Monitoring Oil Spill Bioremediation Using Marsh Foraminifera As Indicators

Jennifer A. Sabean

Submitted in Partial Fulfillment of the Requirements for the Degree of
Bachelor of Science
Department of Earth Sciences
Dalhousie University, Halifax, Nova Scotia
March 2001

Monitoring Oil Spill Bioremediation Using Marsh Foraminifera As Indicators

Jennifer A. Sabean

ABSTRACT

A controlled experiment was conducted by Fisheries and Oceans Canada and the United States Environmental Protection Agency in June 2000, to identify the impacts of an oil spill on an Atlantic coastal salt marsh and to evaluate the effectiveness of *in situ* biological remediation techniques to help restore the environment. Foraminifera, a type of marsh microfossil known to be sensitive to several types of environmental stress, were used to monitor the effects of the oil spill and the treatments.

The study site was situated within Petpeswick Inlet on Conrod's Beach, along the Eastern Shore of Nova Scotia. Plots were laid out and weathered crude oil was applied to the surface of the designated plots in early June at low tide. Six different treatments were used in triplicate for a total 18 plots, including a control plot with nutrients (no oil), a control plot without nutrients (no oil), an oiled plot (natural attenuation), and plots with the added enrichment of nutrients, cut plants and/or agricultural disking.

Results show that the foraminifera responded quickly to the oil and that the oil had a statistically significant negative impact on at least one particular species, *Miliammina fusca*. This was seen by a dramatic increase in deformities in the shape of the test, in comparison to specimens observed from the non-oiled control plots, and to previous observations from an analogous inlet nearby. Remediation measures appear to have had no significant mitigating effect and in fact may have had a negative impact on foraminiferal assemblages within the treated plots. The percentages of deformed tests were some of the highest ever observed, appearing within three days of the application of the oil. These results clearly show that foraminifera can be excellent indicators of oil pollution. In addition to the sensitivity of the tests to external stress, the advantages of using foraminifera also include ease of sampling, processing and examination. Furthermore, because these organisms leave a fossil record, we can detect the effects of previous oil spills in buried sediment from coastal marshes.

ERRATUM

Throughout the entire document entitled "Monitoring Oil Spill Bioremediation Using Marsh Foraminifera as Indicators", there are six separate treatments referred to as follows:

- Treatment A- Control with nutrient enrichment (no oil);
- Treatment B- Control without nutrient enrichment (no oil);
- Treatment C- Oiled plot without treatments; natural attenuation;
- Treatment D- Oiled plot with nutrient enrichment
- Treatment E- Oiled plot with nutrient enrichment and cut plants;
- Treatment F- Oiled plot with nutrient enrichment and agricultural disking.

Please note that Treatment A and B have been incorrectly labeled throughout the text. In each case where Treatment A is referred to as a "control with nutrient enrichment (no oil)", it should read "control with*out* nutrient enrichment (no oil)". In the same respect, Treatment B should be referred to as a "control *with* nutrient enrichment (no oil)". As a result, Treatment A is therefore a completely natural control, while Treatment B is a control with nutrient enrichment. The data from the plots with both these treatments with no oil will be used to compare against the data from plots with the other four treatments with oil.

TABLE OF CONTENTS

ABSTRACT i

TABLE OF CONTENTS ii

TABLE OF FIGURES v

TABLE OF TABLES viii

ACKNOWLEDGEMENTS x

CHAPTER 1: INTRODUCTION
- 1.1 Objective and General Statement 1
- 1.2 Importance of Project 2
- 1.3 Study Area 5
  - 1.3.1 Physical Environment 5
  - 1.3.2 Selection of Plots 7
  - 1.3.3 Salinity and Temperature 7
  - 1.3.4 Organic Matter 9
- 1.4 Background on Foraminifera 9
  - 1.4.1 Foraminifera as Indicators 9
  - 1.4.2 Change in Species Composition 10
  - 1.4.3 Deformities 10
- 1.5 Why Foraminifera are being Used 11
  - 1.5.1 Environmental Sensitivity 11
  - 1.5.2 Sample Size and Abundance 11
- 1.6 Organization of Thesis 12

CHAPTER 2: PREVIOUS WORK
- 2.1 Introduction 15
- 2.2 Local Estuarine Studies 15
  - 2.2.1 Chezzetcook Inlet, Nova Scotia 15
- 2.3 Pollution Studies 18
  - 2.3.1 Foraminifera as Pollution Indicators 19
- 2.4 Other Oil Mitigation Studies 21
  - 2.4.1 Biodegradation and Bioremediation 21
  - 2.4.2 Oil-Impacted Shorelines 22
  - 2.4.3 Oil-Contaminated Salt Marsh Environments 23

CHAPTER 3: METHODS
- 3.1 Sampling Grid 25
- 3.2 Treatments 27
- 3.3 Collection and Sampling Period 29
- 3.4 Processing 33

3.4.1 Sediment Processing 33
3.4.2 Photography 33
3.4.3 Organic Matter 35
3.5 Examination 35
3.5.1 Splitting 35
3.5.2 Counting and Identification 35
3.6 Data Presentation 36
3.7 Other Data 37

CHAPTER 4: RESULTS
4.1 Weekly Results 38
4.1.1 Description of Results Format 38
4.1.2 Foraminifera 40
4.1.2.1 Treatment A- Control Plot with Nutrient Enrichment (no oil) 41
4.1.2.2 Treatment B- Control Plot without Nutrient Enrichment (no oil) 50
4.1.2.3 Treatment C- Oiled Plot (natural attenuation) 60
4.1.2.4 Treatment D- Oiled Plot with Nutrient Enrichment 70
4.1.2.5 Treatment E- Oiled Plot with Nutrient Enrichment and Cut Plants 80
4.1.2.6 Treatment F- Oiled Plot with Nutrient Enrichment and Agricultural Disking 91
4.1.2.7 Summary of Morphological Change 95
4.1.3 Field Results 104
4.2 Core Results 104
4.2.1 Foraminifera 105

CHAPTER 5: DISCUSSION
5.1 Introduction 109
5.2 Trends in Core 110
5.2.1 Species 110
5.2.2 Deformities 110
5.3 Trends over Time 111
5.3.1 Deformities Within Control Plots With No Oil 112
5.3.2 Deformities Within Oiled Plots 113
5.3.3 Summary 115
5.4 Comparison with Previous Work 117
5.5 Implications 118

CHAPTER 6: CONCLUSIONS
6.1 Conclusions 121
6.2 Recommendations 123

TAXONOMY 125

REFERENCES 127

APPENDIX A- Data Tables A1

TABLE OF FIGURES

Figure 1.1a Map of Nova Scotia with site location

Figure 1.1b Site Location: Conrod's Beach, Petpeswick Inlet, Nova Scotia

Figure 1.2 Aerial photograph of site location

Figure 1.3 Map of the Conrod's Beach Salt Marsh with locations of study plots

Figure 1.4 Surface Water Salinity Levels Over Sampling Period

Figure 1.5a Surface Temperatures Within Non-Oiled Plots

Figure 1.5b Surface Temperatures Within Oiled Plots

Figure 2.1 Station 7c percentages of living populations (vertical bars represent variation between replicate samples for each interval).

Figure 2.2 Living and total population variations for all species, Station 7c (vertical bars represent variation between replicate samples for each interval).

Figure 2.3 Percentages of total populations, Station 7c (vertical bars represent variation between replicate samples for each interval).

Figure 3.1 Sampling plot

Figure 3.2 Sampling grid

Figure 3.3 Oil application with spray boom connected to backpack sprayer

Figure 3.4 Scott surface marsh sampler

Figure 3.5 Extracting samples from experimental plots using corer, trowel and knife

Figure 3.6 Core sampler with trowel

Figure 3.7 Tools used in sampling and processing foraminiferal specimens

Figure 4.1 Foraminiferal occurrences for Treatment A (Control plot with nutrient enrichment; no oil), Plot 1, from week 0 to week 22. Solid lines represent maximum values, dashed lines represent minimum values, vertical lines are used to show range between representative samples for each week. L= living, T= total (living plus dead), Ld= living deformed, Td= total (living plus dead) deformed. Note: y-axis scale variable. Percentages appearing along the y-axis for living and total *M. fusca* represent the percentage out

of living and total numbers for all species. Percentages appearing along the y-axis for living deformed and total deformed *M. fusca* represent the percentage out of the living and total *M. fusca* only.

Figure 4.2 Foraminiferal occurrences for Treatment A (Control plot with nutrient enrichment), Plot 2, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.3 Foraminiferal occurrences for Treatment A (Control plot with nutrient enrichment; no oil), Plot 3, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.4 Foraminiferal occurrences for Treatment B (Control plot without nutrient enrichment; no oil), Plot 1, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.5 Foraminiferal occurrences for Treatment B (Control plot without nutrient enrichment), Plot 2, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.6 Foraminferal occurrences for Treatment B (Control plot without nutrient enrichment; no oil), Plot 3, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.7 Foraminiferal occurrences for Treatment C (Oiled plot without treatments; natural attenuation), Plot 1, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.8 Foraminiferal occurrences for Treatment C (Oiled plot without treatments; natural attenuation), Plot 2, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.9 Foraminiferal occurrences for Treatment C (Oiled plot without treatments; natural attenuation), Plot 3, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.10 Foraminiferal occurrences for Treatment D (Oiled plot with nutrient enrichment), Plot 1, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.11 Foraminiferal occurrences for Treatment D (Oiled plot with nutrient enrichment), Plot 2, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.12 Foraminiferal occurrences for Treatment D (Oiled plot with nutrient enrichment), Plot 3, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.13 Foraminiferal occurrences for Treatment E (Oiled plot with nutrient enrichment and cut plants), Plot 1, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.14 Foraminiferal occurrences for Treatment E (Oiled plot with nutrient enrichment and cut plants), Plot 2, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.15 Foraminiferal occurrences for Treatment E (Oiled plot with nutrient enrichment and cut plants), Plot 3, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.16 Foraminiferal occurrences for Treatment F (Oiled plot with nutrient enrichment and agricultural disking), Plot 1, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.17 Foraminiferal occurrences for Treatment F (Oiled plot with nutrient enrichment and agricultural disking), Plot 2, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.18 Foraminiferal occurrences for Treatment F (Oiled plot with nutrient enrichment and agricultural disking), Plot 3, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.19a Normal *Miliammina fusca* individual (~60μ)

Figure 4.19b Deformed *Miliammina fusca* individual (~60μ)

Figure 4.20 Treatment A- Control Plot with Nutrient Enrichment (no oil), Plot 3, week 22

Figure 4.21 Treatment B- Control Plot without Nutrient Enrichment (no oil), Plot 2, week 22

Figure 4.22 Treatment C- Oiled Plot with No Treatments (natural attenuation), Plot 3, week 22

Figure 4.23 Treatment D- Oiled Plot with Nutrient Enrichment, Plot 3, week 22

Figure 4.24 Treatment E- Oiled Plot with Nutrient Enrichment and Cut Plants, Plot 2, week 22

Figure 4.25 Treatment F- Oiled Plot with Nutrient Enrichment and Agricultural Disking, Plot 2, week 22

TABLE OF TABLES

Table 3.1 Sampling Schedule

Table 4.1 Average Percentages of Deformed *Miliammina fusca*

Table A-1 Table of results for foraminiferal occurrences for Treatment A (Control plot with nutrient enrichment; no oil), Plots 1 and 2, for weeks 0-22. The living and total (live plus dead) number of the total number of species per 10cc, and the living and total (live plus dead) number of the total number of individuals per 10cc are included. Relative percentages of both living and total (live plus dead) foraminiferal species are also included. Percentages of living and total per individual species represent the percentage out of living and total numbers for all species. Percentages of living deformed and total deformed per individual species represent the percentage out of the living and total for that species only. The whole number of living Ostracods is also included at the bottom of the table. L= living, T= total (live plus dead), Ld= living deformed, Td= total (live plus dead) deformed.

Table A-2 Table of results for foraminiferal occurrences for Treatment A (Control plot with nutrient enrichment; no oil), Plot 3 and for Treatment B (Control plot without nutrient enrichment; no oil), Plot 1, for weeks 0-22. Same format as Table A-1.

Table A-3 Table of results for foraminiferal occurrences for Treatment B (Control plot without nutrient enrichment; no oil), Plot 2 and 3, for weeks 0-22. Same format as Table A-1.

Table A-4 Table of results for foraminiferal occurrences for Treatment C (Oiled plot with no treatments; natural attenuation), Plot 1 and 2, for weeks 0-22. Same format as Table A-1.

Table A-5 Table of results for foraminiferal occurrences for Treatment C (Oiled plot with no treatments; natural attenuation), Plot 3 and for Treatment D (Oiled plot with nutrient enrichment), Plot 1, for weeks 0-22. Same format as Table A-1.

Table A-6 Table of results for foraminiferal occurrences for Treatment D (Oiled plot with nutrient enrichment), Plot 2 and 3, for weeks 0-22. Same format as Table A-1.

Table A-7 Table of results for foraminiferal occurrences for Treatment E (Oiled plot with nutrient enrichment and cut plants), Plot 1 and 2, for weeks 0-22. Same format as Table A-1.

Table A-8 Table of results for foraminiferal occurrences for Treatment E (Oiled plot with nutrient enrichment and cut plants), Plot 3 and for Treatment F (Oiled plot with nutrient enrichment and agricultural disking), Plot 1, for weeks 0-22. Same format as Table A-1.

Table A-9 Table of results for foraminiferal occurrences for Treatment F (Oiled plot with nutrient enrichment and agricultural disking), Plot 2 and 3, for weeks 0-22. Same format as Table A-1.

Table A-10 Table of results for foraminiferal occurrences from Core 002, taken from Plot 2 (see Fig. 1.3). The living and total (live plus dead) number of the total number of species per 10cc, and the living and total (live plus dead) number of the total number of individuals per 10cc are included. Relative percentages of both living and total (live plus dead) foraminiferal species are also included. Percentages of living and total per individual species represent the percentage out of living and total numbers for all species. Percentages of living deformed and total deformed per individual species represent the percentage out of the living and total for that species only. The whole number of living Ostracods is also included at the bottom of the table. L= living, T= total (live plus dead), Ld= living deformed, Td= total (live plus dead) deformed.

ACKNOWLEDGEMENTS

Special thanks to Dr. Dave Scott for his guidance and advice throughout the year, and for giving me the opportunity to work on this project. Without his continued encouragement and direction, this honors thesis would never have been completed. Thanks to Dr. Marcos Zentilli and Dr. Martin Gibling for offering their personal encouragement and support in both current and future endeavors. I would like to thank Dr. Kenneth Lee and Dr. Albert Venosa for giving me the opportunity to be a member of their research team, and to contribute to an extremely important field of work. The organized and thorough sampling process in the field could not have been accomplished without the combined efforts of the research team and the Bedford Institute of Oceanography crew. Thank you to Chloe Younger for all of the help in the field and in the lab, with the sampling and processing, and to Tom Duffett for his technical support and assistance. Finally, I would like to thank the immeasurable support and encouragement that was given to me from an amazing family and group of friends, not only through this last hurdle, but throughout the entire race.

CHAPTER 1: INTRODUCTION

1.1 OBJECTIVE AND GENERAL STATEMENT

Marsh microfossils (such as foraminifera and thecamoebians) can be used to detect and monitor a wide variety of environmental parameters, such as sea-level change, pH, salinity, temperature and pollution, within the marsh surface (Scott et al., 2001). The goal of this project is to monitor the effects of a weathered crude oil spill on a coastal salt marsh carried out in June 2000, and the effectiveness of *in situ* bioremediation treatments, with the use of marsh foraminifera as indicators.

This research is part of a large multidisciplinary project called "Evaluation of Salt Marsh Oil Spill Countermeasures", which was run from May to October 2000, by Fisheries and Oceans Canada (DFO), and by the United States Environmental Protection Agency (USEPA). After a controlled oil spill, the study will determine "the extent of environmental impacts, the natural rates of recovery, and the effectiveness of *in situ* remediation techniques" (Fisheries and Oceans Canada, 2000, p.4). Among the different aspects of research that this overall project incorporates, such as toxicology, chemistry and biology, this thesis concentrates solely on the marine micropaleontology aspect, dealing with salt marsh microfossil assemblages (foraminifera) and their response to the oil and corresponding treatments.

The experiment was carried out on the Eastern Shore of Nova Scotia in a salt marsh along Conrod's Beach, at the mouth of Petpeswick Inlet (44° 42' N; 63° 11' W), east of Chezzetcook Inlet (Fig. 1.1 and 1.2). The results from this experiment are expected to contribute to new "operational guidelines for remediation strategies for use on oil-contaminated, coastal salt marsh environments" (Fisheries and Oceans Canada, 2000,

p.2), as well as to demonstrate the feasibility of an environmental monitoring tool based on foraminifera.

1.2 IMPORTANCE OF PROJECT

Salt marshes of Atlantic Canada are highly susceptible to marine oil spills. They are inundated twice a day by tides that may transport spilled oil to the shore, which then may be incorporated into the sediments (Alexander and Webb, 1987). As low-energy ecosystems, the rates of oil removal by physical processes (e.g. scouring associated with wave activity) are generally slow. Moreover, impacts may continue for extended periods of time (>10 years) as oil stranded in the fine-grained, oxygen-limited sediments of coastal salt marshes is highly resistant to natural degradation (Lee and Levy, 1991). To test restoration techniques in a marsh environment with the minimum amount of impact on its habitants after the oil spill, and to determine how successful the recovery of vegetation and other biota has been, it is important to have a controlled experiment. There is an immediate need to develop less intrusive restoration techniques that effectively remove the pollutant without endangering the environment, while enabling restoration of the habitat to its original state. For this reason, the use of benthic foraminifera as monitors of bioremediation efforts -"the modification of environmental parameters to stimulate the degradation of contaminants" (Fisheries and Oceans Canada, 2000, p.5) -provides a relatively quick and concise indication of progress, enabling new and natural countermeasure strategies to be implemented.

Figure 1.1a Map of Nova Scotia with site location

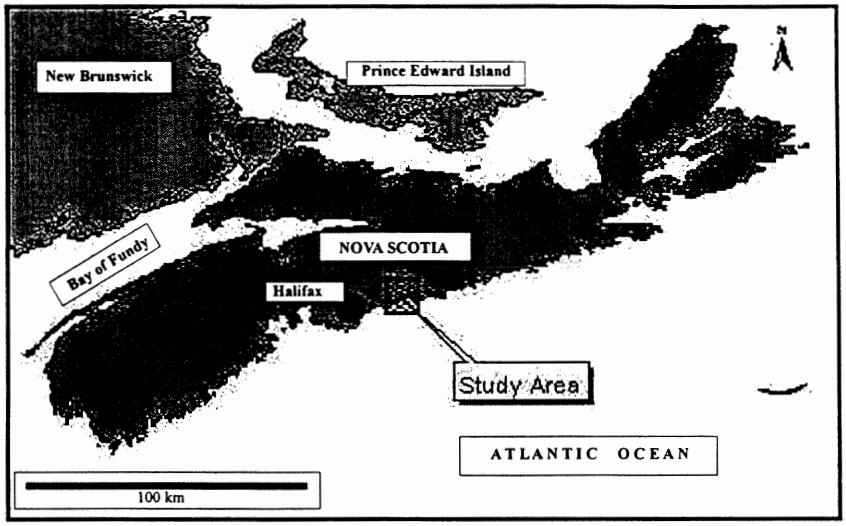
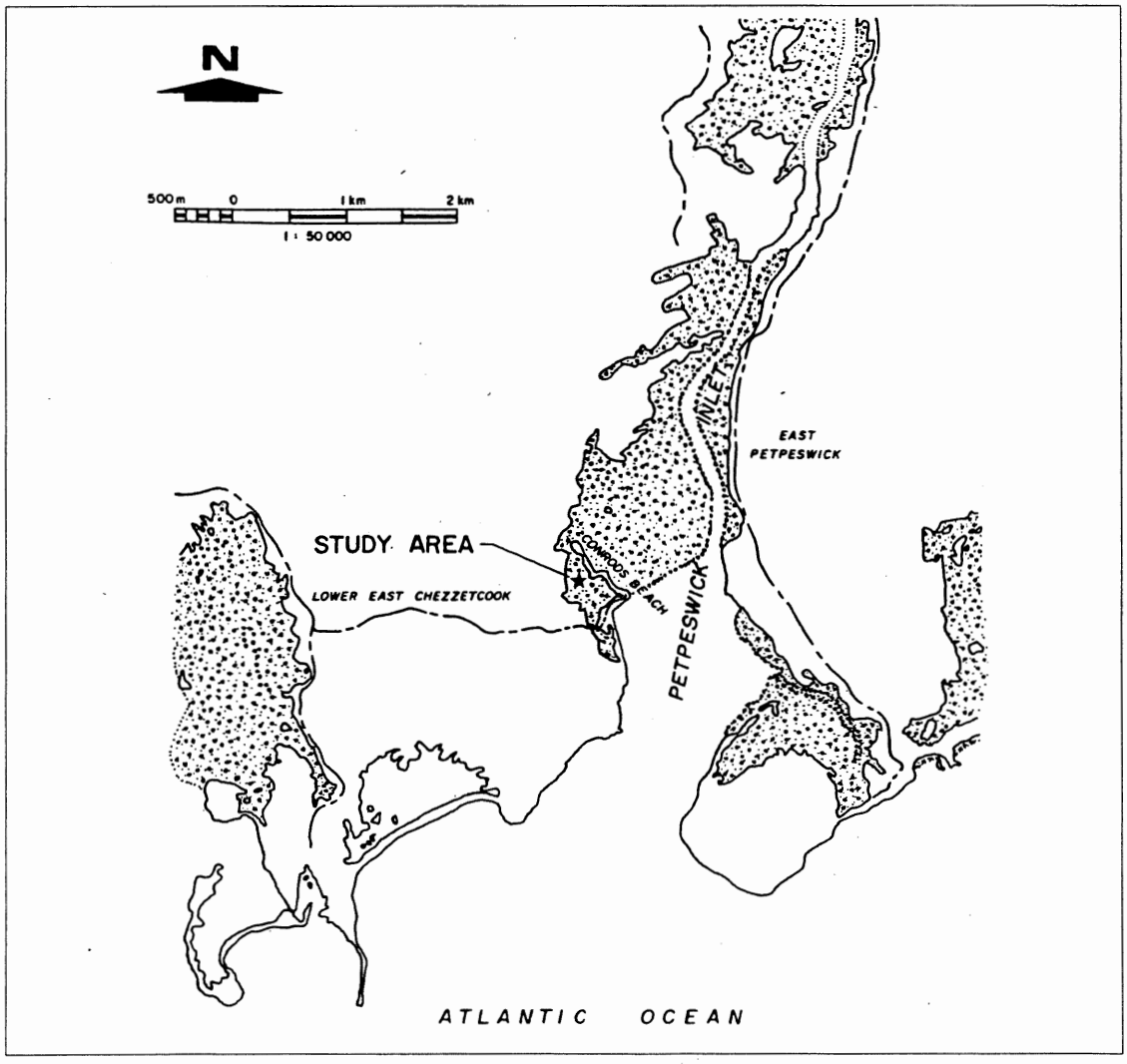


Figure 1.1b Site Location: Conrod's Beach, Petpeswick Inlet, Nova Scotia



Source: Lane et al., 1987

Fig. 1.2 Aerial photograph of the site location, Conrod's Beach, Petpeswick Inlet

1km

Source: Courtesy of Canadian Coast Guard

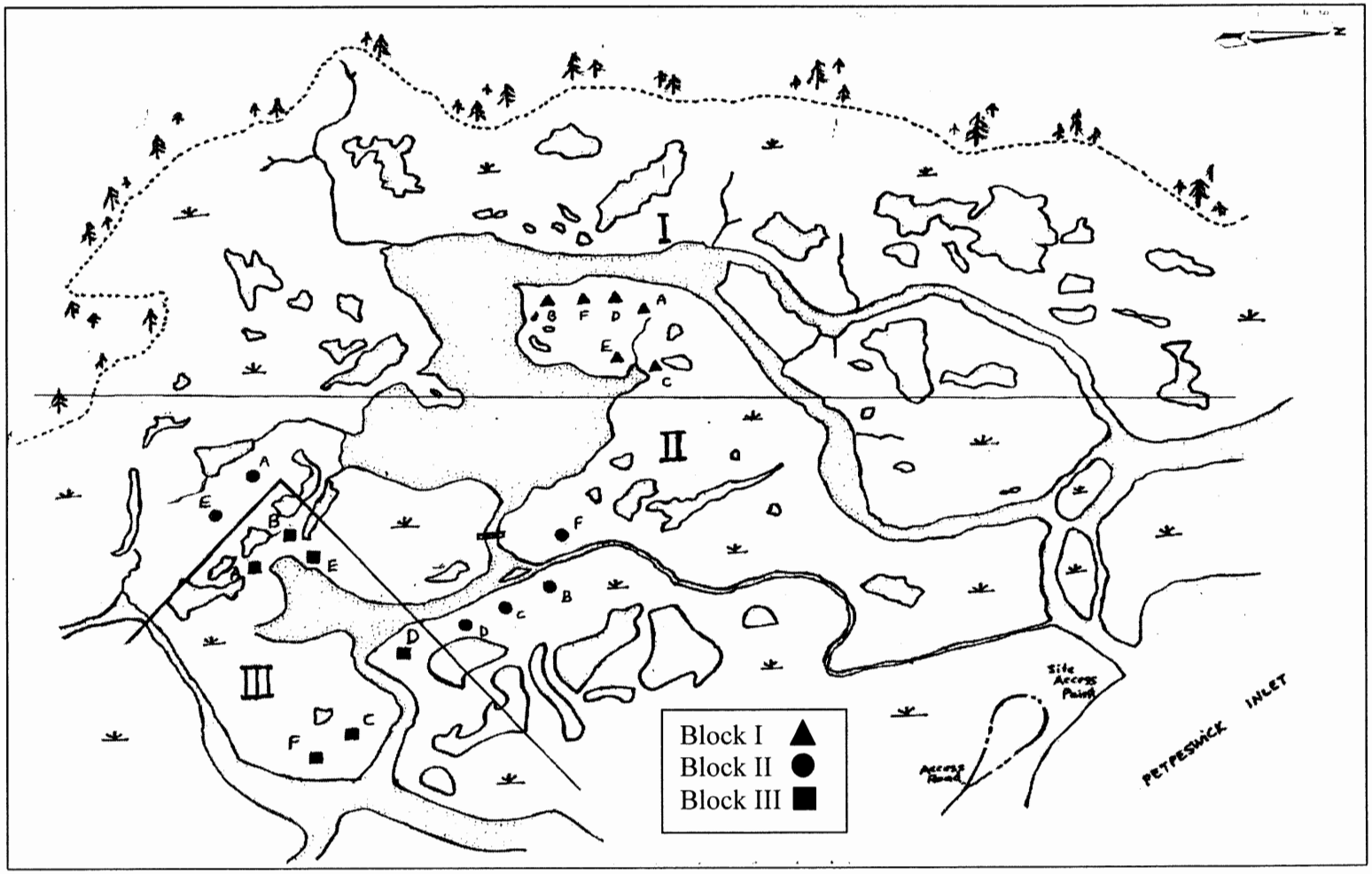
1.3 STUDY AREA

1.3.1 Physical Environment

Conrod's Beach salt marsh is situated 2km from the mouth of Petpeswick Inlet, an estuarine system that extends approximately 11km inland from behind a dune system, located along the Eastern Shore of Nova Scotia (Fig. 1.1 and 1.2). A combination of sandy, cobble and boulder beaches separates the marsh from mud and sand flats (Fisheries and Oceans Canada, 2000). As in all salt marshes, a continued supply of sediment is required for the persistence, growth and development of the marsh, which can be derived either from the sea bed or the land, according to local conditions (Long and Mason, 1983). During low tide, the marsh is drained by a single channel that breaches the dune system (Lane et al., 1987). This area is inundated twice a day by relatively low amplitude tides, with a recorded mean water level of 0.7m at high tide (Fisheries and Oceans Canada, 2000), and is a protected area, which makes for ideal conditions for this type of experiment.

One of the most distinctive characteristics of a salt marsh system is its vertical zonation of vegetation, including three main zones: creek-edge, middle/intertidal-marsh, and high-marsh zones (Lane, 1987). It is within the middle marsh zone that stands of the predominant salt marsh grass in Atlantic Canada, *Spartina alterniflora,* are characteristic (Hatcher et al., 1981), and among which the experiment was run.

Figure 1.3 Map of the Conrod's Beach Salt Marsh with locations of the study plots



Source: Department of Fisheries and Oceans, 2000

1.3.2 Selection of Plots

Experimental plots were strategically placed within the intertidal marsh zone, where medium to high tide influences the marsh surface twice a day (Fig. 1.3). This zone contains the necessary fauna and wildlife to suit the requirements of the study, and it is the average mean high tide level where most oil would naturally come to rest in a real oil spill. Three sets of six plots were set up across the marsh within this zone, to achieve a broad range of data from which suitable averages could be derived. "The experimental plots will be laid out a week prior to the commencement of the experiment on the basis of results from botanical and hydrographic surveys" (Fisheries and Oceans Canada, 2000, p.3).

1.3.3 Salinity and Temperature

Water and ground temperatures, as well as salinity levels, vary according to the change of seasonal conditions within the salt marsh. Among other factors, each benthic foraminiferal species has specific limits of tolerance to salinity for survival, growth and reproduction. Marshes represent the most extreme of all marine environments with large variations in temperature, salinity and pH. Very few species of marine foraminifera thrive in this environment (Scott et al., 2001), and therefore the measured values recorded throughout the sampling period may be considered as contributing factors to the population distributions among the plots.

The salinity levels of the tidal pool and the tidal creek were recorded throughout the experiment, and values were plotted against time (Fig. 1.4) and show a range of 30-36‰. Temperatures of the surface sediments were also recorded within the oiled and non-oiled plots, and were plotted against time (Fig. 1.5). Values ranged from 10-25 °C,

Figure 1.4 Surface Water Salinity Levels Over Sampling Period

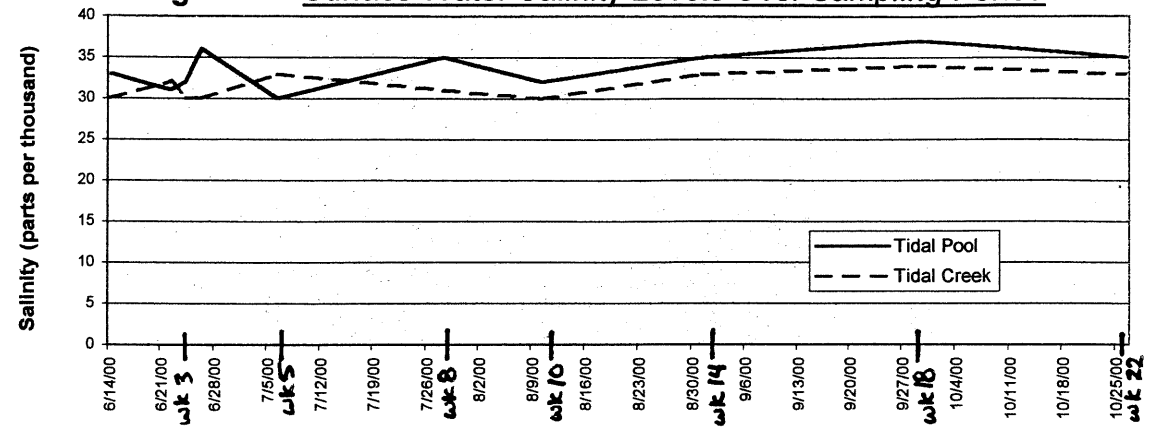


Figure 1.5a Surface Temperatures Within Non-Oiled Plots

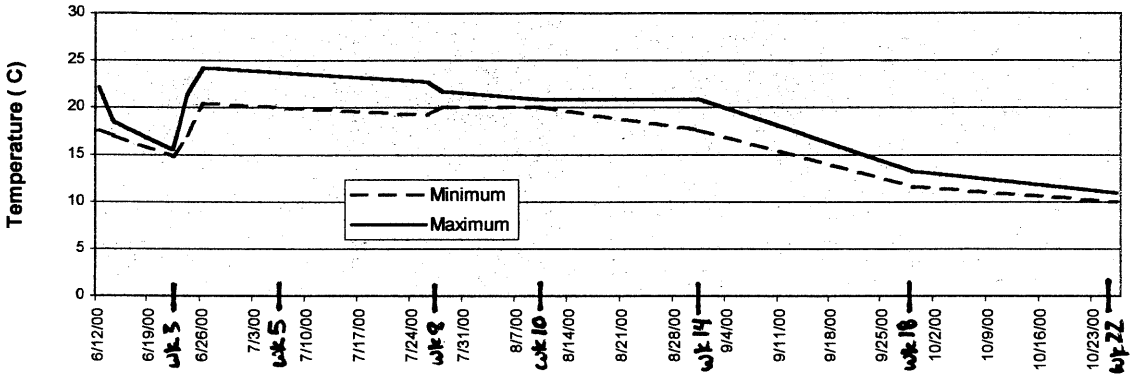
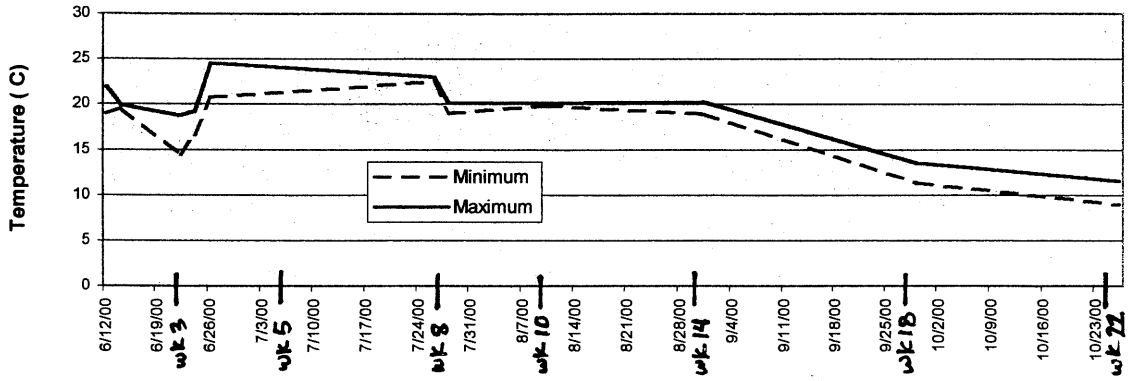


Figure 1.5b Surface Temperatures Within Oiled Plots



with lows in early June and slowly decreasing from the end of August to the end of the experiment on October 26th, 2000. Peak temperatures occurred at the end of June. Unfortunately, measurements of temperature and salinity were not recorded previous to June 12th, 2000.

1.3.4 Organic Matter

One of the ecological parameters that can affect the benthic foraminiferal distribution within the marsh is the presence of organic matter (OM). Within the estuarine system, OM comes in a variety of textures, compositions and densities, all of which are dependent on the source. Although OM is not toxic on its own, it often creates anoxic (low oxygen) conditions which creates reducing conditions that are harmful to most marine fauna (Scott et al., 1995). However, some foraminiferal species appear to survive in areas where OM is abundant. This may be because those foraminifera actually use the biodegradable OM as food, or it may be a result of reduction in competition between species (Williamson, 1999). Specific conditions of OM within each of the core samples are discussed in Chapter 3 and 4.

1.4 BACKGROUND ON FORAMINIFERA

1.4.1 Foraminifera as Indicators

Foraminifera are one-celled microorganisms, and when they die, their shell (or test) remains in the sediment record as a fossil. This allows reconstruction of the environmental history of a site in the absence of original (i.e. real time) physiochemical baseline data (Scott et al., 2001). As well, foraminifera occur in large abundance within the marine setting, with certain species unique to particular environmental conditions.

The extraction and storage of foraminiferal samples is relatively simple and cost-effective, which is not always the case with other types of biological environmental indicators commonly used to monitor and assess an impacted site, such as molluscs, polychaetes or bacteria (Scott et al., 2001). There is a long history of the use of foraminifera as indicators in a range of environmental site assessment work, and this will be explored in more detail in the following chapter of previous work.

1.4.2 Change in Species Composition

The most typical marsh foraminifera are agglutinated- they have an organic lining with a fine to coarsely agglutinated test composed of silt and sand grains that the organism collects from the substrate and cements together to make a rigid shell. These tests are resistant to low oxygen and low pH, reducing conditions that characterize salt marsh deposits, and are therefore preserved in the marsh sediments. Available data for benthic foraminifera, including areas close to Petpeswick Inlet, have demonstrated that distinct species assemblages serve as proxies to characterize the marsh environment (Scott and Medioli, 1980b). Because of this, although the biological controlling factors of these organisms are not fully known, data obtained from Petpeswick Inlet can be used to interpret fossil assemblages.

1.4.3 Deformities

As few as 10% of the total population being deformed specimens suggests a contaminated environment (Scott et al., 2001). Percentages of deformed tests that are above background values, as well as a relatively high number of species exhibiting deformities, are features of foraminiferal populations occupying intensely polluted environments (Boltovskoy et al., 1991). However, Alve (1991) pointed out that these

abnormalities among tests are not only a result of contamination, but can also indicate environmental stress arising from either anthropogenic or natural forcing. The test deformation parameter yields best results when used in conjunction with other population indices, and with environmental data that independently define pre- and post-contaminated intervals. For this reason, both the control plots and the contaminated plots within the site were sampled before the experiment began, and will be sampled again in the spring of 2001 when the new season of growth commences.

1.5 WHY FORAMINIFERA ARE BEING USED

1.5.1 Environmental Sensitivity

The comparatively high species diversity and sensitivity range of benthic foraminiferal populations yields local assemblages that are responsive to a broad range of environmental changes. Within heavily polluted sites, foraminifera are often among the last organisms to disappear completely, and can be also found in transition zones that do not appear to support other kinds of marine organisms (Schafer, 1971). Certain species of foraminifera appear to withstand a significant amount of environmental change, while others respond to contaminants by deforming in shape, or dying out. Either way, these sensitivities are indicative of environmental change, and provide an informative account of the direct effects the contaminant is having on the location and its inhabitants. The following chapter will demonstrate this point with specific case studies.

1.5.2 Sample Size and Abundance

Because foraminifera occur in large numbers in small areas, often a 10cc sample provides sufficient material for a statistically significant population. Within one centimeter of the surface marsh, for example, as many as several thousand individuals

can be found. A comprehensive data field base exists that has been compiled for these organisms over a wide range of marine settings, because they have been found to live and remain preserved in every marine environment worldwide, from high water to deep sea (Scott et al., 2001). Therefore, after analyzing a site's population concentration, the relative abundance of the species present will indicate if there has been an environmental change to which the foraminifera responded. Between environments, in particular physically variable nearshore environments, local foraminiferal variability usually does not exceed the differences caused by physical factors differentiating distinct environments (Scott and Medioli, 1980b). This is a key point in the use of foraminifera for environmental analysis, because it enables the recognition of distinct zones in both present-day and ancient sediments that should stand out in relation to spatial distribution "background noise" (Scott et al., 2001, p.28).

1.6 ORGANIZATION OF THESIS

This thesis is divided into six chapters. The introductory chapter describes the study area and its environmental components, explaining the use of marsh foraminifera as indicators and their benefit as informative and reliable tools. The second chapter summarizes a variety of previous work done in this field of study, demonstrating the progress that has been made, as well as the ongoing need for further research. The different background work compares local studies with other estuarine studies, along with several different types of pollution studies performed in the past. Although foraminifera have been used in a wide range of pollution-type studies, such as heavy metals or chemical contaminants, this will be the first known study to use marsh foraminifera as

monitors for oil spill impacts and recovery in an Atlantic salt marsh. A third chapter is dedicated to methodology. From the field to the lab, the sampling grids, sampling period and amount, and the individual treatments are described in detail, followed by the steps involved in processing and examining each sample, and finally how the data are presented so that it can be comparable to other work.

The fourth chapter describes the results obtained from the experiment, relating both the weekly and core data from the foraminiferal analysis of sediments from various test plots and organic matter evaluation, to other data from previous studies within the region. In this manner, the results from this experiment will be comparable with other parts of the study, and contribute to future site restoration work. Experimental results such as the population and species, the type of species and their abundance, the living vs. total populations and the deformities within the different species, are covered in the Discussion chapter. Based on previous work, and background knowledge of foraminifera and their typical distribution patterns, the significance of the results are discussed, indicating whether or not the treatments had an effect on the oil-contaminated plots. The neighboring inlet to the study area, Chezzetcook Inlet, provides an excellent collection of comparative data because of the large amount of previous foraminiferal research that has taken place there, and because of its similarities to the physical environment of Petpeswick Inlet.

The final chapter presents conclusions drawn from this study, based on the results, interpretations and discussion. These incorporate the project's original objectives: the extent of environmental impacts of the oil on the salt marsh, the natural rates of recovery within the foraminiferal assemblages, and the effectiveness of *in situ* remediation

techniques on these microfossils. In conclusion, with knowledge gained form this study, recommendations of alternate methods that could have been used for the conduct of this particular experiment are given. Based on the success of this research, project recommendations are given for the application of micro-indicators in future environmental studies.

CHAPTER 2: PREVIOUS WORK

2.1 INTRODUCTION

A large area of research concerning microfossil assemblages, in particular foraminifera, has investigated their sensitivity to environmental change, and their role as indicators of change in a marine setting. Distribution patterns reflect both natural and anthropogenic-caused (inorganic as well as organic) change, and as a result, foraminifera have become known as one of the most sensitive and inexpensive markers for indicating degeneration of marginal marine habitats (Alve, 1991, 1995). As our understanding of benthic foraminiferal ecology has advanced over the past 50 years, information on the distribution of foraminifera in unpolluted environments has provided a base for studies using benthic foraminifera as proxy indicators in polluted regions. These studies are widespread across the globe, and have dealt with organic waste discharges, from sewage outfalls or from paper and pulp mills (Alve, 1995), thermal and various kinds of chemical pollution, and heavy metal contamination (Alve, 1991, Campbell, 2000), to name a few.

2.2 LOCAL ESTUARINE STUDIES

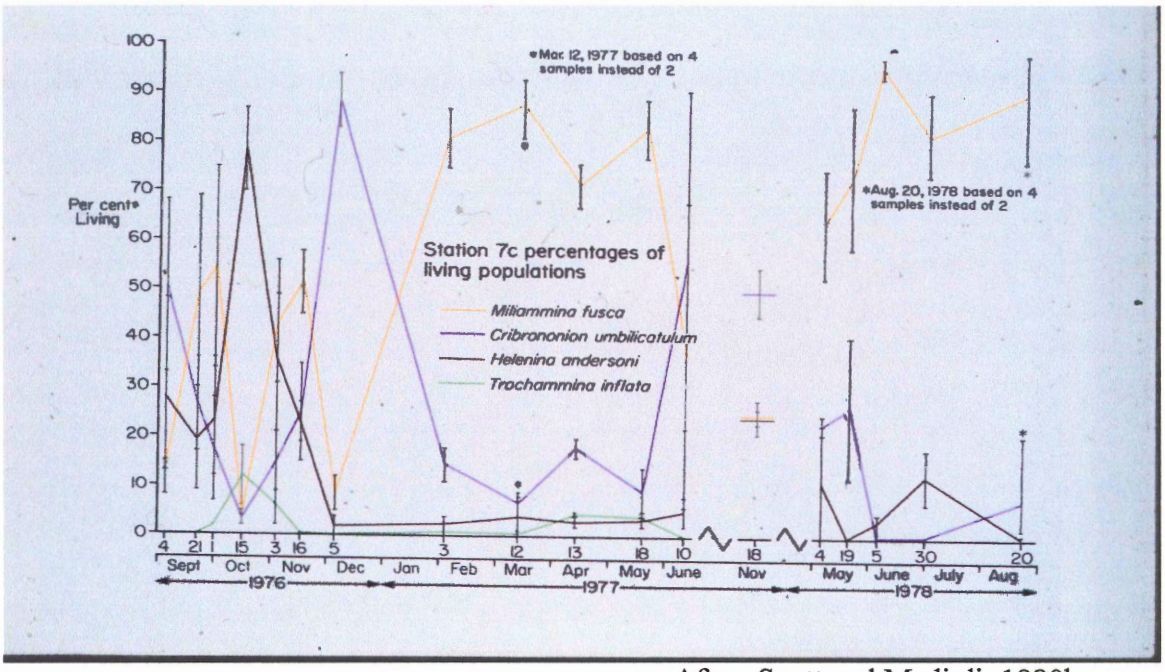
2.2.1 Chezzetcook Inlet, Nova Scotia

One of the advantages accompanying the choice of location for this experiment is that the neighbouring inlet, Chezzetcook Inlet, N.S., is a well-studied and highly similar environment to that of Petpeswick Inlet. Much foraminiferal-based research has been performed there, which has proven to be highly useful and comparable to other estuarine environments, especially in the intertidal zone. The data accumulated from past research will provide good pre-impact, background data for this project.

