.97	48%

Table 8: Rank Correlations Between the Benthic Dimensions from NMDS analysis of 2010 Data and the Abundance Counts of the Nine Major Taxanomic Groups

Taxonomic Group	Correlation (r_s) with[1]:	
	Benthic Dim 1	Benthic Dim 2
Echinodermata	**0.439****	-0.123
Bivalvia	**0.553****	-0.179
Gastropoda	**0.780****	0.091
Crustacea (Amphipoda)	-0.095	**-0.563****
Crustacea (Other)	**0.600****	**-0.708****
Polychaeta Errantia	**-0.391****	-0.055
Polychaeta Sedentaria (Other)	0.119	-0.025
Capitella capitata Complex	**-0.948****	0.033
Miscellaneous Taxa	**0.502****	**-0.729****

[1] Statistical significance (2-tailed): ** = $p < 0.01$; * = $p < 0.05$.
Significant results shown in **boldface**.

Table 9: Summary of Benthic Pattern Clasifications by Distance and Distance-Direction from the Outfall			
Species	Pattern Classification		Organism Count
	Distance	Distance-Direction	
Capitella capitata complex (Annelida:Sedentaria)	A	A	11272
Axinopsida serricata (Mollusca:Bivalvia)	B2	C	8764
Euclymeninae indet. (Annelida:Sedentaria)	B1	B1	3502
Euphilomedes producta (Crustacea:Ostracoda)	D	E	2833
Scoletoma luti (Annelida:Errantia)	B2	B2	1413
Leptochelia dubia (Crustacea:Tanaidacea)	A	A	1361
Exogone lourei (Annelida:Errantia)	A	A	1259
Parvilucina tenuisculpta (Mollusca:Bivalvia)	C	D	1167
Mediomastus californiensis (Annelida:Sedentaria)	A	A	998
Notomastus tenuis (Annelida:Sedentaria)	D	D	715
Acila castrensis (Mollusca:Bivalvia)	B2	F	653
Lirobittium munitum (Mollusca:Gastropoda)	E	E	625
Astyris gausapata (Mollusca:Gastropoda)	B2	B2	592
Aphelochaeta sp. indet. *(Annelida:Sedentaria)*	D	D	578
Oligochaeta indet. *(Annelida:Oligochaeta)*	A	A	574
Lumbrineridae indet. (Annelida:Errantia)	F	D	540
Macoma elimata (Mollusca:Bivalvia)	D	D	528
Prionospio jubata (Annelida:Sedentaria)	B1	B1	519
Glycera nana (Annelida:Errantia)	D	D	380
Rhepoxynius bicuspidatus (Crustacea:Amphipoda)	C	E	366
Aoroides inermis (Crustacea:Amphipoda)	F	B2	365
Lucinoma annulatum (Mollusca:Bivalvia)	C	D	358
Photis brevipes (Crustacea:Amphipoda)	A	A	349
Nutricola lordi (Mollusca:Bivalvia)	E	E	340
Glycinde armigera (Annelida:Errantia)	B2	B2	335
Sphaerodoropsis sphaerulifer (Annelida:Errantia)	B2	B2	283
Aoroides exilis (Crustacea:Amphipoda)	A	A	272
Decamastus gracilis (Annelida:Sedentaria)	D	D	264
Adontorhina cyclia (Mollusca:Bivalvia)	E	E	226
Paraprionospio pinnata (Annelida:Sedentaria)	C	C	219
Thysanocardia nigra (Sipuncula)	C	D	186
Magelona longicornis (Annelida:Sedentaria)	D	D	169
Pulsellum salishorum (Mollusca:Scaphopoda)	E	E	158
Nephtys cornuta (Annelida:Errantia)	B2	B2	157
Diopatra ornata (Annelida:Errantia)	F	B1	149
Aoroides sp. (Crustacea:Amphipoda)	A	B1	147
Macoma golikovi (Mollusca:Bivalvia)	A	A	145
Yoldia seminuda (Mollusca:Bivalvia)	D	E	145

Table 9: Summary of Benthic Pattern Clasifications by Distance and Distance-Direction from the Outfall			
Species	**Pattern Classification**		**Organism Count**
	Distance	**Distance-Direction**	
Nephtys ferruginea (Annelida:Errantia)	**C**	**C**	140
Spiochaetopterus costarum (Annelida:Sedentaria)	**B1**	**F**	136
Sternaspis cf. *fossor* (Annelida:Sedentaria)	**D**	**D**	134
Maldane glebifex (Annelida:Sedentaria)	**C**	**E**	132
Lumbrineris californiensis (Annelida:Errantia)	**B2**	**B2**	130
Polycirrus sp. *complex* (Annelida:Sedentaria)	**B1**	**F**	125
Gammaropsis thompsoni (Crustacea:Amphipoda)	**A**	**A**	123
Laonice cirrata (Annelida:Sedentaria)	**B2**	**C**	120
Armandia brevis (Annelida:Sedentaria)	**A**	**A**	119
Desdimelita desdichada (Crustacea:Amphipoda)	**B1**	**B1**	116
Galathowenia oculata (Annelida:Sedentaria)	**D**	**D**	115
Nichomache personata (Annelida:Sedentaria)	**B1**	**B2**	110
Eudorellopsis integra (Crustacea:Cumacea)	**B2**	**F**	107
Chaetozone nr. setosa (Annelida:Sedentaria)	**C**	**C**	104
Mediomastus sp. (Annelida:Sedentaria)	**F**	**F**	104
Ampelisca hancocki (Crustacea:Amphipoda)	**C**	**C**	102
Ampelisca brevisimulata (Crustacea:Amphipoda)	**D**	**C**	101
Byblis millsi (Crustacea:Amphipoda)	**B2**	**D**	101
Heterophoxus sp. (Crustacea:Amphipoda)	**B2**	**C**	101
Pattern Summary			
A	**11**	**10**	-
B1	**6**	**5**	-
B2	**12**	**8**	-
C	**9**	**8**	-
D	**11**	**13**	-
E	**4**	**8**	-
F	**4**	**5**	-
Total	**57**	**57**	-

Table 10: 2010 Sediment Chemistry Data for Macaulay Point

Station	AVS	% gravel	% fines	TOC	aluminum	antimony	arsenic	cadmium	chromium	copper	lead	mercury	nickel	phosphorus	selenium	silver	zinc
M0	10.30	19.00	20.6	2.50	22100	1.45	8.84	0.60	67.50	224	35.30	1.66	23.80	2010	0.37	1.48	137
M1E	14.97	3.23	35.8	3.66	17867	0.74	10.27	1.31	27.90	50.27	28.63	QA	17.70	877	0.50	0.75	84.50
M1N	5.15	3.31	45.1	2.48	19467	0.66	6.70	0.21	29.73	30.25	35.33	QA	19.10	724	0.33	0.13	164
M1NE	0.75	0.77	40.9	1.08	18000	0.34	5.00	0.22	28.40	19.60	11.80	QA	16.80	698	0.30	0.13	59.30
M1NW	1.55	0.70	37.5	0.85	19500	0.29	5.80	0.19	29.50	19.60	10.20	QA	17.30	662	0.29	0.30	56.60
M1S	3.22	6.19	37.0	2.95	23300	0.58	6.90	0.27	34.30	50.40	50.00	QA	20.40	936	0.32	0.82	70.70
M1SE	44.80	10.30	34.2	3.00	18400	1.03	13.00	0.99	32.30	238	111	QA	22.20	1060	0.61	0.82	337
M1SW	25.77	1.66	39.8	3.76	18200	1.71	15.10	1.01	36.57	109.27	QA	0.86	26.57	917	0.66	0.62	158
M1W	12.17	0.88	42.2	2.83	18133	1.38	7.53	0.41	41.10	67.67	QA	0.32	21.77	774	0.33	0.41	80.73
100 metre stations	13.55	3.38	39.1	2.58	19108	0.84	8.79	0.57	32.48	73.13	41.16	0.59	20.23	831	0.42	0.50	126
M2E	40.90	<0.10	40.0	2.09	17600	0.45	5.60	0.34	27.90	32.40	QA	0.30	18.50	681	0.35	0.10	65.70
M2N	9.73	4.40	44.2	1.49	19100	0.65	5.50	0.24	28.40	25.20	QA	0.06	21.00	663	0.31	0.10	79.00
M2NE	7.82	1.32	47.4	3.80	18400	1.27	8.20	0.28	29.60	55.30	QA	0.06	23.70	663	0.34	0.11	102
M2NW	4.13	<0.10	39.2	0.79	19700	0.34	5.10	0.19	29.50	19.30	QA	0.05	18.20	611	0.28	0.08	58.00
M2S	0.89	<0.10	48.2	1.66	17100	QA	7.20	0.16	26.00	14.50	11.00	0.07	19.80	522	0.16	QA	46.60
M2SE	15.33	4.36	34.9	3.38	16633	QA	8.87	0.56	26.90	59.90	24.57	0.56	18.47	656	0.45	QA	77.20
M2SW	2.71	<0.10	40.7	1.14	23100	QA	6.60	0.22	34.80	19.70	9.35	0.05	19.40	671	0.30	QA	63.20
M2W	3.24	<0.10	41.9	9.42	16400	QA	7.30	0.22	25.20	17.00	8.43	0.12	18.70	507	0.29	QA	46.70
200 metre stations	10.59	1.29	42.1	2.97	18504	0.68	6.80	0.27	28.54	30.41	13.34	0.16	19.72	622	0.31	0.10	67.30
M4E	1.59	4.35	41.4	2.20	19400	QA	6.63	0.24	30.47	73.50	27.63	0.07	21.07	736	0.32	QA	87.00
M4SE	9.32	0.17	34.5	1.27	22600	QA	9.06	0.26	33.60	36.40	19.40	0.15	20.10	753	0.45	QA	69.90
M4SW	0.89	<0.10	45.1	0.74	19800	0.27	5.62	0.11	28.00	13.60	5.93	0.04	13.40	551	0.26	0.07	48.40
M4W	1.51	0.77	42.1	0.89	20033	0.25	4.73	0.13	28.33	15.47	5.91	0.05	13.97	544	0.27	0.10	50.57
400 metre stations	3.33	1.33	40.8	1.28	20458	0.26	6.51	0.18	30.10	34.74	14.72	0.08	17.13	646	0.32	0.09	63.97
M8E	1.06	3.38	44.1	1.77	13600	0.32	7.00	0.09	20.80	12.90	QA	0.25	11.40	472	0.32	0.07	39.80
M8W	<0.20	<0.10	43.1	0.66	21500	0.22	5.37	0.10	30.30	14.10	5.98	0.04	13.70	598	0.21	0.06	51.20
800 metre stations	0.58	1.72	43.6	1.22	17550	0.27	6.19	0.10	25.55	13.50	5.98	0.14	12.55	535	0.27	0.06	45.50
PB1	<0.21	<0.10	31.5	0.53	18333	0.22	5.20	0.11	29.87	12.40	5.32	0.03	17.77	575	0.21	0.06	47.70
PB2	<0.20	<0.10	28.6	0.54	15700	0.19	6.24	0.09	25.83	9.80	4.25	0.03	13.67	486	0.21	0.04	38.87
PB3	<0.20	<0.10	43.2	0.69	19100	0.20	5.53	0.08	27.90	13.00	5.20	0.04	13.90	596	0.22	0.05	47.20
PB4	<0.20	<0.10	39.9	0.71	20800	0.22	5.10	0.11	30.40	13.70	5.50	0.04	16.00	607	0.21	0.05	51.00
PB5	<0.21	<0.10	56.4	0.85	19000	0.22	5.40	0.12	29.10	16.10	QA	0.04	18.70	629	0.32	0.06	56.30
Reference Stations	0.10	0.05	39.9	0.66	18587	0.21	5.49	0.10	28.62	13.00	5.07	0.04	16.01	579	0.23	0.05	48.21
Near-field Stations	25.03	5.96	35.0	3.35	17633	0.89	10.71	0.95	29.03	116	54.73	0.56	19.46	864	0.52	0.78	166
Mid-field Stations	14.40	2.09	40.3	2.70	19662	1.08	8.43	0.40	33.36	60.70	32.34	0.29	21.73	780	0.40	0.41	90.58
Far-field Stations	2.64	1.14	42.7	1.91	18942	0.37	5.99	0.17	28.25	18.43	11.55	0.08	16.90	602	0.28	0.11	63.60

Notes:

Concentrations are in mg/kg unless otherwise noted.

QA = result failed data quality objectives and was excluded from analyses.

TOC = total organic carbon; AVS = acid volatile sulphides.

Near-field includes: M1E, M1SE and M2SE.

Mid-field includes: M1W, M1SW, M1S, M2E, M2NE, M4SE and M4E.

Far-field indludes: M1N, M1NE, M1NW, M2N, M2NW, M2S, M2SW, M2W, M4SW, M4W, M8W and M8E.

Reference includes: PB1 to PB5.

Distance group averages were calculated using 1/2 the detection limit for non-detected concentrations.

Table 10: 2010 Sediment Chemistry Data for Macaulay Point (continued)

Station	phenols	anthracene	benzo[a] pyrene	benzo[b] fluoranthene	benzo[g,h,i] perylene	benzo[k] fluoranthene	chrysene	fluoranth-ene	fluorene	indeno[1,2,3-c,d] pyrene	2-methyl naphthalene	naphthal-ene	phenanthr-ene	pyrene
M0	8.71	0.15	0.73	0.82	0.24	0.35	0.61	1.36	0.04	0.34	0.02	0.03	0.36	1.07
M1E	2.81	QA	0.52	0.75	0.24	0.21	QA	QA	0.04	0.29	0.05	0.07	0.36	QA
M1N	0.81	QA	0.18	0.18	0.09	0.07	QA	QA	0.04	0.10	0.05	0.05	0.26	QA
M1NE	1.77	QA	QA	QA	0.10	QA	QA	QA	0.04	0.12	0.04	0.03	0.34	QA
M1NW	0.29	QA	0.05	0.06	0.02	0.02	QA	QA	0.02	0.03	0.05	0.03	0.11	QA
M1S	1.73	QA	0.06	0.06	0.02	0.02	QA	QA	0.01	0.02	0.04	0.06	0.06	QA
M1SE	1.55	QA	QA	QA	QA	QA	QA	QA	0.69	QA	0.08	0.08	8.70	QA
M1SW	1.10	0.13	0.67	0.68	0.37	0.27	0.32	0.68	0.05	0.39	0.09	0.11	0.42	0.73
M1W	3.11	0.05	0.11	0.09	0.04	0.04	0.09	0.18	0.04	0.05	0.06	0.05	0.18	0.16
100 metre stations	1.65	0.09	0.26	0.30	0.13	0.10	0.21	0.43	0.11	0.14	0.06	0.06	1.31	0.45
M2E	2.43	0.37	1.47	1.42	0.76	0.52	1.13	3.03	0.09	0.90	0.05	0.05	1.22	2.69
M2N	2.08	0.02	0.08	0.09	0.05	0.04	0.06	0.15	0.02	0.05	0.05	0.05	0.09	0.13
M2NE	0.84	0.02	0.06	0.08	0.03	0.03	0.06	0.10	0.02	0.03	0.06	0.03	0.09	0.10
M2NW	1.66	0.00	<0.010	<0.010	<0.010	<0.010	<0.010	0.02	0.01	<0.010	0.04	0.02	0.05	0.02
M2S	QA	<0.0040	<0.010	0.01	<0.010	<0.010	<0.010	0.01	0.01	<0.010	0.04	0.03	0.05	0.01
M2SE	QA	0.17	0.41	0.51	0.17	0.20	0.34	0.70	0.07	0.22	0.06	0.09	0.58	0.59
M2SW	QA	0.01	0.03	0.04	0.01	0.02	0.04	0.06	0.01	0.02	0.05	0.04	0.06	0.05
M2W	QA	0.01	0.03	0.04	0.01	0.02	0.03	0.06	0.01	0.01	0.04	0.02	0.07	0.05
200 metre stations	1.75	0.08	0.26	0.27	0.13	0.10	0.21	0.52	0.03	0.16	0.05	0.04	0.28	0.45
M4E	QA	0.01	0.04	0.05	0.02	0.02	0.05	0.06	0.02	0.03	0.05	0.05	0.07	0.06
M4SE	QA	0.00	<0.020	0.01	<0.010	<0.010	0.01	0.02	<0.010	<0.010	0.03	0.03	0.04	0.02
M4SW	0.87	0.01	<0.020	0.02	<0.010	<0.010	0.02	0.03	<0.010	<0.010	0.04	0.02	0.05	0.03
M4W	0.64	0.02	0.04	0.05	0.02	0.02	0.05	0.08	0.01	0.02	0.05	0.03	0.07	0.07
400 metre stations	0.76	0.01	0.03	0.03	0.01	0.01	0.03	0.05	0.01	0.01	0.04	0.03	0.06	0.04
M8E	0.32	0.01	<0.020	0.02	<0.010	<0.010	0.01	0.03	0.01	<0.010	0.04	0.03	0.05	0.03
M8W	0.61	<0.0040	<0.020	0.01	<0.010	<0.010	<0.010	0.02	<0.010	<0.010	0.04	0.02	0.05	0.02
800 metre stations	0.47	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.04	0.02	0.05	0.02
PB1	0.31	<0.0040	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.03	0.02	0.03	<0.010
PB2	0.37	<0.0040	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.03	0.01	0.03	<0.010
PB3	0.42	0.01	0.02	0.02	0.01	<0.010	0.02	0.03	0.01	0.01	0.05	0.02	0.05	0.03
PB4	0.32	<0.0040	<0.010	0.01	<0.010	<0.010	0.01	0.03	0.01	<0.010	0.04	0.02	0.06	0.02
PB5	0.54	<0.0040	<0.010	<0.010	<0.010	<0.010	0.01	0.01	0.01	<0.010	0.05	0.02	0.05	0.01
Reference Stations	0.39	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.02	0.04	0.01
Near-field Stations	2.18	0.17	0.47	0.63	0.21	0.20	0.34	0.70	0.27	0.25	0.06	0.08	3.22	0.59
Mid-field Stations	1.84	0.10	0.35	0.34	0.18	0.13	0.28	0.68	0.03	0.20	0.05	0.05	0.30	0.63
Far-field Stations	1.01	0.01	0.04	0.05	0.03	0.02	0.02	0.05	0.02	0.03	0.04	0.03	0.10	0.04

Notes:
Concentrations are in mg/kg unless otherwise noted.
QA = result failed data quality objectives and was excluded from analyses.
TOC = total organic carbon; AVS = acid volatile sulphides.
Near-field includes: M1E, M1SE and M2SE.
Mid-field includes: M1W, M1SW, M1S, M2E, M2NE, M4SE and M4E.
Far-field indludes: M1N, M1NE, M1NW, M2N, M2NW, M2S, M2SW, M2W, M4SW, M4W, M8W and M8E.
Reference includes: PB1 to PB5.
Distance group averages were calculated using 1/2 the detection limit for non-detected concentrations.

Table 11: Rank Correlations Between 2010 Sediment Chemistry and Benthic Community Metrics

Metric	AVS	TOC	% Gravel	% Fines	Aluminum	Antimony	Arsenic	Cadmium	Chromium
Total Abundance	-0.170	-0.251	-0.260	-0.255	0.346	-0.199	-0.257	-0.098	0.166
Total Richness	**-0.675****	**-0.642****	**-0.383***	0.345	0.140	**-0.726****	**-0.620****	**-0.683****	-0.218
Polychaete Abundance	**0.744****	**0.677****	**0.457***	**-0.411***	-0.025	**0.776****	**0.591****	**0.846****	0.312
SDI	**-0.449***	-0.350	-0.175	**0.473***	-0.128	**-0.439***	**-0.375***	**-0.546****	-0.294
ITI (Standard)	**-0.751****	**-0.608****	**-0.587****	**0.547****	0.183	**-0.682****	**-0.651****	**-0.768****	-0.267
ITI (Regional)	**-0.887****	**-0.802****	**-0.739****	0.302	0.186	**-0.860****	**-0.778****	**-0.856****	-0.197
Echinodermata	**-0.382***	**-0.410***	-0.367	0.119	0.117	**-0.606****	-0.232	-0.341	-0.087
Bivalvia	**-0.619****	**-0.529****	**-0.624****	0.276	0.327	**-0.599****	**-0.675****	**-0.569****	-0.091
Gastropoda	**-0.773****	**-0.784****	**-0.542****	0.045	0.046	**-0.921****	**-0.624****	**-0.758****	-0.281
Crustacea (Amphipoda)	0.308	0.229	0.151	0.077	-0.010	0.282	0.041	0.248	0.113
Crustacea (other)	**-0.650****	**-0.653****	**-0.451***	0.148	0.189	**-0.624****	**-0.668****	**-0.657****	-0.134
Polychaeta Errantia	**0.412***	**0.488****	0.133	-0.012	0.080	**0.570****	0.240	**0.525****	0.244
Polychaeta Sedentaria	-0.028	-0.039	-0.249	0.234	0.016	-0.054	-0.219	-0.019	-0.182
***Capitella capitata* complex**	**0.797****	**0.769****	**0.520****	**-0.462***	-0.062	**0.826****	**0.712****	**0.872****	0.354
Miscellaneous Taxa	**-0.602****	**-0.775****	**-0.409***	-0.081	**0.459***	**-0.608****	**-0.640****	**-0.528****	0.137

Metric	Copper	Lead	Mercury	Nickel	Phosphorus	Selenium	Silver	Zinc
Total Abundance	-0.056	-0.150	-0.029	-0.090	-0.112	-0.314	0.020	-0.201
Total Richness	**-0.581****	**-0.654****	**-0.734****	-0.363	**-0.515****	**-0.620****	**-0.681****	**-0.460***
Polychaete Abundance	**0.776****	**0.675****	**0.729****	**0.604****	**0.656****	**0.650****	**0.852****	**0.583****
SDI	**-0.490****	**-0.480***	**-0.445***	-0.242	**-0.445***	-0.329	**-0.630****	-0.328
ITI (Standard)	**-0.703****	**-0.541***	**-0.685****	**-0.516****	**-0.652****	**-0.761****	**-0.698****	**-0.581****
ITI (Regional)	**-0.819****	**-0.782****	**-0.891****	**-0.609****	**-0.682****	**-0.867****	**-0.827****	**-0.698****
Echinodermata	-0.315	**-0.510***	**-0.497***	-0.149	-0.256	-0.276	**-0.727****	-0.246
Bivalvia	**-0.516****	**-0.471***	**-0.605****	**-0.400***	**-0.470***	**-0.743****	-0.408	**-0.533****
Gastropoda	**-0.747****	**-0.751****	**-0.732****	**-0.628****	**-0.554****	**-0.614****	**-0.851****	**-0.647****
Crustacea (Amphipoda)	0.330	0.133	**0.673****	**0.374***	0.174	0.134	0.161	0.260
Crustacea (other)	**-0.592****	**-0.621****	**-0.619****	**-0.408***	**-0.508****	**-0.679****	**-0.605****	**-0.478***
Polychaeta Errantia	**0.483****	0.376	**0.557****	**0.477***	**0.374***	0.267	**0.551****	0.303
Polychaeta Sedentaria	-0.063	-0.136	0.038	0.034	-0.125	-0.184	-0.001	-0.161
***Capitella capitata* complex**	**0.814****	**0.783****	**0.867****	**0.620****	**0.681****	**0.732****	**0.864****	**0.611****
Miscellaneous Taxa	**-0.48****	**-0.568****	**-0.611****	**-0.385***	-0.253	**-0.507****	**-0.545****	-0.309

OC - organic carbon normalized concentration
Bolded values are statistically significant: ** = $p < 0.01$; * = $p < 0.05$

Table 11: Rank Correlations Between 2010 Sediment Chemistry and Benthic Community Metrics (continued)

Metric	Phenols	2-Methyl-naphthalene	Anthracene	Benzo[a] pyrene	Benzo[b] fluoranthene	Benzo[g,h,i] perylene	Benzo[k]fluor-anthene
Total Abundance	-0.053	-0.003	-0.130	-0.248	-0.263	-0.212	-0.200
Total Richness	**-0.628****	-0.238	**-0.533***	**-0.511****	**-0.512****	**-0.434***	**-0.510****
Polychaete Abundance	**0.785****	0.271	**0.692****	**0.636****	**0.626****	**0.621****	**0.652****
SDI	**-0.443***	-0.129	-0.306	-0.336	-0.328	-0.322	-0.369
ITI (Standard)	**-0.507***	-0.052	**-0.748****	**-0.721****	**-0.698****	**-0.678****	**-0.699****
ITI (Regional)	**-0.658****	-0.110	**-0.847****	**-0.824****	**-0.826****	**-0.755****	**-0.785****
Echinodermata	**-0.468***	-0.201	-0.373	-0.364	-0.362	-0.336	**-0.389***
Bivalvia	-0.417	0.162	**-0.539****	**-0.556****	**-0.563****	**-0.483***	**-0.514****
Gastropoda	**-0.705****	-0.309	**-0.746****	**-0.740****	**-0.750****	**-0.649****	**-0.774****
Crustacea (Amphipoda)	0.214	0.326	**0.694****	**0.514****	**0.513****	**0.545****	**0.527****
Crustacea (other)	-0.390	-0.291	**-0.458***	**-0.434***	**-0.438***	**-0.387***	**-0.390***
Polychaeta Errantia	**0.612****	**0.548****	**0.541****	**0.474***	**0.458***	**0.436***	**0.485***
Polychaeta Sedentaria	0.132	0.236	0.051	-0.053	-0.046	0.033	-0.044
***Capitella capitata* complex**	**0.693****	0.273	**0.667****	**0.637****	**0.625****	**0.602****	**0.658****
Miscellaneous Taxa	-0.381	**-0.396***	**-0.495***	**-0.432***	**-0.445***	**-0.385***	**-0.402***

Metric	normalized)	naphthalene (OC-	normalized)	(OC-normalized)	hene (OC-	ene (OC-	hene (OC-
Total Abundance	0.401	0.257	-0.091	-0.155	-0.160	-0.091	-0.097
Total Richness	-0.086	**0.557****	-0.376	-0.293	-0.302	-0.177	-0.262
Polychaete Abundance	0.293	**-0.573****	**0.483***	**0.454***	**0.447***	0.366	**0.400***
SDI	-0.266	0.250	-0.274	-0.310	-0.313	-0.241	-0.306
ITI (Standard)	0.054	**0.553****	**-0.630****	**-0.614****	**-0.595****	**-0.496****	**-0.566****
ITI (Regional)	0.018	**0.762****	**-0.615****	**-0.616****	**-0.631****	**-0.454***	**-0.511****
Echinodermata	-0.194	0.363	-0.236	-0.190	-0.178	-0.169	-0.192
Bivalvia	0.177	**0.582****	**-0.448***	**-0.450***	**-0.462***	-0.362	**-0.403***
Gastropoda	-0.036	**0.683****	**-0.549****	**-0.526****	**-0.538****	-0.342	**-0.485***
Crustacea (Amphipoda)	0.193	-0.201	**0.505***	**0.466***	**0.471***	**0.490****	**0.446***
Crustacea (other)	0.280	**0.520****	-0.252	-0.227	-0.255	-0.085	-0.145
Polychaeta Errantia	0.272	-0.338	0.249	0.221	0.215	0.101	0.170
Polychaeta Sedentaria	0.311	0.093	-0.093	-0.107	-0.092	-0.046	-0.160
***Capitella capitata* complex**	0.102	**-0.660****	**0.423***	**0.412***	**0.410***	0.296	0.379
Miscellaneous Taxa	0.294	**0.657****	-0.149	-0.076	-0.088	0.056	0.006

OC - organic carbon normalized concentration
Bolded values are statistically significant: ** = $p < 0.01$; * = $p < 0.05$

Table 11: Rank Correlations Between 2010 Sediment Chemistry and Benthic Community Metrics (continued)

Metric	Chrysene	Fluoranthene	Fluorene	Indeno[1,2,3-c,d]pyrene	Naphthalene	Phenanthrene	Pyrene
Total Abundance	-0.144	-0.075	-0.156	-0.171	-0.303	-0.062	-0.099
Total Richness	**-0.457***	**-0.534***	**-0.580****	**-0.451***	**-0.571****	**-0.551****	**-0.532***
Polychaete Abundance	**0.643****	**0.629****	**0.647****	**0.643****	**0.680****	**0.634****	**0.623****
SDI	-0.274	-0.356	**-0.438***	-0.345	**-0.380***	**-0.462***	-0.346
ITI (Standard)	**-0.702****	**-0.629****	**-0.703****	**-0.672****	**-0.694****	**-0.655****	**-0.639****
ITI (Regional)	**-0.785****	**-0.764****	**-0.781****	**-0.748****	**-0.870****	**-0.750****	**-0.772****
Echinodermata	-0.275	-0.376	**-0.512****	-0.360	-0.333	**-0.525****	-0.376
Bivalvia	**-0.540****	**-0.477***	**-0.515****	**-0.466***	**-0.592****	**-0.466***	**-0.483***
Gastropoda	**-0.719****	**-0.788****	**-0.676****	**-0.672****	**-0.717****	**-0.721****	**-0.786****
Crustacea (Amphipoda)	**0.686****	**0.692****	**0.379***	**0.563****	0.291	**0.390***	**0.700****
Crustacea (other)	-0.347	-0.360	**-0.486****	**-0.386***	**-0.771****	**-0.399***	-0.369
Polychaeta Errantia	**0.465***	**0.506***	0.266	**0.460***	**0.389***	0.251	**0.507***
Polychaeta Sedentaria	-0.009	-0.044	-0.072	0.036	-0.037	-0.095	-0.047
***Capitella capitata* complex**	**0.582****	**0.608****	**0.674****	**0.627****	**0.736****	**0.646****	**0.610****
Miscellaneous Taxa	-0.386	-0.408	**-0.526****	-0.368	**-0.652****	**-0.462***	-0.415

Metric	normalized)	normalized)	normalized)	c,d]pyrene (OC-	normalized)	normalized)	normalized)
Total Abundance	-0.063	0.008	0.167	-0.059	0.198	0.196	-0.004
Total Richness	-0.247	-0.382	-0.121	-0.201	0.286	-0.287	-0.384
Polychaete Abundance	**0.462***	0.394	0.211	**0.404***	-0.106	0.281	0.404
SDI	-0.235	-0.374	-0.284	-0.264	-0.082	**-0.445***	-0.373
ITI (Standard)	**-0.556****	**-0.456***	-0.333	**-0.501****	0.014	-0.345	**-0.467***
ITI (Regional)	**-0.547****	**-0.504***	-0.257	**-0.463***	0.119	-0.285	**-0.517***
Echinodermata	-0.091	-0.261	-0.325	-0.209	0.074	-0.341	-0.251
Bivalvia	**-0.453***	-0.365	-0.193	-0.349	0.232	-0.242	-0.372
Gastropoda	**-0.482***	**-0.579****	-0.157	-0.372	0.256	-0.258	**-0.581****
Crustacea (Amphipoda)	**0.493***	**0.486***	0.302	**0.483***	0.046	0.208	**0.502***
Crustacea (other)	-0.143	-0.124	0.101	-0.092	0.056	0.034	-0.144
Polychaeta Errantia	0.167	0.158	-0.260	0.149	-0.269	-0.226	0.180
Polychaeta Sedentaria	-0.098	-0.208	-0.075	-0.032	0.130	-0.221	-0.201
***Capitella capitata* complex**	0.345	0.340	0.136	0.327	-0.216	0.246	0.355
Miscellaneous Taxa	-0.016	-0.028	0.121	0.053	0.277	0.098	-0.036

OC - organic carbon normalized concentration

Bolded values are statistically significant: ** = $p < 0.01$; * = $p < 0.05$

Table 12: Summary Statistics for Benthic Community Parameters (2000-2010 and 2008-2010)

A. Total Abundance

Distance Group	2000-2010 station means							2008-2010 station means						
	n	Mean	Median	SD	Min	Max	%Ref	n	Mean	Median	SD	Min	Max	%Ref
Outfall	10	1539	1496	963	559	3662	399	3	1070	719	631	693	1799	251
100 m stations	80	638	541	414	249	3293	165	24	533	506	175	249	1027	125
200 m stations	80	593	529	289	207	2374	154	24	513	524	142	246	766	120
400 m stations	40	542	492	182	279	995	141	12	579	492	192	397	995	136
800 m stations	20	490	548	225	185	796	127	6	470	456	249	185	796	110
Near-field stations	30	762	541	666	207	3293	197	9	496	481	187	249	731	116
Mid-field stations	70	502	458	201	242	1534	130	21	488	448	110	341	735	114
Far-field stations	120	600	587	221	185	1309	155	36	560	577	196	185	1027	132
Reference stations	42	386	358	147	209	832	100	15	426	409	115	256	702	100
All Stations	272	594	509	398	185	3662	154	84	530	484	219	185	1799	124

B. Polychaete Abundance

Distance Group	2000-2010 station means							2008-2010 station means						
	n	Mean	Median	SD	Min	Max	%Ref	n	Mean	Median	SD	Min	Max	%Ref
Outfall	10	1040	1012	624	391	2043	878	3	768	597	481	397	1311	678
100 m stations	80	365	268	341	102	2679	308	24	285	268	82.8	144	444	251
200 m stations	80	288	219	219	90.0	1538	243	24	256	239	91.8	163	541	225
400 m stations	40	216	191	118	68.3	594	183	12	223	210	66.1	129	368	197
800 m stations	20	176	131	132	91.3	554	149	6	134	134	36.7	91.3	180	118
Near-field stations	30	582	439	504	139	2679	491	9	377	385	113	205	541	333
Mid-field stations	70	297	252	139	110	851	251	21	281	269	58.2	188	402	247
Far-field stations	120	218	163	157	68.3	858	184	36	199	206	52.5	91.3	324	175
Reference stations	42	118	102	57.8	60.3	362	100	15	113	115	22.0	72.7	145	100
All Stations	272	293	203	306	60.3	2679	248	84	243	219	158	72.7	1311	215

C. Total Richness

Distance Group	2000-2010 station means							2008-2010 station means						
	n	Mean	Median	SD	Min	Max	%Ref	n	Mean	Median	SD	Min	Max	%Ref
Outfall	10	47.2	46.9	11.9	29.6	68.0	70	3	37.5	36.4	8.45	29.6	46.4	53
100 m stations	80	63.5	65.3	13.4	30.0	95.0	94	24	57.9	57.5	16.7	30.0	95.0	82
200 m stations	80	66.1	69.8	11.5	39.3	87.5	98	24	60.5	59.5	11.2	39.3	81.7	86
400 m stations	40	74.3	72.8	11.2	54.0	96.7	110	12	72.4	70.7	9.29	60.7	89.7	103
800 m stations	20	75.2	73.8	10.9	57.0	102	111	6	71.8	73.8	9.77	57.0	82.3	102
Near-field stations	30	50.3	49.3	12.0	30.0	76.0	74	9	40.1	39.5	7.47	30.0	54.3	57
Mid-field stations	70	70.1	71.8	12.5	43.3	96.7	104	21	61.8	60.7	11.1	43.3	89.7	88
Far-field stations	120	70.2	70.7	9.58	49.0	102	104	36	69.0	67.5	10.8	49.0	95.0	98
Reference stations	42	67.6	67.1	8.64	50.3	87.8	100	15	70.3	68.3	5.28	61.3	79.0	100
All Stations	272	66.7	68.0	12.8	29.6	102	99	84	63.2	65.7	14.0	29.6	95.0	90

Table 12: Summary Statistics for Benthic Community Parameters (2000-2010 and 2008-2010)

D. SDI

Distance Group	2000-2010 station means							2008-2010 station means						
	n	Mean	Median	SD	Min	Max	%Ref	n	Mean	Median	SD	Min	Max	%Ref
Outfall	10	3.34	3.11	1.75	1.33	6.99	16	3	2.57	1.62	1.90	1.33	4.76	14
100 m stations	80	10.6	10.8	4.89	0.962	27.4	52	24	9.73	8.06	5.52	0.962	27.4	54
200 m stations	80	12.3	12.0	5.20	1.13	26.3	61	24	11.2	10.4	6.04	2.87	26.0	62
400 m stations	40	16.3	14.0	7.24	6.22	30.6	81	12	13.4	13.9	1.98	10.3	18.0	74
800 m stations	20	20.1	18.1	9.63	8.62	36.3	99	6	18.2	18.1	7.92	8.62	26.4	100
Near-field stations	30	5.93	4.79	3.43	0.962	12.8	29	9	4.58	4.36	2.23	0.962	8.26	25
Mid-field stations	70	15.2	13.9	6.12	5.04	30.6	75	21	11.2	10.8	3.41	5.65	18.0	62
Far-field stations	120	13.7	12.1	6.46	4.26	36.3	67	36	13.8	12.1	6.30	5.48	27.4	76
Reference stations	42	20.2	19.2	11.1	10.2	86.3	100	15	18.2	18.2	3.27	12.2	22.6	100
All Stations	272	13.9	12.6	8.10	0.962	86.3	68	84	12.5	11.9	6.26	0.962	27.4	69

E. Echinodermata

Distance Group	2000-2010 station means							2008-2010 station means						
	n	Mean	Median	SD	Min	Max	%Ref	n	Mean	Median	SD	Min	Max	%Ref
Outfall	10	0.942	0.433	1.13	0	3.00	31	3	0	0	0	0	0	0
100 m stations	80	1.63	0.667	2.19	0	11.0	54	24	0.410	0.333	0.518	0	1.67	15
200 m stations	80	1.66	1.00	2.07	0	10.0	55	24	0.740	0.583	0.903	0	3.33	26
400 m stations	40	2.37	1.33	2.44	0	10.0	78	12	2.28	1.00	2.79	0	7.75	81
800 m stations	20	3.30	1.50	4.33	0	16.7	109	6	1.22	1.17	0.720	0.333	2.33	43
Near-field stations	30	1.57	0.708	1.93	0	7.67	52	9	0.324	0.333	0.369	0	1.00	11
Mid-field stations	70	3.09	2.33	2.77	0	11.0	102	21	1.77	0.750	2.33	0	7.75	63
Far-field stations	120	1.34	0.667	2.22	0	16.7	44	36	0.620	0.667	0.575	0	2.33	22
Reference stations	42	3.04	3.00	1.83	0	8.00	100	15	2.82	3.00	1.75	0	6.33	100
All Stations	272	2.06	1.29	2.41	0	16.7	68	84	1.25	0.667	1.68	0	7.75	44

F. Bivalvia

Distance Group	2000-2010 station means							2008-2010 station means						
	n	Mean	Median	SD	Min	Max	%Ref	n	Mean	Median	SD	Min	Max	%Ref
Outfall	10	68.3	56.8	56.5	19.2	188	46	3	20.0	20.4	0.69	19.2	20.4	13
100 m stations	80	177	125	170	3.67	850	120	24	146	100	148	3.67	607	95
200 m stations	80	228	217	162	12.0	629	155	24	173	118	131	12.0	446	113
400 m stations	40	237	157	192	26.0	697	161	12	237	171	184	45.7	626	154
800 m stations	20	212	178	196	18.5	580	144	6	194	167	181	23.7	412	127
Near-field stations	30	32.0	27.2	21.1	3.67	99.0	22	9	20.0	18.3	13.8	3.67	52.3	13
Mid-field stations	70	113	96.3	71.4	26.0	397	77	21	98.6	100	27.7	45.7	140	64
Far-field stations	120	310	316	171	18.5	850	211	36	261	260	159	23.7	626	170
Reference stations	42	147	125	77.2	54.3	349	100	15	153	120	77.1	54.3	349	100
All Stations	272	195	138	163	3.67	850	132	84	167	118	141	3.67	626	109

Table 12: Summary Statistics for Benthic Community Parameters (2000-2010 and 2008-2010)

G. Gastropoda

Distance Group	2000-2010 station means							2008-2010 station means						
	n	Mean	Median	SD	Min	Max	%Ref	n	Mean	Median	SD	Min	Max	%Ref
Outfall	10	10.5	11.6	7.67	0.800	22.3	45	3	1.20	1.00	0.529	0.800	1.80	4
100 m stations	80	18.4	16.5	10.8	2.50	53.7	80	24	15.7	13.3	12.7	2.50	53.7	52
200 m stations	80	20.8	17.7	16.4	1.67	126	90	24	16.9	16.0	10.7	1.7	41.3	56
400 m stations	40	18.2	17.3	8.03	4.50	40.7	78	12	20.5	21.3	7.24	9.33	34.3	68
800 m stations	20	23.5	24.6	9.61	3.00	39.7	102	6	29.8	31.5	8.74	18.7	39.7	98
Near-field stations	30	11.5	9.00	8.30	1.67	31.0	50	9	8.19	6.75	8.26	1.67	28.0	27
Mid-field stations	70	21.1	20.0	11.2	2.50	57.7	91	21	18.9	18.3	12.5	2.50	53.7	62
Far-field stations	120	20.9	18.7	13.7	2.33	126	90	36	20.4	20.5	10.1	2.33	41.3	67
Reference stations	42	23.2	17.2	17.2	2.00	73.7	100	15	30.4	26.0	20.2	10.0	73.7	100
All Stations	272	19.9	17.5	13.5	0.800	126.0	86	84	19.8	17.8	14.3	0.800	73.7	65

H. Amphipoda

Distance Group	2000-2010 station means							2008-2010 station means						
	n	Mean	Median	SD	Min	Max	%Ref	n	Mean	Median	SD	Min	Max	%Ref
Outfall	10	235	114	317	13.6	1076	582	3	75.5	95.8	37.3	32.4	98.2	171
100 m stations	80	76.5	55.3	89.5	5.33	623	190	24	56.6	38.0	44.2	12.3	167	128
200 m stations	80	68.0	47.6	84.1	12.7	712	169	24	44.6	31.7	34.6	12.7	164	101
400 m stations	40	69.8	62.7	44.2	17.3	235	173	12	55.5	40.8	35.8	17.3	141	125
800 m stations	20	50.9	47.0	21.6	20.7	94.8	126	6	42.3	34.5	25.5	20.7	88.7	96
Near-field stations	30	113	57.8	174	12.3	712	280	9	54.8	18.3	62.0	12.3	167	124
Mid-field stations	70	72.6	56.2	51.1	5.33	235	180	21	64.3	44.5	46.6	16.5	164	145
Far-field stations	120	57.5	50.0	35.7	17.3	242	142	36	41.8	37.3	17.9	17.3	88.7	94
Reference stations	42	40.3	35.0	33.1	11.0	216	100	15	44.2	45.0	22.1	18.0	99.0	100
All Stations	272	71.4	50.3	96.9	5.33	1076	177	84	50.5	37.8	35.4	12.3	167	114

I. Crustacea (other)

Distance Group	2000-2010 station means							2008-2010 station means						
	n	Mean	Median	SD	Min	Max	%Ref	n	Mean	Median	SD	Min	Max	%Ref
Outfall	10	264	163	270	14.6	825	463	3	146	157	119	22.4	259	209
100 m stations	80	26.7	16.0	27.4	2.33	152	47	24	25.6	14.0	31.4	2.33	147	37
200 m stations	80	19.6	17.8	13.2	1.67	70.0	34	24	17.3	19.2	12.1	1.67	37.3	25
400 m stations	40	24.4	18.5	17.6	4.67	79.7	43	12	33.4	24.3	26.7	4.67	79.7	48
800 m stations	20	40.9	26.5	38.7	5.33	137	72	6	57.6	29.3	58.8	5.33	137	82
Near-field stations	30	36.8	24.3	38.0	3.00	152	64	9	32.0	11.8	46.7	4.00	147	46
Mid-field stations	70	15.9	12.5	11.9	2.00	79.7	28	21	18.7	15.0	17.9	2.00	79.7	27
Far-field stations	120	27.3	21.2	22.3	1.67	137	48	36	30.4	20.0	31.0	1.67	137	43
Reference stations	42	57.1	45.5	38.3	10.3	161	100	15	69.9	63.0	44.0	11.0	161	100
All Stations	272	38.7	22.0	71.9	1.67	825	68	84	38.8	22.7	45.7	1.67	259	56

Table 12: Summary Statistics for Benthic Community Parameters (2000-2010 and 2008-2010)

J. Polychaete Errantia

Distance Group	2000-2010 station means							2008-2010 station means						
	n	Mean	Median	SD	Min	Max	%Ref	n	Mean	Median	SD	Min	Max	%Ref
Outfall	10	70.1	60.1	42.5	27.6	168	240	3	53.0	64.2	20.3	29.6	65.2	167
100 m stations	80	72.2	59.5	57.0	8.67	407	247	24	64.4	59.0	30.6	8.67	134	203
200 m stations	80	63.1	58.2	27.9	20.7	161	216	24	64.5	66.3	25.1	20.7	127	204
400 m stations	40	63.6	52.7	35.1	25.0	215	218	12	69.5	69.0	26.1	33.3	118	220
800 m stations	20	60.8	50.5	44.9	29.0	238	208	6	45.6	45.7	12.2	29.7	64.3	144
Near-field stations	30	59.4	43.5	70.4	8.67	407	203	9	41.2	43.7	23.4	8.67	87.0	130
Mid-field stations	70	81.2	71.0	39.2	36.3	249	278	21	79.8	79.7	26.4	36.3	127	252
Far-field stations	120	59.3	51.5	33.9	25.0	268	203	36	59.9	56.2	22.7	28.7	134	189
Reference stations	42	29.2	27.8	8.34	14.7	54.0	100	15	31.6	33.3	7.81	20.3	45.7	100
All Stations	272	60.7	52.0	42.0	8.67	407	208	84	57.6	50.5	27.1	8.67	134	182

