Ecological and experimental studies on sedimentary infauna with particular reference to sediment stability, the physical and chemical properties of sediments and bioturbation.

By

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Being a Thesis submitted for the degree of Doctor of Philosophy in the University of Glasgow

Department of Zoology

University of Glasgow

1990

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ACKNOWLEDGMENTS

I wish to express my deep thanks and debt to Mr. P.S. Meadows F.I.Biol. for his invaluable supervision and helpful criticism of the work reported in the thesis. I would like to thank Professor K. Vickerman D.Sc., F.R.S. and Professor R.S. Phillips F.I.Biol. in whose department the work was carried out.

I would like to acknowledge as well my thanks to my wife and my children Mussa'b and Nossibah for their patience and support during the study. I would like also to express my many thanks to my mother, brothers, sisters and my wife's parents for their support and encouragement during my study.

I would like to extend my gratitude to my colleagues in rooms GO2 and GO4, and the technical staff in the Zoology department in general for their assistance during my study.

Finally, I would like to thank the Marine Biology Department, Marine Science College, King Abdul Aziz University, and the Ministry of High Education for their financial support which enabled me to complete my study.

CONTENTS

ABSTRACT

The present work has been carried out between 1983 and 1990, mainly to measure animal populations and physical and chemical properties of sediment. The work was also conducted to study the effect of infaunal invertebrates on physical and chemical properties of sediment, and using a quantitative approach to assess the bioturbation caused by burrowing animals.

A survey has been carried out in the period between 1984 and 1985 to study animal populations in and physical and chemical properties of sediment of the low tide area of Ardmore Point, Clyde Estuary, Scotland. Abundance of meiofauna has been estimated using a technique involving extraction of meiofauna from preserved sediment. Nematodes gave the highest abundance, followed by copepods and ostracods. Abundance and biomass of macrofauna animals have been estimated. Six species were found. Some physical properties have been estimated. Shear strength generally increased with increasing depth. The type of sediment was quite permeable, particle size in the range of medium and fine sand was generally well sorted. Redox potential (Eh) generally decreased with depth, pH slightly decreased with depth, salinity increased in summer and decreased in winter, and organic carbon was low.

Laboratory experiments have been carried out to measure the effect of two infaunal polychaetes on physical and chemical properties of sediment. *Pygospio elegans* was found to increase the shear strength and permeability of sediment and the redox potential of the sediment surface. *Fabricia sabella* was found to increase shear strength and

redox potential of sediment surface, and to increase permeability at high density.

In these experiments, a significant mortality occurred at the high population density of *P.elegans*, and at medium and high population densities of *F.sabella*.

A new quantitative approach has been conducted to assess the bioturbation caused by burrowing animals. Statistical analyses have been measured using a computer program, and the differences between these statistical analyses have been described and discussed.

GENERAL SUMMARY

Chapter 1

The extraction of meiofauna organisms from sediment

1- Five laboratory experiments were carried out to extract meiofauna organisms from preserved sediments using a modification of De Jonge and Bouwman's technique.

2- Ludox solution extracts more meiofaunal animals from sediment than Agar and Sucrose solutions, and three washes extracted more animals than two washes (experiment 1).

3- The number of meiofauna animals extracted from sediment increased with increasing volume of sediment, and the number of animals extracted from small volumes of sediment (i.e. 1ml or 2ml) were more than the numbers extracted from large volume of sediment (experiment 2).

4- A period of one hour used between washes was sufficient to extract meiofauna from sediment rather than using a longer period (experiment 3).

5- There were no significant differences in the number of meiofauna extracted from sediment using high concentrations of Ludox (more than 25% of pure solution) (experiment 4).

6- There were no significant differences between the number of meiofauna extracted using the ludox separation technique and the simple decantation technique.

Chapter 2

A survey of biological, physical and chemical studies of the sediment in the intertidal zone

1- Monthly samples were carried out to study the biological aspects and the physical and chemical properties of sediment at low tide area of Ardmore Point, Clyde Estuary, Scotland.

2- The abundance of nematodes ranged from about $85x10^3$ to $3.6x10^6$ m^{-2}, harpacticoid copepods ranged from about $4x10^3$ to $2x10^5$ m^{-2}, and ostracods ranged from about 110 to $2.5x10^4$ m^{-2}.

Nematodes occurred in all sampler depths of sediment, while copepods and ostracods were only found between 0 and 10cm depth.

Nematodes represented the highest percentage of the meiofauna population, followed by copepods and ostracods.

3- Six macrofauna species were found at low tide. Three macrofauna species were found throughout the survey namely *Pygospio elegans*, *Bathyporeia pilosa* and *Arenicola marina*, while the other species namely *Eteone longa*, *Hediste diversicolor* (adult and last larval stages), *Scoloplos armiger* and juvenile of *A.marina* were found in some months but not in others.

The abundance of *P.elegans* ranged from about 318 to 7000 m^{-2}, *B.pilosa* ranged from 127 to 3800 m^{-2}, and *A.marina* from 18 to 90 m^{-2}.

Most species were found in the top 5cm sediment, with the exception of *A.marina* which was found to about 40cm sediment.

The number of macrofauna animals increased in summer months and decreased in winter months.

3- Biomass of macrofauna fluctuated from month to month, and the highest biomass occurred in June 1984.

A.marina had the highest biomass relative to the biomass of other species.

4- The *In situ* shear strength of the sediment was measured using the vane test, and strength generally increased with depth.

5- The *in situ* permeability of the sediment was calculated from auger hole data using two methods (Hooghoudt and Ernst). Using the Hooghoudt method permeability was about 0.0001 ± 0.0001 ms^{-1}. Using Ernst method permeability was about 0.001 ± 0.0005.

6- Water content of the sediment was from 22% to 30%, and decreased slightly with depth.

7- From particle size analyses the sediment at low tide at Ardmore Point was classified as well sorted and medium to fine sand.

In general, there was little variation in mean particle size, sorting, skewness and kurtosis between months of the survey.

Mean particle size was generally the same to 25cm depth and then increased slightly at deeper depths. The sediment was well sorted in the top depth of sediment to 25cm depth and then moderately well sorted below that depth.

8- Specific gravity of sediment was 2.66 throughout the survey, indicating that the sediment was predominantly quartz.

9- The *in situ* Eh decreased from the surface of the sediment to 5cm depth, and then generally increased from 5cm to 20cm depth, and then decreased again to 30cm. Values of Eh ranged from 6.5 ± 10.61 to 407 ± 15.56.

10- There was no difference in the pH between samples obtained from low tide area throughout the survey.

11- The Salinity of the overlying water and interstitial water increased in spring and summer months and decreased in autumn and winter months.

There was a good negative correlation between the salinity and the amount of rainfall occurred during the survey.

12- Percentage of organic carbon of low tide area was low, indicating that the site was clean.

Chapter 3

Effect of biological activities on the physical and chemical properties of sediment

1- The effect of *Pygospio elegans* on sediment permeability, shear strength and redox potential (Eh) and pH at specific population densities was studied over a fifteen day experimental period.

In general, low, medium and high population densities of *P.elegans* (2,333, 7,000 and 21,000 animals m^{-2} respectively) increased permeability, shear strength, and redox potential of sediment surface.

2- The effect of *Fabricia sabella* on sediment permeability, shear strength, and Eh and pH at specific population densities was studied over a fifteen day experimental period.

The low density of *Fabricia* (5,667 animals m^{-2}) decreased permeability, and increased shear strength, and decreased Eh. Medium density of *F.sabella* (17,000 animals m^{-2}) decreased

permeability, increased shear strength and Eh. High density of *F.sabella* (51,000 animals m^{-2}) increased permeability, shear strength and Eh. In general, pH changed slightly at the end of experiment.

3- The effect of mixed population of *P.elegans* and *F.sabella* on sediment permeability, shear strength and Eh and pH was studied over a 15 day experimental period. Low, medium and high densities of both species increased permeability, shear strength and Eh. Permeability slightly decreased after 5 days, while shear strength increased after 5 days particularly at the high density of mixed species.

4- A negative relationship was found between the Eh and pH for control and single and mixed species of *P.elegans* and *F.sabella*.

5- The mortality of *Pygospio elegans* at different population densities was studied at the end of the single species and mixed species experiments. In general, mortality occurred at the high population density in the permeability experiment (45 animals/core = 21,000 animals m^{-2}) and at all population densities in the shear strength experiment. The mortality increased with increasing population density.

6- Mortality of *Fabricia sabella* at low, medium and high population densities was studied at the end of single and mixed species experiments. Mortality occurred in all population densities of *F.sabella* for single and mixed species in the permeability and shear strength experiments.

7- The length and weight of tubes of *Pygospio elegans* of low, medium and high population densities were studied at the end of single

species experiments. In general, the length and weight of tubes decreased with increasing density.

8- The length and weight of tubes of *Fabricia sabella* of different population densities were studied at the end of single species experiments. The length and weight of tubes decreased with increasing density.

Chapter 4

Assessment of bioturbation

1- A new quantitative approach was described to give an assessment of bioturbation using the measurement of tube diameters.

2- A model of bioturbation was constructed, mimicking the natural sediment on which the number of burrows at each depth can be counted, and the diameter and the angle of each burrow can be measured.

3- A computer program was developed to calculate the perimeter and surface area of each burrow, the total number of burrows and the total perimeter and surface area. The program then calculated the statistical measurements of the burrow perimeter and surface area.

4- The model data were fed into a computer and the results showed that as the total number of burrows decreased with depth, the total perimeter and surface area of the burrows decreased.

The standard deviations of the perimeter and surface area of burrows fluctuated, while the coefficients of variation (%), skewness and kurtosis decreased with increasing depth.

The values of skewness and kurtosis decreased from positive values at the upper depths to negative values at the lower depths. Significant differences in the skewness and kurtosis, for the perimeter and surface area of burrows, occurred at the top depths of sediment, but not at the lower depths.

GENERAL INTRODUCTION

Definition of Estuary

Geomorphologically, an estuary is a funnel-shaped opening of a river into the sea. Hydrographically, the estuary is characterized by tidal movements, and a highly differentiated development of water (Reineck and Singh, 1980). Pritchard (1967) and Levinton (1982) defined an estuary as a semi-enclosed coastal body of water which has free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage. Other investigators give similar definitions (e.g. Ketchum, 1951; Emery and Stevenson, 1957; and Caspers, 1967).

Estuaries are very important areas for the development of industries and for access to the hinterland (Dyer, 1979). Estuaries are often thought of as sediment sinks where sediment entering is trapped and transported by water currents (Davis, 1983). Sediment transported in estuarine and coastal waters is derived from three principle sources: rivers, the bed of the continental shelf, and dumping by man (Perkins, 1974). The unstable conditions of estuaries determine their main biological features (Caspers, 1967). In brackish water lagoons, the environmental conditions, especially salinity, are relatively stable. In estuaries, however, large variations in salinities influence the whole ecosystem (Caspers, 1967).

Definition of Tides and Intertidal Zone

Tides produced by the lunar cycle usually occur twice a day, and are most obvious at the shore (Meadows and Campbell, 1988). They can

move less than a metre (e.g. in the Mediterranean and around Jamaica), or up to 15 metres (e.g. in the Bay of Fundy, Canada). Tidal variations in the water level of estuaries are generally greater than those in the open sea because of the funneling effect of the estuary (Glen, 1979). The intertidal zone extends from the lowest level exposed to air by tides or waves to the highest level washed by tides or waves. This is sometimes divided into the upper, mid, and lower shore or tidal zone. The limits of these zones are often difficult to define exactly (Meadows and Campbell 1988). The intertidal zone is one of the best understood and most examined natural marine habitats in the sea (Levinton, 1982). A wide range of flora and fauna live on or in the sediment of estuaries and intertidal environments.

Clyde Estuary and Firth of Clyde

The Estuary and Firth of Clyde (Scotland) is one of the largest waterways in Britain but it is not the largest one. For example, the Severn Estuary and the Firth of Forth are much larger. In terms of scientific and technical achievements, however, 'The Clyde' ranks as one of the great waterways of the world. It was one of the major foci of the Industrial Revolution in Britain, particularly in the fields of marine transport and engineering (Tivy, 1986). The Clyde Estuary became grossly polluted by domestic sewage and industrial wastes. This gave rise to deoxygenation problems (Mackay and Leatherland, 1976). Recent developments to reduce the inputs of pollutants have been described in some detail by Mackay et al., (1978). The reduction of pollution increases the production of flora (Wilkinson et al., 1986),

changes the structure and composition of epilithic diatom communities (McLean et al., (1986), and increases fish populations (Henderson and Hamilton, 1986).

The geology of the Clyde Estuary and Sea Area has been studied by a number of authors. Deegan (1974) describes the geological features of the Estuary and Firth of Clyde. He recorded three main facies in the Clyde Estuary and Sea area that are closely related to water depths. These facies are briefly described below.

1- The coarse littoral facies contains clean sands and gravel. Most of the particles in these sediments are coarser than 62.5μm. The facies extends from high water to about 40m.

2- The transitional facies has a wide range of grain size and has a somewhat limited distribution.

3- The deep silty clay facies is usually found only in the deeper parts of the Clyde, but in terms of area is the most common facies.

Deegan et al., (1973) state that the coarse littoral facies contains the most diverse fauna (highest number of species), the transitional facies is intermediate, and the silty clay facies contains the least diverse fauna. The coarse littoral facies sediments vary in thickness from zero to a few tens of centimetres, but the sediments in the deep silty clay facies are much thicker.

Water and sediment movements in the Firth of Clyde and Clyde Estuary have been described by several workers (Collar, 1974; Johnston et al., 1974; Poodle, 1986). Collar (1974) reported Fleming's (1970) survey of sediment inflow from the River Clyde and the major tributaries of the estuary. Fleming estimated that the total sediment inflow was just under 250,000 tons per year. Poodle (1986) described

the fresh water inflows to the Firth of Clyde as follows. The major inflow is from the upper firth (46% of the total), with the River Clyde and River Leven each providing 12% of this. The other inflows are from Ayrshire (15%), The sea direct (13%), Loch Fyne (9%), Arran (7%), Kintyre (6%), and the Kyles of Bute (4%).

The ecology and biology of fauna and flora of the Clyde Estuary and the Sea Area have been studied extensively by many investigators. Anderson and Morris (1974) reviewed studies carried out on the microorganisms (yeast, bacteria, blue-green algae, and simple microalgae) in the Clyde Sea Area. Marshall (1974) studied the populations of plankton (e.g. phytoplankton and zooplankton) in the Firth of Clyde. Furness et al. (1986) showed that the numbers of waders on the Clyde Estuary have declined considerably recently. The most likely explanation of this decline is either the reduction in organic pollution which reduced the densities of the main prey, or the higher oxygen levels over the mudflats which allowed fish to enter the estuary and compete with the waders for the available prey. Boney (1986) studied the seasonal changes of phytoplankton and primary production in the inner Firth of Clyde. He showed that the dynamics of the diatom population spring increase was controlled by narrow 'windows' of climatic events, and that subsequent fluctuations in cell numbers were linked with the interplay between zooplankton grazing and wind induced dispersion. Adams (1986) shows that the Firth of Clyde has a rich and varied zooplankton community which forms the food of commercial species such as mackerel and herring.

The abundance and distribution of benthic animals of the Firth of Clyde and the Estuary have been studied by many workers (e.g.

Clark, 1960; Allen, 1962, 1967; Barnett, 1974; Barnett and Watson, 1986; Eleftheriou et al., 1986; Pearson et al., 1986). Clark (1960) described keys to identify polychaete animals found in the Clyde Estuary and the Firth. Barnett (1974) described an assessment of the present state of knowledge of benthos in the Firth of Clyde. Smyth (1974) described the fauna and flora found in the Clyde Estuary. Hardy and Barnett (1986) described seasonal changes in the subtidal harpacticoid copepods in the Firth of Clyde. They found that most of the population of this group is restricted to the top one cm layer of sand and this is considered to be related to food availability.

The use of the Clyde Estuary and the Firth for the disposal of effluents is described by Haig (1986). He concludes that in recent years there have been important improvements in effluent treatment and disposal.

The fishery and management of fish and shellfish in the Firth of Clyde have been studied by several workers (Bailey et al., 1986; Hislop, 1986; Mason and Fraser, 1986). Vertebrates of The Clyde have been studied by Gibson (1986).

Most of the above papers on the Clyde environment are referred to in a report on the Clyde Estuary and Firth which was published by the Natural Environment Research Council (1974), and in a symposium on the Environment of the Estuary and Firth of Clyde held at the Royal Society of Edinburgh (Allen et al., (edit.) 1986).

The biological effects on sediment properties

The biological activities of fauna and flora have major influences on sediment properties and structure. The burrowing

activity of animals, called bioturbation, often causes changes in the physical and chemical properties of sediment. The effect of biological activities on the stability of sediments is complex. The degree of these effects depends on the distribution of animals and the nature of sediment. This type of activity can stabilise or destabilise the body of sediments. Many workers have shown that the influence of benthic communities modifies the physical and chemical properties of marine sediments (Rhoads, 1974; Aller, 1978; 1980; Nowell et al. 1981; Eckman et al., 1981; Rhoads and Boyer, 1982; Meadows and Tait, 1985; 1989; Meadows, 1986; Meadows and Tufail, 1986; Meadows and Shand, 1989; Meadows, Tait and Hussain, 1990). To avoid repetition, a review on the biological effects on sediment stability will be presented in Chapter Three.

With this short introduction and background the objectives of my research were as follows.

My main purpose was to study the effects of benthic fauna on sediment stability by field and laboratory investigations. My thesis is divided into four chapters. **Chapter One**, the extraction of meiofauna organisms from sediment, describes experiments I conducted to determine the most suitable method for extracting meiofauna from preserved sediment. This work was necessary before the main survey was undertaken in chapter two. **Chapter Two**, a survey of biological, physical and chemical studies of the sediment in the intertidal zone, describes the results of an ecological survey conducted over one year at Ardmore Point on the physical and chemical properties of sediment and the abundance and biomass of the fauna. **Chapter Three**, effect of

biological activities on the physical and chemical properties of sediment, describes laboratory experiments testing the effects of two polychaete species on the physical and chemical properties of sediment. **Chapter Four**, assessment of bioturbation, describes a new approach to the quantitative assessment of bioturbation.

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Note

Nereis diversicolor has been referred to as *Hediste diversicolor* throughout the thesis because of a recent change in taxonomic nomenclature.

CHAPTER ONE

The extraction of meiobenthic organisms from sediment

INTRODUCTION

The term meiofauna has been in use for a relatively brief period. Earlier researchers (Mortensen, 1925; Krogh and Spark, 1936; and Rees, 1940) who recognized the existence of a distinct assemblage of smaller organisms referred to this assemblage as 'microfauna'. The term meiofauna (from Greek meio, smaller) was first used by Mare (1942), in her study of mud in the English Channel, to distinguish organisms of intermediate size that were smaller than those usually classed as 'macrofauna' but larger than the 'microfauna'. The term has been used to refer to the permanent members of meiofauna and has been restricted to particular animal groups such as nematodes, harpacticoid copepods, ostracods, archiannelids, polychaetes, turbellarians, gastrotrichs, kinorhynchs, and tardigrades. Interest in the study of meiofauna has increased in the last forty years. The ecology and distribution of meiofauna have been studied by many investigators: Moore, (1931); Capstick, (1959); Wieser & Kanwisher, (1961); Bush, (1966); Fenchel, (1967); Boaden, (1968); McIntyre, (1968 and 1969).

Methods of collection have been described by: Moore and Neill, (1930); Holme, (1964); Hopkins, (1964); Muus, (1964); Ockelmann, (1964); Craib, (1965); Burns, (1966); Corey and Craib, (1966); Teal and Wieser, (1966); Bieri and Tokioka, (1968); McIntyre, (1971); Elmgren, (1973) and Holme and McIntyre, (1984). There are also various techniques used for extraction of meiofauna from different types of sediment: Overgaard, (1948); O'Conner, (1955); Sellmer, (1956); Anderson, (1959); Teal, (1960); Wieser, (1960); Dillon, (1964); Hamilton, (1969); Uhlig et al., (1973); Heip et al., (1974); Thiel et

al., (1975); De Jonge and Bouwman, (1977); Tiemann and Betz, (1979); Barnett, (1980); Hockin, (1981); and Schwinghamer, (1981). The extraction of meiofauna from sandy sediment does not represent any serious difficulty (Hulings and Gray, 1971, review of techniques), but much greater problems arise when the sediment is muddy or when it contains large amounts of organic detritus (Heip et al. 1974).

Meiofauna can be extracted from sediments while they are living or after preservation. Living meiofauna has been extracted using several methods (Uhlig, 1968; Hulings and Gray, 1971; Price et al., 1978; Schwinghamer, 1981; McIntyre and Warwick, 1984; Armonies and Hellwig, 1986). Dead meiofauna from preserved sediment have been extracted by a range of techniques (Anderson, 1959; Dillon, 1964; Hamilton, 1969; Heip et al., 1974; Thiel et al., 1975; De Jonge and Bouwman, 1977; Barnett, 1980; Hockin, 1981; McIntyre and Warwick, 1984).

The main purpose of this chapter is to describe experiments on the extraction of meiofauna from preserved sediment using a modified technique based on the technique described by De Jonge and Bouwman (1977), and to compare it with a simple decantation technique used by other investigators for the extraction of meiofauna from sediments. Five experiments were carried out.

This work was necessary before the annual survey described in chapter two was conducted, because a reliable meiofaunal extraction technique was needed in that survey.

MATERIALS AND METHODS

Sediment samples were collected at low tide from Ardmore shore on the Clyde estuary. The top 5cm of sediment was taken and distributed equally in 500ml bottles, then preserved with 4-5% formalin (Steedman, 1974). The following experiments were carried out to extract the meiofauna from sediment.