Scott and Medioli (1980a) showed the overall distribution of foraminifera in many maritime salt marshes. A salt marsh in Chezzetcook Inlet, N.S. was used by Scott and Medioli (1980b) to assess both the living and total foraminiferal assemblages, which allowed for the comparison of seasonal variability between two groups (live and total), as opposed to just the living. By considering both types of fluctuation, the contribution of the living population to the total can be better understood. Their goal was to provide insight on the reliability of the total population as an environmental indicator of climatic or micro-environmental changes. Two stations of that project (7c and 7d), which represent outer estuarine zone IIA (upper low marsh) and zone IIB (lower low marsh), are almost identical to the stations plotted for this project (Fig. 2.1- 2.3). These two stations present complicated seasonal curves for total population percentages and live population percentages, indicating that seasonal variations were significant, as well as significant variations in and the presence or absence of calcareous species (Scott and Medioli, 1980b). These natural variations are similar to the responses we can expect to see in our project, and will be referred to when analyzing results (refer to Chapter 5).

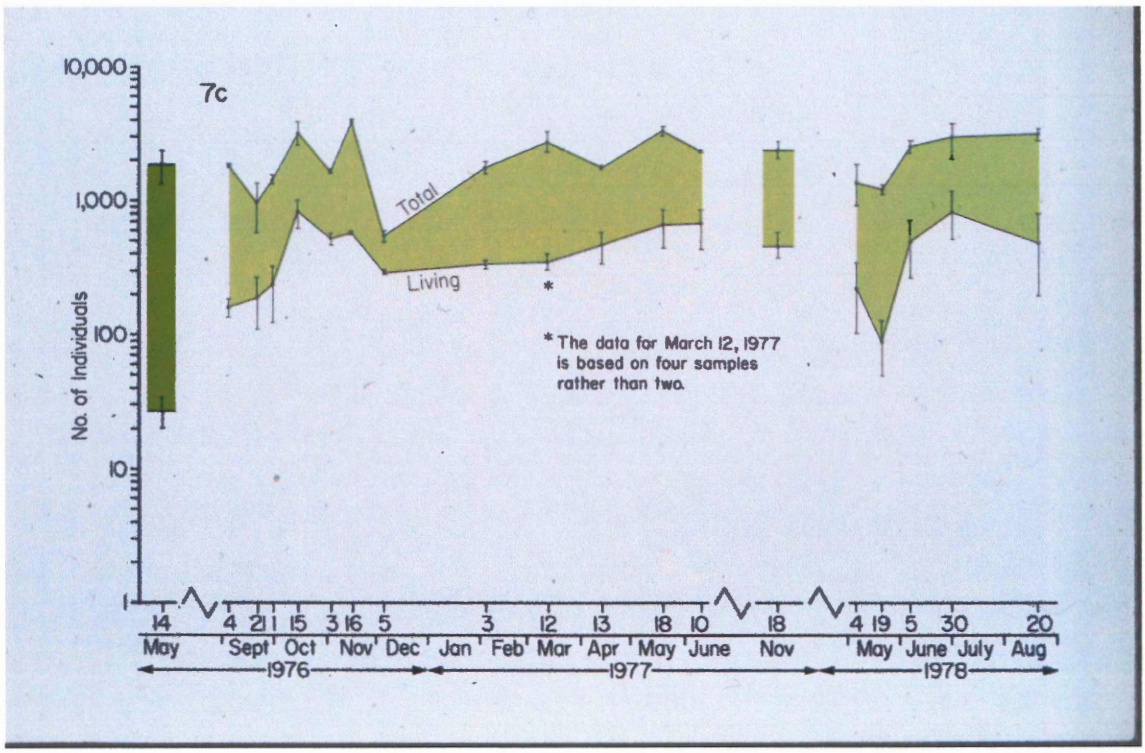
Another study was performed by Scott, Schafer and Medioli (1980) to provide an environmental framework for explaining the differences of distribution patterns and assemblages among different estuarine systems, comparing those of the Miramichi Estuary, N.B., the Restigouche Estuary, N.B., and Chezzetcook Inlet, N.S. The goal of this study was to "demonstrate how foraminiferal assemblage zones, when related to oceanographic data, can be used to derive a classification scheme for estuaries" (Scott et al., 1980, p. 206).

Figure 2.1 Station 7c percentages of living populations (vertical bars represent variation between replicate samples for each interval)



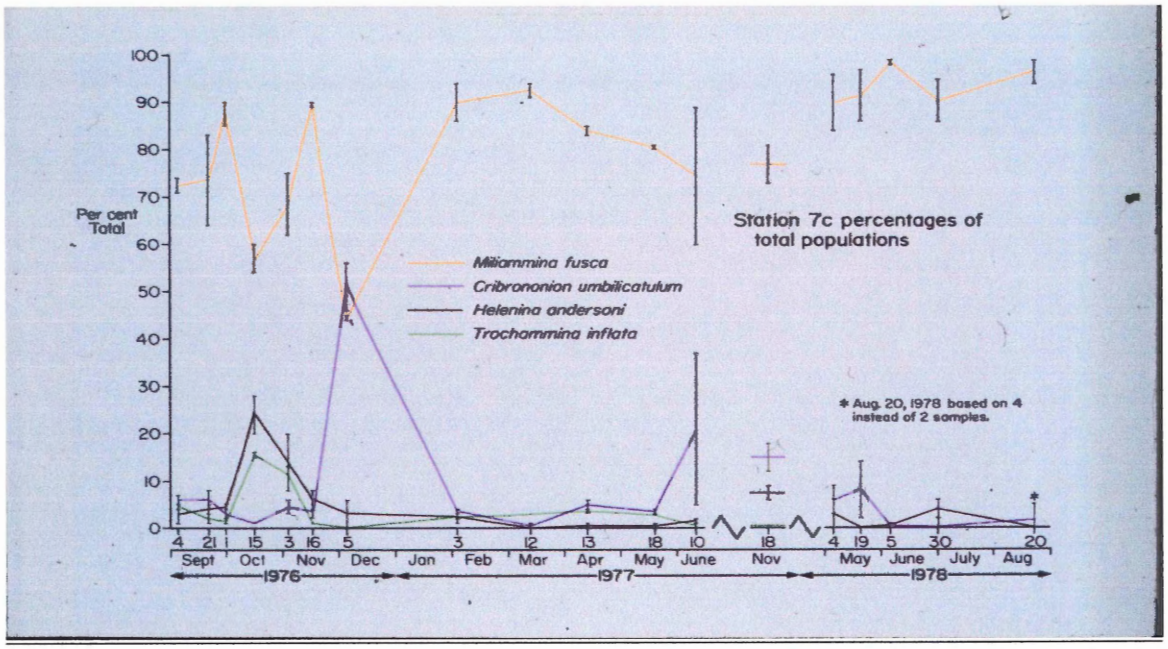
After: Scott and Medioli, 1980b

Figure 2.2 Living and total population variations for all species; Station 7c (vertical bars represent variation between replicate samples for each interval)



After: Scott and Medioli, 1980b

Figure 2.3 Percentages of total populations, Station 7c (vertical bars represent variation between replicate samples for each interval)



Source: Scott and Medioli, 1980b

2.3 POLLUTION STUDIES

Boltovskoy and others (1991) summarized the main environmental parameters that can cause morphological deformities among benthic foraminiferal tests. Deformation of tests can be related to changes in temperature, salinity, carbonate solubility, depth, nutrition, substrate, dissolved oxygen, illumination, pollution, water motion, trace elements, and rapid environmental fluctuations. In response to certain forms of pollution, relatively high numbers of species show deformities above what normal background percentages show, in intensely contaminated areas (Boltovskoy et al., 1991). These abnormalities can be related not only to environmental pollution, but also to anthropogenic or natural stresses affecting the environment, as Alve (1991) demonstrates. To evaluate the effects of pollution on the biota, particularly in estuaries, it is best to compare the present day assemblages with natural, pre-pollution assemblages (Alve, 1995), as is being done in this project. This allows the researcher

to "evaluate what environmental effects different kinds of pollution have on a system" (Alve, 1991, p. 17).

2.3.1 Foraminifera as Pollution Indicators

A number of studies in the past have shown the value of benthic foraminifera as indicators of pollution in different estuarine and marine environments.

Benthic foraminifera from the Restigouche Estuary in Chaleur Bay, New Brunswick, were observed by Schafer (1973), near isolated sources of sewage and/or industrial effluent. The distribution patterns reflect different responses between several species near the effluent source, where diversity decreased close to the outfall, but increased farther offshore. The higher values are most likely a result of a temporary artificial environment produced by certain components of the effluent, that actually supports the co-existence of a greater number of species and/or specimens (Schafer, 1973). In the same area, an experiment was later run by the Geological Survey of Canada (Atlantic) to assess the impact of anthropogenic pollution in the form of heavy metals, using foraminifera as indices (Campbell, 2000), showing similar trends.

A study executed in Sorfjord, Western Norway by Alve (1991) showed the response of benthic foraminifera to heavy metal enrichment of the sediment. Among the 70 species observed, different modes of test deformation were found, including double apertures, reduced size of one or more chambers, protuberances on one or more chambers, twisted chamber arrangement, enlarged apertures and twinned forms (Alve, 1991). These deformities were found to be a response to contaminants. Deformed specimens typically make up less than 10% of the total population occupying polluted environments (Scott et al., 2001).

Foraminifera from Guayanilla Bay, Puerto Rica, were observed by Seiglie (1975), based on the effects different pollutants have had on the natural characteristics of the bay, and the assemblages within it. He showed that a small percentage (5%) of those populations that were under chemical and thermal pollution were deformed, while test abnormalities, such as pronounced spiraling and distorted chamber arrangement, were common (Seiglie, 1975). Test abnormalities among several of the observed species, such as individuals with a thin and transparent last chamber or more pronounced spiraling, were attributed to stressed conditions provoked by organic matter contamination, while those with deformed chambers and a distorted chamber arrangement were linked to thermally-polluted lagoonal environments. The final results from this study showed that "test abnormalities appear to be of greater significance than the species composition of indigenous assemblages in establishing differences among closely similar contaminated environments" (Scott and Medioli, 2001, p. 64). It was reported by Stubbles (1997), based on estuarine studies in the southern U.K., that heavy metal contamination and the deformation of tests are directly connected, and that any instance of deformed tests exceeding 5% could be classified as contaminated (Scott and Medioli, 2001).

Whitcomb (1978) claimed that deformations among benthic foraminifera could be caused by oil contamination, based on species sampled from the tidal flat complexes of the lower York River, that were polluted by hydrocarbons spilled by the American Oil Company refinery in Yorktown, Virginia. Test deformities were up to 10% among several individual species. This was believed to be a result of the starvation of foraminifera, due to the weakening of the foraminiferids' prey organism (diatoms), as a secondary effect of the toxicity of the crude oil present (Whitcomb, 1978). Similarly,

three types of irregularities affected the tests of the benthic foraminifera living in Câle du Dourduff, following the oil spill of the Amoco Cadiz (Venec-Peyre, 1981). These three anomalies included a reduced size of one chamber, calcification defects causing additional chambers or folded tests, and, one year after the spill, a parasitic attack. The anomalies were present prior to the contact of the hydrocarbons with the study area, but affected assemblages from only a minor part of the populations (Alve, 1995).

2.4 OTHER OIL MITIGATION STUDIES

2.4.1 Biodegradation and Bioremediation

Because offshore oil spills continue to be a threat to shoreline environments, research projects continue to try to find ways of reducing the impact of harmful hydrocarbons on the fragile coastal environments. In the past, chemical (dispersants) and physical (booms) methods have been used to reduce the amount of spilled oil from reaching the shoreline. However, due to certain constraints, much of the oil often does reach and affect shoreline habitats (Lee and De Mora, 1999, Lee and Merlin, 1999). An alternative spill-response strategy is that of *in situ* bioremediation, which is defined as "the addition of substances or modification of habitat at contaminated sites to accelerate natural biodegradation processes" (Lee and De Mora, 1999, p. 783). Microbial degradation is "a principal process in the elimination of petroleum pollutants from the environment" (Zobell, 1964, p.85), and natural rates of hydrocarbon biodegradation can be limited by abiotic environmental factors (Atlas and Bartha, 1992). Bioremediation has been demonstrated to be an effective countermeasure to this effect, and can be approached in two ways: bioaugmentation (addition of oil-degrading bacteria) and

biostimulation (addition of nutrients) (Lee, 1999; Lee and De Mora, 1999; Lee and Merlin, 1999).

2.4.2 Oil-Impacted Shorelines

A number of elaborate and thorough experiments have been performed in different areas to monitor and assess the effectiveness of bioremediation on oil-impacted shoreline environments. Following the disastrous oil spill from the Exxon Valdez in Prince William Sound, Alaska, Prince and others (1993) studied the role of bioremediation in the cleanup. In this case, it involved the application of selected fertilizers to provide assimilable nitrogen and phosphorus to the indigenous microbial populations, which did in fact increase as a result (Prince et al., 1993). Later, Prince and others (1999) carried out a field trial on an Arctic beach using an intermediate fuel oil and soluble and slow fertilizers. While the dominant mechanism of oil removal from the shoreline was physical, there was good evidence that biodegradation was stimulated by the bioremediation treatment employed (Prince et al., 1999).

A collection of field investigations of different bioremediation techniques are reviewed by Swannell and others (1996), to provide suggestions and operational guidelines for the use of bioremediation in response to a marine oil spill. They demonstrate from a range of spill incidents and field trials that "bioremediation is a potential new tool for the cleaning of certain oil-contaminated shoreline types" (Swannell et al., 1996, p.362). Based on these findings, other experiments were run by Swannell and others (1997a, b), such as an investigation of the use of bioremediation to treat oil-contaminated fine sand in the intertidal zone of Stert Flats, Somerset, UK. Within this mudflat environment, it was determined that regular additions of inorganic nutrients

(fertilizer) were effective in the stimulation of biodegradation of oiled subsurface sediments, and that monitoring CO_2 evolution *in situ* was an effective tool of measuring the success of the bioremediation (Swannell et al., 1997a, b).

2.4.3 Oil-Contaminated Salt Marsh Environments

Salt marshes have been the focus of many oil bioremediation studies because they are known as low-energy coastal environments, where oil is likely to be buried in the sediment, and where microbial degradation plays an important role in its removal (Lee and Levy, 1991). One experiment by Lee and Levy (1991) examined the degradation of a waxy crude oil that was spilled on sand beach and salt marsh environments in Nova Scotia. They found that at high concentrations, waxy crude oils could be effectively countermeasured by nutrient enrichment in the form of agricultural fertilizers (Lee and Levy, 1991). Another project was conducted to compare the effectiveness of bioremediation strategies based on inorganic and organic fertilizer additions to accelerate the biodegradation rates and reduce toxicity in oiled sediments in the intertidal zone of a low-energy beach located on the eastern shore of Nova Scotia (Lee et al., 1996).

The impact of crude oil on the vegetation of salt marshes has also been studied. Lane and others (1993) conducted an experiment at the same study site as this experiment, Conrod's Beach on Petpeswick Inlet, to compare salt marsh vegetation in control and oil- and/or dispersant-treated plots, in the third and fifth growing seasons following treatment. Twelve 0.5m x 4.0m plots were established at random locations in the marsh in each of the three vegetation zones, and four treatments (control, oil, dispersant, or oil+dispersant) were randomly assigned to each zone in 1986. A variety of characteristics were measured, from late August to early September in 1986, 1988 and

1990, including: plant height, stem density, biomass, species cover (of *Spartina alterniflora* and *Spartina patens*), fluorometry, and soil chemistry. The saltmarsh vegetation plots that were treated in 1986 and re-measured in 1988 and 1990 showed a range of positive and negative results, with respect to the long-lasting effects of the treatments (Lane et al., 1993).

Lin and Mendelssohn (1996) looked at the effects of crude oil on the dominant vegetation of fresh, brackish and salt marshes in South Louisiana, including *Spartina alterniflora* and *Spartina patens*. From laboratory experiments run in a greenhouse, it was found that *Spartina patens* were the least sensitive to the crude oil (Lin and Mendelssohn, 1996). In a similar experiment run by Pezeshki and DeLaune (1993), the effect of crude oil on gas exchange functions of two important U.S. Gulf Coast plant species was examined. Both *Juncus roemerianus* and *Spartina alterniflora* were exposed to petroleum hydrocarbons in a laboratory setting, and their growth responses and recovery were monitored and determined (Pezeshki and DeLaune, 1993).

CHAPTER 3: METHODS

3.1 PLOTS AND SAMPLING GRID

In the field, experimental plots were laid out a week prior to the commencement of the experiment in early June, 2000, based on the results from botanical and hydrographic surveys, and guidelines developed from previous studies. Three sets of six plots were laid out by the research team for each of the blocks (I, II and III), and labeled IA through to III F to account for the different treatments, for a total of eighteen plots (Fig. 1.3). Each plot measured 3m x 3m, and comprised four steel posts bound by orange plastic mesh, and blue oil-absorbent padding for the oiled plots (Fig. 3.1). To minimize edge effects, a buffer or 'no-sample' zone was established around the entire perimeter of each plot, along with benchmarks in each of the four corners. Within each plot, four equal sectors were established, excluding the buffer zone and a small walkway in the middle, and each sector was subdivided into 9 sub-sampling zones (Fig. 3.2), corresponding to the sampling events (Fisheries and Oceans Canada, 2000). The walkway was used to access the sub-sampling zones, but also to limit human impact on the surface to within one area inside the plot. To ensure unbiased estimates of treatment effects on oil biodegradation rates, a statistical design (i.e. generalized randomized complete block –GRCB) was used (Addelman, 1969, 1970). As shown in Fig. 1.3, Block I, II and III each has six plots with a random order of treatments (from A to F). In this manner, no one sub-sampling zone was ever sampled twice.

Fig. 3.1 Experimental plots in the field (each $3m^2$)

Fig. 3.2 Sampling Grid

	BUFFER ZONE						
	A1	**A2**	**A3**	W	**A4**	**A5**	**A6**
	B1	**B2**	**B3**	A	**B4**	**B5**	**B6**
	C1	**C2**	**C3**	L	**C4**	**C5**	**C6**
	D1	**D2**	**D3**	K	**D4**	**D5**	**D6**
	E1	**E2**	**E3**	W	**E4**	**E5**	**E6**
	F1	**F2**	**F3**	A	**F4**	**F5**	**F6**
	BUFFER ZONE			Y	BUFFER ZONE		

For each sampling date, two different sub-samples were taken, excluding the first and last sampling dates (week 0 and week 22), from which only one sub-sample was needed. For example, week 5 (July 6th, 2000), samples were taken from A2 and F4. Following a schedule based on a statistical design (Table 3.1), no one sub-sample was ever sampled twice. Designated sub-sample locations were not in place for the June 2nd (week 0) sampling.

Table 3.1 Sampling Schedule

Date	June 9th		June 23rd		July 6th		July 27th		Aug. 10th		Aug. 31st		Sep. 28th		Oct. 26th
Week	Week 1		Week 3		Week 5		Week 8		Week 10		Week 14		Week 18		Week 22
Sub-sample	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5	A3	D6	A1

3.2 TREATMENTS

To simulate the conditions of an offshore oil spill impacting an Atlantic coastal salt marsh, prior to application, the oil was weathered by aeration to remove low-molecular weight components, reducing the oil volume by approximately 14% (Fisheries and Oceans Canada, 2000). A medium sulphurous light crude oil (MESA: specific gravity 29.7 API; flash point 4°C) from the Petro-Canada refinery in Montreal was used in this study. The oil was applied at low tide to twelve of the eighteen plots within the first week, using a spray boom system adapted to a backpack sprayer (see Fig. 3.3). Using this device, 6L/plot/day of oil was sprayed evenly onto the surface of the designated plots during the low tide period, over two consecutive days, for a total of 144L of oil {12L/plot (2L/m) x 12 plots}. Three blocks with six different treatments were applied to the plots, for a total of eighteen experimentally treated plots. The six different treatments were as follows, each one represented by a letter:

TREATMENTS:

A- Control with nutrient enrichment (no oil added);

B- Control without nutrient enrichment (no oil added);

C- Natural attenuation control (no treatments added);

D- Bioremediation by nutrient enrichment NH_4NO_3 + $Ca(H_2PO_4)_2$ H_20;

E- Bioremediation by nutrient enrichment (NH_4NO_3 + $Ca(H_2PO_4)_2$ H_2O) with reduction in plant effects, surface vegetation continuously cut back to ground level;

F- Bioremediation by nutrient (NH_4NO_3 + $Ca(H_2PO_4)_2$ H_2O) and oxygen enrichment by agricultural disking.

Throughout the text, each treatment will be referred to as follows, with respect to the experimental plots: Treatment A-Control plot with nutrient enrichment (no oil), Treatment B- Control plot without nutrient enrichment (no oil), Treatment C- Oiled plot without treatments (natural attenuation), Treatment D- Oiled plot with nutrient enrichment, Treatment E- Oiled plot with nutrient enrichment and cut plants, Treatment F- Oiled plot with nutrient enrichment and agricultural disking.

The main nutrients required for the growth of the dominant grass species within this type of salt marsh (*Spartina alterniflora*) are carbon (in the form of CO_2), phosphorus, and nitrogen. Therefore, granular nitrogen and phosphorus in the form of agricultural fertilizer were initially broadcast at a dosage of 450 g-N and 134 g-P per oiled plot. As well, during the sampling period, 3 specific plots were aerated (disked) using a small tilling machine, to enhance oxygen penetration within the sediments.

Fig. 3.3 Oil-spray boom system with backpack sprayer

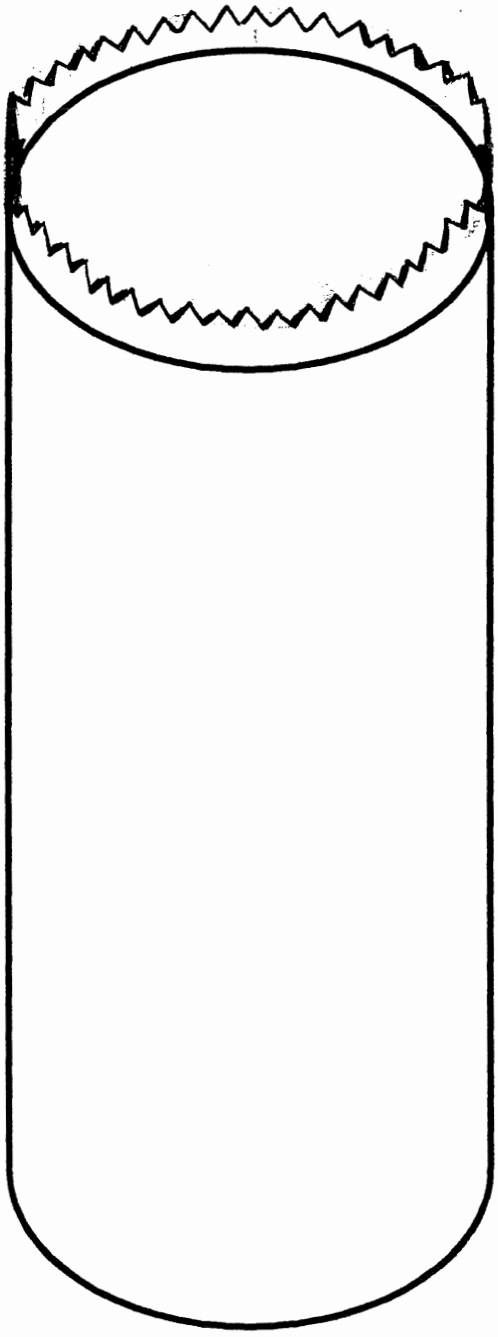
3.3 COLLECTION AND SAMPLING PERIOD

In the week prior to the application of the oil, time zero (T_0) sampling of the surface sediments within the experimental plots began, to have base data from each of the eighteen locations (referred to as week 0, representing June 2nd, 2000). As well, three 10cm long cores were taken from each zone in which one set of the six treatments were applied, outside of the experimental plots, prior to the oiling. These cores were used to determine the stability of the fauna from the past few years, and demonstrate whether or not the assemblages have been stable, or subject to change. If changes occur all the time, it would be difficult to interpret conclusive results from samples taken during this experiment.

The oil was applied to the plots on June 6th and 8th, 2000, and time one (T_1) sampling continued two days after the second incremental oiling event (referred to as week 1, representing June 9th, 2000). Subsequent sampling followed at weeks 3, 5, 8, 10, 14, 18 and 22 (from June 23rd to October 26th, 2000). On each sampling date, two representative sub-samples were taken from each plot, so that a total of 36 samples were analyzed for each date. This was done to account for any discrepancies between values, which may occur within the $3m^2$ area. For the first sampling day (week 0) and the last (week 22), only one representative sample was needed per plot, because of stabilized conditions. In the spring of 2001, one last set of samples will be taken to assess the rate of natural recovery and to determine the concentration of residual oil remaining at the site (Department of Fisheries and Oceans Canada, 2000).

Samples were collected by walking out on to the marsh at low tide and from each subdivided sub-sampling zone, a 10cc core was used (Fig. 3.4) to extract the top 1cm of surface sediment from the experimental plots. This corer, developed by Scott (1977), has a stainless steel body and a serrated edge to penetrate the strong, rootbound marsh material. As well, a rounded metal garden trowel was used, along with a stainless steel steak knife, to make the extraction of the samples less difficult (Fig. 3.5). Each sample was stored in its own plastic container to transport the specimen from the field to the lab, and contained in a refrigerator until processed within 36 hours from the time of sampling. The three cores that were taken were collected prior to oiling from the marsh at low tide. A 10cm, metallic core sampler was used, as well as a trowel to extract the core from the root-bound marsh (Fig. 3.6).

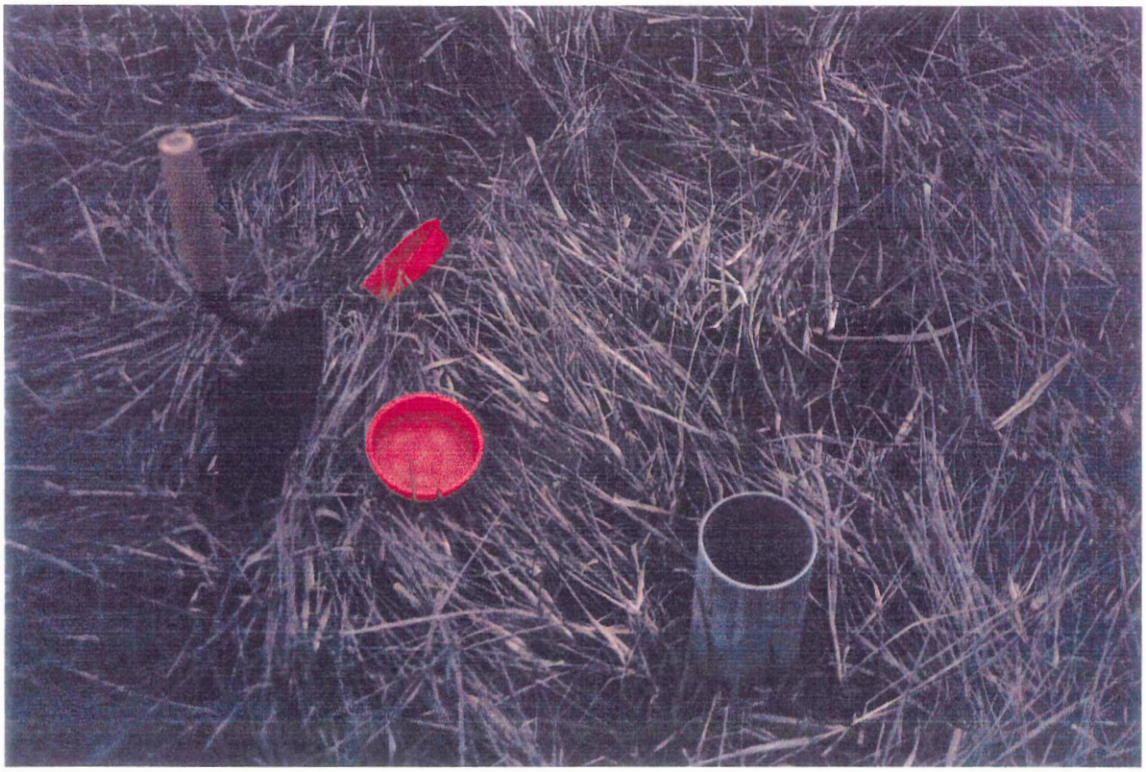
Fig. 3.4 Scott surface marsh sampler: dimensions- i.d.=3.5cm, o.d.=3.8cm, length=8-10cm. Notice serrated edge, which is inserted into marsh surface. Made from stainless steel tubing.



Source: Modified from Scott, 1977

Fig. 3.5 Extracting samples from experimental plots using corer, trowel and knife

Figure 3.6 Core sampler with trowel



3.4 PROCESSING

3.4.1 Sediment Processing

Following the sampling in the field, the samples were refrigerated in the lab at Dalhousie University until they were processed, within 36 hours of being extracted, to prevent fouling. During the processing, each sample was washed through a >500 μ sieve to concentrate and eliminate large debris, as well as through a >63 μ sieve (Fig. 3.7), to eliminate all silt and clay particles. As a result, only sand and larger organic particles were captured in the >63 μ sieve, including the desired foraminifera specimens. It has been demonstrated by previous researchers (e.g., Schröder et al., 1987) that up to 99% of the fauna can be lost using the >125 μ sieve instead of the 63 μ sieve in soft sediment samples. In the case of the oiled samples, a mild detergent was used to 'break up' clumps of consolidated mud, and to maintain a clean screen through which the samples were washed.

The final stage in processing involved the containment of the washed sample into a clean, sealed plastic container, with the addition of formaldehyde and Rose Bengal stain. The purpose of the addition of formaldehyde was to kill the specimens and fix the tissues so that the Rose Bengal could stain any of the formerly living tissue. The utilitarian technique of Rose Bengal stain was discovered by Walton (1952), and has since been used by foraminiferal specialists throughout the world to identify living foraminifera (Scott et al., 1999).

3.4.2 Photography

Selected foraminifera were isolated and mounted on the imaging stage of the Dynaphot® Scanning Light microscope and were photographed using Fuji 64T color

35mm slide film, and images were then scanned and edited in Microsoft Photo Editor. These particular individuals were representative specimens of those species with the most severe deformities. Photographs of the experimental plots and the oiling and sampling process in the field were taken with a 35mm camera using Kodak film.

Figure 3.7 Tools used in sampling and processing foraminiferal specimens

After: Scott et al., 2001

3.4.3 Organic Matter

Because of the high concentration of organic matter present in salt marshes, for the purpose of this study, the washed residues were placed in alcohol and water for permanent storage and examination. It has been shown that highly organic residue, when dried, can consolidate like 'pancake mix', a phenomenon that causes individuals to mould together and is often irreversible (Scott et al., 2001).

3.5 EXAMINATION

3.5.1 Splitting

When a sample contains many thousands of individuals, as is the case in this study, it can be split into smaller equivalent sub-samples. Because the organic-rich samples required wet storage, they were split using a settling column splitter (Fig. 3.7), which is designed to divide the sample into eight equal divisions through the properties of water turbulence and settling gravity (Scott and Hermelin, 1993). One eighth of the sample was then observed under the microscope, and the values obtained were multiplied by eight to give a representative value for the entire sample. This technique has proven to be accurate to within 5% or less on most occasions (based on tests done by Scott and students over the last 10 years).

3.5.2 Counting and Identification

For the purposes of this study and statistical analysis, it has been shown that an adequate number to count is approximately 300 specimens, and that larger counts do not significantly improve accuracy. Once the samples had been split and concentrated in a petri dish, it became easier to identify and count the microfossil specimens using a

stereomicroscope, at magnifications of 20-60x. Each sample was carefully counted in this manner, and required great familiarity with the species involved. This technique does not require specimens to be picked out of the water and alcohol, which can be difficult to do with a fine #000 brush in organic rich sediments, reducing the time required to process the large number of samples taken for this experiment (Scott et al., 1999). Several photographic plates, textbooks and sample trays were used in the identification of the foraminiferal species found in the samples from Petpeswick Inlet. As well, background knowledge acquired from a micropaleontology course, which focused on foraminifera in the laboratory, assisted in the recognition and interpretation of the specimens observed.

3.6 DATA PRESENTATION

Data has been compiled and presented in Microsoft Excel spreadsheets and graphs. Total foraminiferal numbers including number of species, total living and total numbers, percentage abundance and deformations have been recorded within tables, along with salinity and temperature levels over the sampling period (Appendix A). The percent abundance of foraminiferal species was determined from the total number of individuals per 10cc sample. The relationships between living and total abundances, as well as the normal and deformed percentages, from the various species observed within the treated and control plots, are compared and discussed in chapters 4 and 5. No statistics were performed on the data because the graphical techniques used adequately showed exactly what took place within the plots because of the small scale of the experiment, and dealt with the concerns within the scope of the project.

The careful and lengthy analysis of foraminiferal assemblages was done to determine the total number of living and total (living plus dead) number of species (per 10cc), the total number living and total number (living plus dead) of individuals (per 10cc), the number of living and total (living plus dead) individuals for each species, as well as the number of living deformed and total (living plus dead) deformed individuals for each species.

The results were grouped into tables according to the six different treatments, ie: Treatment A (control plot with nutrient enrichment) through to Treatment F (oiled plot with nutrient enrichment and agricultural disking) for each of the three sets of treated plots (1, 2, and 3), over the twenty-two-week sampling period (Appendix A).

3.7 OTHER DATA

The results from this study will be compared against those from previous work in the neighboring inlet, Chezzetcook Inlet, for a base comparison, in particular, from the work performed by Scott and Medioli, 1980b. The cores taken from the site of the experiment before the oil was spilled are compared with previous data obtained from Chezzetcook Inlet, to compare trends over time, for as far back as a 10cm core will show. For samples taken from oiled plots, the percentages of deformities and trends of living vs. total values are compared with those taken from the non-oiled plots, but also from previous data from Chezzetcook Inlet.

CHAPTER 4: RESULTS

4.1 WEEKLY RESULTS

Following a schedule based on statistical design (as mentioned in Chapter 3), samples were taken from the eighteen plots over a twenty-two week sampling period. Two samples were taken from the experimental plots from week 0 to week 22. A total of 288 samples were taken over the entire sampling period, each of which was carefully analyzed for foraminiferal content.

4.1.1 Description of Results Format

Once each sample was counted, the data were put into tables using Microsoft Excel spreadsheets. The total living (L) and total (T) (living plus dead) number of species (per 10cc) and the total number of living (L) and total number (T) of individuals (per 10cc) are shown as whole numbers. The living (L) and total (T) values for each individual species are shown as relative percentages, so the results can be comparable with previous work. More specifically, the number of living individuals (L) for each species was divided by the total number of living individuals (T) for the entire sample, and divided by 100. The total number of individuals (T) (living plus dead) for each species was divided by the total number of individuals (T) (living plus dead) for that sample, and divided by 100.

For those species with a significant number of deformed specimens, the number of living deformed individuals (Ld) for each species was divided by the number of living (L) individuals for that species and not for the entire sample. This is because the total values were too high to divide by to show any significant impact of deformation within the individual species. Similarly, the total number of deformed individuals (Td) (living

plus dead) for each species was divided by the total number of individuals (T) of that species, and not for the entire sample.

Based on the foraminiferal analysis, there was a maximum of twelve different species present in the top one centimeter of the samples collected from the plots within the intertidal marsh zone, each of which were observed to have living representatives throughout. These include: *Eggellera advena, Elphidium excavatum, Glomospira gordialis, Miliammina fusca, Pseudothurammina limnetis,* Thecamoebians, *Tiphotrochammina comprimata, Trochammina inflata, Trochammina macrescens f., Trochammina macrescens f. polystoma,*and *Trochammina ochracea*, as well as inner linings.

While not all of these species were present in each of the samples, results show that the two most common species were *Trochammina macrescens f. polystoma* and *Miliammina fusca* within each plot over the entire sampling period. Furthermore, it was within these two species that deformities were most common, as shown in Tables 1-9 (Appendix 1), with respect to living deformed (Ld) and total deformed (Td) occurrences. In some cases, several of the *Miliammina fusca* and *Trochammina macrescens f. polystoma* were black as a result of the oil, in both the living and dead individuals present (as well as in both the normal and deformed individuals). As mentioned earlier, as few as 10% of the total population being deformed specimens suggests a contaminated environment (Scott et al., 2001), and that a relatively high number of species exhibiting deformities, particularly at percentages well above background values, indicates polluted surroundings (Boltovskoy et al., 1991). For these reasons, although there was a significant percentage of *Trochammina macrescens f. polystoma*, the percentage of

deformities within this species was not sufficiently high enough to be significant for the purpose of this study. On the other hand, the percentage of deformities within *Miliammina fusca* throughout the study period was noticeably high (Appendix 1, Tables 1-9), especially in the oiled plots. Therefore, these values were plotted in graphs to show variability throughout the sampling period, in response to the various environmental stresses (natural parameters, oil and *in situ* treatments) (Fig. 4.1- 4.18).

For those dates where two samples were taken and analyzed from each plot, observations show that there was variability between values within the same plot, so that there was a maximum and minimum value for each count. This was dealt with by plotting all minimum values together on graphs (shown as dashed lines in Fig. 4.1 – 4.18), and all maximum values together (shown as solid lines in Fig. 4.1 – 4.18), distinct from each other. Vertical lines were used to show the range between the maximum and minimum values for each sampling week. For week 0 and week 22 there is only one data point.

4.1.2 Foraminifera

The results were analyzed based on the three sets of six treatments (Treatment A through F). The foraminiferal occurrences within the three blocks are discussed based on the graphs described above (Fig. 4.1- 4.18). As mentioned earlier, *Miliammina fusca* is the species that showed significant deformation (Fig. 4.19), and so for the purpose of this report, this species will be discussed in detail and not the others. It should be noted that where percentages of *M. fusca* are discussed (both living and total), the values that are not shown that make up the rest of the 100% are accounted for in tables 1-9 in Appendix 1 (such as *Trochammina macrescens f. polystoma*, which occur in large amounts).

4.1.2.1 Treatment A- Control plot with nutrient enrichment (no oil)

- **Number of living individuals and total number of individuals**

Within the three control plots treated with nutrient enrichment and no oil (Treatment A), values for the number of living individuals per 10cc show similar trends (Fig. 4.1-4.3). The number of living individuals increases from values of less than 2000/10cc after the first week in all three plots (1,2, and 3), remaining relatively high until the end of the sampling period (always >3000/10cc by week 22).

In plot 1, the maximum number of living individuals increases to 3000/10cc by week 3 before decreasing slightly to 2500/10cc, then climbs again to a peak of >4000/10cc by week 8. This is followed by another decrease to 2000/10cc by week 10, and then an increase back up to >3000/10cc where it levels out until week 22. The minimum number of living increases more slowly from week 0 to week 8, reaching a peak of 4000/10cc, and then follows the same pattern as the maximum values, with very little variability (Fig. 4.1).

The number of living individuals for Plot 2, Treatment A, (Fig. 4.2) starts off at ~1700/10cc at week 0 and gradually climbs to a maximum value of 3500/10cc by week 5, where it dips down to 2500/10cc before climbing to a peak of ~4200/10cc by week 18, and decreases again by week 22 to ~3800/10cc. Minimum values increase from ~1700 in week 0 to 2500/10cc by week 3, followed by a decrease to <2000/10cc by week 5, after which values increase to 3000/10cc by week 8. Values then decrease again to 1500/10cc by week 14, where they match the increase of maximum values to a peak of ~4000/10cc by week 18. The variability between maximum and minimum values is small. This is the case for the number of living individuals present in plot 3, where there is an increase

from ~1700/10cc in week 0 to a peak of 6000/10cc for minimum values and a peak >8000/10cc for maximum values by week 3. At week 8 there is a low of ~4000/10cc, followed by a gradual increase to ~7500/10cc by week 14, after which values remain stable and high. Very similar trends occur for the total number of individuals per 10cc for each case mentioned above within the three plots (Fig. 4.1-4.3).

- **Percent *Miliammina fusca***

In each plot with Treatment A, there is an increase in both the percent living (L) and total (T) *M. fusca*, following week 0. In Plot 1, maximum values of percent living *M. fusca* climb from <5% to ~27% by week 1, and decrease after week 3 to a low of ~11% by week 10, followed by an increase to ~33% by week 14, after which values decrease to almost 0% by week 22. Minimum values remain quite low, increasing from <5% to ~12% by week 5, after which values decrease to ~5% and remain constant until week 22. Similarly, for the total percent *M. fusca*, values start off at ~15% at week 0 and climb to a maximum value of >30% by week 3, followed by a decrease to ~12% by week 10. There is another peak for maximum values to >30% by week 14, after which values drop off to a low of almost 0 by week 22. Minimum values for total percent *M. fusca* show some variability, where they decrease from ~15% at week 0 to ~2% by week 1, followed by a slight increase to >10% by week 5 and then remain fairly constant at ~5% until week 22.

Of the *M. fusca* present in Plot 1, Treatment A, the percent living deformed (Ld) and total deformed (Td) decreases from 20% and ~7% respectively from week 0 to 0% by week 1 (Fig. 4.1). In both cases, values increase to 7.5% and 5% respectively by week 3, after which there is a decrease until week 8. For percent living deformed, values increase from ~7% at week 8 to a maximum of 10% by week 10, after which values

decline to 0% by week 22. For percent total deformed, values increase to ~4% by week 10, and decline to 0% by week 22 as well. Minimum values in both cases are only slightly variable, and often at 0% (Fig. 4.1-4.3).

Similar to Plot 1, Treatment A, percent living *M. fusca* within Plot 2 increases after week 0, from a low of ~2% to a maximum of ~17% by week 5 (Fig. 4.2). After this, values decrease to ~12% by week 8, followed by another peak of ~17% by week 10, another dip to ~7% by week 14, another peak to ~12% by week 18, and decrease to 5% by week 22. Minimum values are more stable, increasing from ~2% at week 0 to a peak of ~10% by week 3, followed by a steady and gradual decrease to values of ~7% from week 5 to week 10, and to ~4% by week 14.

Percent living deformed (Ld) and total deformed (Td) in Plot 2, Treatment A, of *M. fusca*, increases from 0% after week 1 to a maximum value of 22% and 10% respectively, after which values decrease again to 0% by week 8. In both cases, there is a slight increase by week 10 followed by another decrease to 0% by week 14,after which values increase slightly but remain below 3% until week 22, where they reach 0% again.