K. Polychaete Sedentaria

Distance Group	2000-2010 station means							2008-2010 station means						
	n	Mean	Median	SD	Min	Max	%Ref	n	Mean	Median	SD	Min	Max	%Ref
Outfall	10	84.3	78.6	36.4	39.2	151	111	3	73.7	63.6	40.6	39.2	118	90
100 m stations	80	102	95.3	46.9	43.7	356	134	24	109	113	33.7	43.7	183	133
200 m stations	80	105	98.3	39.2	53.7	241	138	24	114	116	13.3	91.3	138	140
400 m stations	40	104	96.3	42.4	31.3	215	137	12	126	128	32.0	80.0	193	155
800 m stations	20	87.7	76.5	55.1	33.0	298	116	6	87.2	89.2	27.1	56.7	128	107
Near-field stations	30	98.8	97.3	29.3	43.7	180	130	9	86.2	96.3	30.2	43.7	130	106
Mid-field stations	70	111	102	44.8	52.0	310	147	21	120	118	28.8	59.3	193	147
Far-field stations	120	97.1	86.8	46.3	31.3	356	128	36	114	116	24.1	56.7	183	139
Reference stations	42	75.9	71.0	25.8	37.7	147	100	15	81.6	81.0	16.8	52.0	106	100
All Stations	272	97.2	91.6	42.6	31.3	356	128	84	105	106	29.7	39.2	193	129

L. *Capitella capitata* complex

Distance Group	2000-2010 station means							2008-2010 station means						
	n	Mean	Median	SD	Min	Max	%Ref	n	Mean	Median	SD	Min	Max	%Ref
Outfall	10	748	656	505	208	1759	801907	3	642	528	495	213	1183	481300
100 m stations	80	159	93.5	288	0	2200	170303	24	112	111	95.7	4.3	374	83651
200 m stations	80	80.8	32.2	178	0	1304	86698	24	77.1	45.3	102	0	394	57820
400 m stations	40	17.0	11.0	20.4	0	67.3	18243	12	27.0	17.8	25.4	0	66.0	20286
800 m stations	20	1.02	0.583	1.65	0	7.25	1095	6	0.833	0.667	0.888	0	2.33	625
Near-field stations	30	403	298	444	42.3	2200	432234	9	250	251	111	106	394	187444
Mid-field stations	70	79.3	58.3	81.9	3.00	473	85039	21	80.8	72.0	50.3	11.3	190	60619
Far-field stations	120	18.6	6.13	32.1	0	234	19933	36	25.3	10.0	31.7	0	122	18958
Reference stations	42	0.093	0	0.337	0	2.00	100	15	0.133	0	0.516	0	2.00	100
All Stations	272	101	17.7	249	0	2200	107849	84	80.8	26.0	158	0	1183	60570

Table 12: Summary Statistics for Benthic Community Parameters (2000-2010 and 2008-2010)

M. Miscellaneous Taxa

Distance Group	2000-2010 station means							2008-2010 station means						
	n	Mean	Median	SD	Min	Max	%Ref	n	Mean	Median	SD	Min	Max	%Ref
Outfall	10	58.3	47.5	45.2	7.750	137	661	3	59.1	45.4	48.1	19.4	113	612
100 m stations	80	5.82	4.58	5.41	0	35.3	66	24	4.99	5.58	2.80	0	10.3	52
200 m stations	80	5.97	4.83	5.05	0	28.5	68	24	4.65	4.83	2.24	0.667	9.33	48
400 m stations	40	6.18	6.29	3.55	0.667	14.0	70	12	6.97	6.50	2.87	1.00	10.7	72
800 m stations	20	8.92	9.13	6.26	2.00	26.0	101	6	9.50	5.33	8.98	2.33	26.0	98
Near-field stations	30	5.38	3.00	7.45	0	35.3	61	9	3.27	2.67	2.14	0.333	7.67	34
Mid-field stations	70	4.77	4.33	3.36	0	16.5	54	21	4.85	5.33	2.84	0	10.7	50
Far-field stations	120	7.28	6.00	5.05	0.667	28.5	83	36	6.69	6.33	4.26	0.667	26.0	69
Reference stations	42	8.82	7.50	5.16	0.333	30.3	100	15	9.67	8.00	7.26	0.333	30.3	100
All Stations	272	8.54	5.67	13.7	0	137	97	84	8.27	6.13	13.2	0	113	86

I. ITI (Standard)

Distance Group	2000-2010 station means							2008-2010 station means						
	n	Mean	Median	SD	Min	Max	%Ref	n	Mean	Median	SD	Min	Max	%Ref
Outfall	5	24.7	16.4	14.5	12.0	41.0	42	3	22.8	16.4	15.1	12.0	40.1	38
100 m stations	40	46.1	46.7	11.8	12.2	63.7	78	24	44.9	44.6	12.5	12.2	63.7	76
200 m stations	40	52.5	55.7	10.0	19.1	69.0	89	24	52.0	55.7	12.2	19.1	69.0	87
400 m stations	20	57.5	58.4	3.69	49.7	62.1	97	12	57.8	58.8	3.88	49.7	62.1	97
800 m stations	10	58.3	59.4	4.21	48.2	63.2	98	6	60.1	60.3	2.53	55.8	63.2	101
Near-field stations	15	32.1	35.9	10.6	12.2	46.9	54	9	28.0	29.0	10.0	12.2	39.5	47
Mid-field stations	35	49.6	49.7	6.38	36.4	61.7	84	21	49.3	49.0	7.22	36.4	61.7	83
Far-field stations	60	57.7	58.0	4.33	45.6	69.0	97	36	58.1	58.4	4.64	45.6	69.0	98
Reference stations	25	59.3	59.2	3.19	52.4	66.0	100	15	59.5	59.2	3.87	52.4	66.0	100
All Stations	140	52.1	56.4	11.5	12.0	69.0	88	84	51.7	56.6	12.7	12.0	69.0	87

Table 13: Spearman Rank Correlations between Benthic Community Parameters and Distance from the Outfall (2000-2010)

Parameter	2000-2010[1]	2008-2010	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total Abundance	**-0.355**	**-0.251**	**-0.686**	**-0.586**	**-0.474**	**-0.530**	**-0.485**	-0.298	-0.333	-0.361	-0.278	-0.092
Polychaete Abundance	**-0.571**	**-0.733**	**-0.629**	**-0.677**	**-0.489**	**-0.565**	**-0.638**	**-0.731**	**-0.774**	**-0.740**	**-0.792**	**-0.720**
Total Richness	**0.266**	**0.487**	**0.541**	0.183	0.126	0.017	0.098	0.205	**0.436**	**0.597**	**0.411**	**0.635**
Echinodermata	**0.302**	**0.582**	0.225	-0.053	0.258	0.156	0.141	0.341	**0.546**	**0.647**	**0.432**	**0.711**
Bivalvia	0.095	**0.234**	0.041	0.003	-0.090	-0.045	0.090	0.128	0.154	0.104	**0.375**	0.232
Gastropoda	**0.131**	**0.442**	-0.301	-0.237	-0.146	0.051	0.016	-0.074	0.232	0.271	0.232	**0.772**
Crustacea (amphipoda)	**-0.209**	-0.062	**-0.466**	-0.215	-0.286	**-0.594**	**-0.487**	0.206	-0.153	0.332	**-0.417**	-0.327
Crustacea (other)	**0.212**	**0.318**	0.131	0.132	0.317	-0.240	0.249	0.324	0.299	**0.464**	0.326	**0.477**
Polychaete Errantia	**-0.377**	**-0.360**	**-0.477**	**-0.493**	-0.231	**-0.566**	**-0.454**	-0.270	**-0.411**	-0.371	-0.362	**-0.481**
Polychaete Sedentaria (other)	**-0.185**	**-0.245**	0.057	**-0.585**	0.139	-0.356	-0.170	**-0.465**	**-0.578**	**-0.408**	-0.224	-0.062
Capitella capitata complex	**-0.739**	**-0.755**	**-0.817**	**-0.740**	**-0.600**	**-0.751**	**-0.737**	**-0.792**	**-0.770**	**-0.788**	**-0.730**	**-0.753**
Miscellaneous Taxa	**0.149**	0.182	-0.158	0.102	-0.024	-0.136	**0.436**	**0.457**	0.192	0.216	-0.220	**0.470**
SDI	**0.544**	**0.618**	**0.604**	**0.624**	**0.549**	**0.514**	**0.449**	**0.498**	**0.402**	**0.696**	**0.560**	**0.620**
ITI-Standard[2]	**0.577**	**0.595**	NM	NM	NM	NM	NM	**0.573**	**0.499**	**0.704**	**0.611**	**0.573**

[1] Excluding 2001 (due to anomalous invertebrate taxonomy)

[2] ITI-Standard data available only from 2006 through 2010

NM = parameter was not measured this year

Statistically significant correlations ($p < 0.05$) are **bolded**

X = strong correlation ($|r_s| > 0.6$)

X = moderate strength correlation ($0.4 < |r_s| < 0.6$)

Bold & underlined = weak ($|r_s| < 0.4$) but statistically significant correlation.

Table 14: Spearman Rank Correlations between Benthic Community Parameters and Distance-Direction Gradient (i.e., Outfall/Mid-field/Near-field/Far-field/Reference; 2000-2010)

Parameter	2000-2010[1]	2008-2010	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total Abundance	**-0.225**	-0.145	**-0.474**	**-0.488**	-0.236	-0.290	**-0.377**	0.001	-0.215	-0.092	**-0.375**	0.072
Polychaete Abundance	**-0.686**	**-0.824**	**-0.769**	**-0.914**	**-0.910**	-0.311	**-0.933**	**-0.828**	**-0.891**	**-0.829**	**-0.918**	**-0.782**
Total Richness	**0.270**	**0.576**	**0.561**	-0.021	0.077	0.059	-0.022	0.219	**0.390**	**0.624**	**0.579**	**0.734**
Echinodermata	0.059	**0.349**	-0.089	-0.332	-0.151	0.005	-0.197	0.133	0.204	0.370	0.363	0.318
Bivalvia	**0.492**	**0.543**	**0.621**	**0.413**	**0.449**	**0.443**	**0.520**	**0.572**	**0.458**	**0.422**	**0.589**	**0.596**
Gastropoda	**0.186**	**0.433**	-0.367	**-0.394**	0.125	0.256	0.102	0.123	**0.393**	0.238	0.292	**0.779**
Crustacea (amphipoda)	**-0.251**	-0.044	**-0.582**	-0.178	**-0.565**	**-0.512**	**-0.487**	0.263	-0.319	**0.406**	**-0.555**	-0.184
Crustacea (other)	**0.243**	**0.311**	**0.451**	-0.134	0.240	0.074	0.370	0.371	0.186	**0.414**	0.161	**0.656**
Polychaete Errantia	**-0.401**	**-0.334**	**-0.585**	**-0.480**	-0.318	**-0.504**	**-0.526**	-0.311	**-0.598**	-0.353	-0.300	**-0.495**
Polychaete Sedentaria (other)	**-0.255**	-0.156	0.034	**-0.775**	-0.265	**-0.510**	**-0.515**	**-0.471**	**-0.696**	**-0.457**	-0.083	0.143
Capitella capitata complex	**-0.849**	**-0.853**	**-0.817**	**-0.883**	**-0.895**	**-0.877**	**-0.918**	**-0.858**	**-0.864**	**-0.855**	**-0.867**	**-0.856**
Miscellaneous Taxa	**0.246**	**0.284**	0.219	0.326	-0.072	-0.219	**0.519**	**0.585**	**0.424**	**0.418**	-0.182	**0.549**
SDI	**0.450**	**0.649**	**0.426**	**0.419**	0.271	**0.430**	0.293	0.211	**0.401**	**0.720**	**0.692**	**0.550**
ITI-Standard[2]	**0.716**	**0.698**	NM	NM	NM	NM	NM	**0.839**	**0.700**	**0.771**	**0.768**	**0.719**

[1] Excluding 2001 (due to anomalous invertebrate taxonomy)

[2] ITI-Standard data available only from 2006 through 2010

NM = parameter was not measured this year

Statistically significant correlations ($p < 0.05$) are **bolded**

X = strong correlation ($|r_s| > 0.6$)

X = moderate strength correlation ($0.4 < |r_s| < 0.6$)

Bold & underlined = weak ($|r_s| < 0.4$) but statistically significant correlation.

Table 15: Results of Analysis of Variance (ANOVA or Kruskall-Wallis) and *Post hoc* Statistical Comparisons to Reference for Macaulay Point Distance Groups (2000-2010)

Parameter	All Years (2000-2010)[1]						Recent Years (2008-2010)					
	ANOVA/ Kruskall-Wallis	Comparison with Reference					ANOVA/ Kruskall-Wallis	Comparison with Reference				
		Outfall	100 m	200 m	400 m	800 m		Outfall	100 m	200 m	400 m	800 m
Total Abundance	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	1.00	**0.044**	0.054	0.217	0.391	0.179	1.00
Polychaete Abundance	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.027**	**<0.001**	**0.038**	**<0.001**	**<0.001**	**<0.001**	1.00
Total Richness	**<0.001**	**<0.001**	0.806	1.00	**0.034**	0.063	**<0.001**	**0.038**	**0.027**	**0.023**	1.00	1.00
Echinodermata	**<0.001**	**0.005**	**<0.001**	**<0.001**	0.163	0.584	**<0.001**	0.096	**<0.001**	**0.001**	0.851	0.192
Bivalvia	**0.007**	**0.005**	1.00	0.158	1.00	1.00	0.088	NC	NC	NC	NC	NC
Gastropoda	**0.041**	0.163	1.00	1.00	1.00	1.00	**<0.001**	**0.038**	**0.039**	0.216	1.00	1.00
Crustacea (amphipoda)	**<0.001**	**0.007**	**0.001**	**0.004**	**<0.001**	0.057	0.558	NC	NC	NC	NC	NC
Crustacea (other)	**<0.001**	**0.048**	**<0.001**	**<0.001**	**<0.001**	0.066	**<0.001**	1.00	**0.002**	**<0.001**	0.096	1.00
Polychaete Errantia	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.548	**<0.001**	**<0.001**	**<0.001**	0.079
Polychaete Sedentaria (other)	**<0.001**	1.00	**<0.001**	**<0.001**	**0.012**	1.00	**<0.001**	1.00	**0.011**	**<0.001**	**0.004**	1.00
Capitella capitata complex	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.001**	**<0.001**	**<0.001**	**<0.001**	**0.034**
Miscellaneous Taxa	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.051	1.00	**0.001**	0.075	0.057	**0.015**	1.00	1.00
SDI	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.118	1.00	**<0.001**	**0.038**	**<0.001**	**0.002**	**0.003**	1.00
ITI-Standard[2]	**<0.001**	**0.003**	**<0.001**	**0.002**	0.965	1.00	**<0.001**	**0.038**	**<0.001**	0.090	1.00	1.00

[1] Excluding 2001 (due to anomalous invertebrate taxonomy)

[2] ITI-Standard data available only from 2006 through 2010

Significant differences relative to references ($p < 0.05$) are bolded.

NC = Not calculated; no comparison made as ANOVA (or non parametric Kruskal-Wallis test if applicable) was not significant.

Table 16: Results of Analysis of Variance (ANOVA or Kruskall-Wallis) and Post hoc Statistical Comparisons to Reference for Macaulay Point Distance-Direction Groups (2000-2010)

Parameter	All Years (2000-2010)[1]					Recent Years (2008-2010)				
	ANOVA/ Kruskall-Wallis	Comparison with Reference				ANOVA/ Kruskall-Wallis	Comparison with Reference			
		Outfall	Near-field	Mid-field	Far-Field		Outfall	Near-field	Mid-field	Far-Field
Total Abundance	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.015**	**0.043**	1.00	0.577	0.056
Polychaete Abundance	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.031**	**<0.001**	**<0.001**	**<0.001**
Total Richness	**<0.001**	**<0.001**	**<0.001**	0.858	0.509	**<0.001**	**<0.001**	**<0.001**	**0.040**	0.976
Echinodermata	**<0.001**	**0.004**	**0.002**	1.00	**<0.001**	**<0.001**	0.077	**0.005**	0.155	**<0.001**
Bivalvia	**<0.001**	**0.004**	**<0.001**	**0.022**	**<0.001**	**<0.001**	**0.031**	**<0.001**	0.091	0.126
Gastropoda	**<0.001**	0.131	**0.005**	1.00	1.00	**<0.001**	**0.031**	**0.003**	0.526	0.651
Crustacea (amphipoda)	**<0.001**	**0.005**	0.232	**<0.001**	**<0.001**	0.276	NC	NC	NC	NC
Crustacea (other)	**<0.001**	**0.038**	**0.015**	**<0.001**	**<0.001**	**<0.001**	0.818	**0.011**	**<0.001**	**0.003**
Polychaete Errantia	**<0.001**	**<0.001**	**0.006**	**<0.001**	**<0.001**	**<0.001**	0.438	1.00	**<0.001**	**<0.001**
Polychaete Sedentaria (other)	**<0.001**	0.945	**0.007**	**<0.001**	**0.004**	**<0.001**	0.969	0.981	**<0.001**	**<0.001**
Capitella capitata complex	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.001**	**<0.001**	**<0.001**	**<0.001**
Miscellaneous Taxa	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.045**	**<0.001**	0.060	**0.011**	**0.029**	0.321
SDI	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.031**	**<0.001**	**<0.001**	**0.015**
ITI-Standard[2]	**<0.001**	**0.002**	**<0.001**	**<0.001**	0.540	**<0.001**	**0.031**	**<0.001**	**<0.001**	1.00

[1] Excluding 2001 (due to anomalous invertebrate taxonomy)

[2] ITI-Standard data available only from 2006 through 2010

Significant differences relative to references ($p < 0.05$) are bolded.

NC = Not calculated; no comparison made as ANOVA (or non parametric Kruskal-Wallis test if applicable) was not significant.

Table 17: Spearman Rank Correlations for Temporal Trends in Benthic Community Parameters (2000-2010)[1]

Parameter	All Outfall Monitoring Stations	By Distance Group						By Distance-Direction Group		
		Outfall	100 m	200 m	400 m	800 m	Reference (untransformed)	Near-field	Mid-field	Far-field
Total Abundance	**-0.393**	**-0.745**	**-0.570**	**-0.502**	-0.085	-0.229	0.279	**-0.843**	**-0.415**	**-0.324**
Polychaete Abundance	-0.039	-0.576	-0.102	-0.059	0.161	-0.347	0.047	**-0.549**	-0.098	0.016
Total Richness	**-0.258**	-0.394	**-0.280**	**-0.415**	-0.095	-0.178	0.073	**-0.489**	**-0.418**	**-0.188**
Echinodermata	**-0.350**	**-0.841**	**-0.456**	**-0.402**	-0.072	-0.139	-0.115	**-0.573**	**-0.378**	**-0.289**
Bivalvia	**-0.170**	**-0.685**	-0.189	**-0.280**	-0.002	-0.133	0.062	**-0.384**	-0.171	**-0.261**
Gastropoda	**-0.399**	**-0.927**	**-0.543**	**-0.385**	-0.134	-0.057	**0.436**	**-0.631**	**-0.526**	**-0.252**
Crustacea (amphipoda)	**-0.296**	**-0.709**	**-0.307**	**-0.297**	-0.249	-0.235	-0.067	**-0.584**	-0.145	**-0.299**
Crustacea (other)	**-0.180**	-0.309	**-0.227**	**-0.308**	0.152	0.057	0.260	-0.223	**-0.281**	-0.113
Polychaete Errantia	**-0.294**	-0.588	**-0.345**	-0.219	-0.155	**-0.534**	0.201	**-0.372**	**-0.436**	**-0.241**
Polychaete Sedentaria (other)	0.116	-0.079	0.102	0.168	0.249	-0.160	0.117	-0.203	0.082	**0.272**
Capitella capitata complex	-0.088	-0.394	-0.126	-0.087	0.099	-0.207	-0.132	**-0.488**	-0.101	-0.041
Miscellaneous Taxa	**-0.198**	0.127	**-0.222**	**-0.354**	-0.045	-0.175	0.099	-0.159	-0.167	**-0.287**
SDI	-0.074	-0.103	-0.099	-0.151	-0.151	-0.205	**-0.308**	-0.023	**-0.356**	-0.013
ITI-Standard[2]	0.023	-0.200	-0.086	0.119	0.049	0.394	-0.122	-0.436	-0.026	0.122

[1] Excluding 2001 (due to anomalous invertebrate taxonomy)

[2] ITI-Standard data available only from 2006 through 2010

Statistically significant correlations ($p < 0.05$) are bolded.

Bold & underlined = weak ($|r_s| < 0.4$) but statistically significant correlation.

X = strong correlation ($|r_s| > 0.6$)

X = moderate strength correlation ($0.4 < |r_s| < 0.6$)

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2010 Benthic Report Tables for CRD gsl.xlsx [Table 17]

Table 18: Summary of Van Belle Test for Homogeneity of Temporal Trends in Benthic Community Parameters Among Macaulay Point Stations (2000-2010)[1]

Parameter	Chi-square Homogeneity Test Statistics			
	All Stations	*p* -value	Reference Excluded	*p* -value
Total Abundance	39.8	0.05	16.3	0.80
Polychaete Abundance	34.6	0.15	21.1	0.51
Total Richness	41.4	**0.04**	21.5	0.49
Echinodermata	32.3	0.22	18.6	0.67
Bivalvia	34.8	0.14	26.0	0.25
Gastropoda	48.6	**0.01**	36.4	**0.03**
Crustacea (amphipoda)	21.9	0.74	7.2	1.00
Crustacea (other)	27.1	0.46	23.0	0.40
Polychaete Errantia	25.9	0.52	18.7	0.66
Polychaete Sedentaria (other)	28.2	0.40	19.7	0.60
Capitella capitata complex	22.4	0.61	21.5	0.49
Miscellaneous Taxa	14.0	0.98	10.2	0.98
SDI	32.2	0.23	30.2	0.11
ITI-Standard[2]	22.2	0.72	21.0	0.52

[1] Excluding 2001

[2] ITI-Standard data available only from 2006 through 2010

Statistically significant values ($p < 0.05$) are **bolded**.

Figure 1 - Macaulay Point 2010 Seafloor Monitoring - Locations of Benthic Community Stations

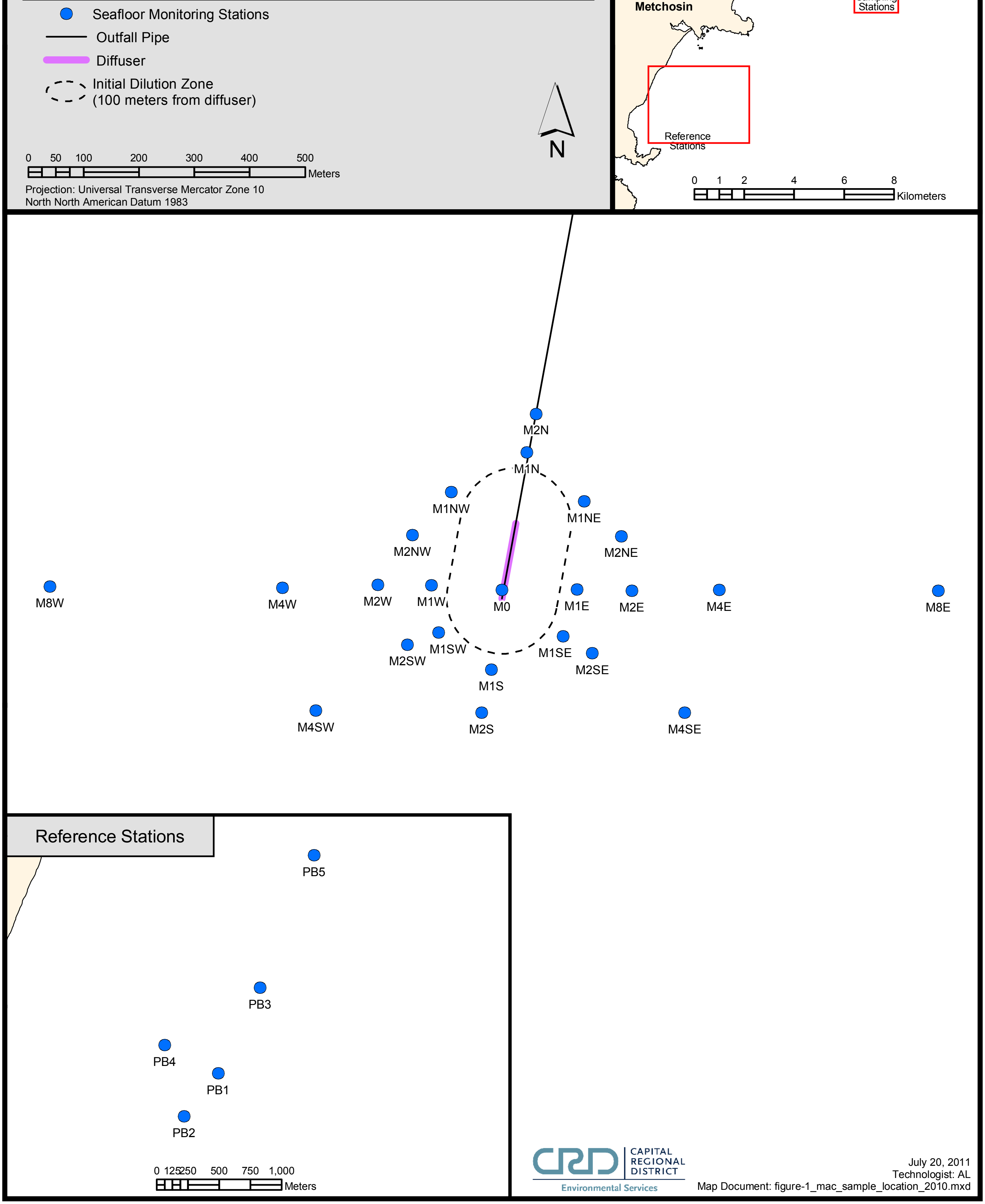

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Figure 2 - Conceptual Model of Macaulay Point Outfall, Showing Relationship between Sediment and Resident Biota

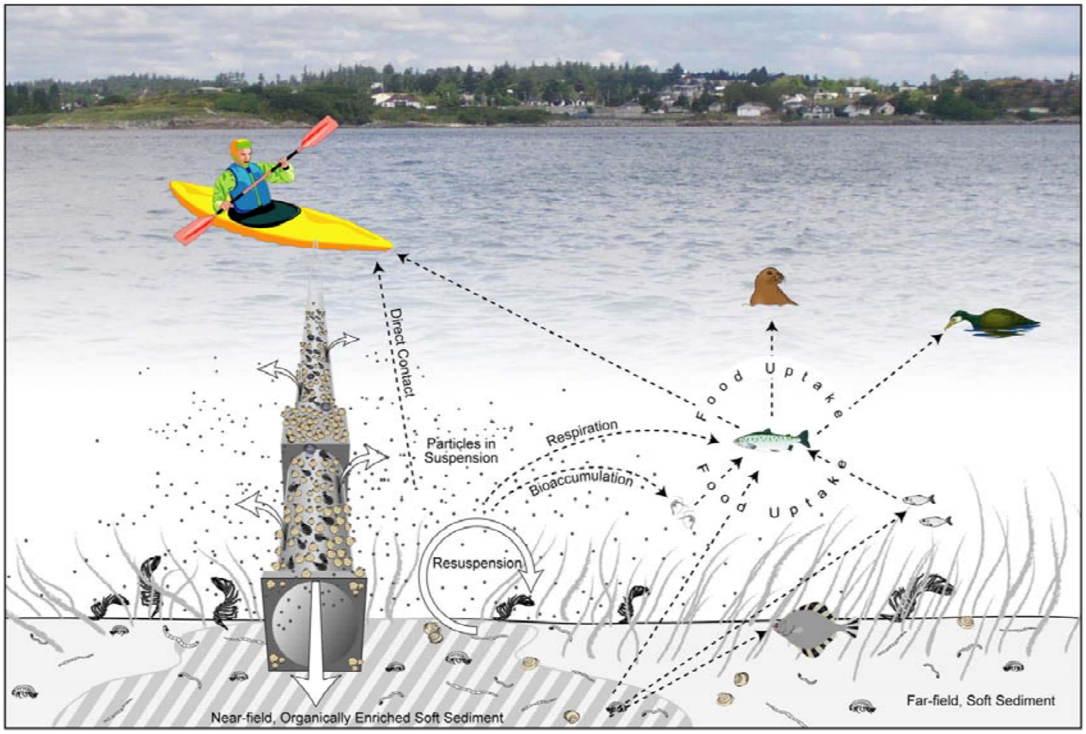
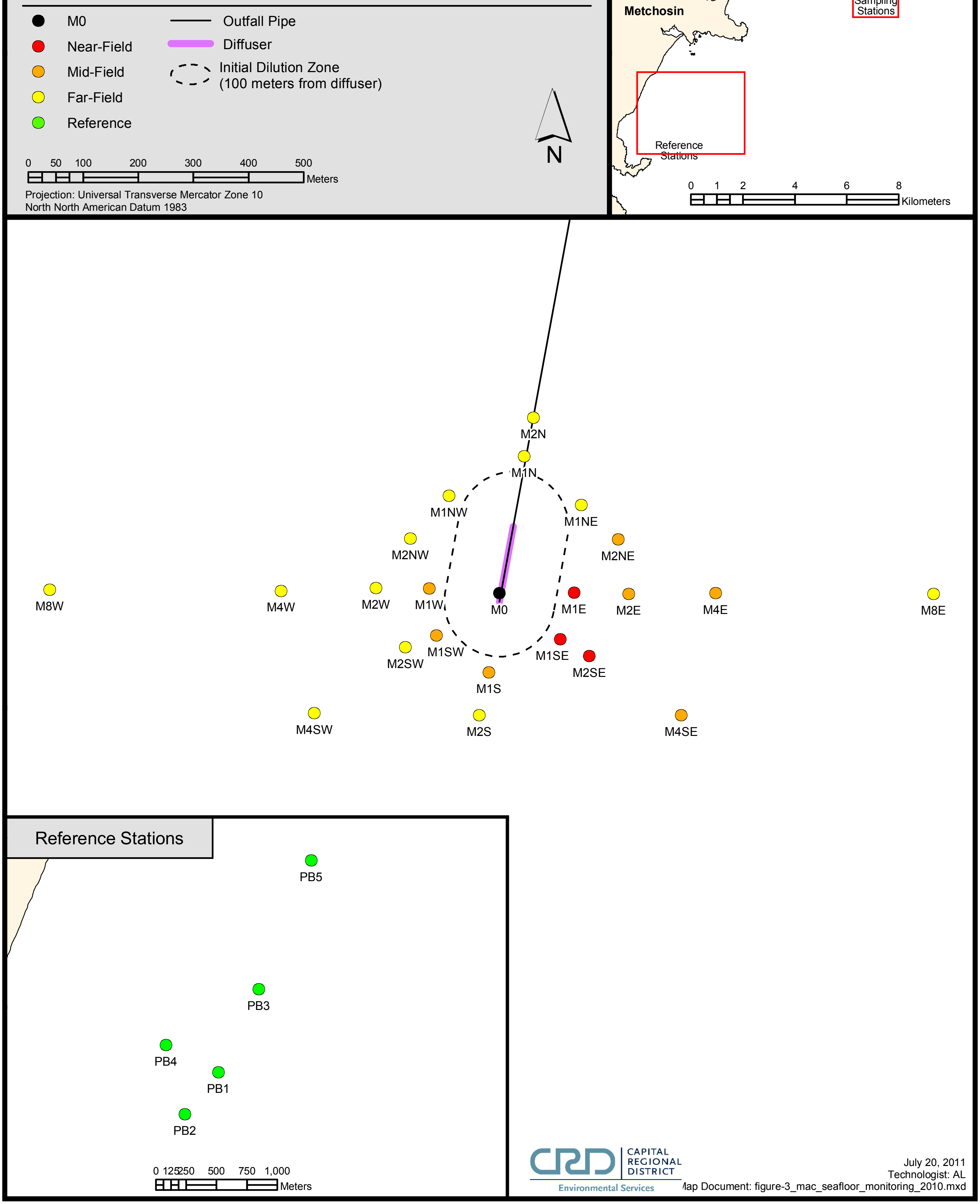


Figure 3 - Macaulay Point 2010 Seafloor Monitoring - Locations of Benthic Community Stations by Distance-Direction Group



July 20, 2011
Technologist: AL
Map Document: figure-3_mac_seafloor_monitoring_2010.mxd

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Figure 4 - Categorization of Spatial Patterns in Individual Taxa

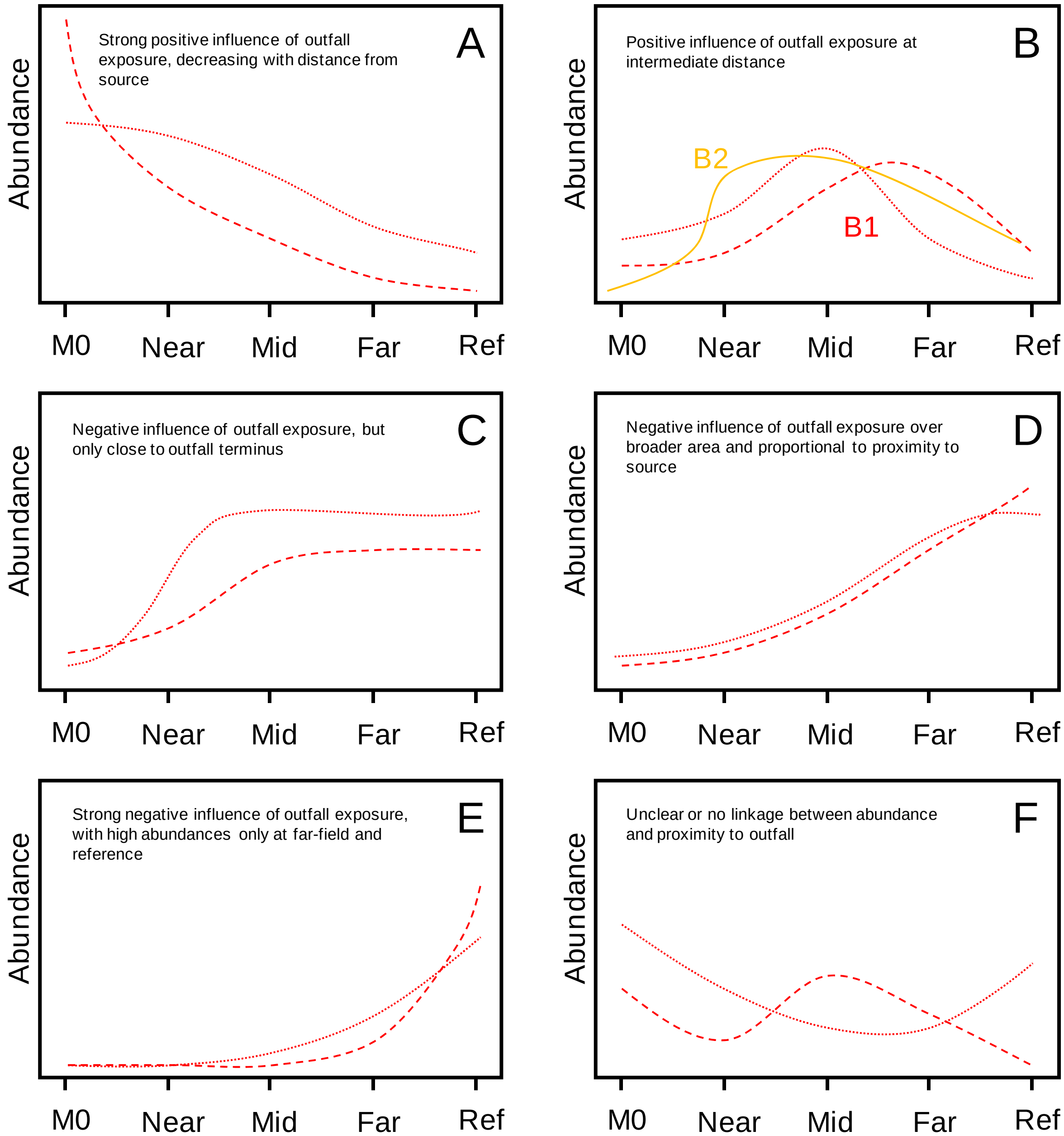


Figure 5 - Conceptual Model of Benthic Community along Gradient of Environmental Disturbance

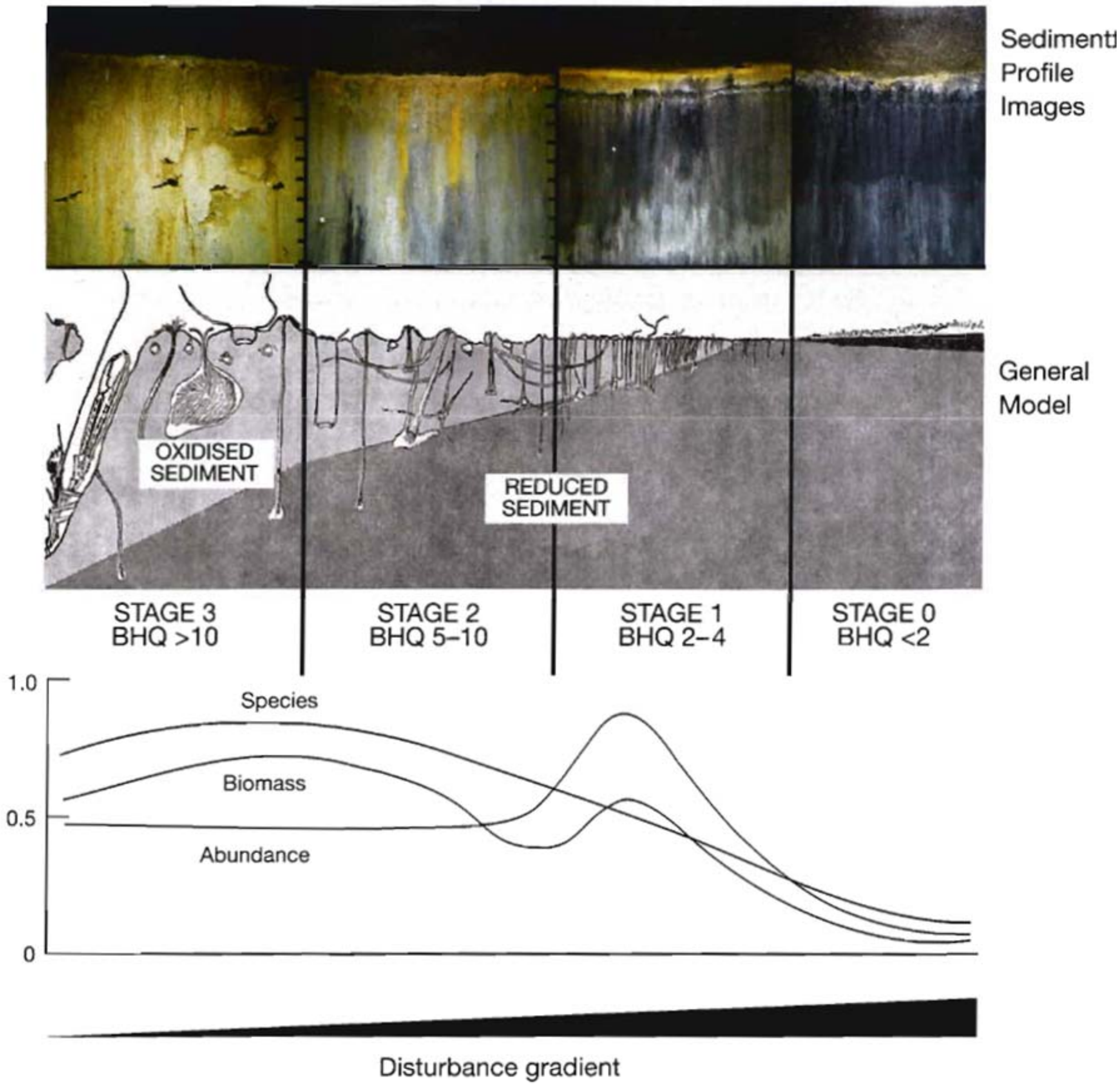


Figure 6: Multidimensional Scaling of 2008-2010 Macaulay Point Benthic Community Major Taxonomic Abundances Coded Based on Distance-Direction Groups

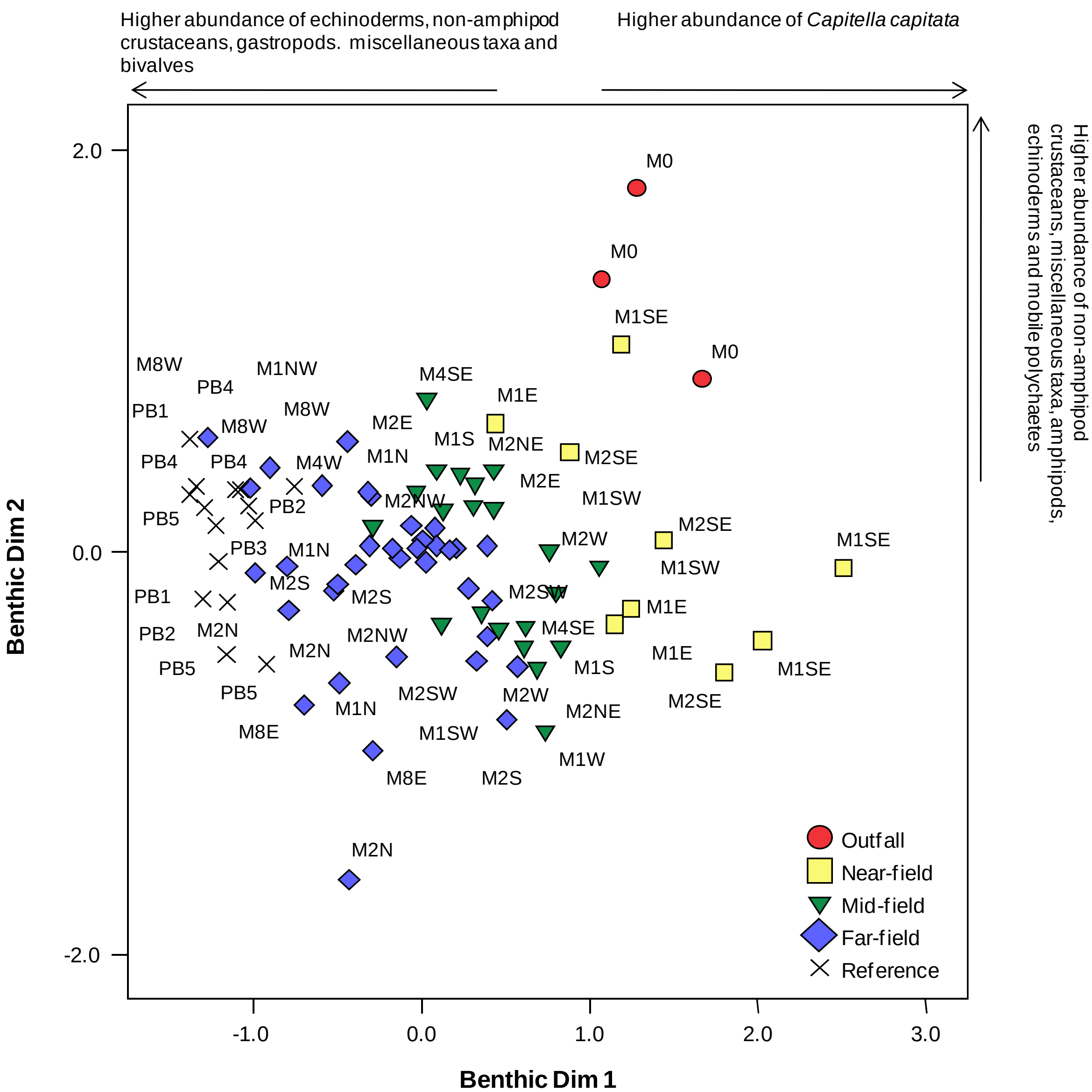


Figure 7: Multidimensional Scaling of 2008-2010 Macaulay Point Sediment Chemistry Parameters Coded Based on Distance-Direction Groups

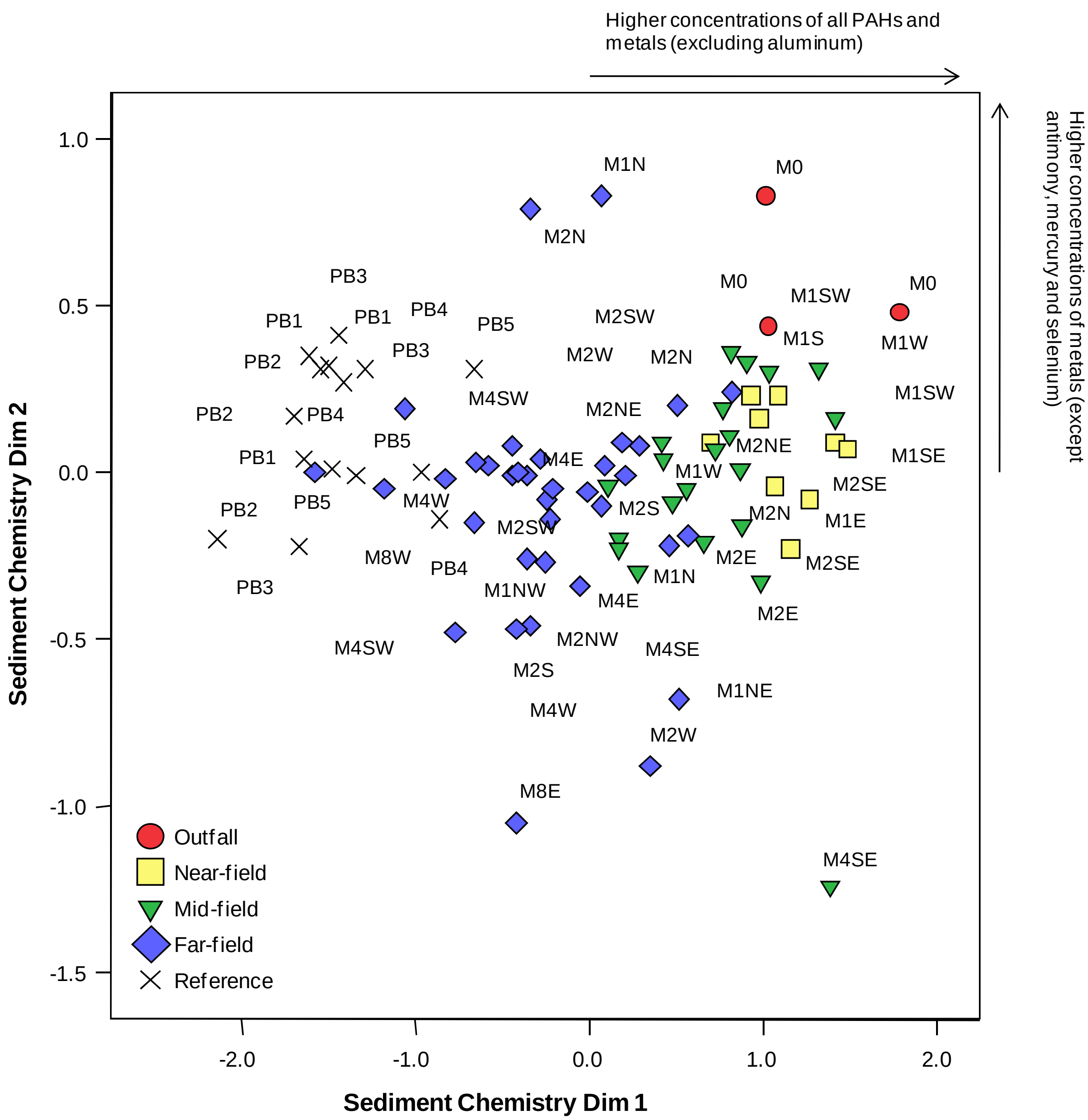


Figure 8: Box and Whisker Plots (Top Panel) and Means ± 95% Confidence Intervals (Bottom Panel) for 2010 Benthic Community Metrics