Experiment 1: Testing different solution for the extraction of meiobenthic organisms from sediment

De Jonge and Bouwman (1977) described a simple density separation technique for quantitative isolation of meiobenthos using Ludox-TM (Colloidal Silica). The method described in this experiment is based on the use of different solutions namely, Ludox-TM, Agar, Sucrose and Methyl Cellulose for extracting meiobenthic organisms by the flotation technique. This method was modified from the method described by De Jonge and Bouwman 1977. The focus was on the identified groups of meiobenthos rather than individual species.

One of the bottle containing the sediment sample collected was used in this experiment. Ludox-TM, Agar, Sucrose and Methyl Cellulose solutions were used to extract meiobenthic organisms from the sediment. The following concentrations were tested for each solution : 100%, 75%, 50%, 25% and 12.5%.

Two beakers (12 x 8.5 cm diameter) were taken for each concentration, and filled with 300ml of solution. Subsamples (2 cm^3) were taken from preserved sediment and put into 25ml glass tubes

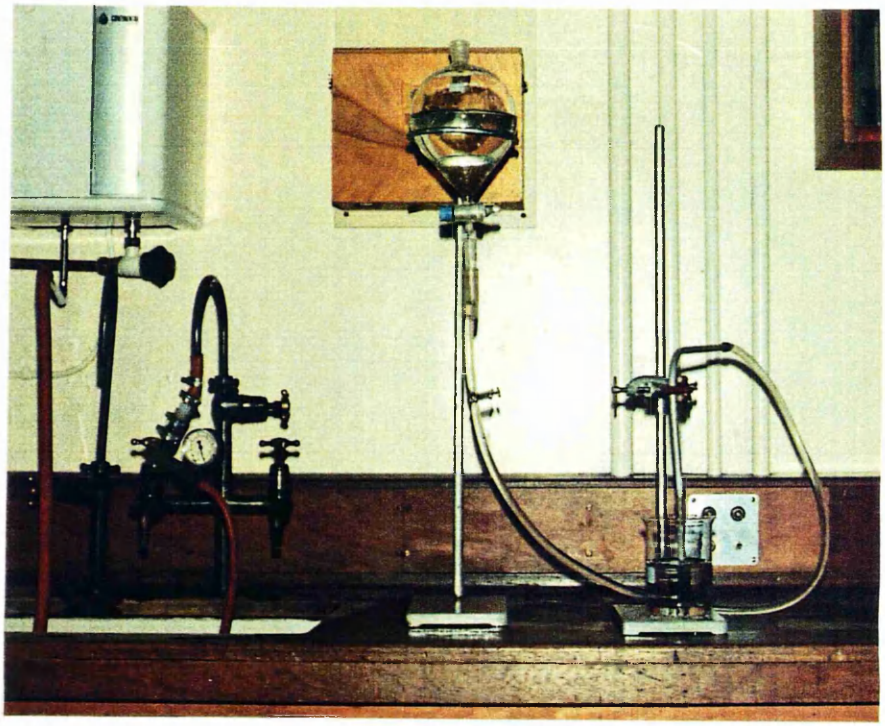
(two tubes for each concentration). The tube were stoppered and vigorously shaken by hand for 30 seconds. Each beaker with its contents was placed on a magnetic stirrer and the sediment was added from the tubes while stirring vigorously. The beaker was stirred for 2-3 minutes and then removed from the stirrer. After about 16hrs, the heavy sediment particles and the bulk of detritus had sunk to the bottom, while meiobenthic organisms floated near the solution's surface. At this stage, 5cm of liquid was above the sediment. The upper 2.5cm of liquid was removed by the suction arrangement shown in plate (1.1) using a vacuum water pump. The meiofauna in the suspension was retained in a vacuum flask. The meiobenthic organisms in suspension were then run off from the bottom of the flask onto a 35 um mesh-sieve of nylon gauze. The organisms were rinsed on this gauze with distilled water to remove the extracting solution (e.g. Ludox). The meiobenthic organisms then were washed out of the sieve with distilled water and collected in a petri-dish. This whole procedure was then repeated for the lower 2.5cm of supernatant liquid. The numbers of organisms were subsequently counted under a dissecting microscope. This flotation process was repeated 3 times for each 2ml of sediment sample in the beaker. This process incorporated 3 washes. The number of organisms of different meiofauna groups were counted using a binocular microscope. Rose Bengal was added before counting to stain the animals.

The results of this experiment indicate that the Ludox solution gives the best results in the extraction of meiofauna. Therefore, the next two experiments were carried out testing different time intervals and volumes of sediment, using the ludox solution for extracting

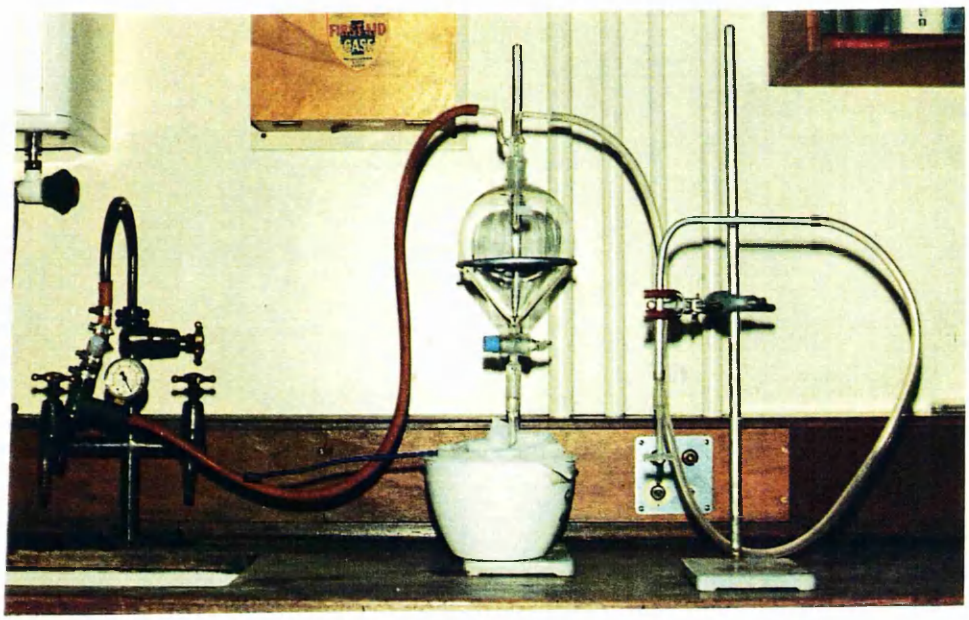
Plate (1.1)

The apparatus used in my modified technique for the extraction meiofauna from sediment using different solutions (e.g. Ludox).

(I) The apparatus used for forming a water layer upon the ludox surface.



(II) The apparatus used for removing the floating meiobenthic organisms from the top layer of solution. Organisms are collected in the vacuum flask (volume 2 litres).



meiofauna. In these two experiments only nematodes were counted because in the first experiment the abundance of nematodes accurately reflected the abundance of the other meiofauna groups.

Experiment 2. Testing different volumes of sediment.

One bottle containing preserved sediment was shaken by hand vigorously for some minutes until the sediment was disturbed, and then left for more than 24hrs. Different volumes of sediment 1ml, 2ml, 5ml, 10ml, 20ml and 40ml were taken after the overlying liquid in the bottle was carefully sucked out using a water pump. Two replicate samples were taken for each volume of sediment and each replicate was treated as follows.

The sediment was put into a test tube half filled with 25% ludox. Then a 600 ml beaker containing 300 ml of ludox was placed on a magnetic stirrer. While the beaker was stirring, the test tube was stopped and vertically shaken until the sediment was disturbed. Then it was poured into the beaker. The beaker was stirred for 2-3 minutes. The beaker was then removed from the stirrer and left to settle for 16hrs. A water pump was used to remove the upper 5cm of ludox into a vacuum flask. The ludox with meiofauna was run off from the bottom of the flask onto a 35 um nylon gauze. The material retained on the mesh was rinsed with distilled water to remove the ludox, washed out of the sieve with distilled water, and then collected in a petri-dish. Another 300 ml of 25% ludox was added to the sediment in the beaker and placed on the magnetic stirrer. The same procedure described above was followed for the second wash. The sediment in each beaker was washed three times to extract the meiofauna. The number of nematodes

extracted from each volume of sediment were counted using a binocular microscope.

Experiment 3. Testing different time intervals.

De Jonge and Bouwman (1977) separated each wash by 16hrs inorder to extract meiofauna from sediment. I also used 16hrs between each wash. This is a long period to use if a large number of samples need to be washed. Therefore, different time intervals: 1hr, 3hrs, 6hrs, 12hrs and 18hrs were tested to select the best time to use to extract the meiofauna in each wash.

One bottle containing preserved sediment was used for this experiment. Serial volumes of 10ml of sediment were taken and meiofauna was extracted at different time intervals (1hr, 3hrs, 6hrs, 12hrs and 18hrs). Two samples of 10ml of sediment were used at each time interval and each sample was treated using the same procedure described in experiment 2.

Experiment 4. Testing different concentrations of Ludox-TM

In the previous experiments, a 25% pure Ludox solution was used. To choose the best concentration which could be used for extracting more meiofauna from the sediment, different concentrations of ludox: 100%, 125%, 150%, 175% and 200% were tested. These concentrations corresponded to 25%, 31.25%, 37.75% and 50% respectively of the original 100% of ludox solution. Two replicates of 2ml of the preserved sample were used for each concentration. The procedure used in experiments two and three was followed in conducting this experiment.

Experiment 5. Comparison of my technique with decantation

This experiment was carried out to compare the modified ludox separation technique and the simple decantation technique (Uhlig et al. 1973).

A- The ludox separation technique.

Meiobenthic organisms were extracted from two volumes of sediment (2ml and 20ml) at different time intervals 1hr, 3hrs, 6hrs, 12hrs and 18hrs. Two replicate samples of each volume of sediment were used at each time interval. The meiofauna was extracted from each replicate using the method described in the experiment 2. However, the stage of sucking off the ludox with the water pump was omitted because it is not essential (as tested in a preliminary experiment). The technique was then carried out as follows.

The sediment was put in a test tube half filled with ludox and stoppered. A 250ml beaker containing 150ml ludox was placed on a magnetic stirrer. The test tube was shaken for about 30 seconds, and the contents poured into the beaker. The beaker was stirred for 2-3 minutes. The beaker was then removed from the stirrer and left to settle for the following time intervals: 1hr, 3hrs, 6hrs, 12hrs and 18hrs. The ludox was then carefully decanted through a 35µm nylon gauze. The material retained on the mesh was rinsed with tap water to remove the ludox, and then washed out of the mesh with tap water into a petri-dish. This was the first time sediment was washed in the beaker. The 25% of ludox used in the first wash was replaced, then stirred and the same procedure described above was carried out for second wash. Three washes were conducted and the meiofauna was

collected in the same petri-dish. The number of nematodes were then counted.

B- The simple decantation technique.

The meiofauna was extracted from three volumes of preserved sediment (10ml, 20ml and 40ml). Two replicates were taken for each volume. Three volumes of water (100ml, 200ml and 400ml) were added to each replicate of sediment in a measuring cylinder to give different ratios of the volume of sediment and the volume of water (i.e.. 1:10, 1:20 and 1:40, respectively). The decantation process for each ratio was conducted as follows.

The measuring cylinder containing the sediment and water (e.g. the ratio 1:10) was stoppered and shaken by hand vertically for 30 seconds until the sediment was suspended. The cylinder was then left for 30 seconds to allow the particles to settle and then the water was decanted through the 35µm mesh. More water was then put into the cylinder, stoppered and the same procedure described above was carried out. The decantation was conducted six times in total and the material retained on the mesh was removed and placed in a 250ml beaker using a wash bottle filled with 25% ludox. The beaker was then filled with ludox to a volume of 150ml. The beaker was left to settle for 1hr interval. The same process mentioned in the ludox separation technique was followed to extract the meiofauna from the material in the 250ml beaker.

The number of nematodes were counted for each replicate of the ratios: 1:10, 1:20 and 1:40) of each volume of sediment.

RESULTS

The results of the five experiments are described separately.

Experiment 1.

The original data for meiobenthic organisms is presented in appendix 1, tables 1, 2 and 3 for Ludox-TM, Agar and Sucrose solutions. (No organisms were found in the Methyl Cellulose solution. This solution is therefore no longer considered). The means and standard deviations of the number of meiobenthic organisms per ml in Ludox-TM , Agar and Sucrose solutions are shown in tables 1.1, 1.2, 1.3, 1.8, 1.9 and 1.10 and figures 1.1, 1.2 and 1.3. These tables and figures show the number of organisms in the 3 washes in the two layers, and then in subsequent washes and layers combined for each of the solution. Statistical analyses of results are given in tables 1.4, 1.5, 1.6 and 1.7. The analyses show significant differences between the extracted number of meiobenthic organisms.

(i) Analysis of differences between the total number of organisms in Ludox,Agar and Sucrose solutions.

Tables 1.1, 1.2 and 1.3 and figure 1.1 show that there are large variations in the number of organisms in the concentrations of these solutions. For instance, at the 100% and 75% concentrations, ludox gave the highest number of organisms. On the other hand, at 50%, 25% and 12.5%, the greatest number of organisms were found in the Agar solution.

Table (1.1)

Total, means and standard deviations of meiobenthic organisms .ml^{-1} for different concentrations of Ludox-TM solution of the replicate of samples (A and B) of the upper and lower layers of solution (i and ii).

Data combined		Ludox-TM concentration %									
		100		75		50		25		12.5	
		A	B	A	B	A	B	A	B	A	B
Washes	Total in layer (i)	90	81	34	25	8	3	-	-	2	1
	Mean ± s.d.	86 ± 6.364		30 ± 6.364		6 ± 3.536		0		2 ± 0.707	
	Total in layer(ii)	32	26	9	10	7	4	2	1	1	2
	Mean ± s.d.	29 ± 4.243		10 ± 0.707		6 ± 2.121		2 ± 0.707		2 ± 0.707	
	Grand total number of organs. in both layers	122	107	43	35	15	7	2	1	3	3
	Mean ± standard dev.	114 ± 11.31		39 ± 6.364		11 ± 4		2 ± 0.707		3 ± 0	

Table (1.2)

Total, means and standard deviations of meiobenthic organisms .ml^{-1} for different concentrations of Agar solution of the replicate of samples (A and B) of the upper and lower layers of solution (i and ii).

Data combined	Agar concentration %									
	100		75		50		25		12.5	
	A	B	A	B	A	B	A	B	A	B
Total in layer (i)	31	18	18	21	17	8	5	27	4	9
Mean ± s.d.	25 ± 9.190		20 ± 2.121		13 ± 6.360		16 ± 15.56		7 ± 3.540	
Washes										
Total in layer(ii)	45	31	39	30	44	37	28	21	6	10
Mean ± s.d.	38 ± 9.890		35 ± 6.360		41 ± 4.950		25 ± 4.950		8 ± 2.828	
Grand total number of organs. in both layers	75	49	57	50	60	44	32	48	10	19
Mean ± standard dev.	62 ± 18.39		53 ± 4.243		52 ± 11.31		40 ± 11.31		15 ± 6.364	

Table (1.3)

Total, means and standard deviations of meiobenthic organisms .ml^{-1} for different concentrations of Sucrose solution of the replicate of samples (A and B) of the upper and lower layers of solution (i and ii).

Datacombined	Sucrose concentration %									
	100		75		50		25		12.5	
	A	B	A	B	A	B	A	B	A	B
Total in layer (i)	5	7	14	15	1	1	-	1	-	-
Mean ± s.d.	6 ± 1.414		15 ± 0.707		1 ± 0		0.5 ± 0.707		-	
Washes										
Total in layer(ii)	5	7	16	20	1	2	2	-	-	-
Mean ± s.d.	6 ± 1.414		18 ± 2.828		2 ± 0.707		1 ± 1.414		-	
Grand total number of organs. in both layers	10	14	30	35	2	2	2	1	-	-
Mean ± standard dev.	12 ± 2.828		33 ± 3.536		2 ± 0		2 ± 0.707		-	

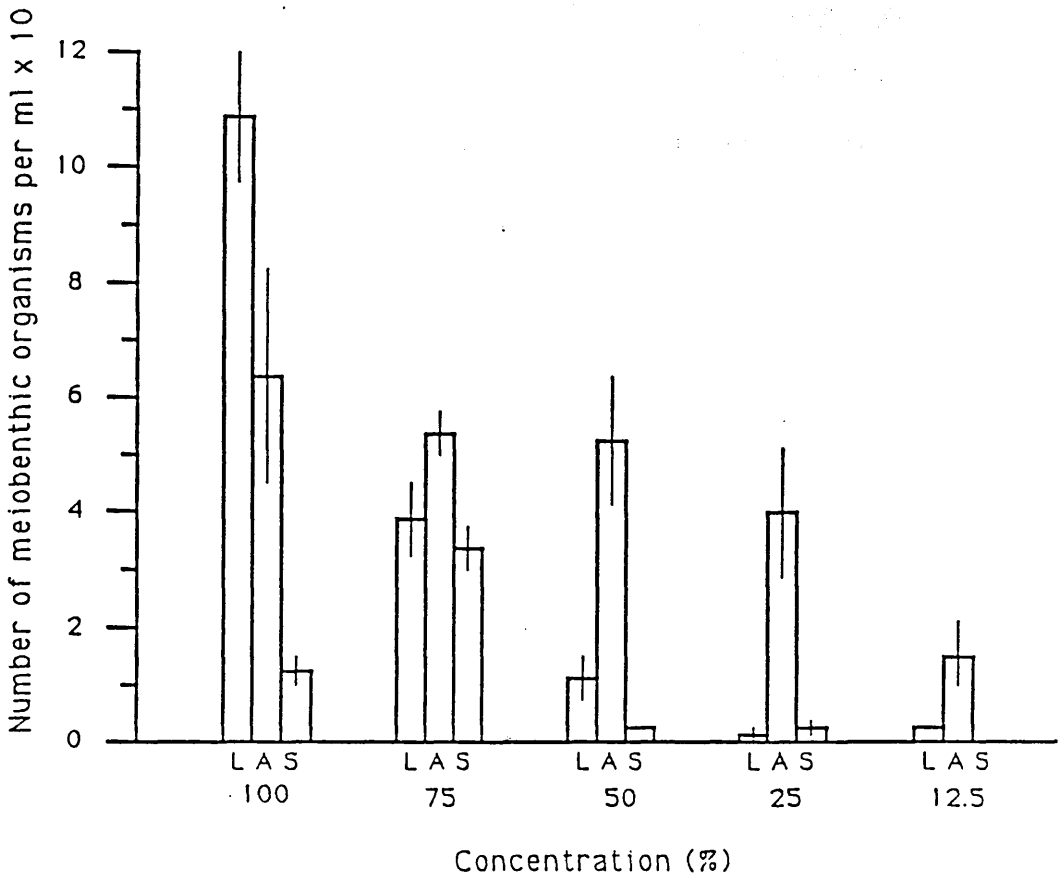


Figure (1.1)

The number of meiobenthic organisms $.ml^{-1}$ extracted from sediment by different concentrations of three test liquids (Ludox-TM (L), Agar (A) and Sucrose (S)). Vertical lines show the standard deviations of two replicate counts (A and B). Data from three washes and two layers (I and II) were combined for each count.

These differences were tested by a two way analysis of variance (table 1.4). The table shows a highly significant first order interaction. Nothing can therefore be concluded about the two main factors A: Solutions and B: Concentrations. Two series of breakdown one way analyses of variance were therefore conducted on the different concentrations for each solution (table 1.5), and on the three solutions at each concentration (table 1.6). These one-way anovars show that there are significant differences between the number of extracted organisms in the different concentrations for each solution (table 1.5). There is also a significant difference in the different solutions for each concentration (table 1.6).

(ii) Analysis of differences between layers I and II.

Tables 1.1, 1.2 and 1.3 and figure 1.2 show that there is some variation in the number of organisms in the two layers (I and II). For example, in the 100% and 75% ludox, the upper layer contained a greater number of organisms than the lower layer. In contrast, in the Agar and Sucrose the lower layers always contained more organisms than the upper layers. These differences were tested by a series of t tests (table 1.7). These tests show three out of fifteen were significant. Hence, there is no statistical difference between the number of meiobenthic organisms in the two layers (I and II).

Table (1.4)

Two way of variance on number of meiobenthic organisms per ml. Factor A: solution (Ludox, Agar and sucrose).Factor B: concentration (100%, 75%, 50%, 25% and 12.5%).

Factor	Sum of square	Mean square	Degrees of freedom	F.ratio	Probability
A (Solution)	12561.0	3140.3	4	54.33	
B Concentration	6306.5	3153.2	2	54.55	
Interaction	9616.9	1202.1	8	20.80	P<0.001
Error 867.0	57.8		15		
Total	29351.4		29		

Table (1.5)

The number of meiobenthic organisms per ml. Three one way analyses of variance for the three solutions, testing differences between 100%, 75%, 50%, 25% and 12.5%. (Each analysis was a 1 x 5 one way anovar).

Solution	Factor	Sum of square	Mean square	Degrees of freedom	F.ratio	Probability
Ludox-TM	Cons.	17977	4994	4	116.13	P<0.001
	Error	193.5	38.7	5		
	Total	18170.5		9		
Agar	Cons.	2709.6	677.4	4	5.19	P=0.05
	Error	652.5	130.5	5		
	Total	3862.1		9		
Sucrose	Cons.	1491.4	372.9	4	88.77	P<0.001
	Error	21.0	4.2	5		
	Total	1512.4		9		

Table (1.6)

The number of meiobenthic organisms per ml. Five one way analyses of variance for the five concentrations, testing differences between Ludox-TM, Agar and sucrose. Each analysis was a 1 x 3 one way anovar.