Values of percent living and total *M. fusca* within Plot 3, Treatment A, are the most prominent of the three plots, never going below 25% (Fig. 4.3). Percent living increase from 25% at week 0 to >60% by week 5, followed by a slight decrease to 50% by week 10, and another to 40% by week 18, followed by a sharp increase to >60% by week 22. Minimum values are similar, ranging from a low of 25% at week 0 to a high of ~58% by week 3, followed by a decrease to ~35% by week 8, an increase to 50% by week 10 and a decrease to 35% by week 14, increasing again to 40% by week 18.

Figure 4.1 Foraminiferal occurrences for Treatment A (Control plot with nutrient enrichment; no oil), Plot 1, from week 0 to week 22. Solid lines represent maximum values, dashed lines represent minimum values, vertical lines are used to show range between representative samples for each week. L= living, T= total (living plus dead), Ld= living deformed, Td= total (living plus dead) deformed. Note: y-axis scale variable. Percentages appearing along the y-axis for living and total *M. fusca* represent the percentage out of living and total numbers for all species. Percentages appearing along the y-axis for living deformed and total deformed *M. fusca* represent the percentage out of the living and total *M. fusca* only.

Figure 4.1
Treatment A- Control plot with nutrient enrichment (no oil)

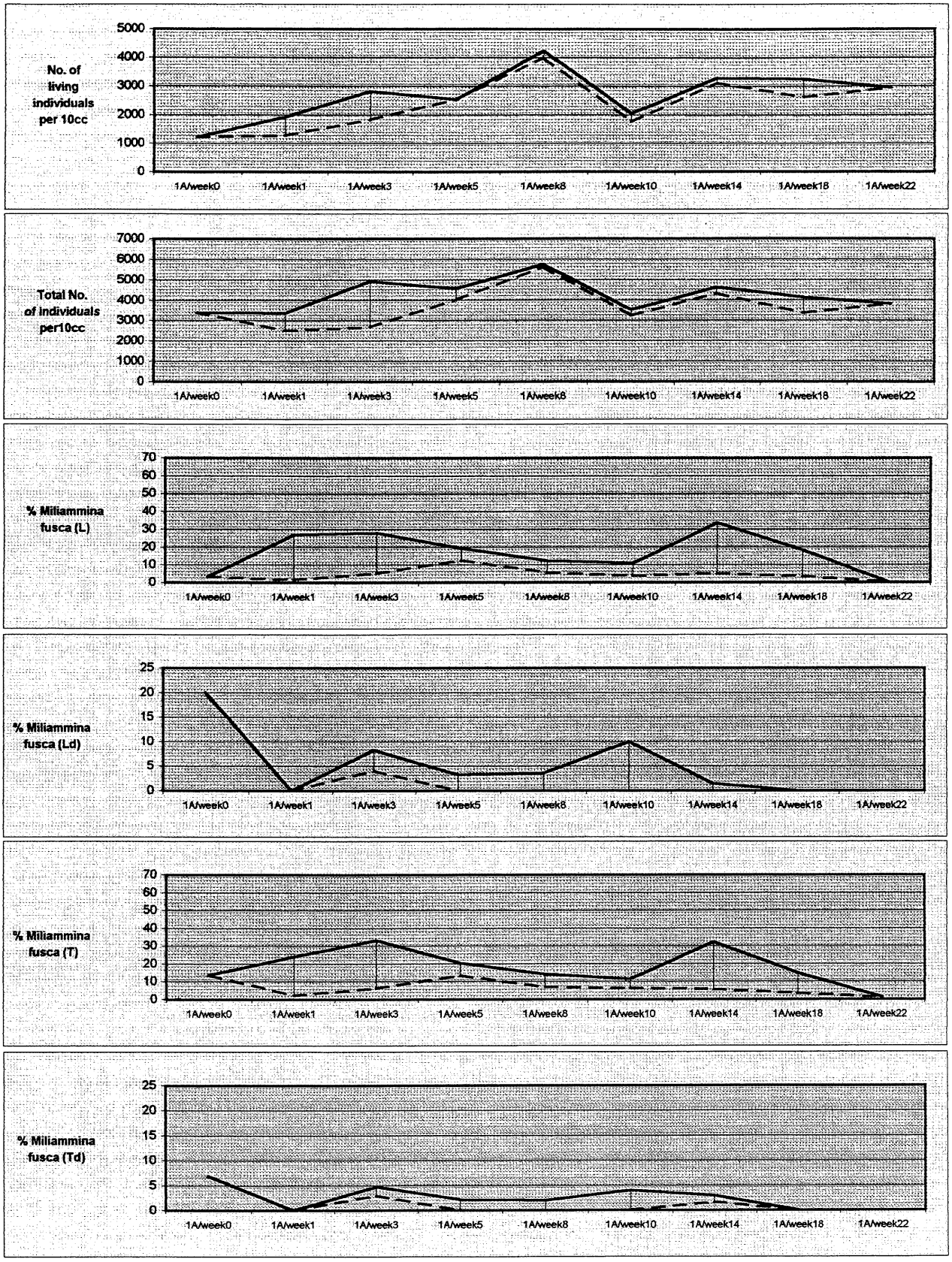


Figure 4.2 Foraminiferal occurrences for Treatment A (Control plot with nutrient enrichment; no oil), Plot 2, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.2
Treatment A- Control plot with nutrient enrichment (no oil)

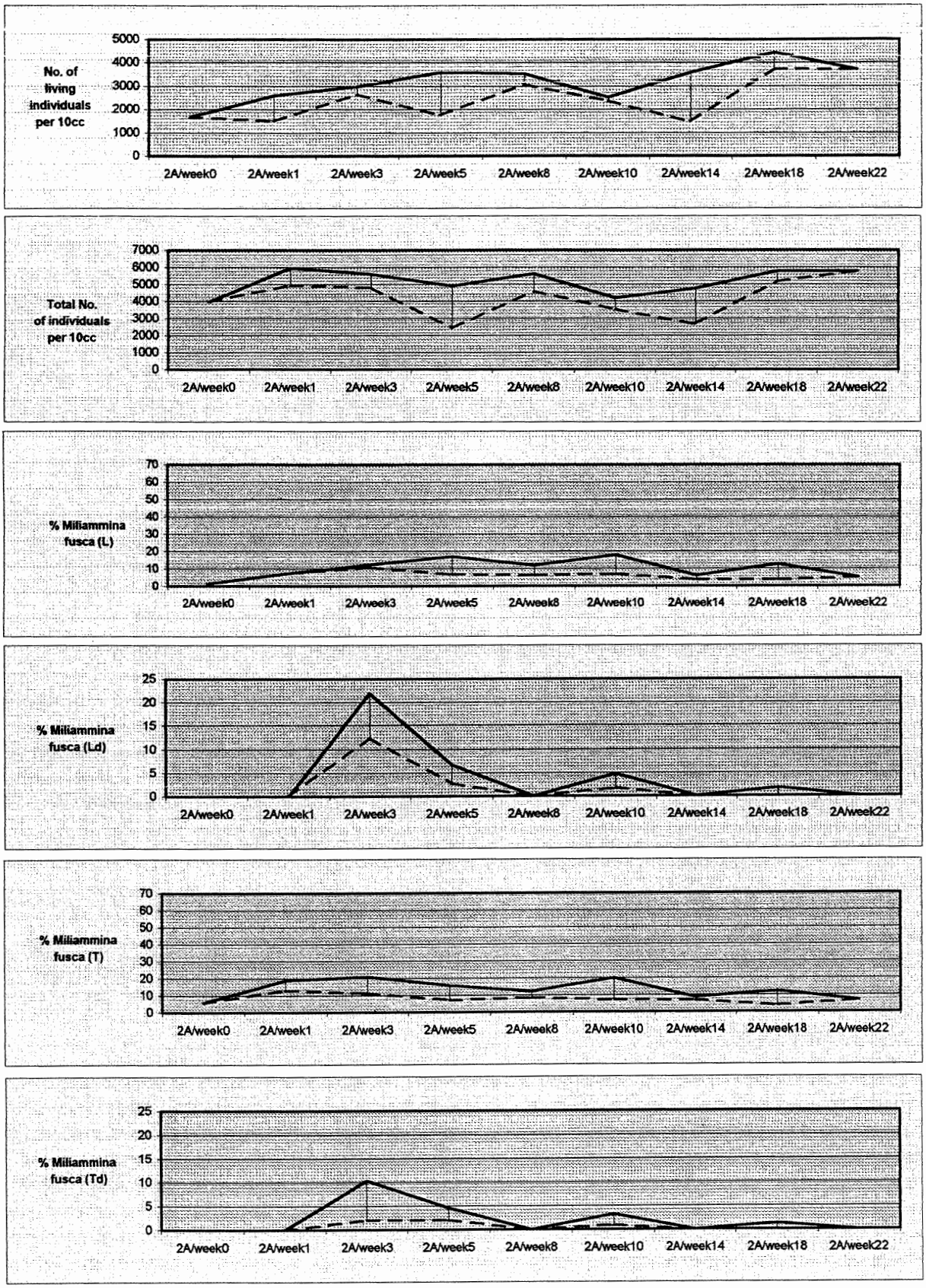
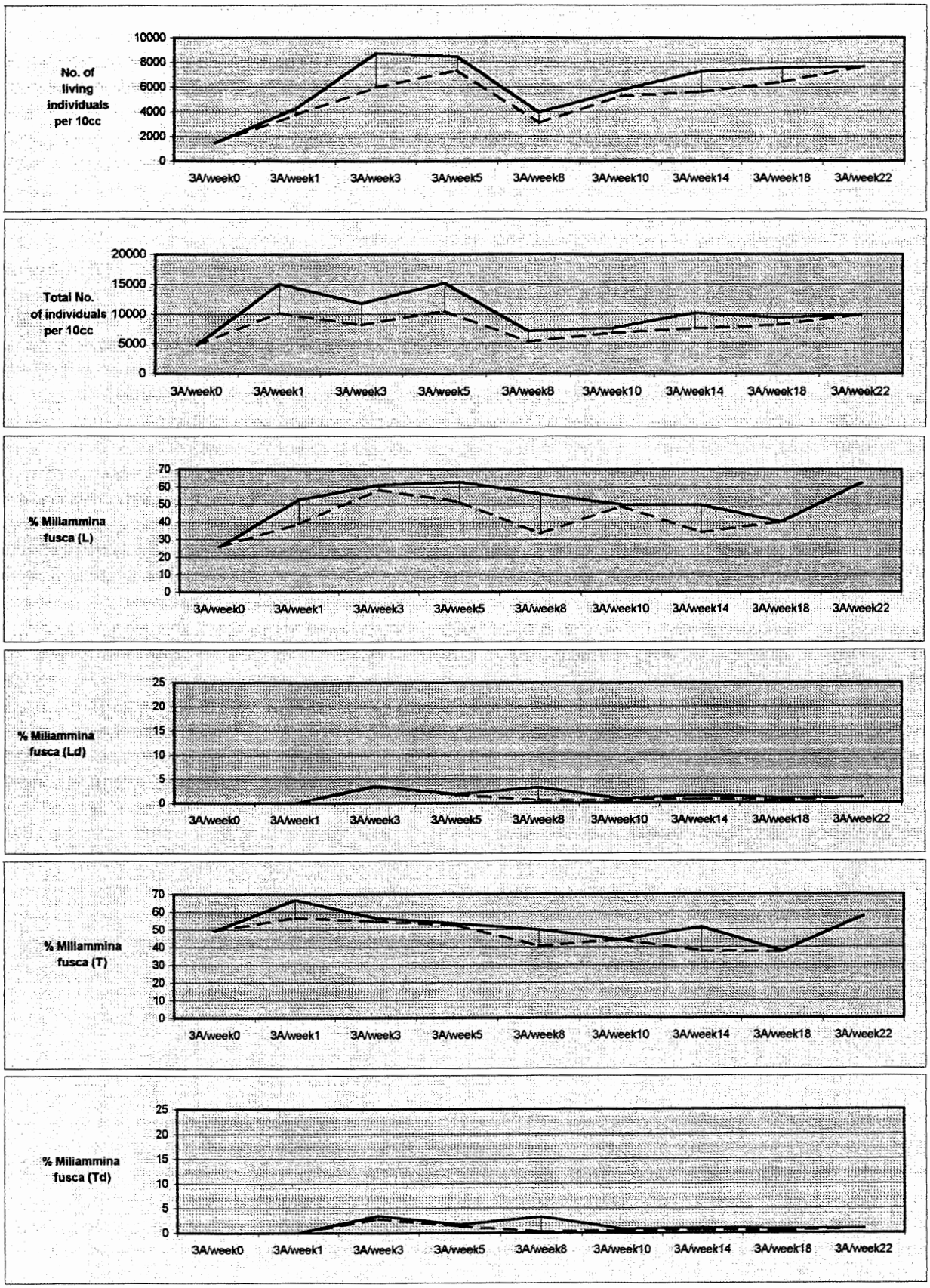


Figure 4.3 Foraminiferal occurrences for Treatment A (Control plot with nutrient enrichment; no oil), Plot 3, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.3
Treatment A- Control plot with nutrient enrichment (no oil)



Percent living deformed (Ld) and total deformed (Td) in Plot 3, Treatment A, of the percentages of *M. fusca* present are very low. Initially at 0%, values increase to a maximum of only 3.5% by week 3 in both cases, and fluctuate up and down between <2% and >3%, until they reach 1% by week 8 and remain fairly constant. In both cases, where there was a peak in maximum values by week 8, minimum values remained quite low (<1%), and are otherwise not variable (Fig. 4.3).

4.1.2.2 Treatment B- Control plot without nutrient enrichment (no oil)

- **Number of living individuals and total number of individuals**

The number of living and the total number of individuals within the three plots without nutrient enrichment and without oil (Treatment B), all show similar results; increasing from low values (~1000/10cc) after week 0 to maximum values of at least 3500/10cc (Fig. 4.4-4.6). In Plot 1, Treatment B (Fig. 4.4), the number of living individuals starts off low (1000/10cc at week 0), and increases to ~3800/10cc by week 8, after which values decrease to ~2200/10cc by week 14, and increase again to a maximum value of 3500/10cc by week 22. Similarly, minimum values increase from 1000/10cc at week 0 and climb to ~2000/10cc and remain constant until week 8 where values peak to ~3200/10cc, and decrease again to a low of 1000/10cc by week 18, increasing to a maximum value of 3500/10cc by week 22. The total number of individuals follows very similar trends, with a range of values between 1500/10cc and 5300/10cc. Variability between maximum and minimum values is fairly significant.

In Plot 2 (Fig. 4.5) of Treatment B, the maximum number of living individuals increases from <1000/10cc to >3000/10cc from week 0 to week 5, and remains constant until week 10, after which values decrease to ~2500/10cc by week 14. This number

remains constant until after week 18, increasing to 4500/10cc by week 22. Minimum values are variable, increasing from ~1000/10cc at week 0 to only ~1500/10cc by week 3, and decrease to 1000/10cc by week 5, then increasing to ~3000/10cc by week 8. After week 8, values decrease gradually to ~1800/10cc by week 14, and remain constant until a peak of 4500/10cc by week 22. The results for the total number of individuals per 10cc follow very similar trends, with a range of values from 1500/10cc to >6000/10cc.

The number of living individuals in Plot 3, Treatment B (Fig. 4.6) increases from 200/10cc to 4000/10cc by week 5, and then ranges between 2800/10cc (week 14) to 4000/10cc (week 18) to 2200/10cc (week 22). Variability between maximum and minimum values is fairly consistent, with a difference of ~800/10cc. The values for the total number of individuals within Plot 3 follow similar trends, increasing from 2000/10cc to 6000/10cc by week 1, after which values remain consistently high at ~5300/10cc until week 10, decrease to ~4200/10cc, and then peak again to 5500/10cc at week 18, declining to ~3200/10cc by week 22. Variability between maximum and minimum values is fairly consistent as well, with a difference of ~ 1500/10cc.

- **Percent *Miliammina fusca***

The percent living (L) *M. fusca* within each of the Treatment B plots is fairly low, at values less than 25%, and showing a slight decrease following week 0, followed by an increase. In Plot 1 (Fig. 4.4), maximum values of percent living *M. fusca* decline from 10% at week 0 to ~6% by week 1, after which they climb to ~14% by week 8, declining again to ~11% by week 10, and then climbing to a maximum value of ~18%. Values decrease again at week 18 to ~12% and then climb again to ~16% by week 22. Minimum values remain quite low, decreasing from <10% at week 0 to ~3% by week 1, then

climbing again to ~11% by week 5, and decline to ~4% by week 10. They remain below 10% until week 18, after which they increase to >15% by week 22. For the total percent *M. fusca* in Plot 1 (Fig. 4.4), values start off at <15% at week 0 and remain constant until week 3, where maximum values increase to 20%, decline again to ~13% by week 8, and climbing back up to a peak at >25% by week 14, followed by a drop to ~12% by week 18. Values increase again slightly to 15% by week 22. Minimum values for total percent *M. fusca* remain fairly low, and range between 5 and 12%.

Percent living deformed (Ld) and total deformed (Td) of overall *M. fusca* present in Plot 1, Treatment B, decrease from 25% and 13% respectively at week 0 to 0% by week 1 (Fig. 4.4). For percent living deformed, values remain at 0% until week 8, when there is an increase to ~22% by week 10, and then a sharp decline to 4% by week 14, and then to 0% by week 18. There is a slight increase in values by week 22, but below 3%. Results for percent total deformed, trends are the same, with the maximum value at week 0 being 13%, and the second peak at week 10 being 8%.

Similar to Plot 1, Treatment B, percent living *M. fusca* within Plot 2 (Fig. 4.5) begin low (<5%), and remain low until week 3 when values climb to a peak of ~12%. After this, values decrease to ~4% by week 14, followed by another peak of ~12% by week 18, and decline again to <5% by week 22. Minimum values are more stable, and remain between 2 and 5%, with a peak of 7% at week 18. Percent total values follow very similar trends, ranging from <5% to ~13%.

Percent living deformed (Ld) and total deformed (Td) of the overall percentage living and percent total *M. fusca* in Plot 2, Treatment B, are fairly low (Fig. 4.5). Values are at 0% until week 1, after which there is an increase to 8% and 5% accordingly. This

peak is followed by a decrease in values in both cases, and by week 8, percent living deformed has reached 0%, increasing again after week 14 to 5% by week 18 and decreasing again to 0% by week 22. Percent total deformed values decrease to 0% by week 10, and increase to ~5% by week 18, and return to 0% by week 22 as well. Variability is small between maximum and minimum values, significant only at the peaks at week 3 and week 18, where minimum values remain at 0%.

Similar to Plot 1 and 2, Treatment B, the percent of living and total *M. fusca* in Plot 3 decreases after week 0, (Fig. 4.6). The values of percent living decrease from <15% to >5% by week 1, and then increase gradually to a maximum value of ~22% by week 18, after which values drop to ~7% by week 22. Minimum values follow a similar pattern, with a range of values between 7-12%, and while the maximum value increases at week 18, the minimum value decreases to ~5%. The percent total trend is similar, decreasing from ~27% at week 0 to ~12% by week 1, then increasing from week 8 to week 14, reaching a maximum value of ~22% before declining to 5% by week 22.

The percent living deformed and percent total deformed of the *M. fusca* present in Plot 3, Treatment B, shows an increase following week 0, and then sharply declines and remains fairly low, until increasing again at week 22. The percent living deformed increases from 0% at week 0 to ~13% by week 1, and then declines to less than 5% for the remainder of the sampling period, with a slight increase at week 22 to 5%. Similarly, the percent total deformed increases from 0 to 7% by week 1, but then remains below 5% for the rest of the weeks, increasing only slightly at week 22.

Figure 4.4 Foraminiferal occurrences for Treatment B (Control plot without nutrient enrichment; no oil), Plot 1, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.4
Treatment B- Control plot without nutrient enrichment (no oil)

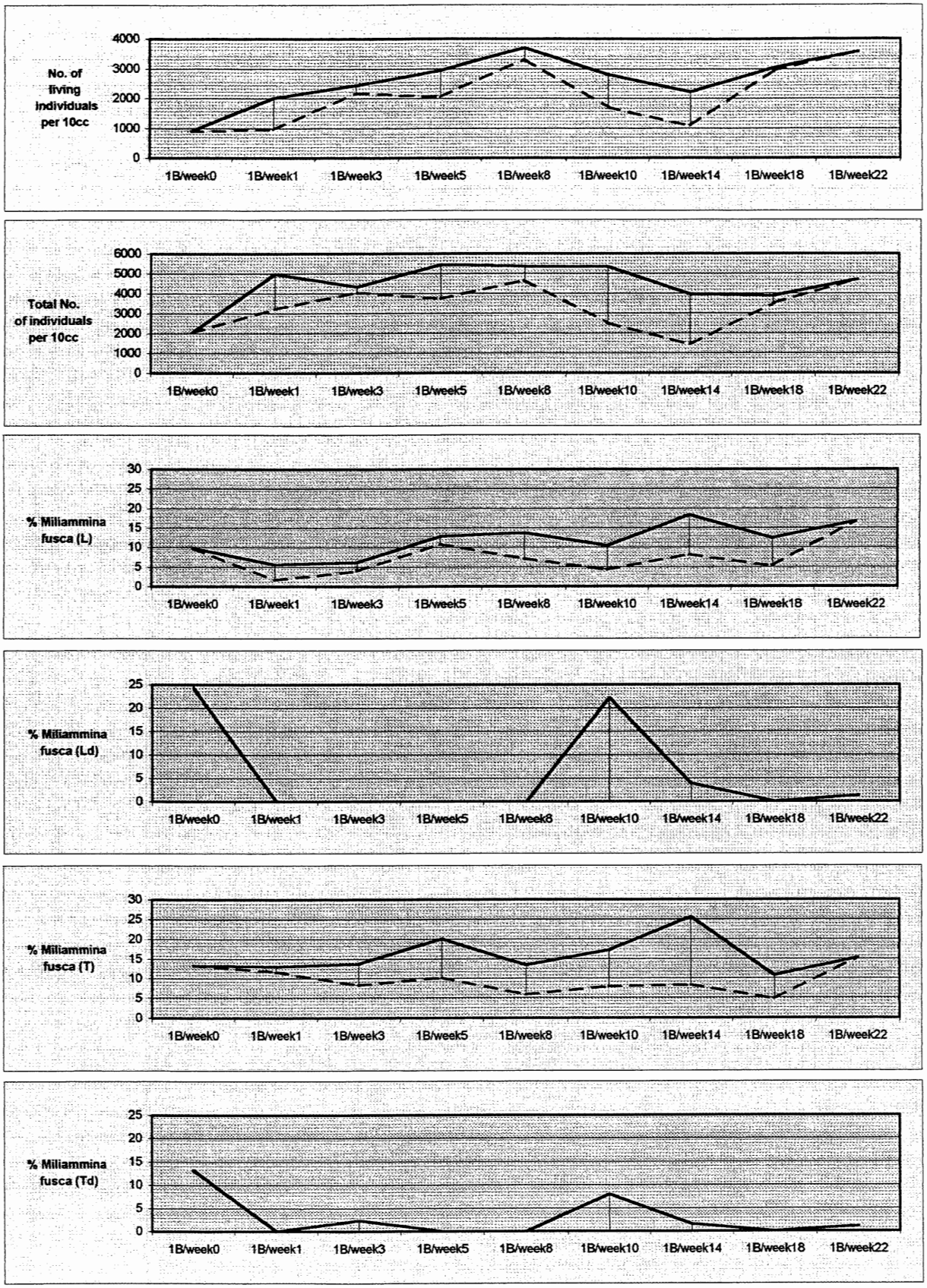
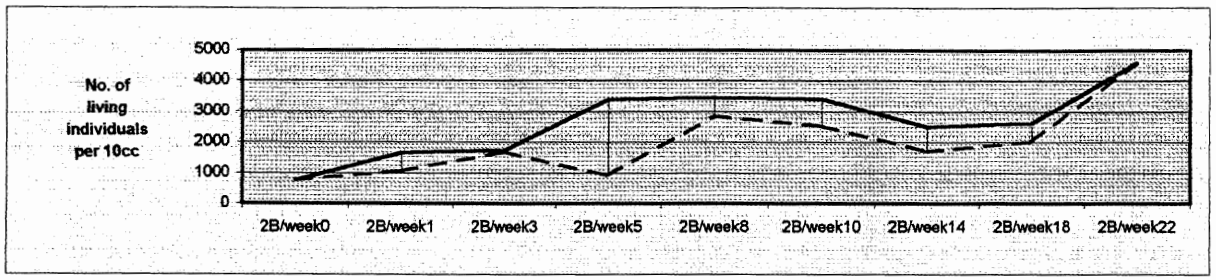
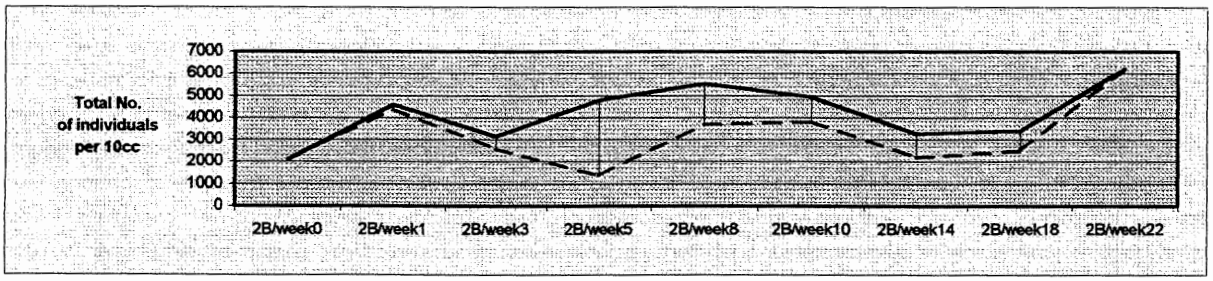
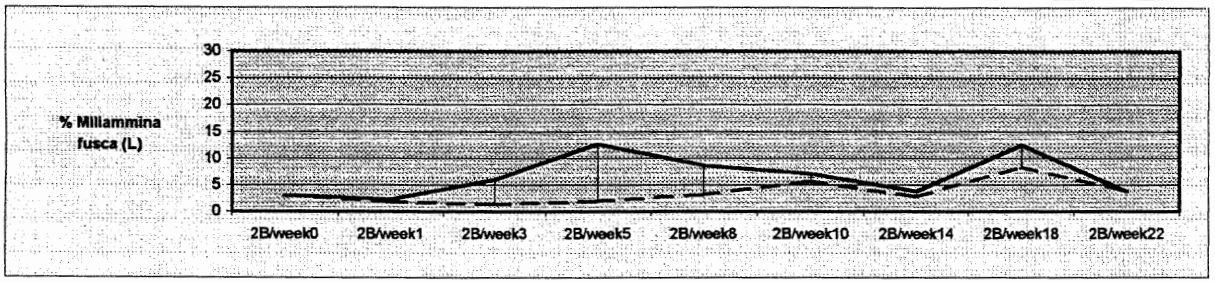


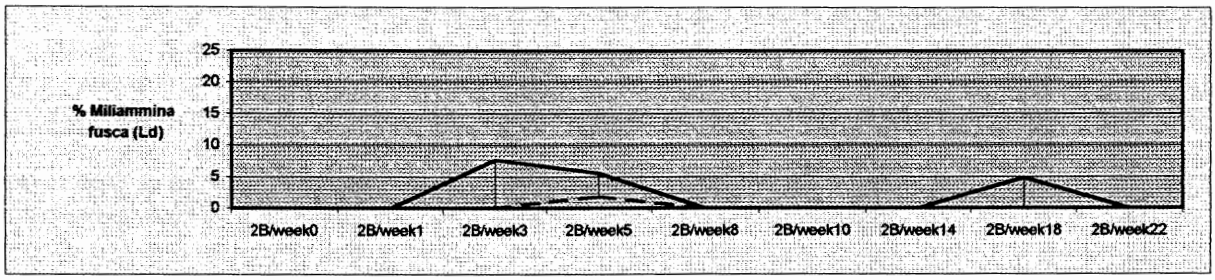
Figure 4.5 Foraminiferal occurrences for Treatment B (Control plot without nutrient enrichment; no oil), Plot 2, from week 0 to week 22. Same format as Figure 4.1.

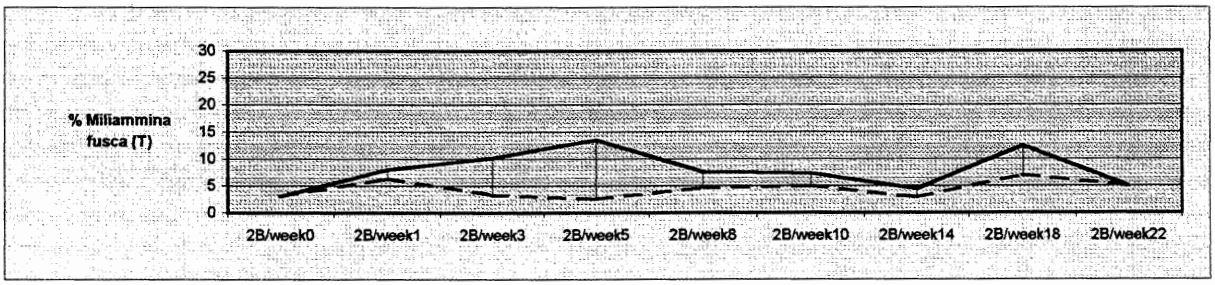
Figure 4.5
Treatment B- Control plot without nutrient enrichment (no oil)











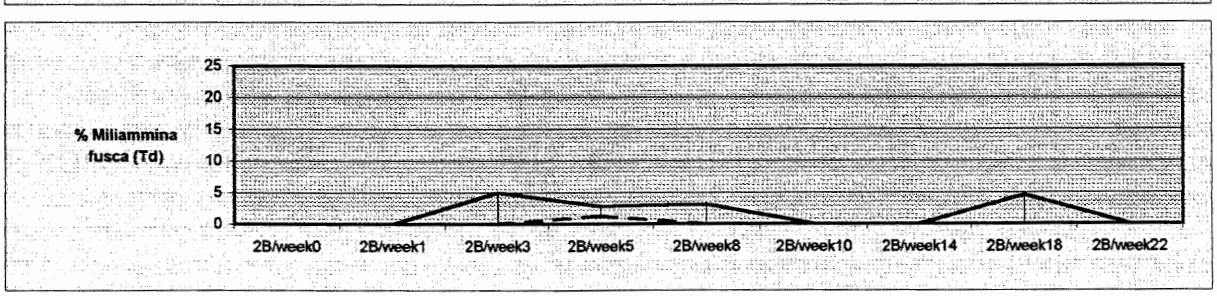
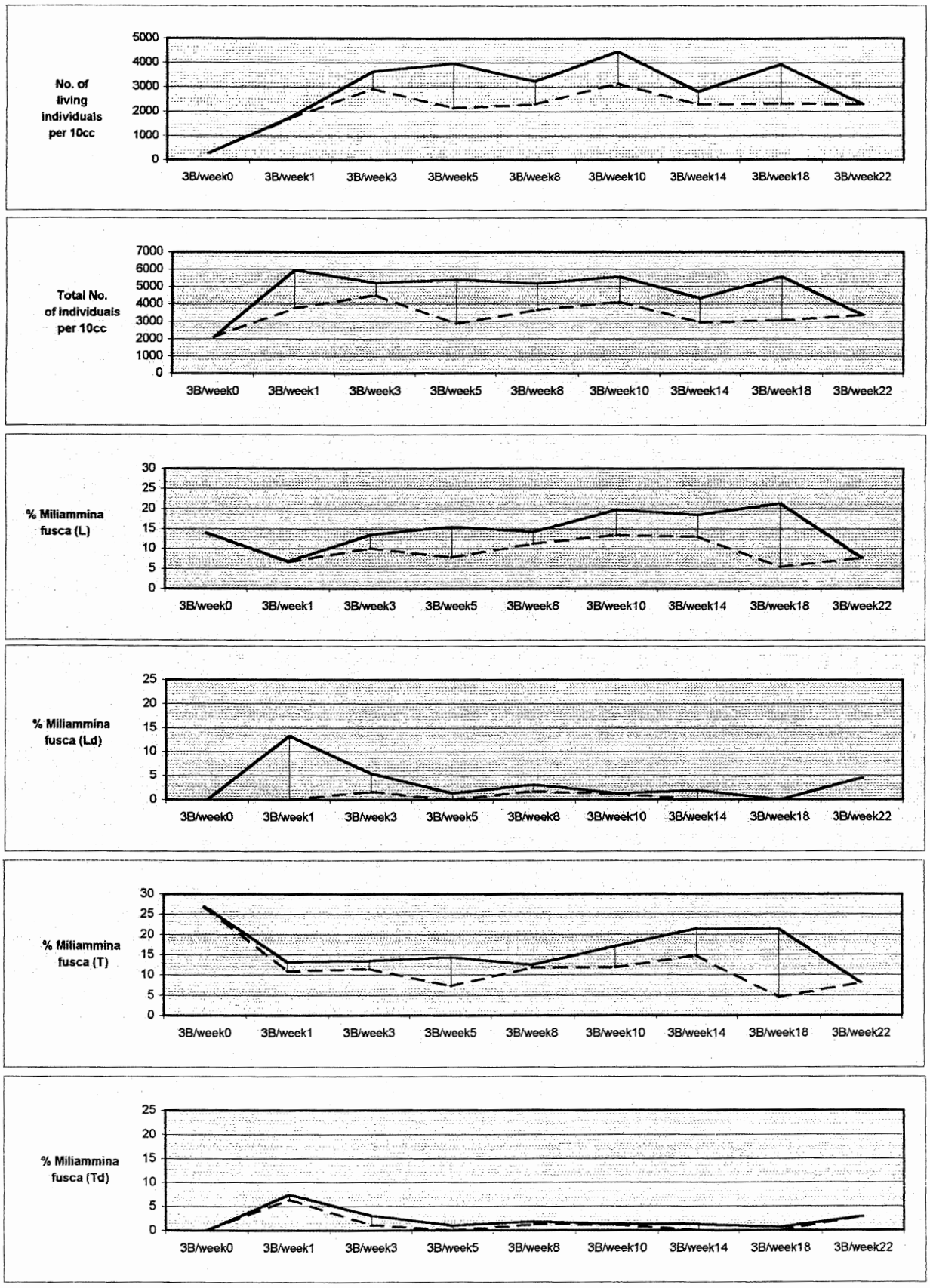


Figure 4.6 Foraminiferal occurrences for Treatment B (Control plot without nutrient enrichment; no oil), Plot 3, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.6
Treatment B- Control plot without nutrient enrichment (no oil)



4.1.2.3 Treatment C – Oiled plot with no treatments (natural attenuation)

- **Number of living individuals and total number of individuals**

The number of living individuals and the total number of individuals within Plots 1,2 and 3 that were treated with Treatment C, all show an increase from the first week, followed by varying degrees of variability (Fig. 4.7-4.9). Within Plot 1, the number of living individuals quadruples from week 0 (<2000/10cc) to week 1 (>8000/10cc), and then reduces by half by week 3 (4000/10cc), after which values remain relatively stable until week 14, where values decrease to ~3000/10cc, and then climb back to ~3800/10cc by week 22. Similarly, the total number of individuals climbs from 4000/10cc in week 0 to >12000/10cc, after which values decrease to ~8000/10cc, where they remain relatively constant until a slight decrease by week 10, and then a slight increase by week 22 (reaching ~9000/10cc). Minimum values are more stable in both cases, and where maximum values reach their peak by week 1, minimum values remain lower, ranging overall between 1000/10cc and 4000/10cc for the number of living individuals, and between <4000/10cc and 8000/10cc for total number of individuals (Fig. 4.7).

For Plot 2, Treatment C, the number of living individuals increases from <1500/10cc to >3000/10cc by week 1, after which values decrease to ~2100/10cc by week 3, climbing again to a maximum of 4500/10cc by week 5. Values then decrease to <3000/10cc, where they plateau until week 18, after which they drop to ~1700/10cc by week 22. At the same time, maximum values for the total number of individuals increase from 3000/10cc to 7000/10cc by week 1, followed by a decline to 3800/10cc by week 3, and then increase to 6000/10cc by week 5. After this, values decrease to 4000/10cc by week 10 and remain relatively constant until a slight decline to ~3800/10cc by week 22.

Variability is greatest at week 1, where maximum values reach a peak of 3000/10cc for living individuals and 7000/10cc for total individuals, and minimum values remain lower at ~1500/10cc and ~3700/10cc respectively (Fig. 4.8).

Plot 3, Treatment C, has the lowest of values within the three plots, but shows similar trends (Fig. 4.9). The number of living individuals increases from 1500/10cc to 3500/10cc by week 3, and decreases to <3000/10cc by week 5, followed by a peak at >4000/10cc by week 8. Following this peak, values decline to ~2000/10cc by week 14, then climb again to >3000/10cc before descending to a low of ~400/10cc by week 22. The total number of individuals follows a similar trend, where the initial value of 4000/10cc increases to 6500/10cc by week 1, and then decreases to <4000/10cc by week 5. This is followed by an increase to 6000/10cc by week 8, and then values decrease to ~3000/10cc before increasing again to ~6000/10cc by week 18, and then decreasing to <4000/10cc by week 22. Minimum values are not significantly variable, except for week 1 for living individuals, where the maximum value climbs to 3000/10cc and the minimum value decreases to 1000/10cc.

- **Percent *Miliammina fusca***

The percentage of *M. fusca* (living and total) within the three plots treated with Treatment C is fairly significant, but most noticeably within Plot 1. In each of the plots, percentages (living and total) are markedly high. In Plot 1, maximum values start off fairly high, at 55% for percent living and 65% for percent total, decreasing to a low by week 3 at 25% and 35% respectively, while minimum values go as low as 15% and 20%. These values increase to a peak at week 5, with a maximum value of ~47% for percent living and percent total, followed by another decrease to a new low by week 10, at ~25%

in both cases (Fig. 4.7). Values increase again to a maximum value of 45 for percent living and >55% for percent total by week 18, after which values decrease to 15% for percent living and <35% for percent total.

The percent of living deformed (Ld) and total deformed (Td) of the living and total *M. fusca* within Plot 1, Treatment C, both follow a similar trend. Starting off well below 10%, both maximum curves increase to 40% by week 1. After this, values decrease to a maximum value of 15% and a minimum value of ~2% within the percent living deformed by week 5. Values rise again to a maximum of ~22% by week 10, declining to 10% by week 14, rising again to 25% by week 18, and decreasing to <10% again by week 22. After the peak in week 1 in percent total deformed, values decrease to ~15% and remain fairly consistent until a slight decrease at week 14 (10%), and then a small increase to 13% by week 18, decreasing again to 5% by week 22.

Values of percent living and percent total *M. fusca* within Plot 2 (Fig. 4.8) and Plot 3, Treatment C, are lower than those in Plot 1. Starting off at >10% in week 0, values for percent living in Plot 2 increase to a maximum of >20% by week 5, and then decrease to ~12% by week 8, after which values climb and plateau at 15% until a slight increase at week 17% for maximum values, and a slight decrease for minimum values of <10%, reaching 12.5% by week 22. For percent total in Plot 2, values decrease from week 0 (23%) to ~12% by week 8 and remain low (between 10 and 20%) through to week 22.

Again, percent living deformed and percent total deformed *M. fusca* within Plot 2 increase from low values to a maximum value by week 1, followed by a decline. For percent living deformed, values start at 10% and reach a high of 45% by week 1,

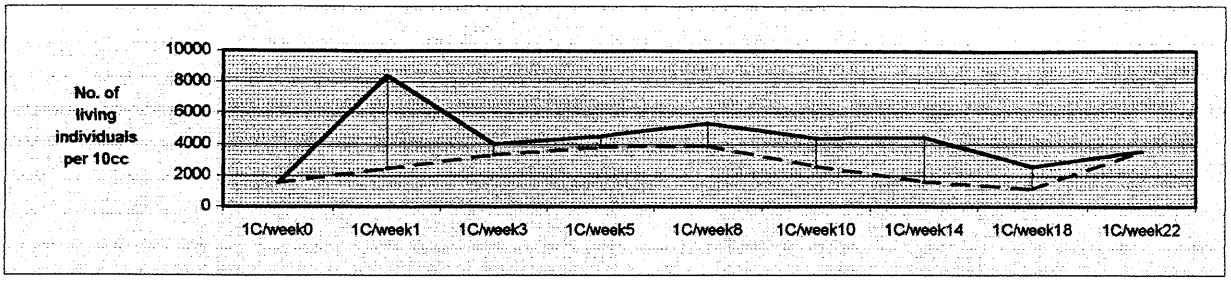
dropping down to 15% by week 3, and then stabilizing between 12 and 22% until week 18, where minimum values reach 0% and maximum values climb to 35% by week 22. Percent total values also increase, from 5% to 30% by week 1, and then decrease and remain between 5 and 18% for the remainder of the sampling period (Fig. 4.8).

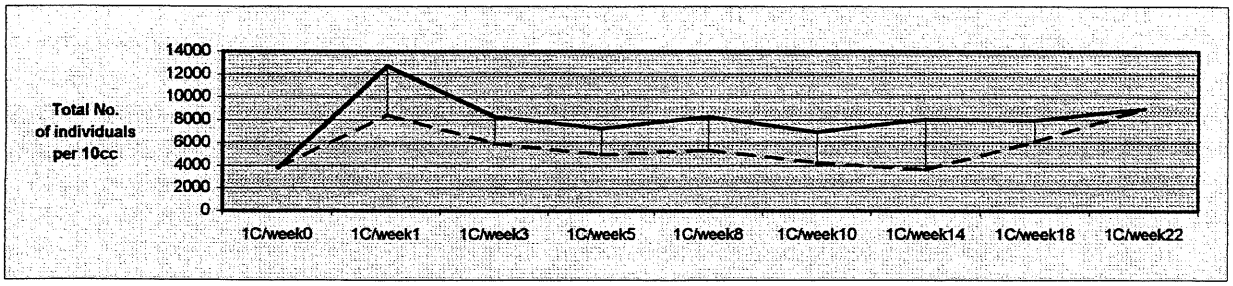
Within the third plot, Treatment C (Fig. 4.9), the maximum values for percent living *M. fusca* increase from 15% at week 0 to 27% by week 8, and then decline to 15% by week 10, before peaking again to ~27% and then decreasing to a low of ~7% by week 22. Minimum values are more variable, whereby they decrease from week 0 to a low of <5% by week 1, and then slowly climb to reach 15% by week 10 and 14, decreasing again by week 18. The percent total values start off fairly high (33%) and decline to ~15% (or a minimum of 5%) by week 3, after which values climb again to reach a maximum of 25% and a minimum of 10% by week 8, and maximum values decrease again to 12% by week 10. Following this, values increase to >25% by week 14, decline again to 12% by week 18, and then increase to a maximum of 37% by week 22.

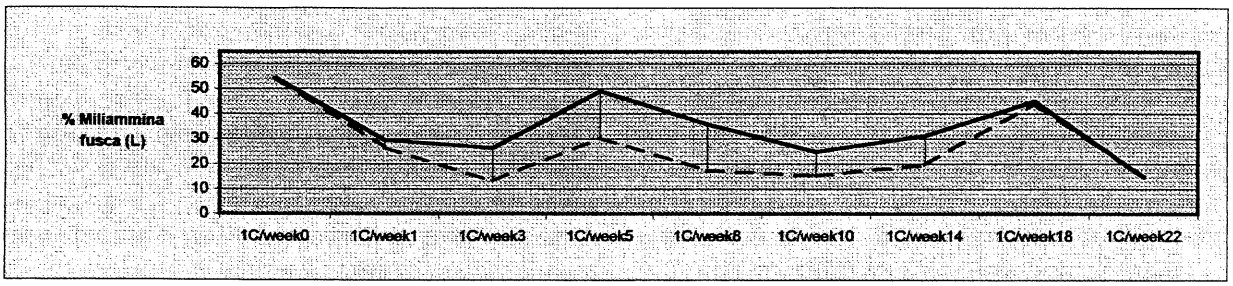
Percent living deformed and percent total deformed *M. fusca* within Plot 3, Treatment C, are variable. Values for percent living deformed start at 0% and increase to 25% by the first week, after which they decrease to 5% by week 3 and remain between 5 and 15% until a significant increase to 50% by week 22, similar to that of the peak in week 22 within the percent total *M. fusca*. On the other hand, while percent total deformed values start off at 0% and increase to 20% by week 1, they decline to 5% by week 3, and then increase again to >20% by week 5, decreasing again to <5% by week 10. There is another peak in values at week 14 (to 15%), followed by a decrease in values to almost 0% by week 22.