(a) Total Organism Abundance

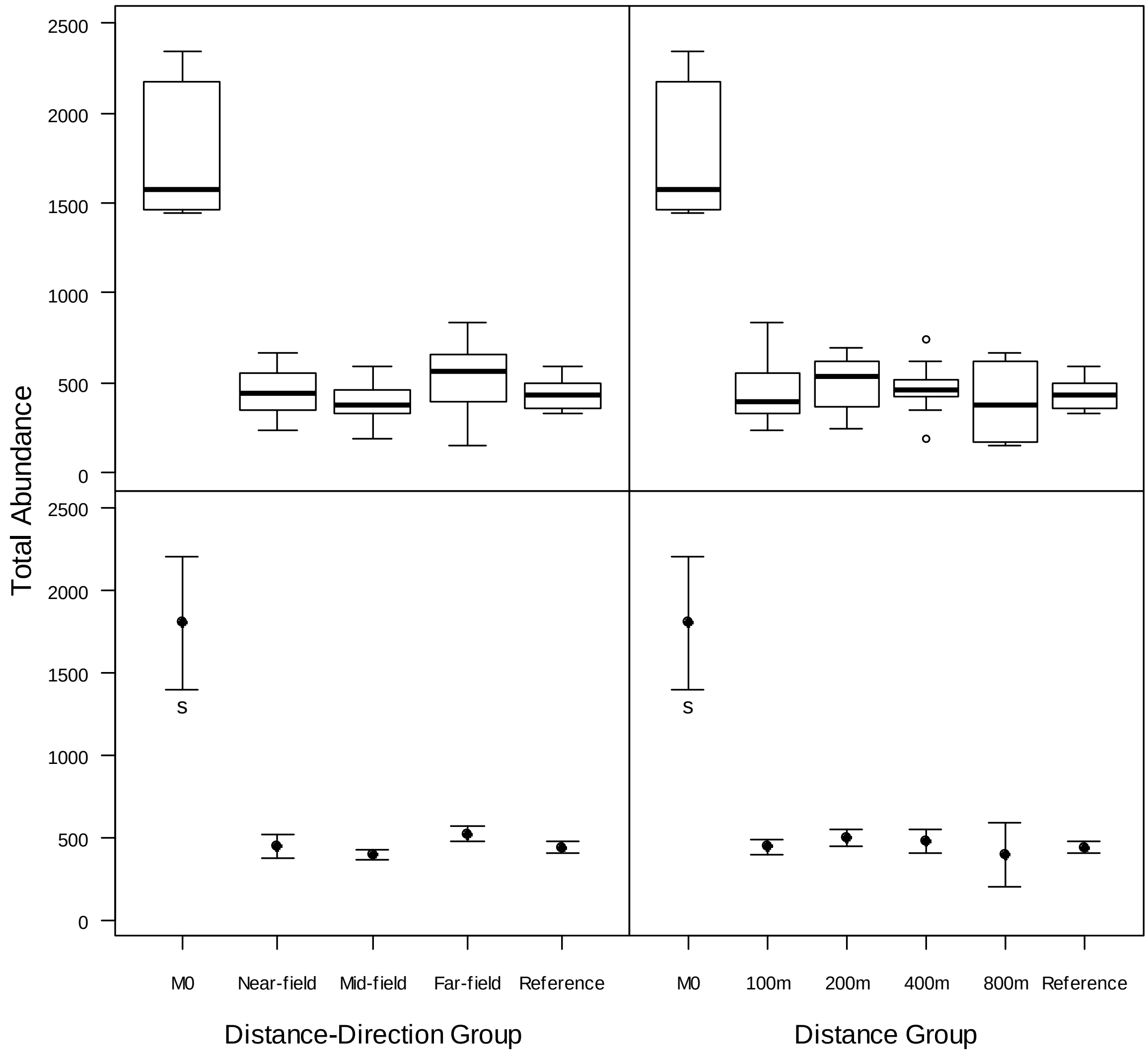


Figure 8: (Continued)

(b) Polychaete Abundance

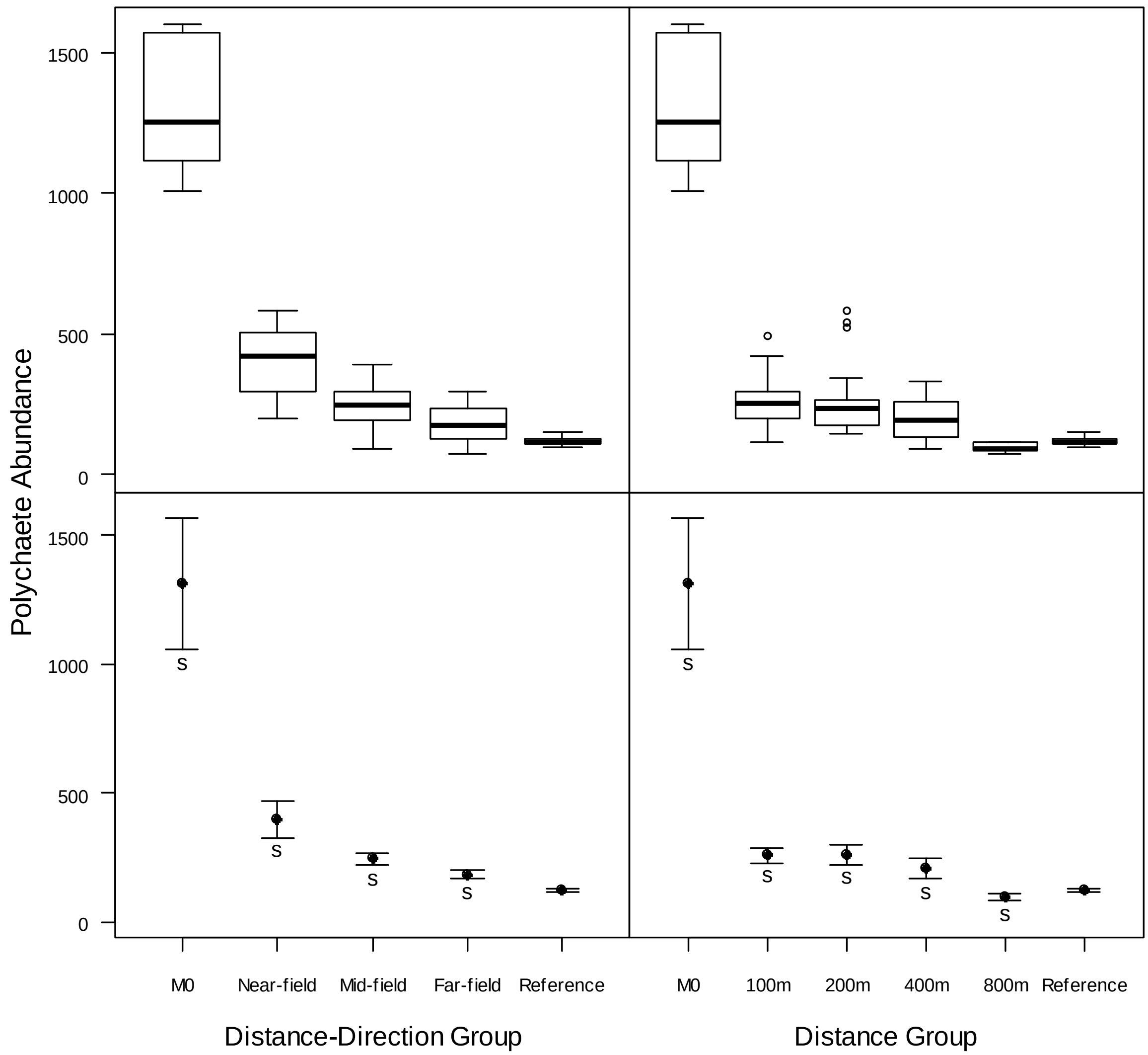


Figure 8: (Continued)

(c) Taxonomic Richness

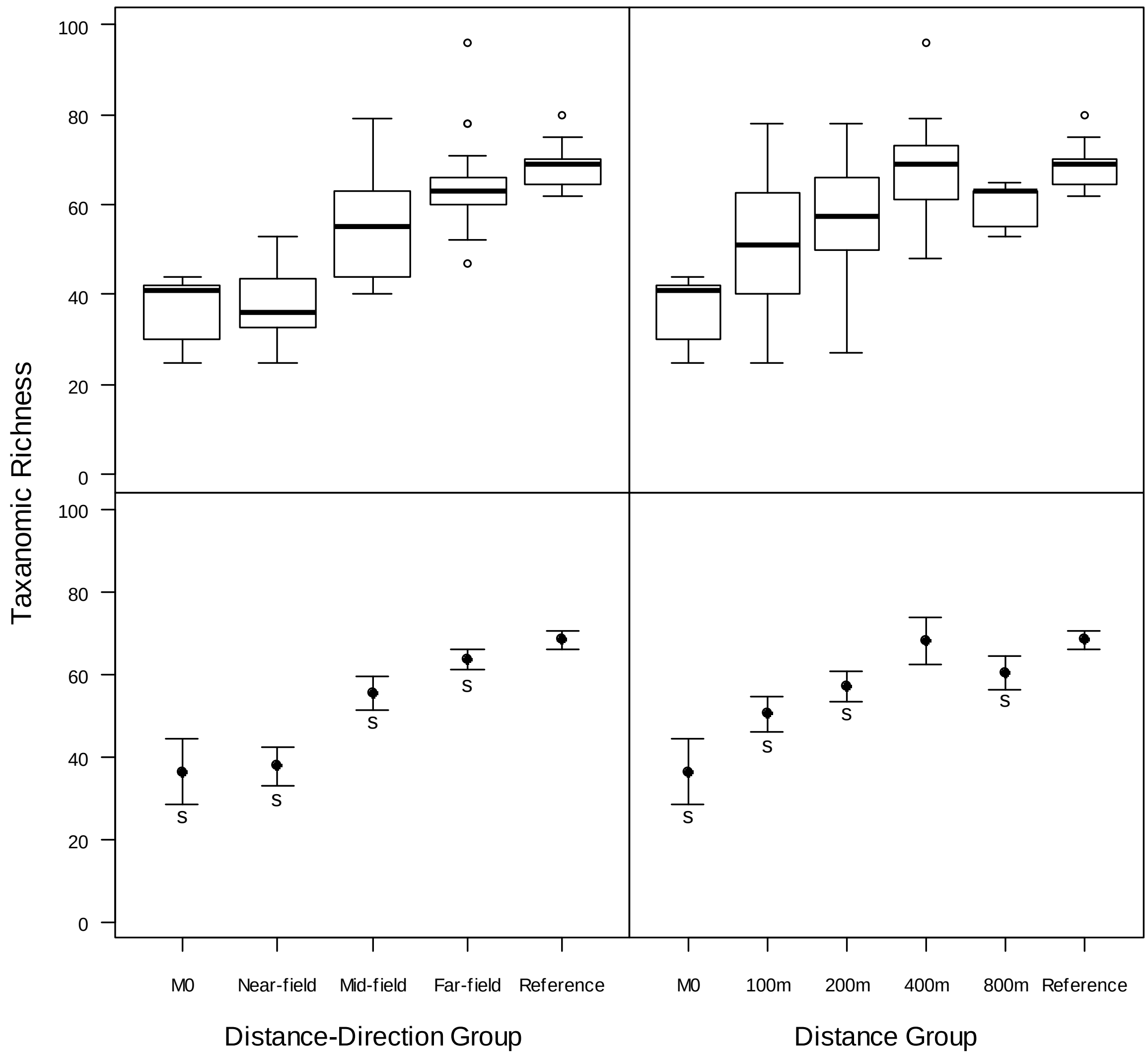


Figure 8: (Continued)

(d) Swartz Dominance Index

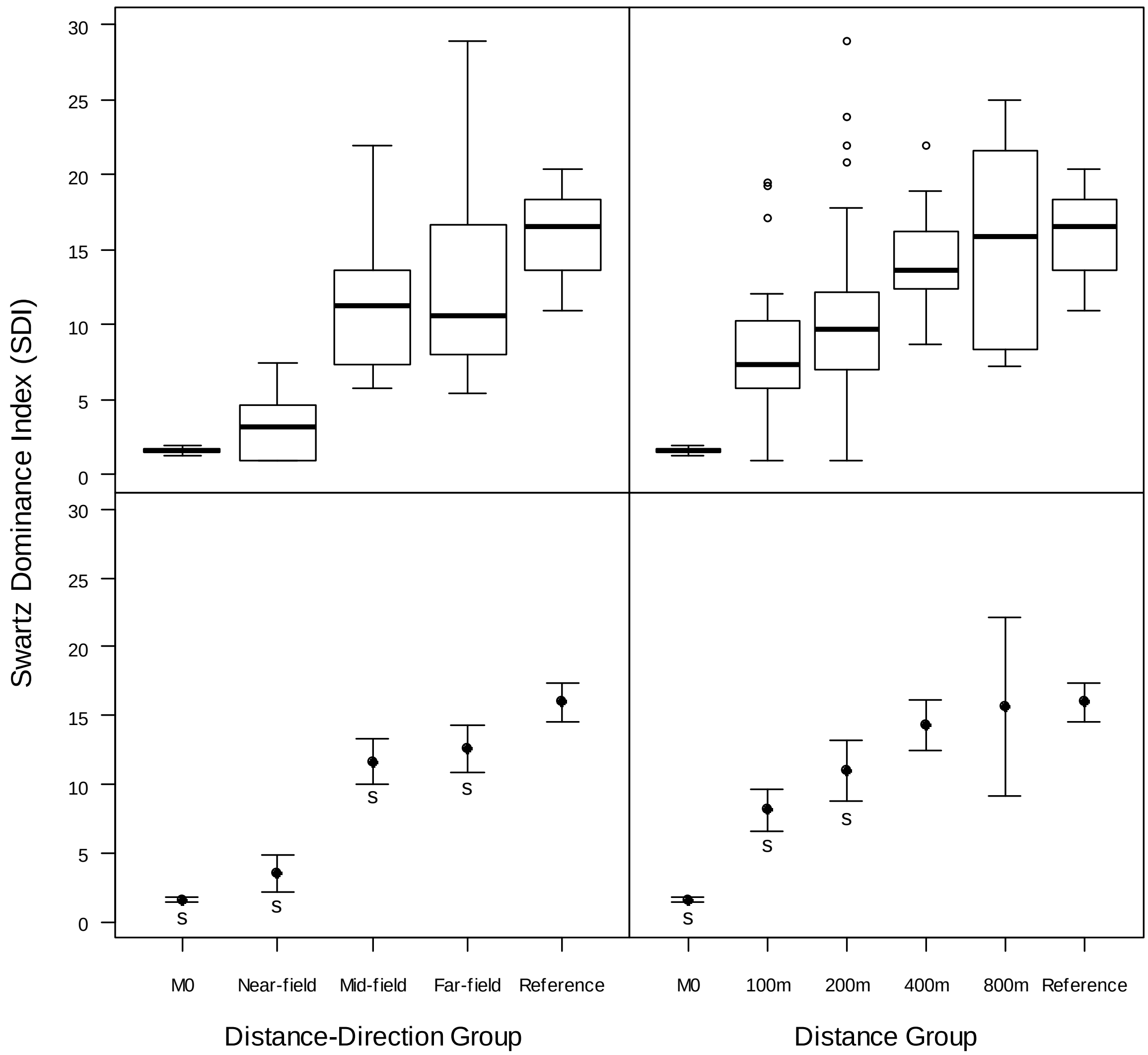


Figure 8: (Continued)

(e) Infaunal Trophic Index – Standard

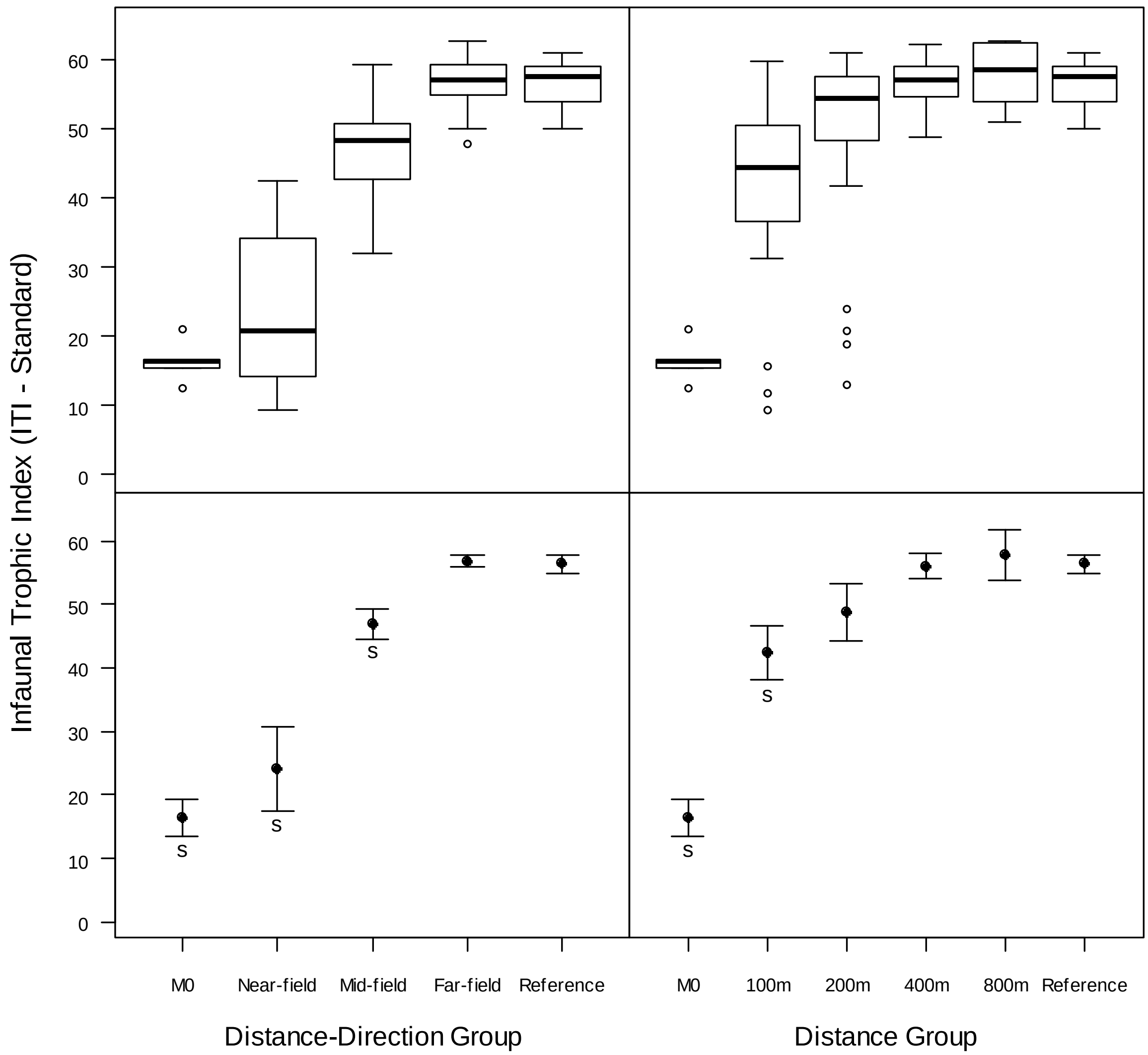


Figure 8: (Continued)

(f) Infaunal Trophic Index – Regional

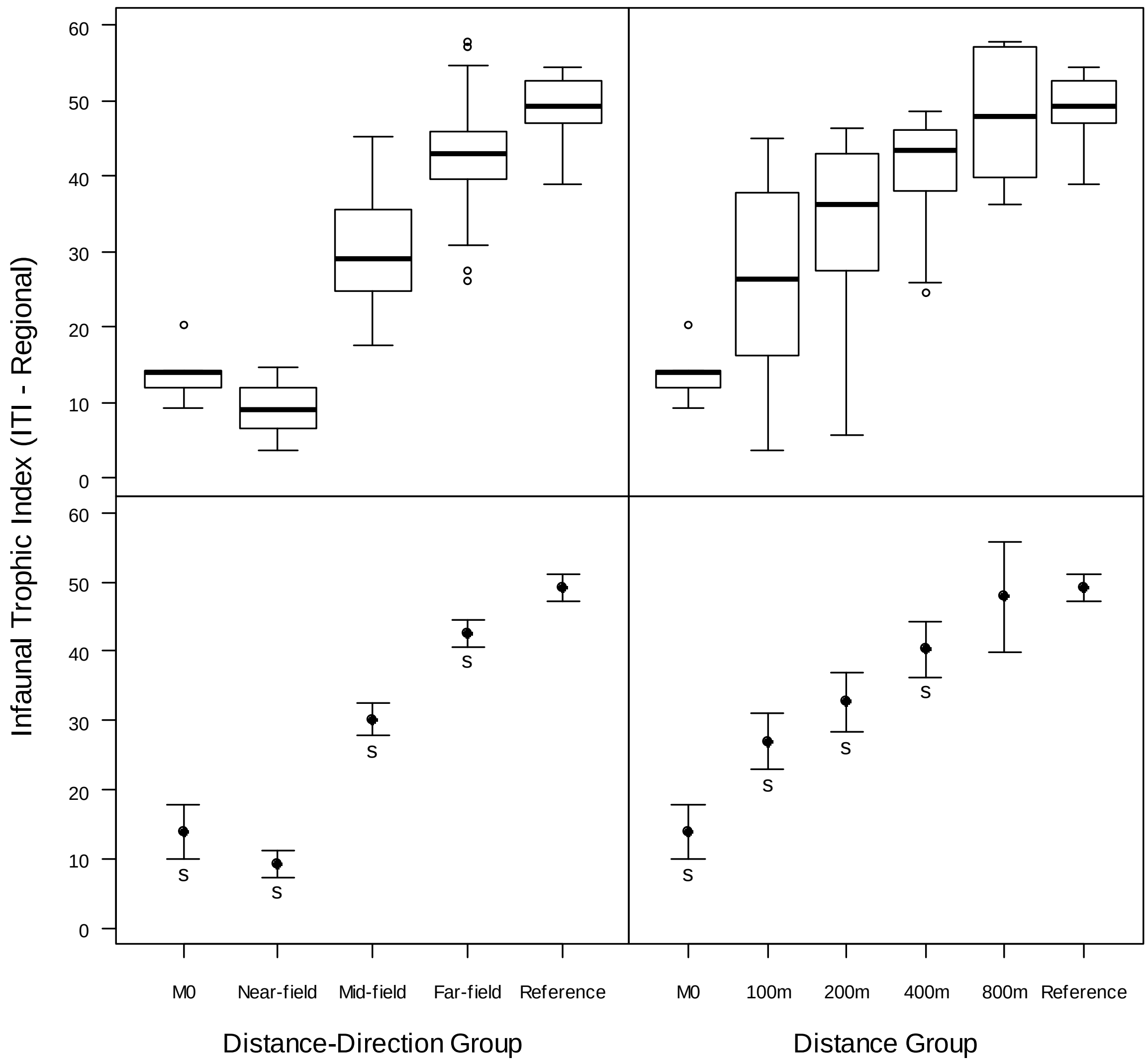


Figure 8: (Continued)

(g) Echinoderm Abundance

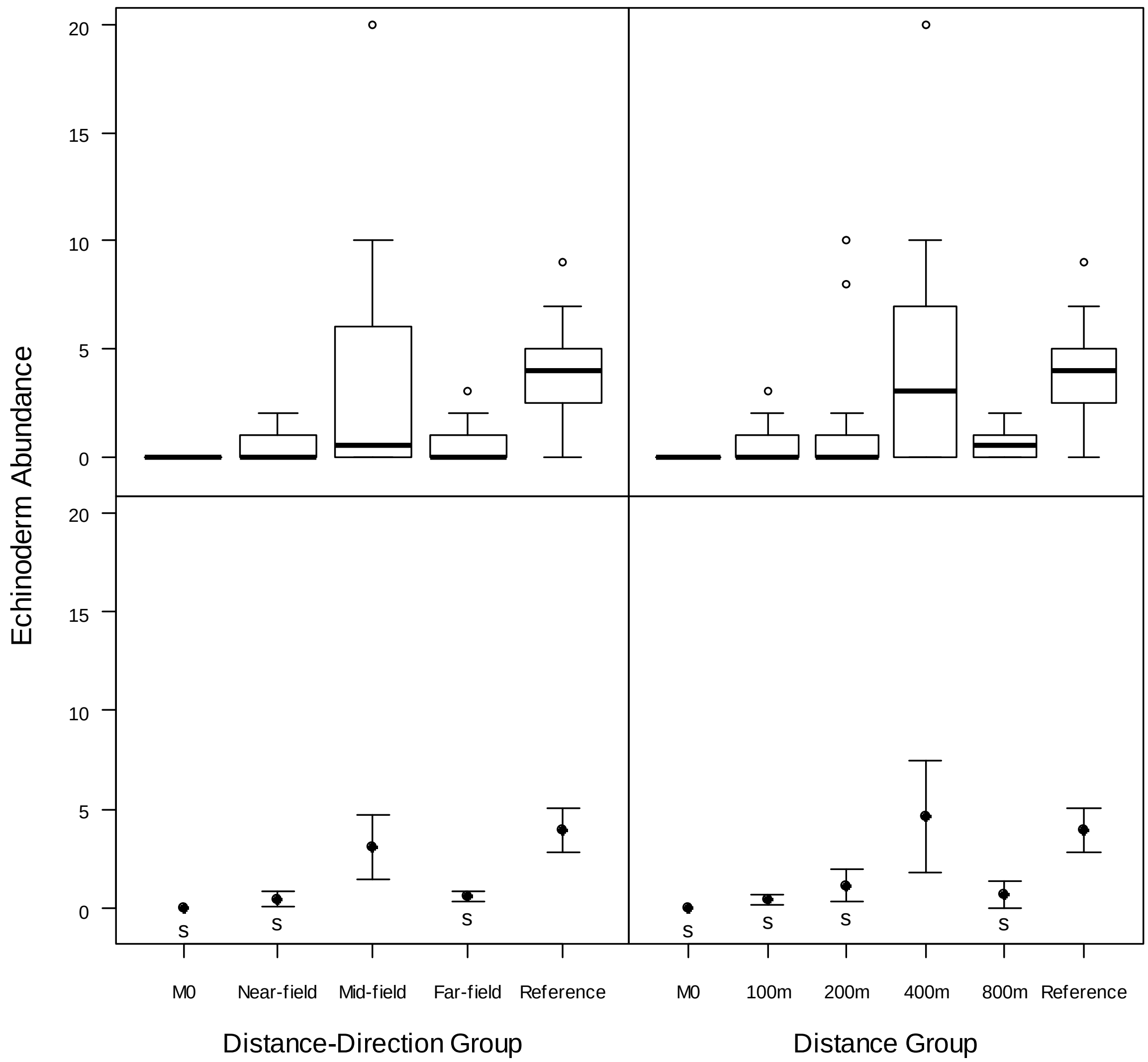


Figure 8: (Continued)

(h) Bivalve Abundance

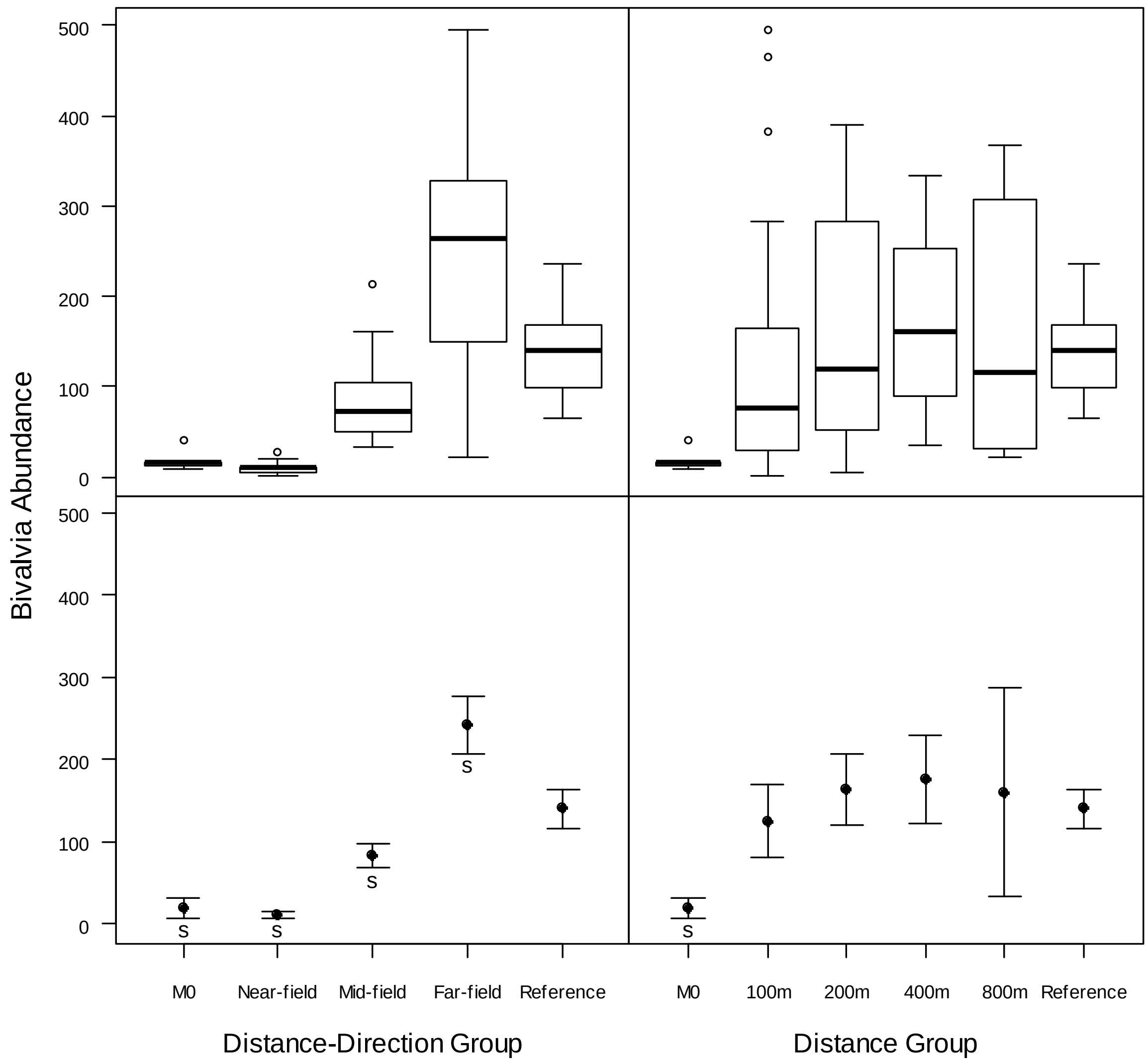


Figure 8: (Continued)

(i) Gastropod Abundance

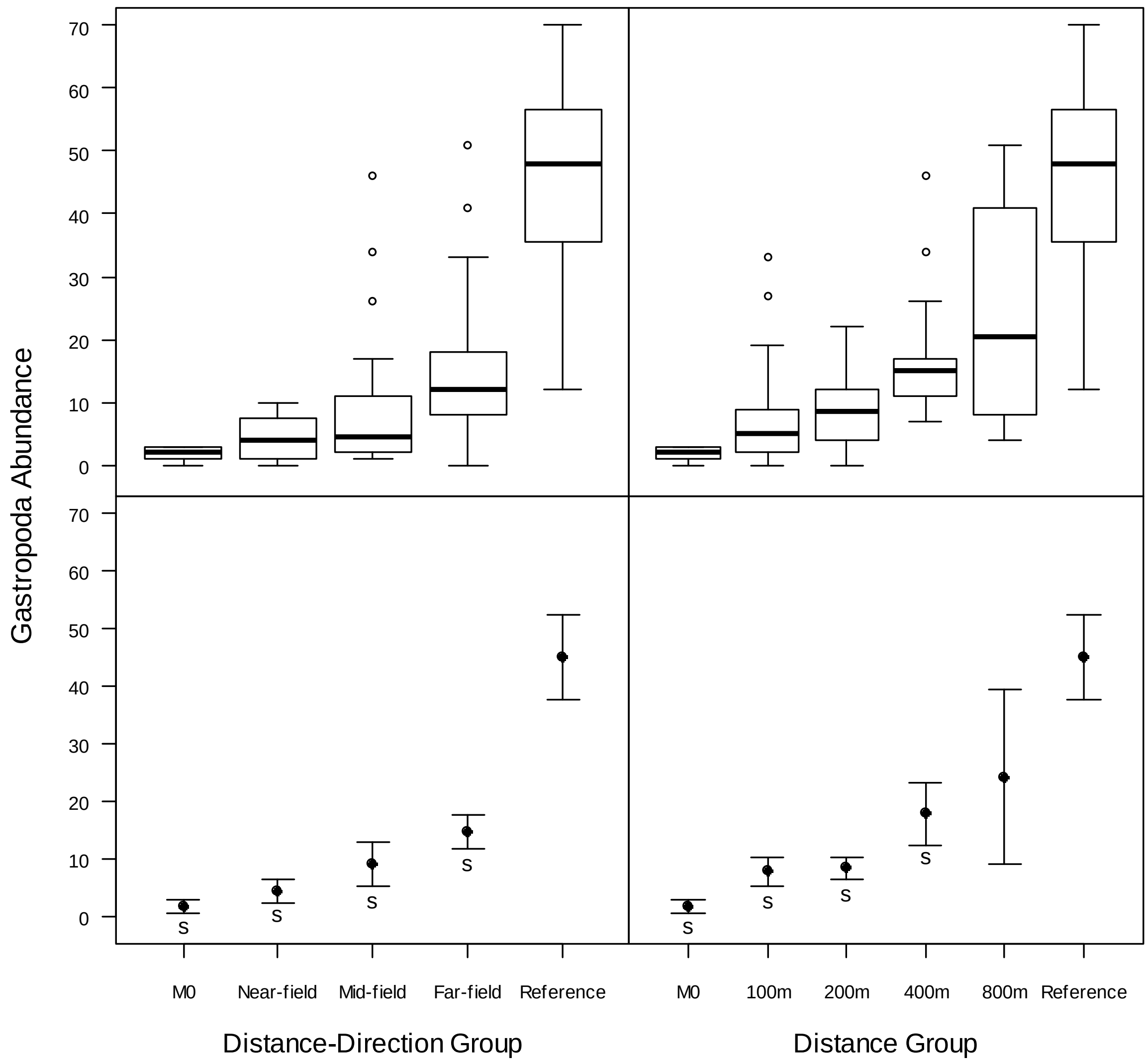


Figure 8: (Continued)

(j) Amphipod Abundance

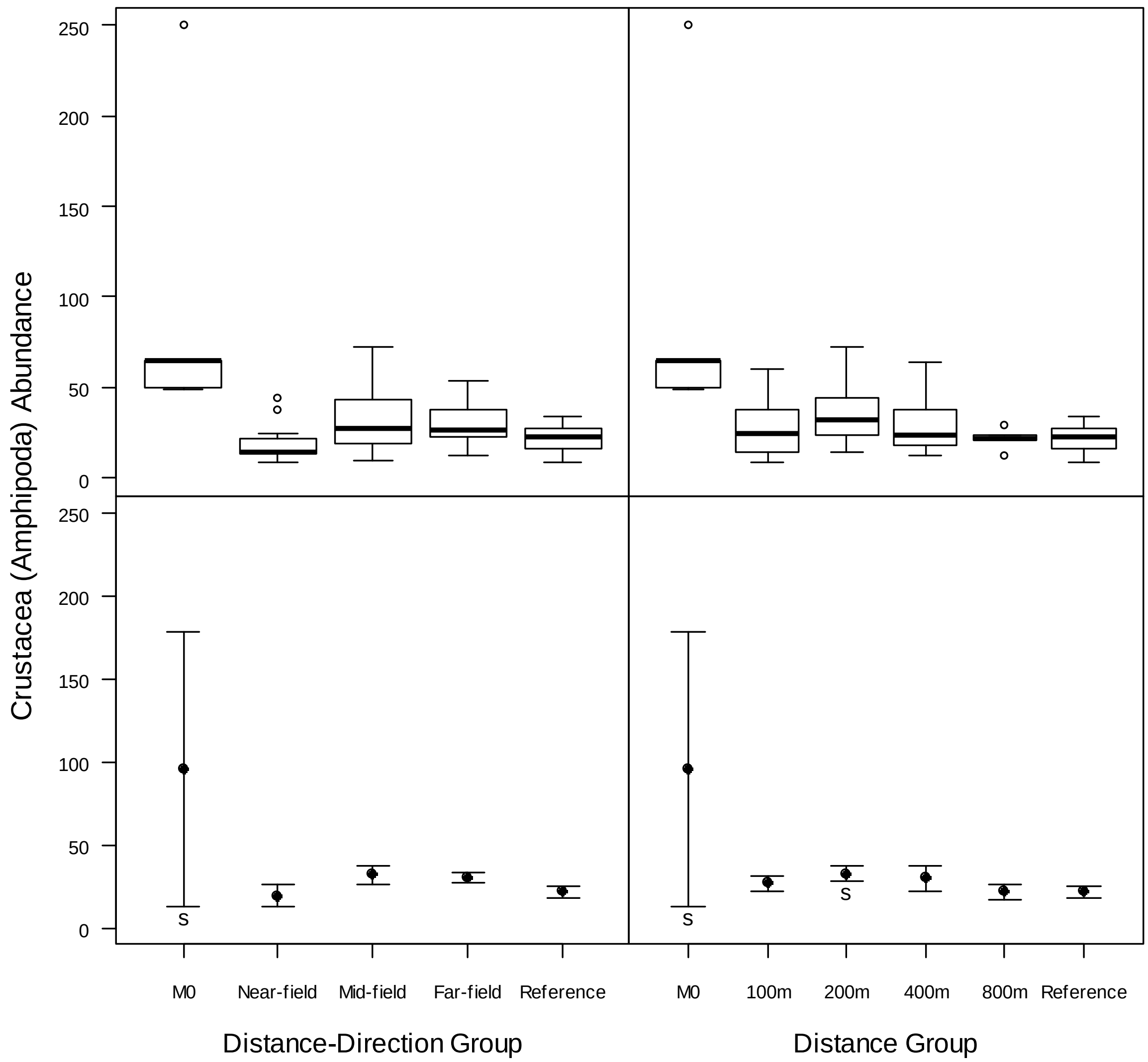


Figure 8: (Continued)

(k) Crustacean Abundance (non-amphipod only)

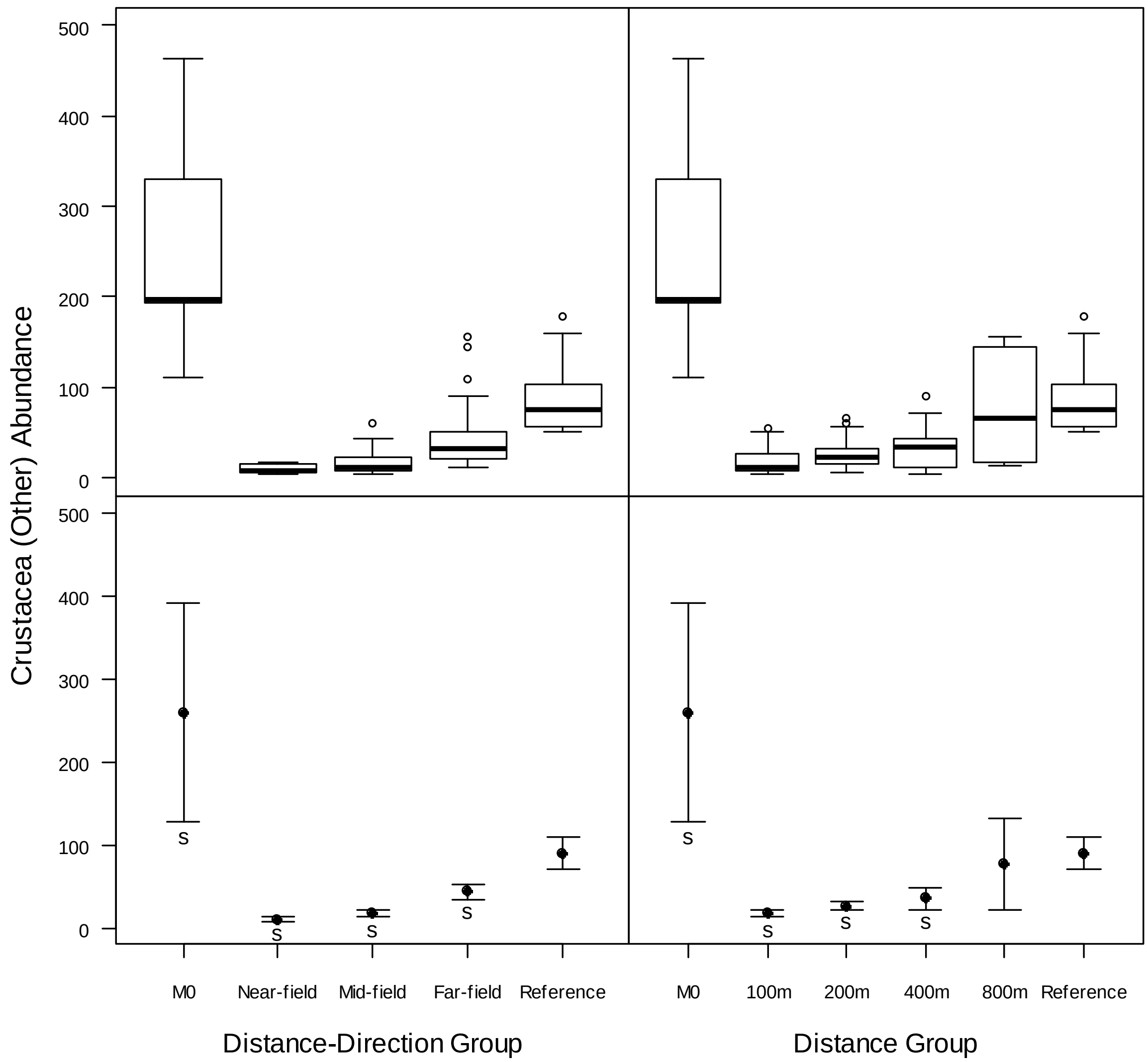


Figure 8: (Continued)

(l) Mobile Polychaete Abundance

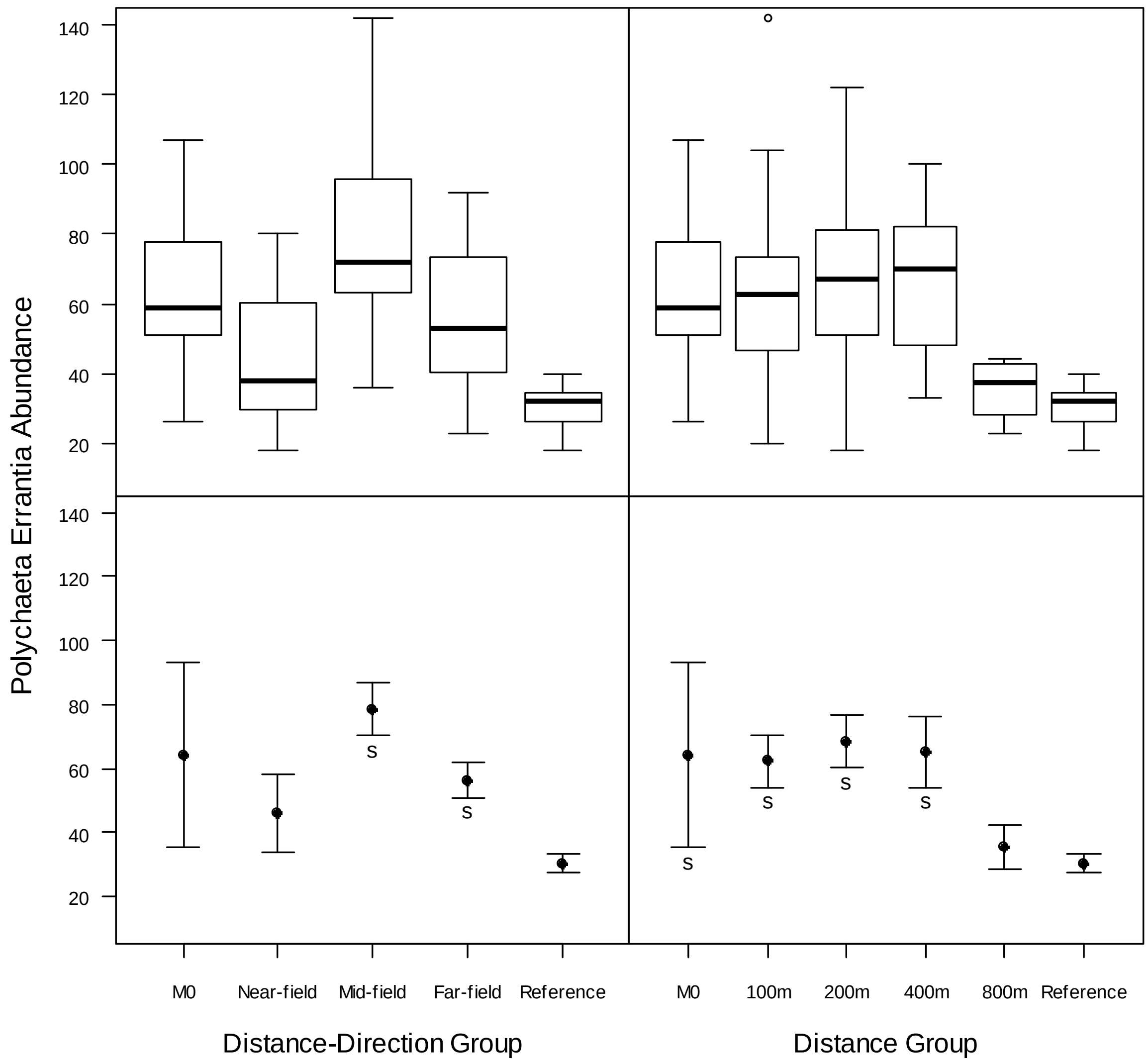


Figure 8: (Continued)