Concents. %	Factor	Sum of square	Mean square	Degrees of freedom	F.ratio	Probability
100	Solution	10405.3	5202.7	2	32.93	P<0.001
	Error	474.0	158.0	3		
	Total	10879.3		5		
75	Solution	444.3	222.2	2	9.39	0.025>P>0.01
	Error	71.0	23.7	3		
	Total	515.3		5		
50	Solution	2862.0	1431.5	2	28.16	0.005>P>0.001
	Error	152.5	50.8	3		
	Total	3015.5		5		
25	Solution	1976.3	988.2	2	22.98	0.005>P>0.001
	Error	129.0	43.0	3		
	Total	2105.3		5		
12.5	Solution	234.3	117.2	2	8.68	0.025>P>0.01
	Error	40.5	13.5	3		
	Total	274.8		5		

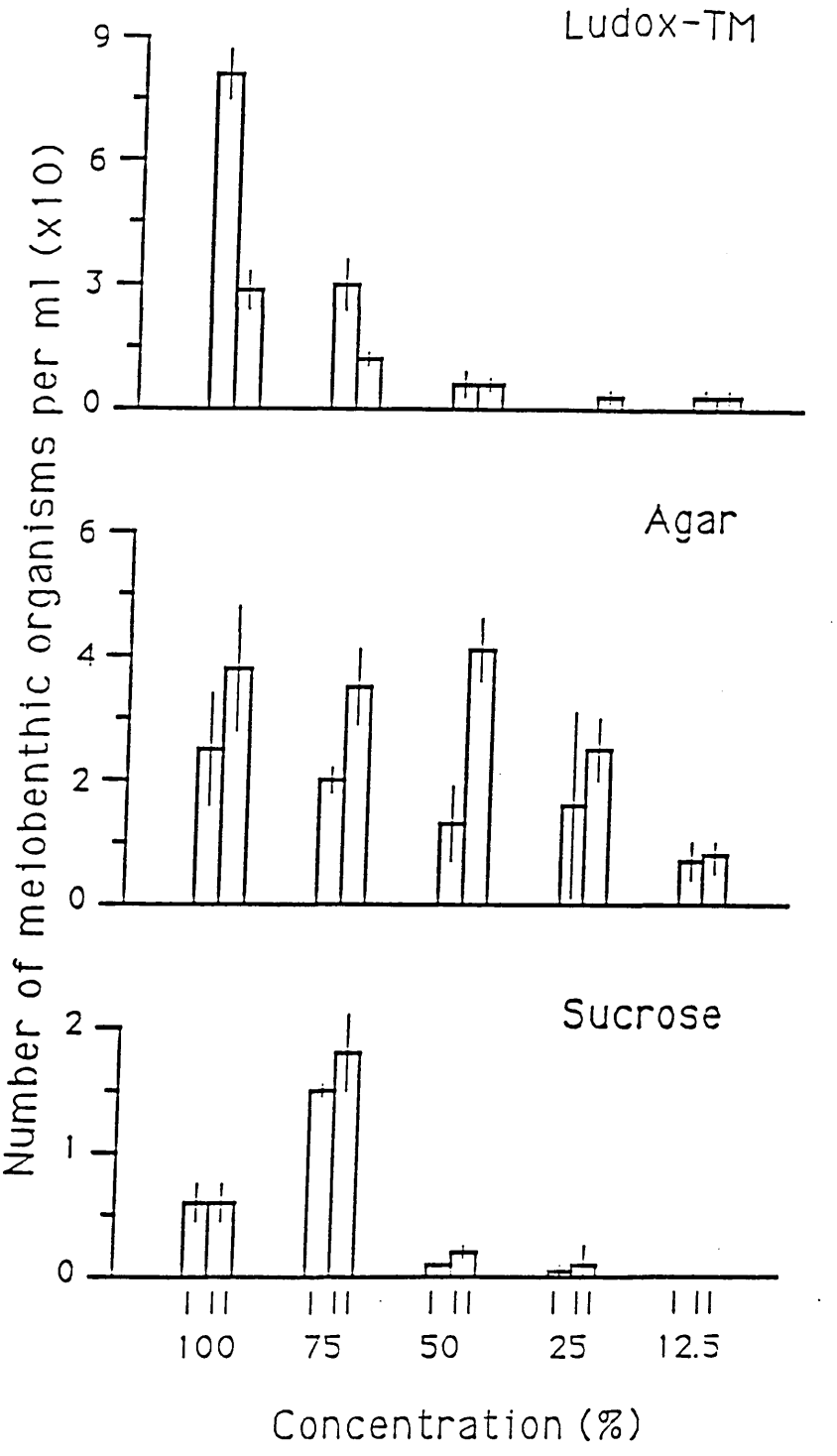


Figure (1.2)

Number of meiobenthic organism per ml extracted from sediment by different concentrations for two layers (I and II) of three solutions (Ludox, Agar and Sucrose). Vertical lines show the standard deviations of two counts. Data from three washes combined for each solution.

Table (1.7)

T tests on number of meiobenthic organisms per ml for layers I and II at different concentrations of different solutions.

Solution	Cons.	Layers compared	t	Degrees of freedom	Probability
Ludox	100	I/II	9.601	2	0.02>P>0.01**
	75	I/II	4.417	2	0.05>P>0.02*
	50	I/II	0	2	-
	25	I/II	3	2	0.10>P>0.05
	12.5	I/II	0	2	-
Agar	100	I/II	1.413	2	0.30>P>0.20
	75	I/II	3.162	2	0.10>P>0.05
	50	I/II	4.912	2	0.05>P>0.02*
	25	I/II	0.736	2	0.60>P>0.50
	12.5	I/II	0.469	2	0.70>P>0.60
Sucrose	100	I/II	0	2	-
	75	I/II	1.698	2	0.40>P>0.30
	50	I/II	1	2	0.50>P>0.40
	25	I/II	0.447	2	0.70>P>0.60

* Statistically significant results.

(iii) Analysis of differences between washes 1-3, and justification for using three washes.

Tables 1.8, 1.9 and 1.10 and figure 1.3 show that the first wash always contained the greatest number of organisms, while very few organisms were present in the second and the fewest were found in the third wash. This was obvious when the numbers were expressed as percentages of the mean of organisms counted in layers I and II for each wash (tables 1.11, 1.12 and 1.13). For example, in the third wash, 8/15 solutions contained no organisms; 5/15 solutions contained less than 10%; two solutions contained 20% and 25%, respectively.

These results show that three washes are satisfactory for removing most of the meiobenthic organisms from the sediments I have studied. It is interesting to note in this context that De Jonge and Bouwman (1977) only used two washes with the equivalent of my 100% ludox solution. De Jonge and Bouwman recorded virtually no organisms in their second wash, while I recorded 11% in the second and 1.7% in the third wash.

2- Experiment 2.

Table 1.14 shows the original data of the number of nematodes counted from the volumes of sediment: 1ml, 2ml, 5ml, 10ml, 20ml and 40ml, and the numbers per ml of each given volume. The table also shows the means and standard deviations. The data was then plotted in figures 1.4 and 1.5. Figure 1.4 shows the number of nematodes extracted for the different volumes of sediment and figure 1.5 represents the number of nematodes per ml expressed from the numbers

Table (1.8)

Total, means and standard deviations of meiobenthic organisms $.ml^{-1}$ for different concentrations of Ludox-TM solution of the two replicate samples (A and B) of the three washes. Layers I and II were combined in each wash.

Data combined		Ludox-TM concentration %									
		100		75		50		25		12.5	
		A	B	A	B	A	B	A	B	A	B
I and II layers	Total of 1st wash	113	93	34	30	10	5	1	-	3	2
	Mean ± s.d.	103 ± 14.14		32 ± 2.828		8 ± 3.536		0.5 ± 0.707		3 ± 0.707	
	Total of 2nd wash	12	12	5	5	1	1	1	-	-	1
	Mean ± s.d.	13 ± 0.707		5 ± 0		1 ± 0		0.5 ± 0.707		0.5 ± 0.707	
	Total of 3rd wash	1	3	1	4	1	4	-	-	-	-
	Mean ± s.d.	2 ± 1.414		3 ± 2.121		3 ± 2.121		0		0	

Table (1.9)

Total, means and standard deviations of meiobenthic organisms .ml^{-1} for different concentrations of Agar solution of the two replicate samples (A and B) of the three washes. Layers I and II were combined in each wash.

Data combined		Agar concentration %									
		100		75		50		25		12.5	
		A	B	A	B	A	B	A	B	A	B
I and II layers	Total of 1st wash	47	24	35	38	47	32	26	46	8	19
	Mean ± s.d.	36 ± 16.26		37 ± 2.121		40 ± 10.61		36 ± 14.14		14 ± 7.778	
	Total of 2nd wash	28	23	17	12	13	13	7	2	2	-
	Mean ± s.d.	26 ± 3.536		15 ± 3.536		13 ± 0		5 ± 3.536		1 ± 1.414	
	Total of 3rd wash	2	3	-	1	-	-	-	-	-	-
	Mean ± s.d.	3 ± 0.707		0.5 ± 0.707		0		0		0	

Table (1.10)

Total, means and standard deviations of meiobenthic organisms .ml^{-1} for different concentrations of sucrose soution of the two replicate samples (A and B) of the three washes. Layers I and II were combined in each wash.

Data combined		Sucrose concentration %									
		100		75		50		25		12.5	
		A	B	A	B	A	B	A	B	A	B
I and II layers	Total of 1st wash	10	14	12	29	2	1	2	-	1	-
	Mean ± s.d.	12 ± 2.828		21 ± 12.02		2 ± 0.707		1 ± 1.414		0.5 ± 0.707	
	Total of 2nd wash	-	-	17	6	-	-	-	1	-	-
	Mean ± s.d.	-		12 ± 7.778		-		0.5 ± 0.707		-	
	Total of 3rd wash	-	-	2	-	-	1	-	-	-	-
	Mean ± s.d.	-		1 ± 1.414		0.5 ± 0.707		-		-	

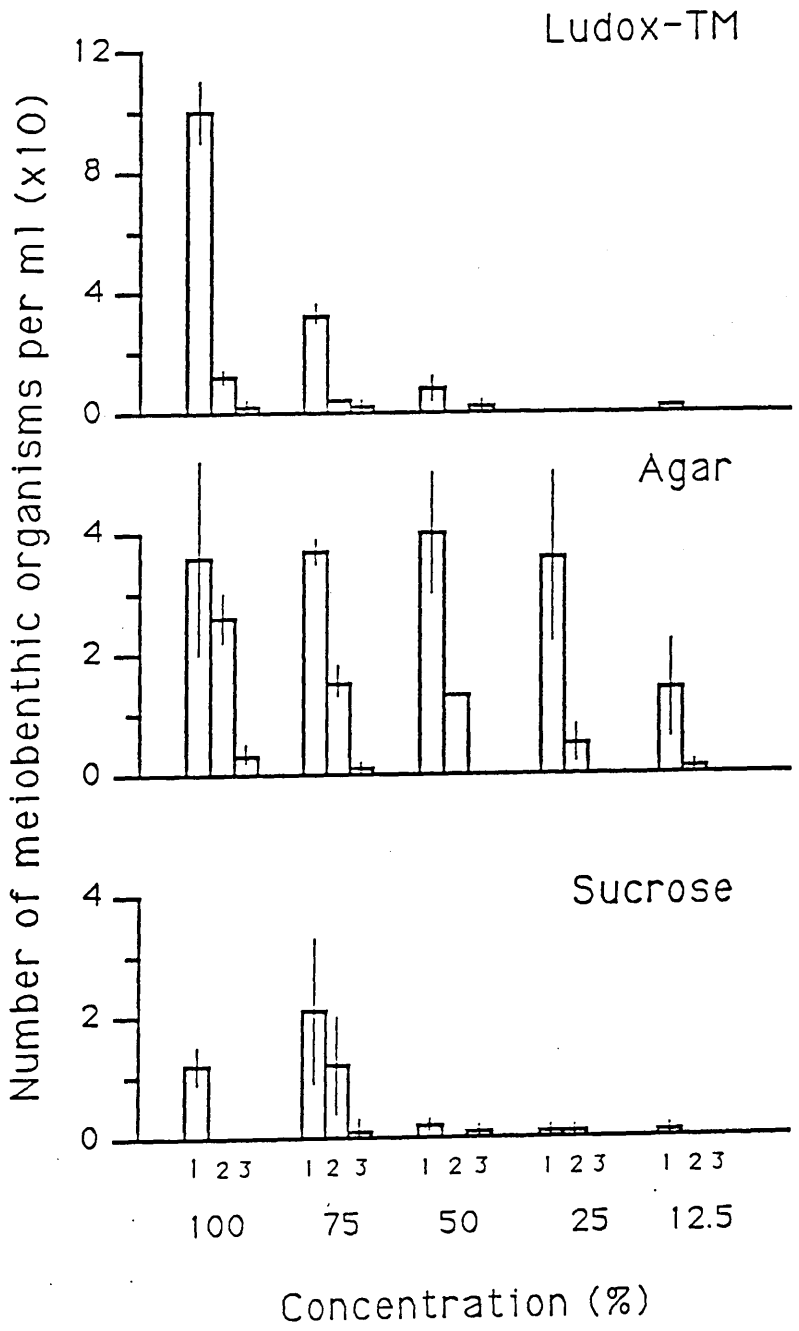


Figure (1.3)

Number of meiobenthic organisms per ml extracted from three (1, 2 and 3) washes at different concentrations of test solutions (Ludox, Agar and Sucrose). Vertical lines show the standard deviations of two counts. Data from two layers (I and II) combined for each wash.

Table (1.11)

The percentage of meiobenthic organisms per ml for three washes of Ludox-TM solution. This was calculated from the mean of organisms counted in layers I and II for each wash.

Concentration %		Number of organism in wash			
		First	Second	Third	Total
100	N	103	13	2	118
	%	87.29	11.01	1.7	100
75	N	32	5	3	40
	%	80	12.5	7.5	100
50	N	8	1	3	12
	%	66.67	8.33	25	100
25	N	0.5	0.5	0	1.0
	%	50	50	0	100
12.5	N	3	0.5	0	3.5
	%	85.71	14.29	0	100

N= Number of organisms. %= percentage of the mean number of organisms

Table (1.12)

The percentage of meiobenthic organisms per ml for three washes of Agar solution. This was calculated from the mean of organisms counted in layers I and II for each wash.

Concentration		Mean number of organisms in wash			
		First	Second	Third	Total
100	N	36	26	3	65
	%	55.39	40	4.61	100
75	N	37	15	0.5	52.5
	%	70.48	28.57	0.95	100
50	N	40	13	0	53
	%	75.47	24.53	0	100
25	N	36	8	0	44
	%	87.8	12.2	0	100
12.5	N	14	1	0	15
	%	93.33	6.67	0	100

N= Number of organisms. %= percentage of the mean number of organisms

Table (1.13)

The percentage of meiobenthic organisms per ml for three washes of Sucrose solution. This was calculated from the mean of organisms counted in layers I and II for each wash.

Concentration		Mean number of organisms in wash			
		First	Second	Third	Total
100	N	12	0	0	12
	%	100	0	0	100
75	N	21	12	1	34
	%	61.77	35.29	2.94	100
50	N	2	0	0.5	2.5
	%	80	0	20	100
25	N	1	0.5	0	1.5
	%	66.67	33.33	0	100
12.5	N	0.5	0	0	0.5
	%	100	0	0	100

N= Number of organisms. %= percentage of the mean number of organisms

Table (1.14).

The number of nematodes counted in different volumes of preserved sediment. Two replicates were taken at each volume. Three washes were conducted for each replicate and the total numbers from these are given in column 3 of the table at each volume. The number of Nematodes $.ml^{-1}$ were calculated for each volume of sediment (column 4).

Volume of sediment (ml)	Replicate	Number of nematodes	
		In a given volume of sediment	In 1ml of sediment
1	I	112	112
	II	79	79
	Mean ± s.d.	95.5 ± 23.33	95.5 ± 23.33
2	I	194	97
	II	136	68
	Mean ± s.d.	165 ± 41.0	82.5 ± 20.51
5	I	325	65
	II	289	58
	Mean ± s.d.	307 ± 25.46	61.4 ± 5.09
10	I	459	46
	II	563	56
	Mean ± s.d.	511 ± 14.14	51.1 ± 7.35
20	I	741	37
	II	761	38
	Mean ± s.d.	511 ± 73.54	37.6 ± 0.7071
40	I	1506	38
	II	1490	37
	Mean ± s.d.	1498 ± 11.31	37.5 ± 0.2828

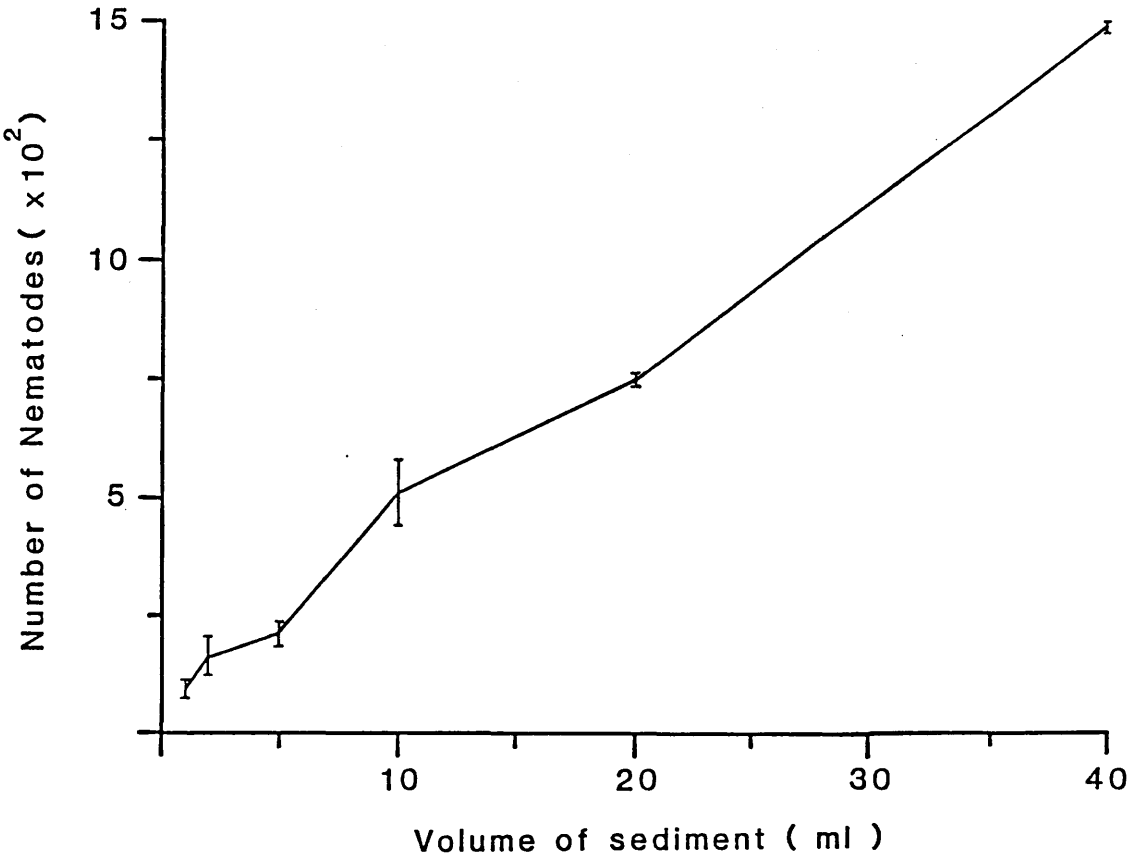


Figure (1.4)

The number of nematodes extracted from different volumes of the preserved sediment: 1ml, 2ml, 5ml, 10ml, 20ml and 40ml. The means and standard deviations of the two counts of each volume were calculated.

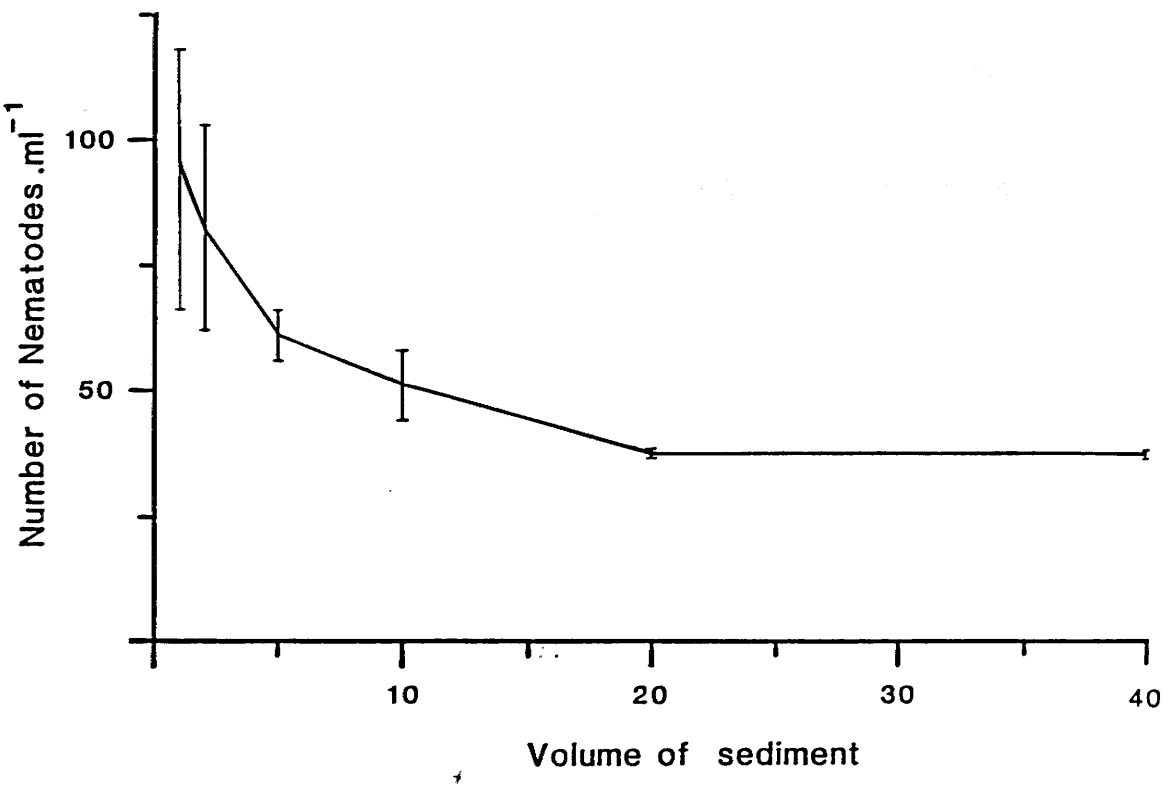


Figure (1.5).