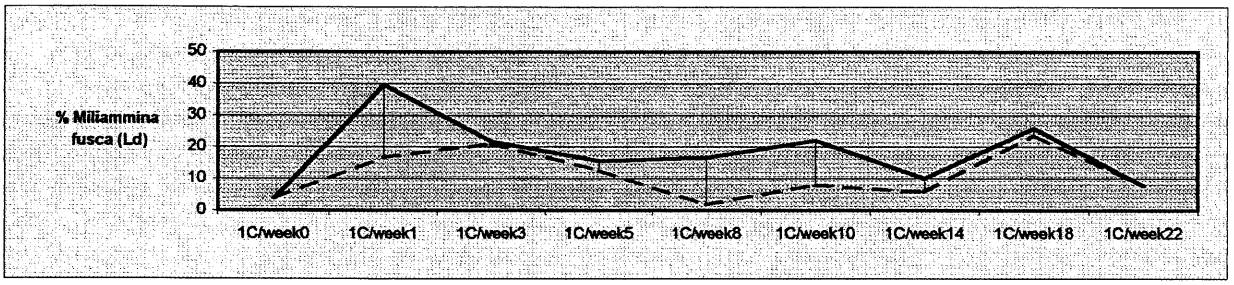
Figure 4.7 Foraminiferal occurrences for Treatment C (Oiled plot without treatments; natural attenuation), Plot 1, from week 0 to week 22. Same format as Figure 4.1.

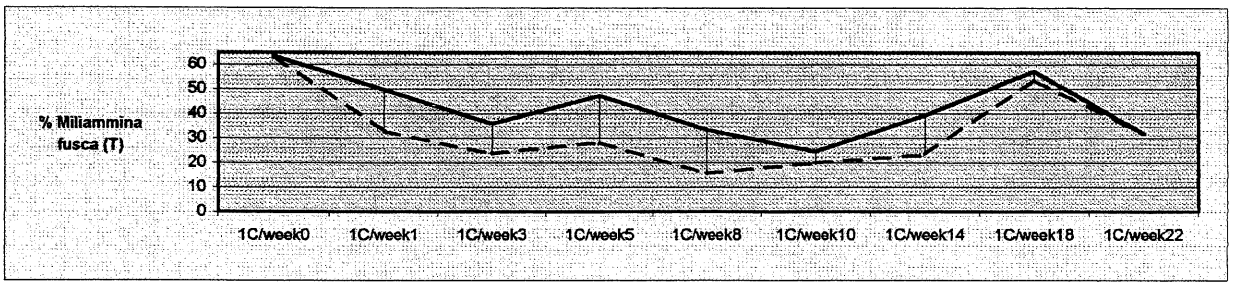
Figure 4.7
Treatment C- Oiled plot without treatments (natural attenuation)











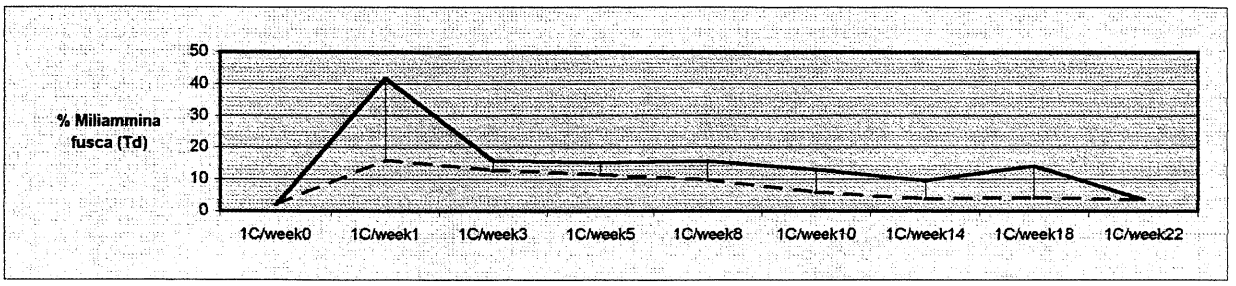


Figure 4.8 Foraminiferal occurrences for Treatment C (Oiled plot without treatments; natural attenuation), Plot 2, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.8
Treatment C- Oiled plot without treatments (natural attenuation)

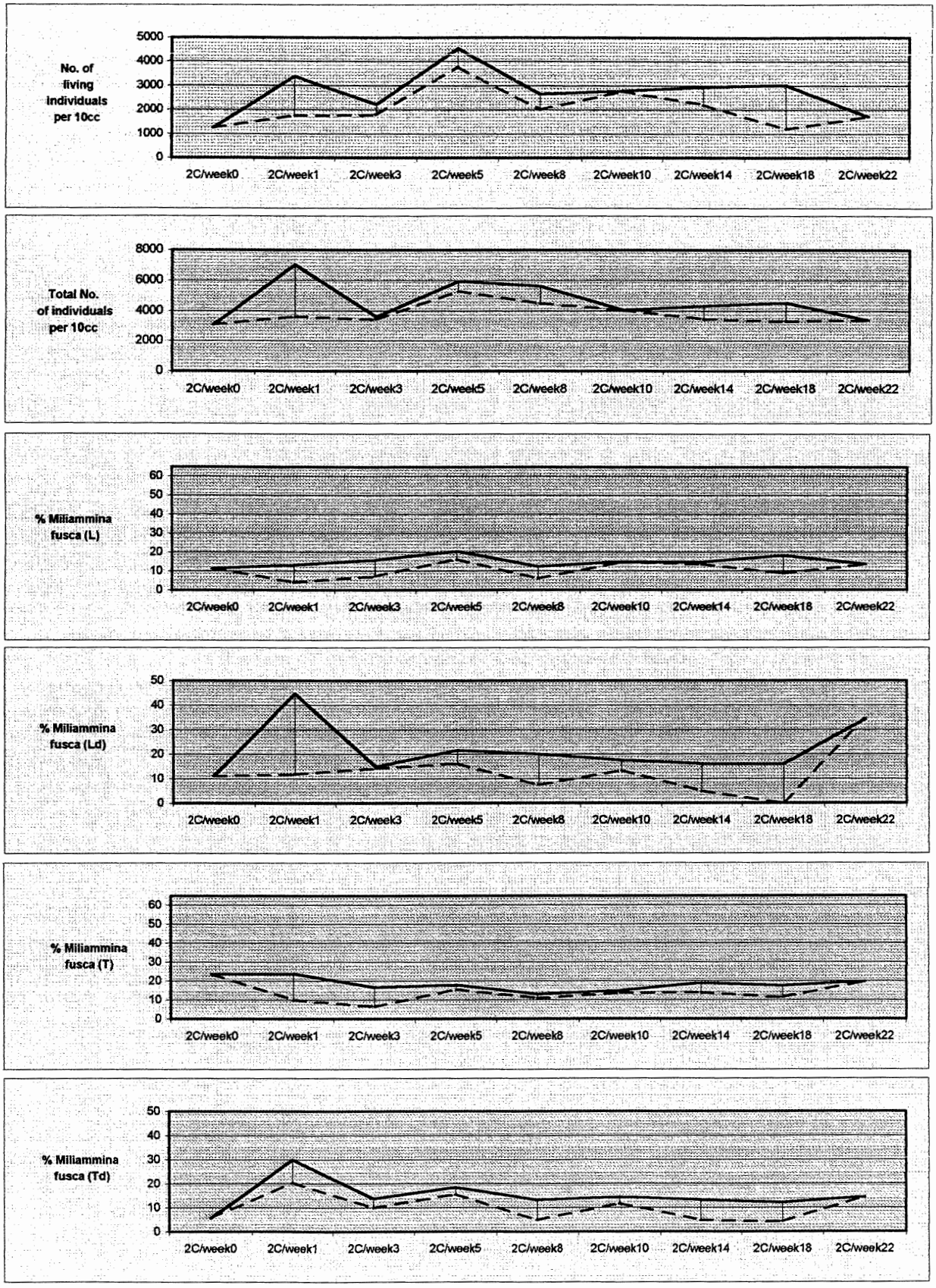
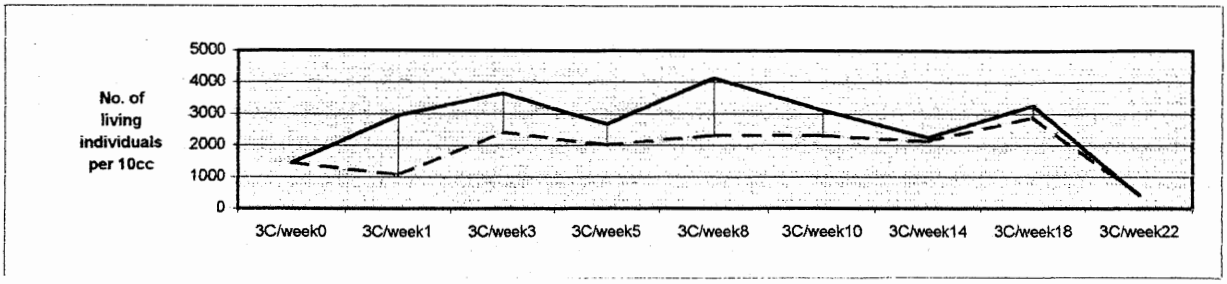
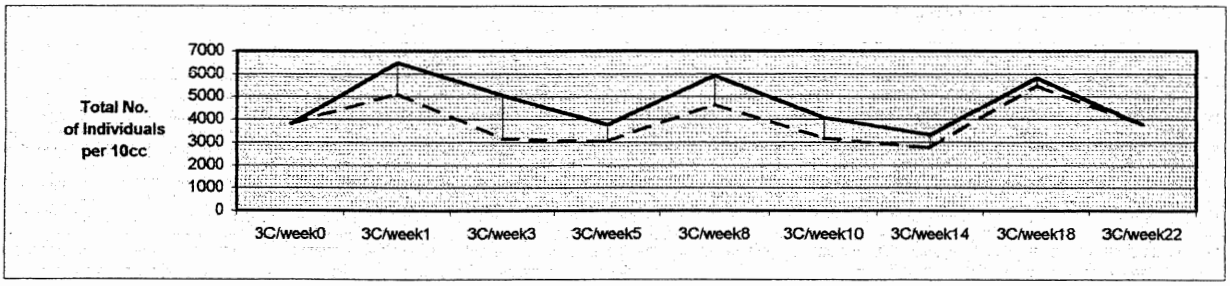
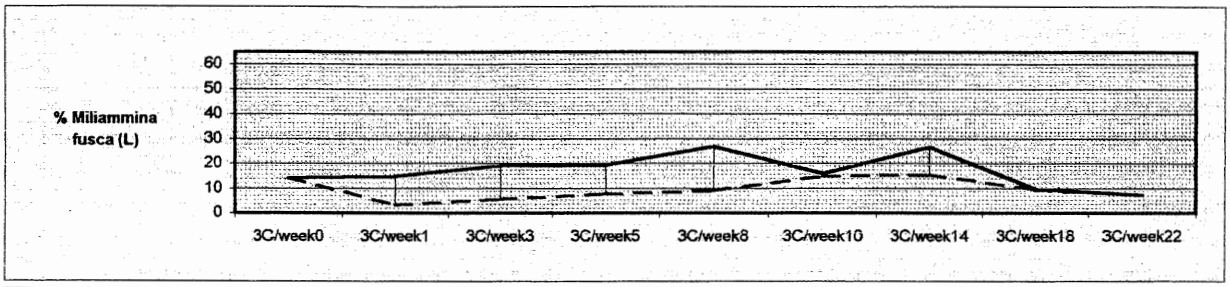


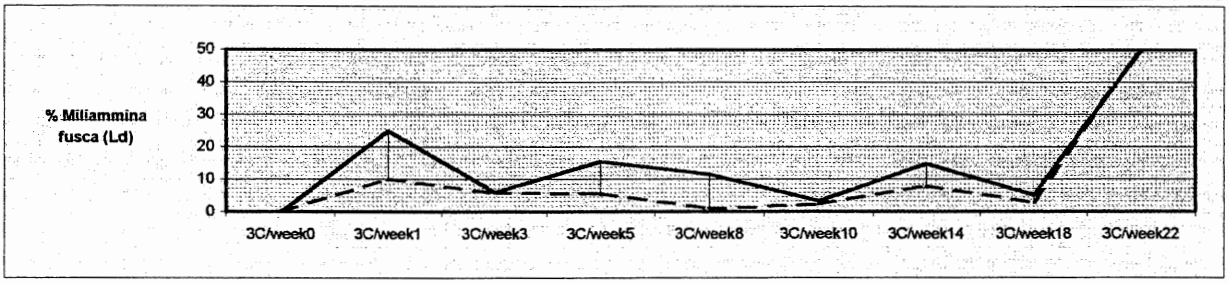
Figure 4.9 Foraminiferal occurrences for Treatment C (Oiled plot without treatments; natural attenuation), Plot 3, from week 0 to week 22. Same format as Figure 4.1.

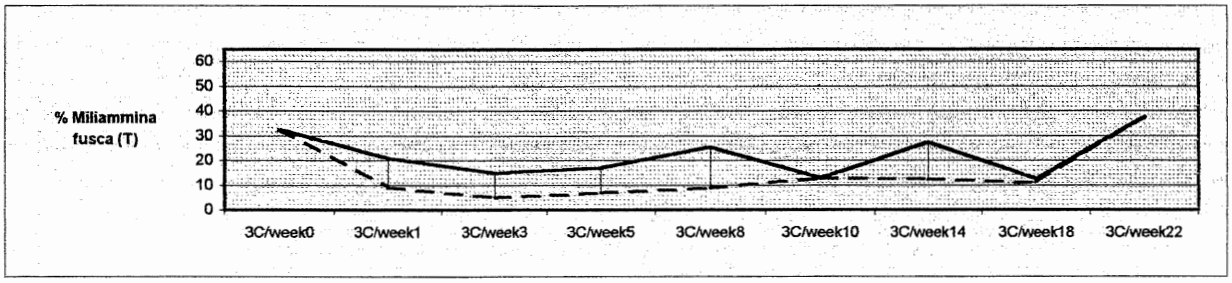
Figure 4.9
Treatment C- Oiled plot without treatments (natural attenuation)

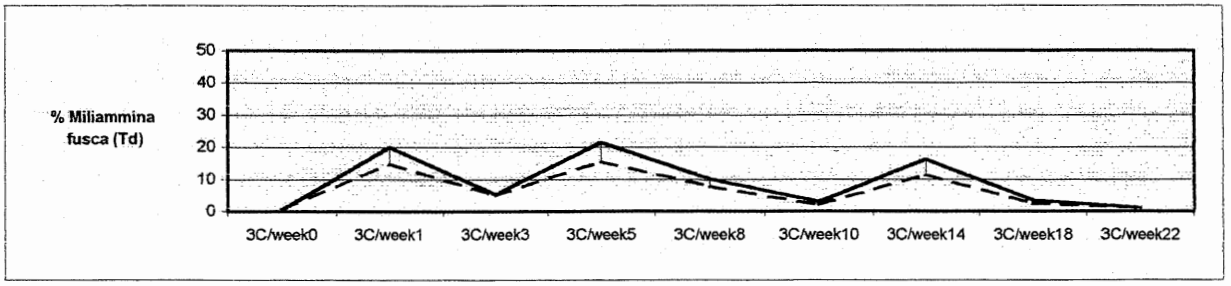












4.1.2.4 Treatment D- Oiled plot with nutrient enrichment

- **Number of living individuals and total number of individuals**

The number of living individuals and the total number of individuals within plots 1, 2 and 3 with Treatment D (oiled plot with nutrient enrichment), have fairly high values, ranging from ~500/10cc to >5000/10cc living and total (Fig. 4.10-4.13). In Plot 1, Treatment D, maximum values of living individuals increase from 750/10cc to 2200/10cc by week 1, and then decline to almost half by week 3 (1300/10cc), while minimum values remain quite low (500/10cc) until week 5, where they double to 1000/10cc. Values then decrease again to <500/10cc by week 10, rising to >1000/10cc by week 14 and then to 2300/10cc by week 22. Maximum values increase from 1300/10cc to 1600/10cc by week 5, and then decline to ~800/10cc by week 8, doubling to 1600/10cc by week 10, and then decreasing to 1000/10cc by week 18. There is a peak by week 22 to 2300/10cc. The total number of individuals for Plot 1 show very similar trends, starting off at ~1500/10cc at week 0, and peaking to a maximum of 4200/10cc by week 1 (minimum values remain low at ~1500/10cc), reaching the second peak by week 22 of 4000/10cc.

Within Plot 2, Treatment D, values increase more gradually from week 0 (Fig. 4.11). The maximum number of living individuals increases from >1000/10cc to >3500/10cc by week 5, and then decreases to 2200/10cc by week 10, climbing to a second peak by week 18 (<3000/10cc), before decreasing to ~1200/10cc by week 22. Minimum values are more stable, increasing only slightly, and remaining between 1700-2000/10cc for most of the sampling period. Values for the total number of individuals also increase from week 0 to week 3 (<3000/10cc to >5000/10cc), decreasing at week 5

to 4000/10cc, and then increasing to 5000/10cc by week 8. Values decrease again to 3000/10cc by week 10, and then gradually increase to 4500/10cc by week 18, where they level off, not showing the decrease at week 22 for the number of living individuals.

Within Plot 3, Treatment D, values are more variable (Fig. 4.12). Starting off at 500/10cc at week 0, the maximum number of living individuals increases to ~2700/10cc by week 3, where they plateau until after week 5, decreasing to ~1500/10cc by week 8. Values climb again to ~2700/10cc by week 10, then fall to ~1200/10cc by week 14, and slowly rise to <2000/10cc by week 22. Minimum values are less variable, increasing from week 0 to only ~2000/10cc by week 5, and remaining between <1000/10cc and 1500/10cc. The maximum values for the total number of individuals increase from 1000/10cc at week 0 to 4000/10cc by week 1, where they plateau until week 14, after which values decline to ~2000/10cc, climbing again to 3000/10cc by week 22. Minimum values are also stable, remaining between 1500 and 2500/10cc for the duration of the time.

- **Percent *Miliammina fusca***

Values for percent living and percent total *M. fusca* present in Plots 1, 2 and 3, Treatment D, are variable, showing different trends relative to each other, but each containing a fairly significant amount of deformities. Within Plot 1, Treatment D, values for both percent living and percent total show a steady increase from week 0 to week 22. In both cases, maximum values start at almost 0% and climb to ~20%, where they increase very gradually to ~30%, declining slightly at week 14 for percent living and at week 18 for percent total, before peaking to ~40% by week 22. Minimum values follow a similar trend, ranging between ~2-12%.

The percent living deformed and percent total deformed of the *M. fusca* within Plot 1, Treatment D, also increases after week 0, and then becomes more stable (Fig. 4.10). Maximum values in both cases increase from 0% at week 0 to >20% by week 1, then remain between 18 and 22% until week 8, after which values decrease to ~10% by week 10 and week 14. This decrease is followed by an increase to ~25% by week 18, and then a decrease to <10% by week 22, where there had been a peak for the percent living and percent total *M. fusca*. Minimum values are more variable, ranging between 0 and 20%, with an average difference of ~10% between the maximum values (Fig. 4.10).

Within Plot 2, Treatment D, results are more variable (Fig. 4.11). The values of percent living *M. fusca* start off at ~15% at week 0, and maximum values increase to ~40% by week 3, start to decline again after week 8 to ~22% by week 14, increasing to >30% by week 18, before decreasing again to ~15% by week 22. Minimum values decrease from week 0 to ~5% by week 1, before increasing to >20% by week 3, where they remain relatively stable until decreasing to ~10% by week 14. The percent total *M. fusca* is different in that both maximum and minimum values decrease from week 0 (<40%) to a minimum of 15% by week 1, and a maximum of ~35. Values then increase to a minimum of ~28% and a maximum of ~45%, before declining again to a low by week 14 (minimum of ~11% and maximum of ~28%). Maximum values increase again by week 18 to ~35%, before decreasing to ~25% by week 22, similar to the dip displayed by percent living *M. fusca*.

Percent living deformed and percent total deformed within *M. fusca*, Plot 2, Treatment D, is fairly high, with maximum values remaining above 10% (Fig. 4.11). For both percentages, values increase from 0% at week 0 to ~25% by week 1, after which

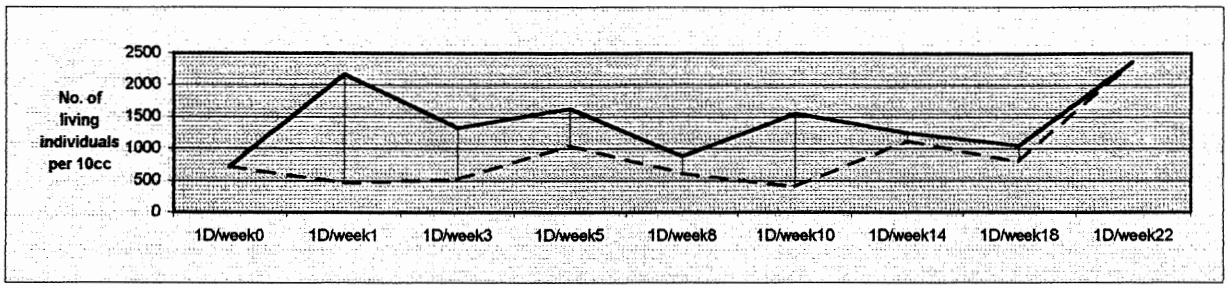
values decrease and remain between 18-22% until week 8, after which values decrease further. For percent living deformed, values decline to ~12% by week 10, then increase to~17%, decrease again, and then increase to a significant peak of ~27% by week 22. The variability between maximum and minimum values is fairly significant, with an average difference of ~10%. For percent total deformed, after week 8, values decline consistently to <10% by week 18 and level out. In this case, there is less variability between maximum and minimum values.

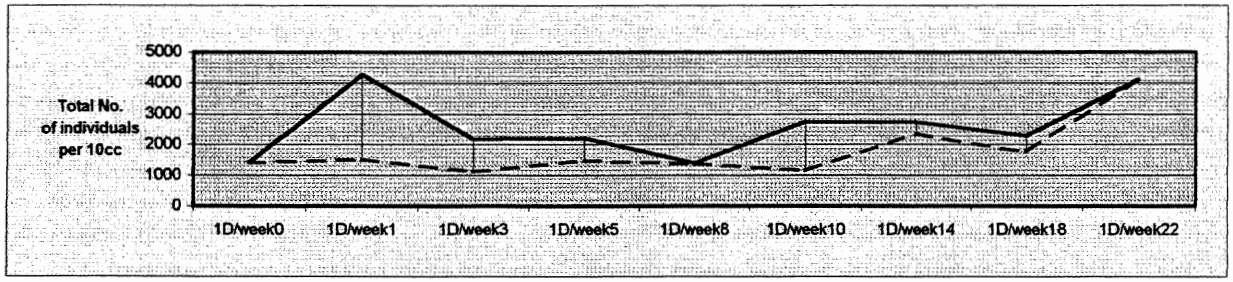
Values for percentages of *M. fusca* within Plot 3, Treatment D, are different still (Fig. 4.12). The percent living starts off at <20% and decreases to ~10% by week 1. Maximum values then climb to >25% by week 3 and fluctuate between 20 and 25% until reaching a low of ~12% by week 10. This is followed by an increase to a maximum of >30% by week 14, dropping again to ~17% by week 18, and then climbing back up to ~25% by week 22. Minimum values are much more stable, and after week 3, climb very gradually to 15% by week 14, then drop to <10% by week 18, climbing back up by week 22.

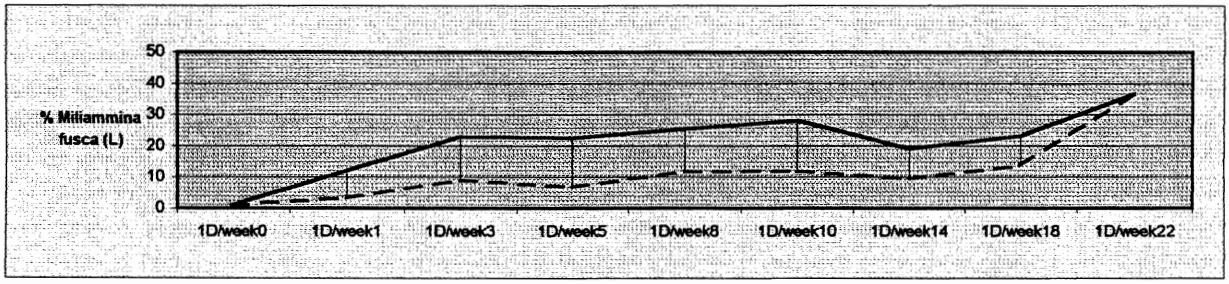
The total percent *M. fusca* for Plot 3 starts off at >20%, and maximum values remain around 20% until after week 5, where values increase to >35%, then decline again to a low of 10% by week 10. Values increase again to ~30% by week 14, decreasing to ~15% by week 18, and then climb again to >20% by week 22. Minimum values decrease after week 0, reaching ~5% by week 3, and increasing after week 5 to 15% by week 8, after which they decrease to <10% before climbing again to ~30% by week 14, and similar to the maximum values, decreasing to 10% by week 18 before climbing back up to >20% by week 22.

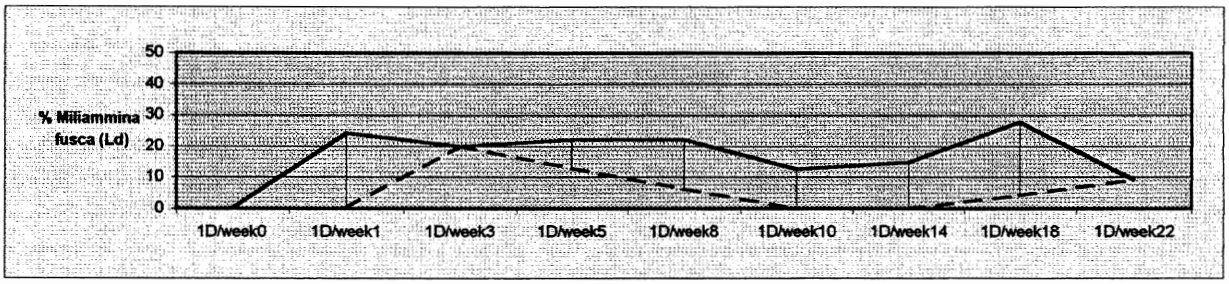
Figure 4.10 Foraminiferal occurrences for Treatment D (Oiled plot with nutrient enrichment), Plot 1, from week 0 to week 22. Same format as Figure 4.1.

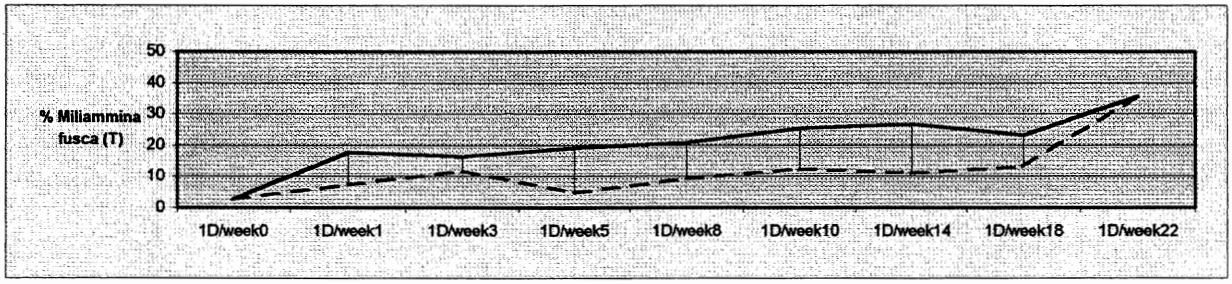
Figure 4.10
Treatment D- Oiled Plot with nutrient enrichment











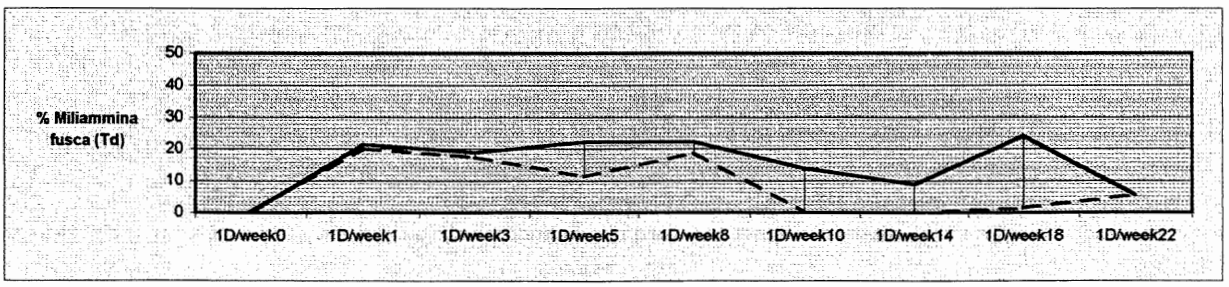
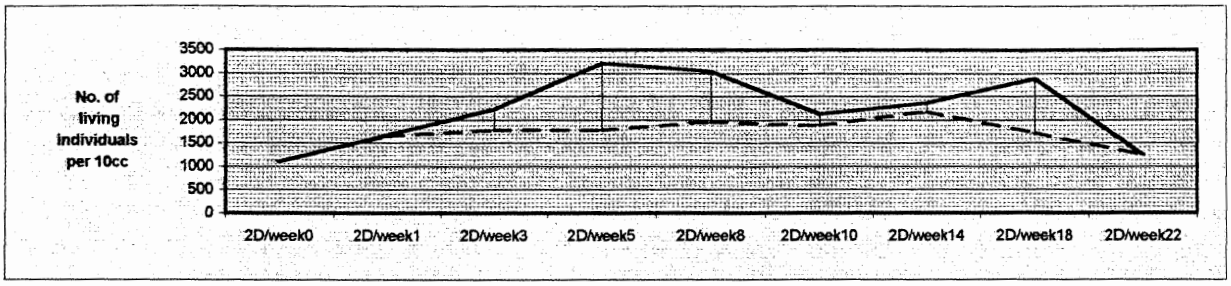
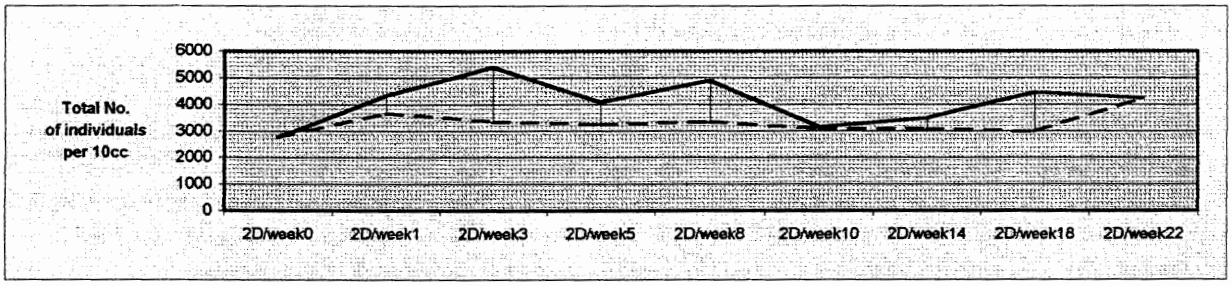
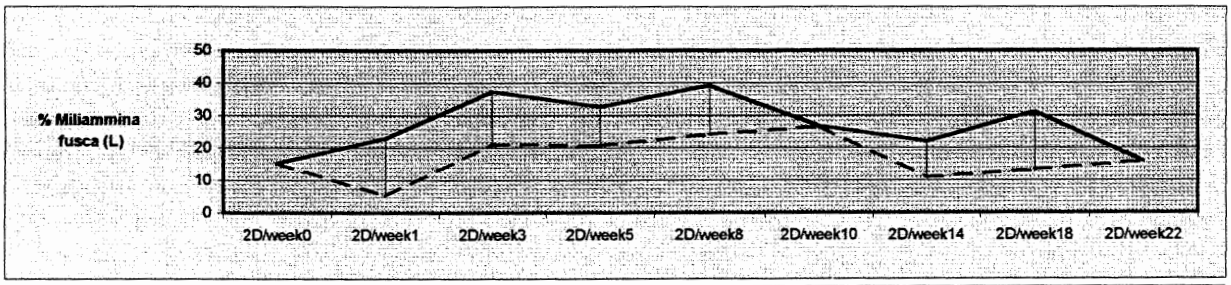


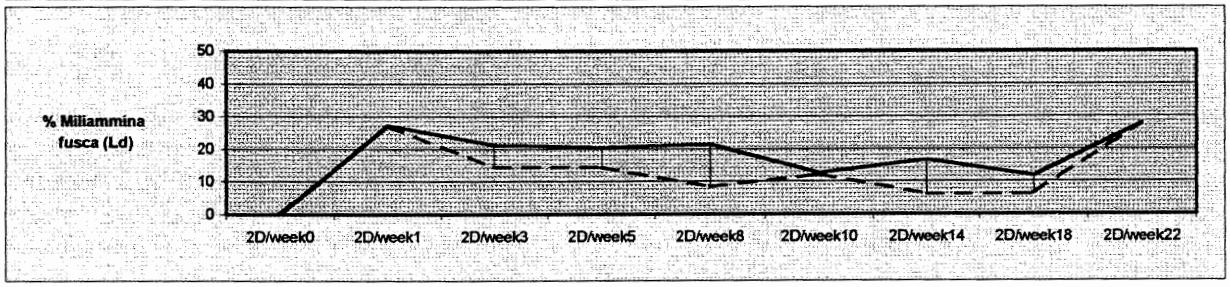
Figure 4.11 Foraminiferal occurrences for Treatment D (Oiled plot with nutrient enrichment), Plot 2, from week 0 to week 22. Same format as Figure 4.1.

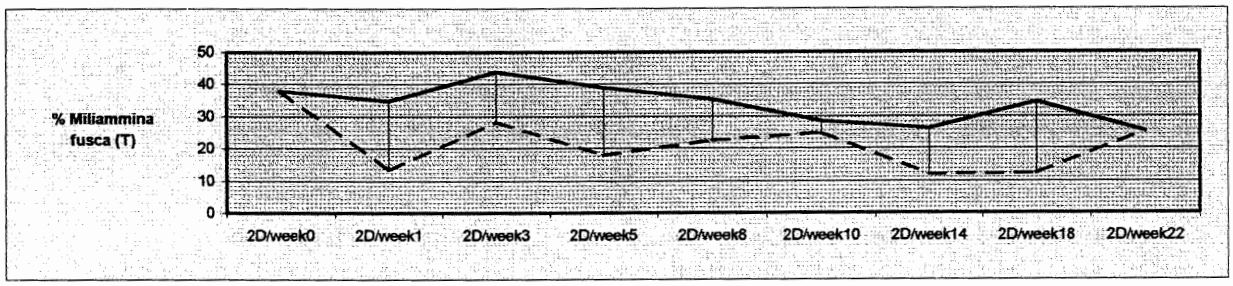
Figure 4.11
Treatment D- Oiled plot with nutrient enrichment











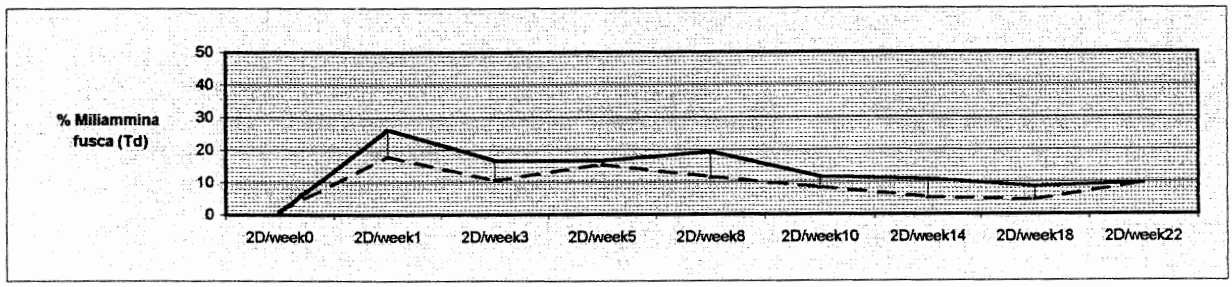
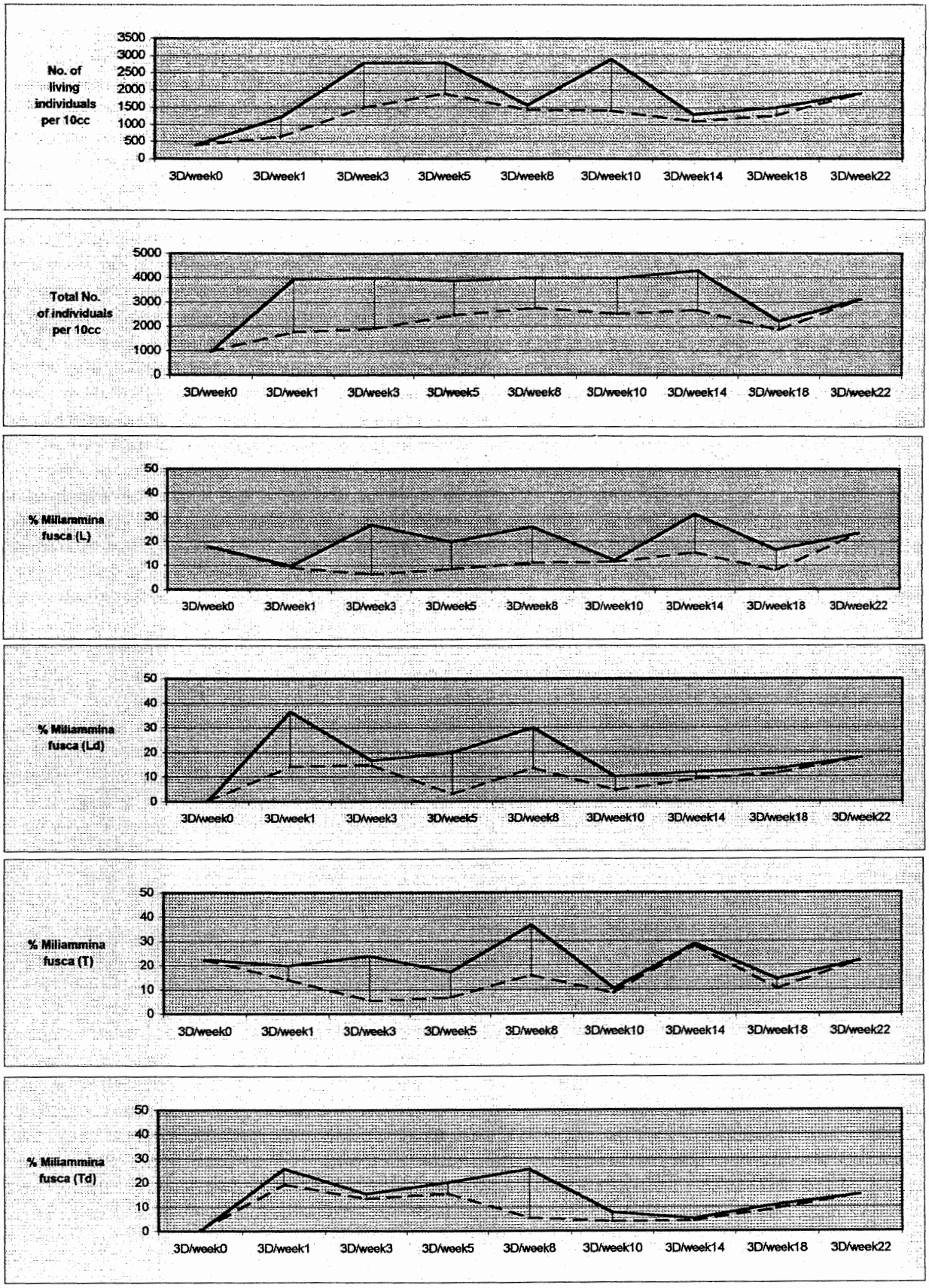


Figure 4.12 Foraminiferal occurrences for Treatment D (Oiled plot with nutrient enrichment), Plot 3, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.12
Treatment D- Oiled plot with nutrient enrichment



Percent living deformed and percent total deformed within the *M. fusca* present in Plot 3, Treatment D, are similar to each other in trends (Fig. 4.12). Both show an increase from the first week, followed by a decline and another peak, before reaching a low, and increasing gradually from that low to reach a smaller peak by week 22. For the percent living deformed, maximum values increase from 0% at week 0 to >35% by week 1, then decline to ~17% by week 3, and climb again to ~30% by week 8. Following this second peak, values decrease to 10%, and then climb slowly to ~17% by week 22. Minimum values climb from 0% at week 0 to only 15% by week 1, where they plateau until reaching a new low of <5% by week 5, and then climb to ~15% by week 8. After this small increase, minimum values decrease again to 5% before gradually increasing to >15% by week 22. The maximum values for percent total deformed follow a similar trend for those of percent living deformed, with ranges between 0% and 25%. Minimum values are most unlike the maximum values at week 8, where the second peak occurs.

4.1.2.5 Treatment E- Oiled plot with nutrient enrichment and cut plants

- **Number of living individuals and total number of individuals**

The number of living individuals and the total number of individuals for Plots 1, 2 and 3, Treatment E (oiled plot with nutrient enrichment and cut plants), although different in trends, all seem to start off low and finish off low, within the sampling period. Maximum values for number of living individuals and total number of individuals within Plot 1, start off low at week 0 (at <2000/10cc and 6000/10cc respectively) and climb to 6000/10cc and 11000/10cc by week 1. Values for the number of living decrease to ~4200/10cc by week 3, and then climb to a new peak of ~7000/10cc by week 8, before declining steadily to <2000/10cc by week 22. Minimum values are not

highly variable. After peaking to 11000/10cc at week 1, maximum values of the total number of individuals decrease to ~8000/10cc, before climbing again to >10000/10cc, and then decreasing again to reach a new low of <5000/10cc by week 22.

Within plot 2, Treatment E, values for the number of living individuals and the total number of individuals are much smaller than those in Plot 1, but show similar trends. For the number of living, values increase from >500/10cc to several small peaks over time, reaching a maximum of ~3500/10cc by week 14, after which values decrease to ~1250/10cc by week 22. Where maximum values peak at week 14, minimum values do not, and are already decreasing. Otherwise, there is very little variability between maximum and minimum values. This is also the case for the total number of individuals. Values start at >1500/10cc and climb to a maximum of >5000/10cc and then decline and plateau at ~3500/10cc by week 3, increasing again after week 10 to a peak of >5000/10cc by week 14, followed by a decline to ~2500/10cc by week 22. Minimum values are notably different at the two peaks at week 1 and week 14, with a difference of ~1500/10cc.