(m) Sedentary Polychaete Abundance (non-capitellid)

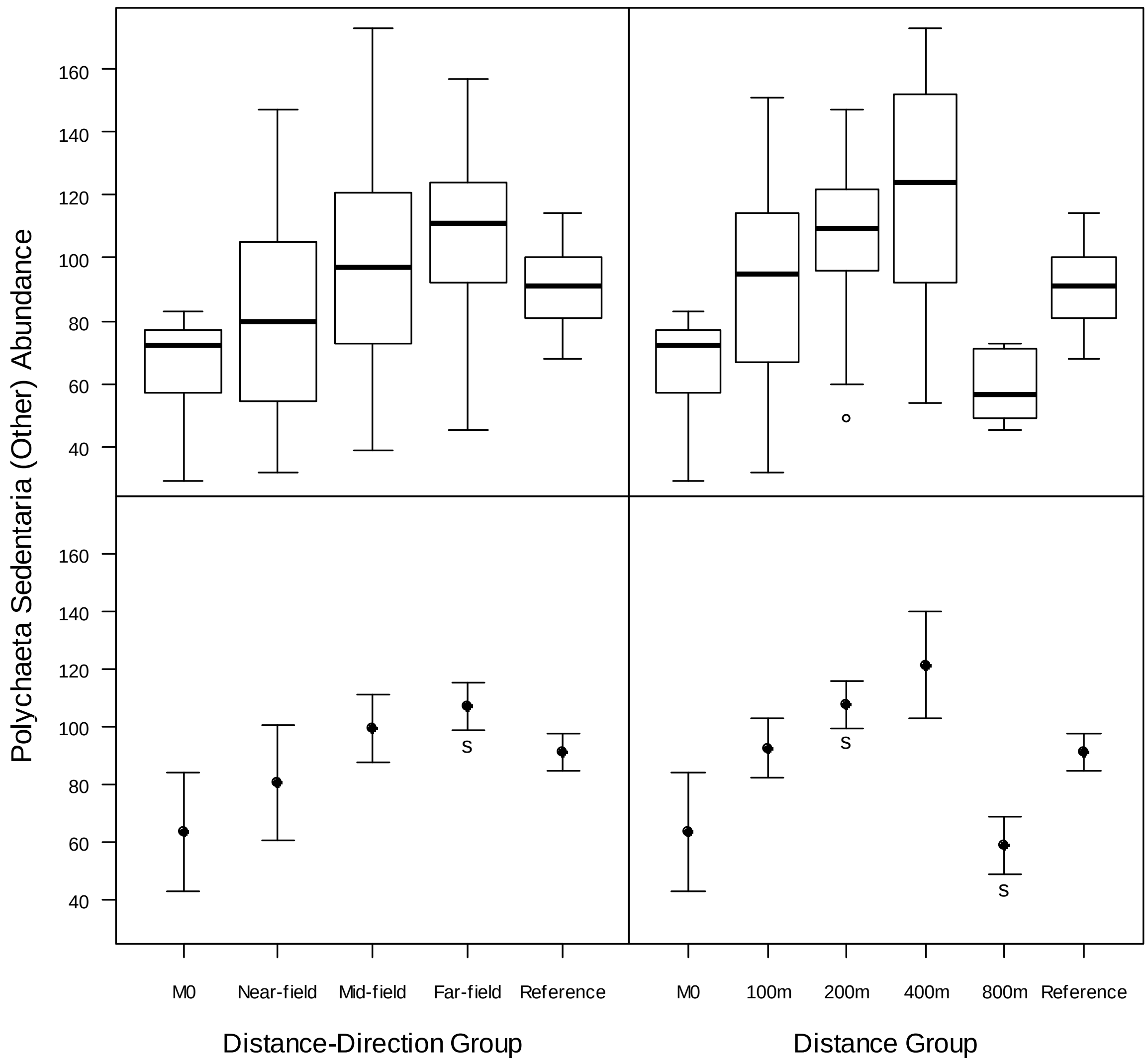


Figure 8: (Continued)

(n) *Capitella Capitata* Abundance

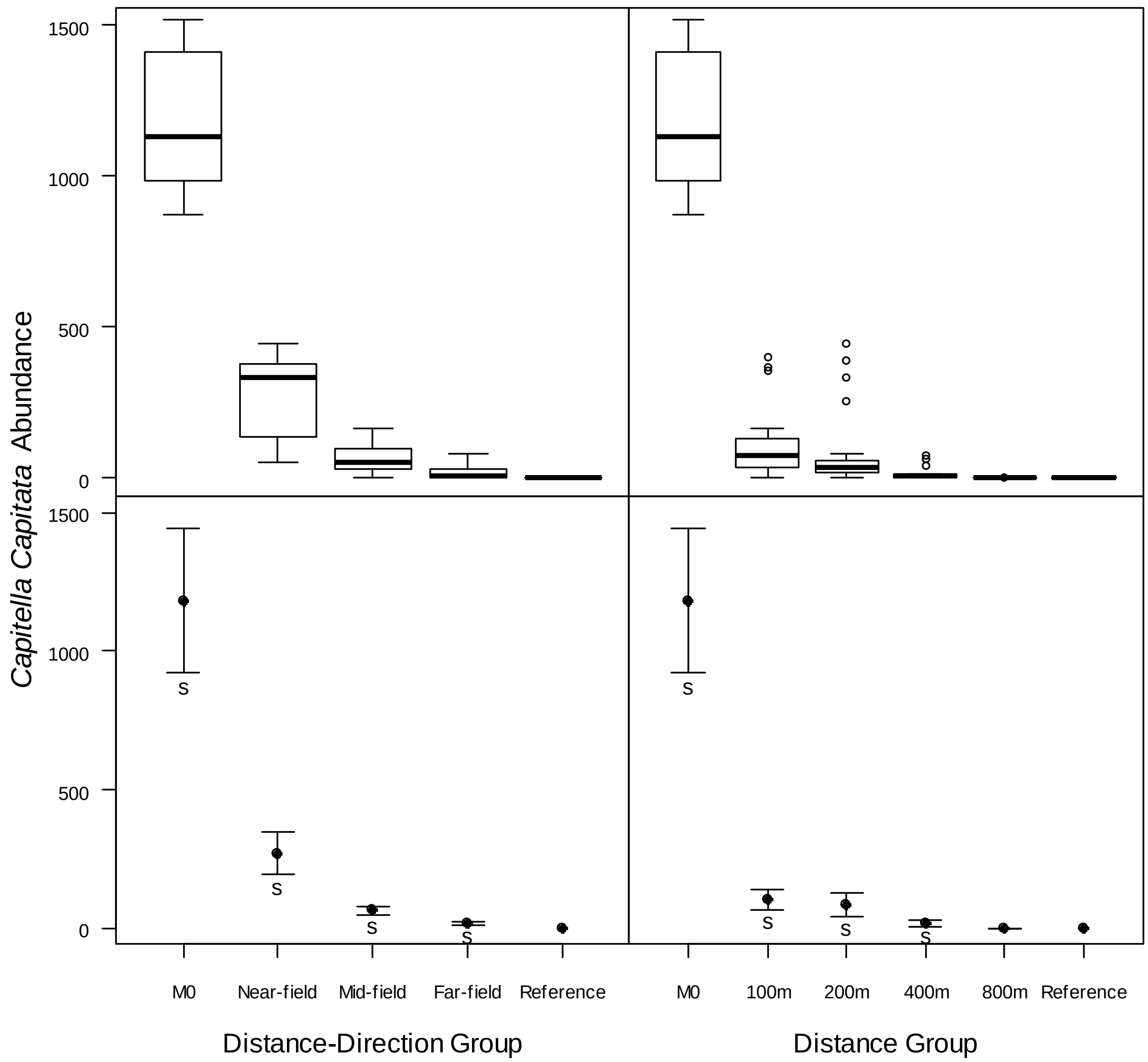


Figure 8: (Continued)

(o) Miscellaneous Taxa Abundance

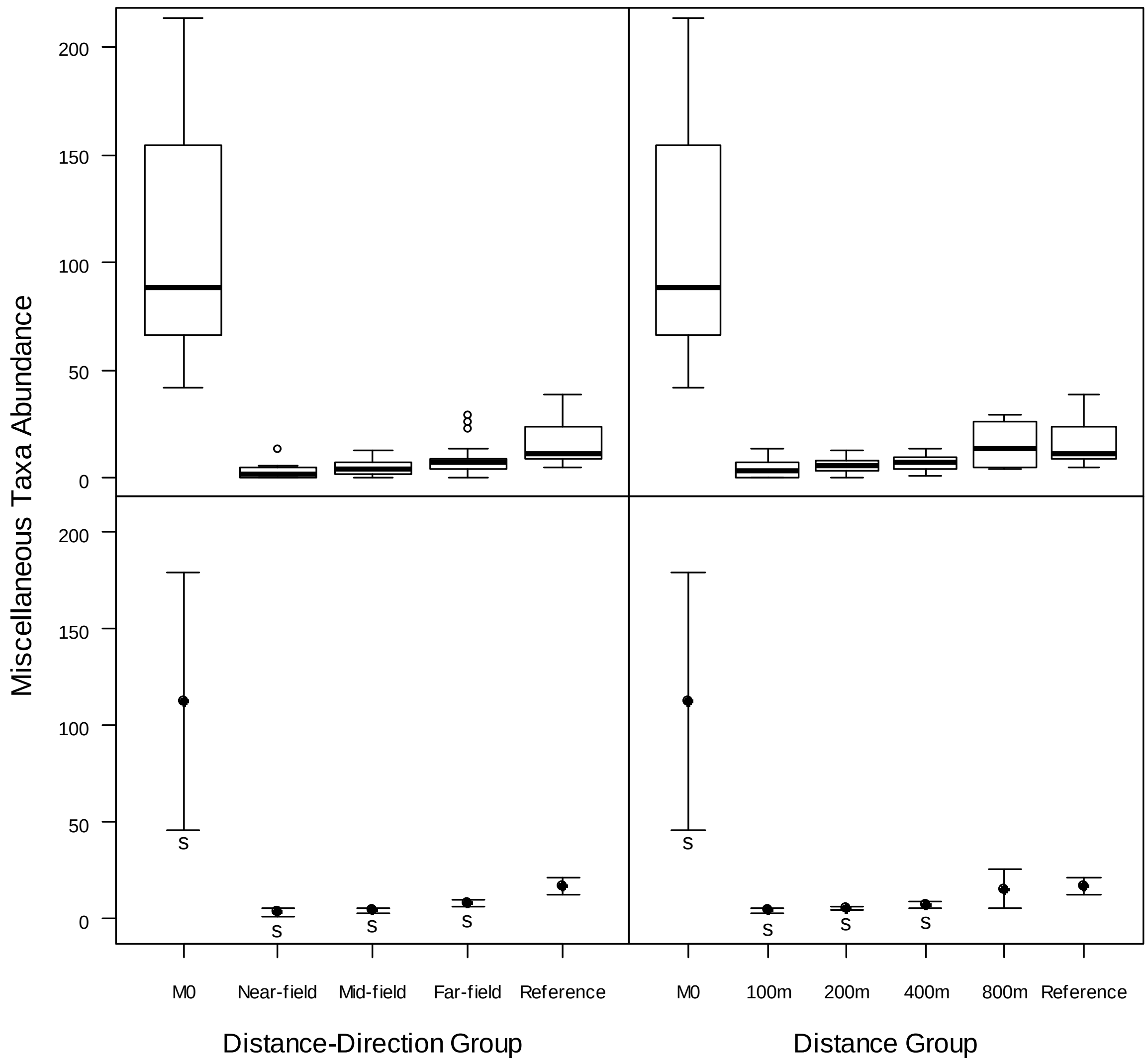
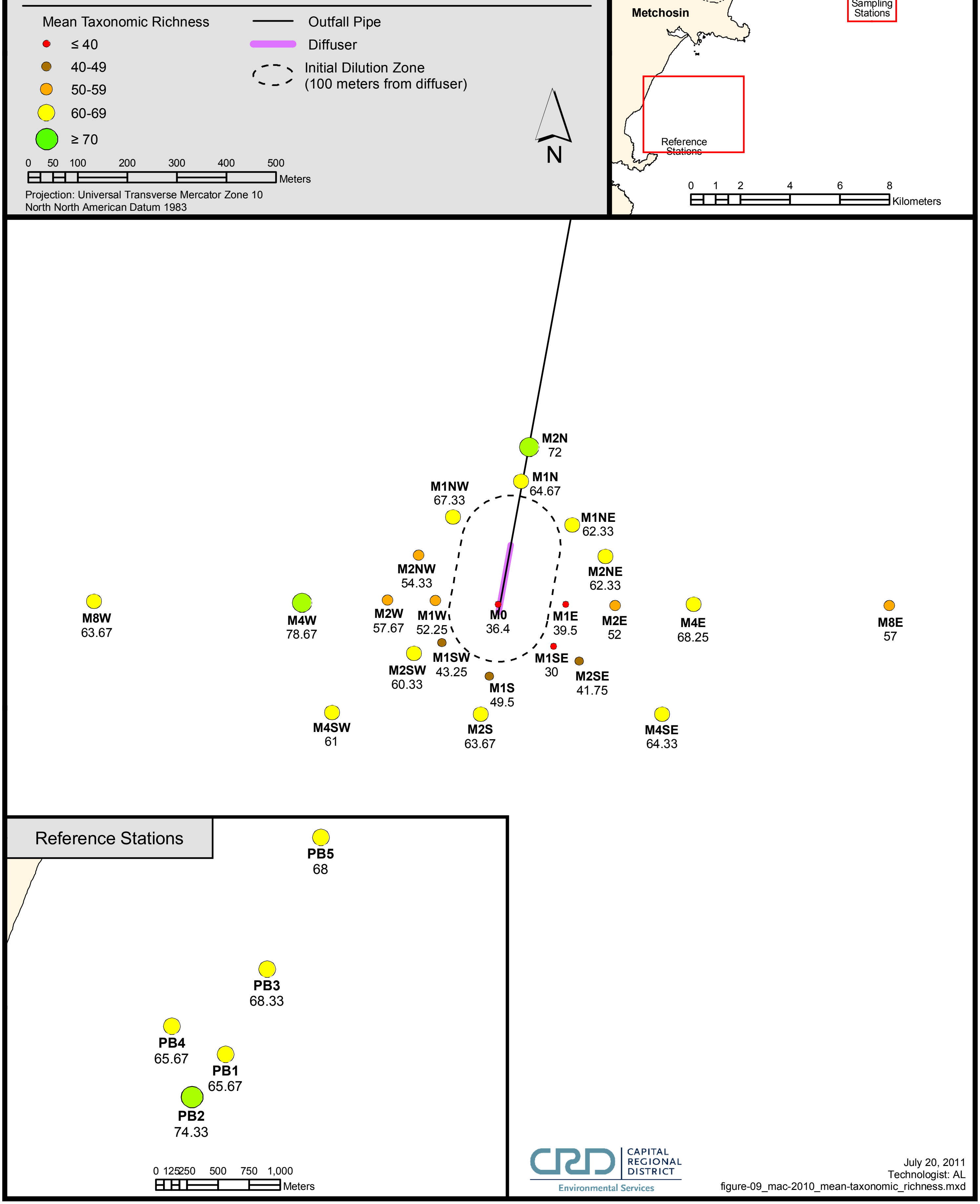


Figure 9 - Macaulay Point 2010 Seafloor Monitoring - Mean Taxonomic Richness by Station



N:\Bur-Graphics\Projects\2010\1421\10-1421-0067\GIS\projects\figure-9_mac_2010_mean_taxonomic_richness.mxd

Figure 10: Cumulative Abundance of Major Taxonomic Groups by Distance (top panel) and by Distance-Direction (bottom panel)

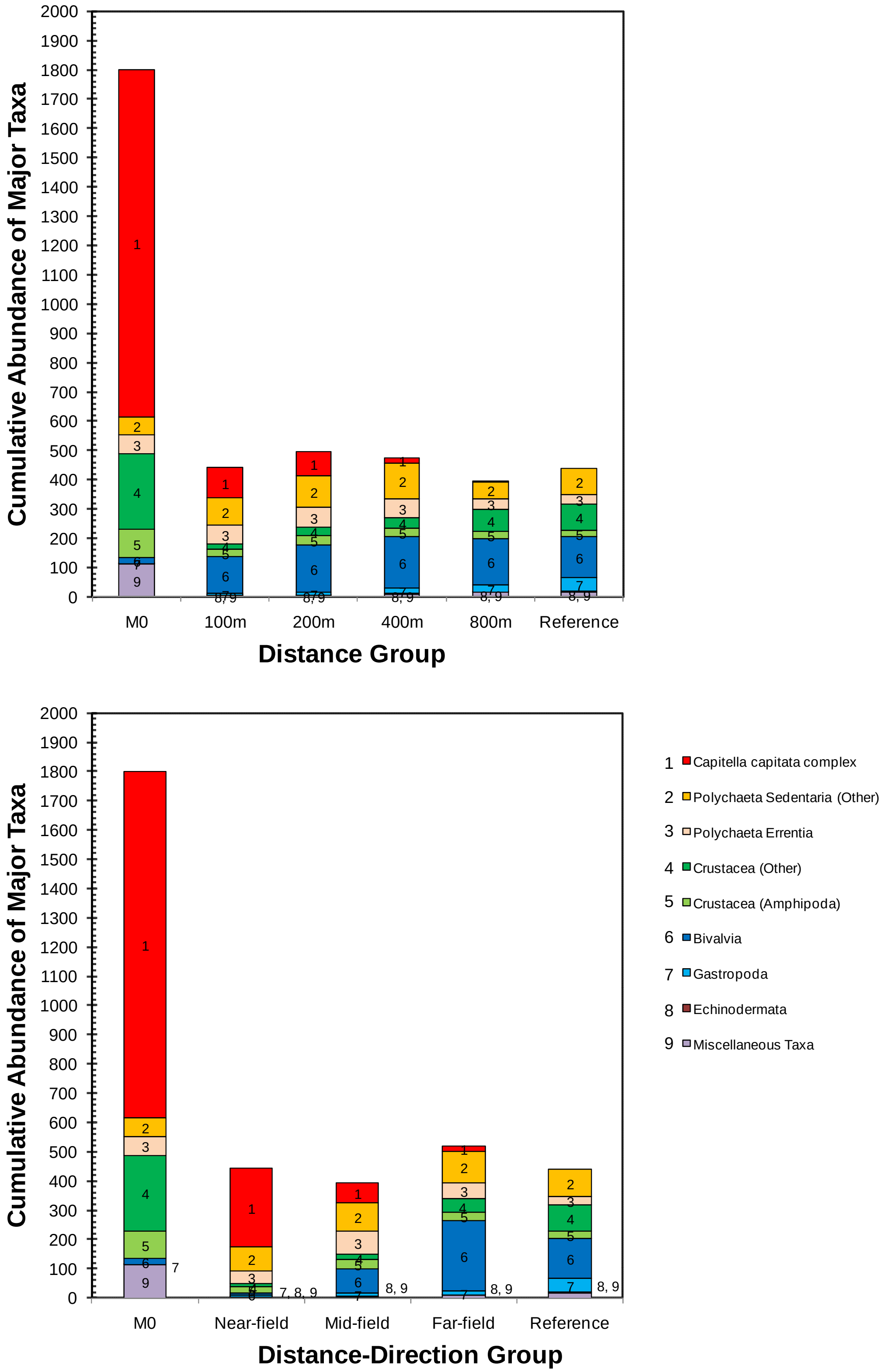


Figure 11: Multidimensional Scaling of 2010 Macaulay Point Benthic Community Major Taxonomic Abundances Coded Based on Distance-Direction Groups

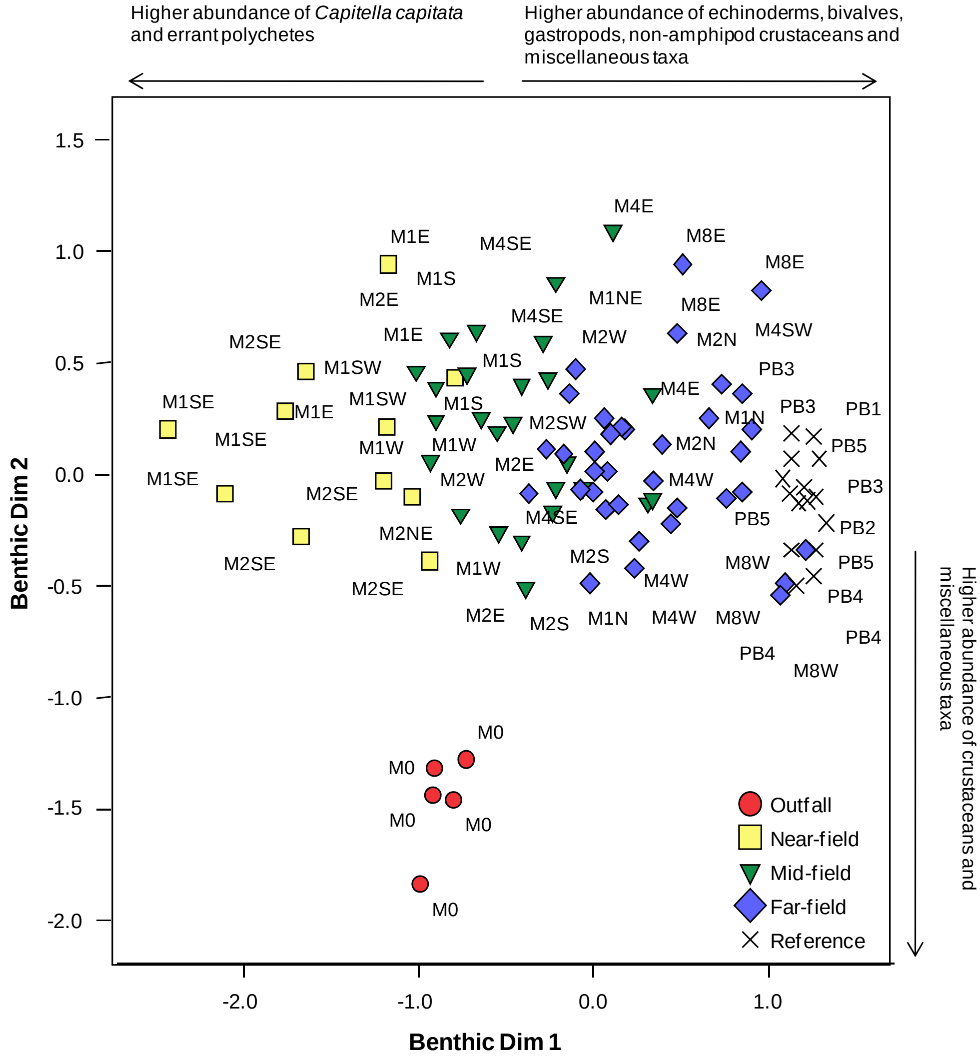


Figure 12: Means ± 95% Confidence Intervals for 2010 NMDS Benthic Dimension 1 Scores (top panel) and Benthic Dimension 2 Scores (bottom panel)

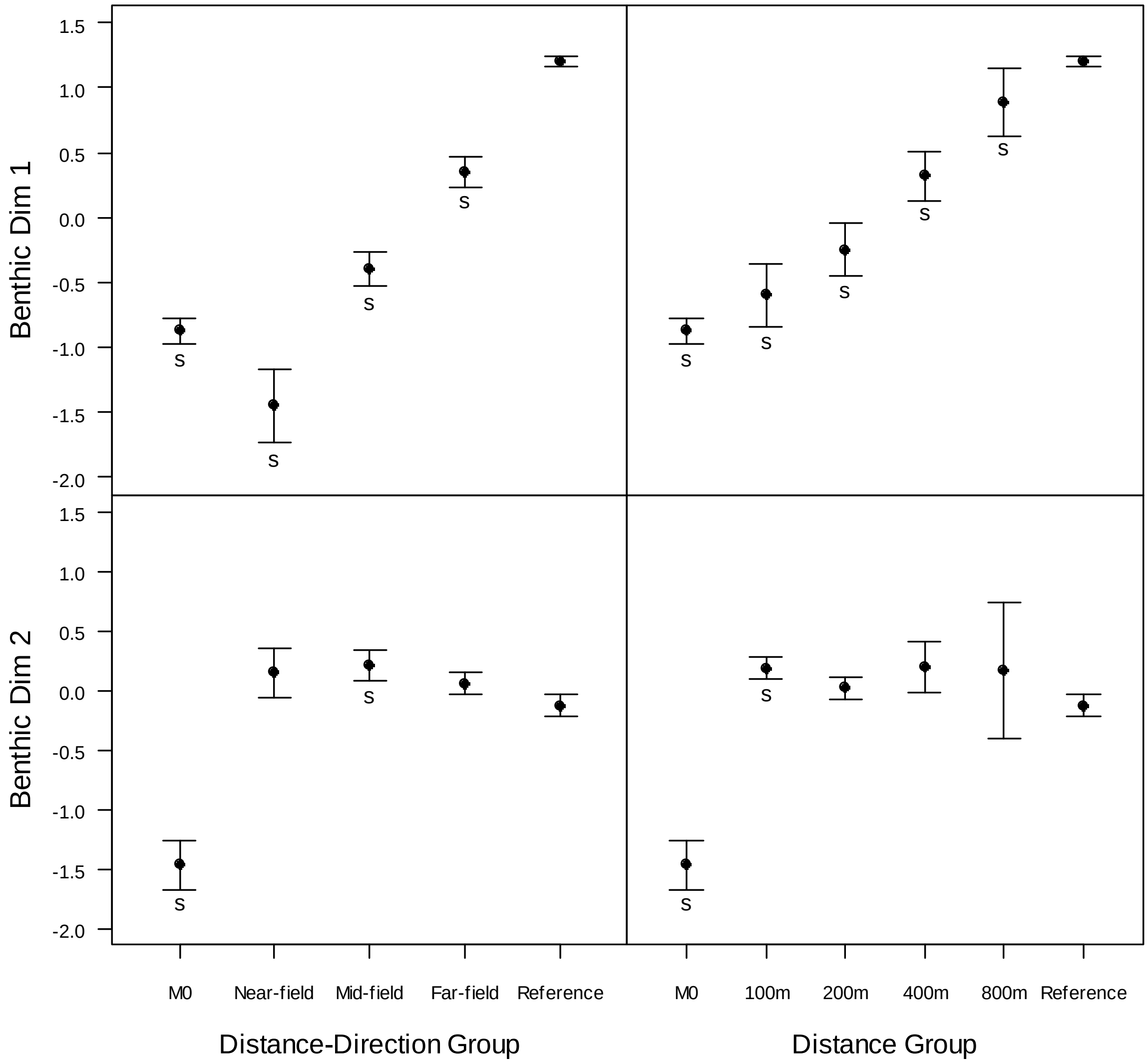
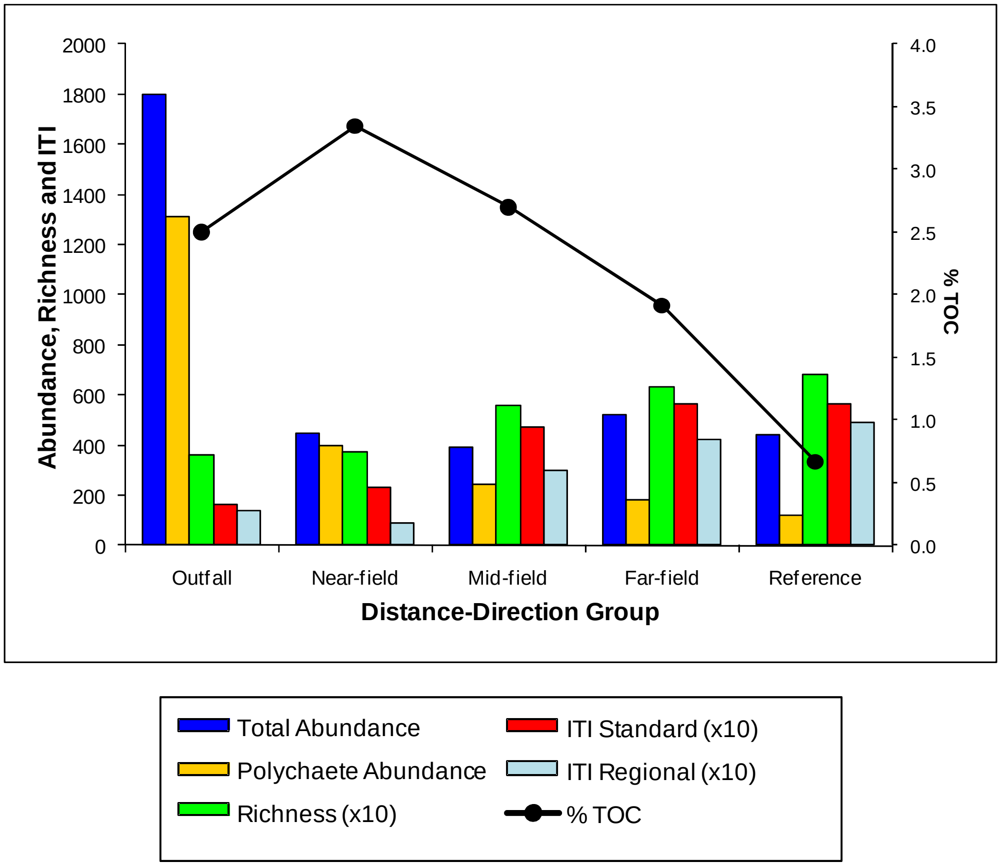


Figure 13: Comparison of TOC and Benthic Community Parameters among Distance-Direction and Distance Based Groups



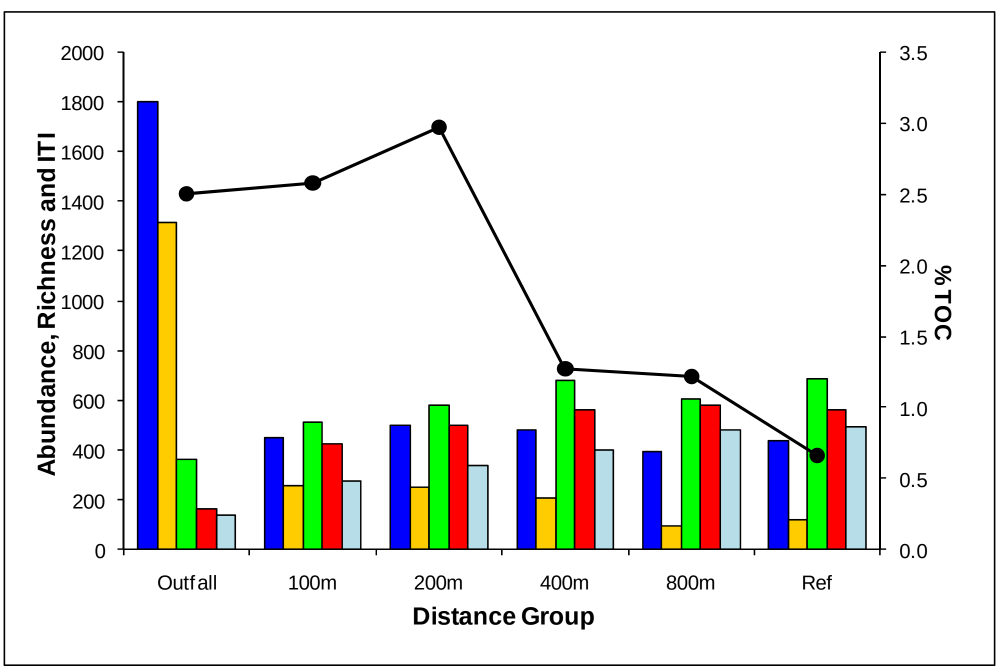
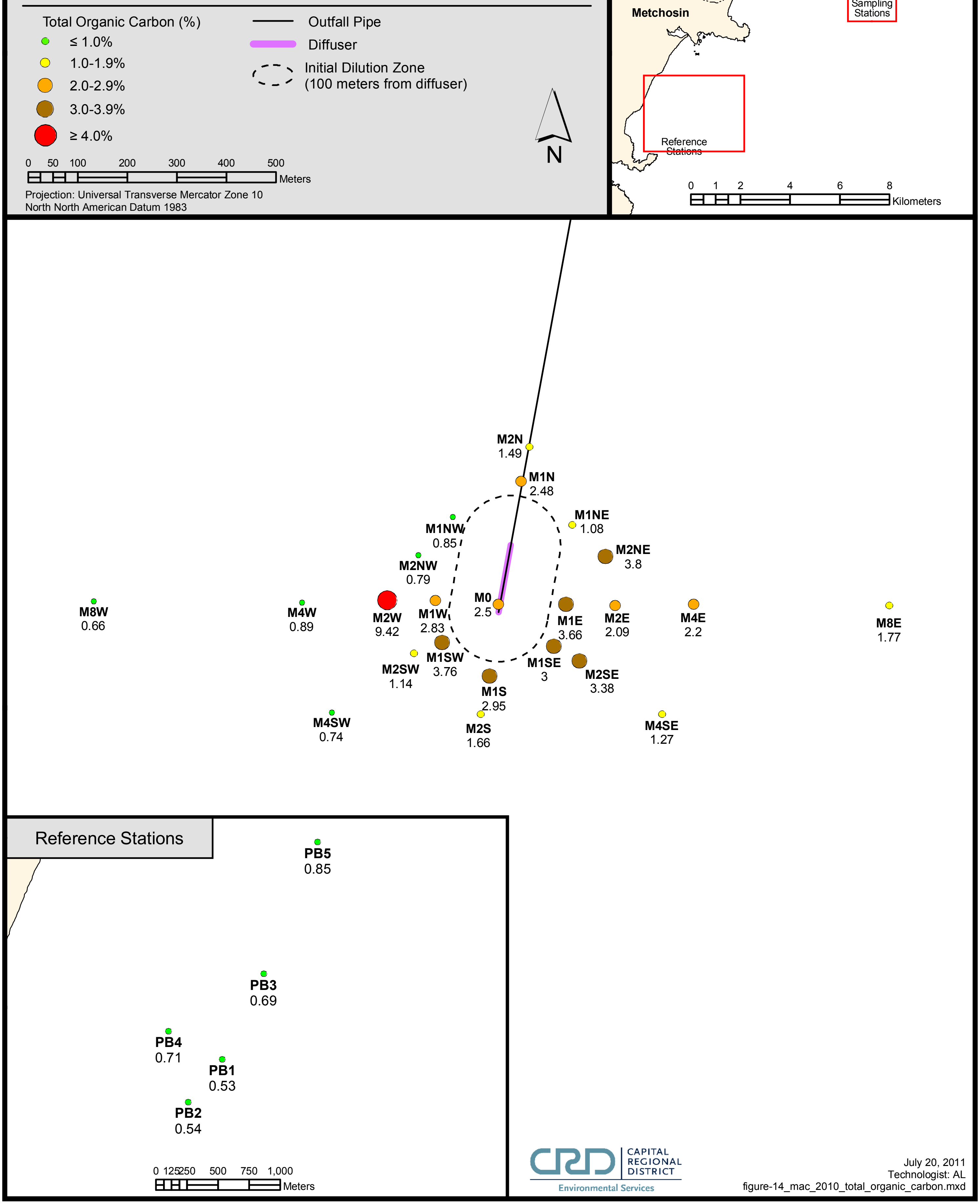
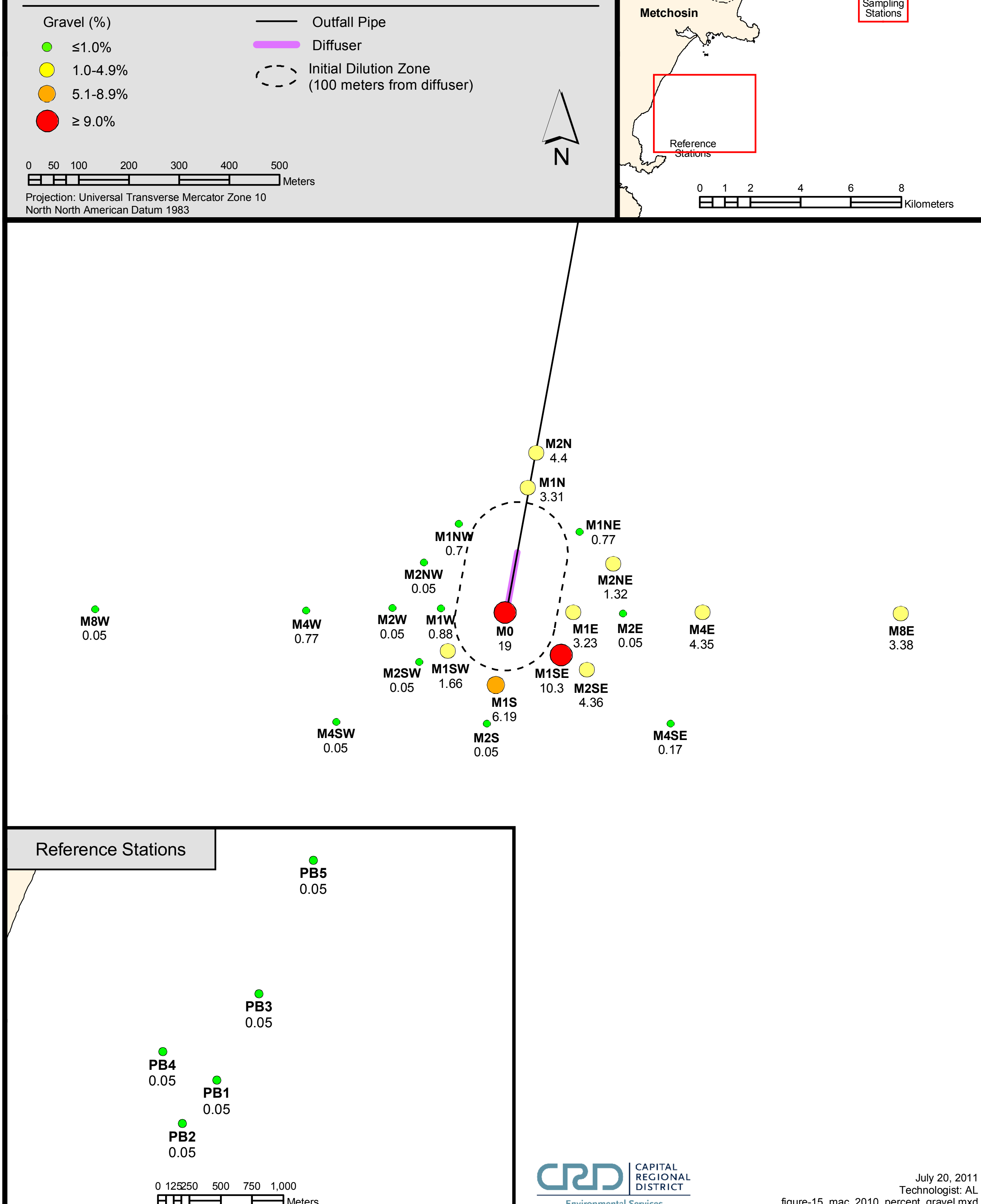


Figure 14 - Macaulay Point 2010 Seafloor Monitoring - Percent Total Organic Carbon by Station



N:\Bur-Graphics\Projects\2010\1421\10-1421-0067\GIS\projects\figure-14_mac_2010_total_organic_carbon.mxd

Figure 15 - Macaulay Point 2010 Seafloor Monitoring - Percent Gravels by Station



N:\Bur-Graphics\Projects\2010\1421\10-1421-0067\GIS\projects\figure-15_mac_2010_percent_gravel.mxd

Figure 16: Means ± 95% Confidence Intervals for Macaulay Point Benthic Community Parameters (2000-2010)

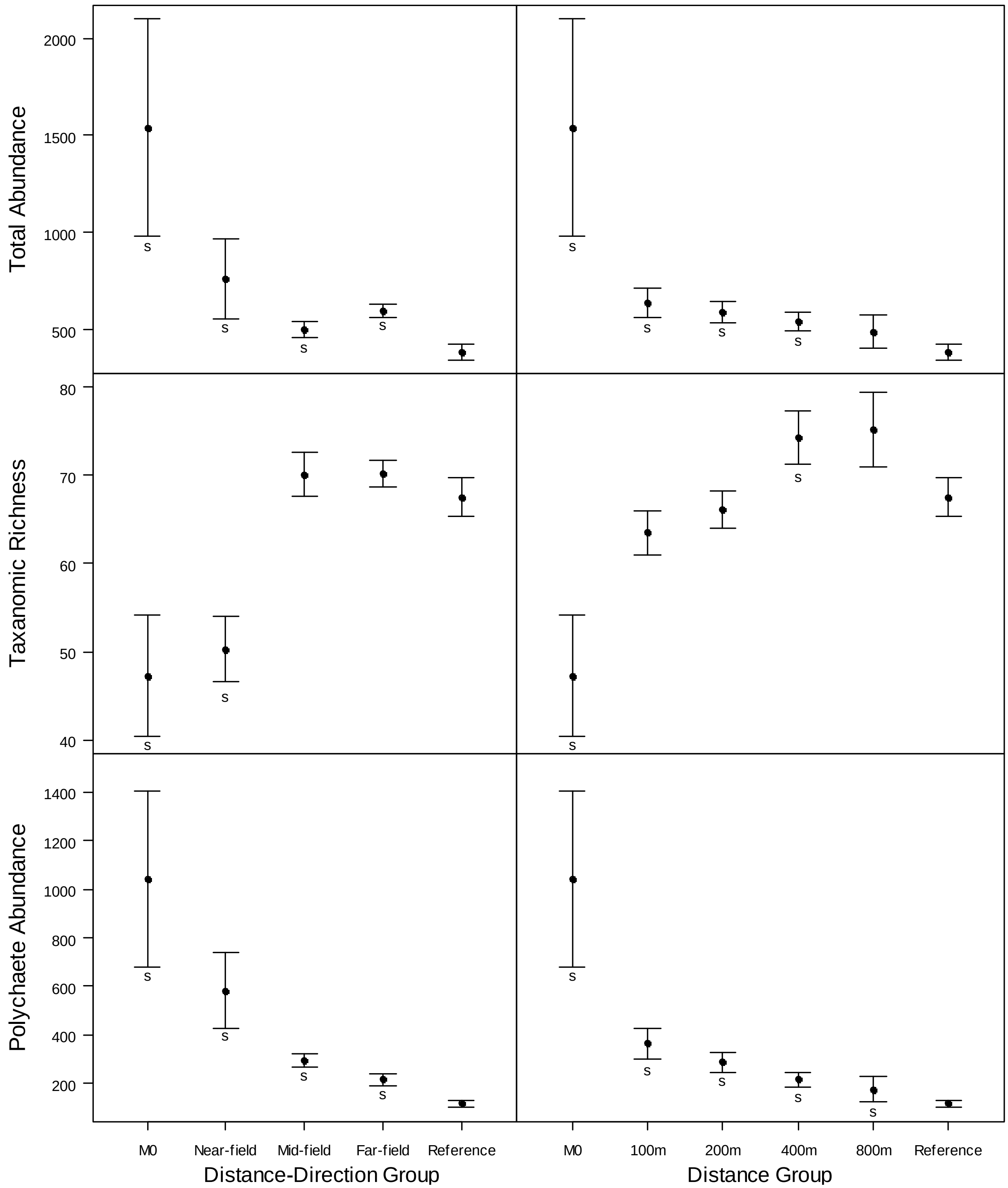
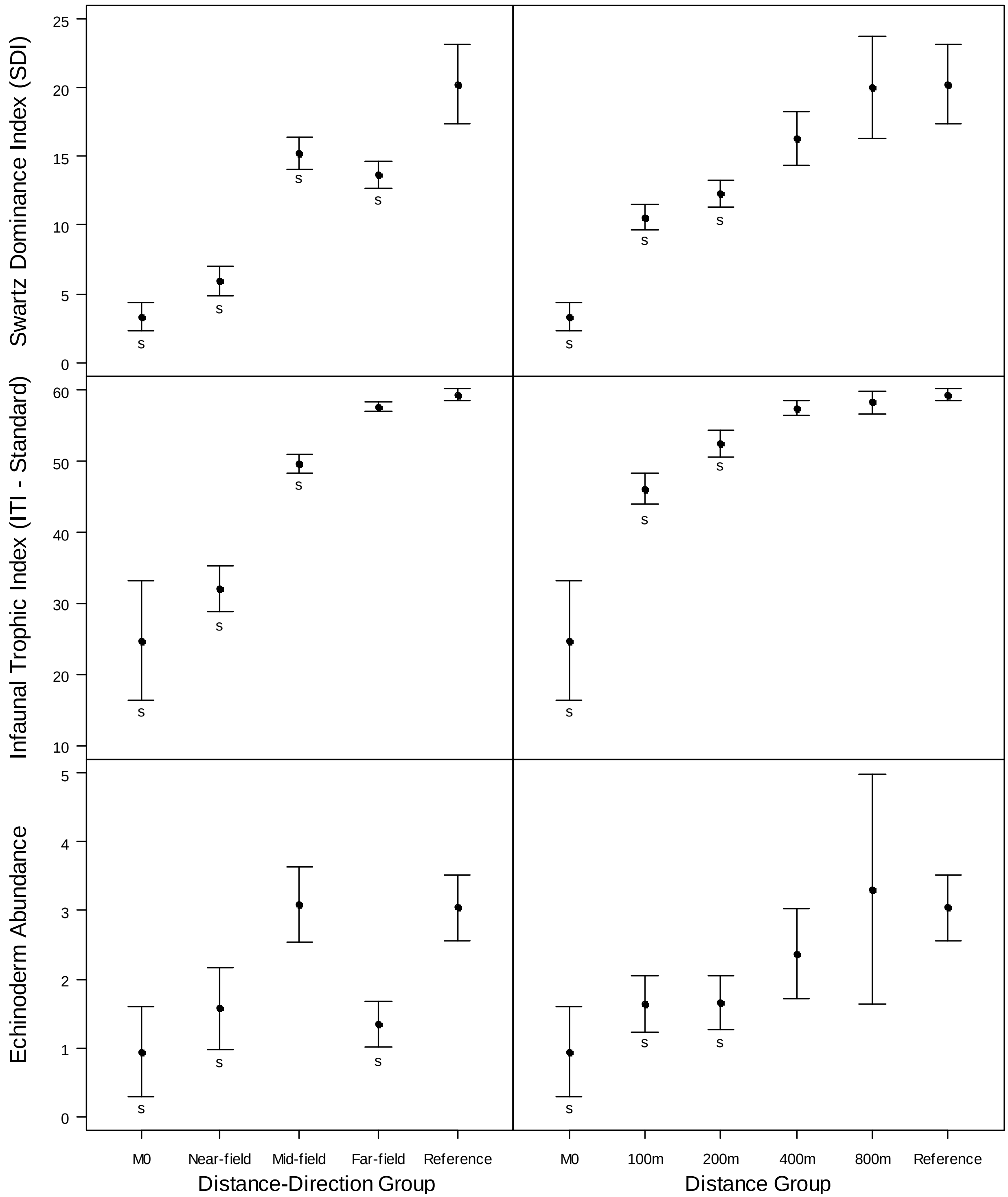