The number of nematodes $.ml^{-1}$ extracted from different volumes of sediment: 1ml, 2ml, 5ml, 10ml, 20ml and 40ml. The means and standard deviations were calculated for two counts at each volume.

counted in different volumes of sediment. From the table and figures, it can be seen that the number of nematodes rose with an increased volume of sediment (table 1.14 column 3 and figure 1.5) but when expressed as numbers per ml the numbers decreased. The variation in the number of nematodes per ml between replicates I and II was high in the small volumes of sediment, particularly in the 1ml and 2ml volumes, but was low in the larger volumes of sediment, i.e. 20ml and 40ml.

2- Experiment 3.

Table 1.15 and figure 1.6 show the number of nematodes extracted from 10ml of sediment at time intervals of 1hr, 3hrs, 6hrs, 12hrs and 18hrs. These show that there were no differences between the number of nematodes extracted at different time intervals. The data was statistically tested using one way analysis of variance (Table 1.16). This table shows that there was no significant difference between the numbers at the different time intervals. These numbers were also tested using t tests comparing pairs of time intervals (table 1.17). These tests show that there was no significant difference between pairs of time intervals.

These results mean that a period of 1 hour is suitable for extracting meiofauna from sediments, and that longer periods of extraction are unnecessary.

3- Experiment 4

Table 1.18 shows the number of nematodes extracted from 2ml of preserved sediment using different concentrations: 100% 125%, 150%,

Table (1.15).

The number of nematodes per 10ml of preserved sediment. Differences between time intervals: 1hr, 3hrs, 6hrs, 12hrs and 18hrs.

Time (hour)	Replicate subsample	Number of nematodes
1	I	549
	II	849
	Mean ± s.d.	699 ± 212.13
3	I	654
	II	486
	Mean ± s.d.	570 ± 118.79
6	I	363
	II	591
	Mean ± s.d.	477 ± 161.22
12	I	555
	II	608
	Mean ± s.d.	581.5 ± 37.48
18	I	569
	II	621
	Mean ± s.d.	595 ± 36.77

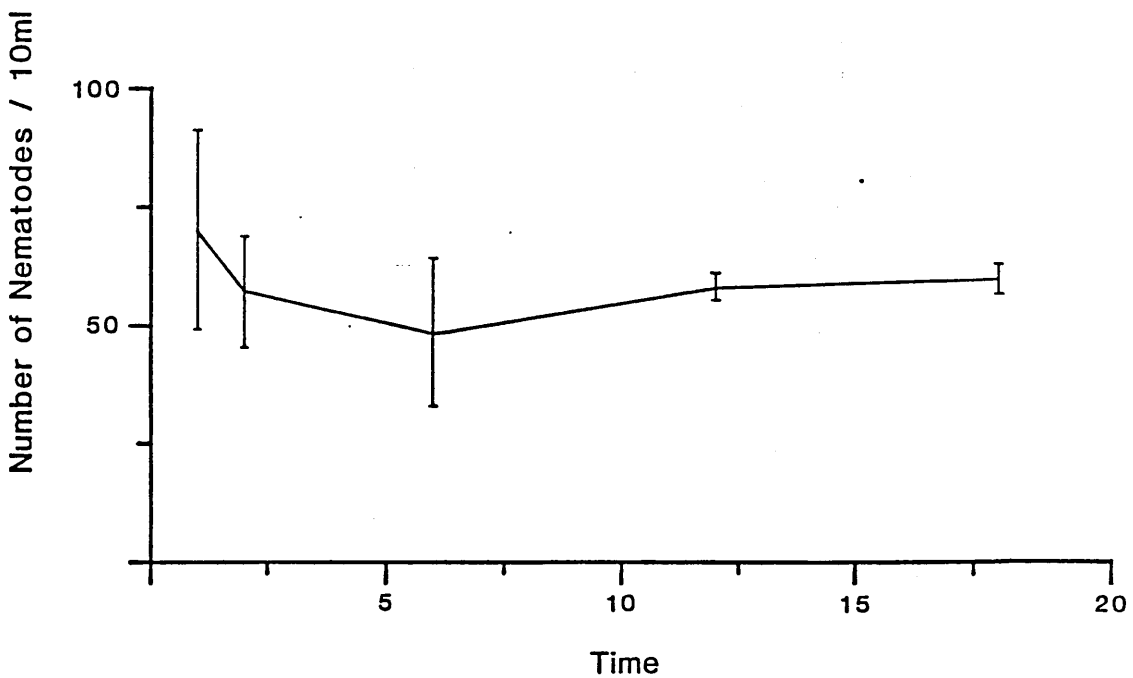


Figure (1.6)

The number of nematodes extracted from 10ml of preserved sediment at different time intervals: 1hr, 3hrs, 6hrs, 12hrs and 18hrs. The means and standard deviations were calculated of two counts at each time interval.

Table (1.16).

The number of nematodes per 10ml of sediment. One way analysis of variance for testing differences between time intervals: 1hr, 3hrs, 6hrs, 12hrs and 18hrs. The analysis was 1 x 5 one way anovar.

Source of variance	Sum of squares	Mean of square	Degrees of freedom	F.ratio	Probability
Time intervals	49992	12498	4	0.7112	0.75>P>0.50
Residual	87860.5	17572.1	5		
Total	137852.5		9		

Table (1.17)

T tests on the number of nematodes per 10ml of sediment. Each t test was conducted on a pair of time intervals: 1hr, 3hrs, 6hrs, 12hrs and 18hrs.

Source of variance	t test	Degrees of freedom	Probability
1hr and 3hrs	0.7504	2	0.6 >P>0.5
1hr and 6hrs	1.1783	2	0.4 >P> 0.3
1hr and 12hrs	0.7714	2	0.6 >P> 0.5
1hr and 18hrs	0.6831	2	0.6 >P> 0.5
3hrs and 6hrs	0.6568	2	0.6 >P> 0.5
3hrs and 12hrs	0.1306	2	P> 0.9
3hrs and 18hrs	0.2843	2	0.9 >P> 0.8
6hrs and 12hrs	0.8929	2	0.5 >P> 0.4
6hrs and 18hrs	1.0092	2	0.5 >P> 0.4
12hrs and 18hrs	0.3636	2	0.8 >P> 0.7

Table (1.18).

Number of nematodes extracted from 2ml of preserved sediment using different concentrations of Ludox solution: 100%, 125%, 150%, 175% and 200%. These concentrations were corresponded to 25%, 31.25%, 37.5%, 43.75 and 50%, respectively of the original percentage of 100% ludox solution.

Number of wash	Concentration % of Ludox-TM									
	100		125		150		175		200	
	I	II	I	II	I	II	I	II	I	II
First	157	137	150	147	132	120	140	135	147	120
Second	11	30	22	13	14	18	15	28	20	26
Third	6	9	4	12	12	4	7	9	7	10
Total	174	169	176	172	158	142	162	172	174	156
Mean ± s.d.	172 ± 3.54		174 ± 2.83		150 ± 11.3		167 ± 7.07		165 ± 12.7	

175% and 200% of ludox solution. The table shows that there was no difference in the number of nematodes extracted from these different concentrations. The results mean that using low concentrations of ludox, i.e. 100% = 25% of pure solution will give the same results as using high concentration in extracting meiofauna from sediment.

3- Experiment 5.

A- <u>The modified ludox separation technique.</u>

Table 1.19 shows the number of nematodes extracted from sediment using the modified ludox separation technique.

The table shows the number of organisms extracted from 2ml and 20ml of sediment at 1hr, 3hrs, 6hrs, 12hrs and 18hrs time intervals. The number of nematodes per ml in the two volumes are also shown for each time interval. From this table the following points can be noted.

- The number of nematodes extracted from 2ml and 20ml at the 1hr and 3hrs intervals exceed the numbers extracted from the two volumes at the 6hrs, 12hrs and 18hrs intervals.
- The number of nematodes per ml in the 2ml volume are greater than the numbers per ml in the 20ml of sediment at all time intervals.

The number of nematodes per ml was tested statistically by two way analyses of variance in order to test the difference between the number of nematodes extracted from different volumes of sediment and at different time intervals (table 1.20). The table shows no significant first order interaction.

The following conclusions were made concerning the two main factors: A: different time intervals 1hr, 3hrs, 6hrs, 12hrs and 18hrs. B: different volumes of sediment 2ml and 20ml. Factors A and B are

Table (1.19).

The number of nematodes extracted from 2ml and 20ml of sediment, testing differences between time intervals: 1hr, 3hrs, 6hrs, 12hrs and 18hrs. Two replicates were used for each volume of sediment. Three washes were conducted for each replicate.

Time (hour)		Volume of sediment in ml			
		2		20	
		I	II	I	II
1	Number of organisms	258	208	1416	1316
	Mean ± s.d.	233 ± 35.35		1366 ±70.71	
	Numbers. ml^{-1}	129	104	71	66
	Mean ± s.d.	116.5 ± 17.68		68.5 ± 3.54	
3	Number of organisms	219	242	1305	1326
	Mean ± s.d.	230.5 ± 16.26		1315 ± 14.85	
	Numbers. ml^{-1}	110	121	65	66
	Mean ± s.d.	115 ± 8.13		66 ± 0.7425	
6	Number of organisms	140	156	1363	1070
	Mean ± s.d.	148 ± 11.31		1216.5 ± 207.18	
	Numbers. ml^{-1}	70	78	68	54
	Mean ± s.d.	74 ± 5.66		61 ± 10.36	
12	Number of organisms	117	193	1305	1130
	Mean ± s.d.	155 ± 53.74		1217.5 ± 123.74	
	Numbers. ml^{-1}	59	97	65	57
	Mean ± s.d.	78 ± 26.87		61 ± 5.657	
18	Number of organisms	153	163	1093	1084
	Mean ± s.d.	158 ± 7.071		1088.5 ± 6.364	
	Numbers. ml^{-1}	77	82	55	54
	Mean ± s.d.	79 ± 3.536		54.5 ± 0.7071	

Table (1.20).

The number of nematodes. ml^{-1} of sediment. Two way analysis of variance of the ludox separation.

Factor A = Time intervals 1hr, 3hrs, 6hrs, 12hrs and 18hrs.

Factor B = Volume of sediment (2ml and 20ml).

Two count for each cell.

Source of Variance	Sum of squares	Mean of squares	Degrees of freedom	F.ratio	Probability
A	2699.26	674.82	4	4.1479	0.25>P>0.10
B	4604.10	4604.10	1	35.1225	P<0.001
Interaction	1192.20	298.05	4	2.2737	
Residual	1310.87	131.09	10		
Total	9806.43		19		

both significant differences between the number of nematodes extracted at different time intervals and from the two volumes. However, the volume effect is greater than the time effect.

Two series of breakdown one way analyses of variance were then conducted to analyse the two factors in more detail. The first series contained two one way anovars testing the differences between the time intervals for each of the two volumes of sediment (table 1.21). These show that there is a possible difference between the time intervals for the 2ml volume ($0.01>P>0.05$), but no difference between time intervals for the 20ml volume ($0.025>P>0.10$).

The second series contained five one way anovars testing the differences between the volumes at each of the five time intervals (table 1.22). These show that there are significant differences between the numbers from the two volumes at 3hrs and 18hrs intervals ($0.025>P>0.01$). However, there is no significant difference at 6hrs and 12hrs intervals ($0.50>P>0.25$) and a possible difference at an interval of 1hr ($0.10>P>0.05$).

These results mean that a short period of time, i.e. 1hr is sufficient for extracting nematodes and hence, presumably other meiofauna groups from sediment. Longer periods of extraction are not necessary. The number of nematodes per ml extracted from 2ml of sediment were always more than the number extracted from 20ml but this difference was only significant in 2 out of 5 time intervals.

B- The simple decantation technique.

Table 1.23 shows the total number of nematodes and the numbers per ml extracted from 10ml, 20ml and 40ml volumes of sediment using

Table (1.21).

The number of nematodes organisms per ml. Two one way analyses of variance of the two volumes of sediment (2ml and 20ml), testing differences between time intervals: 1hr, 3hrs, 6hrs, 12hrs and 18hrs. Each analysis was 1 X 5 one way anovar.

Source of variance		Sum of	Mean	Degrees of	F.ratio	Probability
Volume of sediment (ml)	Factor	squares	square	freedom		
2	Time	3686.1	921.525	4	4.0237	0.10>P>0.05
	Residual	1145.125	229.0250	5		
	Total	4831.225		9		
20	Time	228.056	57.0140	4	1.7832	0.25>P>0.10
	Residual	159.8662	31.9732	5		
	Total	387.9223		9		

Table (1.22)

The number of nematodes organisms per ml. Five one way analyses of variance of the time intervals: 1, 3, 6, 12 and 18 hrs., testing differences between the two volumes of sediment (2ml and 20ml). Each analysis was a 1 X 2 one way anovar.

Source of variance Time (hr)	Factor	Sum of squares	Mean square	Degrees of freedom	F.ratio	Probability
1	Volume of sed.	2323.24	2323.24	1	14.30	0.10>P>0.05
	Residual	325.00	162.50	2		
	Total	2648.24		3		
3	Volume of sed.	2445.30	2445.30	1	73.41	0.025>P>0.01
	Residual	66.63	63.31	2		
	Total	2511.92		3		
6	Volume of sed.	172.92	172.92	1	2.47	0.50>P>0.25
	Residual	140.05	70.02	2		
	Total	312.97		3		
12	Volume of sed.	275.56	275.56	1	0.7245	0.50>P>0.25
	Residual	760.72	380.36	2		
	Total	1036.28		3		
18	Volume of sed.	603.93	603.93	1	95.85	0.025>P>0.01
	Residual	12.60	6.301	2		
	Total	616.53		3		

Table (1.23).

The number of nematodes extracted from different volumes of sediment, testing differences between the ratio of the two volumes of sediment to the volume of water during the decantation process. Two replicates of 2ml of sediment samples were taken for each test. Three washes were conducted in each replicate using 25% ludox solution.

Volume of sediment (ml)		Number in the ratio between the volume sediment to the volume of water					
		1 : 10		1 : 20		1 : 40	
		I	II	I	II	I	II
10	number of orgs.	852	659	819	819	867	861
	Mean ± s.d.	788 ± 111.4		814 ± 5.0		864 ± 4.2	
	numbers. ml^{-1}	85	66	82	81	87	86
	Mean ± s.d.	79 ± 11.1		81 ± 0.5		86 ± 0.5	
20	number of orgs.	1250	1175	1891	2045	1342	1603
	Mean ± s.d.	1213 ± 53.03		1968 ± 108.9		1473 ± 184.6	
	numbers. ml^{-1}	63	59	95	102	67	80
	Mean ± s.d.	61 ± 2.65		98 ± 5.45		74 ± 9.23	
40	number of orgs.	2345	3489	4280	4190	3255	3061
	Mean ± s.d.	2917 ± 808.9		4235 ± 63.63		3158 ± 137.2	
	numbers. ml^{-1}	59	87	107	105	81	77
	Mean ± s.d.	73 ± 20.22		106 ± 1.59		79 ± 3.43	

different volumetric ratios of sediment to water: 1:10, 1:20 and 1:40. The table shows that the number of nematodes extracted from the 1:20 and 1:40 ratios of sediment to water were higher than the 1:10 ratio for all three volumes of sediment, i.e. 10, 20 and 40 ml.

The data of the number of nematodes per ml for the different volumes of sediment and various volumetric ratios were analysed by a two way analysis of variance (table 1.24). Factor A in this anovar was the three volumes of sediment 10, 20 and 40 ml. Factor B was the three ratios 1:10, 1:20 and 1:40. The interaction of this anovar was not significant ($0.25>P>0.10$), therefore, factor A was not significant ($0.50>P>0.25$). In contrast factor B was highly significant ($0.005>P>0.001$). This means that there is no difference between the number of nematodes extracted from the three volumes of sediment, but that there is a difference in the numbers between the three volumetric ratios.

A one-way analysis of variance was then conducted to analyse the two factors in detail (tables 1.25 and 1.26). Six one way anovars were conducted. The first three tested the differences between the three volumetric ratios for each of the three volume of sediment (table 1.25). These show that there are no significant differences between the three ratios for the 10ml and 40ml volumes (10ml: $0.50>P>0.25$; 40ml: $0.25>P>0.10$), but there are significant differences between the three ratios for the 20ml volume ($0.025>P>0.01$). The second three anovars tested the differences between the three volumes of sediment for each of the three volumetric ratios (table 1.26). These show significant differences at the 1:20 ratio ($0.025>P>0.01$), but no

Table (1.24)

The number of nematodes per ml of sediment. Two way analysis of variance testing the differences between different volumes of sediment (factor A) and the ratios of the volumes of sediment to the volume of water (factor B). Two counts in each cell.

Source of Variance	Sum of squares	Mean of squares	Degrees of freedom	F.ratio	Probability
A	211.78	105.89	2	1.324	0.50>P>0.25
B	1983.02	991.51	2	12.20	0.005>P>0.001
Interaction	838.02	209.74	4	2.57	
Residual	731.77	81.31	9		
Total	3765.54		17		

Table (1.25).

The number of nematodes organisms per ml. Three one way analyses of variance for the volume of sediment: 10ml, 20ml and 40ml, testing differences between the ratio of the volume of sediment to the volume of water: 1:10, 1:20 and 1:40. Each analysis was a 1 X 3 one way anovar.

Source of variance						
Volume sediment (ml)	Factor	Sum of squares	Mean of square	Degrees of freedom	F.ratio	Probability
	Volumetric ratio	117.91	58.955	2	0.9475	0.50>P>0.25
10	Residual	186.67	62.22	3		
	Total	304.58		5		
	Volumetric ratio	1473.16	736.58	2	18.14	0.025>P>0.01
20	Residual	121.83	40.61	3		
	Total	1594.99		5		
	Volumetric ratio	1230.91	615.45	2	4.362	0.25>P>0.10
40	Residual	423.27	141.09	3		
	Total	1654.13		5		

Table (1.26).

The number of nematodes per ml of sediment. Three one way analyses of variance for the ratio between the volume of sediment to the volume of water in the decantation: 1:10, 1:20 and 1:40, testing differences between volumes of sediment, factor A: 10ml, 20ml and 40ml. Each analysis was a 1 x 3 one way anovar.

Source of variance		Sum of squares	Mean square	Degrees of freedom	F.ratio	Probability
Ratio	Factor					
1:10	Volume of sediment	245.02	127.01	2	0.6327	0.75>P>0.50
	Residual	602.26	200.75	3		
	Total	856.28		5		
1:20	Volume of sediment	632.04	316.02	2	29.24	0.025>P>0.01
	Residual	32.42	10.81	3		
	Total	664.45		5		
1:40	Volume of sediment	164.69	82.36	2	2.544	0.25>P>0.10
	Residual	97.09	32.36	3		
	Total	261.78		5		

significant differences at the 1:10 and 1:40 volumetric ratios (1:10: 0.75>P>0.50; 1:40: 0.25>P>10).

The results of these statistical analyses mean that there are significant differences between the number of nematodes per ml between the different volumes (10, 20 and 40ml) at the intermediate ratio (1:20), and between the different ratios (1:10, 1:20 and 1:40) at the intermediate volume (20ml).

The results of the two techniques namely, the modified ludox separation technique and the simple decantation technique were compared and tested statistically. A one-way analysis of variance was conducted to analyse the differences between the number of nematodes per ml extracted from sediment (table 1.27). The table shows that there is no significant difference between the number of nematodes extracted by both techniques (0.75>P>0.50). This lack of significance means that my modified technique is suitable and can be used for extraction of meiofauna from preserved sediment.

Table (1.27).

The number of nematodes per ml. A one way analysis of variance of the results of the number of organisms extracted from sediment, testing the differences between the two techniques,i.e. the Ludox separation technique and the simple decantation technique.

Source of variance	Sum of squares	Mean of squares	Degrees of freedom	F.ratio	Probability
Techinques	172.8	172.8	1	0.4573	0.75>P>0.50
Residual	13604	377.89	36		
Total	13776.8		37		

SUMMARY

I- Testing different solutions experiment.

This summary is divided into two sections. The first summarises the design of the apparatus for removing meiobenthic organisms from sediments and the way in which it is used. The second summarises the results of testing different solutions using this apparatus.

1. The design of apparatus and the way in which it is used.

- De Jonge and Bouwman (1977) used two types of apparatus (figure 1.7). One of them was used for pumping the layer of distilled water onto the surface of ludox solution by a peristaltic pump to prevent desiccation. The other was used for removing the liquid with organisms from the beaker to the vacuum flask using a vacuum pump.
- I designed an apparatus which can be used for both operations (plate 1.1). Firstly it can be used for forming a layer of distilled water on the surface of a ludox solution and secondly, it can used to remove the liquid. The sediment is washed three times with a given solution and in each wash the solution is removed as an upper layer and then a lower layer. This method is different from that of De Jonge and Bouwman (1977), who only washed the sediment twice and removed only the upper layer of liquid.