Within Plot 3, Treatment E, values for the number of living individuals and the total number of individuals are most variable, but seem to start and finish off low as well (Fig. 4.15). Maximum values of the number of living individuals starts off at ~1000/10cc and remains low until after week 3, reaching a maximum peak of ~8000/10cc by week 5, followed by a decline to 3000/10cc by week 8, where values are fairly stable until week 14. At this time, values increase slightly to >4000/10cc, and then decline to 2000/10cc by week 22. Minimum values are similar, ranging between <1000/10cc and >6000/10cc.

The total number of individuals within Plot 3, Treatment E, are quite variable (Fig. 4.15). Maximum values start off at 4000/10cc and increase to ~7000/10cc by week 1, decreasing to <5000/10cc by week 3, and then increasing again to a peak of >8000/10cc by week 5. Values then decline to ~4000/10cc where they are fairly stable, reaching a low at ~3800/10cc by week 22. Minimum values are similar, and after week 1, they dip to <2000/10cc, then climb to 8000/10cc by week 5, and dip down again to ~1000/10cc by week 8. Minimum values then climb to ~4000/10cc where they remain fairly stable.

- **Percent *Miliammina fusca***

The percentages for *M. fusca* present in Plots 1-3, Treatment E, are highly variable (Fig. 4.13-4.15). In Plot 1, Treatment E, the percent living *M. fusca* remains fairly consistent at ~30% until after week 3, where values climb to a maximum of ~55% at week 10, and then decline to a new low of 20% by week 22. Minimum values follow a similar trend, and where the maximum curve peaks at week 10, minimum values are different by ~20%. The percent total values start off high (at 55%) and decline to ~35% by week 5, where they don't start to increase until after week 8, reaching a maximum of >50% by week 10. Values decline again to ~35% by week 18, followed by a slight increase towards 40% by week 22. Minimum values are most variable at week 10 and week 14, with a difference of ~15%.

The percent deformed within those *M. fusca* present in Plot 1 are fairly consistent, remaining above 10% for the most part (Fig. 4.13). The percent living deformed increases from ~2% at week 0 to a maximum of >20% by week 1, and then slowly decline to 15% by week 5, where they plateau until week 14, followed by an increase to a

maximum of >20%. Minimum values are variable, different by an average of 15%, and most different at week 1 and week 10, ranging between 5% and <15%. The percent total deformed values also start off low and increase by week 1. Maximum values reach 15% by week 1, from <3% in week 0, and then plateau until a gentle decline after week 5, reaching a low at ~10% by week 14, where values remain fairly stable. Minimum values follow a similar trend and range between <3% and 11%.

In plot 2, the percent living *M. fusca* increases from <10% at week 0 to a maximum value of 35% by week 1, and then decreases to ~15% by week 3. Maximum values then climb gradually to 30% by week 10, dipping back down to ~15% by week 14, where they plateau until after week 18, where there is an increase to ~25% by week 22. Minimum values remain low (between 5 and 11%), until week 10 where they peak at ~30%, and then decrease to <10% by week 14. The percent total maximum values also increase after week 0, from >20% to 40% by week 1, and then decline to 20% by week 3 where they remain fairly stable until a slight increase at week 10 to 25%, and remain at ~20% through to week 22. Conversely, minimum values decrease gradually after week 0 to reach a low point of <10% by week 5 and remain constant until an increase to ~25% at week 10, matching the peak for the maximum values, and decrease to 10% again by week 14, followed by a gradual increase.

Percent living deformed and percent total deformed of the *M. fusca* from Plot 2, Treatment E, both increase from week 0, and remain fairly low throughout the sampling period. Percent living deformed values increase from 0% to a maximum of 30% by week 3, and then decrease to ~10% by week 8, followed by a slight increase to ~20%, where values remain fairly constant until a slight decline at week 22. Minimum values are

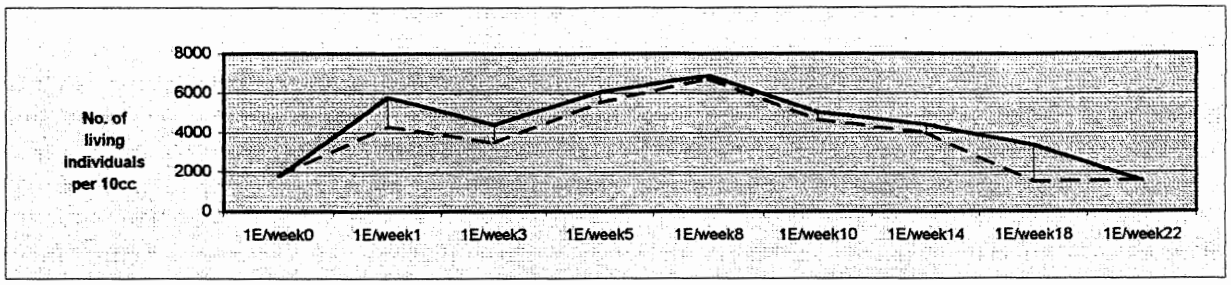
similar in trend, ranging between 0% and 15%. Similarly, percent total values increase after week 0, from 2% to a maximum of >20% by week 3, followed by a decline and a plateau at around 15% through to week 22. In both cases, where maximum values peak at week 3, minimum values remain below 10%.

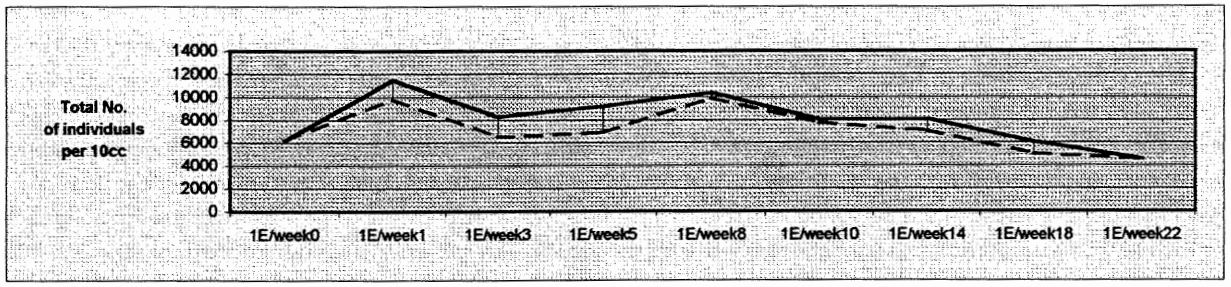
Percent living and percent total *M. fusca* within Plot 3, Treatment E, show the greatest variability, compared to the other two plots (Fig. 4.15). Maximum values for percent living are stable at ~20% until week 3, and then increase to 55% by week 5, declining to ~25% by week 10, climbing again to ~45% by week 18, and then falling to <30% by week 22. Minimum values also start off low and increase after week 3, to >40% by week 5, decreasing to <20% by week 8, and remaining below 30% until week 22. The greatest variability occurs between maximum and minimum values at week 14 and week 18, with a difference of ~30%. Maximum values for percent total *M. fusca* start off at <30% and increase after week 0 to 40% by week 1, then decrease to 20% by week 3, climbing to a new peak of 50% by week 5. Maximum values then decrease to ~20% by week 8, where they remain relatively stable until after week 10, increasing to 45% by week 18, and decreasing again to ~35% by week 22. Minimum values are similar, differing by only ~7%, until week 14, where minimum values decline to <15% at week 18, before increasing to week 22.

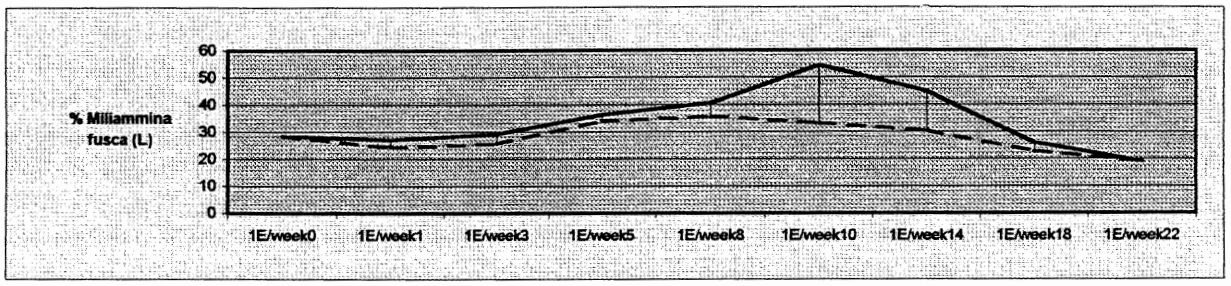
Percent living deformed values for *M. fusca* within Plot 3, Treatment E, are highly variable (Fig. 4.15). Starting off at 0%, maximum values increase to 20% by week 1, and then decline to >10% by week 5, and then decreasing again to ~7% by week 10, where they plateau before increasing to ~23% by week 22. Minimum values are much lower, increasing to only 7% by week 1, and then remaining between 3 and 7% through to week

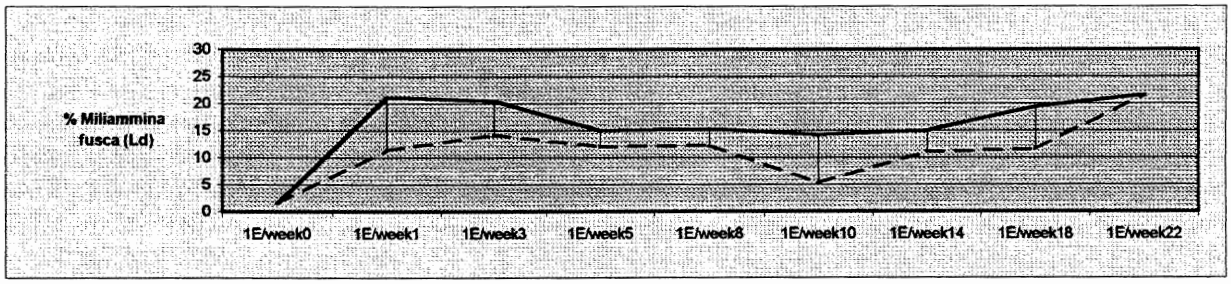
Figure 4.13 Foraminiferal occurrences for Treatment E (Oiled plot with nutrient enrichment and cut plants), Plot 1, from week 0 to week 22. Same format as Figure 4.1.

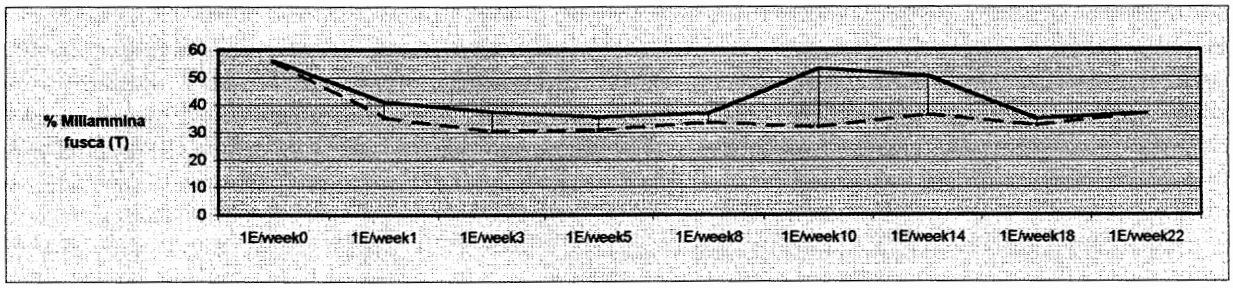
Figure 4.13
Treatment E- Oiled plot with nutrient enrichment and cut plants











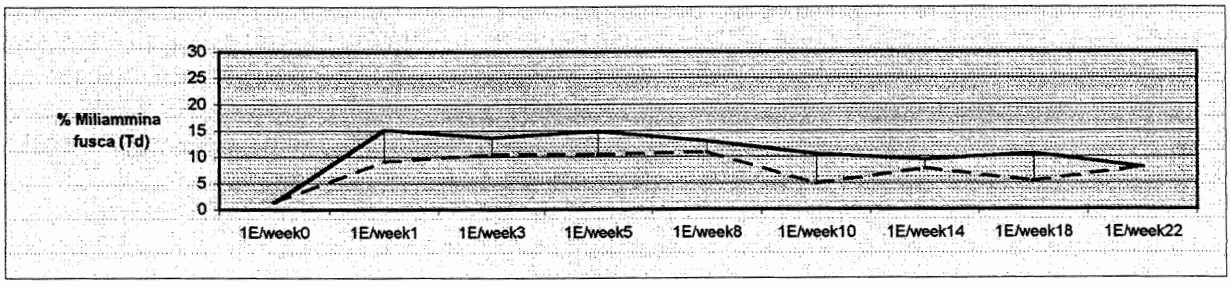
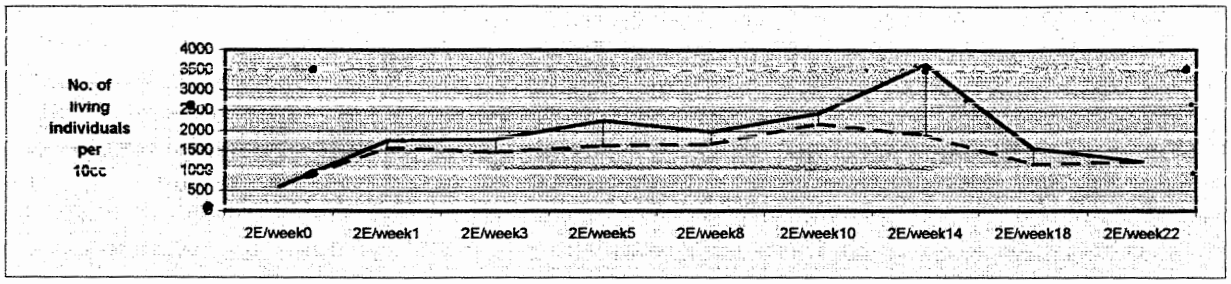
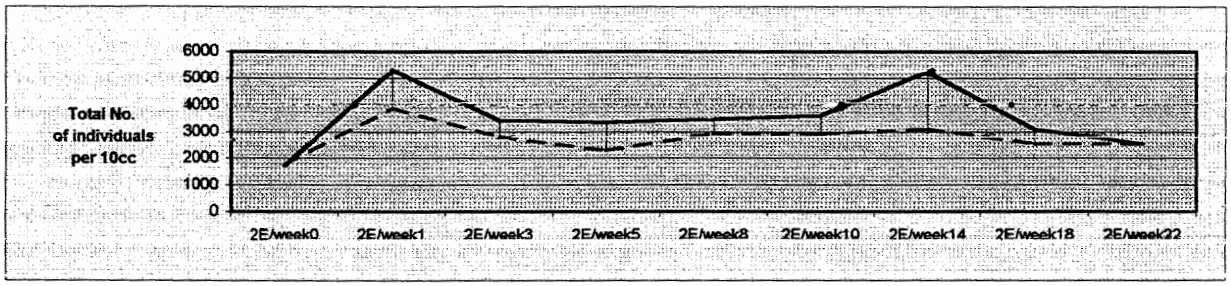
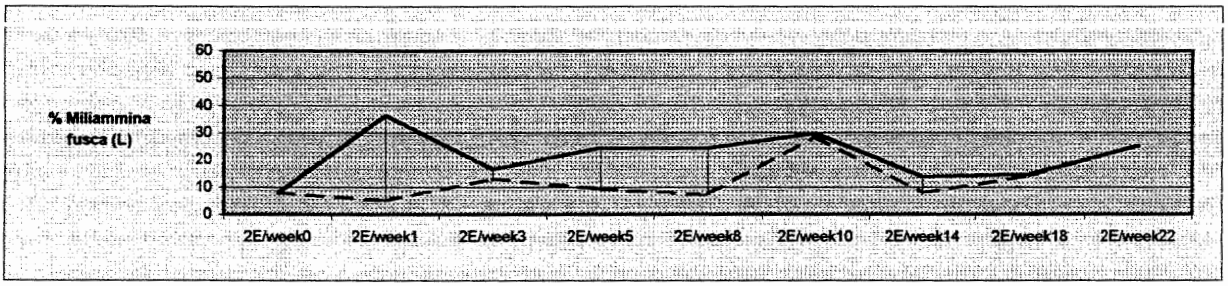


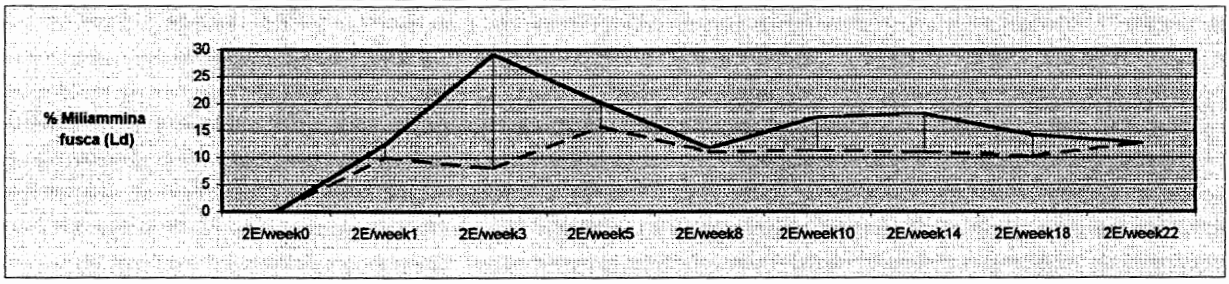
Figure 4.14 Foraminiferal occurrences for Treatment E (Oiled plot with nutrient enrichment and cut plants), Plot 2, from week 0 to week 22. Same format as Figure 4.1.

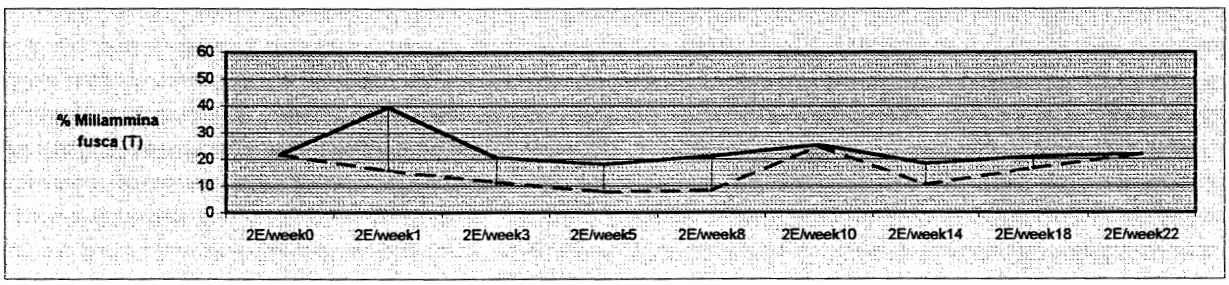
Figure 4.14
Treatment E- Oiled plot with nutrient enrichment and cut plants











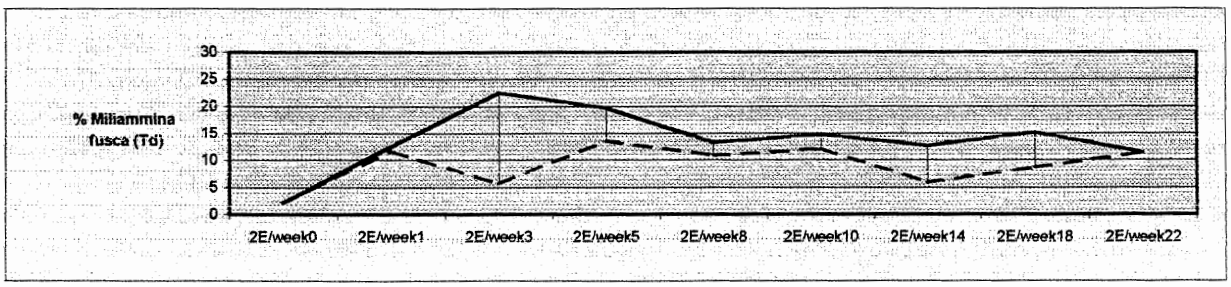
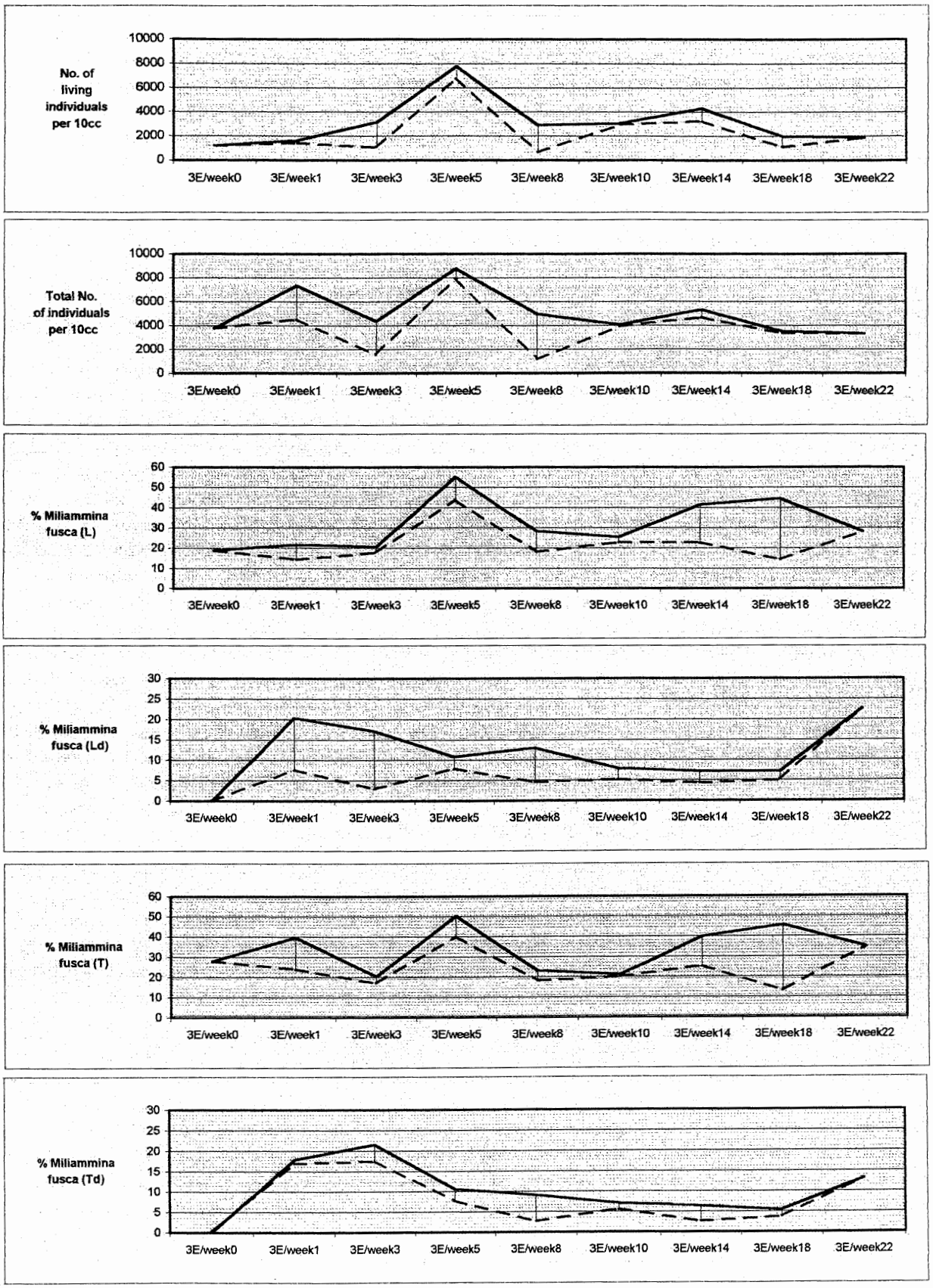


Figure 4.15 Foraminiferal occurrences for Treatment E (Oiled plot with nutrient enrichment and cut plants), Plot 3, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.15
Treatment E- Oiled plot with nutrient enrichment and cut plants



18. Maximum and minimum values are much less variable for percent total deformed, increasing from 0% at week 0 to >20% by week 3, and then decreasing to a low of 5% by week 18. After week 18, values increase again to ~12% by week 22, similar to the peak for percent living deformed in Plot 3, but unlike the low value within Plots 1 and 2.

4.1.2.6 Treatment F- Oiled plot with nutrient enrichment and agricultural disking

- **Number of living individuals and total number of individuals**

The number of living individuals and the total number of individuals within Plots 1, 2, and 3, with Treatment F (oiled plot with nutrient enrichment and agricultural disking), show a range of trends, with values ranging between 500 and 9000/10cc living and total. Within Plot 1, Treatment F, the maximum number of living individuals remains fairly consistent between 1400-1800/10cc, with minimal variability, increasing from ~1700 at week 8 to >2500/10cc by week 14, declining to <1000/10cc by week 18, and then climbing again to ~1200/10cc by week 22. Minimum values remain lower, and decline from ~1700/10cc at week 5 to ~800/10cc by week 8, and plateau at ~1200/10cc until week 18, reaching a low of ~700/10cc. The total number of individuals starts off fairly stable as well. Maximum values increase slightly from >3000/10cc to 3500/100cc by week 1, and then decline, with no variability, to week 5 at ~2500/10cc. Maximum values then increase to reach >4000/10cc by week 14, and then decline to ~1700/10cc by week 18, followed by another increase to ~2200/10cc by week 22. Minimum values are more stable, and after week 3, gradually decrease from ~3000/10cc to ~1700/10cc where values plateau until week 18.

Values for the number of living individuals and the total number of individuals within Plot 2 show the greatest variability between minimum and maximum values (Fig.

4.17). Maximum values for the number of living increases from ~500/10cc to >5000/10cc by week 3, decreasing to 2000/10cc by week 8, and then climbing again to >3000/10cc by week 3 before decreasing again to ~1500/10cc by week 18, where values plateau. Minimum values are much lower, and remain below 1000/10cc until increasing to 2000/10cc by week 5, and then decrease to 1000/10cc by week 8, increasing to ~2000/10cc by week 10, and then declining to ~1000/10cc. Maximum values for the total number of individuals start off at 1000/10cc and increase to >8000/10cc by week 1, decreasing to ~4500/10cc by week 5, and remaining fairly stable at ~5000/10cc until after week 10, decreasing to ~2000/10cc by week 18. Minimum values are again much lower, increasing from week 0 at 1000/10cc to 2500/10cc, and then remaining between 2000 and 2300/10cc until week 18. At this time, there is a slight dip below 2000/10cc.

The number of living individuals and the total number of individuals within Plot 3, Treatment F, show less variability (Fig. 4.18), but similar trends to Plot 2. Maximum values for the number of living increase from 500/10cc to >6000/10cc by week 5, and then decline fairly smoothly to week 14, where values plateau at ~2000/10cc, declining further still to ~1500/10cc by week 22. Minimum values are most variable at week 5, where the maximum value reaches >6000/10cc, and the minimum value is ~2000/10cc. Similarly, maximum values for the total number of individuals increases from 1000/10cc to >8000/10cc by week 5, and then decline to ~3000/10cc by week 14. At week 18, there is an increase to >4000/10cc, followed by another decline to <3000/10cc by week 22. Minimum values are somewhat variable, with the greatest difference occurring again at week 5, where the maximum value reaches >8000/10cc and the minimum value decreases slightly to <4000/10cc.

- **Percent *Miliammina fusca***

The percentages of *M. fusca* present in the three plots treated with Treatment F show the widest range of variability of all the treatments, varying in percentages of <5% to >35%, with deformities ranging between 0-50%. In Plot 1, Treatment F, values for percent living start off and remain very low (Fig. 4.16). Starting at <6%, maximum values increase slightly to >8% by week 5, and then decline to ~3%, climbing again to ~5% before decreasing to <2% by week 22. Minimum values decline from <6% to <2% by week 1, and then increase back to ~6% by week 3, before decreasing to <2% over time to week 22. Maximum values for percent total *M. fusca* start off fairly high at ~17% and increase slightly to 20% before decreasing to <5%, and remain below 5%, except for a small increase at week 14, through to week 22. Minimum values decline from the start, reaching <5% by week 1, and remaining below 5% through to week 22.

The percent living deformed *M. fusca* in Plot 1 are quite high (Fig. 4.16). Maximum values increase from <10% at week 0 to ~40% by week 1, and then decrease to ~15% by week 3, climbing again to >30% by week 8. They decrease slightly to 20% by week 10 before climbing to a peak of 50% by week 18, and then crash to 0% by week 22. Minimum values are much lower, decreasing to 0% after week 1 and remaining there until week 10, where they increase to ~17% before returning to 0% for the rest of the sampling period. The total percent deformed *M. fusca* is also variable. Maximum values increase from week 0 at ~2% to ~30% by week 1, and then decline to ~10% by week 3, before increasing to >20% by week 5. Following week 5, maximum values decline gradually to ~10% by week 10, climb to ~30% by week 14, and then drop to ~20% by week 18, and increase again by week 22 to ~25%. Minimum values are much lower, and

after week 1, decrease to 0%, rising only at week 10 to >10%, after which they fall to 0% again.

Within Plot 2, Treatment F, values continue to be highly variable (Fig. 4.17). The percent living and percent total for *M. fusca* are very similar, ranging between 1 and >30%. Maximum values in both cases increase from <10% to >30% by week 1, and then fall to <20% by week 3, climbing gradually back up to ~30% before dropping out to <10% by week 14. There is a slight increase in values again after week 14, reaching no higher than ~13% by week 22. Minimum values are variable, and follow a similar trend to maximum values, but differ by 5-25%, and never quite reach 0%.

The maximum values for percent living deformed in Plot 2, Treatment F, start at 0% and climb to 40% by week 1, and then decrease to ~15% by week 3. They then climb to ~30% by week 5, and then decline to ~20% until week 14 where they decrease further to reach ~5% by week 14, and then increase again to 20% by week 18 before decreasing to <10% by week 22. Minimum values are lower, ranging between 0% and 20% accordingly (Fig. 4.17). The values for percent total deformed are very similar and follow similar trends, reaching a maximum value of ~35%, and declining at the end to <10% by week 22. Minimum values are variable, with an average difference of ~13%.

Within Plot 3, Treatment F, percent living and percent total *M. fusca* continue to show a different range of values (Fig. 4.18), with respect to the other two plots. Maximum values for percent living start off at ~15% and decline to ~12% by week 1 before increasing to ~35% by week 3, and then decreasing gradually to ~13% by week 10. Values then climb to >20% by week 14, and then slowly decrease to ~15% by week 22. Minimum values are somewhat lower and more stable, remaining between 10-28%,

with a slight dip below 10% at week 10. The maximum values for percent total also decrease from week 0, from 25% to ~18% by week 1, and then climb back up to >30% by week 3. Values then decline to ~12% by week 10, climbing to 20% by week 14, and then gradually decreasing to ~15% by week 22. Minimum values follow a similar trend and range between 8-20%, with a greatest difference from maximum values at week 5 of ~18%.

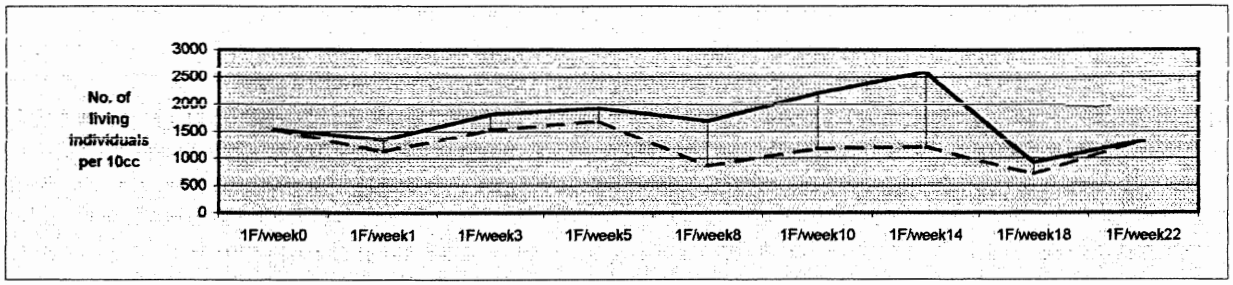
The percent living deformed and percent total deformed *M. fusca* are less variable and show similar trends to each other within Plot 3, Treatment F. For percent living deformed, maximum values increase from ~12% to 25% by week 1, and then decrease to ~16% by week 3 where they remain fairly stable until after week 8, where they reach a low of <5%, and then climb steadily to a peak of >25% by week 22. Minimum values are within 5% of maximum values, except at week 1, where the maximum value reaches 25% and the minimum value remains at ~12%. For percent total deformed, maximum and minimum values are different by only ~3%. Maximum values increase from 10% to ~23% by week 1, and then fall to ~12% by week 5, where they plateau before decreasing again to <5% by week 10, climbing steadily back up to ~17% by week 22.

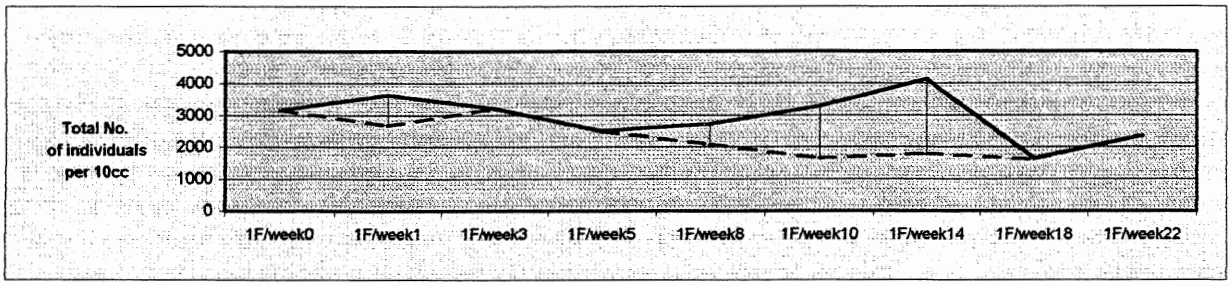
4.1.2.7 Summary of Morphological Change

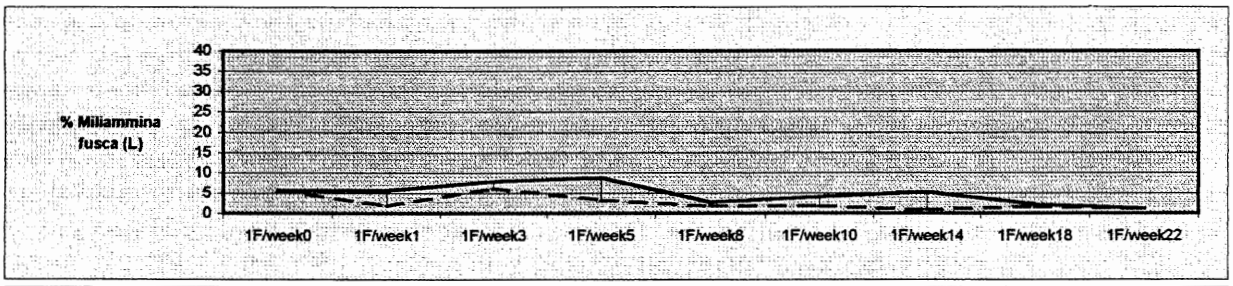
With respect to the overall measure of deformed *Miliammina fusca,* Table 4.1 shows the average rate of deformities within the eighteen plots over the sampling period. These values were calculated by adding the maximum percentages for each category of *M. fusca* (percent living, percent living deformed, percent total, and percent total deformed) and dividing by the amount of sampling days. The same was done for minimum values. Note the difference between the percent total deformed for Treatment

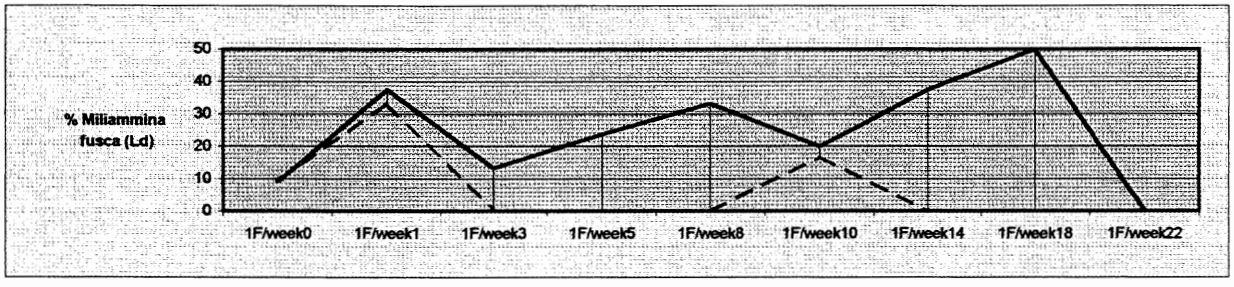
Figure 4.16 Foraminiferal occurrences for Treatment F (Oiled plot with nutrient enrichment and agricultural disking), Plot 1, from week 0 to week 22. Same format as Figure 4.1.

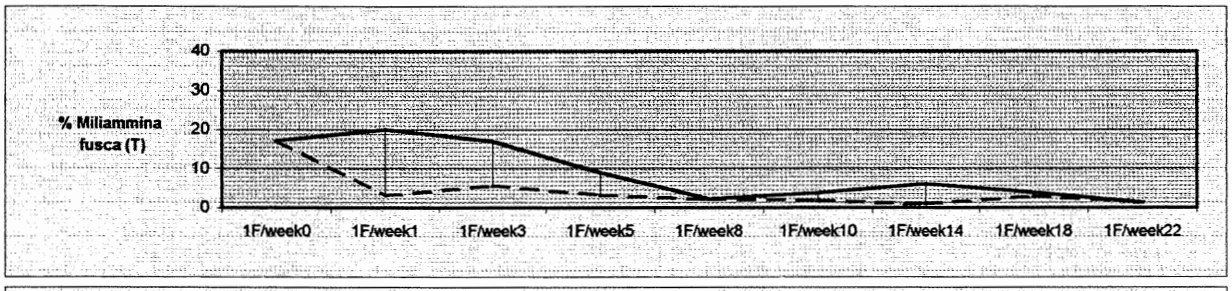
Figure 4.16
Treatment F- Oiled plot with nutrient enrichment and agricultural disking











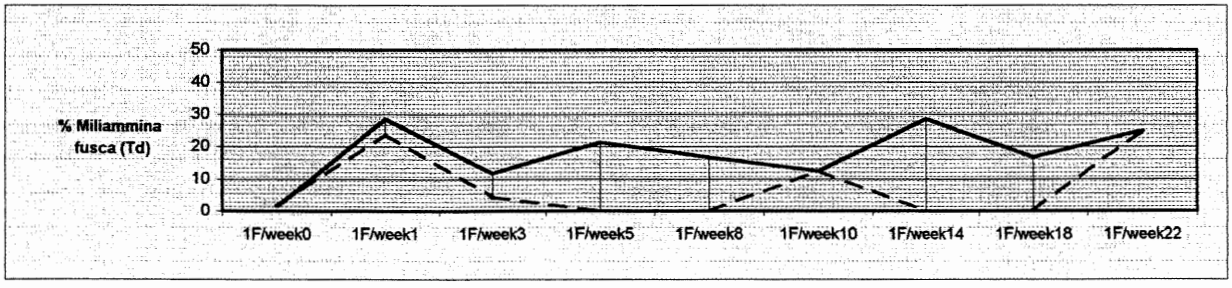


Figure 4.17 Foraminiferal occurrences for Treatment F (Oiled plot with nutrient enrichment and agricultural disking), Plot 2, from week 0 to week 22. Same format as Figure 4.1.