Figure 16: (Continued)



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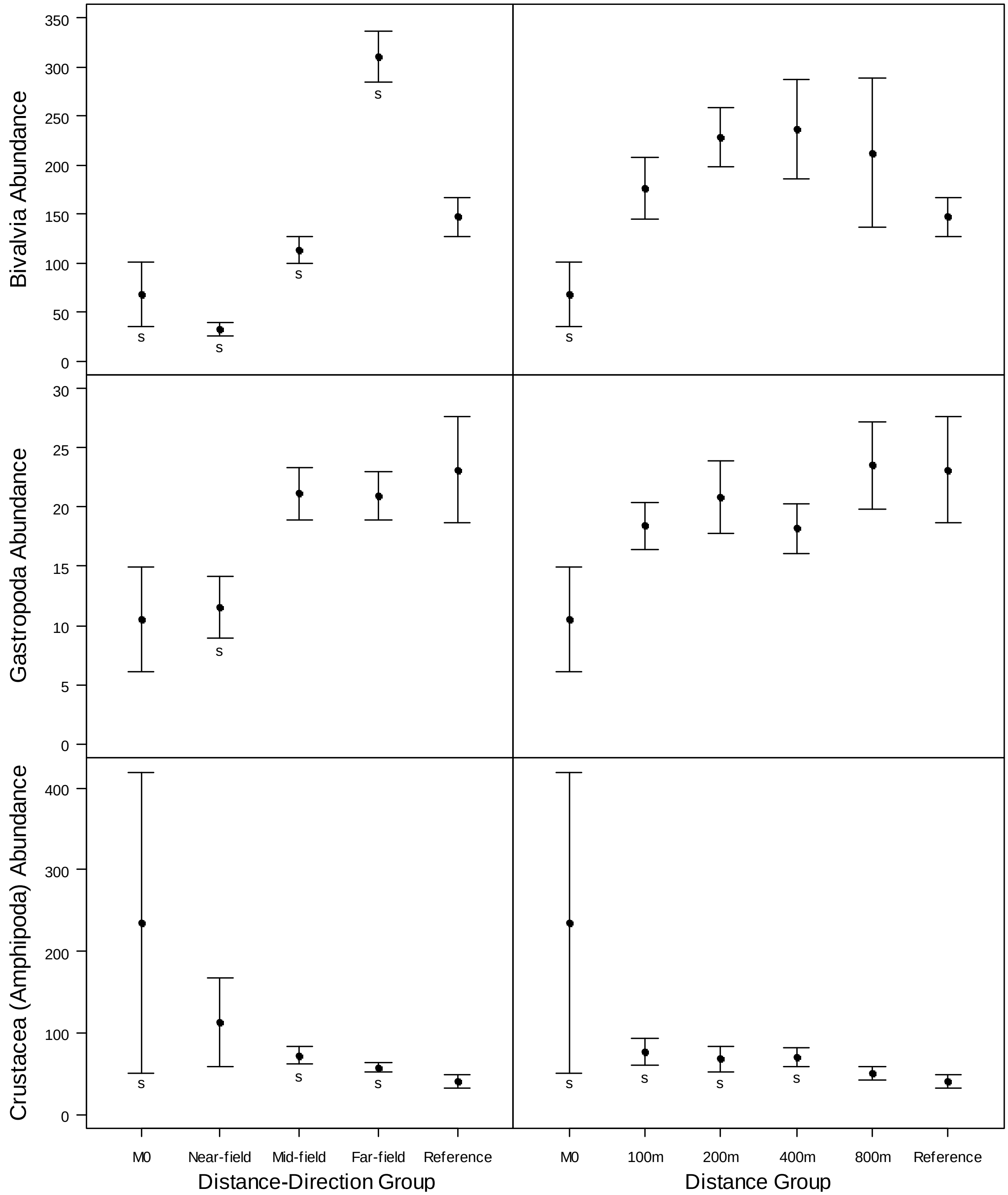

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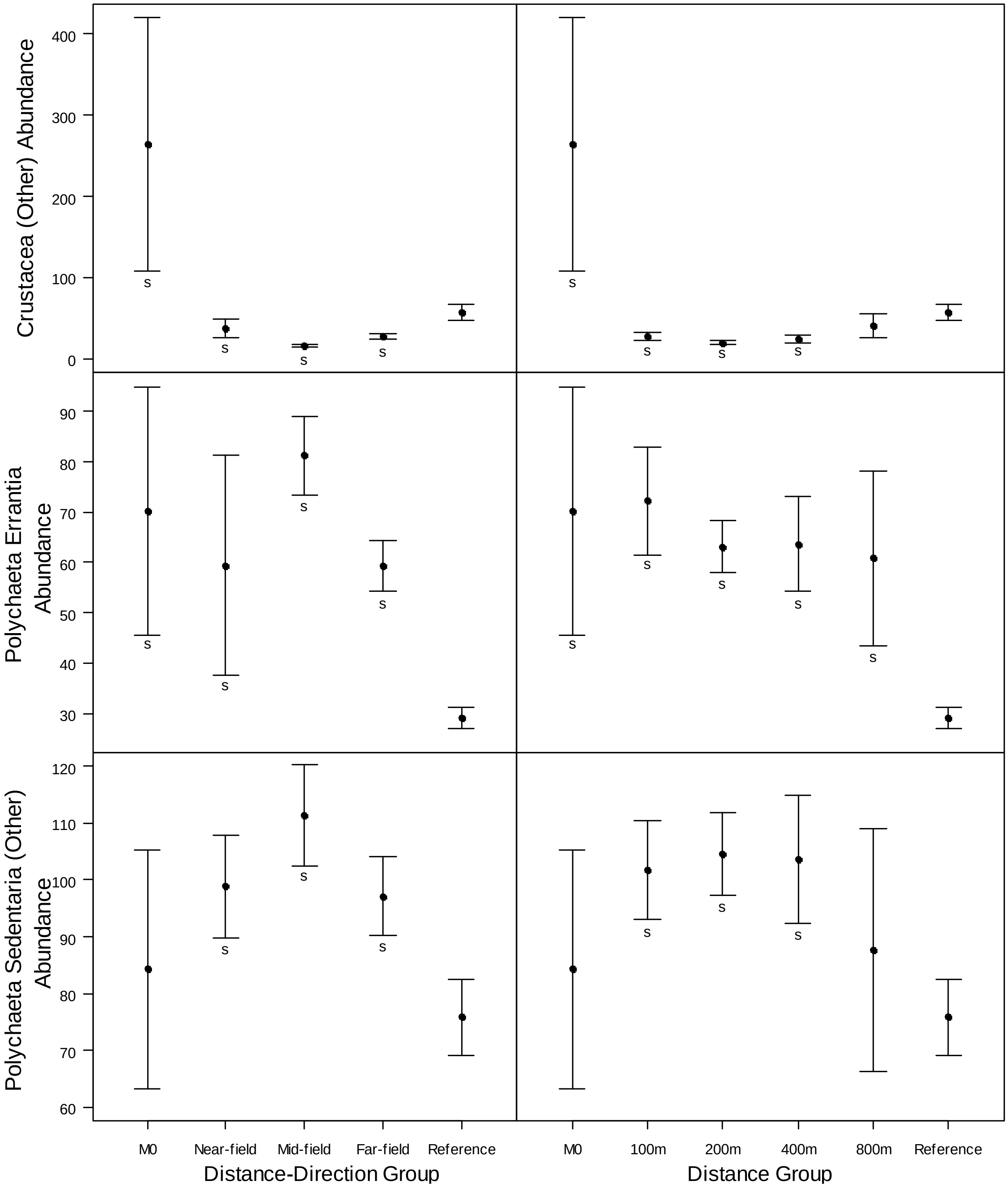


Figure 16: (Continued)

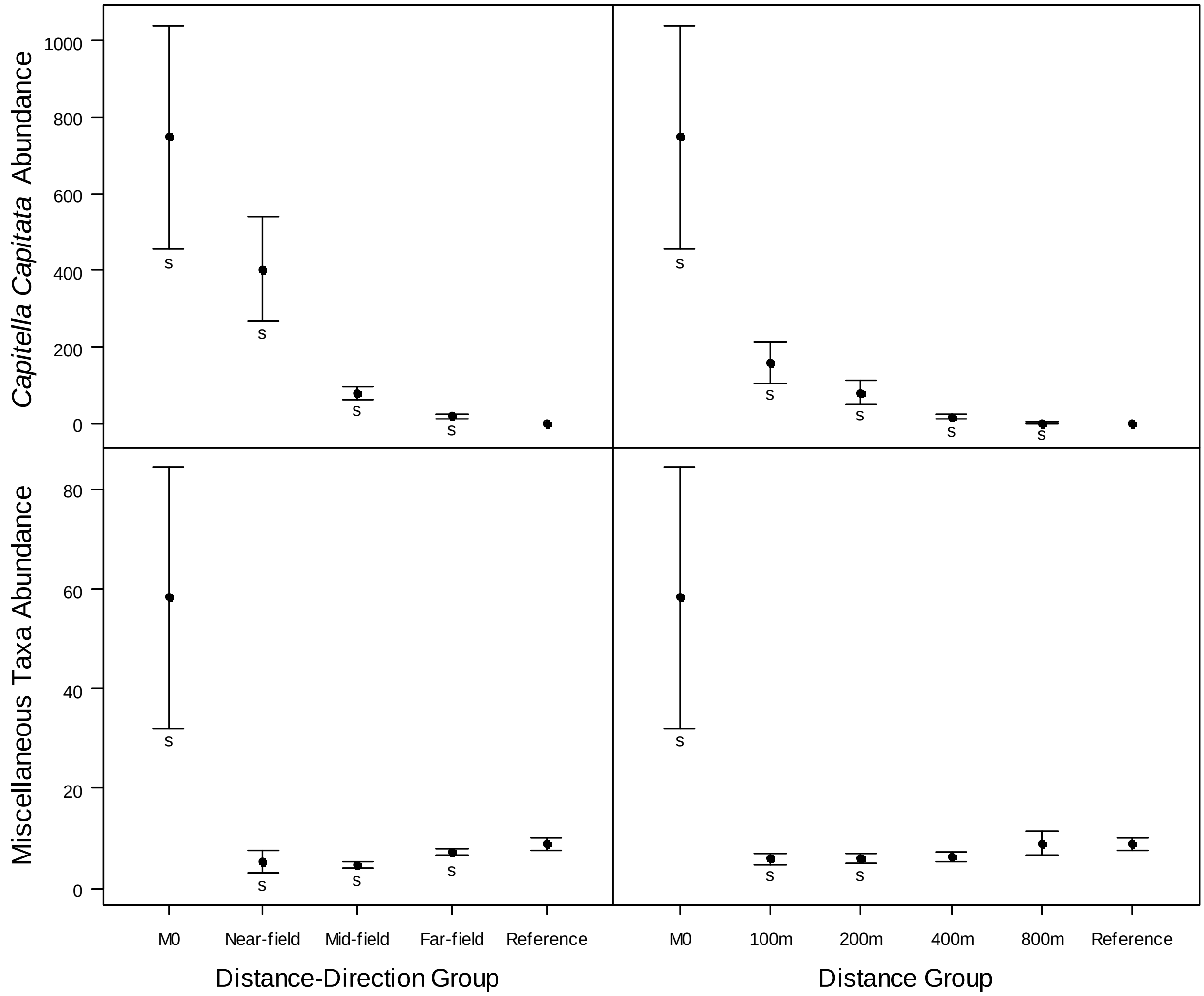
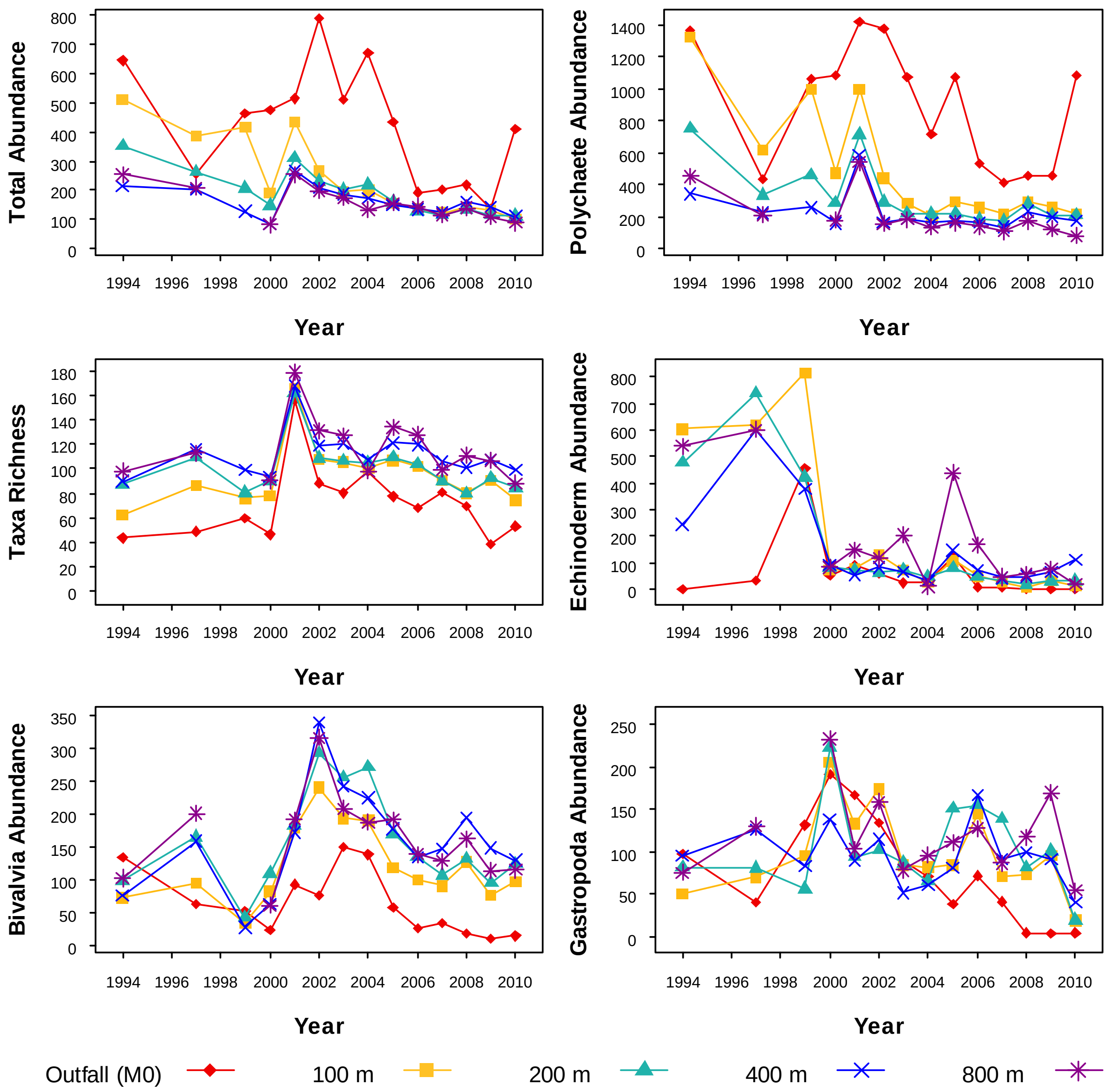
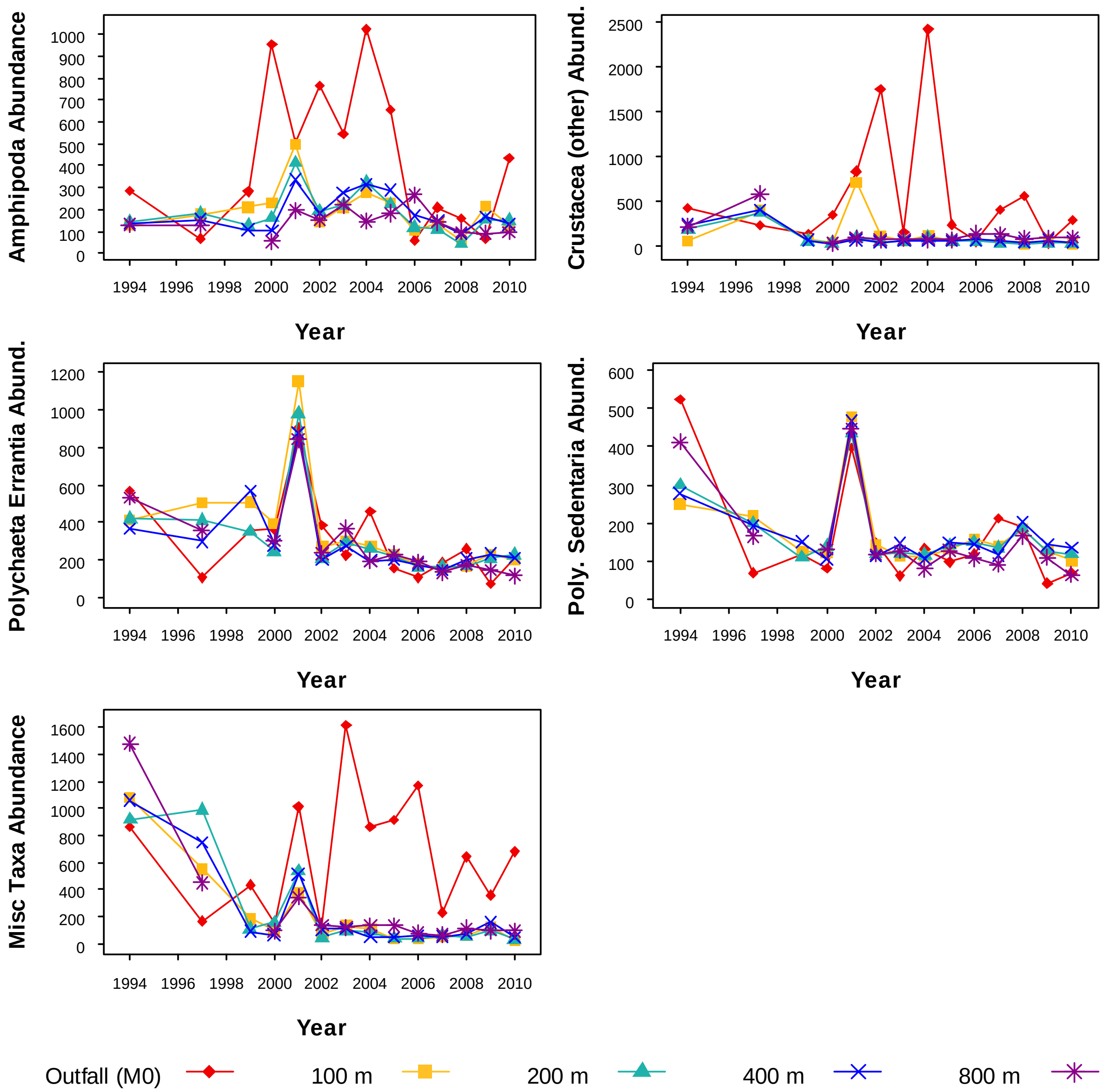


Figure 17: Plots of Macaulay Point Benthic Community Metrics Over Time (Normalized to Reference), Grouped by Distance from M0



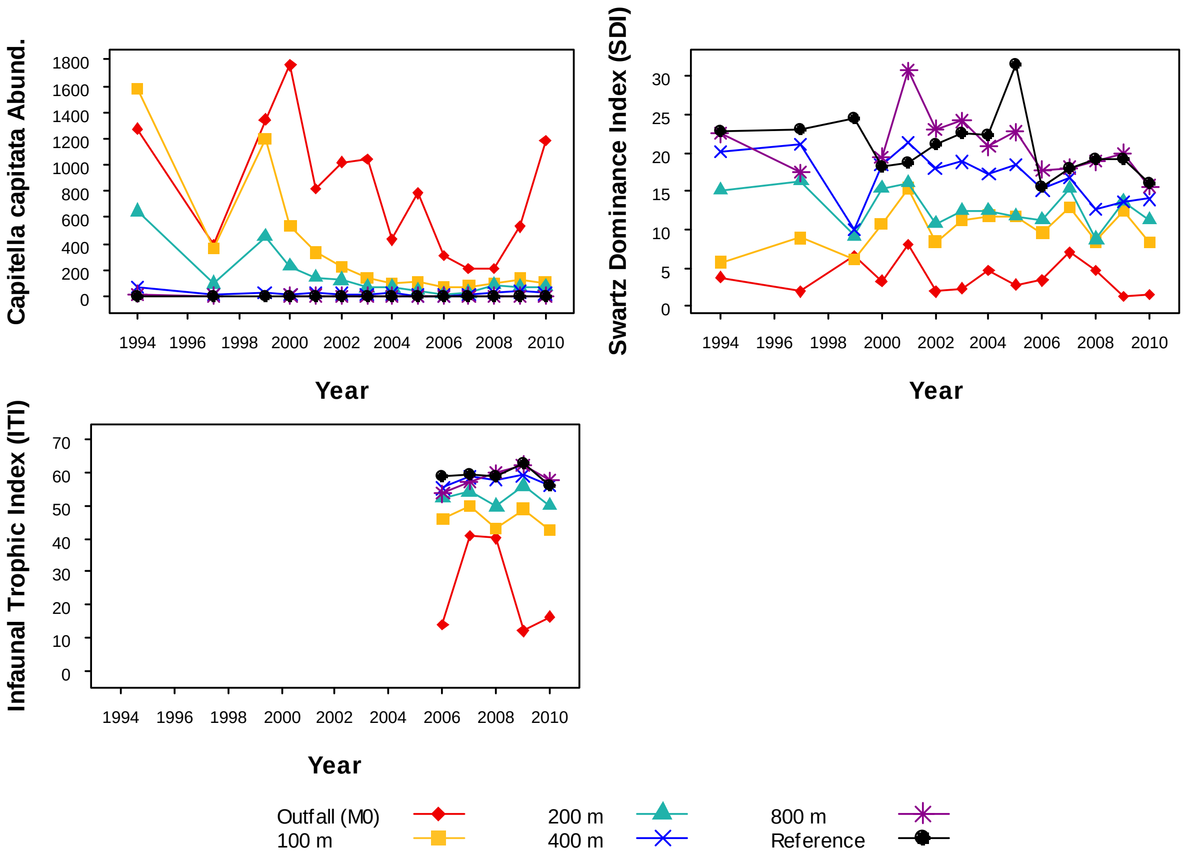
Note: Benthic community metrics were normalized to reference area
Vertical axis represents percent of reference
No 800 m stations were sampled in 1999

Figure 17: (Continued)



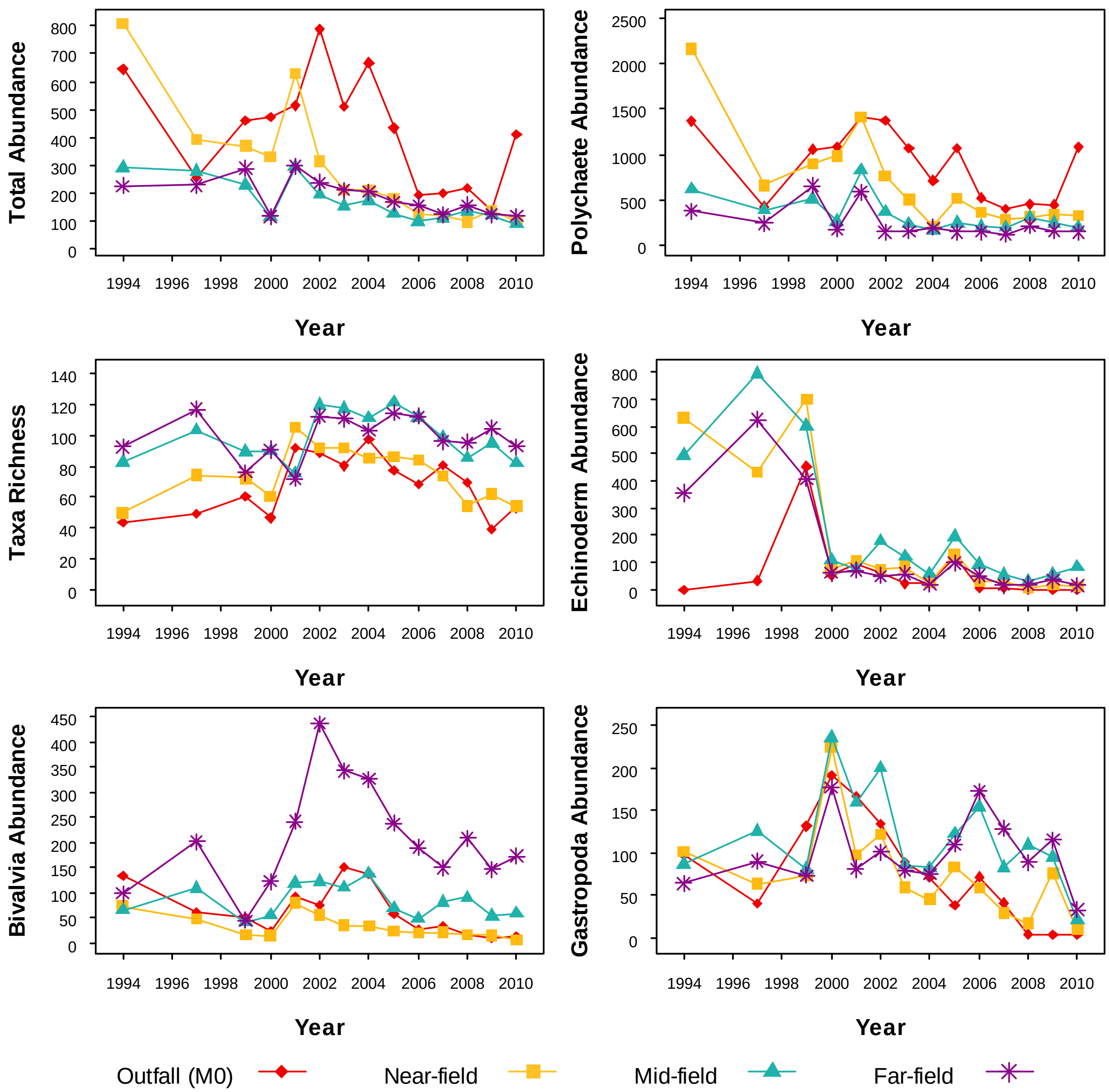
Note: Benthic community metrics were normalized to reference area
Vertical axis represents percent of reference
No 800 m stations were sampled in 1999

Figure 17: (Continued)



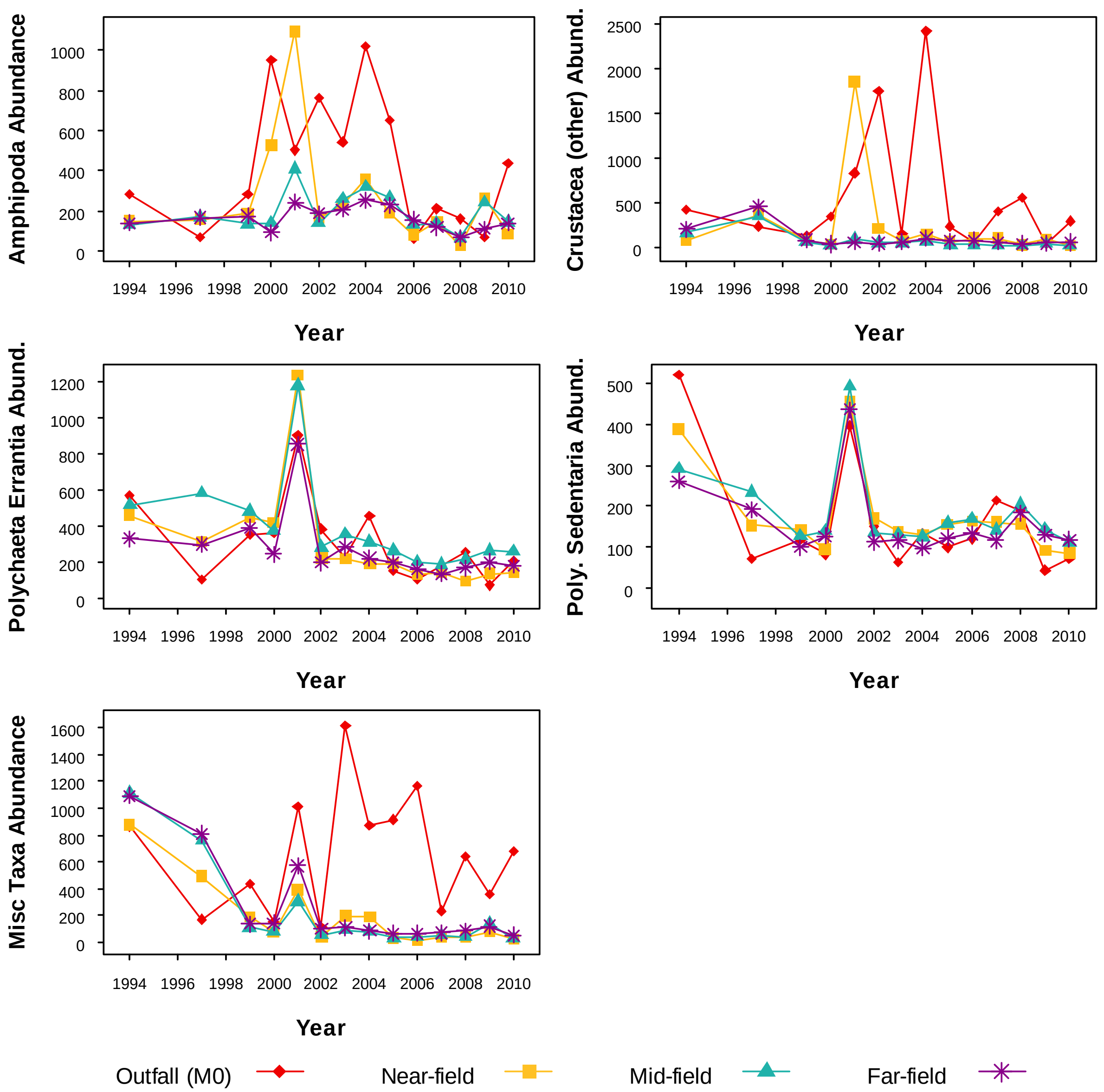
Note: *Capitella capitata* abundance, SDI and ITI were not reference normalized
No 800 m stations were sampled in 1999

Figure 18: Plots of Macaulay Point Benthic Community Metrics Over Time (Normalized to Reference), Grouped by Distance-Direction



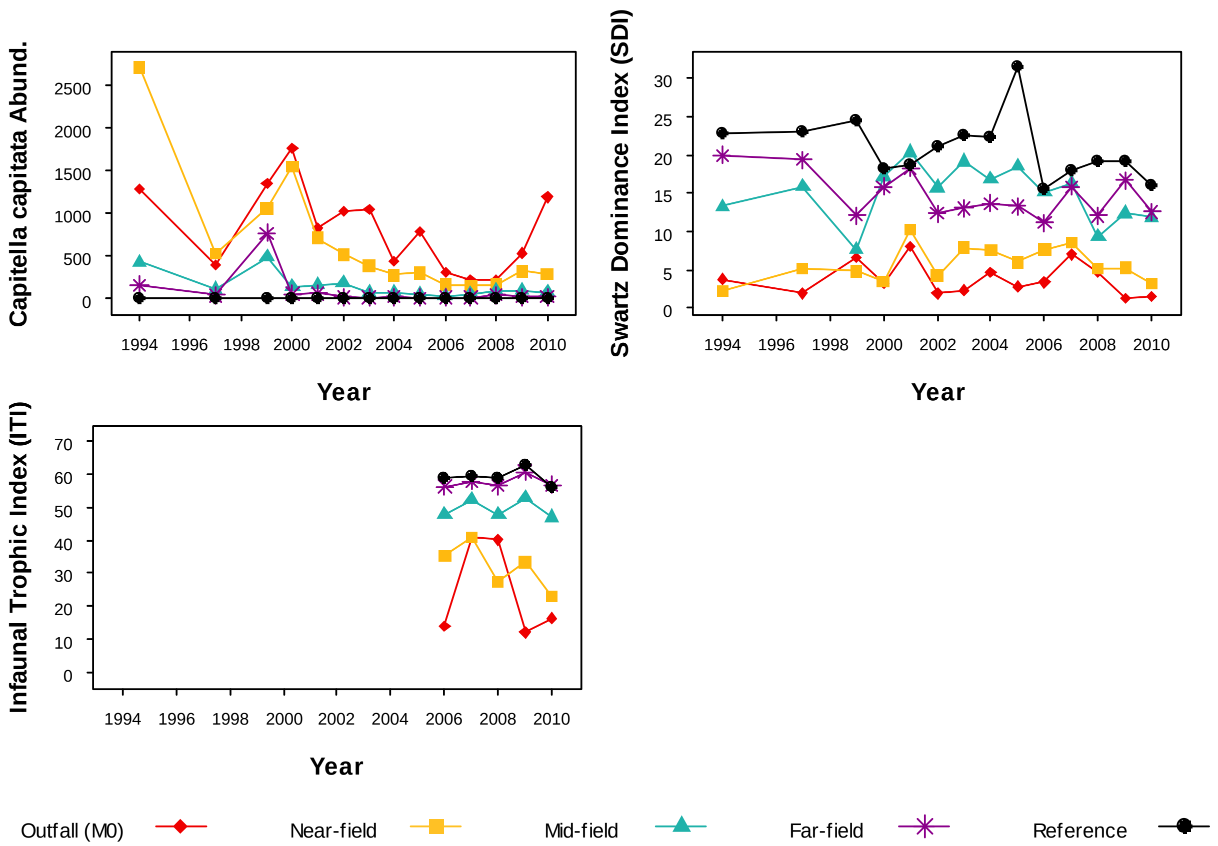
Note: Benthic community metrics were normalized to reference area
Vertical axis represents percent of reference

Figure 18: (Continued)



Note: Benthic community metrics were normalized to reference area
Vertical axis represents percent of reference

Figure 18: (Continued)



Note: *Capitella capitata* abundance, SDI and ITI were not reference normalized

Figure 19: Temporal Trends in Benthic Metrics (Mean of Replicates) for Parry Bay Reference Stations

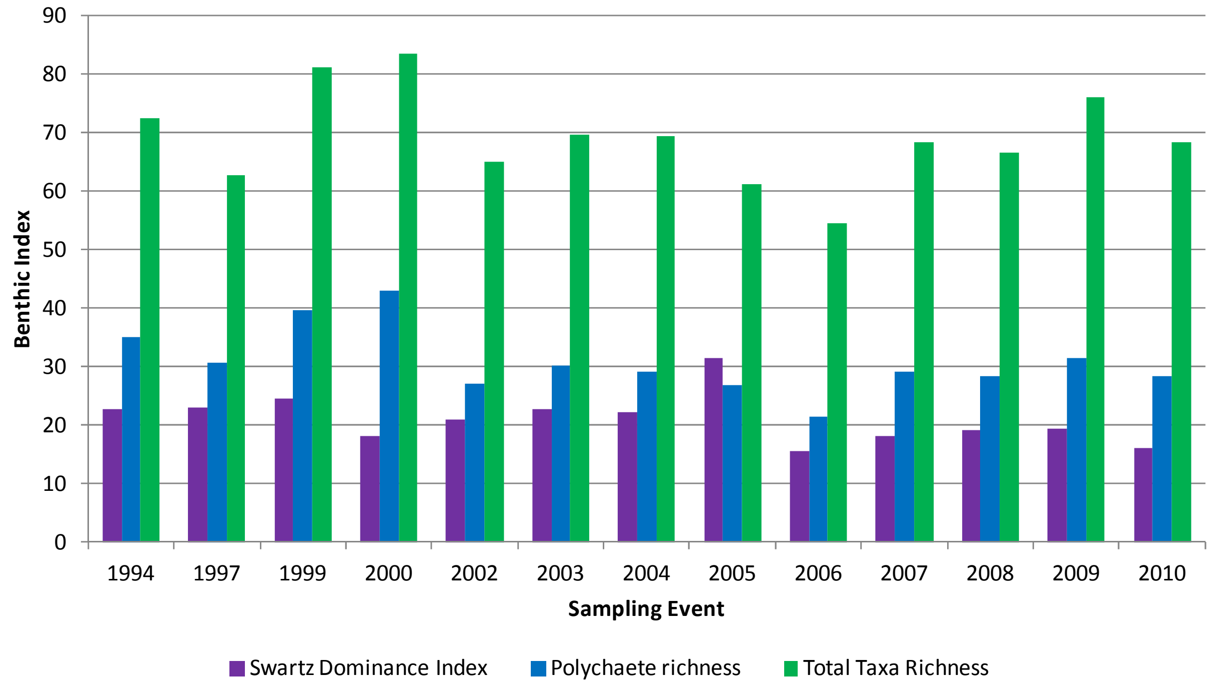
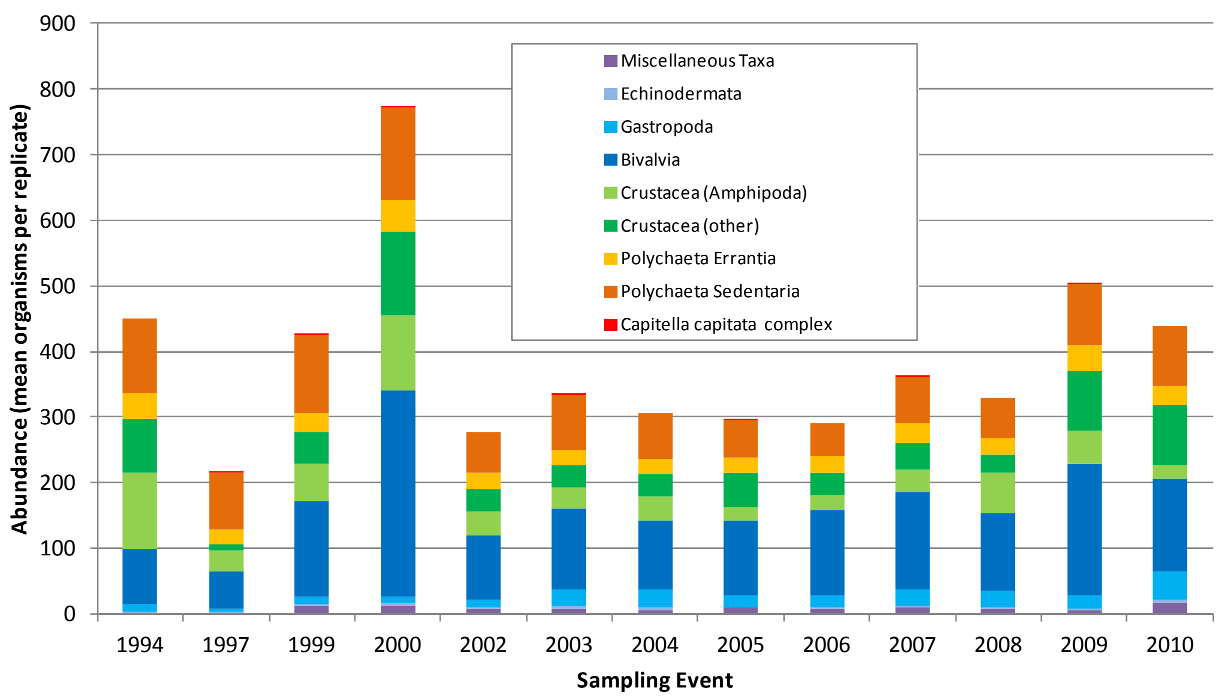


Figure 20: Temporal Trends in Cumulative Abundances of Organisms (Mean of Replicates) for Parry Bay Reference Stations



APPENDIX A

ITI Classification

1.0 INTRODUCTION

The Infaunal Trophic Index (ITI) is a numerical representation of the distribution of dominant feeding groups of benthic fauna; it has been used to quantitatively model community response to organic material in the water column and/or substratum (Maurer *et al.* 1999). The ITI and its response to organic matter is based on the principle that with increasing organic carbon concentration the dominant feeding type changes from species that feed at the interface of the sediment and water to species that are predominantly deposit feeders.

To calculate the ITI, the fifty (50) most abundant taxa (across all stations) were assigned to one of four feeding groups, as defined by Word (1979) and Maurer *et al.* (1999):

- Group I: suspended detritus feeders;
- Group II: surface detritus feeders;
- Group III: surface deposit feeders; and
- Group IV: sub-surface deposit feeders.

The ITI classifications for the 50 most abundant organisms in the 2010 dataset are presented in **Table B-1**. The classifications in 2010 are provided for two separate ITI systems, one based on the traditional approach as used in previous monitoring reports, and a new system based the extension on a standardized system from the work of Macdonald *et al.* (2010).

2.0 RATIONALE FOR NEW CLASSIFICATIONS

Most of the taxa in the 2010 dataset had already been categorized in previous benthic community assessments conducted as part of the 2006-2009 benthic monitoring studies of Macaulay Point biota. However, two (2) taxa (*Maldane glebifex*, *Polycirrus* sp. complex) were identified that had not previously been included in ITI calculations. Neither of these taxa was categorized at the species level in Word (1979) or Maurer *et al.* (1999).

Rationales for the classification for each of these organisms are presented below. The assignments were based on literature reviews conducted preferentially at the species and genus levels of taxonomy. If insufficient information was available, the review was broadened to include family or sub-order level information.

2.1 *Maldane glebifex* (ITI Category III)

The polychaete genus *Maldane* is found in the taxonomic subclass Scolecida, the family Maldanidae, and subfamily Maldaninae. The sedentary worms of the family Maldanidae, often called “bamboo worms”, are examples of direct deposit feeding tube-dwellers, as they live upside down and ingest the substratum at the bottom of the sand-grain tube (Marine Species Identification Portal 2011). Bamboo worms are large, cylindrical worms and feed as bulk consumers of sediment using a balloon-like proboscis.

The maldanids are highly specialised burrowers feeding on organic particles such as protozoans and diatoms buried in mud. They burrow head-downwards cementing the surrounding materials together to form a fairly compact tube. The feeding classification for this genus is complicated by the fact that it processes material originating from suspended matter, but also processes bed sediment to extract these small organic particles (*i.e.*, consumes sediment particles that are coated with organic material). Maurer (1999) lists the family Maldanidae as suspended detritus feeder, whereas Bellan (2011a) lists the genus *Maldane* as a subsurface deposit feeder and grazer. The food for maldanids is usually characterized as detritus (Fauchald and Jumars 1979). Some species within the genus, such as *Maldane sarsi*, not only engulf sediment for food but also construct tubes from the sediment (Reish 1983).

Macdonald *et al.* (2010) provides following ecological characterization of the genus *Maldane* spp.:

- Food source: subsurface;
- Motility: discretely motile;
- Life habit: tubiculous;
- Diet: omnivorous;
- Food type/size: sediment, particulate organic matter, benthic microfauna (*e.g.*, diatoms and other single-celled organisms);
- Feeding mode: deposit feeding; and
- Combination feeding description: subsurface – deposit feeder.