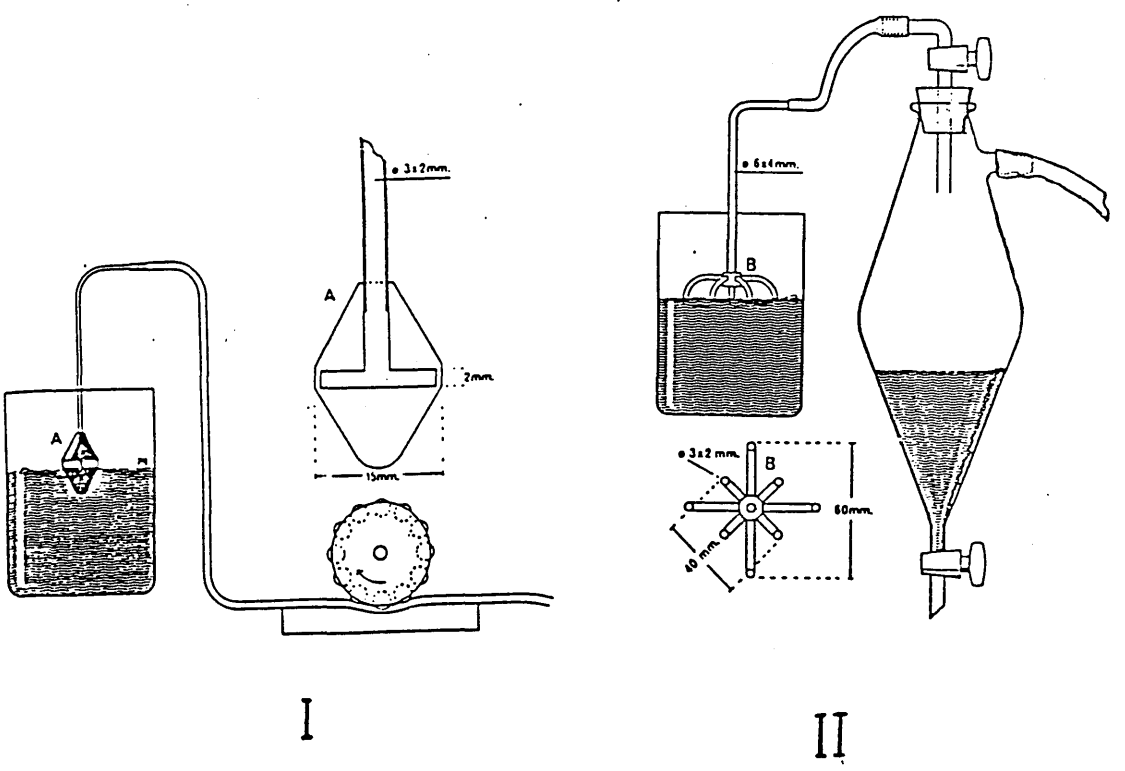


Figure (1.7)

De Jonge and Bouwman apparatus.

I- Arrangement for pumping a water layer upon the Ludox surface.

A- Detail of conical part through which the water is pumped in a horizontal direction upon the Ludox surface.

II- Arrangement for collecting the floating (supernatant) meiobenthic organisms from the Ludox surface.

B- Detail of the sucking-appratus.

(reprinted from De Jonge and Bouwman, 1977).

2. Results of testing different solutions.

(a) Ludox, Agar and Sucrose solutions were used for extracting meiobenthic organisms from sediment. Concentrations of 100%, 75%, 50%, 25% and 12.5% of all three solutions were tested. The 100% ludox solution contained 250ml ludox. L^{-1}, the 100% Agar solution contained 0.25g. L^{-1} and the 100% Sucrose solution contained 1000g. L^{-1}. All concentrations were made with distilled water. Methyl Cellulose was also tested but found to be unsuitable.

(b) Statistical analyses of the results show that there are significant differences in the number of meiobenthic organisms extracted from the three solutions.

(c) Concentrations of 100% Ludox, 100% Agar and 75% Sucrose remove the greatest number of meiobenthic organisms from the sediment.

(d) The 100% Ludox solution extracts the largest number of organisms from the sediment. This concentration contained over twice the number of organisms obtained using 100% Agar, and over 4.5 times the number of organisms obtained using 75% Sucrose.

(e) Statistical analyses show that in general there are no differences in the number of meiobenthic organisms between the upper and lower layers of the solutions.

(f) The first wash of the solutions contain between 50-100% of the extracted meiobenthic organisms, the second 5-40%, and third 0.5-25%.

II- The four experiments for the extraction of meiofauna.

The results of the four experiments conducted in the extraction of meiofauna from sediment are summarised as follows:

1- The number of nematodes extracted from sediment increase with increasing the volume of sediment (experiment 2).

2- The number of nematodes per ml extracted from small volumes of sediment, i.e. 1ml, 2ml and 5ml were more than the numbers per ml extracted from larger volumes of sediment, i.e. 20ml and 40ml.

3- A period of one hour between washes is sufficient to extract meiofauna from sediment rather than using a longer period.

4- There is no significant difference between the number of nematodes extracted when the results of my modified technique namely, the ludox separation technique are compared with the results of the simple decantation technique.

CHAPTER TWO

A survey of biological, physical and chemical studies of the sediment in the intertidal zone of Ardmore Point, Clyde estuary. (1984-1985)

INTRODUCTION

A monthly survey was carried out to study the biological aspects, and physical and chemical properties of sediment at Ardmore Point (latitude 55^{o} 58′ N, longitude 4^{o} 41′ W), Clyde Estuary (map 2.1). This survey was conducted in the low tide area of Ardmore Point in the period between February 1984 and February 1985. The low tide area is about 520 metres from high tide and the sediment surface consisted of long low dunes. The sediment of this area consists of fine sand (plate 2.1).

The introduction is divided into the following parts, and each part will be described separately:

I- Biological aspects

II- Physical properties of sediment

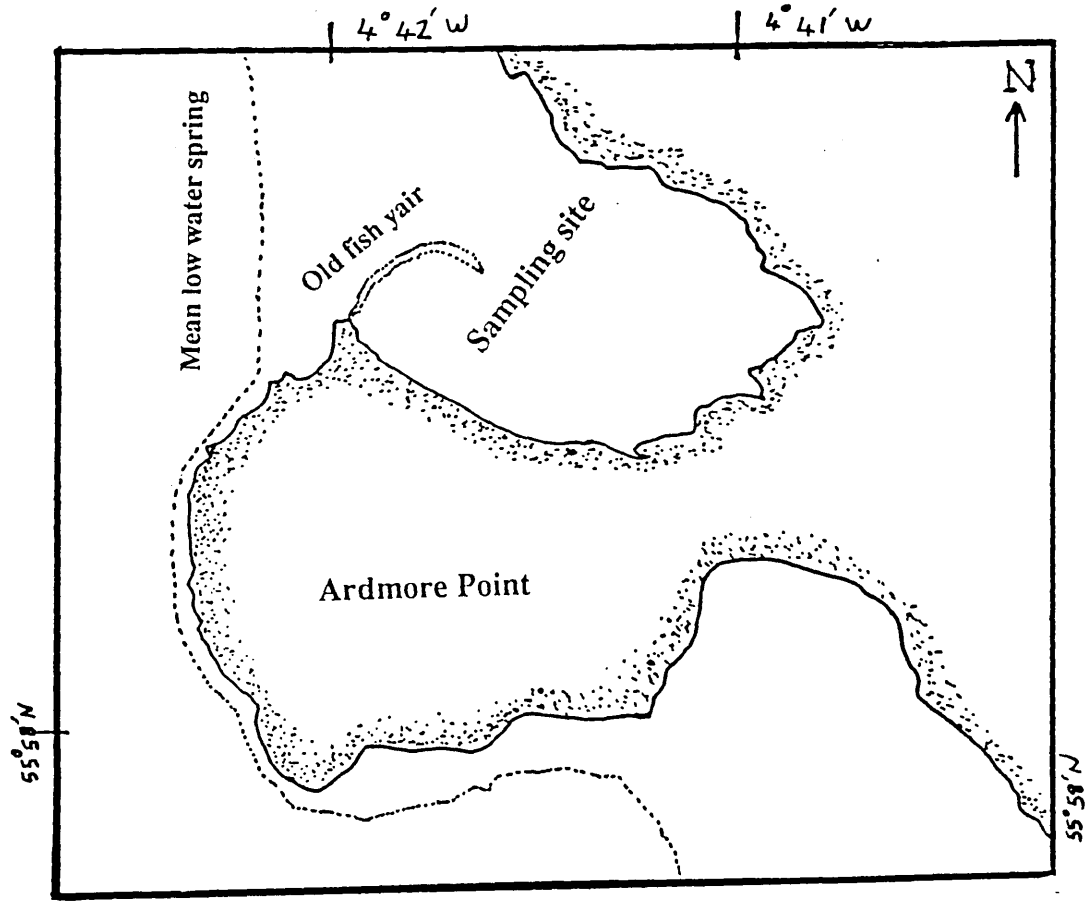
III- Chemical properties of sediment

I- Biological aspects

This part contains the biological features of some groups of meiofauna and macrofauna.

A- Meiofauna

Meiofauna is the name of the animals adapted for living in the spaces between sand grains also called interstitial fauna (Barnes, 1982). They are between 0.5 and 2mm in length. Their abundance is often very high (Fenchel, 1978). McIntyre (1969) shows that abundance of meiofauna in the intertidal zone is $1.1x10^{4}$ $.m^{-2}$ to $1.6x10^{7}$ $.m^{-2}$, in the continental shelf $4x10^{3}$ $.m^{-2}$ to $3.2x10^{6}.m^{-2}$, and on the abyssal



Map (2.1)

The location of Ardmore Point (Clyde Estuary, Scotland).

Plate (2.1)

Ardmore Point: Low tide level.

plain $1x10^4$ $.m^{-2}$ to $1.7x10^5.m^{-2}$. Meiofaunal animals are either temporary or permanent. The temporary ones are the young of the macrofauna and sometimes very abundant. The permanent meiofauna includes almost all major metazoan phyla. The main factors controlling distribution on intertidal beaches are sediment particle size, salinity, oxygen content, and temperature (Pollock, 1971; Hulings and Gray, 1976; Fleeger et al., 1984). Some meiofaunal species have unusually wide tolerances. The harpacticoid genus *Platychelipus* can withstand freezing sea ice at -9 ^{o}C for nine hours (Barnett, 1968).

Meiofaunal animals are preyed upon by a number of fish including flat fish and gobies, by hydroids and polychaetes (e.g. *Hediste diversicolor*). The vertical distribution of meiofauna in sediment is very localised. It has been investigated by a number of workers (e.g. Harris, 1972; Joint et al., 1982; Dye, 1983). Meiofauna usually occur within a few centemetres of the sediment surface whether intertidally or in the deep sea. Their density decreases with depth (Dye, 1977, 1983; McLachan et al., 1979; Teal and Wieser, 1966). In some habitats they can occur at unexpectedly deep levels in the sediment. For example Harris (1972) reports that meiofauna were found at a depth greater than 30cm in winter, on Whitsand Bay, Cornwall. Marine meiofauna also occur in the water column particularly harpacticoid copepods (Palmer and Gust, 1985).

The most abundant groups found in my survey at Ardmore Point were nematodes, harpacticoid copepods and ostracods, and these were found throughout the year. The general biology and ecology of these three groups is summarized in the following.

- Nematodes

The phylum Nematoda, called roundworms, includes about 10,000 parasitic and free living species, and contains some of the most wide-spread and numerous of all multicellular animals (Barnes, 1982). Free-living nematodes are found in the sea, fresh water, and in the soil, and they are mostly thought to be true sediment-dwelling animals (Jensen, 1984). The vast majority of free living nematodes are benthic animals and live in interstitial spaces of algal mats and especially aquatic sediment and soil (see Nicholas, 1975). The size and form of nematodes are adapted for living in interstitial spaces. The body is slender and elongated at both ends. The majority of free-living nematodes are less than 2.5mm in length and are often microscopic. However, some marine species attain a length of 5mm.

Many free-living nematodes are carnivorous and feed on small metazoan animals including other nematodes. Other species are phytophagous. Many marine and freshwater species feed on diatoms, algae and fungi.

Most nematodes are dioecious. Males are typically smaller than females, and the posterior of the male is curled like a hook. The deposition of the eggs of free-living nematodes is still not well known. Marine species rarely produce more than 50 eggs, which are often deposited in clusters. The above description was summarized from Barnes (1982).

- Harpacticoid copepods

Harpacticoid copepods appear to be ubiquitous in the marine environment, from tide pools to the abyssal zone (Coull, 1977). The

suborder Harpacticoida contains approximately 1,500 species of which about 85% are marine. It is one of seven orders of the subclass Copepoda, and contains small copepods ranging in size from 0.2 to 2.5mm, which are primarily free living (Coull, 1977, 1982). The body of harpacticoida is divided into two major regions as delineated by its narrowest constriction, i.e. the anterior prosome in front of the constriction and the posterior urosome behind the constriction. The male is always smaller than the female. Males of many species are rare and most of the taxonomically important features are based on female morphology.

The greatest number of harpacticoids live in shallow-water sediments and in the phytal (epiphytic) zone. The benthic harpacticoids are second only to nematodes in overall abundance and in some areas are often the most abundant taxon found in the meiobenthos (Coull, 1977). Harpacticoids usually follow one of three modes of existence in sediment: 1) interstitial, 2) burrowing, and 3)epipelic (surface living). The interstitial harpacticoids are typically vermiform, elongate animals that occupy the interstices of particles. The cephalothorax is generally broadened for pushing sediment particles out of the path or is equipped with spade-shaped appendages for digging in the sediment. These interstitial and burrowing harpacticoids are most common in fine sediments with a median particle diameter below 0.2mm, i.e., mud, silt-clays. The epipels are those harpacticoids that typically live on the surface of sediment and are adapted morphologically to this mode of existence by the great elongation of their body limbs which allows them to walk over the surface of fluid like mud without sinking (Coull, 1977).

Harpacticoids are the most sensitive of the meiobenthic organisms to changes in oxygen tension and are often the first to disappear if conditions become anaerobic. Harpacticoid copepods feed primarily on diatoms, bacteria and small protozoans (Coull, 1977).

- Ostracods

Ostracods, called mussel or seed shrimps, are small crustaceans that are widely distributed in the sea and in freshwater. Over 2000 living species have been described (Barnes, 1982). Ostracods have a solid, heavily calcified carapace consisting of two valves that enclose the simply shaped, unsegmented body. Only the valves are strong enough to be well preserved (Schäfer, 1972). Most ostracods are small, ranging from less than 1mm to several millimetres in length. The body is usually terminated by a caudal furca, consisting of two rami which often bear spines and setae (Green, 1968). The carapace is often heavily calcified and may be ornamented with ridges and tubercles as well as spines around the free margins. Dorsally the two carapace valves meet to form a hinge (Green, 1968). Some species can swim freely in water, and have long setae on their antennae. Species which do not swim lack these setae, or have them present in a reduced form (Green, 1968). The majority of ostracods live near the bottom, where they swim intermittently or scurry over or plough through the upper layer of mud and detritus (Barnes, 1982). They live in sand, and soft mud, on plants, or in the water mass (Schafer, 1972). Ostracods display diverse feeding habits. There are carnivores, herbivores, scavengers, and filter feeders. Algae are a common plant food, and the prey of carnivorous species includes other crustaceans, small snails,

and annelids (Barnes, 1982).

B- Macrofauna

Macrofauna living in or on the surface of sediment include all the major invertebrate groups and those described come mainly from the continental shelf. They feed in one of three ways: by filter feeding, browsing, or ingesting deposited material on the sediment. Filter feeders filter small particles in suspension using a fan, sieve or net. Many molluscs, polychaetes, and sponges feed in this way. Browsers are usually active mobile species that move across the sediment surface eating organic material. Many amphipods isopods and gastropods fall into this category. Deposit-feeding animals eat particles at the sediment surface or within the sediment itself. Many crustaceans, polychaete annelids, and molluscs fall into this class (Meadows and Campbell, 1988). Filter feeders are more common in sandy sediment and deposit feeders in finer muds.

In the intertidal zone, many studies on abundance, biomass, and distribution of macrofauna have been carried out (Stephen, 1930; Holme, 1949; Croker, 1967; Longbottom, 1970; Bloom, et al., 1972; Woodin, 1974; Cadee, 1976; Whitlatch, 1981; Brown, 1982).

The dominant macrofauna species found at low tide at Ardmore Point are *Pygospio elegans, Bathyporeia pilosa, Eteone longa, Arenicola marina, Hediste diversicolor,* and *Scoloplos armiger.*

Their biology is briefly described below, dealing with the most abundant species first.

- *Pygospio elegans*

P.elegans is a burrowing polychaete' that lives intertidally in tubes consolidated with sand grains, and feeds on detritus lying on the sediment (Fauvel, 1923; Schäfer, 1972). A more detailed description of this species is given in chapter three.

- *Bathyporeia pilosa*

Bathyporeia pilosa is an amphipod species which is up to 6mm in length. The body is slender and compressed, especially in the male. The cephalon is obtusely truncated at the front. The coxal plate is small, scarcely as deep as the body. The eyes in the female are small, and rounded or oval in form; in the male they are somewhat larger. The upper antennae are shorter than the lower ones, and have a small branch rising from them. The species lives in coarse sand (Green, 1968). The species is a common and abundant species on the west coast of Britain, and also occurs in the North Sea, Denmark, Norway, and the Baltic (Lincoln, 1979).

- *Eteone longa*

E.longa is a long and thin polychaete worm with numerous segments (200 segments). The body is about 25mm to 60mm long, and its width is about 1 to 2mm. The prostomium is about as long as it is broad. It has two eyes on the prostomium, and there are four short antennae on the proposcsis which are either smooth or covered with transverse ridges. Its anal cirri are very short and almost spherical. Its colour tends to be orange (Fauvel, 1923). The species lives in the littoral or subtidal zone, and is present in small numbers in the

Clyde Estuary (Clark, 1960). The species is found around the British Isles, North Sea, Atlantic coast of Ireland, and in Arctic waters (Fauvel, 1923; Holme, 1949). It is found locally at Kames Bay and White Bay (Isle of Cumbrae) in the sublittoral zone to about 27m water depth (Clark, 1952).

- *Arenicola marina*

A.marina the lugworm, is a polychaete annelid about 10-20cm long. The body of the species is formed of three regions: head, trunk and tail. The head is roughly conical extending forwards from the first chaetigerous segment. The mouth opens anteriorly on the head, and an eversible proboscis is present. The middle region or trunk consists of 19 segments (rarely 20), all of which bear chaetae; the first lacks gills (Fauvel, 1923). Segments 7 to 19 bear hollow contractile gills in a dorso-lateral position above the parapodia. The tail is narrower than the trunk and consists of up to 60 to 70 segments lacking chaetae and gills (Green, 1968). The species feeds by ingesting sand and digesting any organic matter that may be present.

A.marina is very common around British coasts (Green, 1968; Newell, 1970; Schäfer, 1972; McLusky, 1981). It is often abundant in muddy sand, and is usually found burrowing from the middle shore downwards. The worm lives in 20 to 40cm deep U-shaped burrows in tidal flats (Cadee, 1976), and may remain in the same burrow for many months (Green, 1968, Schäfer, 1972).

- *Hediste diversicolor*

This species is a dominant polychaete annelid in soft or

brackish water habitats throughout Europe. The body is 8-10cm long, and contains 90-120 segments with bristles. The head contains two antennae and four eyes. The colour of body is varied, but often yellowish-brown shading to green along both sides. The blood-vessel makes a red line along the back of the animal. This species occurs in the Mediterranean, Atlantic, English Channel, North Sea and West Baltic (Fauvel, 1923; Campbell, 1976; Barrett and Yonge, 1980). It is found in the middle shore down to shallow water, burrowing in sand or mud. It is often found in brackish water, and reaches its greatest abundance in estuarine mud. It is found in high densities in some places (4,000 animals per m^2, Schäfer, 1972). It is very tolerant of low salinities (Smith, 1955) and has been found at salinities as low as 1 $^{o}/_{oo}$ (Green, 1968).

Hediste feeds selectively on a variety of materials including algae, detritus, other annelids and crustacea, but can also filter feed (Nicol, 1960; MacGinitie and MacGinitie, 1968). The reproduction of *H.diversicolor* has been studied by Dales (1950, 1951), Green (1968), Chambers and Milne (1975); and Heip and Herman (1979).

- *Scoloplos armiger*

This polychaete worm is 5-15cm long. The body is made up of about 200 segments bearing chaetae, of which up to twenty segments are in the flattened thoracic region. The body colour is bright red, with rosy-orange tints (Fauvel, 1923; Barrett and Yonge, 1980). The body is divided into two regions. The thoracic half is flattened and enlarged, and the abdominal half is long and cylindrical. The head generally lacks appendages, but possesses two eyes which are sunk deeply in the

head. Parapodia bear simple gills on the dorsal surface. There are two thread-like processes which extend from the tip of the tail. The species generally inhabits sand or mud. It is locally common, and occurs in the Atlantic, English Channel, North Sea, West Baltic and Pacific (Campbell 1976; Kaestner, 1967; Green, 1968; Schäfer, 1972; Barrett and Yonge, 1980).

II- Physical properties of sediment

The physical properties of sediment are described below.