Figure 4.17
Treatment F- Oiled plot with nutrient enrichment and agricultural disking

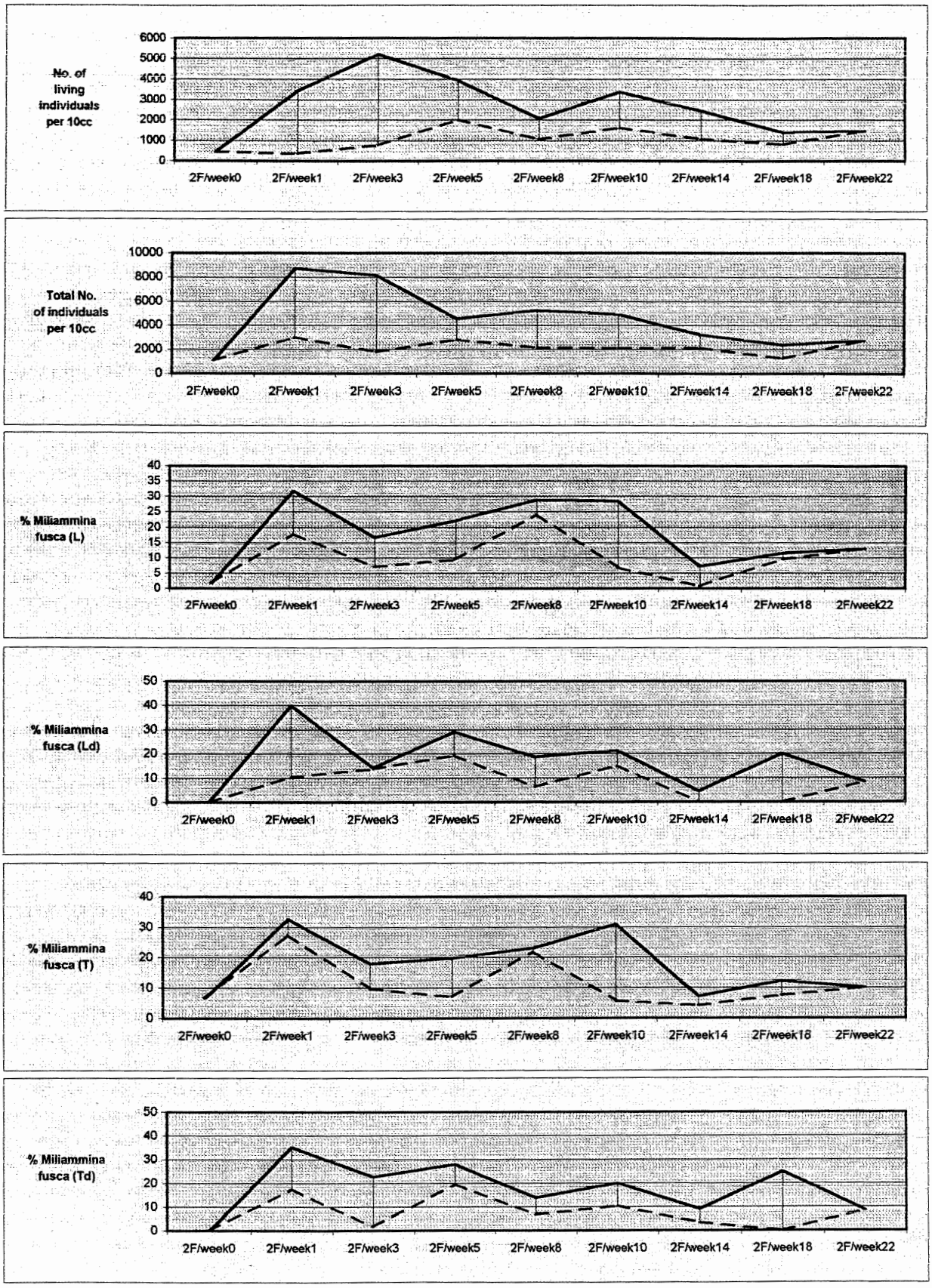
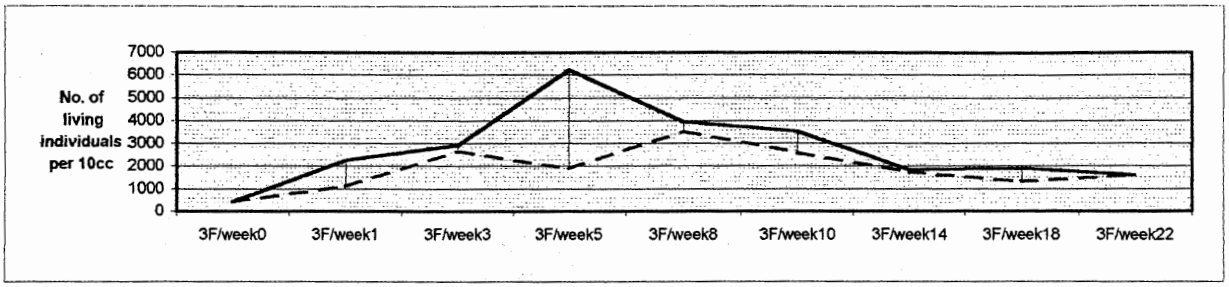
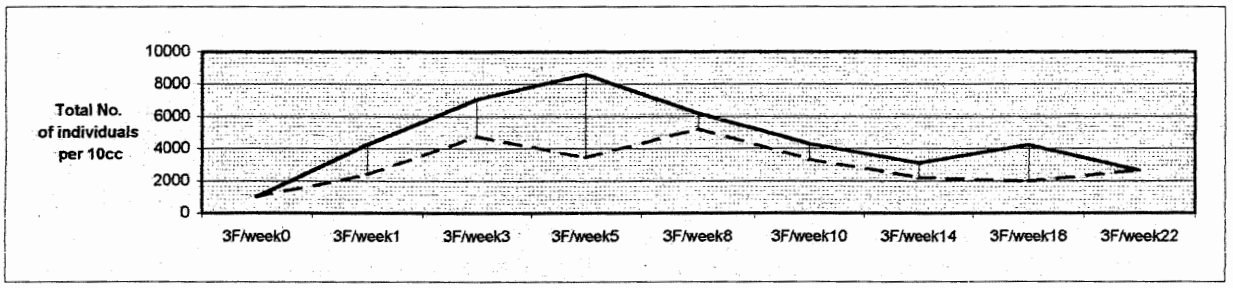
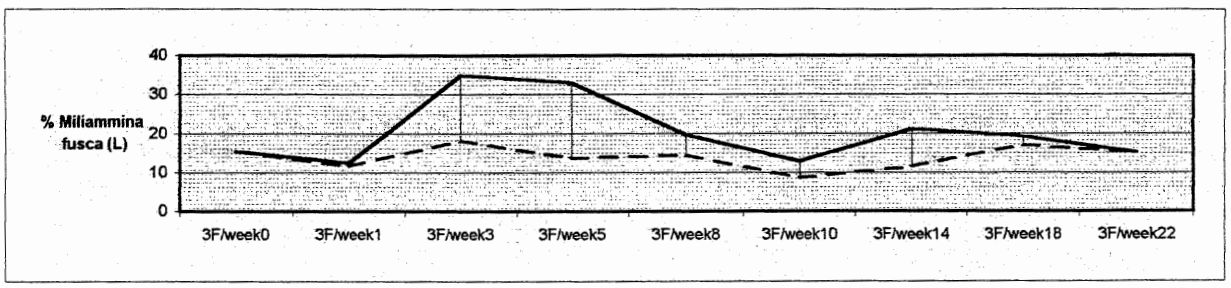


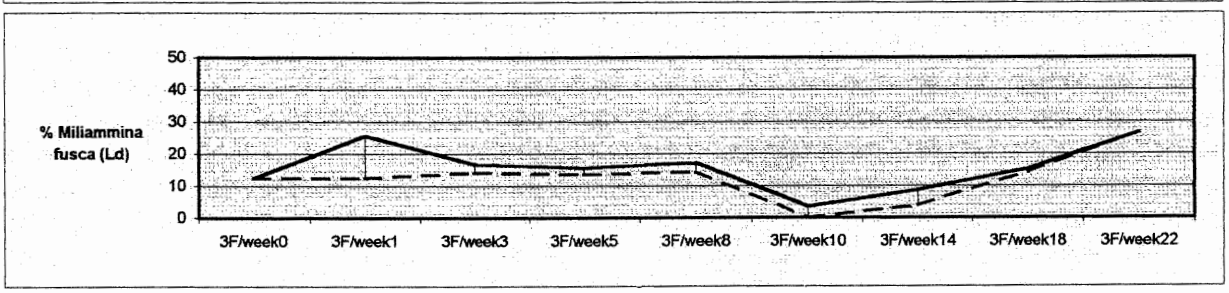
Figure 4.18 Foraminiferal occurrences for Treatment F (Oiled plot with nutrient enrichment and agricultural disking), Plot 3, from week 0 to week 22. Same format as Figure 4.1.

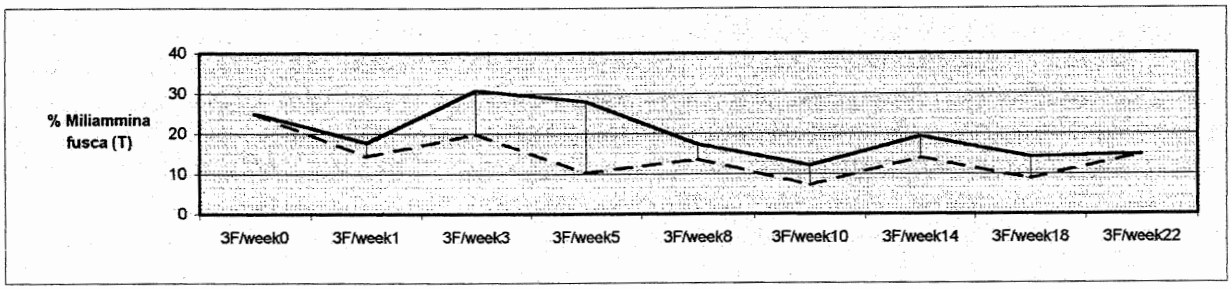
Figure 4.18
Treatment F- Oiled plot with nutrient enrichment and agricultural disking

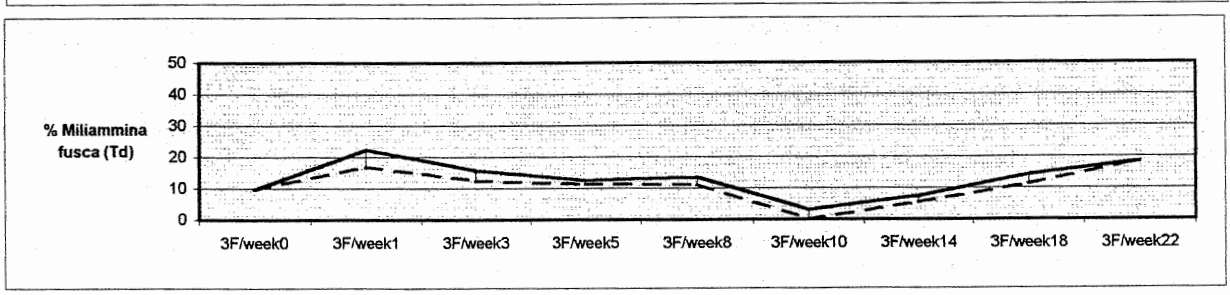












A and B, and those for Treatments C - F. There is a noticeable increase in deformed percentages within this species, between the non-oiled and oiled plots. For comparative purposes, the percentage of deformities within *M. fusca* from the pre-oiling sampling period (week 0) can be found in Appendix 1, Tables 1-9.

Table 4.1 Average Percentages of Deformed *Miliammina fusca*

Treatment	% Living		% Living Deformed		% Total		% Total Deformed	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
A (Control plot; no oil, nutrients enrichment)	11.9	47.9	1.23	3.25	13.1	49.5	1.14	1.72
B (Control plot; no oil, no nutrients)	5.33	12.4	1.24	3.98	6.46	13.8	1.04	1.84
C (Oiled plot; natural attenuation)	12.8	30.0	10.4	16.5	16.7	36.3	8.80	13.0
D (Oiled plot with nutrient enrichment)	15.9	22.8	12.3	15.6	16.1	27.2	12.1	12.9
E (Oiled plot with nutrient enrichment and cut plants)	17.4	32.0	8.99	13.9	18.9	38.3	9.24	12.0
F (Oiled plot with nutrient enrichment + agricultural disking)	3.82	17.4	13.4	17.2	6.30	16.7	11.6	13.9

The deformities among the *M. fusca* within all the plots were similar in that the test became twisted and/or misshapen compared to the normal form. Deformed ranges included twisting in the last chamber, misshapen changes internal to the whorl or on the periphery. Some specimens showed twinning, while others showed only minor deformations, such as the enlargement within a chamber. Figure 4.19a shows a normal *M. fusca* individual, and Figure 4.19b shows one of the deformed individuals picked out from one of the samples. In this case, this specimen had been living at the time the

sample was taken, hence the pink colouring, and had clearly deformed as a result of environmental stress.

Figure 4.19a Normal *Miliammina fusca* individual (~200μ)

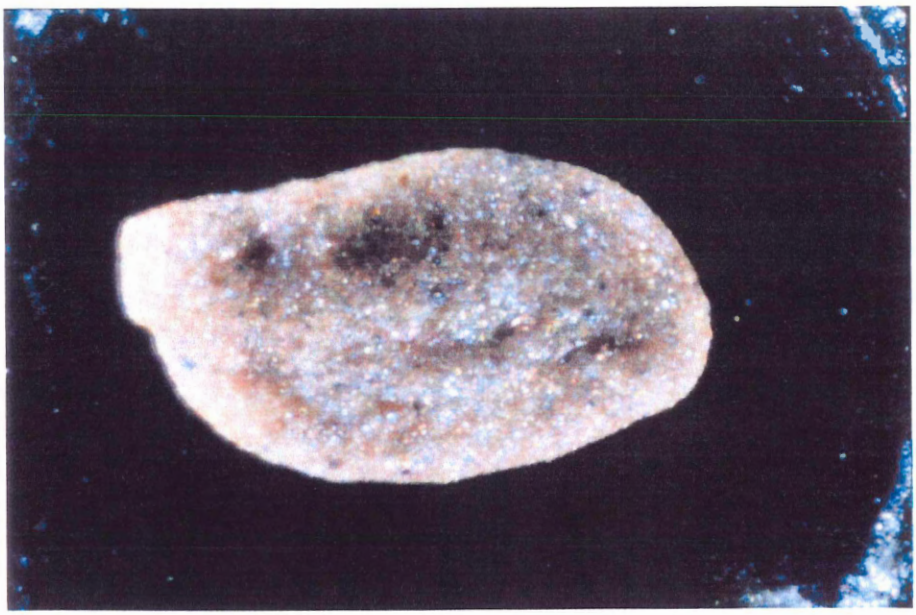


Figure 4.19b Deformed *M. fusca* individual (~200μ)

4.1.3 Field Results

Aside from foraminiferal results, the marsh surface itself within each of the experimental plots showed significant differences in response to the different treatments. Figures 4.20-4.25 are photographs taken in the field on the final sampling day (week 22, October 26th, 2000) to demonstrate the effects of the previous five months of treatment. A picture of each treatment was taken from one of the three blocks, as marked by the number and letter (the number representing the block, the letter representing the treatment). Visually speaking, it is clear to see the recovery rates of the marsh grass and vegetation within the oiled plots (Treatments D-F) were much slower than the foraminifera (Fig. 4.23-4.25). It is important to note that these observations must be based on the grid sub-sections of the plots that were not sampled, because the sub-sections that were sampled had surface material physically removed. This showed that microfauna respond more quickly and lead both macroplant and macroanimals in recovery, although this area did not show complete recovery by the end of the experiment.

4.2 CORE RESULTS

Prior to oiling, three ~10cm cores were taken, one from each zone, to determine the stability of the fauna over the past few years. One core, taken from plot 2 (see Fig. 1.3), was cut into 10 separate 1cm-thick slices to obtain 10cc samples, which were processed and analyzed individually, following the same methods used to process those samples extracted from the experimental plots.

4.2.1 Foraminifera

Data from the ten consecutive samples were calculated in the same format as described above (section 4.1.1), and put into a Microsoft Excel Spreadsheet. However, instead of values being plotted against a time-scale, they were plotted against depth for the core, so that 0-1cm represents the surface and 10cm represents maximum depth (Table 10, Appendix A).

Foraminiferal assemblages show that a maximum of eight different species were observed throughout this range of depth, including: *Eggellera advena, Miliammina fusca,* Thecamoebians, *Tiphotrocha comprimata, Trochammina inflata, Trochammina macrescens f. polystoma, Trochammina ochracea* and inner linings, all of which had living representatives. The core appears to be dominated at all levels by *Trochammina macrescens f. polystoma*, while fairly large populations of *Miliammina fusca* and *Trochammina inflata* also occur. Within the core, there were small numbers of deformities observed within the species *Miliammina fusca*, at various depths within the core. When there were deformities observed, the percentages of living deformed and total deformed were never greater than 2%, and were more often not present (0%). As well, a very small percentage of deformities were observed in *Trochammina macrescens f. polystoma,* while none were observed in the third most dominant species, *Trochammina inflata*.

Figure 4.20 Treatment A- Control Plot with Nutrient Enrichment (no oil), Plot 3, week 22

Figure 4.21 Treatment B- Control Plot without Nutrient Enrichment (no oil), Plot 2, week 22

Figure 4.22 Treatment C- Oiled Plot with no Treatments (natural attenuation), Plot 2, week 22

Figure 4.23 Treatment D- Oiled Plot with Nutrient Enrichment, Plot 3, week 22

Figure 4.24 Treatment E- Oiled Plot with Nutrient Enrichment and Cut Plants, Plot 2, week 22

Figure 4.25 Treatment F- Oiled Plot with Nutrient Enrichment and Agricultural Disking, Plot 2, week 22

CHAPTER 5: DISCUSSION

5.1 INTRODUCTION

Based on the large number of results acquired throughout the experiment, several important factors should be considered. The living and total foraminiferal assemblages in all types of plots showed a variety of fluctuations, indicating natural and anthropogenic changes. To provide the history of faunal assemblages over time, trends of living and total populations, as well as the presence or lack of deformities among species, are discussed. The trends over time among the experimental plots are compared, between non-oiled control plots and their natural variability, and oiled plots and the impact of an increased stressed on natural assemblages.

As mentioned earlier, a three year study was performed in the neighbouring inlet to Petpeswick, in Chezzetcook Inlet, Nova Scotia, by Scott and Medioli (1980b), to compare the seasonal variability between the living and total numbers. Two of the stations from that experiment (7c and 7d) are analogous to the stations plotted for this project, representing the outer estuarine zone IIA (upper low marsh) and zone IIB (lower low marsh), and share similar fluctuation patterns to those observed in Conrod's Beach salt marsh. The investigation by Scott and Medioli (1980b) did not consider deformities among species, however, had they been significant, they would have been noted (Scott, pers.comm.). Therefore, the results from this study will also be compared with previous work that has incorporated deformities among species of foraminifera, particularly in oil-contaminated areas, demonstrating the detrimental effects this type of pollutant can have on a natural environment.

5.2 TRENDS IN CORE

Based on an estimated sedimentation rate of 1cm/year, which is common in this area, it can be assumed the core results taken from the marsh represent a control time series of at least ten years (Table 10, Appendix A). The foraminiferal assemblages observed within the ten centimeters extracted from the marsh subsurface portray natural conditions over this time period, and provide a good faunal assemblage to compare against the results obtained from within the experimental plots. As Scott and Medioli (1980b) discuss, fossil assemblages from buried material can provide reliable indications as to the type of environment that existed at the time of deposition. This is particularly true in Holocene deposits, where modern distributions of the same species are known (Scott and Medioli, 1980b).

5.2.1 Species

The total number of species within each layer of the core ranged from 4-7, with fairly consistent numbers of individuals. Conditions appear to be most favorable to *Trochammina macrescens f. polystoma*, followed by *Miliammina fusca*, which were the two dominant species throughout the core. *Trochammina inflata* were also present in fairly consistent percentages. These agglutinated species, among the others observed at much lower percentages, dominated the marsh subsurface, with no calcareous species present. The salinity levels within this area were clearly too low to support calcareous species, which are typically found in other similar marsh areas.

5.2.2 Deformities

Within the core, there were very few deformities observed throughout the different species (Table 10, Appendix A). Only within *M.fusca*, *T. inflata* and

T.macrescens f. polystoma do we see very low percentages, and never greater than 2% deformed, which is considered within the normal range. Therefore, there is no indication of an increase in environmental stress over time that would have caused these species to deform.

5.3 TRENDS OVER TIME

With respect to the number of living individuals and the total number of individuals present per 10cc sample taken from each of the experimental plots throughout the study period, all species observed were incorporated (Tables 1-9, Appendix A). However, only two of these species appeared in significant amounts, and of these two species, only *M. fusca* is discussed in detail for the purpose of this report, showing significant deformities, with the greatest amount of variability as a result of environmental stress from the experimental treatments. *M. fusca* thrive in fairly stable environments with respect to other species found here, as shown by Scott and Medioli (1980b), and that is why deformities are found within the stressed plots. *Trochammina macrescens f. polystoma* live everywhere throughout the marsh, but dominate the upper reaches of marshes and are more tolerant of stress (ie. test deformation) than a species like *M. fusca*. Although this species shows deformities as well, they are not at levels suggesting high enough stress for the comparative purposes of this study.

Trends in living and total populations, as well as percent changes among the different species, were all within the natural ranges of variability, as observed in the core, and in Chezzetcook Inlet (Scott and Medioli, 1980b) and similar areas.

5.3.1 Deformities Within Control Plots With No Oil

- **Treatment A- Control Plot with Nutrient Enrichment (no oil)**

Deformities within the percentages of *M. fusca* present in the three Treatment A plots were very low, and aside from the rare high peak associated with the seasonal bloom, values were well below 10% throughout the experiment, similar to what was observed in the core. In Plot 1, the deformities were quite high, especially in the living, while percent living and percent total *M. fusca* were quite low. As conditions improved, and temperatures increased, living and total *M. fusca* numbers increased, so although the absolute number of deformed individuals may have remained the same, percentage-wise deformed numbers decreased. In Plot 1, there was a second peak of percent living deformed at the beginning of August, which was simultaneous with a decrease in the living and total populations. This percentage of deformities provides data for a 'natural', non-oiled site, and is well within the limits of natural variability reported elsewhere (ie. Scott and Mediol, 1980b). In Plots 2 and 3, percent living and percent total deformed *M. fusca* numbers were relatively low, remaining below 5% for most of the sampling period, while percent living and percent total *M. fusca* remained fairly stable. In Plot 2 however, there was a peak in both percent living and percent total deformed *M. fusca* by week 3, which was not associated with any particular change in percent living and percent total..

- **Treatment B- Control Plot Without Nutrient Enrichment (no oil)**

Similar to the results from Treatment A, of the *M. fusca* present in Plots 1, 2 and 3, with Treatment B, there were very few deformed species. In particular, aside from a slightly high percentage of living and total percent deformed at the beginning of the spring bloom, values remained well below 5% in both Plots 1 and 2. In Plot 3, it seems

there had been a high percentage of deformities coming out of the winter season, and as total populations climbed in the early weeks of spring, deformation levels bottomed out around 0% for the remainder of the sampling time. There was an unusually high increase in deformities at the beginning of August (week 10) within Plot 1, which should be mentioned. This peak occurred as percentages of *M. fusca* were increasing and total population numbers were decreasing, suggesting this species was having difficulty competing for space within the plot.

It would appear that those plots treated with nutrient enrichment are showing some deformities, and more so than in plots with no nutrient enrichment. However, this is a small difference, probably within the natural range of variability, so it is difficult to see much difference between treated and non-treated non-oiled plots.

5.3.2 Deformities Within Oiled Plots

- **Treatment C- Oiled Plot With No Treatments (natural attenuation)**

Each of the plots treated with oil show an increase in both percent living (Ld) and percent total (Td) deformed *M. fusca* just after the oil was applied in the first week. This first peak is a result of a seasonal warming that occurred at this time, at the beginning of the spring bloom in early June. This peak is simultaneous with the peak in total abundance. This indicates an extremely rapid response to oil contamination not seen in the other macro-organisms observed here. This response might be tied to the fact that the overall population was increasing just as the oil was applied and therefore test deformities were produced in juvenile specimens.

Following the initial peak, deformities appear to have stabilized throughout the summer during non-bloom periods, when reproduction rates were reduced. Near the end

of the sampling period, percentages increased again, and species reproduction appeared to occur at elevated rates. It is clear that the oil was having a negative impact on the reproductive cycle of the *M. fusca*, because more deformities were being generated during active reproduction. It appears that deformities manifest themselves more during reproduction because that is when the test is produced, and the oil apparently enhanced this effect, especially in the spring bloom.

- **Treatment D- Oiled Plot With Nutrient Enrichment**

Results for Treatment D plots show similar trends to Treatment C, particularly within Plots 2 and 3, with an increase in percent living deformed at the beginning of the sampling period and at the end. Plot 1 was different in that the percent deformed decreased after a late summer peak, when percent living and percent total *M. fusca* increased as the living and total population of all species increased. Therefore, living and total individuals of *M. fusca* increased at the expense of the deformed species. In general, however, it appears that at best the treatments had no positive effect on the foraminifera and subjectively it looks as though the plots with treatments were negatively altered with respect to percent deformities.

- **Treatment E- Oiled Plot with Nutrient Enrichment and Cut Plants**

Treatment E had a variety of effects on the experimental plots. In Plots 1 and 3, as living and total populations declined near the end of the summer, so did the percent living *M. fusca*, while percent living deformed *M. fusca* increased. Therefore, what was living over this time became deformed, because the species was having difficulty recovering from the added stress, and reproducing abnormal individuals. In Plot 2, where living and total populations decreased at the end of the fall season, percent living and

percent total *M. fusca* were fairly stable, or increased slightly, and percent living deformed and percent total deformed decreased slightly. This would indicate that the added nutrients and cut plants might have encouraged some recovery within this species. In all three plots, variability of the percent deformed between the replicate samples was greatest during the early spring and early fall, when conditions were more favorable for reproduction, but the added stress to the surrounding environment caused fluctuating results.

- **Treatment F- Oiled Plot With Nutrient Enrichment and Agricultural Disking**

In those plots treated with Treatment F, the results were highly variable among the three plots. In each case, there was an increase in percent deformed at the end of the summer season and into early fall, while living and total populations had decreased, so of the *M. fusca* that were able to reproduce, most were deformed. Particularly in Plot 3, the percent living and total *M. fusca* were less than 20% of the already low living and total populations, and of those *M. fusca*, an increased percent were deformed. In all three plots, although results are highly variable, it is clear the added stress to the environment caused a dramatic decrease in living and total populations, and specifically in *M. fusca*, in which those that did survive, a fair percentage were deformed.

5.3.3 Summary

The most noticeable difference between the treated oiled plots is that those plots treated with Treatment F (nutrient enrichment and agricultural disking) had the greatest variability between the representative samples. The disking introduced sediment from depth to the surface, so that samples taken from those plots contained faunal assemblages that were new and old. Therefore, the minimum values of 0% living and total deformed

are most likely representative of material from previous years, where deformation was less likely because conditions were more stable, and the maximum values (of up to 50% in the case of percent living deformed in Plot 1) are from the recently oiled surface sediment.

Also, the agricultural disking, or tilling, appeared to discourage the recovery rate of the vegetation within these plots, which may have had a detrimental effect on the foraminifera because of the added stress on environmental conditions. In the field, this was obvious from observation of the actual plots (Fig. 4.25), where it was clear that the plants within the plots were physically affected by the tilling. However, tilling was not carried out to stimulate plant growth, but rather to physically provide oxygen (O2) to the bacteria. It was known ahead of time that constant tilling would remove the plants from the plots. With more oxygen in the surface sediment as a result of the tilling, conditions would have been more favorable for the production of calcareous foraminiferal species, but these were not observed. As a result of the disking, surface sediment was removed from the center of the plot, creating an unofficial pond when water drained at low tide, and higher edges bounding this pond. Therefore, water was contained in the plot that may have otherwise drained away. This may have affected the temperature and salinity of the surface material and certainly did decrease the oxygen levels by stagnation, increasing the amount of stress present within the plots.

Because of the abundance of food and nutrients available to foraminifera within the marsh, and the consistent appearance of certain species indicating little to no inter-plot competition for space, variability is undoubtedly a symptom of stress related to the oil and the treatments introduced to the plots. In conclusion, it is clear that the oil caused

extreme amounts of deformation with exceptional rapidity within *M. fusca*. Levels of deformities observed here have never been previously reported, even in other heavily contaminated areas (with heavy metals, PCB's, and others), introducing new evidence of the effects of oil on a salt marsh to oil spill research.

5.4 COMPARISON WITH PREVIOUS WORK

Several experiments dealing with foraminifera as pollution indicators were discussed in Chapter 2. Of those, each reported signs of deformed populations as a result of stressed environments. Two of these experiments studied the specific effects of oil contamination on benthic foraminifera. The first, by Whitcomb (1975), showed that test deformities ranged from 10% to 15% among several foraminiferal species within tidal flat complexes of the lower York River, where hydrocarbons had been spilled. These findings, although lower than most percentages observed in our experiment, were believed to be directly related to the effects of the toxicity of the crude oil. Test deformities were suggested to have occurred as a result of starvation of foraminifera from loss of diatoms, as a result of the hydrocarbons in the water (Whitcomb, 1975).

A subsequent investigation, by Venec Peyre (1981), also related test abnormalities among certain benthic foraminiferal species to an oil spill. Although percentages of deformities were not recorded, the three main abnormalities found had been present in the study area before it came into contact with hydrocarbons from the spilled oil, but they only affected a minor part of the populations (Alve, 1995). Therefore, increased levels of anomalies were directly related to the presence of crude oil in the study area.

5.5 Implications

Several important points can be inferred from the findings of this study. The two most significant results that came from this experiment include the fact that, other than deformities, there was little change in foraminiferal assemblages within most of the plots, and the fact that at the end of the fall season there were still significant deformities in the populations, indicating no recovery from the oil spill. Although variability between the replicate samples appears high, it is naturally high, as seen in Chezzetcook Inlet from the study run by Scott and Medioli (1980b). However, what was unnatural was the high percentage of deformities within our plots compared to data collected from the core, which represents a time series from at least the last ten years, and with data collected from neighboring areas.

It is important to consider why only one of the species (*M. fusca*) observed in the samples showed statistically significant deformities. This occurrence is most likely related to the location of the experimental plots within the marsh at Conrod's Beach. *M. fusca* are likely to be more susceptible to environmental stress within the upper part of the low marsh area, whereas *Trochammina macrescens f. polystoma* would likely be the more stable species in the higher marsh. Therefore, if the plots had been stationed at a different elevation within the salt marsh, deformed percentages may have been more abundant in *T. macrescens f. polystoma*, if not among other species as well. If calcareous foraminiferal species had been present, it is likely that these would have been either highly deformed or eliminated altogether, since they are the most stressed species in low pH environments such as this. Unfortunately, no calcareous species were observed. This absence cannot necessarily be attributed to the presence of oil because fluctuations in

similar inlets happen naturally as well (refer to Ch.2, Fig. 2.1 and 2.3, where no calcareous species were observed in the third year of the study during the summer (Scott and Medioli, 1980b)).

Based on the results of this study, we have gained insight as to how foraminifera respond to an oil spill, especially the rapidity of their response. Within a coastal salt marsh, there are statistically significant changes in values following the application of the oil. These findings are useful in several different applications. For instance, we now have a better idea of what you could expect to see in a core from an old oil spill site. The thickness of an affected layer of sediment would probably not be very large (~1cm) but would condense a year of data into that one thin slice. Depending on the rates of bioturbation within the sediment, the extent of the depth of contamination can vary. In an area such as ours, where bioturbation rates are very low, the oil-affected layer would be fairly thin (~1cm). However, in places like South Carolina, where various burrowing organisms create notable disruptions in stratigraphic layers, the oil-contaminated layer, and therefore the deformed foraminiferal species within the layer, might be found at greater depths.

As discussed, marshes are highly susceptible to contamination from offshore oil spills. At the same time, fossil records within marshes remain well intact compared to other marine environments, like beaches and mud flats, and are therefore one of the few coastal zones where you can reconstruct past events. In this respect, foraminifera are highly useful because of the fossil record they provide, compared to other proxy indicators, such as plant roots. They would allow us to determine how long an oil spill affected an impacted shoreline, the level of mitigation, and how long it took the

environment to recover. From this experiment it is clear that foraminifera are cost-effective, rapid and reliable indicators of oil spill contamination within a coastal salt marsh. With the small amount of oil that was applied, there was a tremendous response, as seen in the deformities of one of the dominant species, and it can be assumed that a real oil spill would have an even greater impact.

CHAPTER 6: CONCLUSIONS

6.1 CONCLUSIONS

1. Living and total foraminiferal assemblages in each of the plots in Conrod's Beach marsh showed a variety of fluctuations, indicating natural changes and anthropogenic changes. Because of the abundance of food and nutrients available to foraminifera within the marsh, and the consistent appearance of certain species indicating little to no inter-plot competition for space, increased variability within certain plots is undoubtedly a symptom of stress related to the oil and treatments introduced to the plots.
2. Deformities of foraminiferal species were observed in each of the treated plots, but within the natural range (<10%) for unoiled plots. Within the oiled plots, the percentages of deformities were exceptionally high within one of the more dominant species, *Miliammina fusca*. Increased percentages of both living and total deformed *M. fusca* were observed within three days of the application of the oil. Levels of deformities observed here had never been previously reported, and greatly exceeded levels observed in a core representing faunal assemblages within the marsh over the last decade, as well as data from an analogous marsh in the neighboring inlet.
3. Other than deformities, there was little change in foraminiferal assemblages within most of the plots, and deformities were still present at the end of the fall season, indicating no recovery from the oil spill. Because of the controlled experiment, we can attribute these deformities to the presence of oil. Other studies have shown changes in assemblages because of contributing factors such as salinity or

temperature changes, but here it is clear that the oil had a detrimental effect on the foraminifera.

4. Of the *in situ* bioremediation treatments applied to the plots, none had a significant effect in the recovery of foraminifera by the end of the sampling period. The oil clearly had a negative impact on the reproduction cycle of the foraminifera within the oiled plots with no treatments added (Treatment C) because more deformities were generated during active reproduction. The addition of nutrients to the oiled plots (Treatment D) showed no positive effect on the foraminifera, and may have actually hindered recovery with respect to an increase in percent deformed. The added nutrients and cut plants in the Treatment E plots showed some signs of recovery within *M. fusca*, but not in all plots. The agricultural disking applied in Treatment F appeared to have the most detrimental effects because it mixed decomposed organic matter (low in O_2) from the subsurface with the surface material, and enhanced oil penetration. Variability between replicate samples and percent deformed *M. fusca* actually increased due to the added stress.
5. Foraminifera are cost-effective, rapid and reliable indicators of oil spill contamination on a coastal salt marsh. They showed a response that was not caused by other factors, such as salinity or temperature change, and responded more rapidly than the macro-organisms and vegetation present in the marsh. Foraminifera provide a good fossil record in a marsh environment from which past events can be reconstructed, unlike other proxy indicators. The impact of a previous oil spill can thus be measured, and the level of mitigation and the natural rates of recovery within this type of marine environment can be determined.

6.2 RECOMMENDATIONS

Time and seasonal restrictions permitted only a five-month sampling period for this study. Further studies in the spring of 2001 would be very useful in determining the recovery rates of the vegetation and foraminifera in the new spring bloom. It might be advisable to sample for several years following this project to determine the long-term effects of the oil spill on the marsh and the effectiveness of the various treatments, compared against the natural recovery within those plots with only oil added (Treatment C). This year's unusually long winter and colder conditions may prolong recovery, pushing the spring bloom later into the year.

It would also be of interest to test other parts of the marsh, within the different zones of elevation. For instance, in the lower marsh, distribution and deformation patterns may be different because foraminifera are more sensitive to environmental stress in this area. Conducting a similar experiment under different environmental conditions would contribute additional insight to the implications oil can have on a range of settings, based on how foraminiferal assemblages respond. Farther north, species like *Miliammina fusca* are less abundant, and temperatures decrease metabolic rates within organisms, among other factors. As well, results would be much different because of the composition of the oil with respect to the colder temperatures. For example, at lower temperatures, evaporation may be slower, so toxicity could be worse. Similarly, farther south, warmer and different pH conditions favor much higher levels of calcareous species, which would have had their own reaction and response to increased levels of stress.

Although it is impossible to replicate natural conditions in a laboratory setting, especially for such an environment as a marsh, which represents the most extreme of all

marine environments, it might be beneficial to conduct a similar experiment in this type of controlled atmosphere where certain components could be added. This way, the response of those elements absent from the field (ie: calcareous species) could be observed and measured.

In this type of experiment, there are a variety of factors that may have contributed a certain amount of error to the data collected, especially because of the daily tides and human interference within the marsh. It was therefore important to practice caution and consistency when sampling and processing the samples.

TAXONOMY

The classification of foraminiferal genera is in accordance with Scott, Medioli and Schafer (2001). The following list includes all species of benthic foraminifera and mentioned throughout the text, tables and figures within this paper, and are listed in alphabetical order by genus.

BENTHIC FORAMINIFERA

Eggerella advena (Cushman)

Verneuilina advena Cushman, 1922, p.141.
Eggellera advena (Cushman). Cushman, 1937, p.51, pl.5, figs.12-15; Phleger and Walton, 1950, p.277, pl.1, figs.16-18; Scott et al., 1977, p.1579, pl.2, fig.7; Scott and Medioli, 1980a, p.40, pl.2, fig.7; Scott et al., 1991, p.385, pl.2, figs.1, 2.

Elphidium excavatum (Terquem)

Polystomella escavata Terquem, 1876, p.429, pl.2, fig.2.
Elphidium excavatum (Terquem) formae Miller et al., 1982, (all).

Glomospira gordialis (Jones and Parker)

Trochammina squamata var. *gordialis* Jones and Parker, 1860, p.304.
Glomospira gordialis (Jones and Parker) Cushman and McCulloch, 1939, p.70, pl.5, fig.5, 6.

Miliammina fusca (Brady)

Quinqueloculina fusca Brady, 1870, p.286, pl.11, figs.4.4a, b.
Miliammina fusca (Brady) Phleger and Walton, 1950, p.280, pl.1, figs.19a, b; Phleger, 1954, p.642, pl.2, figs.22, 23; Scott et al., 1977, p.1579, pl.2, figs.8, 9; Schafer and Cole, 1978, p.28, pl.12, fig.2; Scott and Medioli, 1980a, p.40, pl.2, figs.1-3; Scott et al., 1991, p.386, pl.1, fig.14.

Pseudothurammina limnetis (Scott and Medioli)

Astrammina sphaerica (Heron-Allen and Earland), Zaninetti et al., 1977, pl.1, fig.9.
Thurammina (?) limnetis Scott and Medioli, 1980a, p.43, pl.1, figs.1-3.
Pseudothurammina limnetis Scott and others, *In* Scott et al., 1981, p.126; Scott et al., 1991, p.386, pl.2.

Tiphotrocha comprimata (Cushman and Brőnnimann)

Trochammina comprimata Cushman and Brőnnimann, 1948, p.41, pl.8, figs.1-3; Phleger, 1954, p.646, pl.3, figs.20, 21.
Tiphotrocha comprimata (Cushman and Brőnnimann). Saunders, 1957, p.11, pl.4, figs.1-4; Scott et al., 1977, p.1579, pl.4, figs.3, 4; Scott and Medioli, 1980a, p.44, pl.5, figs.1-3; Scott et al., 1990, pl.1, figs.10a, b; Scott et al., 1991, p.388, pl.2, figs.5, 6.

Trochammina inflata (Montagu)

Nautilas inflatus Montagu, 1808, p.81, pl.18, fig.3
Rotalina inflata Williamson, 1858, p.50, pl.4, figs.93, 94.
Trochammina inflata (Montagu). Parker and Jones, 1859, p.347; Phleger, 1954, p.646, pl.3, figs.22, 23; Scott et al., 1977, p.1579, pl.4, figs.6, 7; Scott and Medioli, 1980a, p.44, pl.3, figs.12-14; pl.4, figs.1-3; Scott et al., 1990, p.733, pl.1, figs.3a, b; Scott et al., 1991, p.388, pl.2, figs.7, 8; Scott et al., 1995, p.294, figs.6.10-17.

Trochammina macrescens (Brady)

Trochammina inflata (Montagu) var. *macrescens* Brady, 1870, p.290, pl.11, fig.5; Scott, 1976, p.320, pl.1, figs.4-7; Scott et al., 1977, pl.4, figs.6-7.
Jadammina polystoma Barenstein and Brand, 1938, p.381, figs.1, 2.
Trochammina macrescens Brady. Parker, 1952, p.460, pl.3, fig.3; Phleger, 1954, p.646, pl.3, fig.24; Scott and Medioli, 1980a, p.44, pl.3, figs.1-12; Scott et al., 1990, p.733, pl.1, figs.1a, b, 2a-c; Scott et al., 1991, p.388, pl.2, figs.10, 11; Scott et al., 1995, p.294, p.294, figs.6.6-8.

Trochammina ochracea (Williamson)

Rotalina ochracea Williamson, 1858, p.55, pl.4, fig.112, pl.5, fig.113.
Trochammina squamata Parker and Jones, 1865, p.407, pl.15, figs.30, 31; Scott and Medioli, 1980a, p.45, pl.4, figs.6, 7.
Trochammina squamata Parker and Jones, and related species. Parker, 1952, p.460, pl.3, fig.5.
Trochammina ochracea (Williamson). Cushman, 1920, p.75, pl.15, fig.3; Scott and Medioli, 1980a, p.45, pl.4, figs.4, 5.

REFERENCES

Addelman, S. (1969) The Generalized Randomized Block Design. The American Statistician, **19:** 35-36.

Addelman, S. (1970) Variability of Treatments and Experimental Units in the Design and Analysis of Experiments. Journal of American Statistical Association, **65:** 1095-1108.

Alexander, S.K., Webb, J.W. (1987) Relationship of *Spartina alterniflora* Growth to Sediment Oil Content Following an Oil Spill. *In:* Proceedings of the 1987 Oil Spill Conference, American Petroleum Institute, Washington, D.C., 445-449.

Alve, E. (1991) Benthic foraminifera in sediment cores reflecting heavy metal pollution in Sorfjord, western Norway. Journal of Foraminiferal Research, **21:** 1-19.

Alve, E. (1995) Benthic foraminiferal response to estuarine pollution: a review. Journal of Foraminiferal Research, **25(3):** 190-203.

Atlas, R.M., Bartha, R. (1992) Hydrocarbon biodegradation and oil spill bioremediation. Adv. Microb. Ecol., **12:** 287-338.

Boardman, R.S. (1987) Fossil Invertebrates. *Edited by:* A.H. Cheetham and A.J. Rowell. Blackwell Scientific Publications, Boston, 386p.

Barenstein, H., Brand, E. (1938) Die foraminiferan-fauna des Jade-Gebietes. 1. *Jadammina polystoma* n.g., n.sp. aus dem Jade-Gebietes (for): Senckenbergiana, **20:** 381-385.

Boltovskoy, E., Scott, D.B., Medioli, F.S. (1991) Morphological variations of benthic foraminiferal test in response to changes in ecological parameters: a review. Journal of Paleontology, **65:** 175-185.

Brady, H.B. (1870) Analysis and descriptions of foraminifera, Part II: Annals and Magazine of Natural History, ser.4, **6:** 273-309.

Campbell, R. (2000) Metal Impact on Benthic Foraminifera within Baie des Chaleurs, New Brunswick: A Reconnaissance Review of Marine Geochemistry and Species Diversity. Thesis, Dalhousie University, Halifax, Canada [unpublished manuscript], 92p.

Cushman, J.A. (1920) The foraminifera of the Atlantic Ocean. Part 2. Lituoidae: United States National Museum Bulletin, **104:** 1-111.

Cushman, J.A. (1922) Results of the Hudson Bay expedition, 1920: I- foraminifera: Canada, Biological Board, Contributions to Canadian Biology (1921), 1922, n° 9: 135-147.

Cushman, J.A. (1937) A monograph of the foraminiferal family Valvulinidae: Cushman Laboratory for Foraminiferal Research, Special Publication no.8, 210p.

Cushman, J.A., Brőnnimann, P. (1948) Additional new species of arenaceous foraminifera from shallow waters of Trinidad: Cushman Laboratory for Foraminiferal Research, **24:**37-42.

Cushman, J.A., McCulloch, I. (1939) A report on some arenaceous foraminifera. Allan Hancock Pacific Expeditions, **6:** 1-113.

Department of Fisheries and Oceans Canada (2000) Evaluation of Salt Marsh Oil Spill Countermeasures. *In:* Canadian Environmental Assessment Act, Screening Report, Environment Canada [unpublished manuscript], 20p.

Hatcher, A.I., Patriquin, D.G., Fern, Y.F., Hanson, A.J., Reade, J. (1981) Salt Marsh in

Nova Scotia. Institute of Resource and Environmental Studies, Dalhousie University, Halifax, Nova Scotia, 70p.

Jones, T.R., Parker, W.K. (1860) On the rhizopodal fauna of the Mediterranean, compared with that of the Italian and some other Tertiary deposits. Geological Society of London, Quaterly Journal, **16:** 292-307.

Lane, P. and Associates Limited (1993) Salt Marsh Revisited- The Long-Term Effects of Oil and Dispersant on Salt Marsh Vegetation. Prepared for: Environmental Studies Revolving Funds, Calgary, Alberta.

Lane, P.A., Crowell, M.J., Patriquin, D.G., Buist, I. (1987) The Use of Chemical Dispersants in Salt Marsh. Unpublished report for Environmental Studies Research Funds Report, **070:** 100p.

Lee, K. (1999) Bioremediation of oil impacted shorelines. *In:* Aquatic Restoration in Canada, Ecovision World Monograph Series. *Edited by:* T. Murphy and M. Munawar. Backhuys Publishers, Leiden, The Netherlands, pp. 69-85.

Lee, K., De Mora, S. (1999) *In situ* bioremediation strategies for oiled shoreline environments. Environmental Technology, **20:** 783-794.

Lee, K., Levy, E.M. (1991) Bioremediation: Waxy Crude Oils Stranded on Low-Energy Shorelines. Proceedings of the 1991 International Oil Spill Conference (Prevention, Behavior, Control and Cleanup), San Diego, California, March 4-7, 541-548.

Lee, K., Merlin, F.X. (1999) Bioremediaton of oil on shoreline environments: development of techniques and guidelines. Pure Applied Chemistry, **71 (1):** 161 -171.

Lee, K., Siron, R., Tremblay, G. (1996) Effectiveness of Bioremediation in Reducing Toxicity in Oiled Intertidal Sediments. Bioremediation, **3 (8):** 117-127.

Lin, Q., Mendelssohn, I.A. (1996) A Comparative Investigation of the Effects of South Louisiana Crude Oil on the Vegetation of Fresh, Brackish and Salt Marshes. Marine Pollution Bulletin, **32:** 202-209.

Long, S.P., Mason, C.F. (1983) Saltmarsh Ecology, Chapman and Hall, New York, 160pp.

Miller, A.A.L., Scott, D.B., Medioli, F.S. (1982) *Elphidium excavatum* (Terquem): ecophenotypic versus subspecific variation. Journal of Foraminiferal Research, **12:** 116-144.

Montagu, G. (1808) Testacea Britannica, supplement. S. Woolmer, Exeter, England, 183p

Parker, F.L. (1952) Foraminiferal distribution in the Long Island Sound-Buzzards Bay area. Bulletin of the Harvard Museum of Comparative Zoology, **106:** 438-588.

Parker, W.K., Jones, T.R. (1859) On the nomenclature of the foraminifera, II. On the species enumerated by Walker and Montagu. Annals and Magazine of Natural History, **4(3):** 333-351.