The subsurface deposit-feeding nature of *Maldane* is suggestive of ITI category IV, although the benthic microfauna and detritus in the diet are indicative of an exposure pathway partially driven by surface particulate matter.

From the above information, it appears that the genus *Maldane* has been assigned by various authors to feeding strategies that span a range of ITI classifications. The most appropriate category is considered to be ITI Category III, reflecting a combination of deposit-feeding types and a combination of tube-building and engulfing feeding strategies.

2.2 *Polycirrus* sp. complex (ITI Category II)

This polychaete species complex is found in the taxonomic order Terebellida within the family Terebellidae. The genus *Polycirrus* falls in the subfamily Polycirrinae.

Bellan (2011b) identified a range of feeding strategies for the genus *Polycirrus*, including:

- surface deposit feeder (which aligns with ITI Group III);
- interface grazer (which aligns with ITI Group II); and
- suspension feeder (which aligns with ITI Group I).

At a more general level, Maurer (1999) lists the family Terebellidae as containing suspended detritus feeders (which aligns with ITI Group I). Furthermore, Fauchald and Jumars (1979) described the diet as detritus, usually including diatoms, other unicellular algae, and small invertebrates including larvae. The anterior ends of these animals are equipped with extendable tentacles that are used for feeding.

In contrast to the above information indicating that *Polycirrus* feeds significantly on suspended material, there are strong indications of feeding upon matter in the sediment substratum. Macdonald *et al.* (2010) provides following ecological characterization of the genus *Polycirrus*:

- Food source: surface;
- Motility: discretely motile;
- Life habit: tubiculous;
- Diet: omnivorous;
- Food type/size: sediment/particulate organic matter, benthic microfauna (*e.g.*, diatoms and other single-celled organisms);
- Feeding mode: deposit feeding; and
- Combination feeding description: surface - deposit feeder.

Considering all of the above, it appears that *Polycirrus* feeding is intermediate between a surface deposit feeding strategy (ITI Type III) and the suspension feeding strategy (ITI Type I). This is not uncommon for a species that constructs tubes in the upper sediment layer, as these animals can both circulate overlying water and also consume sediment-associated matter within their burrows. The overall designation was therefore assigned as ITI Type II.

3.0 REGIONAL TROPHIC CLASSIFICATIONS

The ITI classification system applied previously to CRD monitoring data has required adaptation of the original ITI classification systems to categorize new species. Professional judgement is required to assign these new classifications, which can be challenging when the life histories of the animals do not fit neatly within one of the four ITI categories, as evidenced by the discussions in Section 2.1 and 2.2.

In contrast to these “standard” ITI categorizations used in previous monitoring analyses of Macaulay Point benthic communities, Macdonald *et al.* (2010) recently developed a standardized system to the ecological classification of invertebrates in the Georgia Basin. The application of this work to the ITI classification system for the Macaulay Point benthos is detailed below.

3.1 Standardized Trophic Coding System

Rather than rely on a combination of classifications from multiple authors (*e.g.*, Maurer *et al.* 1999, Word 1980, professional judgement for the taxa described in Section 2.0) the Macdonald *et al.* (2010) trophic coding system classifies all species in this database based on their feeding mode, food type/source, and life habit. Trophic information was gleaned by the authors from the literature for each individual species wherever possible, or was assumed to feed in a similar manner to congeneric or confamilial species.

For each taxon in Macdonald *et al.* (2010), the following information was recorded:

- Food source: epibenthic, surface, or subsurface;
- Diet: carnivorous, herbivorous, or omnivorous;
- Food type/size: sediment, particulate organic matter, benthic microfauna (*e.g.*, diatoms and other single-celled organisms), benthic meiofauna (organisms retained on a <500 µm sieve), benthic macrofauna (organisms retained on a >500 µm sieve, including macroalgae), phytoplankton, zooplankton, terrestrial material (*e.g.*, wood); and
- Feeding mode: Deposit feeder (ingests sediment), detritus feeder (ingests particular matter only, without sediment), suspension/filter feeder (strains particles from the water), predator (eats live animals only), scavenger (carrion only), suctorial parasite, chemosynthetic (with symbiotic bacteria), lignivorous (eats wood), grazer (feeds by scraping, either on algae or sessile animals), and browsing (feeds by tearing or gathering particular items).

Of these categories, the food source and feeding mode are the most directly relevant to the ITI classification.

Some advantages of the Macdonald *et al.* (2010) system are:

- Region-relevant classifications from trusted local taxonomists;
- Consistency with the taxonomic system used by CRD;
- Published DFO document;
- Explicit evaluation of feeding type in a consistent and systematic fashion; and
- Comprehensive list of observed taxa (*i.e.*, no missing species requiring assignment based on professional judgement).

Some disadvantages of the Macdonald *et al.* (2010) system are:

- Lack of compatibility for some taxa assignments with designations made by other authors;
- Lack of ITI classification, requiring conversion from the tabulated information in the database to the ITI narratives; and
- Related to above, lack of temporal consistency in ITI scores (*i.e.*, new classifications cannot be directly compared to historical calculations).

3.2 Conversion to ITI Classification

To provide a transparent system of converting Macdonald *et al.* (2010) classifications into ITI categories, the following procedure was applied:

- The "combo code" from Macdonald *et al.* (2010) was considered. For example, the combo code for *Capitella capitata* is SS-De (subsurface – deposit feeder); and
- The ITI narratives for the four categories were linked to appropriately matched feeding descriptions, and summarized in a look-up table (**Table B-2**).

3.3 Comparison to Previous ITI Classifications

Table B-1 presents the ITI classifcations using both the "standard" system used previously in statistical analyses for Macaulay Point biota and the "regional" system based on the work of Macdonald *et al.* (2010). For the vast majority of taxa, the assignments were either identical or matched closely (*i.e.*, ITI values were ±1).

For a few taxa, the assignments diverged; in all of these cases, the regional evaluation indicated a higher ITI category compared to the classifications suggested by Word (1979, 1980) and Maurer *et al.* (1999). These taxa included:

- *Euclymeninae* indet;
- *Mediomastus californiensis*;
- *Glycera nana*;
- *Decamastus gracilis*; and
- *Nephtys cornuta*.

The Macdonald *et al.* (2010) combined classification for all of these taxa was "subsurface deposit-feeder", which exactly matches the ITI narrative descriptor for category IV. The divergence in the ITI classifications for some species may result from the difficulty in assigning the myriad of invertebrate life histories to one of four discrete categories. The ITI narratives reflect a gradient of exposure from water column sources to the deep sediment bed, and therefore it is challenging to allocate a single category to species that combine pathways (*e.g.*, tube-building polychaetes). Furthermore, the distinction between detritus- and deposit-feeding can be ambiguous for some species.

Rather than belabour the individual differences in ITI designations using different systems, it is considered more appropriate to conduct the ITI evaluation using both approaches, providing complementary evaluation of faunal assemblages.

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Table A-1: Species, Groupings, and Functional Feeding Information Used for Calculation of Infaunal Trophic Index (Top 50 Organisms in 2010, Sorted by Abundance)

Rank	Latin Name	Food Source	Motility	Life Habit	Diet	Food Type/Size[1]	Feeding Mode[1]	Combination Feeding Description	Abun-dance	ITI Group (Regional)	ITI Group (Standard)	ITI Group (Standard) Reference
1	*Capitella capitata* complex	Subsurface	Discretely motile	Free-living	Omnivorous	sed/pom/mic	De	Subsurface - Deposit Feeder	11272	4	4	Word (1979)
2	*Axinopsida serricata*	Epibenthic	Discretely motile	Free-living	Omnivorous	pom/phy	Su	Surface - Suspension/Filter Feeder	8764	2	2	Maurer (1999)
3	*Euclymeninae* indet.	Subsurface	Discretely motile	Tubiculous	Omnivorous	sed/pom/mic	De	Subsurface - Deposit Feeder	3502	4	1	Word (1980)
4	*Euphilomedes producta*	Surface	Motile	Free-living	Omnivorous	pom	Dt	Surface - Detritus Feeder	2833	2	2	Word (1979)
5	*Scoletoma luti*	Subsurface	Motile	Free-living	Carnivorous	mei/mac	Pr	Subsurface - Predator - benthic meiofauna	1413	4	4	Professional judgement
6	*Leptochelia dubia*	Surface	Discretely motile	Tubiculous	Omnivorous	pom	Dt	Surface - Detritus Feeder	1361	2	2	Maurer (1999)
7	*Exogone lourei*	Surface	Motile	Free-living	Herbivorous	dia	Gr	Surface - Herbivorous - benthic microfauna	1259	2	2	Woodin (1974)
8	*Parvilucina tenuisculpta*	Surface	Discretely motile	Free-living	Omnivorous	sed/pom/mic	De/Ch	Surface - Chemosynthetic - Omnivorous	1167	2	3	Maurer (1999)
9	*Mediomastus californiensis*	Subsurface	Discretely motile	Free-living	Omnivorous	sed/pom/mic	De	Subsurface - Deposit Feeder	998	4	2	Word (1979)
10	*Notomastus tenuis*	Subsurface	Discretely motile	Free-living	Omnivorous	sed/pom/mic	De	Subsurface - Deposit Feeder	715	4	4	Professional judgement
11	*Acila castrensis*	Subsurface	Motile	Free-living	Omnivorous	sed/pom/mic	De	Subsurface - Deposit Feeder	653	4	4	Zardus (2002)
12	*Lirobittium munitum*	Surface	Motile	Free-living	Omnivorous	pom	Dt	Surface - Detritus Feeder	625	2	3	Professional judgement
13	*Astyris gausapata*	Surface	Motile	Free-living	Carnivorous	mac	Pr	Surface - Predator - benthic macrofauna	592	2	3	Professional judgement
14	*Aphelochaeta* sp. indet.	Surface	Discretely motile	Free-living	Omnivorous	sed/pom/mic/dia	De	Surface - Deposit Feeder	578	3	2	Maurer et al. (1999)
15	*Oligochaeta* indet.	Subsurface	Motile	Free-living	Omnivorous	pom/mic/dia	Dt	Subsurface - Omnivorous - benthic microfauna	574	4	4	Word (1979)
16	*Lumbrineridae* indet.	Subsurface	Motile	Free-living	Carnivorous	mei/mac	Pr	Subsurface - Predator - benthic meiofauna	540	4	4	Petch (1986)
17	*Macoma elimata*	Surface	Discretely motile	Free-living	Omnivorous	sed/pom/mic	De/Su	Surface - Deposit Feeder	528	3	3	Professional judgement
18	*Prionospio jubata*	Surface	Discretely motile	Tubiculous	Omnivorous	sed/pom/mic/dia/ phy	De/Su	Surface - Deposit Feeder	519	3	2	Word (1980)
19	*Glycera nana*	Subsurface	Motile	Free-living	Carnivorous	mac	Pr	Subsurface - Predator - benthic macrofauna	380	4	2	Maurer (1999)
20	*Rhepoxynius bicuspidatus*	Surface	Motile	Burrow-dwelling	Carnivorous	mei	Pr	Surface - Predator - benthic meiofauna	366	2	1	Oakden (1984); Word (1980)

Rank	Latin Name	Food Source	Motility	Life Habit	Diet	Food Type/Size[1]	Feeding Mode[1]	Combination Feeding Description	Abun-dance	ITI Group (Regional)	ITI Group (Standard)	ITI Group (Standard) Reference
21	*Aoroides inermis*	Surface	Discretely motile	Tubiculous	Omnivorous	pom/mic/dia/phy	Su	Surface - Suspension/Filter Feeder	365	2	2	Enequist, 1949; deBroyer and Bellan-Santini, 2009
22	*Lucinoma annulatum*	Surface	Discretely motile	Free-living	Omnivorous	sed/pom/mic	De/Ch	Surface - Chemosynthetic - Omnivorous	358	2	2	Duplessis *et al.* (2004)
23	*Photis brevipes*	Surface	Discretely motile	Tubiculous	Omnivorous	pom/mic/dia/phy	Su	Surface - Suspension/Filter Feeder	349	2	2	Maurer *et al.* (1999)
24	*Nutricola lordi*	Epibenthic	Discretely motile	Free-living	Omnivorous	pom/phy	Su	Epibenthic - Suspension/Filter Feeder	340	1	1	Lees (2006)
25	*Glycinde armigera*	Subsurface	Motile	Free-living	Carnivorous	mac	Pr	Subsurface - Predator - benthic macrofauna	335	4	4	Jumars *et al.* (1977)
26	*Sphaerodoropsis sphaerulifer*	Surface	Motile	Free-living	Omnivorous	pom/mic/dia	Dt	Surface - Detritus Feeder	283	2	3	Kudenov (1984)
27	*Aoroides exilis*	Surface	Discretely motile	Tubiculous	Omnivorous	pom/mic/dia/phy	Su	Surface - Suspension/Filter Feeder	272	2	2	Enequist, 1949; deBroyer and Bellan-Santini, 2009
28	*Decamastus gracilis*	Subsurface	Discretely motile	Free-living	Omnivorous	sed/pom/mic	De	Subsurface - Deposit Feeder	264	4	2	Maurer *et al.* (1999)
29	*Adontorhina cyclia*	Surface	Discretely motile	Free-living	Omnivorous	pom/phy	Su/Ch	Surface - Chemosynthetic - Omnivorous	226	2	1	Jumars and Banse (1989)
30	*Paraprionospio pinnata*	Surface	Discretely motile	Tubiculous	Omnivorous	sed/pom/mic/dia/ phy	De/Su	Surface - Deposit Feeder	219	3	2	Word (1980)
31	*Thysanocardia nigra*	Surface	Discretely motile	Free-living	Herbivorous	pom/alg	Dt/Br	Surface - Herbivorous - benthic macrofauna	186	2	1	Adrianov (2006)
32	*Magelona longicornis*	Surface	Discretely motile	Free-living	Omnivorous	sed/pom/mic/dia	De	Surface - Deposit Feeder	169	3	2	Maurer *et al.* (1999)
33	*Pulsellum salishorum*	Subsurface	Discretely motile	Burrow-dwelling	Carnivorous	mei	Pr	Subsurface - Predator - benthic meiofauna	158	4	3	Glover *et al.* (2003)
34	*Nephtys cornuta*	Subsurface	Motile	Free-living	Carnivorous	mei	Pr	Subsurface - Predator - benthic meiofauna	157	4	2	Maurer *et al.* (1999)
35	*Diopatra ornata*	Surface	Discretely motile	Tubiculous	Herbivorous	pom/alg	Dt	Surface - Herbivorous - benthic macrofauna	149	2	2	Kim (1992), Watanabe (2009)
36	*Aoroides* sp.	Surface	Discretely motile	Tubiculous	Omnivorous	pom/mic/dia/phy	Su	Surface - Suspension/Filter Feeder	147	2	2	Enequist, 1949; deBroyer and Bellan-Santini, 2009
37	*Macoma golikovi*	Surface	Discretely motile	Free-living	Omnivorous	sed/pom/mic	De/Su	Surface - Deposit Feeder	145	3	3	Professional judgement
38	*Yoldia seminuda*	Subsurface	Discretely motile	Burrow-dwelling	Omnivorous	sed/pom/mic	De	Subsurface - Deposit Feeder	145	4	3	Maurer *et al.* (1999)
39	*Macoma carlottensis*	Surface	Discretely motile	Free-living	Omnivorous	sed/pom/mic	De/Su	Surface - Deposit Feeder	141	3	3	Maurer *et al.* (1999)
40	*Nephtys ferruginea*	Subsurface	Motile	Free-living	Carnivorous	mac	Pr	Subsurface - Predator - benthic macrofauna	140	4	2	Maurer et al. (1999)
41	*Spiochaetopterus costarum*	Surface	Sessile	Tubiculous	Omnivorous	pom/mic/dia/phy/ zoo	Su/Dt	Surface - Suspension/Filter Feeder	136	2	3	Word (1979)
42	*Sternaspis* cf. *fossor*	Subsurface	Discretely motile	Burrow-dwelling	Omnivorous	sed/pom/mic	De	Subsurface - Deposit Feeder	134	4	4	Jumars and Banse (1989)

Rank	Latin Name	Food Source	Motility	Life Habit	Diet	Food Type/Size[1]	Feeding Mode[1]	Combination Feeding Description	Abun-dance	ITI Group (Regional)	ITI Group (Standard)	ITI Group (Standard) Reference
43	*Maldane glebifex*	Subsurface	Discretely motile	Tubiculous	Omnivorous	sed/pom/mic	De	Subsurface - Deposit Feeder	132	4	3	This study (Appendix B, Section 2)
44	*Lumbrineris californiensis*	Subsurface	Motile	Free-living	Carnivorous	sed/mic/mei/mac	De/Dt/Pr	Subsurface - Deposit Feeder	130	4	4	Professional judgement
45	*Polycirrus* sp. complex	Surface	Discretely motile	Tubiculous	Omnivorous	sed/pom/mic/dia	De	Surface - Deposit Feeder	125	3	2	This study (Appendix B, Section 2)
46	*Gammaropsis thompsoni*	Surface	Discretely motile	Tubiculous	Omnivorous	pom/mic/dia/phy	Su	Surface - Suspension/Filter Feeder	123	2	3	Professional judgement
47	*Laonice cirrata*	Surface	Discretely motile	Tubiculous	Omnivorous	sed/pom/mic/dia/ phy	De/Su	Surface - Deposit Feeder	120	3	2	Maurer *et al.* (1999); Fauchald and Bellan (2009)
48	*Armandia brevis*	Subsurface	Motile	Free-living	Omnivorous	sed/pom/mic	De	Subsurface - Deposit Feeder	119	4	4	Maurer *et al.* (1999)
49	*Desdimelita desdichada*	Surface	Motile	Free-living	Omnivorous	pom	Dt	Surface - Detritus Feeder	116	2	2	Kennedy (1985)
50	*Galathowenia oculata*	Surface	Discretely motile	Tubiculous	Omnivorous	sed/pom/mic/dia	De	Surface - Deposit Feeder	115	3	2	Coyle *et al.* (2007)

1. Abbreviations provided in the table – full explanations for food type/size and feeding mode are provided in Appendix B, Section 2.1, bullets 3 and 4.

Table A-2: Conversion Table Between Traditional ITI Categories and Functional Feeding Information from Macdonald *et al.* (2010)

ITI Group (Regional)	ITI Narrative	Combination Feeding Description
1	suspended detritus feeders; dominated by suspension feeding animals	Epibenthic - Suspension/Filter Feeder
2	surface detritus feeders; feed on suspended matter or detritus on the sediment surface	Surface - Chemosynthetic - Omnivorous
		Surface - Detritus Feeder
		Surface - Herbivorous - benthic macrofauna
		Surface - Predator - benthic macrofauna
		Surface - Predator - benthic meiofauna
		Surface - Suspension/Filter Feeder
3	surface deposit feeders	Surface - Deposit Feeder
4	sub-surface deposit feeders	Subsurface - Deposit Feeder
		Subsurface - Omnivorous - benthic microfauna
		Subsurface - Predator - benthic macrofauna

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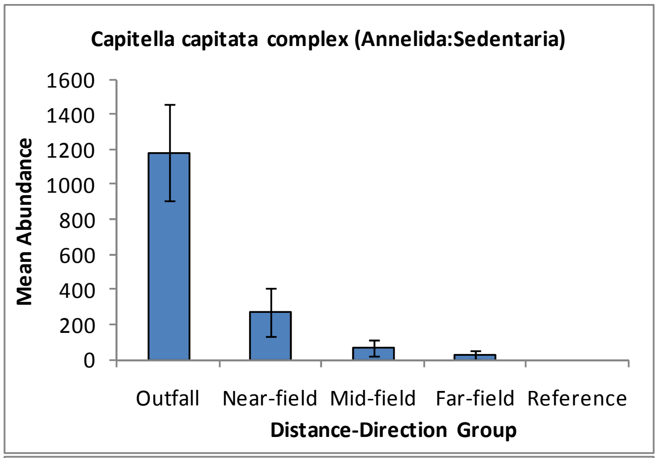
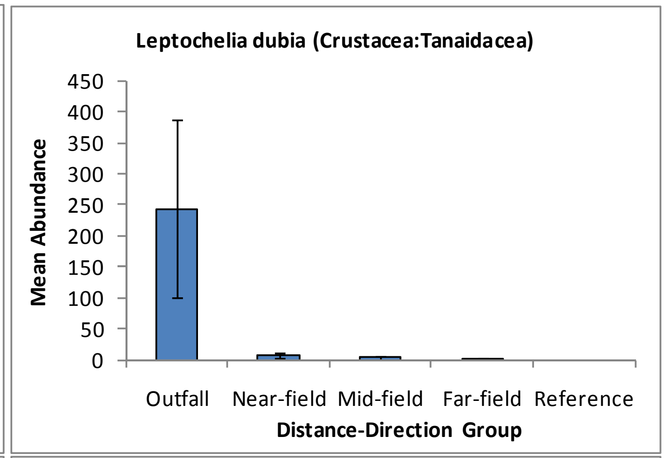
APPENDIX B

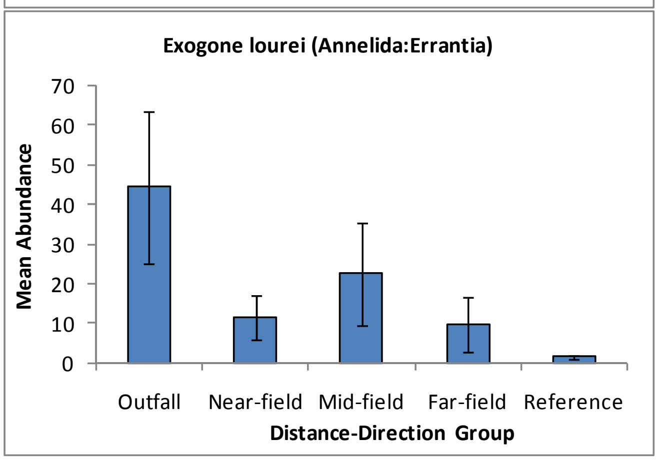
Individual Taxa Abundances

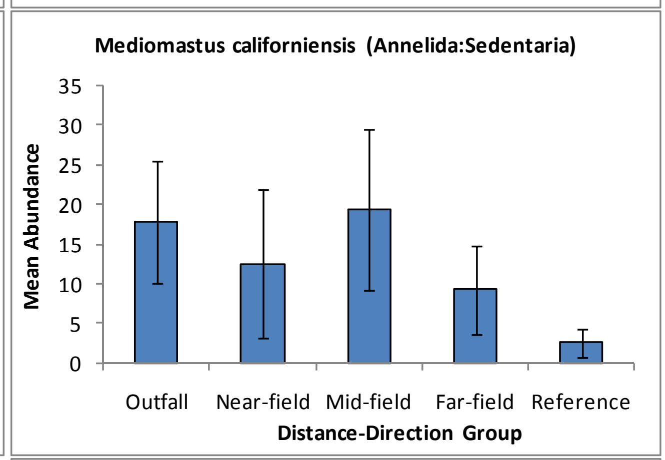
DISTANCE-DIRECTION GROUPS

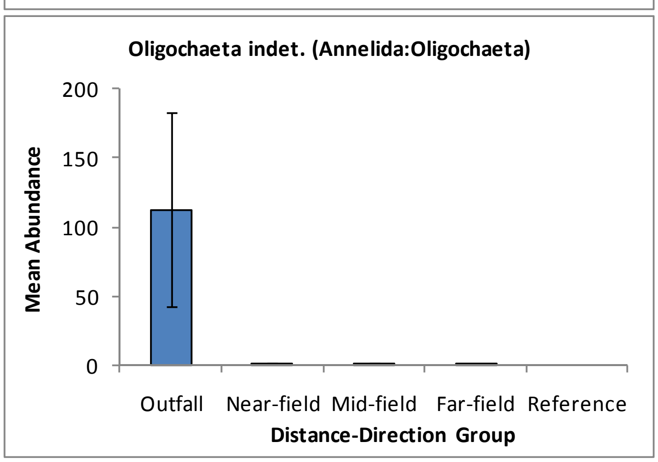
Pattern A (Most Abundant Near the Outfall and Declining with Distance)

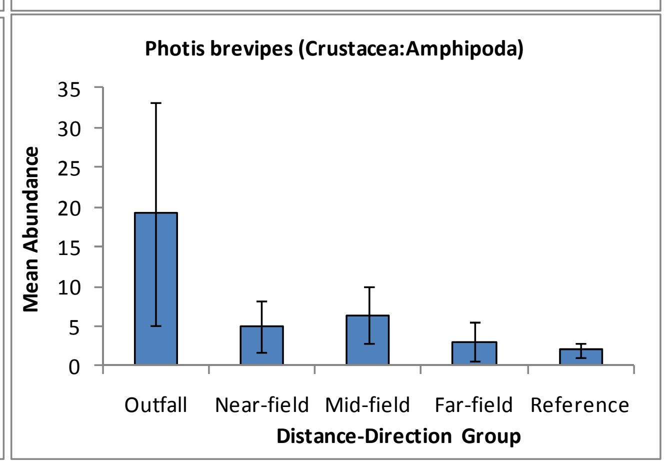




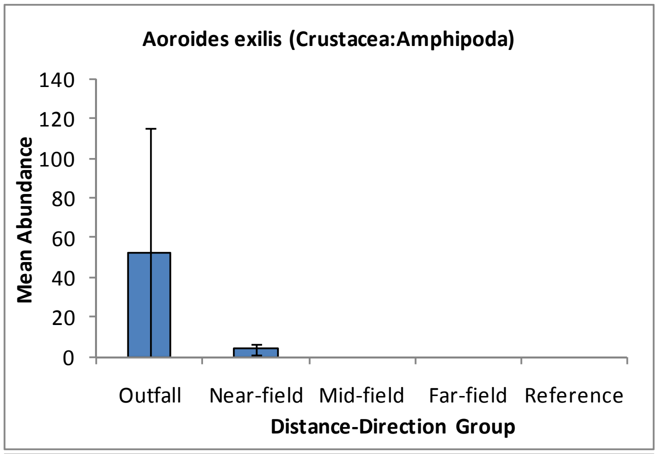


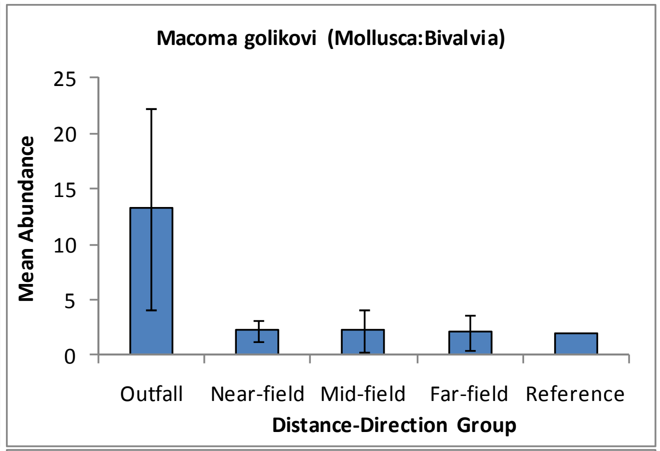


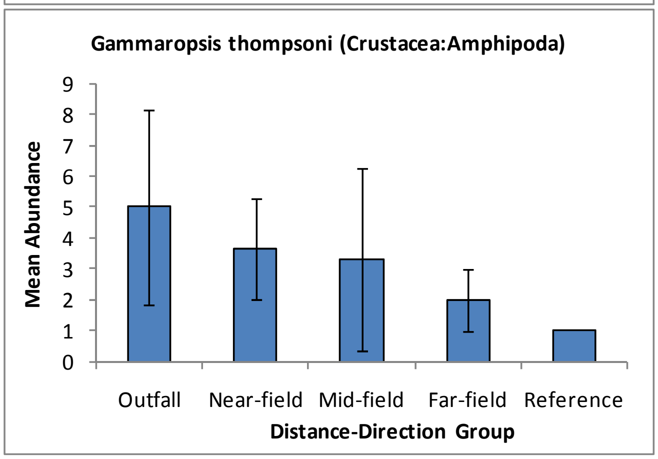


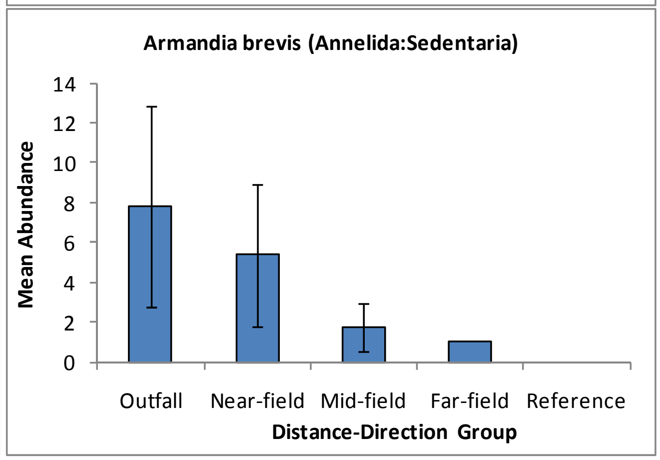


Pattern A (Continued)

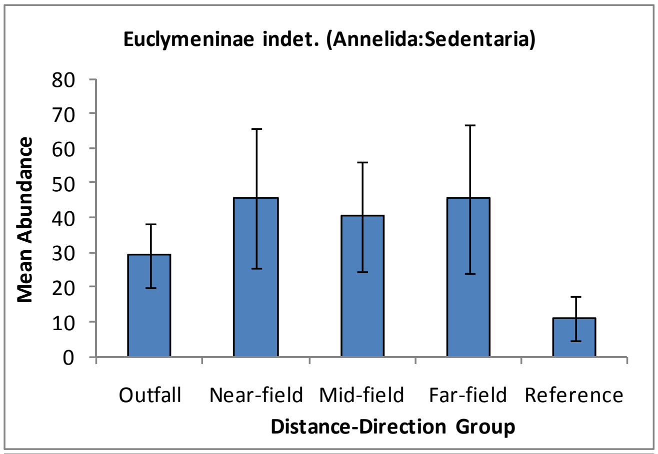


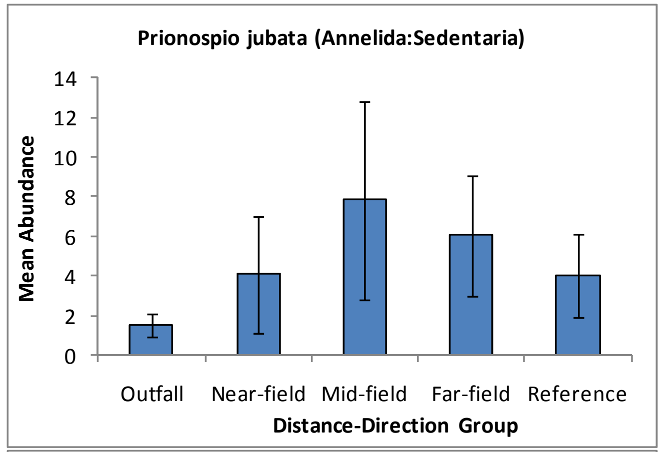


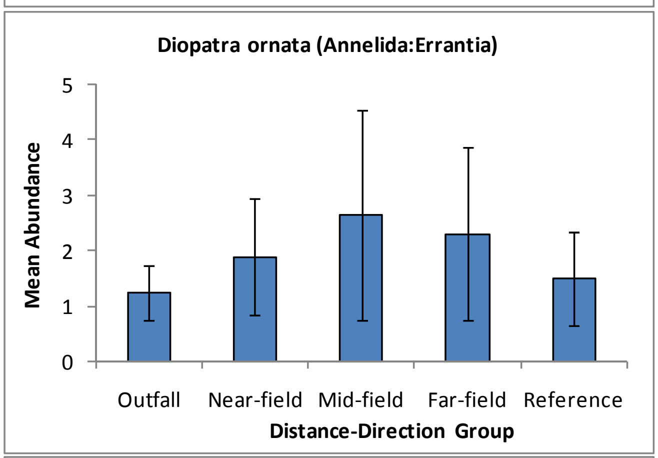


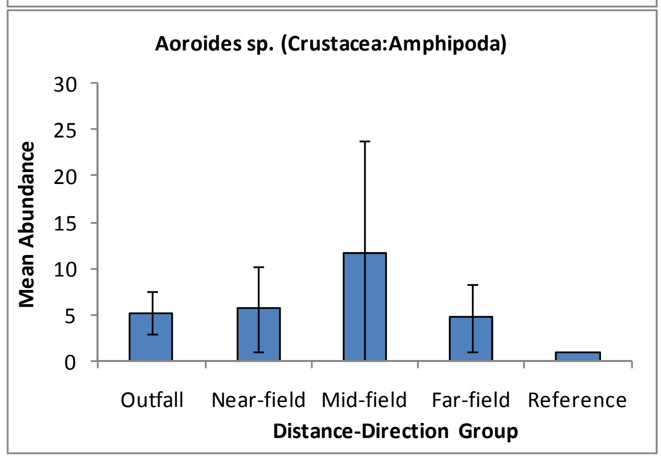


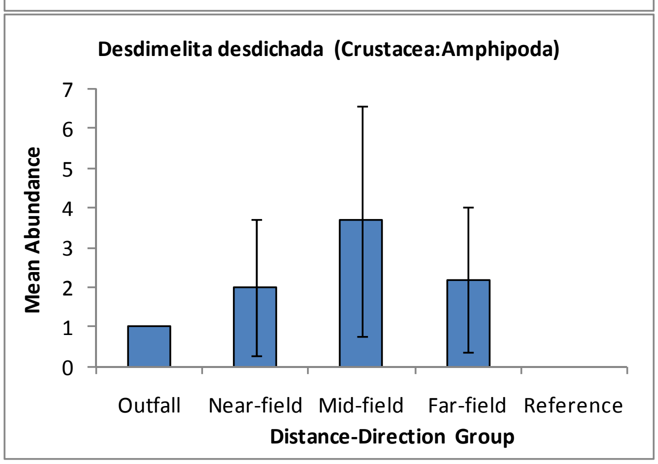
Pattern B1 (Low Abundance at Outfall; Most Abundant at Intermediate Distance from Outfall)



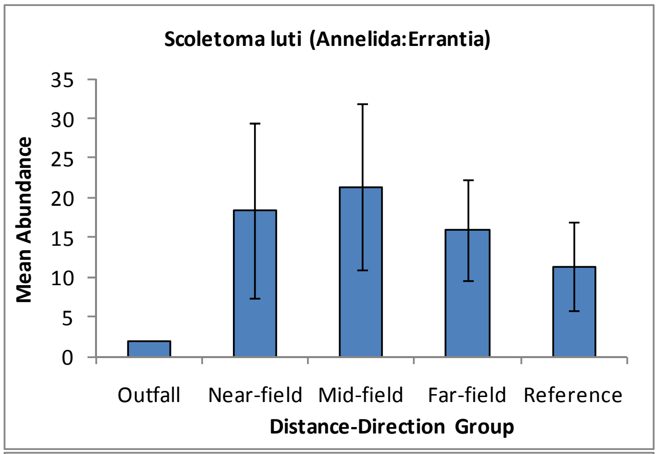


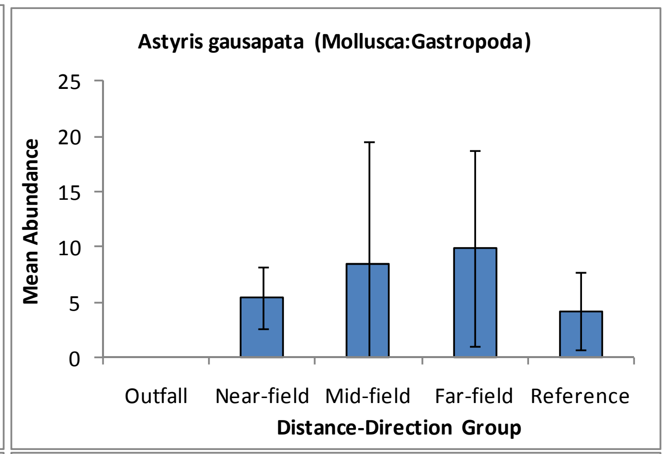


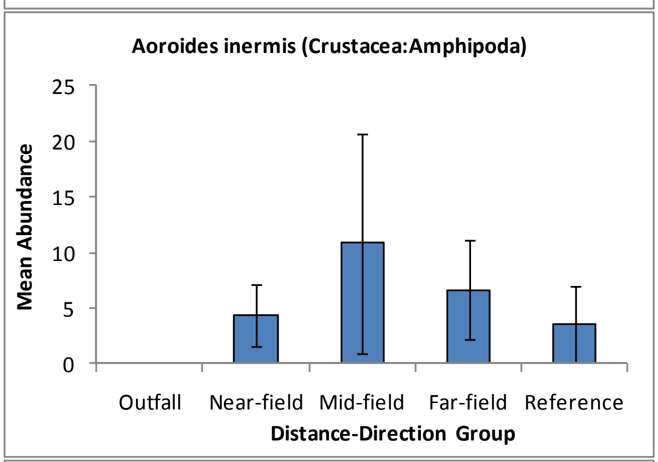


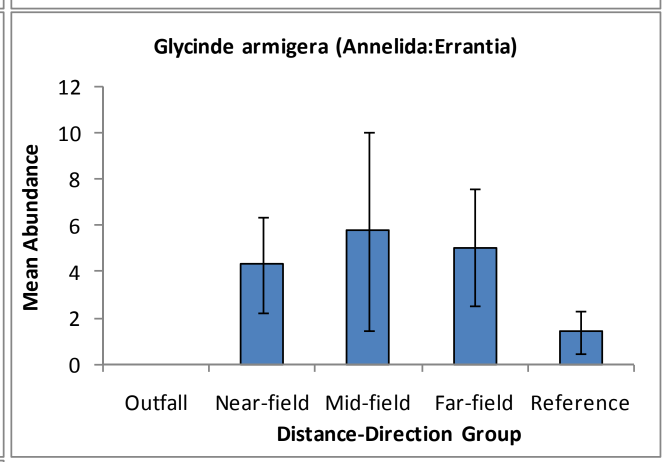


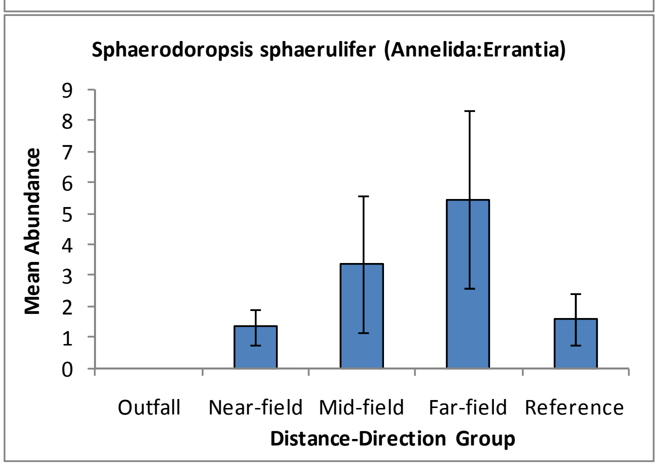
Pattern B2 (Very Low Abundance at Outfall; Most Abundant at Intermediate Distance from Outfall)

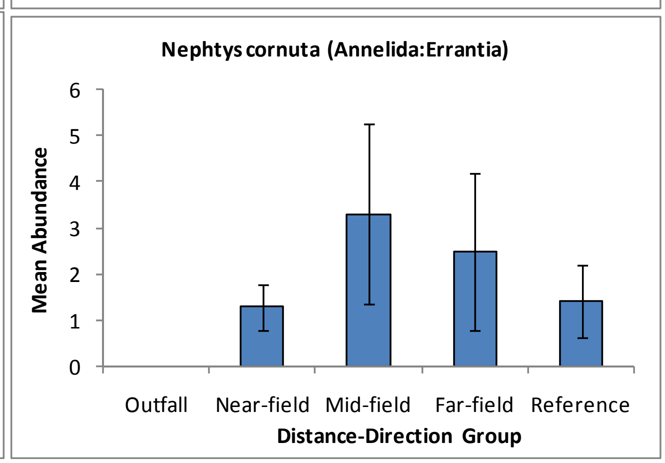












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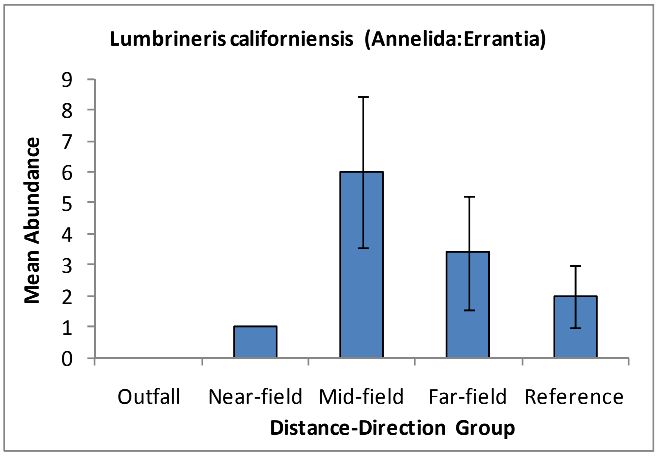
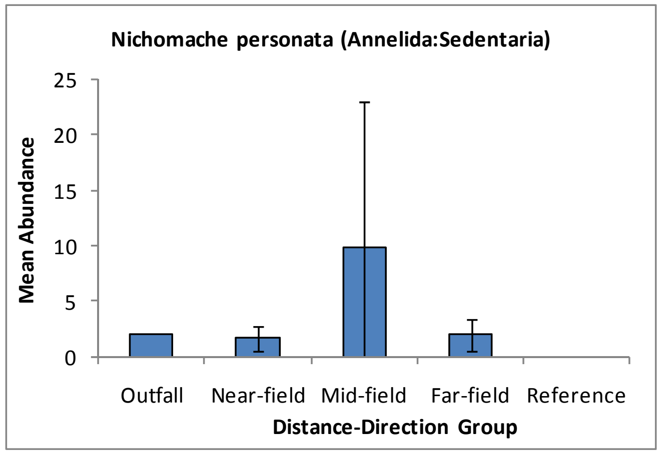
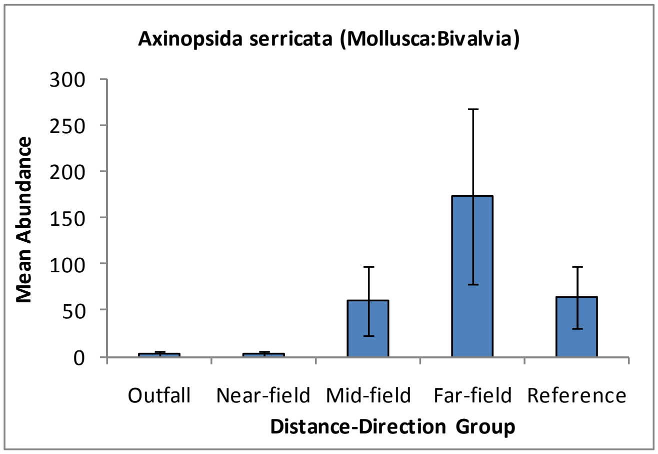
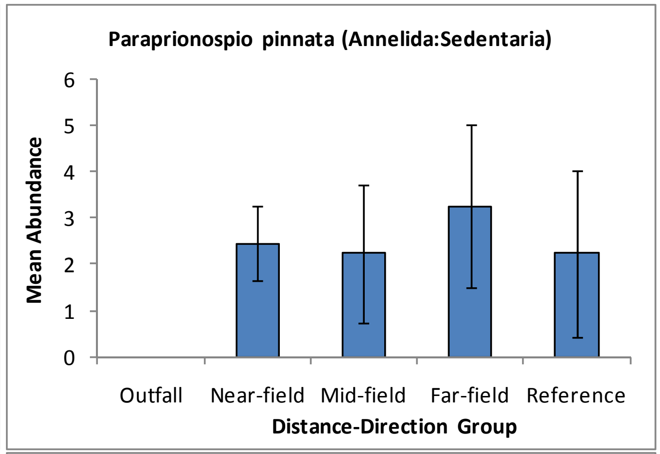
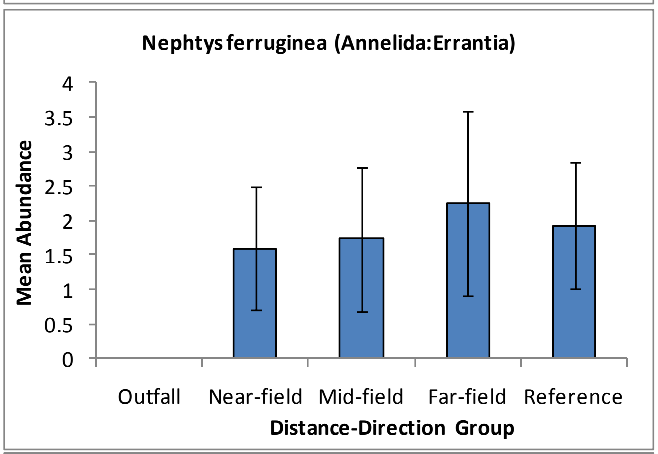