A- Shear strength

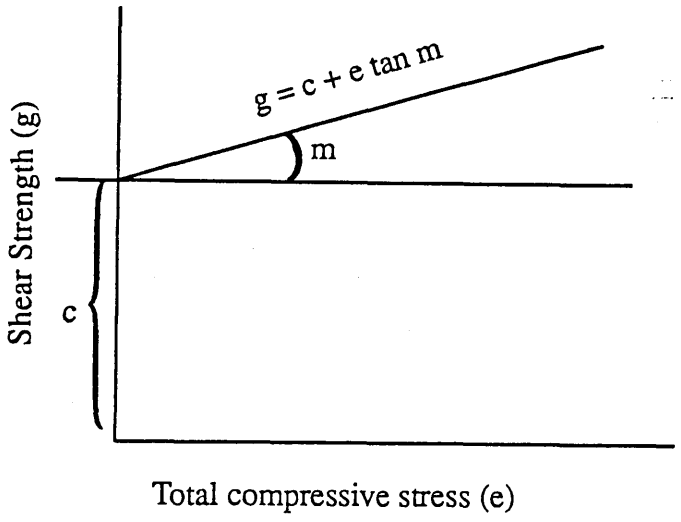
The shear strength of a soil or sediment is its maximum resistance to shearing stresses (Jumikis, 1962; Capper and Cassie, 1976; Lambe and Whitman, 1979). The shear strength of a sediment is controlled by internal friction and cohesion between sediment particles (Capper and Cassie, 1976). Internal friction results from surface roughness and interlocking of individual particles. Cohesion, or sticking together of individual particles is caused by several factors including electrostatic bonding (particles smaller than coarse silt) (Friedman and Sanders, 1978), and the capillary action of sediment moisture content (Jumikis, 1962).

The shear strength of sediment can be described by Coulomb's equation (Lambe and Whitman, 1979) which in its simplest form may be stated as

$$g = C + e \tan m \quad \text{(Smith, 1981)}$$

where g is the shear strength, C is the apparent cohesion, e is the total compressive stress or load, and m is the angle of shearing

resistance (Internal friction angle between particles).



Shear strength can be measured by simple cone or vane tester devices in the field, and is measured in units of pressure (force/unit area) as Kg cm^{-2} or kN m^{-2} (1kg cm^{-2} = 98.1 kN m^{-2}).

B- Permeability

Permeability describes the extent to which a sediment permits water to pass through it (Fraser, 1935). Permeability is a measure of the speed at which water flows through soil and sediment, and is important to the civil engineer who studies seepage under dams, ground water lowering and land drainage (Smith, 1981). Permeability is usually measured as the rate at which water passes a cylindrical section of core (Buchanan, 1984). The coefficient of permeability has the dimensions of a velocity and is usually expressed in m/s or mm/s (Capper and Cassie, 1976; Smith, 1981). It represents the velocity which would produce the same rate of discharge if the water flowed through the whole area instead of through the voids (Capper and Cassie, 1976). Permeability varies between different sediments

(Jumikis, 1962; Hansen et al., 1980). It depends on the size and shape geometry of the voids (Nelson and Baver, 1940; Marshall, 1958), the hydraulic gradient (Fraser, 1935), the presence of entrapped air (Christiansen, 1944), and temperature (Pillsbury and Appleman, 1950; Webb, 1969) which affects the viscosity of water thereby altering the rate at which it flows through the sediment. Generally a coarse-grained sediment such as gravel is more permeable than a fine-grained sediment such as fine sand. This is common sense, since water drains more quickly through sand than through mud.

Permeability plays a vital part in problems related to drainage, wells, groundwater storage, agricultural lands, railroads, building, and seepage through earth dams and levees (Lambe, 1955; Hillel, 1971; Hulings and Gray, 1971; Scott, 1974; Bowles, 1979; Smith, 1981).

The flow of water through sediments is assumed to follow Darcy's law (Lambe and Whitman, 1979; Smith, 1981) which states that

$$K = \frac{Q/t}{Ai}$$

where Q = quantity of water flowing; t = time for quantity Q to flow; K = coefficient of permeability for the soil; A = area of cross-section through which the water flows; and i = the hydraulic gradient which is calculated from the hydraulic head across soil (H) and the length of flow path through soil (l).

Typical values of the permeability coefficient (K) are 10 to 1000 mm s^{-1} for gravels, 0.01 to 10 mm s^{-1} for sands, 10^{-2} to 10^{-5} mm s^{-1} for silts, and less than 10^{-5} mm s^{-1} for clays (Smith, 1981).

Permeability can be measured in the field using different methods. These methods are described in detail in Luthin (1966) and

Dunn et al. (1980). In the work reported in this thesis an auger hole method was used to determine the permeability. This method is described below. The method has been used by several investigators. Hooghoudt (1936) mathematically analysed the auger hole method in a homogeneous soil. Hooghoudt derived the following equation based on his own experimental observations:

$$K = \frac{aL}{(2H+a)t} \ln \frac{Y_1}{Y_2}$$

where, K is the coefficient of permeability, a is the radius of the auger hole, L = rH/0.19 (metres), H is the distance from the bottom of the hole to the water table. Y_1 and Y_2 are the vertical heights at times t_1 and t_2 between the water table in the soil and the water level in the auger hole.

Ernst (1950) also developed an equation which can be used to measure the permeability by the auger hole method. The equation was derived for a homogeneous soil with an impermeable layer at some depth below the bottom of the auger hole. Here, the coefficient of permeability (K) is given by:

$$K = \frac{40}{\left(20 + \frac{H}{a}\right)\left(2 - \frac{y}{H}\right)} \cdot \frac{a}{y} \cdot \frac{\Delta y}{\Delta t}$$

where H is the depth of water in hole before pumping, y is the distance from a static water table to the elevation of the water in the hole, a is the radius of the auger hole, Δ y is the rise of water surface in the auger hole during the time intervals Δ t (Luthin, 1966; Dunn et al., 1980).

Other auger hole methods are available, but the one used in this thesis is the simplest one to use on a beach. For example, Kirkham (1946) described a pipe cavity method which consists of pushing a pipe into an auger hole slightly smaller in diameter than the pipe, using a special technique designed to eliminate compaction, and Childs (1952) and Childs et al. (1953) described a method for non-layered soil using two auger holes.

C- Particle size

Particle size is a fundamental descriptive measure of sediments and sedimentary rock, and is important in understanding the mechanisms operative during transportation and deposition (Lindholm, 1987). In the marine environment the movement of sediment particles is governed by particle size and the flow velocity of the water current. The resistance to movement is related to the size and weight of the particles.

Sediment particles range in diameter from a fraction of a micron to several centimetres in diameter. Most sediments have a log-normal size distribution, that is if the sediment is divided into classes arranged on the log-scale, they show a normal distribution, with a high proportion of particles in the middle class and progressively less towards the extremes (Friedman and Sanders, 1978). However, it is rare to find a perfectly normal distribution (a symmetrical bell-shape curve) for natural sediment. Most sediments show some degree of skewness and kurtosis (Briggs, 1977).

Sediment particle size is measured in metric units (e.g. mm). The size grades most commonly used by geologists were devised by J.A.

Udden and modified by C.V. Wentworth (1922) in what is commonly known as the Udden-Wentworth or Wentworth Grade Scale (Lindholm, 1987). The Wentworth scale is geometric, based on 1mm and a ratio of 2. The class intervals can be decreased by using the ratio $\sqrt{2}$ instead of 2. The Wentworth scale is summarized below (Buchanan, 1984).

		2 scale (mm)	$\sqrt{2}$ scale (mm)	m (phi)
		2	2	-1
	very coarse sand		1.41	-0.5
		1	1	0
			0.71	+0.5
	coarse sand	0.50	0.50	+1.0
Sand			0.351	+1.5
	medium sand	0.250	0.250	+2.0
			0.177	+2.5
	fine sand	0.125	0.125	+3.0
			0.088	+3.5
	very fine sand	0.062	0.062	+4.0
			0.044	+4.5
	coarse silt	0.031	0.031	+5.0
			0.022	+5.5
	medium silt	0.0156	0.0156	+6.0
Mud			0.0110	+6.5
	fine silt	0.0078	0.0078	+7.0
			0.0055	+7.5
	very fine silt	0.0039	0.0039	+8.0
	Clay	< 0.0039	< 0.0039	< +8.0

A logarithmic transformation was applied by Krumbein (1934) to the Wentworth scale in order to produce an arithmetic series of integers. This is the so-called phi notation where phi = $-\log_2$ of the particle diameter in millimeters. The advantages of using this unit are in graphical and statistical analysis (Buchanan, 1984). One of the fundamental purposes in using standard particle size scales is to allow comparison of sediment analyses and to aid in the correlation of sediments from different environments (Inman, 1952).

Several methods can be used to determine particle distribution. These depend on the size of the grains. Particles larger than several centimetres are usually determined by direct measurement with calipers or metre sticks; particles down to about 4 phi (0.062 mm) are analysed by screening (dry sieving); and silts and clays (less than 0.062 mm) are analysed by pipette or hydrometer analysis, utilizing differential settling rate in water (Folk, 1980).

The following parameters are usually determined: mean, median, sorting (standard deviation), skewness and kurtosis. The mathematics of these parameters are complicated and are explained in Folk (1980), Snedecor and Cochran (1980), and Sockal and Rohlf (1981). They can be calculated algebraically or graphically as histograms, cumulative curves, and frequency curves. The mean is the average particle size, and the median divides the frequency distribution of the particles into two halves. If the size distribution follows the normal curve the median equals the mean. The observed particle size distribution can differ from the shape of the normal curve having the same mean and standard deviation in two ways: skewness and kurtosis.

Skewness occurs if the size distribution is peaked towards the larger or smaller particles. If the distribution is peaked towards the larger particle size (small phi) with a tail in the finer particles (larger phi), the median is less than the mean on the phi scale, and the distribution is called negatively skewed. A positive skewed distribution on the phi scale has its peak at the smaller particle sizes (large phi) and tail in the bigger particle sizes (smaller phi). Here the median is greater than the mean.

Kurtosis measures the symmetrical flatness or peaking of the

observed distribution in the central and peripheral parts of its distribution. An observed distribution is leptokurtic if it has a higher central peak falling rapidly on either side of the mean to longer tails, when compared to an equivalent normal curve having the same mean and standard deviation. Conversely an observed particle size distribution is platykurtic if it has a lower central peak, is flat topped, and tends to be convex with little or no tail at the extremes of the distribution.

D- Water content

Water content is the weight of the water divided by the weight of soils in a given volume (Capper and Cassie, 1976). It is calculated using the following equation:

$$\text{Water content} = \frac{\text{Weight of wet sample} - \text{Weight of dry sample}}{\text{Weight of dry sample}}$$

It differs from degree of saturation which is defined as the ratio of water to the volume of the voids (Smith, 1981). The water content of sediment is affected by several factors including particle size and shape, which in turn affect the water holding capacity or porosity of the sediment (Capper and Cassie, 1976).

The activities of marine organisms can affect the water content of sediment. Burrowing animals break up sediment aggregations and affect the compaction and arrangement of sediment particles (Rhoads, 1974). This gives the sediment a more open fabric and increases the porosity and water content. Some marine animals increase the water content of the sediment surface by depositing faecal pellets at the sediment-water interface (Rhoads, 1963; Rhoads and Young, 1970). High

water content sediments are, in general, more easily eroded than low water content sediments (Postma, 1967). Some investigators (Rhoads and Young, 1970) regard the water content of surface sediments as an indicator of the degree of bioturbation.

Water content is an important parameter to measure in sediment studies because it affects other physical factors such as shear strength (Trask and Rolston, 1950), and the distribution of infaunal invertebrates (Harrison and Wass, 1965; Jansson, 1967; Ansari et al., 1980).

E- Specific gravity

The specific gravity of any material is defined as the ratio of the weight of a given volume of that material to the weight of an equal volume of water (Smith, 1981). Values of the specific gravity of different groups of minerals are different (Lambe and Whitman, 1979). The specific gravity of sediment containing a high content of quartz is usually about 2.65 (Smith, 1981), which is the type of sediment found on the beach at Ardmore.

III- Chemical properties

This part is divided into sections as follows.

A- Redox potential (Eh) and pH

Many chemical, geological, and biological processes in sea water and sediment are related to the oxidation-reduction potential, or redox potential (Eh), and to the acidity (pH) of the environment (Zobell, 1946b; Baas Becking et al., 1960; Krauskopf, 1979).

Redox potential (Eh) can be regarded as a quantitative measure of the energy of oxidation or electron-escaping tendency of reversible oxidation-reduction reactions in the environment (Zobell, 1946b).

The acidity (pH) of an environment measures its ability to supply protons (hydrogen ions) to a base or to take up protons from an acid (Krauskopf, 1979). In a complex solution like sea water or water in a sediment the redox potential is determined by a number of reactions, and pH is determined by a combined effect of the carbon dioxide system, the boric acid system, and various organic acids (Krauskopf, 1979). Eh and pH can be measured colorimetrically as well as electrometrically (Langmuir, 1971). The electrodes used in the electrometrical measurement of Eh and pH should be calibrated against standard solutions having a known Eh or Known pH (buffer). The method of calibration is described in the Materials and Methods part of this chapter.

Eh is measured in millivolts (mV) with respect to a reference hydrogen electrode which is taken to have an Eh of 0 mV. Eh is positive in aerobic environments and negative in anaerobic environments. When the Eh is zero or negative the environment contains no free oxygen. A calomel ($Hg/HgCl_2$) reference electrode is normally used in place of a hydrogen reference electrode, whereupon a correction factor of about +250 mV is added to the readings.

Measurements of the redox potential of marine sediments has been increasingly used as a standard method for categorizing their physical-chemical conditions (Whitfield, 1969; Fenchel and Riedl, 1970; Bägander and Niemistö, 1978). Measurement of the redox potential of sediment cores enables reliable comparisons to be made of

the intensity of reducing conditions in sediments from place to place (Whitfield, 1969). A common feature of marine sediments is the decrease in redox potential with depth (Zobell, 1946b; Fenchel, 1969; Revsbech et al., 1980). A redox potential discontinuity (RPD) layer is present where the Eh drops very rapidly over a small vertical distance, and where oxidising processes become displaced by reducing processes (Fenchel and Riedl, 1970). Redox potential discontinuities are often seen as banding in intertidal sediments (Anderson and Meadows, 1978), and serve as a guide to the biological condition of the sediment and degree of organic loading to which it is subjected.

B- Salinity

Salinity (S) is the number of grams of dissolved salts in 1000g of seawater (after all bromine has been replaced by chlorine, all carbonate converted to oxide, and all organic matter destroyed) (Levinton, 1982). It is expressed in parts per thousand ($^{o}/_{oo}$ or ppt) and ranges from 33 to 38 $^{o}/_{oo}$ in the open ocean. Chloride has been used as an index of salinity (Levinton, 1982). Chlorinity (CL) is the number of grams of chloride ions in 1000g of seawater. Salinity can be measured by two methods. The first method is called the titration method, and measures the chlorinity by titration with silver nitrate (Knudsen method). The second method measures the salinity by using modern refractometers. These refractometers are temperature compensated and provide a convenient alternative method for measuring salinity.

Salinity fluctuates in the intertidal zone. Low salinities can be produced by heavy rainfall or by fresh water from run off. High

salinity can be produced by evaporation of water during warm weather. Fresh water flowing over a beach will expose animals which live near it to salinity fluctuations of 0 to 30 $^{o}/_{oo}$ during a single tidal cycle (Meadows and Campbell, 1972). Extreme conditions of salinity can affect the behavior and survival of intertidal animals. Vertical and horizontal fluctuations in salinity always occur in estuaries. Fluctuations in salinity are produced by the effect of tides, fresh water from run off, storms, winds, evaporation, and from local fluctuations in currents (Bowden, 1967; Man gelsdorf, 1967).

C- Organic carbon

The organic carbon in sediments comes from a very wide range of sources. Most sediments contain some remains of dead organisms that were deposited with the sediment. These remains are degraded by micro-organisms and become the organic matter component of the sediment. Organic material can enter the sediment from the land and from the water column in the form of detritus (Anderson and Malahoff, 1977; Barnes, 1974; Renineck and Singh, 1980). Materials coming from animal faeces, secretion from algal mats, and algal sheaths containing mucilage can also be an important source of organic matter (Campbell, 1977; Friedman and Sanders, 1978; Tissot and Welte, 1978).

Organic matter in nearshore or estuarine sediments is often a good index of the environment in which the sediments were deposited (Gaudette et al., 1974). It also may be useful in assessing the effect of pollutants on both sediments and hydrology (Flager, 1972).

The amount of organic carbon in marine sediments, which may range from <0.1% to >30%, is often used as an index of the amount of

food available to benthic animals, or as an indication of the amount and type of food settling to the sediments from the water column (Byers et al., 1978). This measurement is particularly useful in combination with determinations of nitrogen and lignin, because some assessment of the age of organic matter or its origin is possible (Byers et al., 1978). C:N ratios of 6-7:1, derived from the oxidative ratios of plankton, indicate recent fall out from the water column (Byers et al., 1978). Lignin in organic matter indicates terrestrial input (Pocklington, 1976).

Marine organisms living in sediments obtain organic matter from their environments in different ways. They may scrape the film of organic matter from particles, they may swallow the sediment grains and digest the organic material from their surfaces, or they may filter feed (Gordon, 1966; Green, 1968; Longbottom, 1970; Rhoads and Young, 1970; Schäfer, 1972; Barnes, 1974; Nicholas, 1975; Cadee, 1976; Ott et al., 1993; Meadows and Campbell, 1988; Levinton, 1982).

The organic content of sediments can affect the distribution and habitat selection of marine animals and micro-organisms (Longbottom, 1970; Meadows, 1964 ; Meadows and Campbell, 1972; Cadee and Hegeman, 1977; Cammen, 1982). It also has an effect on sediment properties such as permeability (Webb, 1969) and its concentration in sediments is related to particle size - being higher in finer sediments (Longbottom, 1970).

MATERIALS AND METHODS

Monthly samples of sediment were collected from the low tide area at Ardmore Point over the period February 1984 to February 1985. The sampling area covered about 40 x 20m just landward of an old fish yair (map 2.1).

I- Annual cycle of biological aspects.

1- Abundance of Meiofauna.

Each month, two cores (10cm in diameter) of sediment were taken to a depth of 40cm. Each sediment core was divided horizontally into the following sections: 0-5cm, 5-10cm, 10-20cm, 20-30cm and 30-40cm. Each section was put into a polythene bag. In the laboratory, the sections from the first two depths 0-5cm and 5-10cm were both divided into two approximately equal parts. One part was used for the ice extraction technique (Uhlig, 1968) and the other was put into a bottle and preserved with a 10% Steedman's solution (Steedman, 1974) for subsequent extraction using the Ludox technique (see the flow diagram, Appendix 2, figure 1). The meiofauna extracted, using the ice extraction technique, were preserved with 10% Steedman's solution and kept in bottles without analysis.

The reason for dividing these two sections into two parts was that at the beginning of the survey I was not sure whether the Ludox separation technique would give as complete an extraction of meiofauna as the well tried ice extraction technique. Tests of the Ludox extraction technique during the progress of the survey showed that it was quicker than the ice extraction technique in extracting meiofauna.

Allthough it probably does not extract all soft bodied meiofauna (small Polychaetes, small Oligochaetes, Turbellarians and Gastrotrichs) (McIntyre and Warwick, 1984). A typical Ludox extraction took about three hours while a typical ice extraction took about twenty hours. At the completion of the survey therefore, all the sediment samples were extracted using the Ludox technique.

The complete sections of other depths 10-20cm, 20-30cm and 30-40cm were also preserved with Steedman's solution for subsequent Ludox extraction.

The Ludox separation technique used to extract meiofauna was conducted as follows. Each bottle containing sediment and fixative solution, (referred to as the original bottle - see below) was shaken vigorously for 2-3 minutes until the mass of sediment was evenly suspended. The bottle was then allowed to stand for 60 to 120 seconds to let the particles settle. The overlying liquid was then decanted through a 35fm nylon gauze to catch the suspended meiofauna. A small amount of sediment was retained on the gauze during this process. The material retained on the gauze was washed with tap water and poured into a 250ml beaker using a wash bottle containing 25% Ludox solution. The beaker was then filled with 150ml of 25% Ludox. This beaker therefore contained meiofauna from the overlying liquid, and is referred to as beaker 1 (see the flow diagram, appendix 2, figure 1).

Two 20ml subsamples of sediment were then taken from the original bottle. These are termed subsample A and subsample B. Each subsample was treated as follows. The 20ml of sediment was put into a 50ml glass test tube containing 25ml Ludox and then stoppered. The tube was repeatedly inverted for about 30 seconds until the sediment

was suspended. The contents in the test tube were then washed into a 250ml beaker containing 150ml Ludox with 25% Ludox. This process was repeated for the other 20ml subsample of sediment. This gave two beakers, referred to as beaker 2 and beaker 3, each containing meiofauna from one of the two subsamples of sediment from the original bottle.

Three beakers were hence obtained from each depth section of the core -beaker 1, 2 and 3 (see the flow diagram, Appendix 2, figure 1). Beaker 1 contained meiofauna from the overlying liquid plus the small amount of sediment. Beakers 2 and 3 contained meiofauna from the two sediment subsamples A and B.

Each of the three beakers was then treated as follows. The beaker was placed on a magnetic stirrer for 2-3 minutes to mix the contents. The beaker was then removed from the stirrer and left for one hour to let the meiofauna rise to the surface of the Ludox. The Ludox in the beaker was decanted through the 35fm gauze. The meiofauna retained on the gauze were washed with tap water to remove the Ludox, and then washed from the inverted net into a petri dish. The used Ludox was put back into the beaker, and then the process was repeated twice, the meiofauna were then added to the same petri dish.

Three petri dishes were hence obtained, each one containing meiofauna extracted from one of the three of beakers. The meiofauna in the three petri dishes were then identified into groups (e.g. Nematodes, Harpacticoid Copepods etc.) and the number in each group was counted.

The number of organisms of each taxonomic group was then calculated for each depth and expressed as number per m^2 of sediment

surface. This was done in two ways. The first method was used for the 0-5cm and 5-10cm depths, and the second for the 10-20cm, 20-30cm and 30-40cm depths.

1- First method: 0-5cm and 5-10cm.

The number of meiofauna per m^2 in the part that was extracted using the Ludox technique was calculated as follows.