Parker, W.K., Jones, T.R. (1865) On some foraminifera from the North Atlantic and Arctic Oceans, including Davis Strait and Baffin's Bay. Philosophical Transactions of the Royal Society, **155:** 325-441.

Pezeshki, S.R., DeLaune, R.D. (1993) Effect of Crude Oil on Gas Exchange Functions of *Juncus roemerianus* and *Spartina alterniflora*. Water, Air and Soil Pollution, **68:** 461-468.

Phleger, F.B (1954) Ecology of foraminifera and associated microorganisms from Mississippi Sound and environs. Bulletin of the American Association of Petroleum Geologists, **38:** 584-647.

Phleger, F.B, Walton, W.R. (1950) Ecology of marsh and bay foraminifera, Barnstable Mass. American Journal of Science, **248:** 274-294.

Prince, R.C., Bare, R.E., Garrett, R.M., Grossman, M.J., Haith, C.E., Keim, L.G., Lee, K., Holton, G.J., Lambert, P., Sergy, G.A. Owens, E.H., Guenette, C.C. (1999) Bioremediation of a Marine Oil Spill in the Arctic. *In*: In situ Bioremediation of Petroleum Hydrocarbon and Other Organic Compounds. *Edited by:* B.C. Alleman and A. Leeson. Battelle Press, Columbus, Ohio, pp. 227-232.

Prince, R.C., Bare, R.E., George, G.N., Haith, C.E., Grossman, M.J., Lute, J.R., Elmendorf, D.L., Minak-Bernero, V., Seniue, J.D., Keim, L.G., Chianelli, R.R., Hinton, S.M., Teal, A.R. (1993) The Effect of Bioremediation on the Microbial Populations of Oiled Beaches in Prince William Sound, Alaska. *In*: Proceedings of the 1993 Oil Spill Conference, American Petroleum Institute, Washington, DC., 469-475.

Saunders, J.B. (1957) Trochamminidae and certain Lituolidae (Foraminifera) from the recent brackish-water sediments of Trinidad, British West Indies. Smithsonian Miscellaneous Collections, **134:** 1-16.

Schafer, C.T. (1971) Sampling and Spatial Distribution of Benthic Foraminifera. Geological Survey of Canada Paper. **76 (1C):** 27-32.

Schafer, C.T. (1973) Distribution of Foraminifera near pollution sources in Chaleur Bay. Water, Air and Soil Pollution, **2:** 219-233.

Schafer, C.T., Cole, F.E. (1978) Distribution of Foraminifera in Chaleur Bay, Gulf of St. Lawrence. Geological Survey of Canada Paper 77-30, 55p.

Schrőder, C.J., Scott, D.B., Medioli, F.S. (1987) Can smaller benthic foraminifera be ignored in paloenvironmental analysis? Journal of Foraminiferal Research, **17:** 101-105.

Scott, D.B. (1976) Brackish-water foraminifera from southern California and description of *Polysaccamina ipohalina* n.gen., n.sp. Journal of Foraminiferal Research, **6:** 312-321.

Scott, D.B. (1977) Distributions and Population Dynamics of Marsh-Estuarine Foraminifera with Applications to Relocating Holocene Sea-Levels: Ph.D. Thesis, Dalhousie University, Halifax, Canada, 207p.

Scott, D.B., Hasegawa, S., Saito, T., Ito, K., Collins, E. (1995) Marsh foraminiferal and vegetation distributions in Nemuro Bay wetland areas, eastern Hokkaido. Transactions and Proceedings of the Paleontological Society of Japan, no. 180, 282-295.

Scott, D.B., Hermelin, J.O.R. (1993) A device for precision splitting of micropaleontological samples in liquid suspension. Journal of Paleontology, **67:** 151-154.

Scott, D.B., Medioli, F.S. (1980a) Quantitative studies of marsh foraminiferal distributions in Nova Scotia: their implications for the study of sea level changes. Cushman Foundation for Foraminiferal Research, Special Publication, **17:** 58p.

Scott, D.B., Medioli, F.S. (1980b) Living vs. total foraminiferal populations: their relative usefulness in paleoecology. Journal of Paleontology, **54:** 814-834.

Scott, D.B., Medioli, F.S., Schafer, C.T. (1977) Temporal changes in foraminiferal distributions in Miramichi River Estuary, New Brunswick. Canadian Journal of Earth Sciences, **14:** 1566-1587.

Scott, D.B., Medioli, F.S., Schafer, C.T. (2001) Monitoring in Coastal Environments using Foraminifera and Thecamoebian Indicators. Cambridge Press, London, 175p.

Scott, D.B., Reinhardt, E.G., McCarthy, F.M.G., Patterson, R.T., Asioli, A. (1999) Detecting Environmental Effects Using Benthic Foraminifera and Thecamoebians. *In:* Short Course Notes on Applications of Benthic Foraminifera and Thecamoebians for Detecting Environmental Effects, Bologna, Italy, 178p.

Scott, D.B., Schafer, C.T., Medioli, F.S. (1980) Eastern Canada estuarine foraminifera: a framework for comparison. Journal of Foraminiferal Research, **10:** 205-234.

Scott, D.B., Schnack, E.S., Ferrero, L., Espinosa, M., Barbosa, C.F. (1990) Recent marsh foraminifera from the east coast of South America: comparison to the northern hemisphere. *In:* Paleoecology, Biostratigraphy, Paleoceanography and Taxonomy of Agglutinated Foraminifera, NATO ASI Series C, 327. *Edited by:* C. Hemleben, M.A. Kaminski, W. Kuhnt, and D.B. Scott. Math and Physical Sciences, 717-738.

Scott, D.B., Suter, J.R., Kosters, E.C. (1991) Marsh foraminifera and arcellaceans of the lower Mississippi Delta: Controls on spatial distributions. Micropaleontology, **37:** 373-392.

Scott, D.B., Williamson, M.A., Duffett, T.E. (1981) Marsh foraminifera of Prince Edward Island: their recent distribution and application for former sea-level studies. Maritime Sediments and Atlantic Geology, **17:** 98-124.

Seiglie, G.A. (1975) Foraminifers of Guayamilla Bay and their use as environmental indices. Revista Espanola de Micropaleontologia, **7:** 453-487.

Stubbles, S.J. (1997) Post-impact assessment of Restronguet Creek, Southwest Cornwall and investigation into the absence of agglutinated formanifera: abstract to the 5th International Workshop on Agglutinated Foraminifera, Plymouth, U.K., October.

Swannell, R.P.J., Lee, K., McDonagh, M. (1996) Field Evaluations of Marine Oil Spill Bioremediation. Microbiological Reviews, June, 342-365.

Swannell, R.P.J., Mitchell, D.J., Jones, D.M., Willis, A.L., Lee, K., Lepo, J.E. (1997a) An Evaluation of Bioremediation of Oiled Sediments Buried Within a Mudflat Environment. In: Proceedings of the Twentieth Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, June 11-13, Vancouver, B.C. pp. 703-714.

Swannell, R.P.J., Mitchell, D.J., Jones, D.M., Willis, A., Lee, K., Lepo, J.E. (1997b) Field Evaluation of Bioremediation to Treat Crude Oil on a Mudflat. In situ and On-Site Bioremediation, **4:** 401-406.

Terquem, O. (1876) Essai sur les classements des animaux qui vivant sur la plage et dans les environs de Denkerque, Pt.1. M moires de la Soci te Dunkerquoise pour l'Encouragement des Sciences des Lettres et des Arts (1874-1875), **19:** 405-457.

Venec-Peyr , M.T. (1981) Les foraminifers et la pollution: tude de la microfaune de la C le du Dourduff (Embouchure de la Rivi re de Morlaix). Cahiers de Biologie Marine, **22:** 25-33.

Walton, W.R. (1952) Techniques for recognition of living foraminifera. Contributions of the Cushman Foundation for Foraminiferal Research, **3:** 56-60.

Whitcomb, N.J. (1978) Effects of Oil Pollution upon selected species of benthic foraminiferids from the lower York River, Virginia. In: Geological Society of America, Abstracts with Programs, **10:** 515.

Williamson, M.L. (1999) Reconstruction of Pollution History at Mill Cove, Bedford Basin, Using Benthic Foraminifera: B.Sc. Honours Thesis, Dalhousie University, Halifax, Nova Scotia, Canada. 77p. [in press]

Williamson, W.L. (1858) On recent foraminifera of Great Britain. Ray Society, London, 107p.

Zaninetti, L., Brőnnimann, P., Beurlen, G., Moura, J.A. (1977) La mangrove de Guaratiba et la Baie de Sepatiba, état de Rio de Janeiro, Brésil: foraminifères et écologie. Archives des Sciences (Genève), **30:** 161-178.

Zobell, C.E. (1964) The occurrence, effects, and fate of oil polluting the sea. Adv. Water Pollut. Res., **3:** 85.

APPENDIX A

Data Tables

Table A-1 Table of results for foraminiferal occurrences for Treatment A (Control plot with nutrient enrichment; no oil), Plots 1 and 2, for weeks 0-22. The living and total (live plus dead) number of the total number of species per 10cc, and the living and total (live plus dead) number of the total number of individuals per 10cc are included. Relative percentages of both living and total (live plus dead) foraminiferal species are also included. Percentages of living and total per individual species represent the percentage out of living and total numbers for all species. Percentages of living deformed and total deformed per individual species represent the percentage out of the living and total for that species only. The whole number of living Ostracods is also included at the bottom of the table. L= living, T= total (live plus dead), Ld= living deformed, Td= total (live plus dead) deformed.

Table 1

TREATMENT 1A	Control plot with nutrient enrichment (no oil)																
Plot#/date	1A/week0	1A/week1		1A/week3		1A/week5		1A/week8		1A/week10		1A/week14		1A/week18		1A/week22	
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E6	C2	E4	B2	F6	A3	D6	A1	
Total # of species (L)	8	3	4	6	5	5	6	5	6	6	5	6	7	5	6	5	
/10cc (T)	9	6	6	7	7	6	8	5	7	7	6	6	7	5	6	6	
Total # of individuals (L)	1224	1928	1272	1824	2824	2536	2536	4000	4248	2056	1760	3136	3296	3256	2624	2952	
/10cc (T)	3408	3368	2512	2672	4912	4008	4568	5624	5744	3216	3512	4624	4328	4136	3360	3808	
Eggerella advena (L)	0.65	0	0	0	0	0	0	0	0	0.39	0	0	0.73	0	0.3	0.27	
(T)	0.94	0	0	0	0	0	0.18	0	0	0.25	0.23	0	0.74	0	0.24	0.21	
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Inner linings (L)	0.65	0	0	3.07	0.85	0.68	0.32	1	1.69	3.11	1.82	0.77	1.7	0.25	0.61	0	
(T)	0.7	0	0	3.59	1.79	1.2	0.88	1.56	2.65	2.99	4.56	1.38	2.4	1.35	2.14	1.89	
Miliammina fusca (L)	3.27	1.66	27	5.26	28	12.5	19.2	5.6	12.3	3.89	10.9	5.1	33.7	3.69	18.3	0.54	
(Ld)	20	0	0	8.3	4.04	0	3.28	3.57	0	10	0	0	1.44	0	0	0	
(T)	13.6	2.14	23.9	6.29	33.2	13.4	20.5	6.97	14.2	6.22	11.4	5.88	32.3	3.48	14.8	1.26	
(Td)	6.9	0	0	4.76	2.94	0	2.15	2.04	0	4	0	2.94	1.71	0	0	0	
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0.16	0	0.18	0	0.14	0	0	0	0	0	0	0	
Thecamoebians (L)	0	0	0	0.44	0	0	0.63	0	0.19	0	0	0	0	0	0	0	
(T)	0.23	0	0	0.3	0.16	0.6	0.7	0	0.28	0.25	0	0	0	0	0	0	
Tiphotrocha comprimata (L)	0.65	0	0	0	0	0	0	0	0	0	0	0.51	0.24	0	0	0	
(T)	0.23	0.48	1.59	0.3	0	0	0	0	0	0	0	0.87	0.55	0	0	0	
Trocha.inflata (L)	0	1.66	1.89	2.19	1.13	5.05	1.56	4.8	1.51	3.5	0.45	5.87	1.7	13	2.74	5.96	
(Ld)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	1.9	0.96	2.1	0.65	4.39	1.23	4.55	1.39	3.48	0.23	5.02	1.29	11	2.14	5.04	
(Td)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.macrescens (L)	0.65	0	1.26	0	0			0	0	0	0	0	0	0	0	0	
(T)	1.17	0.48	0.64	0	0			0	0	0	0	0	0	0	0	0	
Trocha.mac.polystoma (L)	86.3	96.7	69.8	87.7	69.4	80.7	77.6	88	78.3	86.8	82.7	86.7	58.3	81.8	76.5	93	
(Ld)	0	0	0	0.5	0	0	0	0.23	0	0	0	0	0	0	0	0	
(T)	74.2	92.6	68.2	76.3	58.8	78.6	73	82.8	78.4	78.9	72.2	83	57.5	81.2	75.5	90.5	
(Td)	0	0	0	0.39	0	0	0	0.17	0	0	0	0	0	0	0	0	
Trocha.ochracea (L)	0.65	0	0	1.32	0.57	0.68	0.63	0.6	1.69	2.33	4.09	1.02	3.64	1.23	1.52	0.27	
(T)	4.69	2.38	4.78	11.1	5.21	1.8	3.33	4.13	2.92	7.96	11.4	3.81	5.18	2.9	5.24	1.05	
Ostracods (T#)	16	48	128	96	240	8	88	72	8	8	8	0	8	8	16	8	

TREATMENT 2A	Control plot with nutrient enrichment (no oil)																
Plot#/date	2A/week0	2A/week1		2A/week3		2A/week5		2A/week8		2A/week10		2A/week14		2A/week18		2A/week22	
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E6	C2	E4	B2	F6	A3	D6	A1	
Total # of species (L)	5	3	4	7	5	7	7	5	6	5	4	5	5	7	6	5	
/10cc (T)	9	5	7	7	7	8	8	5	7	5	5	5	5	7	6	5	
Total # of individuals (L)	1664	2592	1520	2976	2656	3584	1752	3544	3088	2376	2528	1456	3584	4440	3720	3704	
/10cc (T)	3976	5952	4952	4800	5584	4896	2424	5608	4600	3528	4192	2640	4752	5760	5168	5760	
Eggerella advena (L)	0	0	0	0.27	0	0.45	0.46	0	0	0	0	0	0	0.18	0	0	
(T)	0.4	0	0	0.33	0	0.33	0.33	0	0	0	0	0	0	0.14	0	0	
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0.32	0	0	0	0	0	0	0	0	0	0	0	0	0	
Inner linings (L)	1.92	0	0	1.88	0.6	1.12	1.37	0.45	0.26	0.67	0	1.1	0.45	0.54	1.72	1.73	
(T)	1.61	0	0	5.17	1.88	1.14	2.31	1	1.39	1.59	1.34	1.82	0.84	0.56	2.48	2.64	
Miliammina fusca (L)	1.44	7.41	7.37	10.8	12.3	17	6.85	12	6.22	7.07	18	3.85	6.03	3.7	12.5	5.18	
(Ld)	0	0	0	12.5	22	2.63	6.67	0	0	4.76	1.75	0	0	0	1.72	0	
(T)	5.63	13.2	18.9	11.2	20.9	15.7	7.26	12.1	8.52	7.03	20	6.97	8.52	3.75	12.2	6.81	
(Td)	0	0	0	10.4	2.05	2.08	4.55	0	0	3.23	0.95	0	0	0	1.27	0	
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0.2	0.13	0.16	0	0.14	0.16	0	0	0.17	0	0	0	0	0	0	0	
Thecamoebians (L)	0	0	0	0	0	0	0.46	0	0.26	0	0	0	0	0	0	0	
(T)	0	0	0	0	0.14	0	0.33	0	0.17	0	0	0	0	0	0	0	
Tiphotrocha comprimata (L)	0	0	0	0.27	0	0.22	0	0	0	0	0	0	0	0.18	0.22	0	
(T)	0.4	0	0.32	0.17	0	0.16	0	0	0	0	0	0	0	0.14	0.48	0	
Trocha.inflata (L)	0	15.4	14.7	9.41	13.9	13.6	5.02	7.9	20.7	7.41	10.4	6.59	10.7	7.57	17.2	10.6	
(Ld)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	9.68	7.43	8.17	10.5	13.6	4.29	8.13	19.3	6.35	9.54	7.58	10.3	7.22	14.7	7.92	
(Td)	0	0	0	2.04	1.37	0	0	0	0	0	0	0	0	0	0	0	
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.mac.polystoma (L)	90.4	77.2	77.4	75.5	72.6	67	83.1	78.6	71.2	84.8	69	87.9	82.6	86.8	66.2	82.1	
(Ld)	0	0	0	0.71	0	0	0	0.29	0	0	0	0	0	0	0	0.53	
(T)	82.5	74.7	68.7	69.8	83.2	65.5	79.5	74.8	67.5	78.2	59.4	79.4	79.1	83.9	65.2	76.9	
(Td)	0	0	0	0.95	0.45	0	0	0.19	0	0	0	0.38	0	0	0	0.36	
Trocha.ochracea (L)	0	0	0.53	1.88	0.6	0.67	2.74	1.13	1.3	2.69	2.53	0.55	0.22	0.9	2.15	0.43	
(T)	2.41	2.28	4.2	5.17	3.3	3.43	5.94	3.99	2.96	6.8	9.73	4.24	1.35	4.31	4.95	5.69	
Ostracods (T#)	112	48	16	176	88	48	8	32	64	0	8	0	8	0	40	40	

Table A-2 Table of results for foraminiferal occurrences for Treatment A (Control plot with nutrient enrichment; no oil), Plot 3 and for Treatment B (Control plot without nutrient enrichment; no oil), Plot 1, for weeks 0-22. Same format as Table A-1.

Table 2

TREATMENT 3A	Control plot with nutrient enrichment (no oil)																	
Plot#/date	3A/week0	3A/week1		3A/week3		3A/week5		3A/week8		3A/week10		3A/week14		3A/week18		3A/week22	
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5	A3	D6	A1	
Total # of species (L)	5	4	4	8	6	7	6	7	7	6	5	5	5	6	6	6	
/10cc (T)	7	6	5	9	8	8	7	8	8	6	6	6	7	6	6	8	
Total # of individuals (L)	1480	3760	4280	5984	8768	7368	8488	3104	3976	5312	5808	7296	5632	7616	6464	7672	
/10cc (T)	4808	10184	15088	8152	11824	10512	15208	5384	7144	6840	7664	10176	7648	9360	8176	9904	
Eggerella advena (L)	0	0	0	0.13	0	0	0	0.26	0	0.15	0.28	0.11	0	0	0	0	
(T)	0.5	0	0	0.1	0	0	0	0.3	0	0.12	0.31	0.16	0.1	0	0	0.08	
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Glomospira gordialis (L)	0	0	0	0.13	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0.1	0	0	0	0	0	0	0	0	0.1	0	0	0	
Inner linings (L)	2.16	0	0	0.27	1.09	0.22	0.57	2.32	0.4	0.75	0	0	0.28	0.42	0.12	0.1	
(T)	1	0	0	1.28	1.89	0.61	1.05	3.27	0.34	1.17	0.94	0.24	0.73	0.68	0.68	0.32	
Miliammina fusca (L)	25.9	52.9	39.1	58.3	61	62.9	51.7	55.9	33.6	49.1	50.1	49.8	34.1	40.1	40.5	62.4	
(Ld)	0	0	0	3.44	3.59	1.73	1.82	3.23	0.6	0.92	0.55	1.54	0.83	1.05	0.61	1.17	
(T)	49.4	66.8	58.9	54.8	58.7	53.4	52.6	50.1	40.6	44.1	44.1	51.3	38	37.8	37.3	57.6	
(Td)	0	0	0	2.86	3.46	1.42	1.7	3.26	0.28	0.8	0.47	1.07	0.55	0.9	0.52	0.98	
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0.17	0.24	0	0.1	0.41	0.46	0.68	0.15	0.22	0	0.21	0	0	0	0	0	
Thecamoebians (L)	0	0	0	0.27	0	0.43	0.09	1.03	0.4	0	0	0	0	0	0	0	
(T)	0	0	0	0.49	0.41	0.91	0.37	0.74	1.07	0	0.1	0	0	0	0	0.32	
Tiphotrocha comprimata (L)	0	0.21	0	0	0.27	0.11	0	0	0.2	0	0	0	0	0.21	0.25	0.21	
(T)	0	0.08	0.16	0	0.27	0.08	0	0	0.11	0	0	0	0	0.17	0.19	0.16	
Trocha.inflata (L)	0	1.49	5.42	1.74	2.01	2.93	2.83	1.03	2.62	2.56	2.2	3.62	2.7	4.73	4.58	5.84	
(Ld)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	1.1	3.08	1.77	1.83	3.5	2.74	1.19	3.53	2.22	1.98	3.69	3.14	4.36	4.01	5.49	
(Td)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.mac.polystoma (L)	21.6	45.3	55.3	38.9	35	33.2	44.5	37.6	62.2	46.8	46.9	46.2	62.6	53.7	53.6	31.2	
(Ld)	0	0	0	0.69	0	0	0	0	0	0	0	0.24	0	0	0	0	
(T)	44.4	30.1	38.8	39.1	35.7	39	41.1	36.3	51.3	48.3	48.7	43.3	58.1	55.5	55.9	33.7	
(Td)	0	0	0	0.5	0	0	0	0	0	0	0	0.18	0	0	0	0	
Trocha.ochracea (L)	1.08	0	0.19	0.27	0.55	0.22	0.28	1.8	0.6	0.75	0.41	0.33	0.28	0.84	0.99	0.31	
(T)	3	1.73	1.11	2.36	2.84	1.98	1.53	8.02	3.14	4.09	3.85	1.26	1.88	1.54	1.9	2.34	
Ostracods (T#)	0	80	120	48	88	56	40	48	8	40	24	0	0	8	8	152	

TREATMENT 1B	Control plot without nutrient enrichment (no oil)																	
Plot#/date	1B/week0	1B/week1		1B/week3		1B/week5		1B/week8		1B/week10		1B/week14		1B/week18		1B/week22	
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5	A3	D6	A1	
Total # of species (L)	6	3	3	6	5	6	7	6	6	6	5	7	5	6	6	6	
/10cc (T)	8	5	5	8	8	8	9	7	7	6	6	7	8	6	7	6	
Total # of individuals (L)	896	2008	960	2440	2176	2944	2056	3704	3304	2808	1696	1080	2224	3032	2944	3576	
/10cc (T)	2040	4976	3224	4048	4336	5448	3744	5376	4656	5344	2512	1432	3968	3680	3488	4721	
Eggerella advena (L)	0	0	0	1.31	0	0.27	0.39	0	0.24	0.28	0	1.48	0	1.06	0.27	0.45	
(T)	0.69	0	0	0.79	0	0.15	0.21	0.3	0.69	0.15	0	1.12	0.2	1.03	0.23	0.68	
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Inner linings (L)	1.79	0	0	1.31	1.1	0.54	1.95	1.73	0.97	0.57	1.89	0.74	0.72	0.28	0.27	0.67	
(T)	1.96	0	0	2.37	3.32	1.47	1.93	1.49	1.37	1.8	4.78	2.79	1.2	1.03	0.46	1.36	
Miliammina fusca (L)	9.82	5.54	1.83	3.93	6.25	12.8	10.9	7.13	13.8	10.5	4.24	8.15	18.3	12.4	5.16	16.8	
(Ld)	24.3	0	0	0	0	0	0	0	0	0	22.2	0	3.92	0	0	1.33	
(T)	13.3	13	11.7	8.3	13.7	10.2	20.1	5.95	13.4	17.2	7.96	8.38	25.6	10.7	4.82	15.3	
(Td)	13.2	0	0	2.38	0	0	0	0	0	0	8	0	1.57	0	0	1.11	
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0.49	0.2	0.74	0.73	0.43	0	0	0	0.32	0	0	0	0	0	
Thecamoebians (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	1.18	0	0	0.4	0.55	0.29	0.21	0	0.52	0	0	0	0.2	0	0	0	
Tiphotrocha comprimata (L)	1.79	0	0	0	0	0	0.39	0.22	0	0	0	1.48	0	0	0	0	
(T)	0.78	0.16	0	0	0	0	0.21	0.15	0	0	0	1.12	0.2	0	0.23	0	
Trocha.inflata (L)	0	8.76	4.17	5.57	8.46	3.53	5.84	6.05	4.6	12	3.3	5.93	2.16	7.39	5.71	3.36	
(Ld)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	4.98	2.23	4.55	5.35	2.5	4.27	5.36	4.81	8.38	2.55	4.47	3.02	6.39	5.05	3.23	
(Td)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.mac.polystoma (L)	66.1	85.7	94.2	85.6	82.7	82.1	79.4	82.7	78.9	75.5	87.7	80	77.7	78.8	85.3	77.9	
(Ld)	0	0	0	0	0	0.66	0	0.52	0	0	0	0	0	0	0	0	
(T)	66.7	77.6	78.7	78.1	69.6	80.6	68.4	81.4	74.2	82.4	78.4	75.4	66.9	75.5	83.3	75.7	
(Td)	0	0	0	0	0.27	0.55	0	0.55	0	0	0	0	0	0	0	0	
Trocha.ochracea (L)	1.79	0	0	2.29	1.47	0.82	1.17	2.16	1.45	1.14	2.83	2.22	1.08	2.11	3.26	0.89	
(T)	5.1	4.18	6.95	7.31	6.64	3.96	4.27	4.61	4.98	10	7.96	6.7	2.62	5.36	5.96	4.92	
Ostracods (T#)	24	40	8	104	64	32	8	24	16	0	8	0	0	8	16	0	

Table A-3 Table of results for foraminiferal occurrences for Treatment B (Control plot without nutrient enrichment; no oil), Plot 2 and 3, for weeks 0-22. Same format as Table A-1.

Table 3

TREATMENT 2B	Control plot without nutrient enrichment (no oil)																	
Plot#/date	2B/week0	2B/week1		2B/week3		2B/week5		2B/week8		2B/week10		2B/week14			2B/week18		2B/week22
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5		A3	D6	A1
Total # of species (L)	4	3	4	4	5	6	4	5	5	5	5	5	5		6	5	3
/10cc (T)	6	8	6	6	7	8	6	6	5	6	5	5	6		6	6	5
Total # of individuals (L)	768	1656	1084	1688	1736	909	3392	2856	3484	2544	3416	2504	1704		2016	2632	4600
/10cc (T)	2104	4384	4592	2592	3144	1381	4792	3696	5544	3824	4936	3264	2200		2504	3408	6224
Eggerella advena (L)	0	0	0	0	0	0	0	0	0	0	0	0	0.47		0	0	0
(T)	0	0	0	0	0	0.14	0	0	0	0.21	0	0	0.36		0	0	0
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
Inner linings (L)	2.08	0	0	1.42	0.46	0.44	0	0.56	0	0.31	0.47	0.32	0.47		0.79	0	0
(T)	1.52	0	0	2.47	0.51	1.16	1.17	0.65	0.72	1.67	0.81	0.49	0.73		1.28	0.94	0.13
Miliammina fusca (L)	3.13	1.93	2.26	1.42	5.99	1.98	12.7	8.68	3.23	5.66	7.03	3.83	2.82		8.33	12.5	3.83
(Ld)	0	0	0	0	7.89	5.56	1.85	0	0	0	0	0	0		4.76	0	0
(T)	3.04	8.03	6.27	3.4	10.2	2.81	13.5	7.58	4.62	5.02	7.29	4.41	2.91		7.02	12.4	5.01
(Td)	0	0	0	0	5	2.78	1.23	0	3.13	0	0	0	0		4.54	0	0
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
(T)	0	0.18	0	0.31	0	0.07	0	0	0	0	0	0	0		0	0	0
Thecamoebians (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
(T)	0	0.18	0	0	0.25	0	0	0	0	0	0	0	0		0	0	0
Tiphotrocha comprimata (L)	0	0	1.5	0	0.46	0.22	0.24	0.28	0	0	0	0	0		0.79	0.91	0
(T)	0.76	0.73	0.7	0	0.25	0.14	0.17	0.43	0	0	0	0	0		0.64	0.7	0
Trocha.inflata (L)	0	24.6	13.5	4.74	45.2	15.4	13.2	13.2	18	15.4	16.2	5.43	8.92		11.1	12.2	8.52
(Ld)	0	0	0	0	0	0	0	2.13	0	0	0	0	0		0	0	0
(T)	0	21.9	16	3.7	39.4	14.5	11.4	12.3	18.2	17.2	15.2	4.9	7.34		10.9	10.6	8.48
(Td)	0	0	0	0	0	0	0	1.75	0	0	0	0	0		0	0	0
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
(T)	0	0.36	0.17	0	0	0	0	0	0	0	0	0	0		0	0	0
Trocha.mac.polystoma (L)	77.1	73.4	82.7	92.4	47.9	81.8	73.8	77.3	76.8	77.6	75.4	90.1	87.3		78.2	74.5	87.7
(Ld)	0	0	0	0.51	0	0	0.64	1.09	0	0	0	0	0		0	0	0.2
(T)	78.7	67.5	74.7	87.9	48.3	79.7	72.8	77.8	76.3	73	73.6	89.2	87.3		77	72.1	85.9
(Td)	0	0	0	0.35	0	1.45	0.46	0.84	0.19	0	0	0	0		0	0	0.3
Trocha.ochracea (L)	0	0	0	0	0	0.11	0	0	0	1.26	0.94	0.32	0		0.79	1.22	0
(T)	2.66	1.28	2.09	2.16	1.02	1.87	1	1.3	0.14	2.93	3.08	0.98	1.09		2.88	3.29	0.51
Ostracods (T#)	168	40	128	40	80	13	160	48	16	0	0	0	16		16	24	40
TREATMENT 3B	Control plot without nutrient enrichment (no oil)																	
Plot#/date	3B/week0	3B/week1		3B/week3		3B/week5		3B/week8		3B/week10		3B/week14			3B/week18		3B/week22
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5		A3	D6	A1
Total # of species (L)	4	4	4	6	6	7	5	7	6	5	6	6	5		4	4	4
/10cc (T)	5	5	6	7	9	7	5	8	7	5	6	6	5		5	5	6
Total # of individuals (L)	288	1704	1760	3644	2936	2144	3988	3232	2288	4472	3152	2296	2832		3936	2312	2288
/10cc (T)	2080	3744	5952	5224	4520	2856	5400	5168	3648	5552	4120	2944	4336		5560	3056	3368
Eggerella advena (L)	0	0	0	0	0	0	0	0	0	0	0	0.7	0		0	0	0
(T)	0	0	0	0	0	0	0	0	0.22	0	0	0.54	0		0	0	0
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
(T)	0	0	0	0	0.18	0	0	0	0	0	0	0	0		0	0	0
Inner linings (L)	5.56	0	0	1.1	0.82	0.37	0.4	0.25	0.35	0.36	0.51	1.05	0.56		0.81	0	0
(T)	0.77	0	0	1.99	1.59	1.12	0.74	0.82	0.44	0.43	0.78	0.82	0.55		0.43	1.05	0.95
Mil ammina fusca (L)	13.9	6.6	6.82	13.4	10.1	7.84	15.5	14.1	11.2	13.4	19.8	18.5	13		21.3	5.54	7.69
(Ld)	0	0	13.3	1.64	5.41	0	1.3	1.75	3.13	1.33	1.28	1.89	0		0	0	4.54
(T)	26.9	13.2	10.9	13.5	11.5	7.28	14.4	12.5	11.8	11.8	17.1	21.5	14.9		21.4	4.45	8.08
(Td)	0	6.45	7.4	1.14	3.1	0	1.03	1.23	1.85	1.22	1.14	1.27	0		0.67	0	2.94
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
(T)	0	0	0.13	0	0	0	0	0.15	0	0	0	0	0		0	0	0
Thecamoebians (L)	0	0	0	0.44	0	0.37	0	1.49	0.35	0	0.25	0	0		0	0	0
(T)	0	0	0	0.31	0	0.84	0	1.39	0.44	0	0.19	0	0		0	0	0.24
Tiphotrocha comprimata (L)	0	0.94	0.91	0	0.27	0.37	0	0.25	0	0	0	0	0		0	0	0
(T)	0	1.07	0.81	0.31	0.18	0.28	0	0.31	0	0	0	0	0		0	0	0
Trocha.inflata (L)	0	23	15.5	16.9	19.6	8.21	12.5	6.66	9.44	20.9	12.4	6.97	14.7		9.96	11.1	11.5
(Ld)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
(T)	0	14.1	7.39	14.5	14.2	6.72	11.3	6.66	8	18.4	9.71	5.71	12.2		8.92	8.64	10.2
(Td)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
Trocha.mac.polystoma (L)	69.4	69.5	78.8	68.3	68.7	82.1	70.4	77	77.6	64.9	66.2	72.5	70.9		67.9	83	80.4
(Ld)	0	0	0	0.64	0.79	0	0	0	0	0	0	0	0		0	0	0
(T)	67.3	70.1	78.9	68	69.6	81.2	71.3	77	77.9	68	70.7	69.6	69.7		66.6	82.5	78.1
(Td)	0	0	0	0.66	0.51	0	0	0	0	0	0	0	0		0	0	0
Trocha.ochracea (L)	0	0	0	0.44	0.54	0.75	1.21	0.25	1.05	0.36	0.76	0.35	0.85		0.81	0.35	0.35
(T)	1.92	1.5	1.88	1.38	2.83	2.52	2.37	1.39	2.63	1.3	1.55	1.9	2.58		2.59	3.4	2.38
Ostracods (T#)	0	88	96	48	32	32	8	16	8	0	0	8	0		16	0	104

Table A-4 Table of results for foraminiferal occurrences for Treatment C (Oiled plot with no treatments; natural attenuation), Plot 1 and 2, for weeks 0-22. Same format as Table A-1.

Table 4

TREATMENT 1C	Oiled plot without treatments (natural attenuation)																	
Plot#/date	1C/week0	1C/week1		1C/week3		1C/week5		1C/week8		1C/week10		1C/week14		1C/week18		1C/week22	
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5	A3	D6	A1	
Total # of species (L)	3	5	5	6	6	5	4	6	5	4	5	5	6	5	4	4	4
/10cc (T)	8	7	7	10	7	6	7	7	6	6	5	6	6	6	5	6	
Total # of individuals (L)	1552	8416	2448	4032	3344	3856	4528	5388	3912	4408	2608	4484	1632	1136	2584	3568	
/10cc (T)	3768	12752	8472	8288	5944	4984	7256	8288	5322	6936	4272	8064	3616	7952	6080	8976	
Eggerella advena (L)	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0.01	0.1	0	0.16	0	0	0	0	0	0	0	0	0	0.1	
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Glomospira gordialis (L)	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0.29	0	0	0	0	0	0	0	0	0	0	0	0	
Inner linings (L)	0	0	0	0.6	1.2	1.04	0	0.3	1.02	0	0.31	0.54	0.98	0	0.31	0.45	
(T)	0.21	0	0.01	1.25	1.88	1.93	0.22	1.16	1.5	0.58	0.94	0.99	1.99	0.4	0.66	0.53	
Miliammina fusca (L)	54.6	26.7	29.7	26.4	13.2	30.5	49.3	17.4	38	25	15.3	31.4	19.6	44.4	45.2	14.6	
(Ld)	3.77	16.7	39.6	21	21.8	15.6	12.5	1.79	16.5	7.97	22	5.71	10	23.8	26	7.69	
(T)	83.5	32.8	49.7	35.9	23.7	28.3	47.5	15.7	33.5	24.6	20	39.4	23.2	57.3	53.8	31.8	
(Td)	2.01	16	41.8	12.9	15.9	15.3	11.6	9.82	15.7	6.1	13.1	3.78	9.52	4.38	14.2	3.84	
Pseudo.limetis (L)	0	0	7.1	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0.21	0.19	13.3	0.39	0.27	0	0.44	0.29	0	0.35	0	0	0	0	0	0	
Thecamoebians (L)	0	0	0	0	0.24	0	0.35	0.3	0	0	0	0	0	0	0	0	
(T)	1.33	0.06	0	0.87	0.54	0	1.1	0.29	0.15	0	0	0	0	0.3	0	0	
Tiphotrocha comprimata (L)	0	0.19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0.21	0.13	0	0.1	0	0	0	0	0	0	0	0.1	0.22	0	0	0	
Trocha.inflata (L)	0	4.85	6	12.9	3.59	2.9	7.42	6.26	3.48	5.63	1.84	6.81	3.43	2.82	5.26	7.4	
(Ld)	0	0	0	1.16	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	4.02	2.5	11	2.96	2.57	6.39	5.89	3.61	4.84	1.31	5.65	5.31	4.53	4.34	6.6	
(Td)	0	0	0	0.88	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.mac.polystoma (L)	41.8	67.7	56.5	55.5	80.9	63.5	42.9	75.6	59.1	68.8	81.9	60.2	75	52.1	49.2	77.6	
(Ld)	0	22.5	0	2.15	1.48	1.31	3.29	0.59	0.35	0	1.12	0.89	1.31	0	1.26	0	
(T)	31.2	61.1	32.9	48.8	68.4	61.8	43.1	74.8	59.4	67.7	73.8	52	66.4	38.1	40	59	
(Td)	0	2.05	0	1.78	0.98	1.56	2.81	0.77	0.51	0	0.76	1.34	1.33	0.84	0.66	0	
Trocha.ochracea (L)	0	0.67	0.3	0	0.96	2.07	0	0.15	0.41	0.54	0.61	1.08	0.98	0.7	0	0	
(T)	1.06	0.02	1.4	1.35	2.29	5.3	1.21	2.02	1.8	1.96	3.93	1.88	2.88	1.31	1.18	1.96	
Ostracods (T#)	8	80	136	64	16	8	72	56	16	0	8	16	0	0	8	0	
TREATMENT 2C	Oiled plot without treatments (natural attenuation)																
Plot#/date	2C/week0	2C/week1		2C/week3		2C/week5		2C/week8		2C/week10		2C/week14		2C/week18		2C/week22	
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5	A3	D6	A1	
Total # of species (L)	5	4	4	5	5	7	6	5	4	5	5	6	5	5	6	5	
/10cc (T)	6	5	6	6	7	8	7	5	6	5	5	6	5	6	7	6	
Total # of individuals (L)	1248	3376	1752	2216	1776	3784	4544	2664	2000	2776	2792	2952	2224	3032	1192	1712	
/10cc (T)	3072	7032	3608	3592	3400	5304	5952	4488	5624	4048	4040	4304	3464	4528	3288	3360	
Eggerella advena (L)	0	0	0	0	0	0.21	0.35	0	0	0	0	0.27	0	0	0	0	
(T)	0	0	0	0	0	0.45	0.27	0	0	0	0	6.32	0	0	0.24	0.24	
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Inner linings (L)	3.85	0	0	1.44	0.9	1.48	1.06	1.82	0.8	0.86	0.57	2.71	1.08	0.53	0.67	0.47	
(T)	2.86	0	0	3.79	3.76	3.77	1.61	3.74	1.99	2.77	2.57	3.53	3.23	1.41	1.48	1.67	
Miliammina fusca (L)	11.5	4.03	13.2	7.22	15.8	20.5	16.2	12.4	6	14.7	14.9	13.6	14.7	18.2	8.72	13.6	
(Ld)	11.1	11.8	44.8	15	14.3	21.6	16.3	7.32	20	17.6	13.5	16	4.88	15.9	0	34.5	
(T)	23.7	10	23.9	6.45	16.7	17.9	15.5	10.9	12.9	13.6	15	13.9	18.9	17.5	11.4	19.8	
(Td)	5.49	20.5	30	13.8	9.86	18.5	15.6	4.93	13.2	14.5	11.8	13.3	4.88	12.1	4.26	14.5	
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0.22	0	0.24	0.3	0	0	0	0	0	0	0	0	0	0	
Thecamoebians (L)	0	0	0	0	0	0.21	0	0	0	0	0	0	0	0	0	0	
(T)	0	0.11	0.22	0	0.24	0.3	0	0	0	0	0	0	0	0	0	0	
Tiphotrocha comprimata (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.67	0	
(T)	0.26	0	0	0.22	0	0	0	0	0	0	0	0	0	0.18	0.48	0	
Trocha.inflata (L)	0	9.95	19.6	4.69	12.6	8.03	6.16	10.3	16.4	17	6.88	3.25	6.12	2.84	7.38	14.5	
(Ld)	0	0	0	0	3.57	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	7.05	25.1	3.34	8.71	6.49	5.24	7.13	11.1	12.6	5.94	2.79	4.16	2.47	7.3	8.57	
(Td)	0	0	0	0	2.7	0	0	0	0	0	0	0	0	0	0	0	
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.mac.polystoma (L)	72.4	85.1	65.8	84.1	70.3	66.6	75.7	75	76.8	66.3	75.4	79.1	77	76.5	81.9	70.6	
(Ld)	0	0.28	0	1.72	0	0.32	0	0	0.52	0	1.14	0	0	0.34	0	1.99	
(T)	61.5	79.3	57.9	75.1	67.1	64.4	74.7	68.3	71	62.8	70.7	72.7	67.9	73.3	73.7	61.9	
(Td)	0	0.14	0	2.08	0.7	0.47	0	0	0.4	0	0.84	0	0	0.24	0	1.15	
Trocha.ochracea (L)	2.56	0.95	1.37	2.53	0.45	2.96	0.53	1.21	0	1.15	2.29	1.08	1.08	2.11	0.67	0.93	
(T)	5.99	3.53	5.54	11.1	3.29	6.33	2.69	9.09	2.84	8.1	5.74	6.32	5.77	5.12	5.35	7.86	
Ostracods (T#)	48	56	40	240	24	16	32	40	32	0	0	16	8	8	0	0	

Table A-5 Table of results for foraminiferal occurrences for Treatment C (Oiled plot with no treatments; natural attenuation), Plot 3 and for Treatment D (Oiled plot with nutrient enrichment), Plot 1, for weeks 0-22. Same format as Table A-1.