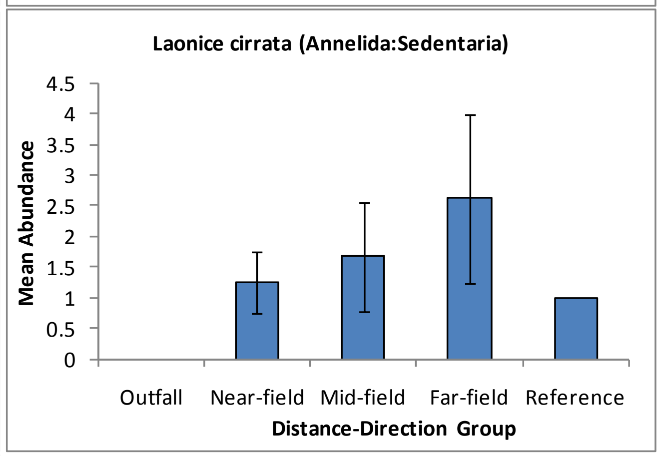


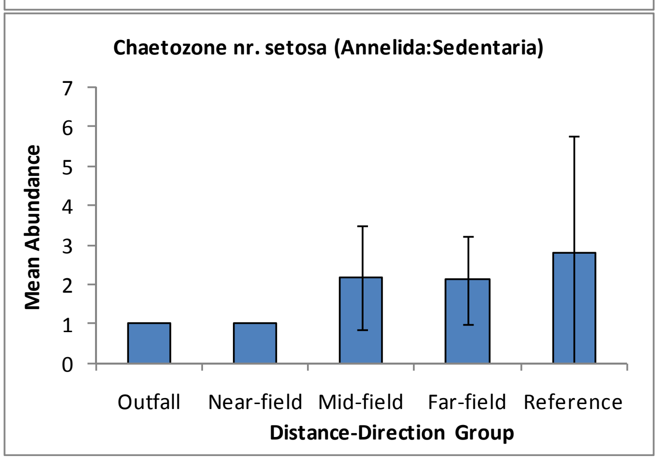
Pattern C (Low Abundance Near Outfall; Similar Abundance Among Other Groups)

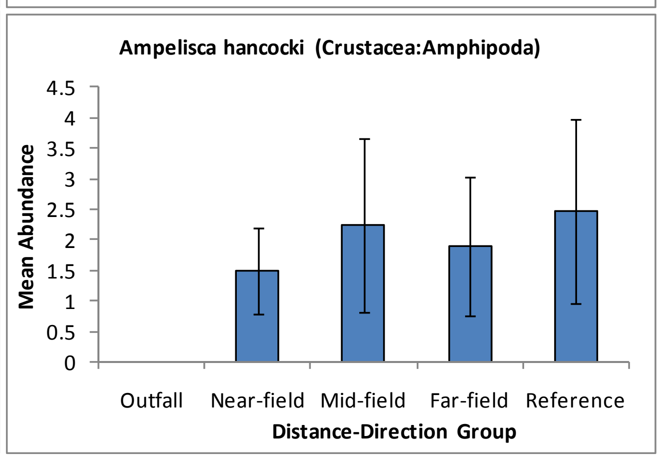












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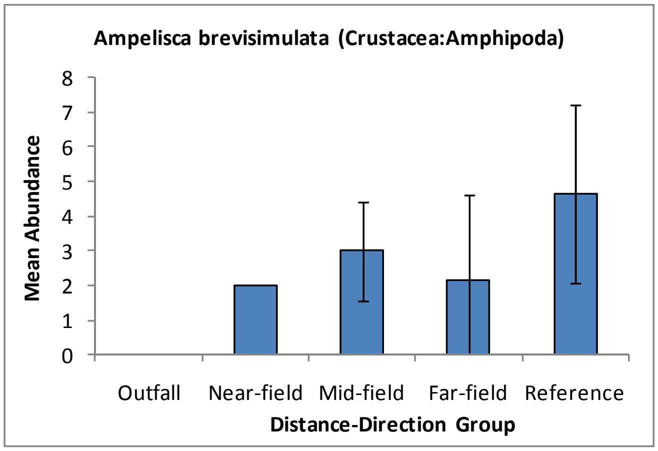
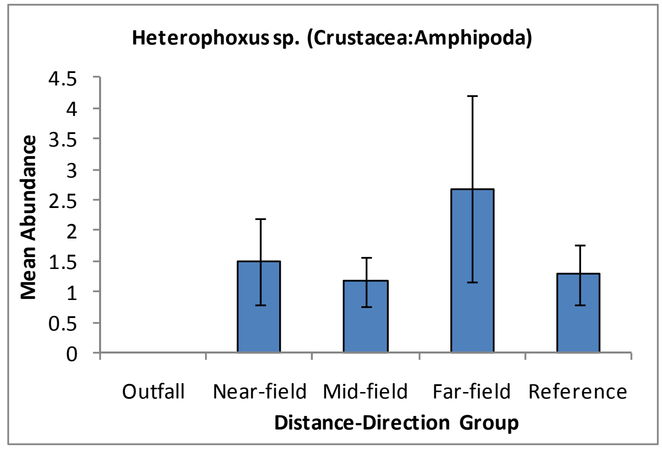
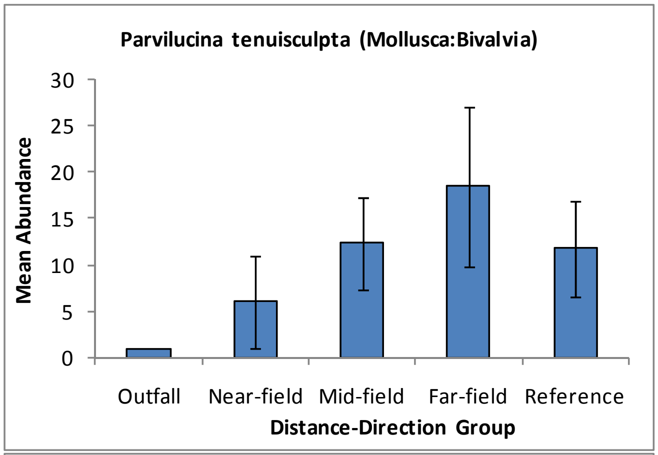
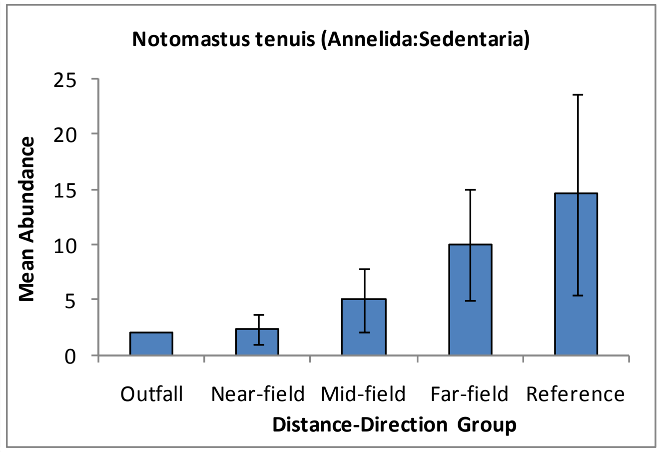
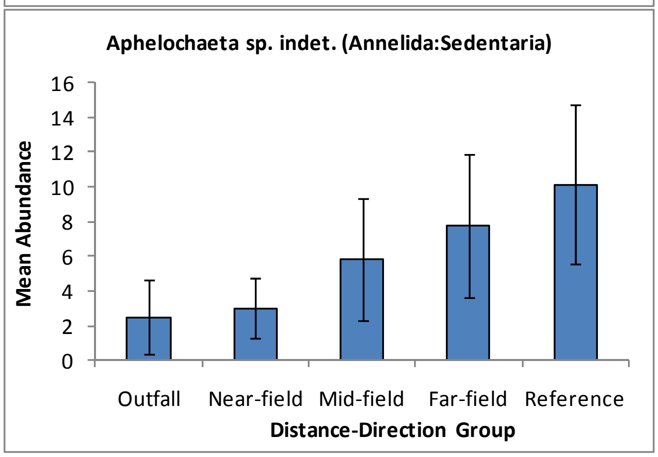


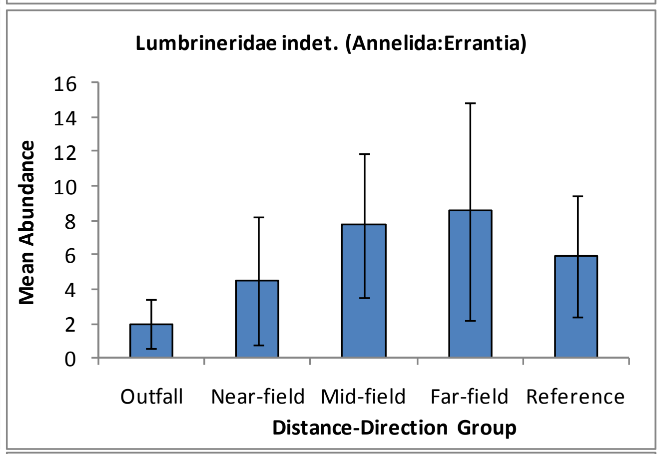


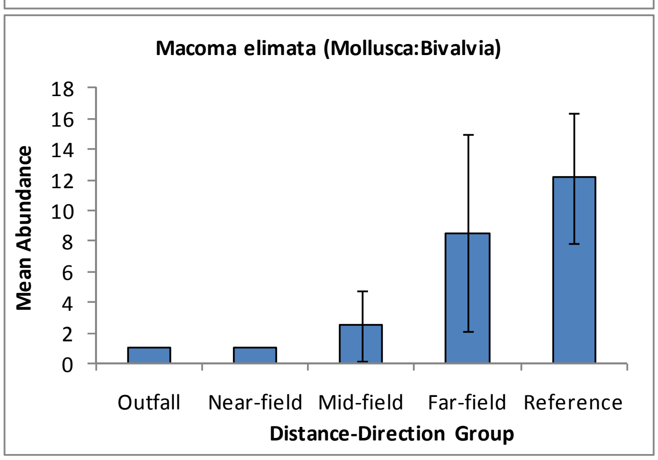
Pattern D (Generally Increasing with Distance from Outfall)

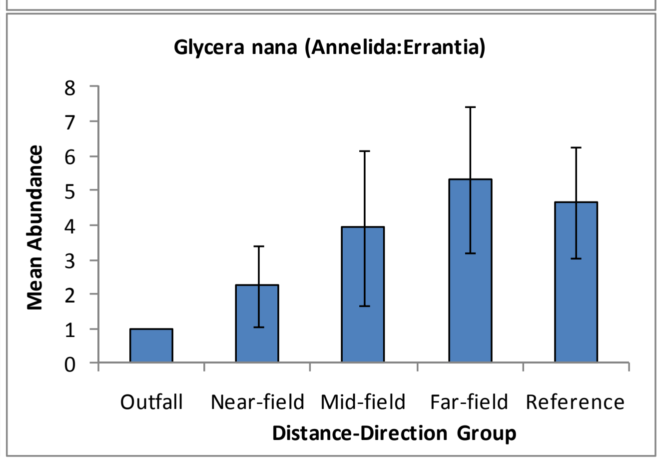












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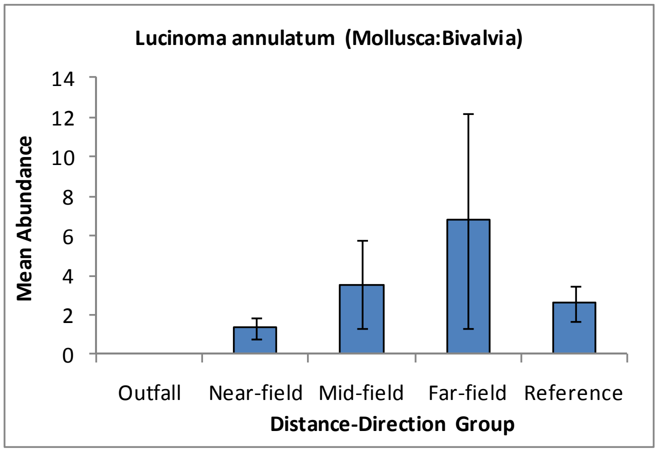
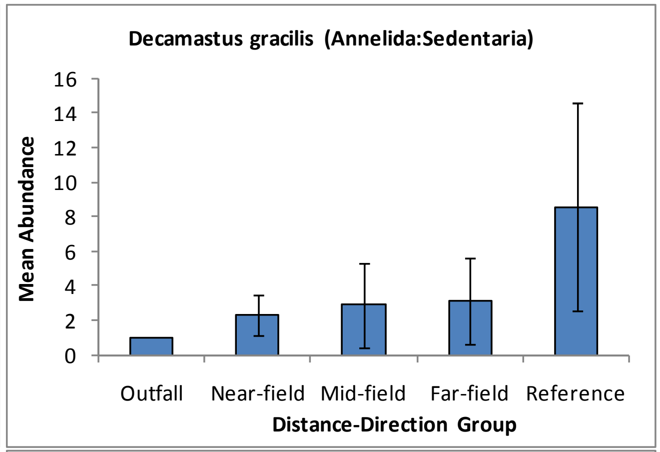
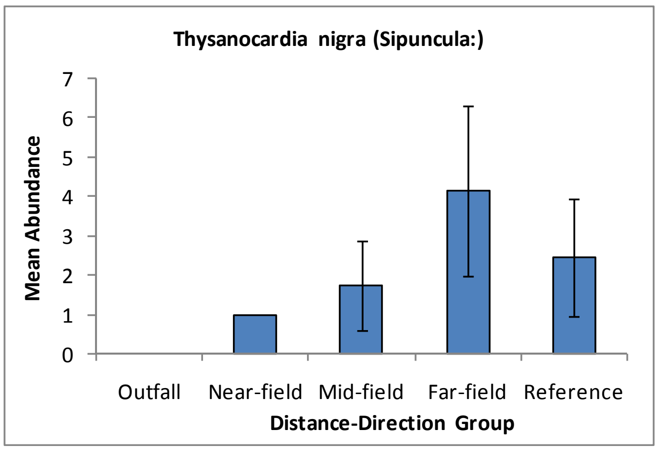
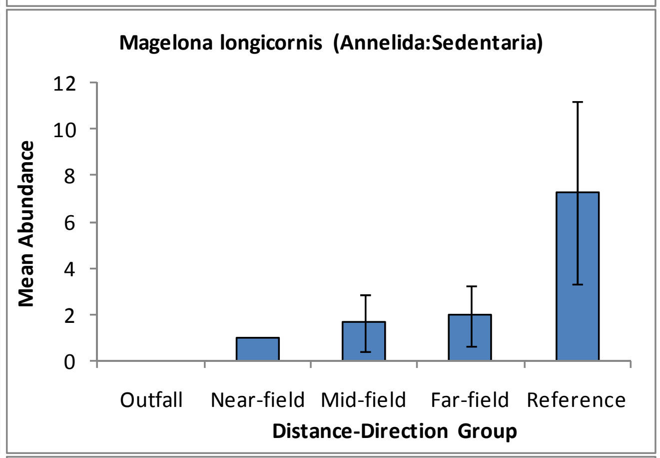
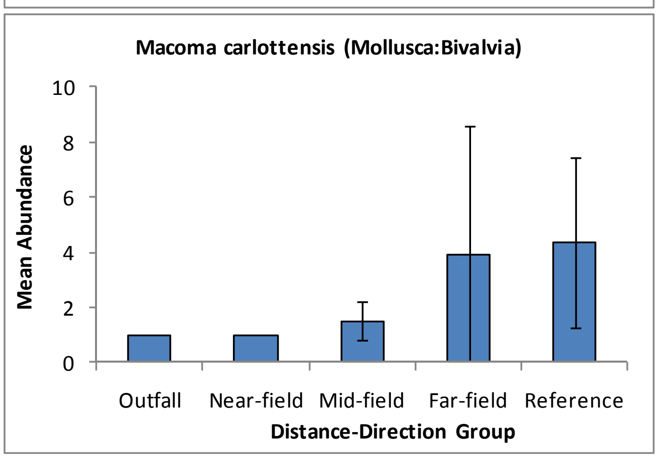
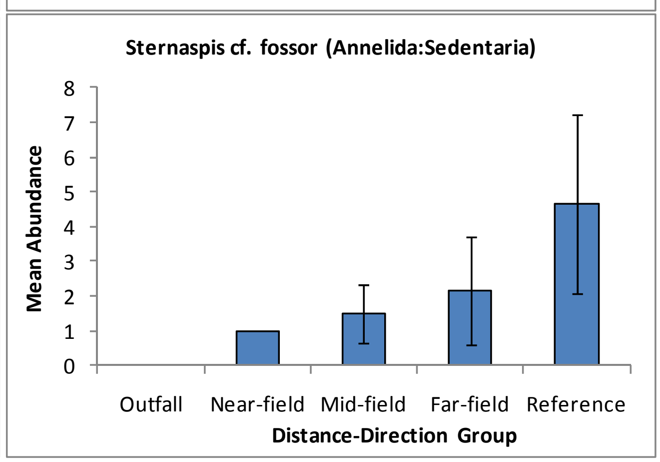




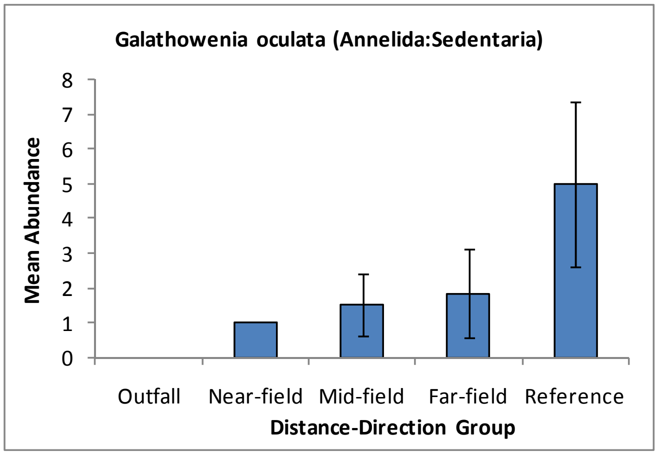


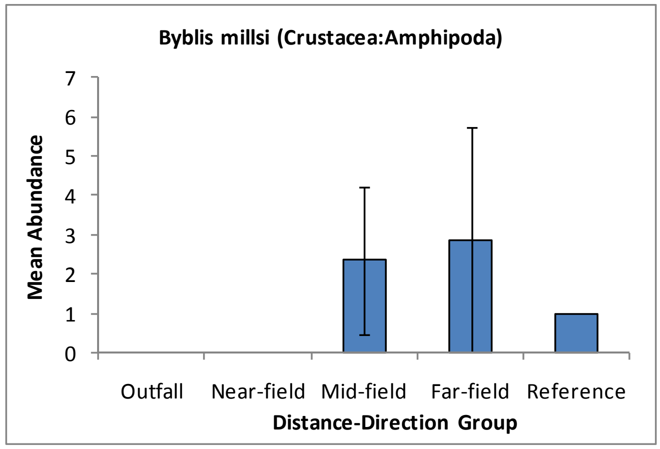




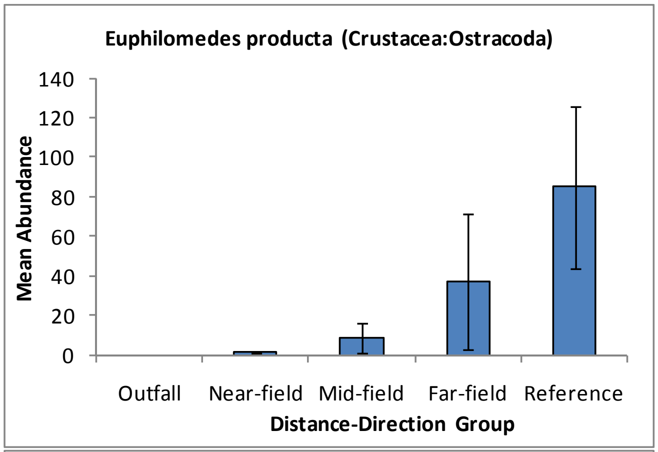


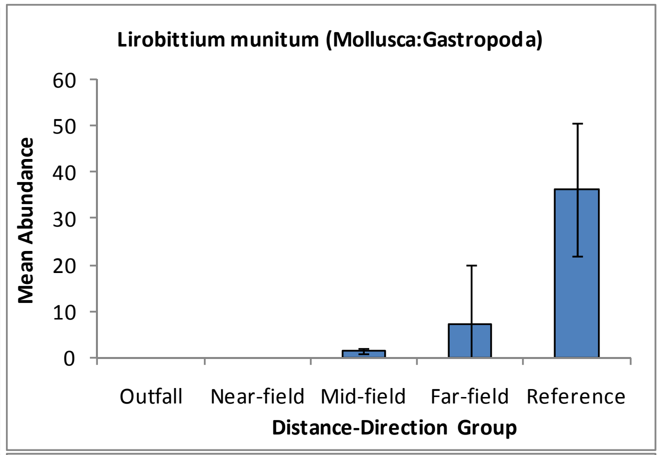
Pattern D (Continued)

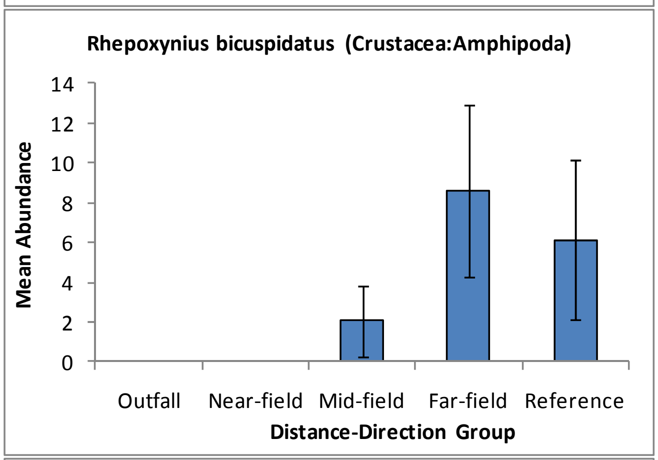


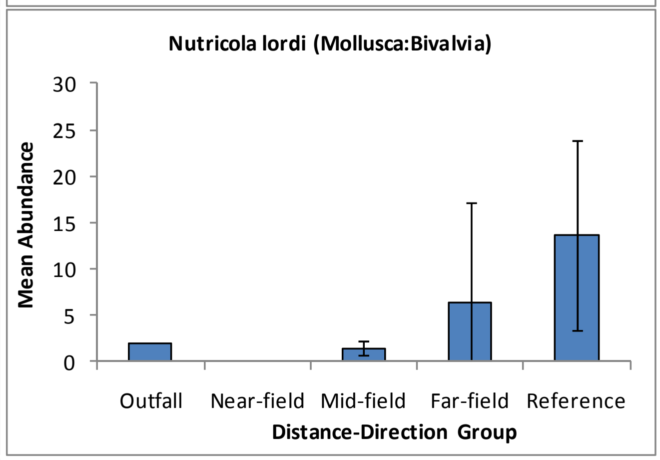


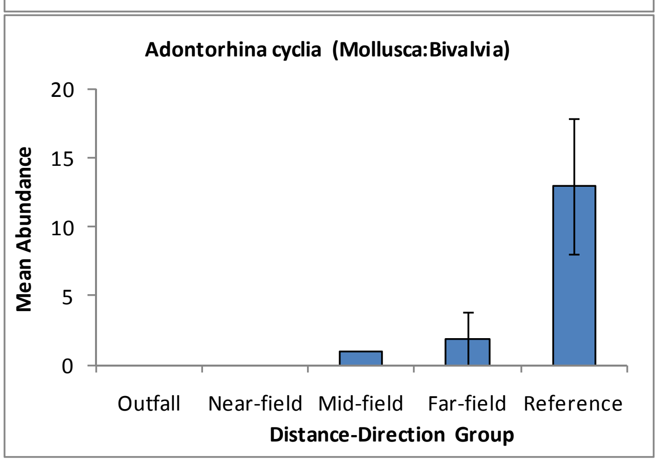
Pattern E (Pronounced Increase with Distance from Outfall)

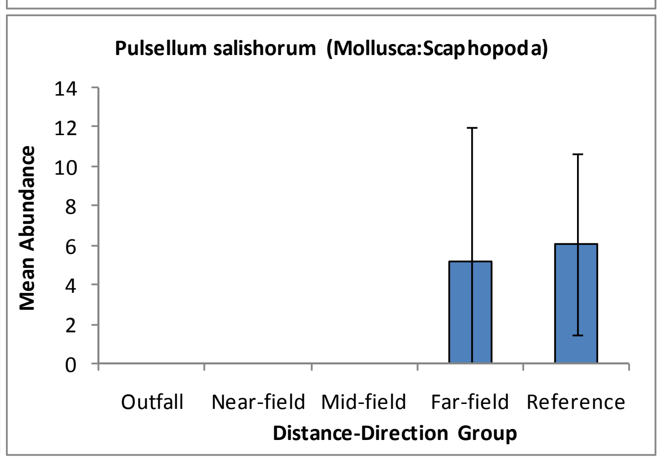




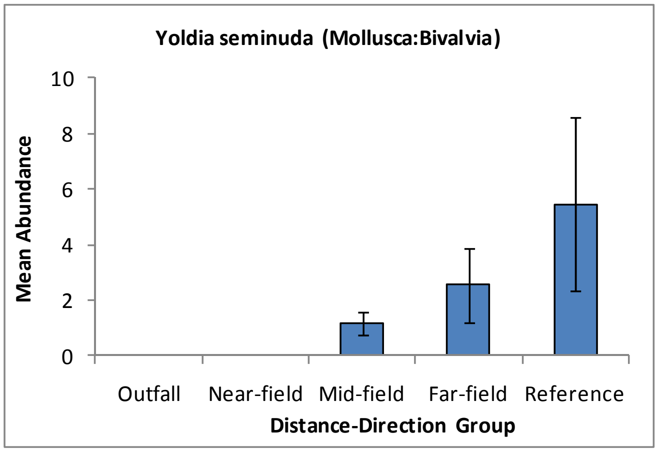


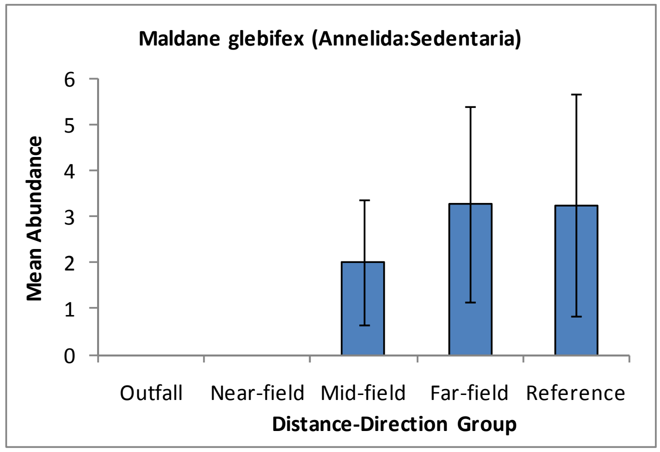




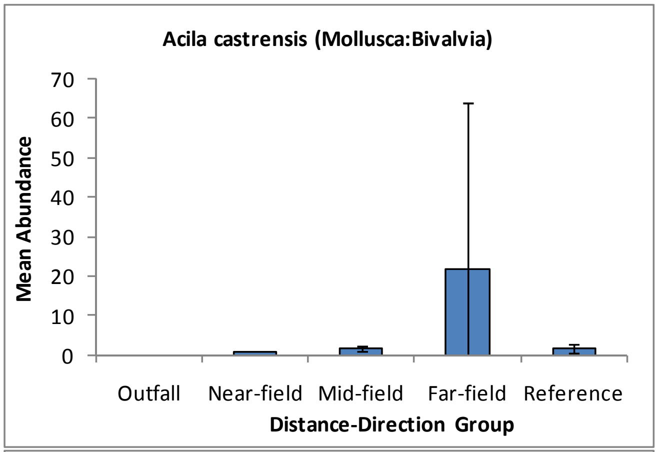


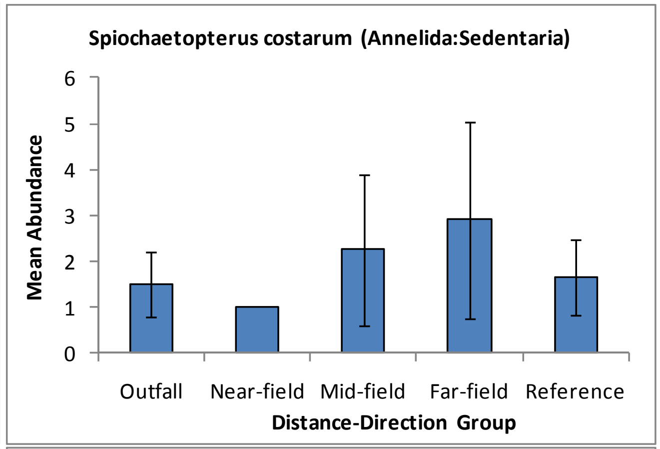
Pattern E (Continued)

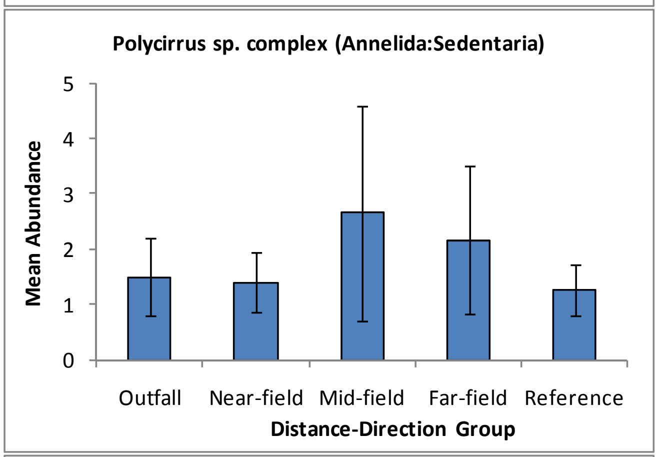


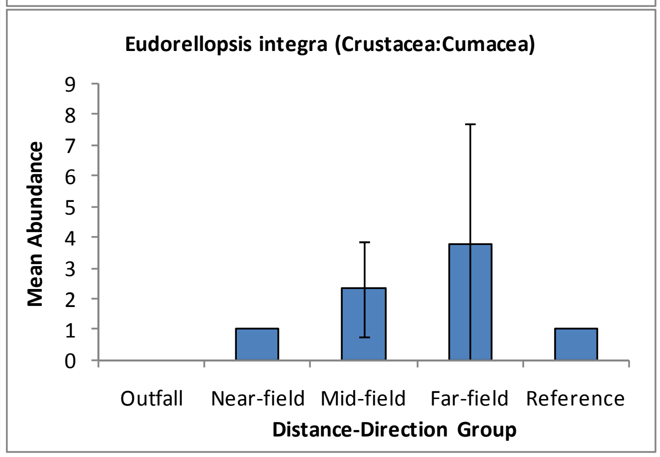


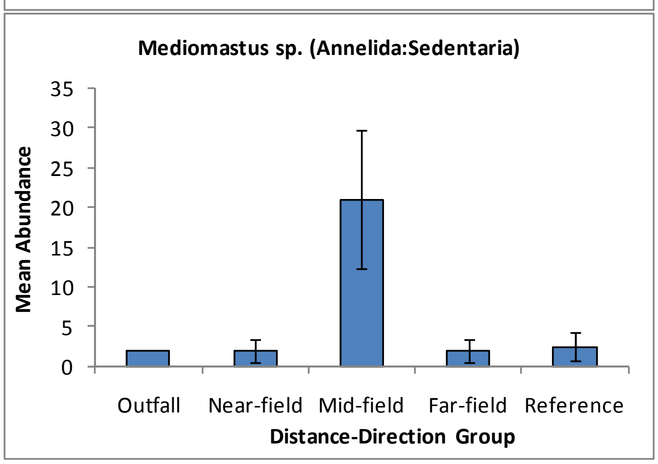
Pattern F (No Discernible Spatial Trend)





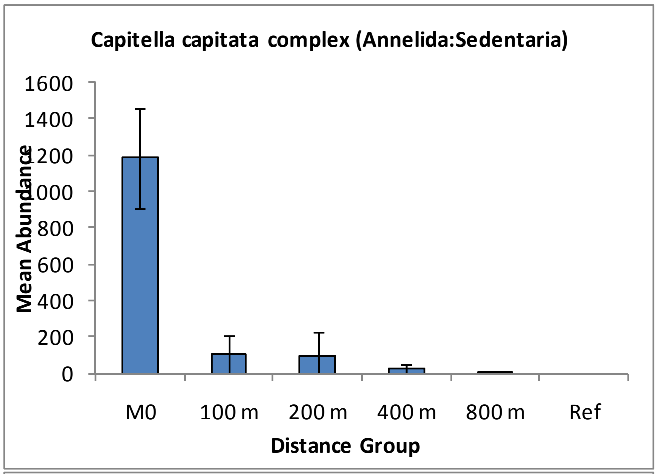


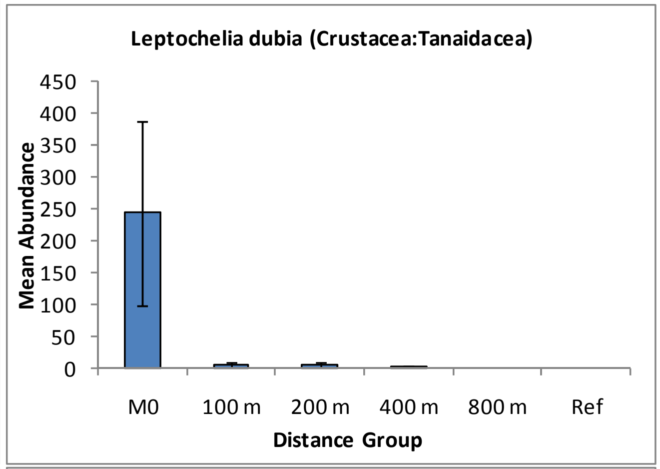


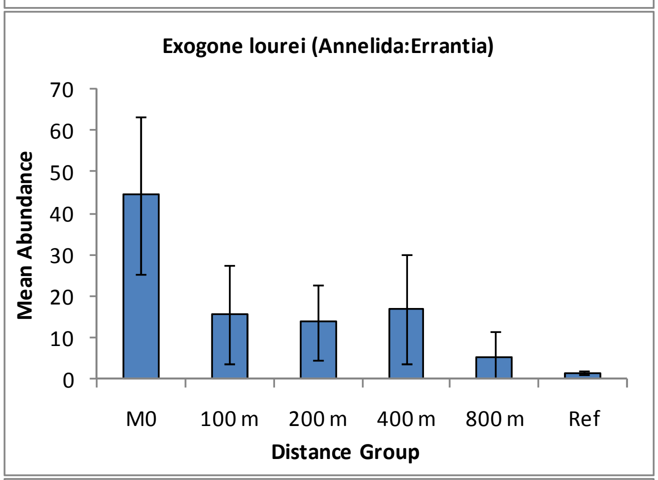


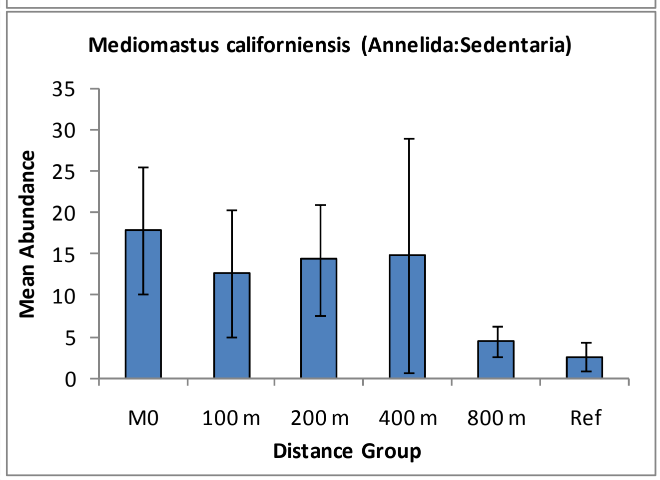
DISTANCE GROUPS

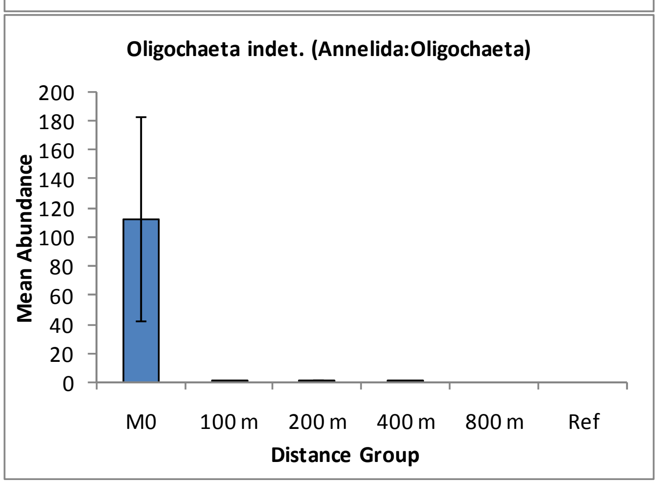
Pattern A (Most Abundant Near the Outfall and Declining with Distance)

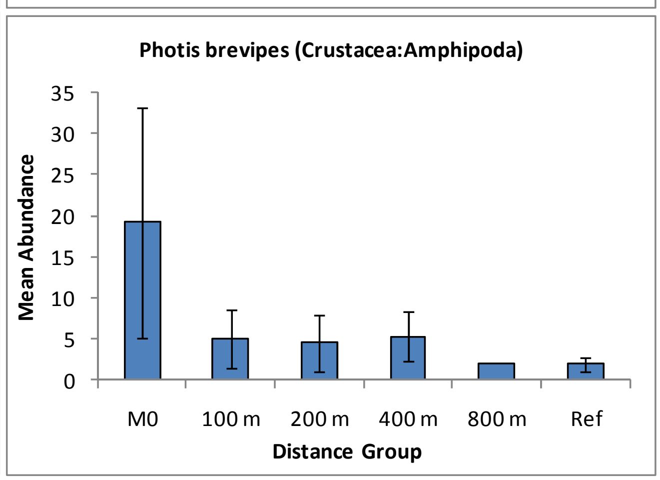




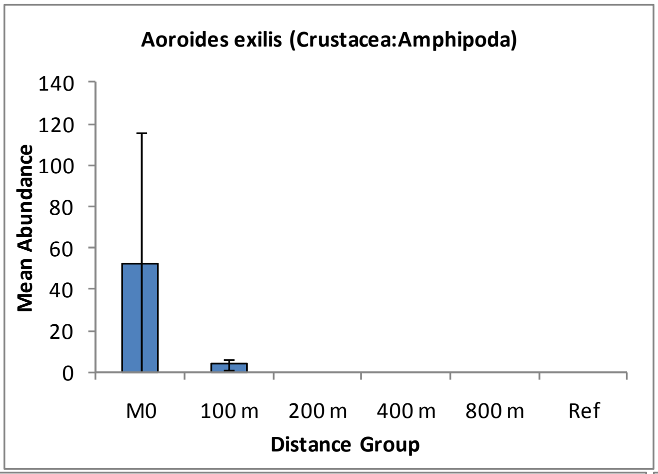


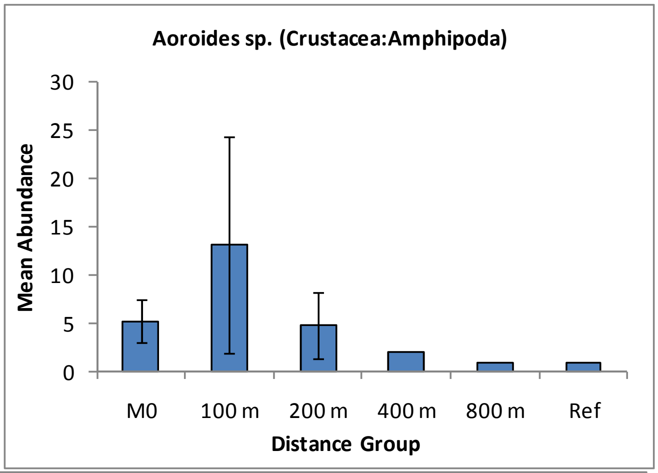


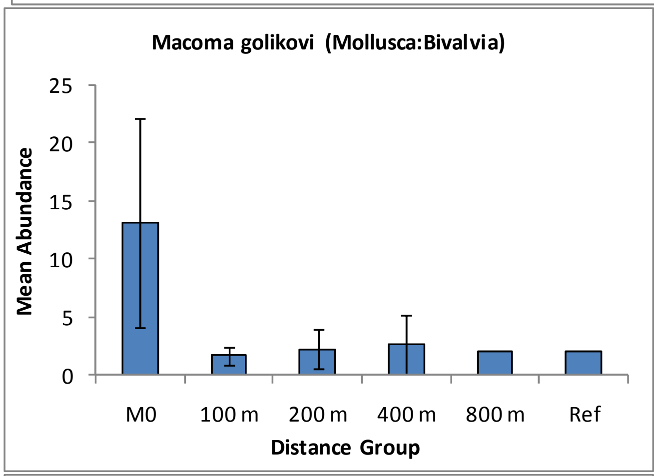


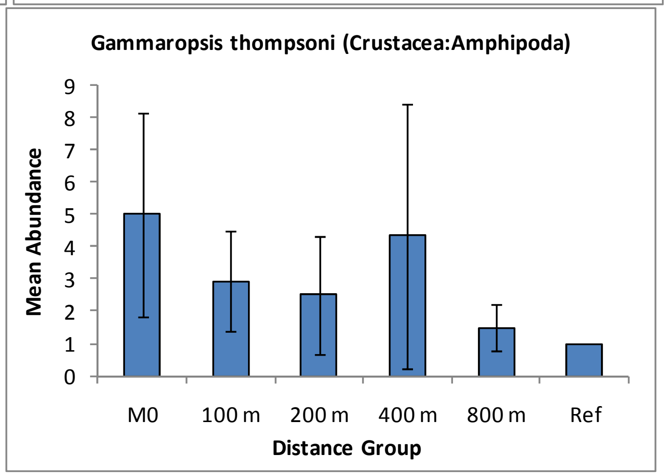


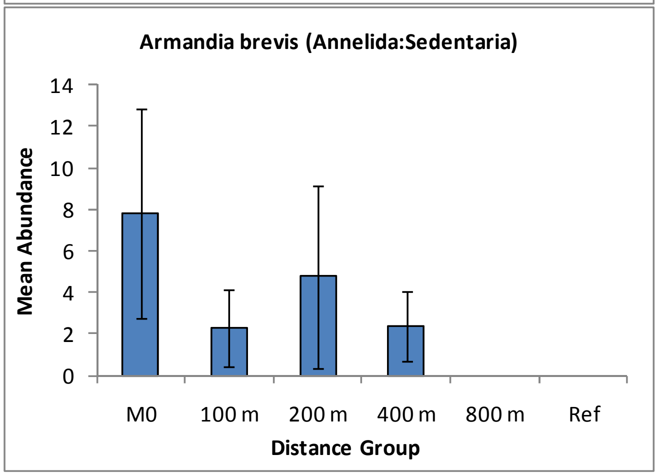
Pattern A (Continued)



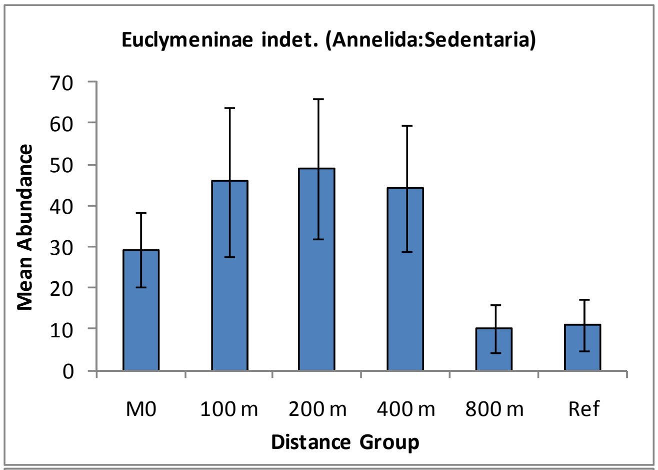


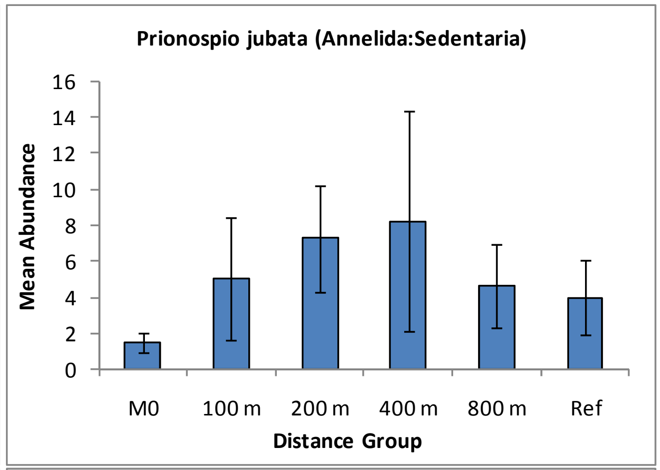


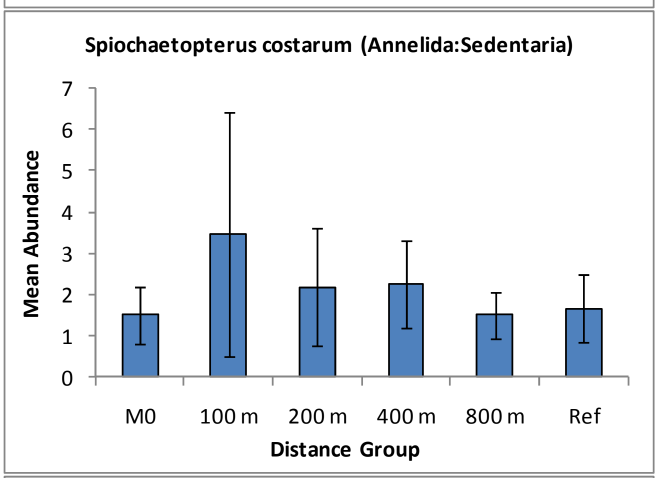


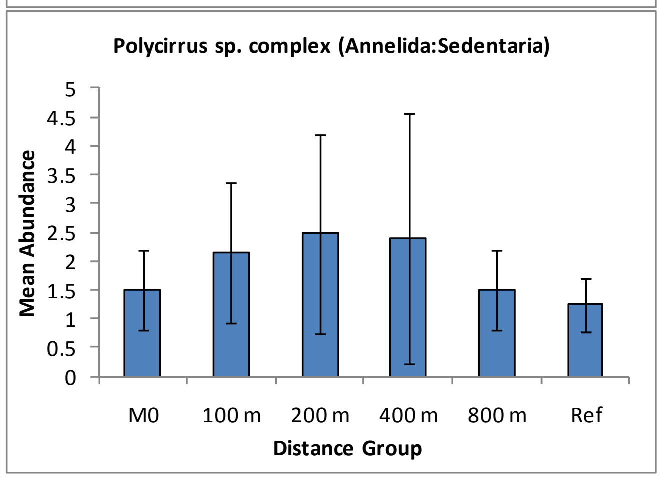


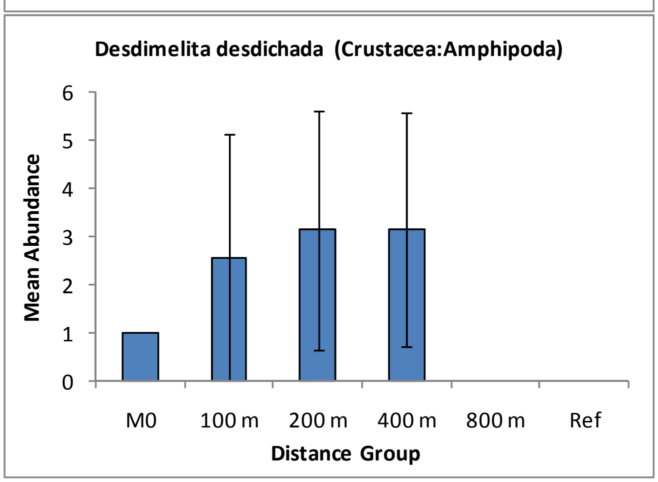
Pattern B1 (Low Abundance at Outfall; Most Abundant at Intermediate Distance from Outfall)