Since the exact volume of sediment was not measured at the time the section was divided an estimate of it was obtained in the following way. A volume of water equivalent to the volume of the preserved sediment was measured in a measuring cylinder. This volume of water is termed the estimated volume of sediment, and was the volume of sediment in the original bottle. The numbers of meiofauna in this sediment were then extracted as described above (Beakers 1, 2 and 3) and classified into major taxonomic groups and counted. The equivalent numbers per m^2 were then calculated from this data.

The method of calculating the numbers per m^2 is best illustrated by an example.

The following data was obtained in February 1984, for the depth 0-5cm.

Taxonomic group	Beaker 1 containing overlying liquid	Beaker 2 containing subsample A (20ml sediment)	Beaker 3 containing subsample B (20ml sediment)
Nematodes	949	309	315
Copepods	4	2	1
Ostracods	6	1	0

The estimated volume of sediment in the 0-5cm section = 234ml.

For each taxonomic group, the numbers per 20ml in beakers 2 and 3 were converted to numbers /234ml by multiplying by 234/20 =11.7, their mean taken, and added to the numbers in beaker 1, to give the total numbers/234ml. These calculations are shown in the following table.

Group	numbers/234ml Subsample A	B	nos./234ml Mean	Total nos. from mean + overlying liquid (total nos. in 234ml)
Nematodes	3615	3689	3650	4599
Copepods	23	12	18	21
Ostracods	12	0	6	12

The numbers per m^2 were obtained from the data in column 5 of the above table as follows. The surface area of the complete core = 78.5cm). The volume of sediment in the section = 392.5ml. The surface area of sediment equivalent to 234ml was calculated as follows:

$$= \frac{234 \times 78.5}{392.5} = 46.75 \text{ cm)} = 46.75 \times 10^{-4} \text{ m)}$$

The number of organisms per m^2 for each group was then calculated as

$$\frac{\text{numbers of orgs. / 234ml}}{46.75 \times 10^{-4}} \quad \text{no./ } m^2$$

As an example, the number of nematodes /m^2 was

$$\frac{4599}{46.75 \times 10^{-4}} = 9.839 \times 10^5$$

The following data was obtained in this way and is shown in table 1.1.

Group	Numbers .m^{-2}
Nematodes	9.839×10^5
Copepods	4620
Ostracods	2545

2- Second method:10-20cm, 20-30cm and 30-40cm sections.

The volume of sediment in each section was calculated by multiplying the area of core (78.5cm}) by the height of the section (10cm). The numbers of meiofauna in this sediment were then extracted as described above (Beakers 1, 2 and 3) and classified into major taxonomic groups and counted. The equivalent numbers per m^2 were then calculated from this data. Each taxonomic group counted in 20ml in beakers 2 and 3 were then converted to the number /780ml by multiplying by 780/20 = 39, their mean taken, and added to the numbers in beaker 1 (referred to the overlying liquid beaker), to give the total number /780ml. The numbers per m^2 were then calculated from the numbers /780ml following the same procedure as described above.

2- Macrofauna abundance

Two cores (10cm in diameter) of sediment were collected to measure the abundance of macrofauna. Each core was divided horizontally as follows: 0-5cm, 5-10cm, 10-20cm, 20- 30cm and 30-40cm. Each segment of sediment sample was put into a polythene bag and taken to the laboratory. In the laboratory, each segment was sieved through a 0.5 mm sieve to remove the animals. The animals were collected, separated into species, placed in bottles and then identified. After identification they were preserved with 4% formalin.

Some species, however, constructed tubes and could not be identified without removing them. These species were removed from their tubes using Girling's method (1984).

Girling's method is described as follows. The tubes collected

from each depth were put into a plastic container containing sea water. A fluorescent lamp was placed in front of the container. The light caused the animals to leave their tubes and move away from the light. After about one hour, the animals were collected and put into glass bottles. I continued this process until no more animals could be found. The live animals were identified under a binocular microscope to species level. The identified animals were separated into species and put into small glass bottles containing 4% formalin.

Abundance of *Arenicola marina*.

The abundance of *Arenicola marina* (linnaeus) was measured by counting numbers of casts, since it was known from previous work on this shore (Girling, 1984) and elsewhere (Holme, 1949; Longbottom, 1970; Cadee, 1976), that the number of casts and the number of animals are linearly related. The number of casts were counted in two square meters in each month during the survey.

Biomass of macrofauna.

The biomass of all species except *Arenicola marina* was estimated as follows.

The animals of a given species in each core were counted as above. These animals were then dried at 60^{o}C for 24 hrs to constant weight . They were then placed in a desiccator to cool. Once cooled, the animals were weighed. This weight was divided by the number of animals in the samples to give the average weight per individual animal. The biomass per m^2 was then calculated by multiplying the dry weight per individual by the numbers of individuals per m^2.

The biomass of *Arenicola marina* was estimated as follows. As the worms live in burrows 20 to 40 cms deep on tidal flats (Cadee, 1976), they were dug out from the sediment using a metal fork. This method yielded between 10 to 18 organisms per month. These organisms were preserved using 4% formalin. The individual worms were then dried at 60^{o}C, for three days. They were then placed into a desiccator to cool. Once cooled, the dry weight of each worm was taken, and then the mean and standard deviation of these weights was calculated. The biomass was then obtained by multiplying the mean dry weight of worms by the number of casts per m^2.

II- The physical and chemical properties of sediment

A number of physical and chemical properties of the sediment were measured each month during the annual survey. Shear strength, permeability and Eh were measured on site. pH, salinity, water content, particle size, organic carbon and specific gravity were measured on return to the laboratory. These methods will now be described.

1- Field measurements

The shear strength and permeability readings were taken jointly by F. Eddeb, myself, P.S. Meadows and A. Tufail. (Each parameter needed two people to take the measurements and this was done in rotation).

A- Shear strength

Several methods are available to measure the shear strength of

sediments the Shear Box test, the Tri-axial test, the compression test and the vane test (BS 1377, 1975; Capper and Cassie, 1976; Dunn et al, 1980; Smith 1981). In my study a hand vane tester was used to measure the shear strength of sediment in situ, because it gave quick and accurate determinations of shear strength. It is used as a British standard test for strength (BS 1377, 1975). The instrument used was a 'Pilcon' direct reading hand-vane tester. This instrument consists of a stainless steel rod of varying length with a small stainless-steel vane (2.5cm in length) at one end consisting of four rectangular vanes (each being 2.5cm x 0.5cm) placed at right-angles to one another. At the other end of the rod is the body of the instrument. This consists of a round steel plate connected to the rod by a geared spindle which allows the body plate to turn relative to the rod when a specific torque is applied to it. On the body plate is a torque gauge which records the torque required to turn the rod. The instrument is supplied by Pilcon Engineering Limited. The shear strength readings were taken within 1/2 hour either side of low tide.

The reading of shear strength was taken as follows. The vane was pushed into the sediment to a known depth. A torque was then applied by hand to the body plate to rotate the vane and shear the sediment. The turning rate should be uniform and relatively slow (Jumikis, 1962). Two replicate sets of shear strength were taken for each month. These replicate sets were obtained by pushing the vane progressively into the sediment at two positions about 1 to 2m apart on the surface of the tidal flat. Two readings, peak and residual, were taken at each of the following depths: 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95 and 100 cm. The

data of peak and residual shear strength were fed into a computer program (MH-SSR, appendix two, table 2) written by myself using the BBC computer. The program calculates the shear strength of sediment in kN per m} for the peak and residual readings. The means and standard deviations were calculated at each sediment depth for the two readings of peak, residual and peak minus residual shear strength.

B- Permeability

The Auger hole method was used to estimate permeability in situ (Dunn et al, 1980; Hooghoudt 1936; Ernst 1950). The procedure for measuring permeability was as follows.

An Auger Hole was bored in the sediment using a soil auger (diameter 10.5cm). After boring, a plastic mesh core (in diameter 10cm), covered on the outside and base with a nylon gauze sleeve to prevent the entry of particles into the core, was pushed into the hole. The diameter of plastic mesh was a 5.7mm. The hole size of the nylon gauze was a 1mm. Every 15 seconds a reading was taken of the vertical length (Hw) between the top of the plastic core and the water level in the hole. This was continued at 15 second intervals until three consecutively identical readings were obtained indicating that the water table level had stabilised. The height of the plastic mesh core above the sediment surface was then measured (Hp). The height of the water below the sediment surface was then calculated as Hw - Hp in cm.

Each month, two replicate cores were taken in this way separated by about 2m horizontally. The permeability was calculated for each month using the equations derived by Hooghoudt (1936) and Ernst

(1950). This was done for each replicate core separately by feeding the water level of the 15 second intervals into a computer program written by Tait (1986). The program calculates the coefficient of permeability (m/sec) using the Hooghoudt and Ernst equations, and also gives the mean and standard deviation for each of the two replicate cores.

C- Redox potential (Eh)

The Eh was measured for the overlying water, interstitial water and sediment during the period from October 1984 to October 1985. The samples were collected monthly from the low tide area. Each month, two bottles of overlying water and interstitial water and one plastic PVC core (10cm in diameter) were taken.

Standardisations of electrodes

The electrodes were standardised using the method described by Ruagh (1981) as follows.

Two electrodes, an inert black platinum electrode(E.I.L. 33-1213-400) and a calomel reference electrode (E.I.L. 33-1370-210) connected to a portable pH meter (I.I.L. Model 30C) were used to take the Eh readings. Each month the two electrodes were standardised using the same method as Jones (1966). A buffer was prepared of pH4 or pH7 and then saturated with quinhydrone (C_6H_4:O.OH.C_6H_4.OH). This was done by adding a few crystals of quinhydrone and stirring well until the solution becomes amber in color. The two electrodes were placed in the buffer solution and the Eh measured in millivolts (mV). The reading of Eh should be within q 10 mV of the readings presented in the following table (Jones 1966, page 42).

Potential (mV) for calomel reference electrode equal:

	Temperature °C		
	20	25	30
pH4	+223	+218	+213
pH7	+47	+41	+34

A correction factor which depend on the reference electrode used should be added to all observed mV readings (ZoBell, 1946b; Jones, 1966; Whitfield, 1969; Pearson & Stanley 1979), in order to express the results in relation to the normal hydrogen electrode as zero. ZoBell (1946b, page 495) gave the correction factor at different temperatures (°C) as follows.

Temperature of the measured sample	15	20	25	30	37
Potential (mV) should be added	+252	+249	+246	+242	+234

Measurement of Eh of overlying and interstitial water, and of sediment

(i) Overlying and interstitial water.

The two bottles of the overlying and interstitial water were collected as follows. The interstitial water was collected by digging a hole on site. As soon as enough interstitial water had appeared at the bottom of the hole, two 50ml glass bottles were completely filled by immersion and then tightly stoppered. The samples of overlying water was obtained by walking to the water edge and completely immersing the two 50ml glass bottles and stoppering them.

The Eh readings were taken from each of the two bottles of overlying and interstitial water as follows. The two electrodes were inserted into the bottle and the first reading taken at 5 seconds. The

electrodes were then removed from the bottle, rinsed with distilled water and wiped with a soft tissue. The electrodes were then inserted again into the bottle and a second reading taken after 5 seconds.

The time elapsing between collecting the overlying and interstitial water samples and taking the Eh reading was between 1-1½ hrs.

(ii) Sediment

The plastic PVC core used to take sediment cores for subsequent Eh measurements was prepared beforehand as follows. It was split along its length, resealed using brown parcel tape, and then lined with a clear polythene bag (8"x30"). This was done to ease the splitting of the core. The polythene bag stopped the sediment sticking to the internal wall of the plastic core when it was opened, and gave an intact column of sediment.

On site, the plastic PVC core was pushed into the sediment to a depth of 40cm. It was then dug out and put carefully into a polythene bag, base first, which was then sealed around the top with tape. The core was then carried carefully to the van and the Eh readings taken. This distance was about 1.5km. The time between collecting the core and taking the Eh readings was between 1 and 1½ hrs. It was assumed that the Eh within the sediment would not change significantly during this period because the core was sealed.

The Eh reading was taken as follows. The wall of the plastic core was split using a scalpel to expose the body of sediment. The Eh reading was taken at the surface and at 5, 10, 20 and 35cm. At each depth, some sediment was removed and then the two electrodes were

inserted into the sediment at an angle to a depth of approximately 1cm. The meter was then switched on and the first reading was taken at 5 seconds. The electrodes were removed and rinsed with distilled water and wiped with a soft tissue. The electrodes were reinserted into the sediment and the second reading taken after 5 seconds. The core was then resealed tightly and brought to the laboratory.

Each reading of Eh was corrected by adding the correction factor value depending on the in situ temperature.

2- Laboratory measurements

In the laboratory, the following parameters were taken.

A- pH measurements.

The pH measurement was taken from the overlying water, interstitial water and sediment. Two 50ml bottles were collected from overlying and interstitial water using the same method described in collecting the Eh samples.

(i) Overlying water and interstitial water.

The measurement of pH was taken from each bottle in the laboratory using one electrode (Russell pH electrode, CE7L) connected to a meter (model PW 9410/10, digital pH meter). Two readings of pH were taken from each bottle as follows. The electrode first was calibrated using pH7 buffer, wiped with soft tissue and then immediately inserted into the bottle. The first reading was taken after 60 seconds. The electrode was then removed from the bottle and rinsed with distilled water and wiped with soft tissue. The electrode

was again calibrated with the pH7 buffer and then reinserted into the bottle for the second reading after 60 seconds.

(ii) Sediment.

The pH readings were taken from the same core used to measure the Eh parameter as follows. A small amount of sediment was taken from the surface and from 5, 10, 20 and 35cm, and then put into a 50ml beaker. Two beakers were obtained from each depth of sediment. One beaker was used to take the reading of pH after adding distilled water and the other was used to take the reading after adding deionized water. Two readings of pH were taken from each beaker as follows. The electrode was inserted into the beaker after being calibrated with the pH7 buffer. The first reading was taken after 60 seconds. The electrode was taken out of the beaker and rinsed with distilled water to remove any adhering sediment, then wiped with soft tissue. The electrode was reinserted into the beaker and the second reading was taken following the same procedure as previously described. There was a slight difference in the readings of pH found in the beaker containing distilled water and the beaker containing deionized water.

B- Salinity

The salinity of the interstitial water and of the overlying water of the low tide was measured. Two 50ml bottles were taken from each place. The interstitial water samples were collected from a hole dug on site. The overlying water samples were collected when the tide came in and covered the area. The reading of salinity was taken using a salinity refractometer (SC-28.SC-10) as follows. The meter was first

calibrated with distilled water. The calibration was done by setting the boundary line to zero using the adjusting screw knob. Before taking any reading, the samples should be kept in a room until the water temperature is the same as the room temperature, regardless of the measuring temperature. The prism of the meter was wiped with soft tissue. One or two drops of the water sample whose salinity was to be measured were put on the prism and the daylight plate was then closed. The reading was taken from the scale through the eyepiece against the light. The scale was focused and the reading of the scale was taken where the boundary line intercepts it. The sample was wiped and cleaned from the prism with tissue paper and water. Two readings of the salinity were obtained from the interstitial water and overlying water.

C- Physical parameters of sediment

One core, 10cm in diameter of sediment was collected each month of the survey. The core was pushed into the sediment to a depth of 45cm. The core was then dug out and the column of sediment was divided to nine horizontal segments: 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40 and 40-45cm. Each segment was put into a polythene bag and brought to the laboratory, where it was weighed. Each sample bag was then gently squeezed by hand to mix the sediment evenly. The following physical parameters were then carried out.

i- Water content

Three 2-6g subsamples of wet sediment were taken from each sediment sample. Each of the subsamples was put on a sheet of foil

which had been previously weighed. The sheets of foil, with contents, were weighed to the nearest 0.001g. The sheets of foil were then transferred to an oven and left to dry for 24 hours at 60°C. The dry subsamples of sediment were then removed from the oven and put into a desiccator to cool. After cooling, each dry subsample was weighed to the nearest 0.001g. The net wet and dry weights were calculated by subtracting the weight of foil with contents from the weight of the foil. This process was carried out for each depth of sediment throughout the survey.

ii- Particle size distribution, organic carbon and specific gravity

The sediment samples from different depths were left to dry at room temperature. Once dry, each sample was divided into four parts. Two parts were used for measurements of the particle size distribution, one for organic carbon and one for specific gravity.

- **Particle size distribution**

The procedure for measuring particle size distribution is described in Buchanan (1984), Folk (1980) and BS 1377 (1975). I followed these authors' procedure with slight modifications.

Two replicate samples of dried sediment from each section were put in an oven at 60°C for 24hrs, and then into a desiccator to cool. An endecott sieve shaker using British standard sieves of mesh sizes: 2mm, 1.4mm, 1mm, 0.71mm, 0.5mm, 0.335mm, 0.25mm, 0.18mm, 0.125mm, 0.09mm, 0.063mm, 0.045mm, 0.038mm and <0.038mm pan was used for the analysis. The sieves were stacked on the shaker in decreasing mesh

size from top to bottom. Each replicate sample was placed on the 2000µm sieve. The sediment was shaken for 30 minutes. The material on each individual sieve was then transferred to a plastic container using a plastic brush. Each container with sediment was weighed to the nearest 0.001g. The weight of each class interval was fed into a computer program written by Kirkham (1984). This program calculated the percentage weight of each class interval of sediment, the cumulative percentage and the moment measures (mean, standard deviation, skewness and kurtosis).

-Determination of organic carbon in sediment.

There are several methods for determining the organic carbon content of sediment, but the most commonly used is a modification of the Schollenberger chromic acid oxidation technique (Buchanan 1984). In this method the sediment sample is digested with a mixture of chromic acid and sulphuric acid. The excess chromic acid not reduced by the organic matter is titrated with a standard ferrous salt. Two routine methods can then be followed. These are described in Walkley & Black (1934) and El Wakeel & Riley (1956).

I have followed the method described in Walkley & Black (1934) as described by Buchanan (1984, pages 62-63).

Reagents

- Normal Potassium dichromate. 49.04g of reagent grade $K_2 Cr_2 O_7$ was dissolved in distilled water and diluted to 1 litre.

- Sulphuric acid. Not less than 96% with 1.25g of silver sulphate was added for every 100ml of acid. (The silver sulphate

removes the interference of chlorides.)

- Phosphoric acid. At least 85%.

- Diphenylamine. 0.5g of reagent was dissolved in 20ml water and 100ml of concentrated sulphuric acid was added.

- Normal Ferrous sulphate. 278g of reagent grade $FeSO_4.7H_2O$ was dissolved in water, 15ml of concentrated sulphuric acid was added and diluted to 1 litre.

Procedure

The sediment sample was gently separated to pass through a 0.5mm sieve. Three weights of dry sediment were weighed. The weight of sediment used depended on the type of sediment. The weight of sediment used was between 3g-12g, and was transferred to three 500ml conical flasks separately. Each flask with sediment was treated as follows.

A 10ml of normal potassium dichromate was added followed by 20ml of concentrated sulphuric acid. The flask was shaken gently by hand for one minute, then placed in a boiling water bath for 30 minutes. The flask was then cooled for 30 minutes. After cooling, 200ml distilled water was added followed by 10ml phosphoric acid and 1ml diphenylamine indicator solution. The solution in the flask was titrated by adding ferrous sulphate from an automatic burette until the solution in the flask was purple or blue. More ferrous sulphate in small lots of about 0.5ml was added until the color flashed to green. Care was needed at this because the color change occurred with little warning. Then 0.5ml dichromate was added to restore an excess of dichromate and the titration was completed by adding ferrous sulphate drop by drop until the blue color disappeared and the color changed

to green.

The amount of carbon presented in the sediment was calculated using this equation.

$$\frac{V_1 - V_2}{W} \times 0.003 \times 1000$$

Where V_1 equals the volume of normal potassium dichromate (10.5ml), V_2 equals the volume of ferrous sulphate in ml, W equals the weight of soil taken.

-<u>Specific gravity</u> (BS 1377:1975).

One portion of the dried sediment at room temperature was used to determine the specific gravity for different depths of sediment. The method used for each month's sample was as follows:

The sediment samples were sieved through a 2mm sieve to remove the large particles. They were then put into the oven to dry for 24hr at 60°C. The samples were then removed and put into the desiccator to cool. The density bottles (BS.733) were rinsed with alcohol (95%), and then dried completely by blowing warm air inside. Each density bottle with its stopper was weighed on accurate balance to the nearest of 0.0001g. This gave the mass of the density bottle (M1). Three bottles were used for each depth. About 5-7g of dry sediment was put into each density bottle and then the bottle with sediment was weighed on accurate scales. This gave the mass of the density bottle and sediment (M2). Sufficient air-free distilled water was then added so that the sediment in the bottle was covered. (air-free distilled water was obtained by boiling a quantity of distilled water for at least 30 minutes in an air-tight container and then cooled). The

bottles were placed in the vacuum oven at 20°C. The vacuum oven was evacuated gradually and the pressure was reduced to about 20 mm of mercury. The bottles remained in the oven for at least 1 hr until no further loss of air was apparent. After this time, the valves of the vacuum oven were released and the lid was removed. The sediment in each bottle was stirred carefully with a spatula, and then the bottle was swirled by hand to ensure that all the sediment particles were fully wetted. The bottles were replaced in the oven which was evacuated again. The bottles remained there overnight and were then removed from the oven. Each bottle was filled by adding air-free liquid, then the stopper was inserted. The bottles were then placed in a constant-temperature bath at 20°C. As the volume of liquid decreased, the stopper was removed and further liquid was added to refill the bottle, then the stopper was replaced. This process was repeated until the volume of liquid in the bottle remained constant. Each bottle with contents was then taken out of the bath, wiped dry and weighed. This weight was the mass of bottle, sediment and liquid (M3). Each bottle was then cleaned and filled completely with just air-free liquid, the stopper inserted, and then immersed in the water bath at 20°C. The bottles remained in the water bath until they had attained the actual bath temperature. As the volume of liquid in the bottle decreased, further liquid was added to re-fill the bottle until the volume of liquid remained constant. Each bottle was then taken out of the bath, wiped dry and the whole weighed. This weight was the mass of the bottle and liquid only (M4).