Table 5

TREATMENT 3C	Oiled plot without treatments (natural attenuation)																	
Plot#/date	3C/week0	3C/week1		3C/week3		3C/week5		3C/week8		3C/week10		3C/week14			3C/week18		3C/week22	
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5		A3	D6	A1	
Total # of species (L)	5	3	3	7	6	5	5	6	3	4	5	4	3		5	5	4	
/10cc (T)	5	9	5	7	8	6	6	7	7	4	5	6	6		6	5	5	
Total # of individuals (L)	1464	1072	2944	2432	3664	2024	2672	4144	2320	3112	2328	2256	2128		2992	3264	432	
/10cc (T)	3808	5120	6496	3168	5064	3040	3768	5920	4648	4064	3176	3328	2744		5504	5832	3768	
Eggerella advena (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0.48	0.29		0	0	0	
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
(T)	0	0.16	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
Inner linings (L)	0.55	0	0	0.99	0	2.77	0	0.19	0	0	0.34	0	0		0.28	0.49	1.85	
(T)	0.42	0	0	1.77	0.95	2.63	0.64	0.41	0	0	1.26	1.66	0.29		0.44	0.55	0.42	
Miliammina fusca (L)	14.2	14.9	3.26	5.59	19.2	19.4	7.78	26.8	8.97	15.9	14.8	26.6	15.4		9.68	9.56	7.41	
(Ld)	0	10	25	5.88	5.68	5.53	15.4	11.5	1.03	3.23	2.33	14.7	7.93		2.86	5.13	50	
(T)	32.4	20.9	9.11	5.05	14.8	17.1	6.79	25.5	8.78	13	12.6	27.4	12.5		12.4	11	37.6	
(Td)	0.65	20.1	14.9	5	5.32	21.5	15.6	10.1	7.84	3.03	2	11.4	16.3		3.53	2.5	1.13	
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
(T)	0	0.16	0	0	0.16	0	0	0.14	0.52	0	0	0	0		0	0	0	
Thecamoebians (L)	0	0	0	0.66	0.22	0	0	0	0	0	0	0	0		0	0	0	
(T)	0	0.78	0.12	0.76	0.16	0.26	0	0.27	0.69	0	0	0	0		0	0	0	
Tiphotrocha comprimata (L)	0	0	0	0.33	0.22	0	0.6	0	0	0	0	0	0		0	0	0	
(T)	0	0.16	0	0.25	0.32	0	0.64	0	0.17	0	0	0	0		0.15	0	0	
Trocha.inflata (L)	0	23.1	29.3	7.89	11.8	11.1	13.2	14.9	14.6	14.6	21.3	20.6	11.6		22.4	13.7	18.5	
(Ld)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
(T)	0	15.5	44.8	6.57	10.4	9.21	10.4	13.8	12.7	12.2	19.4	18.8	9.91		18.9	12.1	20.2	
(Td)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
Trocha.mac.polystoma (L)	67.2	61.9	67.4	83.9	68.1	64.4	77.5	57.7	76.2	69.2	62.5	52.5	72.9		75.5	75.7	72.2	
(Ld)	0	0	1.61	1.18	0.32	0.61	0.39	0	0	1.12	2.2	0	1.03		0	0	0	
(T)	55	60.2	69.3	83.6	72	67.6	79.6	58.8	78.1	73.8	62.5	49.8	75.8		65.3	73.1	38.6	
(Td)	0	0.78	0.89	1.21	0.44	1.56	0.53	0	0	1.07	2.82	1.45	0.77		0	0	0	
Trocha.ochracea (L)	0.55	0	0	0.66	0.44	2.37	0.9	0.39	0	0.26	1.03	0.35	0		0.83	0.49	0	
(T)	2.52	1.72	1.11	2.02	1.11	3.16	1.91	1.08	1.03	0.98	4.28	1.92	1.17		2.91	3.16	3.18	
Ostracods (T#)	192	48	128	16	24	24	104	0	24	0	0	0	0		0	0	8	
TREATMENT 1D	Oiled plot with nutrient enrichment																	
Plot#/date	1D/week0	1D/week1		1D/week3		1D/week5		1D/week8		1D/week10		1D/week14			1D/week18		1D/week22	
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5		A3	D6	A1	
Total # of species (L)	5	4	5	6	6	5	4	5	6	6	5	5	5		5	4	5	
/10cc (T)	7	6	7	8	8	8	7	7	7	6	6	6	6		6	6	5	
Total # of individuals (L)	728	464	2168	520	1328	1048	1632	816	880	400	1560	1256	1128		1048	794	2376	
/10cc (T)	1424	1528	4280	1128	2184	1480	2216	1400	1384	1160	2744	2728	2360		1752	2280	4112	
Eggerella advena (L)	0	0	0	1.54	0.6	0	0	0	0	2	0.51	0	0.71		0	1.01	0	
(T)	0	0	0	0.71	0.73	0	0.36	2.29	0.58	1.38	0.87	0.29	1.02		0.91	0.35	0	
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
(T)	0	0.52	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
Inner linings (L)	3.3	0	0	10.8	4.82	0.76	0	0	5.45	2	0	6.37	7.8		3.05	0	1.68	
(T)	5.62	0	0.56	16.3	5.13	2.16	3.61	1.71	6.67	4.83	0.58	7.62	7.12		3.65	1.05	3.11	
Miliammina fusca (L)	1.1	3.45	12.2	23.1	9.04	6.87	22.5	11.7	25.5	12	28.2	9.55	19.1		13.7	23.2	36.7	
(Ld)	0	0	24.2	20	20	22.2	13	22.2	6.36	0	12.7	0	14.8		27.8	4.35	9.17	
(T)	2.81	7.32	17.8	16.3	11.7	4.86	19.1	9.14	20.8	12.4	25.4	11.1	26.8		13.2	23.2	35.8	
(Td)	0	21.4	20	17.4	18.9	22.2	11.3	18.8	22.2	0	13.8	0	8.86		24.1	1.52	5.46	
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
(T)	0.56	0	0.19	0.71	0.37	0.54	0.36	0	0	0	0	0	0		0	0	0	
Thecamoebians (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
(T)	0	0	0	0.71	0.6	0.54	0	0	0	0	0	0	0		0	0	0	
Tiphotrocha comprimata (L)	0	0	0	0	0	0	0	2.6	0.91	0	0	0	0		0	0	0	
(T)	0.56	0.52	0.19	0	0	0.54	0	1.14	0.58	0	0	0	0		0	0	0	
Trocha.inflata (L)	0	1.72	9.23	1.54	0.6	2.29	1.47	5.19	1.82	2	3.1	4.46	8.51		0.76	0	1.35	
(Ld)	0	0	4	0	0	0	0	0	0	0	0	0	0		0	0	0	
(T)	0	1.57	5.61	0.71	0.37	2.7	1.44	5.14	1.16	1.38	3.21	4.69	4.41		0.46	1.75	1.38	
(Td)	0	0	3.33	0	0	0	0	0	0	0	0	0	0		0	0	0	
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	
Trocha.mac.polystoma (L)	91.2	93.1	78.2	61.5	83.7	87.8	73.5	75.3	64.5	78	64.6	77.7	63.8		80.9	92.7	59.3	
(Ld)	0	0	1.42	0	0	0.76	0.67	0	0	0	0	1.64	0		1.89	0	0	
(T)	78.1	73.3	69	50.4	75.8	83.8	69.7	62.3	56.1	55.8	59.5	64.2	51.9		68.5	67.7	51.3	
(Td)	0	0.71	1.08	0	0	0.65	0.52	0	0	0	0	0.91	0		1.33	0	0	
Trocha.ochracea (L)	1.1	0.02	0.37	1.54	1.2	2.29	2.45	5.19	1.82	4	3.59	1.91	0		1.53	4.03	1.01	
(T)	9.55	16.7	6.72	14.2	5.49	4.86	5.42	16.3	12.1	24	10.5	12	6.81		13.2	5.96	4.86	
Ostracods (T#)	32	120	128	16	40	32	48	24	96	0	0	24	8		16	0	0	

Table A-6 Table of results for foraminiferal occurrences for Treatment D (Oiled plot with nutrient enrichment), Plot 2 and 3, for weeks 0-22. Same format as Table A-1.

Table 6

TREATMENT 2D	Oiled plot with nutrient enrichment																	
Plot#/date	2D/week0	2D/week1		2D/week3		2D/week5		2D/week8		2D/week10		2D/week14		2D/week18		2D/week22	
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5	A3	D6	A1	
Total # of species (L)	4	5	4	5	6	6	6	7	6	6	5	5	5	5	5	5	
/10cc (T)	5	6	5	7	7	6	7	8	6	7	5	6	5	7	5	6	
Total # of individuals (L)	1096	1656	1680	2224	1776	3216	1784	3040	1960	2128	1880	2368	2176	2880	1720	1256	
/10cc (T)	2768	4328	3680	5400	3360	4072	3248	4904	3344	3152	3096	3496	3096	4448	2992	4232	
Eggerella advena (L)	0	0	0	0	0.9	0	0.45	0	0	0	0	0	0	0.56	0	0	
(T)	0	0	0	0.15	0.48	0	0.25	0	0	0.25	0	0.23	0	0.54	0	0.19	
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Inner linings (L)	3.85	0	0	2.16	2.7	1	0.9	2.63	2.86	1.13	2.55	2.36	0.74	0	0.47	1.27	
(T)	3.76	0	0	4.74	3.57	2.55	5.17	4.57	5.26	3.55	3.62	4.35	2.07	0.54	1.6	2.27	
Miliammina fusca (L)	15.3	5.31	22.9	37.4	21.2	20.6	32.7	39.2	24.1	26.6	26.8	22	11	13.3	31.2	15.9	
(Ld)	0	27.3	27.1	14.4	21.3	14.5	20.5	21.5	8.47	12.2	12.7	6.15	16.7	6.25	11.9	28	
(T)	37.9	13.3	34.8	43.9	28.3	17.9	38.9	35.2	22.5	28.4	24.8	26.1	11.9	12.2	34.5	25.3	
(Td)	0.78	18.1	28.3	10.5	16.8	15.4	16.5	19.4	11.7	11.6	8.33	5.26	10.9	4.41	8.53	9.7	
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0.37	0.22	0.3	0.24	0	0	0.82	0	0	0	0	0	0	0	0	
Thecamoebians (L)	0	0.97	0	0	0	0	0	0.26	0	0.38	0	0	0	0	0	0	
(T)	0	0.37	0	0	0	0	0.25	2.45	0	0.25	0	0	0	0	0	0	
Tiphotrocha comprimata (L)	0	0	0	0	0	0.25	0	0.26	0.82	0	0	0	0	0	0	0	
(T)	2.6	0	0	0	0	0.2	0	0.16	0.48	0	0	0	0	0.36	0	0	
Trocha.inflata (L)	0	5.31	5.23	4.68	5.41	3.48	2.24	5	1.22	6.02	2.13	3.04	8.09	9.72	2.33	3.82	
(Ld)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	2.59	2.39	2.37	3.57	3.54	1.23	4.89	0.96	5.08	1.29	2.29	6.72	7.19	2.14	2.27	
(Td)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.mac.polystoma (L)	78.1	86.5	71.4	55.4	69.4	72.6	81.9	51.1	70.2	38.8	65.1	72	79.4	75.6	65.6	77.1	
(Ld)	0	1.11	0.67	0	0	1.03	0	1.03	0	0	0	1.41	1.39	0	0	0.83	
(T)	53.8	75	56.7	41.6	57.4	71.3	48.8	41.4	65.3	50.8	56.6	64.1	73.6	71	57.5	57.5	
(Td)	0	0.49	0.38	0.36	1.24	0.83	0	1.97	0.37	0	0	1.43	1.4	0	0	1.32	
Trocha.ochracea (L)	0	1.93	0.48	0.36	0.45	1.99	1.79	1.58	0.82	4.14	3.4	0.88	0.74	0.83	0.47	1.91	
(T)	0	8.32	5.87	6.96	6.43	4.52	5.42	10.4	5.5	11.7	13.7	2.97	5.88	8.09	4.28	12.5	
Ostracods (T#)	16	224	104	128	32	16	8	48	16	0	8	0	0	16	8	0	
TREATMENT 3D	Oiled plot with nutrient enrichment																
Plot#/date	3D/week0	3D/week1		3D/week3		3D/week5		3D/week8		3D/week10		3D/week14		3D/week18		3D/week22	
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5	A3	D6	A1	
Total # of species (L)	3	4	4	6	6	6	7	8	6	5	5	6	3	6	4	5	
/10cc (T)	4	8	5	6	7	8	8	8	7	5	6	6	7	6	5	5	
Total # of individuals (L)	400	648	1216	1504	2800	1904	2808	1424	1568	1408	2904	1296	1096	1496	1264	1912	
/10cc (T)	968	1768	3944	1920	4000	2448	3880	2760	4000	2512	3992	2688	4312	2216	1848	3136	
Eggerella advena (L)	0	0	0	0	0	0.42	0	0	0.51	0	0	0.62	0	0	0	0	
(T)	0	0	0	0	0	0.65	0	0	0.6	0	0	0.59	0.37	0	0	0	
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0.19	0	0	0	
Inner linings (L)	0	0	0	1.6	0.86	2.94	1.14	0.56	3.06	0.57	0.55	3.09	5.11	0.53	1.27	1.26	
(T)	0	0.45	0	2.5	2	3.27	1.86	1.45	2.6	4.46	2.61	5.06	4.45	1.44	2.6	2.81	
Miliammina fusca (L)	16	9.88	9.21	6.38	26.9	8.4	19.7	11.2	26	11.4	12.1	15.4	31.4	8.02	16.5	23.4	
(Ld)	0	36.5	14.3	16.7	14.9	20	3.13	30	13.7	10	4.54	12	9.3	13.3	11.5	17.9	
(T)	22.3	14	19.9	5.42	23.8	6.54	17.3	15.9	36.6	8.28	10.2	28.3	28.9	10.1	14.3	21.9	
(Td)	0	25.8	19.4	15.4	13.4	20	15.5	25.5	5.46	7.69	3.92	4.21	5.13	10.7	9.09	15.1	
Pseudo.limetis (L)	0	0	0	0	0	0	0	2.25	0	0	0	0	0	0	0	0	
(T)	0	0.45	0	0	0.4	0	0.21	1.16	0	0	0	0	0	0	0	0	
Thecamoebians (L)	0	0	0	0.53	1.14	0.42	0.28	0.56	0	0	0	0	0	0	0	0	
(T)	0	1.81	0.81	0.42	1.2	0.33	0.62	0.58	0.4	0	0.2	0	0	0	0	0	
Tiphotrocha comprimata (L)	0	0	0	0	0	0.42	0.28	0.56	0	0	0	0	0	0.53	0	0	
(T)	0	0.45	0	0	0	0.33	0.21	0.87	0	0	0	0	0	0.36	0	0	
Trocha.inflata (L)	0	3.7	4.61	1.6	3.14	1.26	5.41	4.49	3.06	3.98	4.68	5.56	0	6.95	1.27	8.37	
(Ld)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	1.36	2.84	1.25	2.6	0.98	4.74	3.77	2.8	2.55	3.41	3.57	4.08	5.42	1.73	5.61	
(Td)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.mac.polystoma (L)	84	82.7	85.5	87.8	86.9	81.9	72.1	79.8	68.3	83.5	80.7	72.8	83.5	82.9	81	85.3	
(Ld)	0	0	0	0.61	1.71	0.51	0.4	1.41	0	0	0	1.69	0	0	0	0.84	
(T)	60.3	67	72.8	86.25	66.4	79.1	71.8	71.3	49.4	72.9	76.9	55.7	51.8	75.8	78.4	64.5	
(Td)	0	0.68	0.28	0.48	1.2	0.83	0.29	0.81	0	0	0	1.07	0	0	0	0.79	
Trocha.ochracea (L)	0	3.7	0.66	2.13	1.14	4.2	1.14	0.56	1.02	0.57	0	2.47	0	1.07	0	1.67	
(T)	4.13	14.5	4.06	4.17	3.6	8.82	3.3	4.93	7.6	11.8	0	6.85	10.2	6.86	3.03	5.1	
Ostracods (T#)	112	72	72	40	24	112	56	40	16	0	0	16	16	16	0	8	

Table A-7 Table of results for foraminiferal occurrences for Treatment E (Oiled plot with nutrient enrichment and cut plants), Plot 1 and 2, for weeks 0-22. Same format as Table A-1.

Table 7

TREATMENT 1E	Oiled plot with nutrient enrichment and cut plants																
Plot#/date	1E/week0	1E/week1		1E/week3		1E/week5		1E/week8		1E/week10		1E/week14		1E/week18		1E/week22	
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5	A3	D6	A1	
Total # of species (L)	8	3	4	7	8	7	4	8	8	4	5	5	5	5	5	4	
/10cc (T)	8	5	5	10	8	8	8	8	8	7	7	8	8	7	7	8	
Total # of individuals (L)	1600	4304	5784	4384	3464	5504	6040	6888	6720	5032	4656	4008	4416	1512	3352	1560	
/10cc (T)	6192	9808	11480	8248	6536	8928	9216	10360	9912	7760	8040	8088	7032	5040	6072	4592	
Eggerella advena (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.24	0	
(T)	0	0	0	0	0	0	0	0.08	0	0.21	0	0.1	0.11	0	0.28	0	
Elphidium excavatum (L)	0	0	0	1.28	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0.68	0	0	0	0	0	0	0	0	0	0	0	0	
Glomospira gordialis (L)	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0.13	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	
Inner linings (L)	0	0	0	0.37	0.46	0.15	0	0.7	0.12	0	0.17	1.4	0.72	1.59	0.48	0	
(T)	0.26	0	0	1.16	0.86	0.23	0.35	1.16	0.73	0.72	0.5	1.58	1.02	1.59	0.53	1.05	
Miliammina fusca (L)	28.4	27.1	24.3	25.7	29.3	34	36.2	35.7	40.6	33.2	54.6	44.9	30.3	22.8	25.8	19	
(Ld)	1.56	21.2	11.4	14.2	20.5	15	12.1	15.3	12.3	5.26	14.2	11.1	15	11.6	19.4	21.6	
(T)	58.1	41.3	35.4	30.5	37.6	30.9	35.7	33.7	37	31.9	53.2	50.5	36.3	32.5	34.8	36.9	
(Td)	1.36	15.2	9.25	10.5	13.7	14.9	10.5	13	10.9	4.85	10.5	9.39	7.84	5.37	10.6	8.02	
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0.19	0.49	0.12	0.1	0	0.16	0	0.1	0	0	0.48	0	0	
Thecamoebians (L)	0	0	0	0	0.46	0.29	0	0	0	0	0	0	0	0	0	0	
(T)	0.13	0.16	0.07	0.39	1.59	0.81	0.17	0.08	0.08	0.1	0.1	0	0	0	0	0.17	
Tiphotrocha comprimata (L)	0.44	0	0	0.55	0.23	0.15	0.13	0.12	0.12	0	0	0	0	0	0	0	
(T)	0.26	0	0	0.68	0.24	0.12	0.17	0.08	0.08	0	0	0	0	0.16	0.13	0	
Trocha.inflata (L)	0	3.53	6.78	4.2	10.2	3.2	7.15	5.92	8.81	6.36	3.78	2.2	6.88	4.76	15.3	4.1	
(Ld)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	35.1	4.74	2.61	8.94	2.77	5.64	5.48	8.31	5.46	3.78	2.27	5.69	5.24	10.5	4.36	
(Td)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.mac.polystoma (L)	59.1	69.3	68.3	67.9	59.4	61.2	58.6	57.3	50.1	60.1	41.2	51.1	61.8	70.4	58.2	76.9	
(Ld)	0	1.61	0.81	4.03	1.95	0.71	1.64	0.7	1.43	1.32	0.83	1.95	3.23	0	1.23	0.67	
(T)	35	53.3	57.9	62.3	48.8	63.2	56.9	56.9	51.8	59.5	38.6	42.7	55.7	58.3	50.9	54.2	
(Td)	0	1.53	0.72	2.96	1.25	0.91	1.53	1.22	1.4	0.87	0.52	2.08	3.06	0.82	1.55	0.96	
Trocha.ochracea (L)	0.89	0	55.3	0	0	1.02	0	0.35	0.24	0.32	0.17	0.4	0.36	0.53	0	0	
(T)	2.45	1.71	1.88	1.28	1.47	1.85	1.04	2.47	1.78	2.16	3.68	2.77	1.14	1.75	2.9	3.31	
Ostracods (T#)	136	256	216	112	88	8	16	152	48	0	16	0	16	16	8	16	

TREATMENT 2E	Oiled plot with nutrient enrichment and cut plants																
Plot#/date	2E/week0	2E/week1		2E/week3		2E/week5		2E/week8		2E/week10		2E/week14		2E/week18		2E/week22	
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5	A3	D6	A1	
Total # of species (L)	5	6	6	6	6	5	6	5	5	6	5	6	6	5	5	5	
/10cc (T)	7	9	8	8	8	5	7	7	6	6	5	6	6	5	7	5	
Total # of individuals (L)	600	1752	1584	1792	1480	2256	1640	1680	1984	2432	2176	1904	3656	1552	1176	1232	
/10cc (T)	1728	5312	3896	3424	2808	3360	2280	3472	2936	3616	2920	3112	5248	3088	2552	2544	
Eggerella advena (L)	0	0	0	0	0	0	0	0	0	0.66	0	2.1	0.22	0	0	0	
(T)	0	0	0.21	0	0	0	0.35	0	0	0.66	0	1.29	0.3	0	0.31	0	
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Glomospira gordialis (L)	0	0.46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0.3	0	0.23	0	0	0	0	0.27	0	0	0	0	0	0	0	
Inner linings (L)	2.67	1.83	1.52	2.23	1.08	1.42	0.98	7.14	2.82	1.32	1.1	3.78	1.31	3.09	2.72	1.95	
(T)	2.3	4.67	3.29	3.5	3.13	5.24	2.46	8.76	3.54	5.09	2.74	4.37	4.12	3.37	5.02	5.97	
Miliammina fusca (L)	8	36.5	5.05	16.5	13	24.5	9.27	24.3	7.26	29.9	28.7	13.9	7.86	14.9	14.3	25.3	
(Ld)	0	12.5	10	8.1	29.2	20.3	15.8	11.8	11.1	17.6	11.5	18.2	11.1	10.3	14.3	12.8	
(T)	21.8	39.5	15.8	20.6	11.4	18.1	7.72	21.2	8.17	25.4	24.9	18.3	10.4	21	16.6	22	
(Td)	2.13	12.6	11.7	5.68	22.5	19.7	13.6	10.9	13.3	14.8	12.1	12.7	5.88	8.64	15.1	11.4	
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0.46	0.45	0.21	0.47	0.85	0	0	0.23	0	0	0	0	0	0	0	0	
Thecamoebians (L)	0	0	0	0.89	1.62	0	0.49	0	0	0	0	0	0	0	0	0	
(T)	0	0.15	0	0.93	1.42	0	0.35	0.23	0	0	0	0	0	0	0	0	
Tiphotrocha comprimata (L)	0	0	0.51	0	0.54	0	0	0	0	0	0	0	0	0	0	0	
(T)	0.46	0.3	0.21	0	0.28	0	0	0	0	0	0	0	0	0	0.31	0	
Trocha.inflata (L)	0	2.74	5.56	4.02	1.62	2.13	1.95	0.48	2.42	9.54	5.51	2.1	3.06	7.73	4.76	4.55	
(Ld)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	1.51	2.67	3.74	2.56	1.67	1.75	0.46	2.18	6.86	4.11	2.06	3.05	5.96	3.76	3.36	
(Td)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trocha.mac.polystoma (L)	88.7	57.5	86.4	75.5	82.2	89.9	86.3	65.7	85.9	54.9	62.9	76.5	86.2	72.7	76.2	66.9	
(Ld)	0	1.59	0.58	0.59	1.32	0.51	0	0	0.4	0.6	0	0	0	0	0	0	
(T)	69.4	43.7	69.6	62.1	74.9	67.9	81.8	59.2	83.1	48.5	60.3	64.5	75.2	60.9	63.3	57.9	
(Td)	0	1.03	1.47	1.12	1.9	0.35	0	0.39	0.66	0.46	0	0	0	0	0	0.54	
Trocha.ochracea (L)	0	0.91	1.01	0.89	0	2.13	0.49	2.38	1.81	3.82	1.84	1.68	1.31	1.55	2.04	0	
(T)	3.7	9.49	8.01	8.4	5.41	7.14	5.61	9.91	2.72	13.5	7.95	9.51	7.01	8.81	10.7	0	
Ostracods (T#)	56	176	56	184	56	96	56	24	16	0	0	32	0	8	24	16	

Table A-8 Table of results for foraminiferal occurrences for Treatment E (Oiled plot with nutrient enrichment and cut plants), Plot 3 and for Treatment F (Oiled plot with nutrient enrichment and agricultural disking), Plot 1, for weeks 0-22. Same format as Table A-1.

Table 8

TREATMENT 3E	Oiled plot with nutrient enrichment and cut plants																	
Plot#/date	3E/week0	3E/week1		3E/week3		3E/week5		3E/week8			3E/week10			3E/week14			3E/week18		3E/week22
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5	A3	D6	A1		
Total # of species (L)	4	3	4	7	8	5	4	3	4	6	5	3	4	3	4	5		
/10cc (T)	6	6	7	7	8	6	5	5	6	7	5	5	5	5	6	5		
Total # of individuals (L)	1192	1440	1632	1080	3168	6632	7800	648	2896	2984	3072	4312	3264	2008	1112	1872		
/10cc (T)	3776	4536	7360	1576	4376	7960	8768	1144	4976	4080	3920	5336	4672	3536	3352	3312		
Eggerella advena (L)	0	0	0	0.74	0	0	0	0	0	0	0	0	0	0	0	0		
(T)	0	0	0	0.51	0	0	0	0	0.32	0	0	0	0	0	0	0		
Elphidium excavatum (L)	0	0	0	0	0.76	0	0	0	0	0	0	0	0	0	0	0		
(T)	0	0	0	0	0.55	0	0	0	0	0	0	0	0	0	0	0		
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Inner linings (L)	2.01	0	0.98	2.22	0.51	0.12	0.21	0	0	0.27	0	0	1.23	0	0	0.85		
(T)	2.33	1.23	0.78	1.52	0.55	0.1	0.18	1.4	0.32	1.18	0.61	0.15	1.37	0.23	0.48	0.97		
Miliammina fusca (L)	18.8	14.4	21.6	20.7	17.7	55.3	44	28.4	18	25.5	22.9	41.6	22.8	44.6	14.4	28.2		
(Ld)	0	7.69	20.4	2.96	17.1	10.8	7.93	13	4.62	5.28	7.95	7.14	4.3	7.14	5	22.7		
(T)	28	24	39.7	20.3	17	50.2	40.1	23.1	18.1	21.2	20.2	39.9	25.3	45.7	12.9	34.8		
(Td)	0	16.9	17.8	17.5	21.5	10.6	7.74	9.1	2.66	5.56	7.07	6.39	2.7	5.45	3.7	13.2		
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
(T)	0	0.18	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Thecamoebians (L)	0	0	0	0.74	1.01	0	0	0	0	0	0.26	0	0	0	0	0		
(T)	0.21	0	0.22	0.51	0.73	0	0	0	0	0.2	0.2	0	0	0	0	0		
Tiphotrocha comprimata (L)	0	0	0	0	0.75	0.23	0	0	0	0	0	0	0	0	0	0		
(T)	3.39	0	1.2	0	0.55	0.2	0	0	0	0	0	0	0	0	0.24	0		
Trocha.inflata (L)	0	9.44	15.2	6.15	14.6	10.2	16	6.17	22.7	9.65	14.6	16.9	11.3	9.96	10.8	23.1		
(Ld)	0	0	0	0	0	2.3	1.28	0	0	2.78	0	0	0	0	0	0		
(T)	0	4.23	10.3	7.11	11.9	9.05	14.7	5.59	18.2	8.43	11.6	15.9	10.6	10.4	14.8	17.1		
(Td)	0	0	1.05	0	0	2.22	1.24	0	0	4.65	0	0	0	0	0	0		
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Trocha.mac.polystoma (L)	76.5	76.1	62.3	66.7	63.6	34.2	39.6	65.4	58.8	63.3	61.5	41.6	64.7	45.4	69	47.4		
(Ld)	0	1.46	0	1.11	2.38	0.68	0.77	0	0	1.27	0	0	0.76	1.75	0.97	1.8		
(T)	63.1	67.5	47.4	67.5	67.1	40.4	44.8	65	60.6	65.3	65.3	42.9	60.3	42.1	69	45.4		
(Td)	0	1.31	0.69	0.75	1.91	0.5	0.61	0	0	0.9	0	0	0.57	2.15	0.69	1.06		
Trocha.ochracea (L)	0	0	0	0.74	1.01	0	0	0	0.55	1.07	0.78	0	0	0	0.72	0.43		
(T)	0	2.82	0.43	2.54	1.65	0.1	0.27	4.9	2.57	3.33	2.04	1.2	2.4	1.58	2.63	1.69		
Ostracods (T#)	96	112	224	56	48	64	32	16	16	8	8	8	0	8	8	0		

TREATMENT 1F	Oiled plot with nutrient enrichment and agricultural disking																	
Plot#/date	1F/week0	1F/week1		1F/week3		1F/week5		1F/week8			1F/week10			1F/week14			1F/week18		1F/week22
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5	C2	E4	B2	F5	A3	D6	A1		
Tota # of species (L)	5	6	6	6	5	5	6	5	5	5	5	6	4	4	4	4		
/10cc (T)	6	7	8	8	6	6	6	5	6	5	5	6	5	5	5	5		
Tota # of individuals (L)	1536	1128	1344	1808	1528	1696	1924	864	1696	2208	1176	2600	1216	920	712	1328		
/10cc (T)	3168	2680	3624	3216	3208	2496	2508	2088	2720	3280	1656	4136	1808	1616	1648	2352		
Eggerella advena (L)	0	0	0	0.44	0	0	0	0	0.47	0	0	0.31	0	0	0	0		
(T)	0.51	0	0	0.25	0	0	0	0	0.29	0	0	0.19	0	0	0	0		
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Inner linings (L)	1.56	4.26	1.79	0.88	1.05	3.77	1.66	0.93	0	1.09	2.04	0.92	0.66	0.87	0	0.6		
(T)	1.52	3.58	2.43	1.74	3.49	4.49	2.87	1.15	0	1.22	3.38	0.97	2.65	1.96	1.94	2.04		
Miliammina fusca (L)	5.73	5.67	1.79	6.19	7.85	3.3	8.73	2.78	1.89	1.81	4.08	0.92	5.26	1.74	2.25	1.2		
(Ld)	9.1	37.5	33.3	0	13.3	0	23.8	33.3	0	20	16.7	0	37.5	50	0	0		
(T)	17.2	20	3.09	5.72	17	3.21	8.93	2.3	2.19	1.95	3.86	0.97	6.19	2.97	3.86	1.36		
(Td)	1.47	23.9	28.6	4.35	11.8	0	21.4	16.7	0	12.5	12.5	0	28.6	16.7	0	25		
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
(T)	0	0	0.66	0.25	0	0	0	0	0	0	0	0	0	0	0	0		
Thecamoebians (L)	0	0.71	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
(T)	0	0.29	0.44	0.25	0.5	0	0	0	0	0	0	0	0	0	0	0		
Tiphotrocha comprimata (L)	0	0	0.59	0	0	0	0.42	0	0	0	0	0	0	0	0	0		
(T)	0	0	0.22	0	0	0	0.32	0	0.29	0	0	0	0	0	0	0		
Trocha.inflata (L)	0	6.38	6.55	15.5	10.5	5.19	11.2	13.9	8.96	17.4	8.16	17.5	25.7	13.9	13.5	15.1		
(Ld)	0	0	0	0.44	0	0	0	0	0	0	0	0	0	0	0	0		
(T)	0	4.18	7.73	13.66	6.73	6.41	11.2	11.1	10.6	15.8	7.25	15.9	19.9	12.4	9.71	15		
(Td)	0	0	0	1.82	0	0	0	0	0	0	0	0	0	0	0	0		
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
(T)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Trocha.mac.polystoma (L)	77.6	80.9	87.5	42.3	79.6	83.5	76.5	81.5	87.7	79.3	82.3	80	68.4	83.5	83.1	83.1		
(Ld)	0	0	2.04	0	3.29	1.13	0.54	0	0.54	0	0	1.15	0.96	2.08	0	0.72		
(T)	63.4	64.8	77.9	74.6	66.3	76.3	73.4	83.1	85.3	80	80.7	80.3	68.1	78.2	82	78.9		
(Td)	0	0	1.96	0.67	3.01	1.26	0.43	0.46	0.34	0	0	0.96	0.65	1.27	0	1.29		
Trocha.ochracea (L)	2.6	2.13	1.79	1.77	1.05	4.25	1.46	0.93	0.94	0.36	3.4	0.31	0	0	1.12	0		
(T)	6.62	7.16	7.51	3.48	5.99	9.62	3.35	2.3	1.18	0.98	4.83	1.74	3.1	4.46	2.43	2.72		
Ostracods (T#)	24	72	24	120	32	24	16	8	8	0	16	24	0	0	8	0		

Table A-9 Table of results for foraminiferal occurrences for Treatment F (Oiled plot with nutrient enrichment and agricultural disking), Plot 2 and 3, for weeks 0-22. Same format as Table A-1.

Table 9

TREATMENT 2F	Oiled plot with nutrient enrichment and agricultural disking																	
Plot#/date	2F/week0	2F/week1		2F/week3		2F/week5		2F/week8			2F/week10		2F/week14		2F/week18		2F/week22	
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5		C2	E4	B2	F5	A3	D6	A1	
Total # of species (L)	6	6	5	6	6	5	6	6	7		6	5	5	5	6	4	3	
/10cc (T)	7	6	8	8	8	7	6	8	9		6	5	7	6	6	5	5	
Total # of individuals (L)	464	376	3440	792	5208	2032	3928	1084	2080		1640	3376	1088	2456	832	1392	1480	
/10cc (T)	1096	3024	8728	1816	8176	2848	4552	2152	5240		2096	4912	2152	3248	1280	2360	2768	
Eggerella advena (L)	1.72	0	0	0	0	0	0	0	0		0	0	1.47	0	0.96	0	0	
(T)	1.46	0	0	0	0	0	0	0	0		0	0	1.12	0.25	0.63	0	0	
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0.15		0	0	0	0	0	0	0	
Inner linings (L)	10.3	6.4	0.69	1.01	0.31	1.57	0.2	2.26	1.92		0.96	0.24	0.74	0.98	1.92	0	0	
(T)	5.84	1.57	1.01	10.1	1.96	3.37	1.05	4.83	1.98		2.67	0.96	0.74	1.97	2.5	1.36	2.02	
Miliammina fusca (L)	1.72	31.9	17.9	7.07	16.7	9.45	22.2	24.1	28.8		6.83	28.4	0.74	7.17	9.62	11.5	13	
(Ld)	0	40	10.4	14.3	13.8	29.2	19.3	6.25	16.7		21.4	15	0	4.55	20	0	8.33	
(T)	6.57	32.6	27.4	9.69	17.9	7.02	19.7	21.9	23.1		5.73	30.9	4.09	7.14	7.5	12.2	10.1	
(Td)	0	35.2	17.7	22.7	1.55	28	19.6	6.78	13.9		20	10.5	9.09	3.45	25	0	8.57	
Pseudo.limetis (L)	0	4.3	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
(T)	0	2.61	0.09	0.44	0.1	0.28	0	0.37	0.31		0	0	0	0	0	0	0	
Thecamoebians (L)	0	0	0	0	0	0	0.2	0	0		0.49	0	0	0	0	0	0	
(T)	0	0	0.37	1.32	0.1	0.28	0.35	0.37	0.31		0.38	0	0	0	0	0	0	
Tiphotrocha comprimata (L)	0	0	0	1.01	0.46	0	0	0.75	0.38		0	0	0	0	0	0	0	
(T)	0.73	0	0.09	0.88	0.49	0	0	0.74	1.07		0	0	0.74	0	0	0	0	
Trocha.inflata (L)	0	4.3	4.9	5.05	2.15	9.45	4.07	5.26	7.69		5.85	6.4	2.94	5.86	6.73	9.77	7.57	
(Ld)	0	0	0	0	0	0	5	0	0		0	0	0	0	0	0	0	
(T)	0	2.12	3.85	2.64	1.66	8.71	3.89	2.6	3.66		4.58	6.02	2.6	6.16	7.5	8.47	5.78	
(Td)	0	0	0	0	0	0	4.76	0	0		0	0	0	0	0	0	0	
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
Trocha.mac.polystoma (L)	75.9	48.9	76.3	80.6	80	78.7	72.5	66.2	58.5		84.9	64.2	94.1	85	77.88	78.2	79.5	
(Ld)	0	0	3.66	0	2.68	2.5	1.4	0	3.29		1.15	0.73	3.13	1.53	0	0	0	
(T)	72.3	51.7	85.9	66.1	76	78.4	72.6	61.7	67		84	59.9	90	83	75.6	72.2	80.3	
(Td)	0	0.51	2.92	0.67	2.7	2.15	1.45	1.2	1.82		0.91	0.82	1.85	1.19	0	0	0	
Trocha.ochracea (L)	1.72	4.3	0.09	5.05	0.31	0.79	0.81	1.5	2.31		0.98	0.71	0	0.98	2.88	0.57	0	
(T)	6.57	8.09	1.28	8.81	1.76	1.97	2.64	7.43	2.44		2.87	2.12	0.74	1.48	5.63	5.76	1.73	
Ostracods (T#)	56	96	168	56	88	32	24	16	24		0	0	0	0	0	8	0	

TREATMENT 3F	Oiled plot with nutrient enrichment and agricultural disking																	
Plot#/date	3F/week0	3F/week1		3F/week3		3F/week5		3F/week8			3F/week10		3F/week14		3F/week18		3F/week22	
Composite #	-	B1	D4	B3	F6	A2	F4	C1	E5		C2	E4	B2	F5	A3	D6	A1	
Total # of species (L)	4	5	5	6	6	6	6	7	4		5	5	5	5	4	4	5	
/10cc (T)	5	6	8	7	8	6	7	9	6		5	5	6	6	5	5	5	
Total # of individuals (L)	416	1104	2256	2912	2656	1888	6240	3968	3536		2600	3528	1744	1832	1912	1320	1592	
/10cc (T)	992	2392	4264	4776	7064	3440	8624	6176	5232		3336	4304	2224	3120	4240	1976	2656	
Eggerella advena (L)	0	0	0	0	0.3	0	0	0.2	0		0	0	0	0	0	0	0	
(T)	0	0	0	0	0.11	0	0	0.13	0		0	0	0	0	0	0	0	
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
Inner linings (L)	1.92	1.45	0.71	1.1	0.9	1.27	0.38	0.2	0.68		0.92	0.45	0.92	0.44	0	0.61	0.5	
(T)	1.61	2.66	0.75	1.17	0.79	1.4	1.11	2.22	1.22		0.96	0.74	0.72	0.26	0.36	0.61	0.03	
Miliammina fusca (L)	15.4	11.6	12.4	34.9	18.1	13.6	33.1	19.8	14.5		8.62	12.9	21.1	11.4	19.2	17	15.1	
(Ld)	12.5	12.5	25.7	14.2	16.7	15.6	13.6	14.4	17.2		0	3.51	8.69	3.85	15.2	14.3	26.7	
(T)	25	17.7	14.3	30.7	19.9	10.2	27.9	17.4	13.6		7.19	12.1	19.4	14.1	8.7	14.2	14.8	
(Td)	9.68	16.9	22.4	15.8	12.5	11.4	12.6	11.2	13.5		0	3.08	7.41	5.45	11.2	14.3	18.4	
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
(T)	0	0.33	0.19	0	0.79	0	0	0.6	0.15		0	0	0	0.51	0	0	0	
Thecamoebians (L)	0	0	0	0.27	0.6	0	0	0.4	0		0	0	0	0	0	0	0	
(T)	0	0	0.38	1.17	1.25	0	0.19	1.61	0		0	0	0	0.51	0	0	0	
Tiphotrocha comprimata (L)	0	0	0	0.27	0	0.42	0.13	0	0		0	0	0	0	0	0	0	
(T)	0	0	0.19	0.33	0.11	0.47	0.09	0.13	0		0	0	0	0	0.75	0	0	
Trocha.inflata (L)	0	10.1	9.93	9.34	10.8	6.36	9.49	8.27	8.6		8.92	7.03	7.8	6.55	15.9	12.1	11.1	
(Ld)	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
(T)	0	6.68	8.63	7.2	8.49	5.35	7.61	5.96	7.64		7.67	6.51	7.55	13.6	12.3	10.5	9.04	
(Td)	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
(T)	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	
Trocha.mac.polystoma (L)	76.9	73.2	76.2	54.1	69.3	78	56.8	70.8	76.2		80.9	79.1	69.7	81.7	64	70.3	72.9	
(Ld)	0	1.98	3.28	4.06	0.87	1.63	1.13	0	0		2.66	0.57	0	1.6	0	1.72	1.38	
(T)	64.5	64.9	73.5	58.5	67.7	80.2	62.6	70.3	76		82.9	79.2	71.9	69.5	66.6	74.1	74.1	
(Td)	0	1.55	2.55	3.15	1	1.16	1.04	0	0		2.89	0.47	0	1.48	0.28	1.09	0.81	
Trocha.ochracea (L)	0	1.67	0.35	0	0	0.42	0.13	0.81	0		0.62	0.45	0.46	0	0.84	0	0.5	
(T)	4.84	7.69	2.06	1.01	0.79	2.33	0.46	3.24	1.38		0.96	1.49	0.36	1.54	3.21	0.4	1.81	
Ostracods (T#)	80	208	80	8	8	16	40	0	0		0	0	8	0	8	0	0	

Table A-10 Table of results for foraminiferal occurrences from Core 002, taken from Plot 2 (see Fig. 1.3). The living and total (live plus dead) number of the total number of species per 10cc, and the living and total (live plus dead) number of the total number of individuals per 10cc are included. Relative percentages of both living and total (live plus dead) foraminiferal species are also included. Percentages of living and total per individual species represent the percentage out of living and total numbers for all species. Percentages of living deformed and total deformed per individual species represent the percentage out of the living and total for that species only. The whole number of living Ostracods is also included at the bottom of the table. L= living, T= total (live plus dead), Ld= living deformed, Td= total (live plus dead) deformed.

Table A-10

CORE #002										
Depth (cm)	0-1cm	1-2cm	2-3cm	3-4cm	4-5cm	5-6cm	6-7cm	7-8cm	8-9cm	9-10cm
Total # of species (L)	6	4	5	4	5	5	5	4	5	4
/10cc (T)	7	5	5	5	6	5	6	6	6	6
Total # of individuals (L)	2088	2096	2088	888	1096	976	976	528	1600	1392
/10cc (T)	3128	3040	3200	1768	2048	2672	6056	4152	4256	3504
Eggerella advena (L)	0.77	0	0	0	0	0	0	0	0	0
(T)	0.51	0	0	0	0	0	0	0	0	0.68
Elphidium excavatum (L)	0	0	0	0	0	0	0	0	0	0
(T)	0	0	0	0	0	0	0	0	0	0
Glomospira gordialis (L)	0	0	0	0	0	0	0	0	0	0
(T)	0	0	0	0	0	0	0	0	0	0
Inner linings (L)	1.53	1.15	1.15	2.7	0.73	1.64	1.64	1.52	0	0.57
(T)	2.81	1.05	2	3.62	1.17	1.2	1.06	0.58	0.56	0.46
Miliammina fusca (L)	26.1	20.6	16.9	5.41	2.92	3.28	6.56	7.58	5.06	48.9
(Ld)	0	1.85	0	0	0	9	0	0	0	3.53
(T)	22.8	20.5	16.8	4.52	1.56	3.89	26.3	49.1	5.94	42.9
(Td)	0	1.28	0	0	0	0	0	0	0	0.53
Pseudo.limetis (L)	0	0	0	0	0	0	0	0	0	0
(T)	0	0	0	0	0	0	0	0	0	0
Thecamoebians (L)	0	0	0	0	0	0	0	0	0	0
(T)	0.26	0	0	0	0	0	0	0.39	0	0
Tiphotrocha comprimata (L)	0	0	0	0	0	0	0	0	0.5	0
(T)	0	0	0	0	0.78	0	0.13	0	0.38	0
Trocha.inflata (L)	8.43	3.82	3.83	6.31	5.84	3.28	9.02	9.09	11	6.9
(Ld)	0	0	0	0	0	0	0	0	0	0
(T)	6.91	4.21	4	9.95	6.25	2.69	5.55	4.24	7.71	3.2
(Td)	0	0	0	0	0	0	0	0	0	0
Trocha.macrescens (L)	0	0	0	0	0	0	0	0	0	0
(T)	0	0	0	0	0	0	0	0	0	0
Trocha.mac.polystoma (L)	62.5	74.4	77	85.6	90.5	91	82	81.8	46.5	43.7
(Ld)	0	0	0	0	0.8	0	0	0	0	0
(T)	63.9	72.1	73	80.1	88.7	87.7	65.9	45.1	41.4	49.5
(Td)	0	0	0	0	0.39	0	0	0	0	0
Trocha.ochracea (L)	0.77	0	1.15	0	0	0.82	0.82	0	1.5	0
(T)	2.81	2.11	4.25	1.81	1.56	4.49	1.06	0.58	2.44	3.2
Ostracods (T#)	8	0	0	8	0	0	0	0	0	0