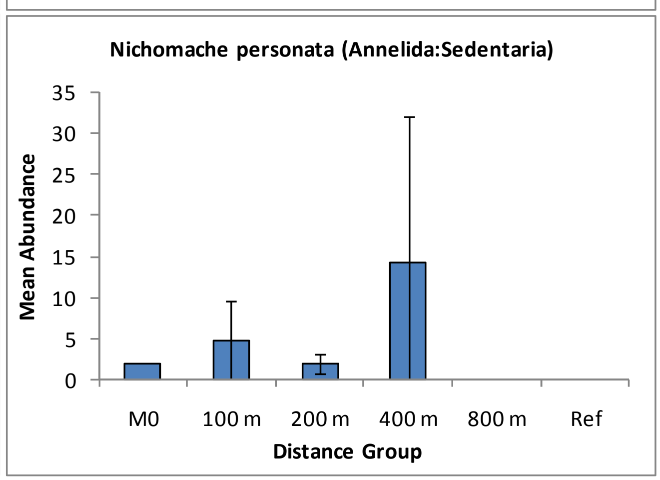




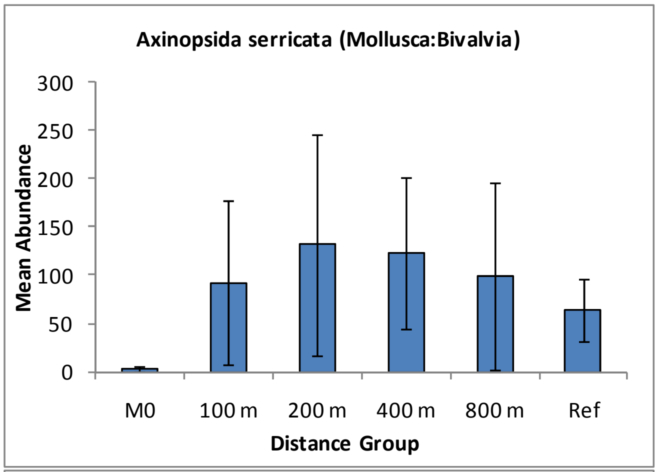


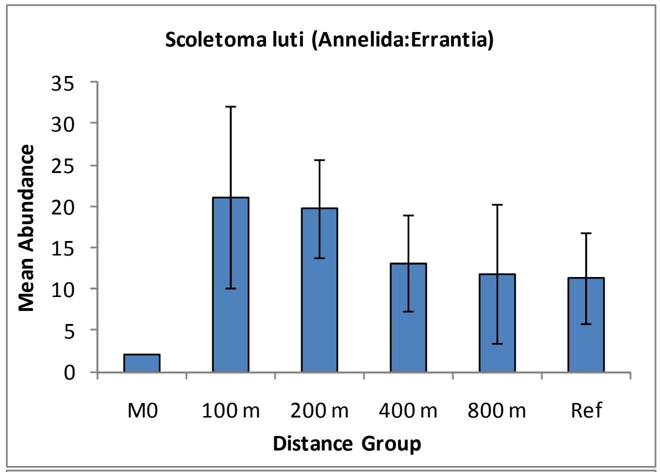


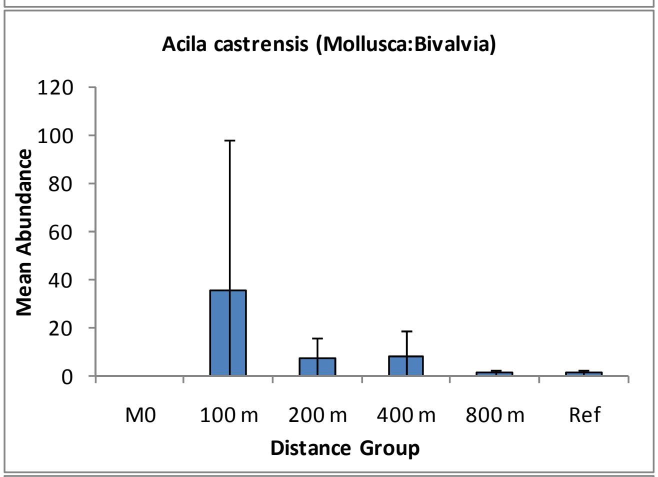


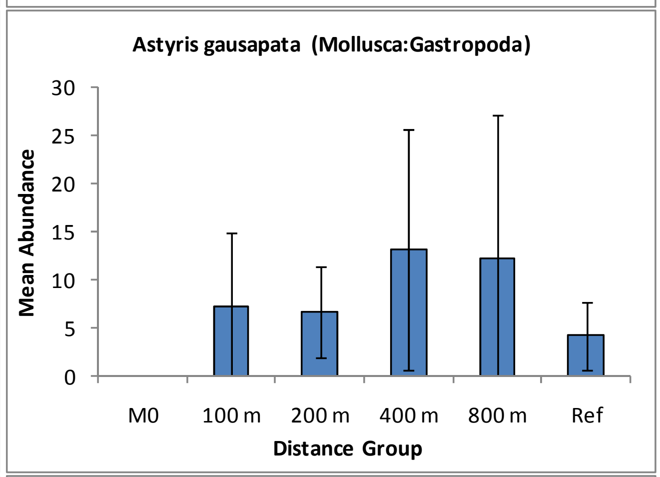


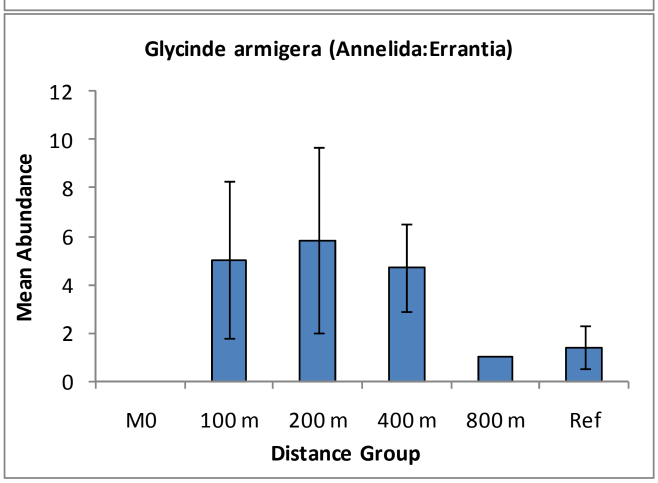
Pattern B2 (Very Low Abundance at Outfall; Most Abundant at Intermediate Distance from Outfall)

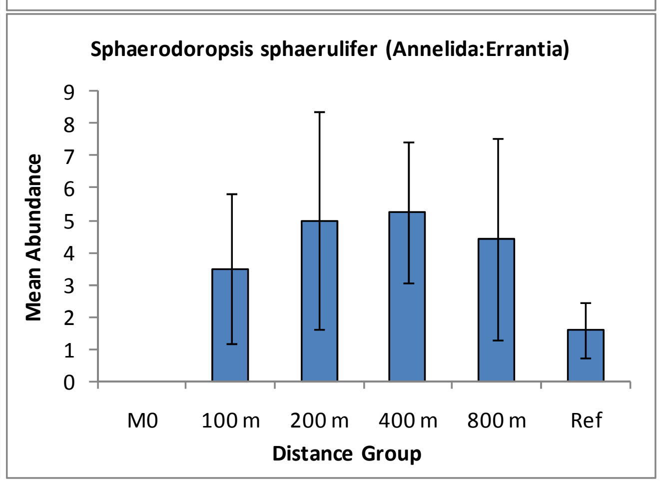




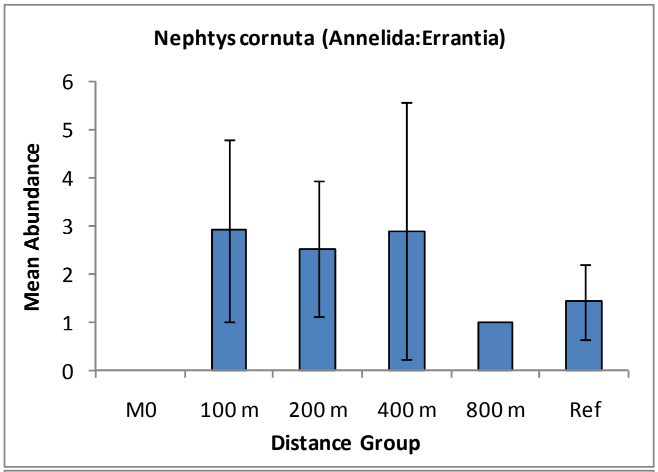


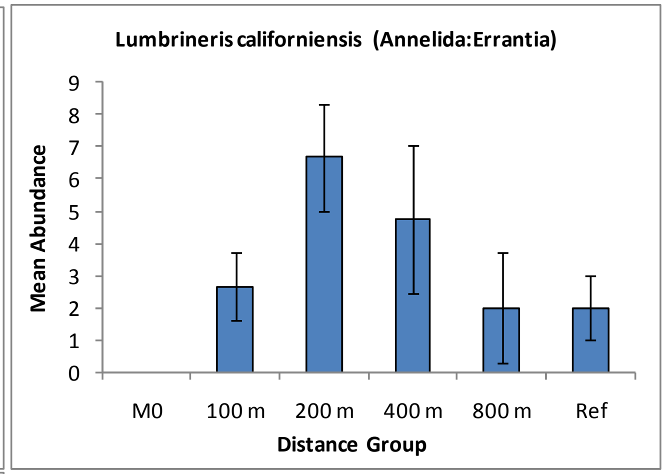


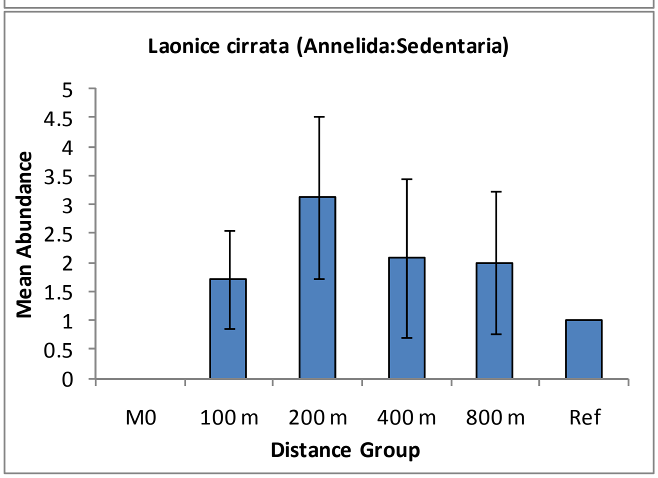


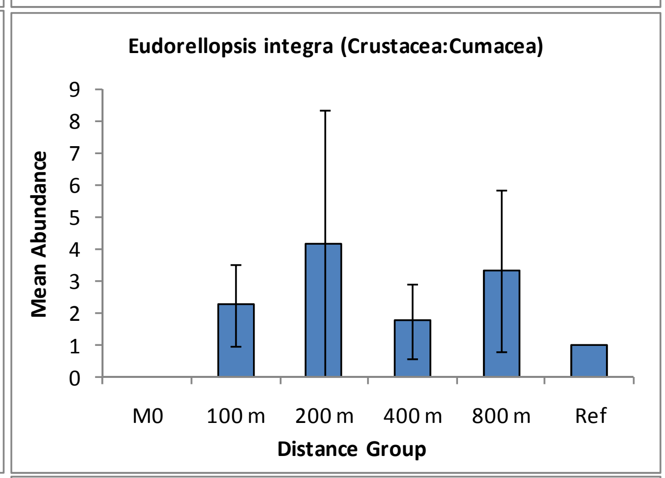


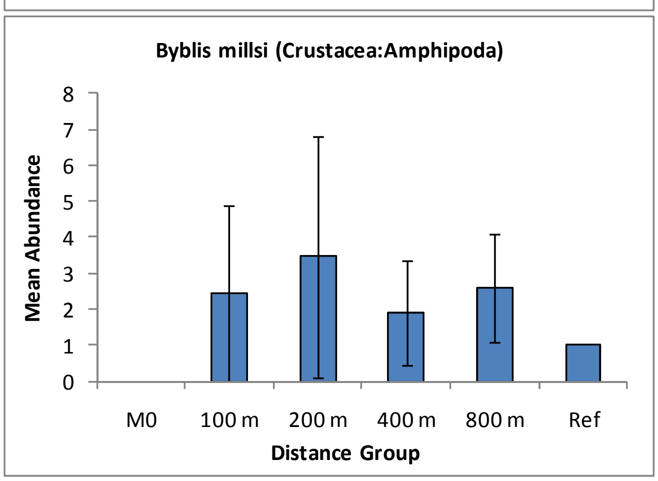
Pattern B2 (Continued)

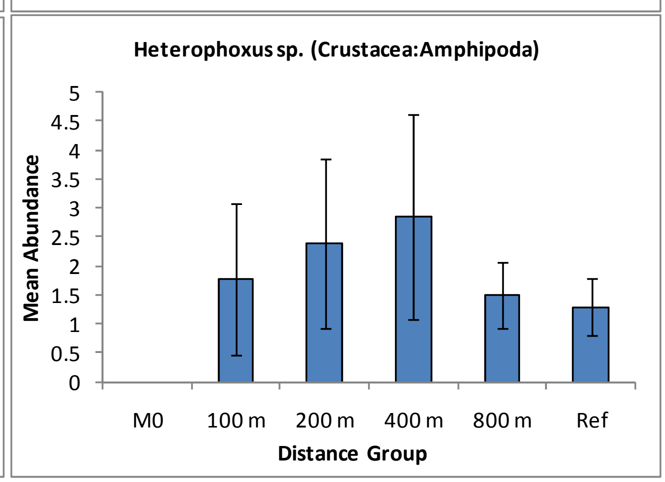




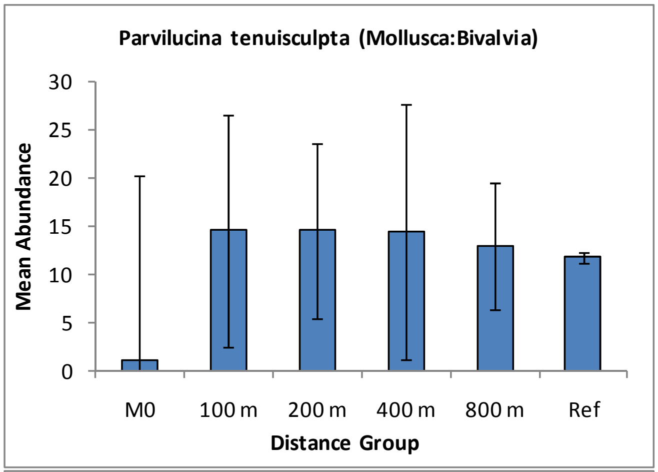


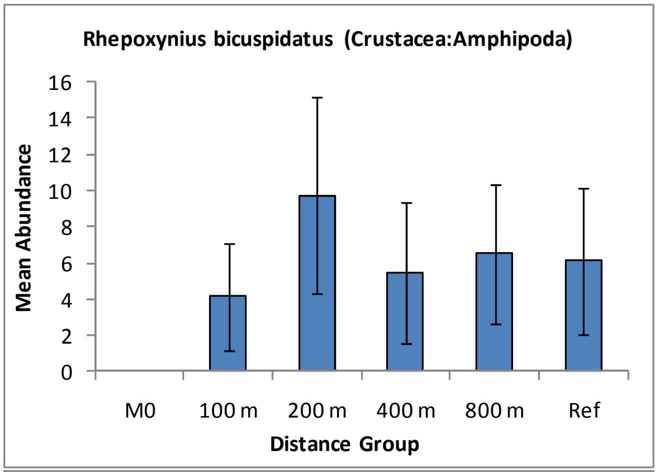


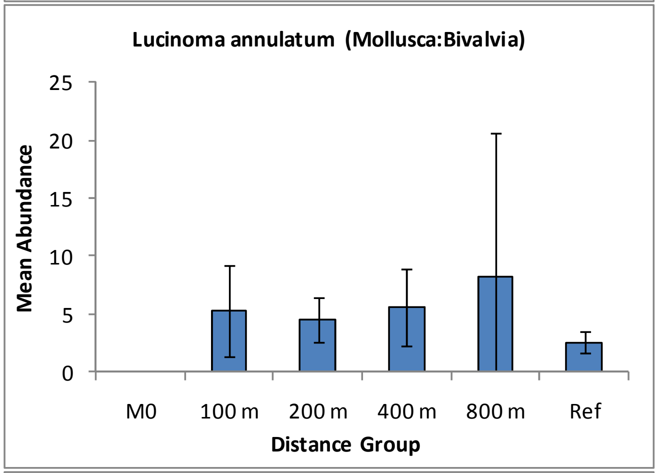


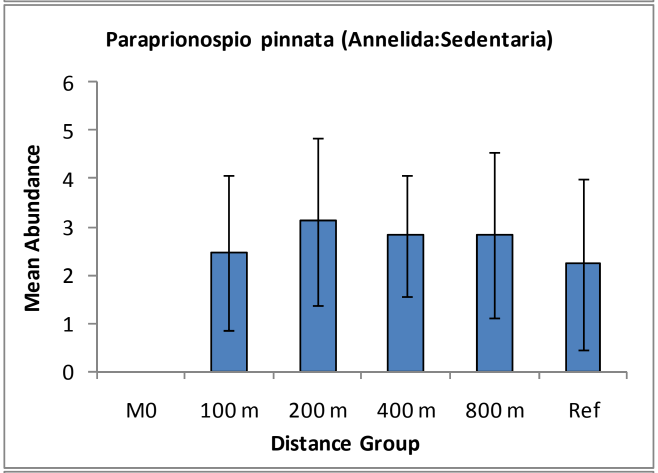


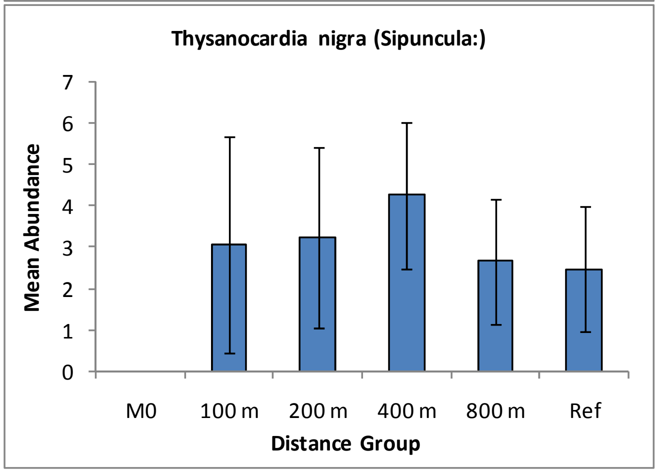
Pattern C (Low Abundance Near Outfall; Similar Abundance Among Other Groups)

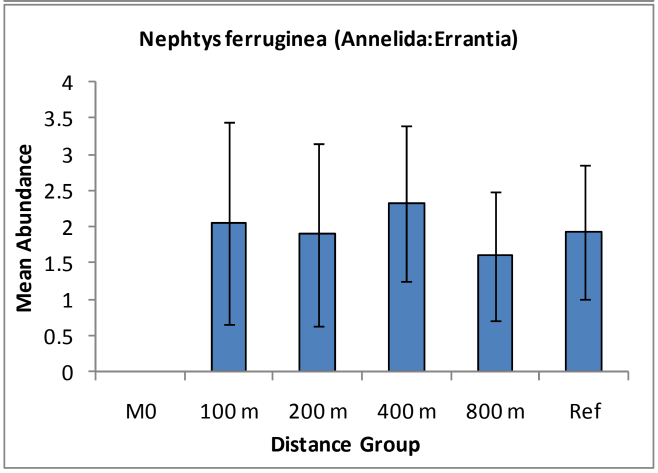




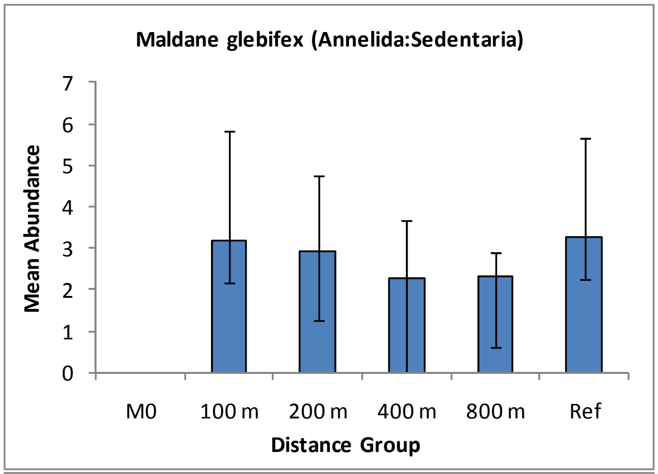


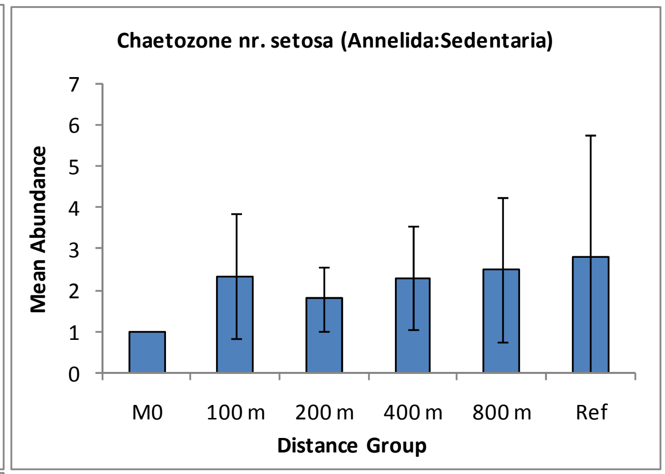


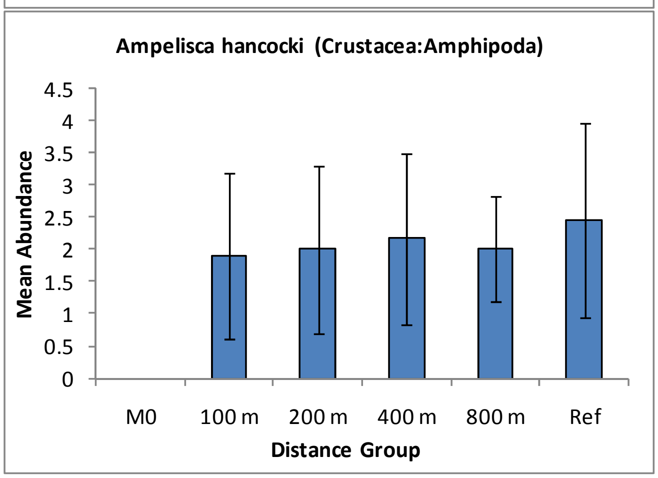




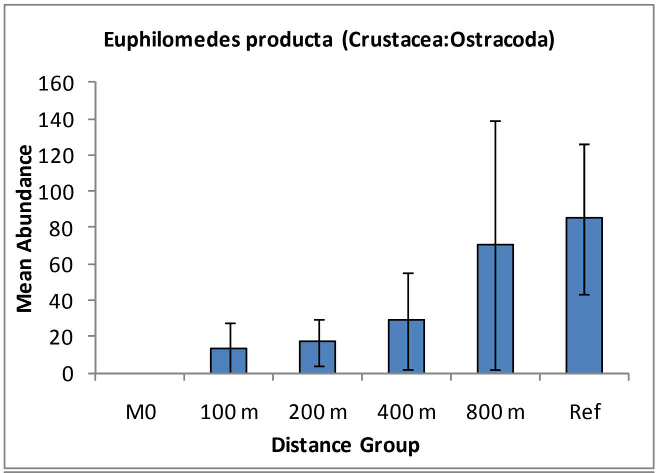
Pattern C (Continued)

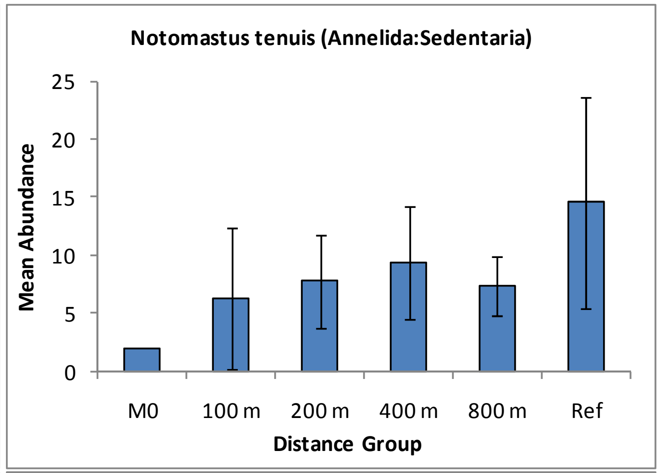


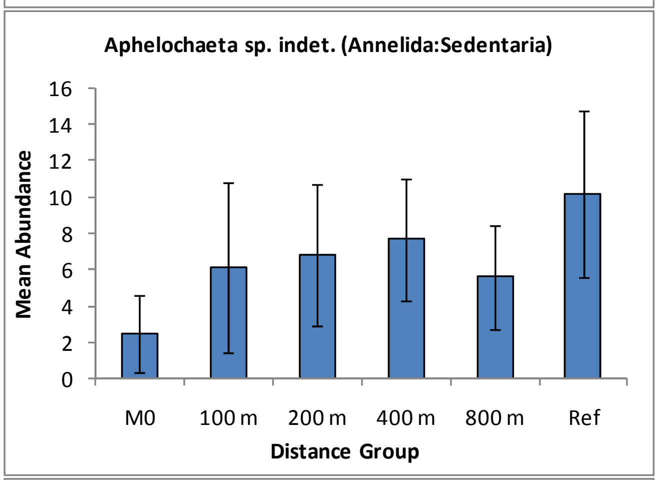


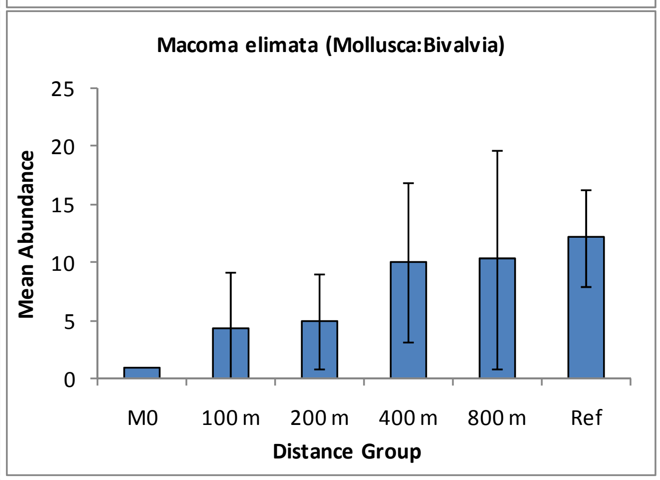


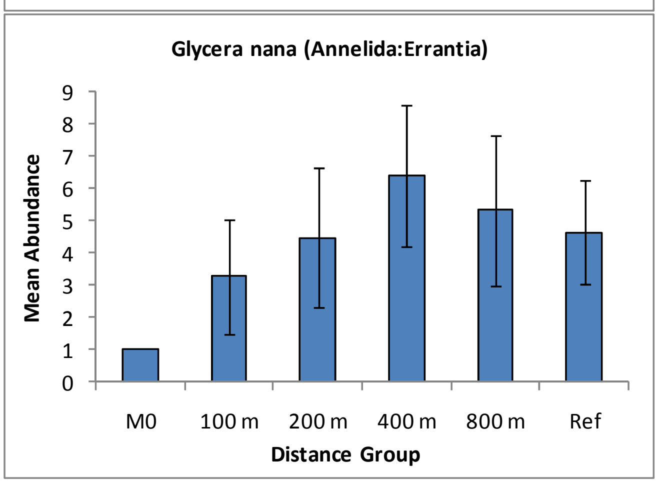
Pattern D (Generally Increasing with Distance from Outfall)

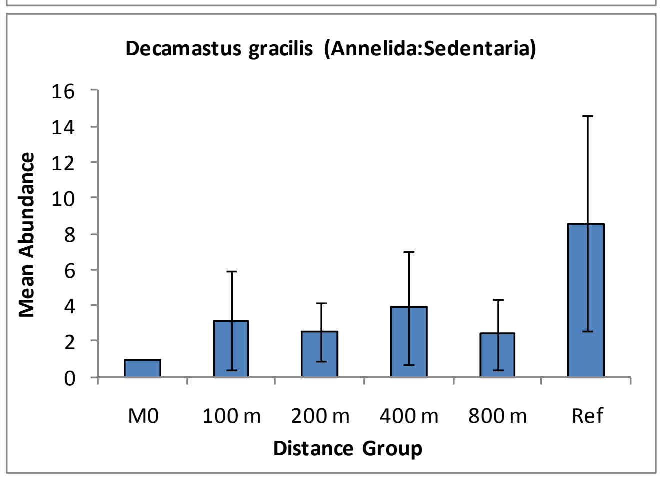


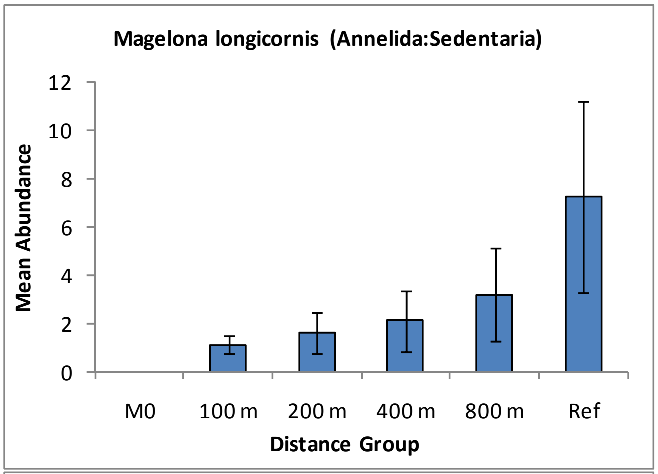


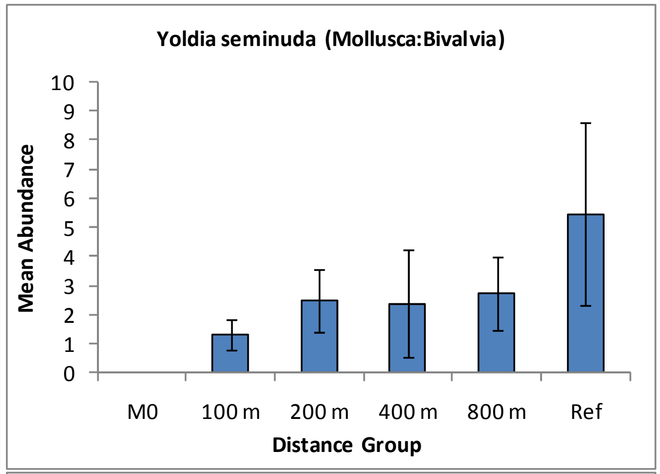


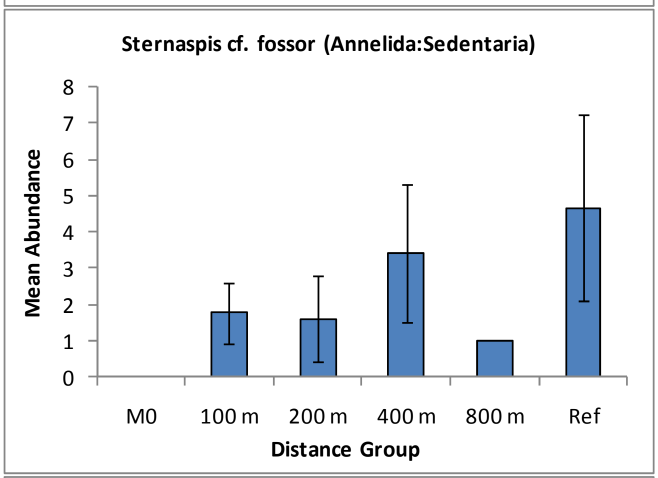


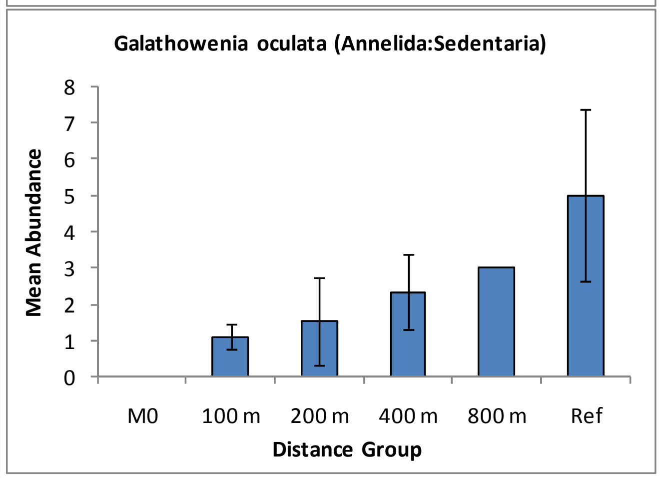


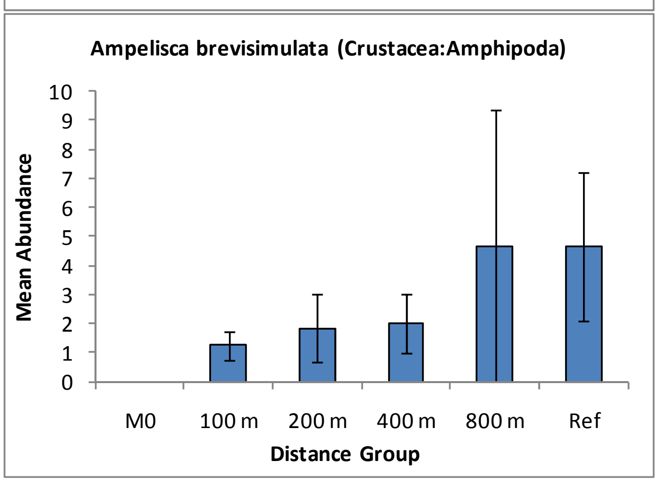



Magelona longicornis (Annelida:Sedentaria)
Mean Abundance
0
2
4
6
8
10
12
M0
100 m
200 m
400 m
800 m
Ref
Distance Group

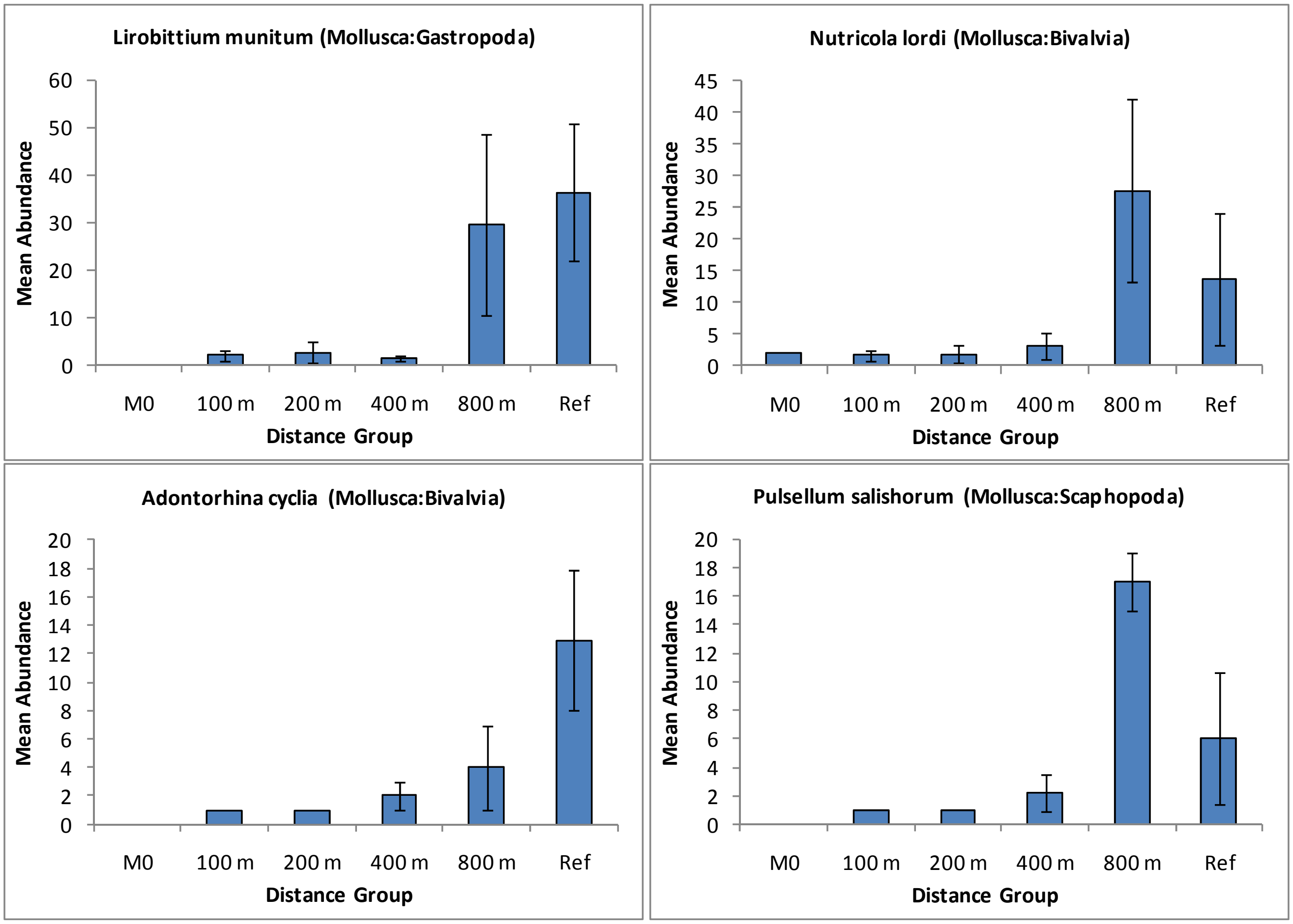

Yoldia seminuda (Mollusca:Bivalvia)
Mean Abundance
0
1
2
3
4
5
6
7
8
9
10
M0
100 m
200 m
400 m
800 m
Ref
Distance Group


Sternaspis cf. fossor (Annelida:Sedentaria)
Mean Abundance
0
1
2
3
4
5
6
7
8
M0
100 m
200 m
400 m
800 m
Ref
Distance Group

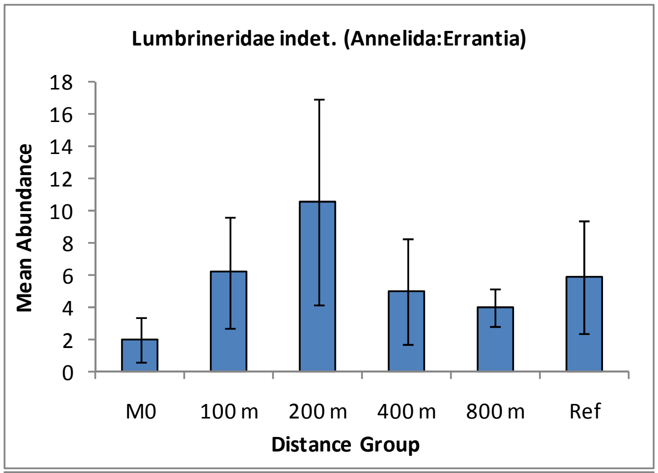

Galathowenia oculata (Annelida:Sedentaria)
Mean Abundance
0
1
2
3
4
5
6
7
8
M0
100 m
200 m
400 m
800 m
Ref
Distance Group

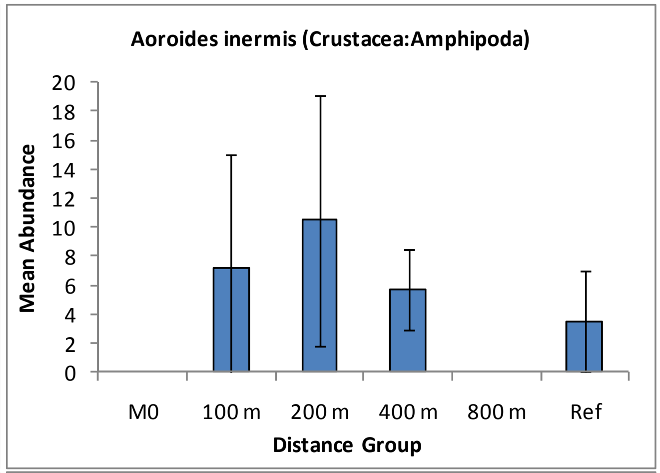

Ampelisca brevisimulata (Crustacea:Amphipoda)
Mean Abundance
0
1
2
3
4
5
6
7
8
9
10
M0
100 m
200 m
400 m
800 m
Ref
Distance Group

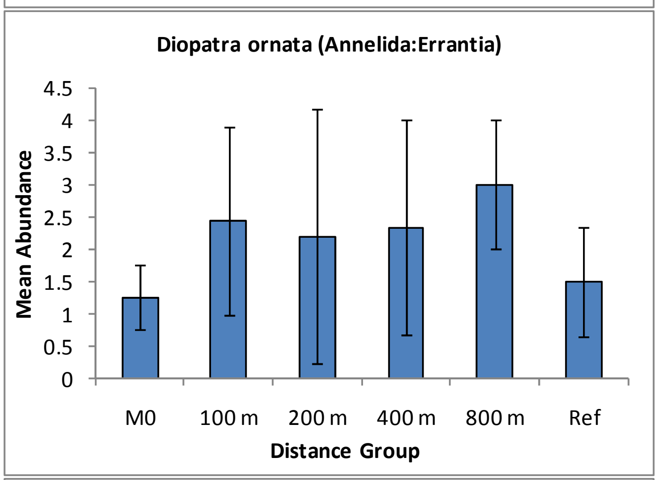
Pattern E (Pronounced Increase with Distance from Outfall)

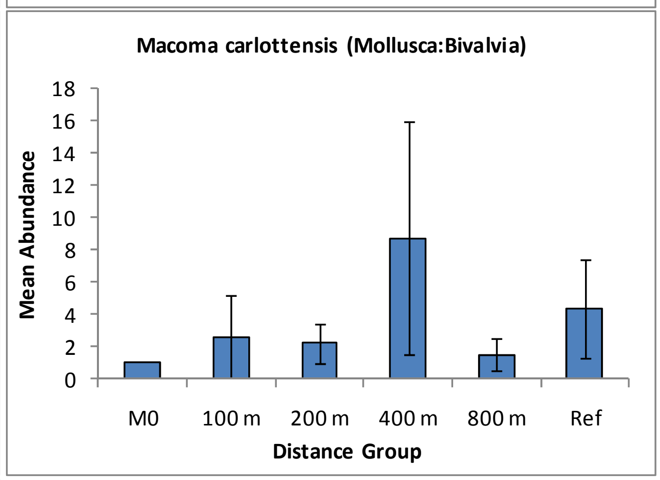


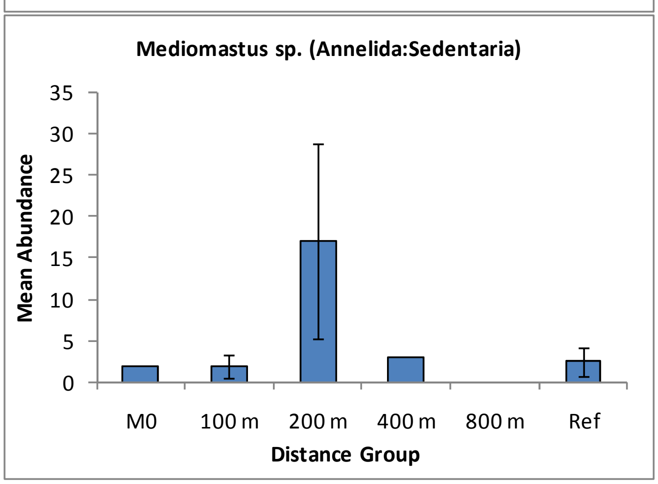
Pattern F (No Discernible Spatial Trend)











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