The specific gravity of sediment, Gs, was then calculated using the following equation.

$$Gs = \frac{(M2 - M1)}{(M4 - M1) - (M3 - M2)} \qquad (BS.1377: 1975)$$

RESULTS

The results of the survey are divided into three sections as follows.

Section 1- The biological studies of the low tide area.

I- Meiofauna counts.

The number of meiofauna of different taxonomic groups counted from the two 20ml subsamples (A and B) of sediment and the overlying water for each of I and II replicate cores in each month is given in appendix 2, table 1. The number of meiofauna groups per m^2 determined at different depths of sediment: 0-5, 5-10, 10-20, 20-30 and 30-40cm during the survey is given in table 2.1. This data was calculated from the original data in the appendix 2, table 1. The table shows the total number, and means and standard deviations of different meiobenthic groups.

The number of organisms counted in each month for each taxonomic group was plotted against months of the survey (figures 2.1, 2.2 and 2.3). These figures show the total numbers of the taxonomic group per m^2 counted from each replicate core I and II for each section of sediment, and also the mean of I and II. Figure 2.1 shows the number of nematodes counted in replicate cores I and II for the different sections of sediment. Table 2.1 and the figure show that the nematodes occurred in all sections of sediment (from 0-5cm to 30-40cm). The highest mean of the total number of nematodes was found in section 0-5cm of sediment (between 0.5×10^6 - 3.5×10^6). The number of nematodes decreased with depth. The figure also shows that

Table (2.1)

Annual survey of meiofauna, Ardmore Low tide area. Number of organisms per m^2. February 1984 to February 1985. I, II replicate sediment cores.

MONTH	GROUP	Depth of sediment in cm. 0 - 5		5 - 10		10 - 20		20 - 30		30 - 40	
		I	II	I	II	I	II	I	II	I	II
February 1984	Nematodes	983900	1707940	708750	643840	593250	535640	509460	498800	251600	299110
	Copepods	4620	4239	1250	-	-	-	-	-	-	-
	Ostracods	2545	271	-	-	-	-	-	-	-	-
	TOTAL	991065	1712450	710000	643840	593250	535640	509460	498800	251600	299110
	Mean ± s.d.	1351758 ± 510096		676920 ± 46782		564445 ± 40736		504130 ± 7538		275355 ± 33595	
March	Nematodes	551800	1373480	293100	348610	510690	672030	239510	628830	27310	235610
	Copepods	4000	5972	-	-	-	-	-	-	-	-
	Ostracods	1976	2778	903	2500	-	-	-	-	-	-
	TOTAL	557776	1382230	294003	351110	510690	672030	239510	628830	27310	235610
	Mean ± s.d.	970003 ± 542977		322557 ± 40381		591360 ± 114084		434170 ± 275290		131460 ± 147290	
April	Nematodes	4384380	2697500	684520	310750	471590	589190	261160	258840	259340	256910
	Copepods	13181	6250	217	-	-	-	-	-	-	-
	Ostracods	227	26250	-	-	-	-	-	-	-	-
	TOTAL	4399833	2710000	684737	310750	471590	589190	261160	258840	259340	256910
	Mean ± s.d.	3554917 ± 1194892		497744 ± 264449		530390 ±q 83156		260000 ± 1641		258125 ± 1718	
May	Nematodes	2892820	1518300	666430	535910	1218970	1194980	153000	204900	59254	65697
	Copepods	1106	16921	1250	-	-	-	-	-	-	-
	Ostracods	19867	15396	1250	-	-	-	-	-	-	-
	TOTAL	2913793	1550617	668930	535910	1218970	1194980	153000	204900	59254	65697
	Mean ± s.d.	2232205 ± 963911		602420 ± 94059		1206975 ± 16964		178950 ± 36699		62476 ± 4556	
June	Nematodes	3393850	2382480	1200860	706010	692530	390480	66181	63456	76367	51628
	Copepods	43112	187710	7381	1157	-	-	-	-	-	-
	Ostracods	15179	25062	1191	-	-	-	-	-	-	-
	TOTAL	3452141	2595252	1209432	707167	692530	390480	66181	63456	76367	51628
	Mean ± s.d.	3023697 ± 605912		958300 ± 355155		541505 ± 213581		64819 ± 1927		63998 ± 17493	

Cont... table (2.1)

MONTH	GROUP	Depth of sediment in cm. 0 - 5 I	0 - 5 II	5 - 10 I	5 - 10 II	10 - 20 I	10 - 20 II	20 - 30 I	20 - 30 II	30 - 40 I	30 - 40 II
July	Nematodes	811260	858930	951780	515540	545730	504860	309990	220730	90779	80594
	Copepods	215000	163460	26910	-	-	-	-	-	-	-
	Ostracods	8333	3209	-	-	-	-	-	-	-	-
	TOTAL	1034593	1025599	978690	515540	545730	504860	309990	220730	90779	80594
	Mean ± s.d.	1030096 ± 6360		747115 ± 327497		525295 ± 28899		265360 ± 63116		85687 ± 7202	
August	Nematodes	3626500	3381620	505010	232980	259800	280910	75819	89290	67823	50813
	Copepods	57353	52096	1262	-	-	-	-	-	-	-
	Ostracods	5882	7453	-	-	-	-	-	-	-	-
	TOTAL	3689735	3441169	506272	232980	259800	280910	75819	89290	67823	50813
	Mean ± s.d.	3565452 ± 175763		369626 ± 193247		270355 ± 14927		82555 ± 9525		59318 ± 12028	
September	Nematodes	1347380	1550190	626530	337460	319340	613900	116430	137000	28125	-
	Copepods	13158	7293	-	-	-	-	-	-	-	-
	Ostracods	65792	6032	1263	-	-	-	-	-	-	-
	TOTAL	1367117	1583515	627793	333699	319340	613900	116430	137000	28125	-
	Mean ± s.d.	1475316 ± 153017		480746 ± 207956		466620 ± 208285		126715 ± 14545		-	
October	Nematodes	1462500	2217520	636430	857360	217370	533390	252260	222750	138180	103660
	Copepods	68750	44167	10714	10417	-	-	-	-	-	-
	Ostracods	15625	22222	-	-	-	-	-	-	-	-
	TOTAL	1546875	2283909	647144	867777	217370	533390	252260	222750	138180	103660
	Mean ± s.d.	1915392 ± 521162		757461 ± 156011		375380 ± 223460		237505 ± 20867		120920 ± 24409	
November	Nematodes	1270380	1576790	629690	498440	263200	289080	276580	280500	139710	104700
	Copepods	29620	36340	-	-	-	-	-	-	-	-
	Ostracods	1359	39948	-	-	-	-	-	-	-	-
	TOTAL	1301359	1653078	629690	498440	263200	289080	276580	280500	139710	104700
	Mean ± s.d.	1477219 ± 248703		564065 ± 92808		276140 ± 182300		278540 ± 2772		122205 ± 24756	

Cont... table (2.1).

MONTH	GROUP	Depth of sediment in cm. 0 - 5		5 - 10		10 - 20		20 - 30		30 - 40	
		I	II	I	II	I	II	I	II	I	II
December 1985	Nematodes	639350	405780	299540	506790	343170	357720	62221	79282	240090	175830
	Copepods	370370	41985	-	1250	-	-	-	-	-	-
	Ostracods	22222	30817	1250	1250	-	-	-	-	-	-
	TOTAL	1031942	478582	300790	509290	343170	357720	62221	79282	240090	175830
	Mean ± s.d.	755262 ± 391285		405040 ± 147432		350445 ± 10288		70752 ± 12064		207960 ± 45439	
January 1985	Nematodes	1052450	923790	161140	185790	336470	218040	232680	249570	255520	159830
	Copepods	19832	41341	1374	-	-	-	-	-	-	-
	Ostracods	24832	14420	-	-	-	-	-	-	-	-
	TOTAL	1097114	979551	162514	185790	336470	218040	232680	249570	255520	159830
	Mean ± s.d.	1038333 ± 83130		174152 ± 16459		277255 ± 83743		241125 ± 11943		207675 ± 67663	
February 1985	Nematodes	1065290	1710120	466850	322610	322650	270670	234740	270990	252250	257890
	Copepods	18750	1330	-	-	-	-	-	-	-	-
	Ostracods	2778	3989	-	-	-	-	-	-	-	-
	TOTAL	1086818	1715439	466850	322610	322650	270670	234740	270990	252250	257890
	Mean ± s.d.	1401129 ± 444502		394730 ± 101993		296660 ± 36755		252865 ± 25633		255070 ± 3988	

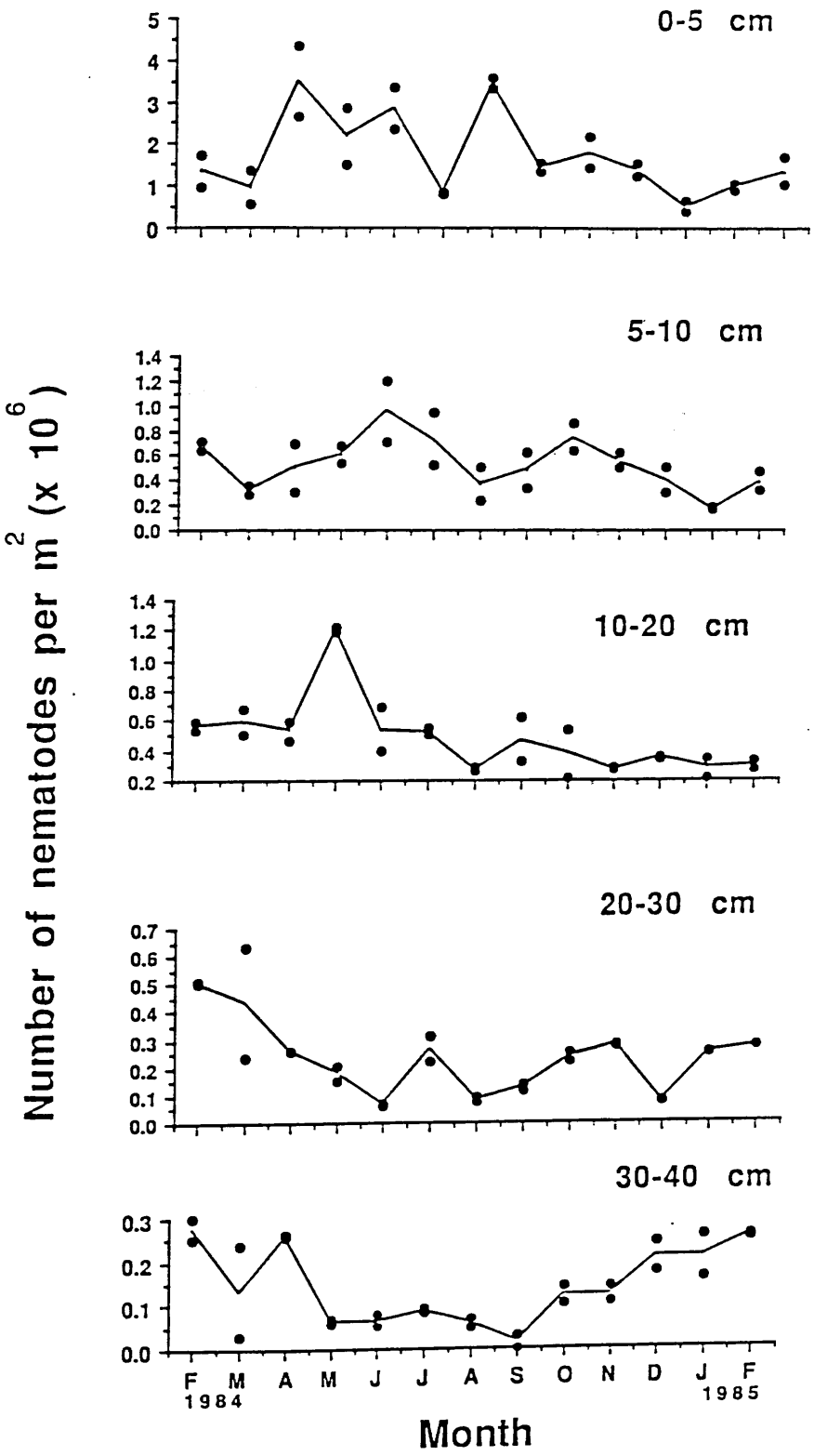


Figure (2.1)

Number of nematodes per m^2, Ardmore, low tide area. February 1984 to February 1985. The filled circles show the two replicate cores and the line joins their means.

the number of nematodes fluctuated most in section 0-5cm and less at deeper depths. The number of nematodes was highest in the months of April, June and August 1984 in the section of 0-5cm.

Figure 2.2 shows the number of copepods found in the different sections of sediment. Table 2.1 and the figure show that the copepods only occurred in two sections: 0-5cm and 5-10cm. In the 5-10cm section, no copepods were found in six of the thirteen months of the survey. The number of copepods found in the 0-5cm section was 10 times greater than the numbers found in section 5-10cm. The highest mean of the total number of copepods found in section 0-5cm occurred in the months of June and December 1984 ($18x10^4$ and $20x10^4$, respectively).

Figure 2.3 shows the total number of ostracods found in section 0-5cm and 5-10cm. Table 2.1 shows that ostracods were not found at the deeper depths. In the 5-10cm section, no ostracods were found in seven months of the survey (February 84, April, July, August, October, November, January 85 and February). The number of ostracods in the 0-5cm section were approximately 10 times more than the numbers in the 5-10cm section. In the 0-5cm section, the number of ostracods rose from February 1984 to June 1984, decreased in July 1984, then rose again to the month of December 1984 and decreased in the next two months. The number of ostracods was high in May and June 1984, and from September 1984 to January 1985. It was low in February, March, April, July and August.

The means and standard deviations of the number of meiofauna per m^2 were then plotted against the different depths of sediment (figure 2.4). This data was obtained from table 2.1. The figure shows that the mean number of meiobenthic organisms decreased with

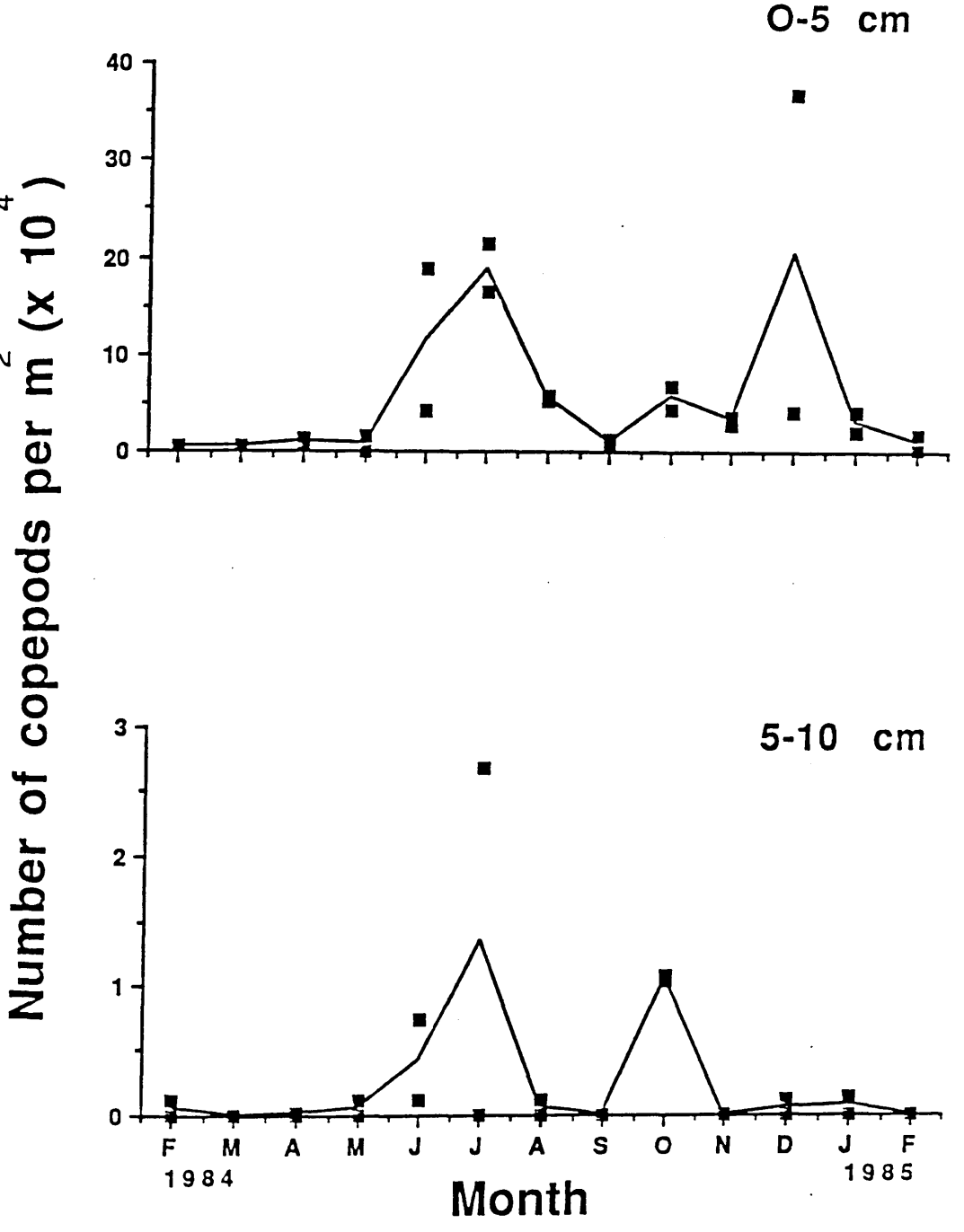


Figure (2.2)

Numbers of copepods per m^2, Ardmore, low tide area. February 1984 to February 1985. The filled squares show the two replicate cores and the line joins their means.

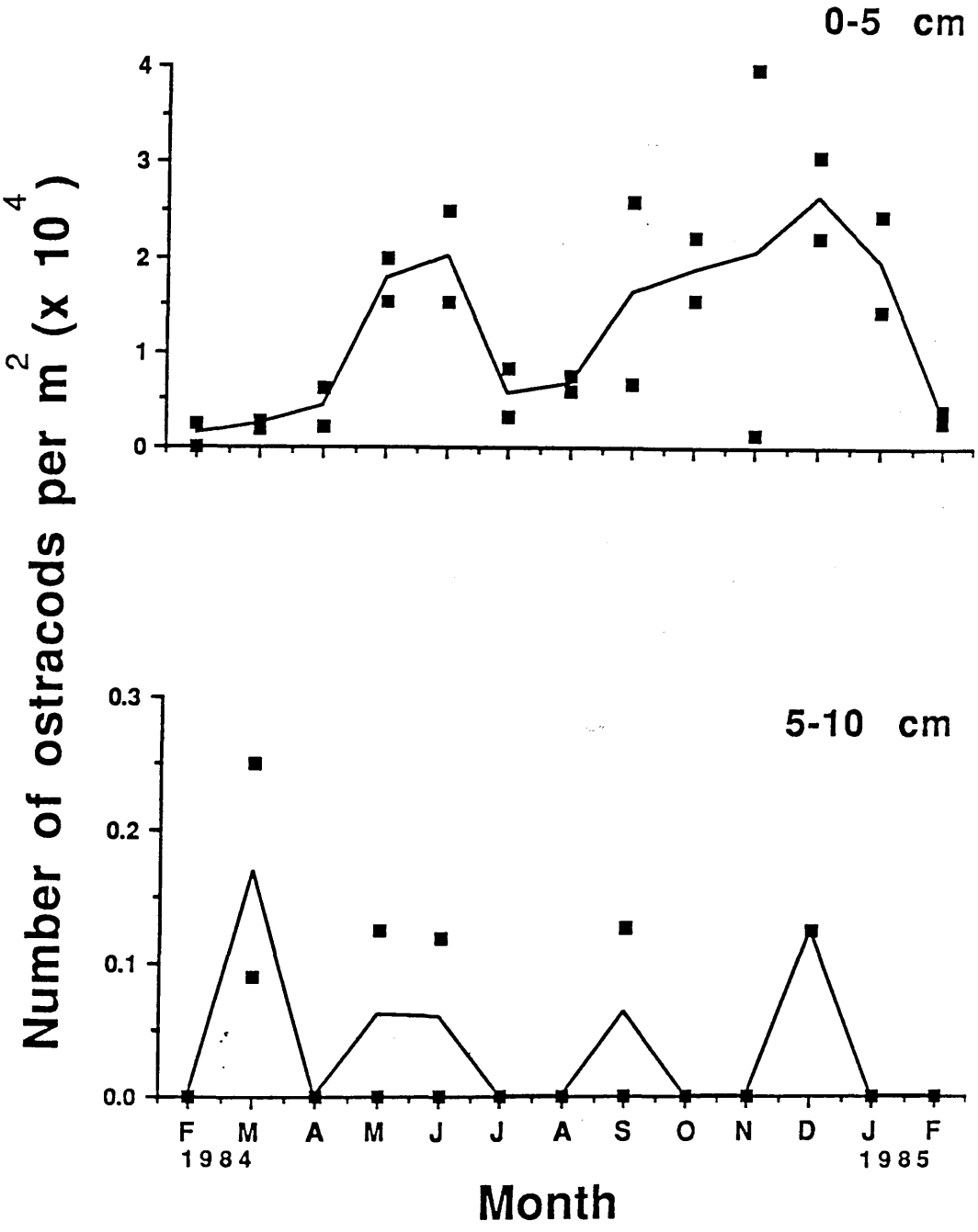


Figure (2.3)

Numbers of ostracods per m^2, Ardmore, low tide area. February 1984 to February 1985. The filled squares show the two replicate cores and the line joins their means.

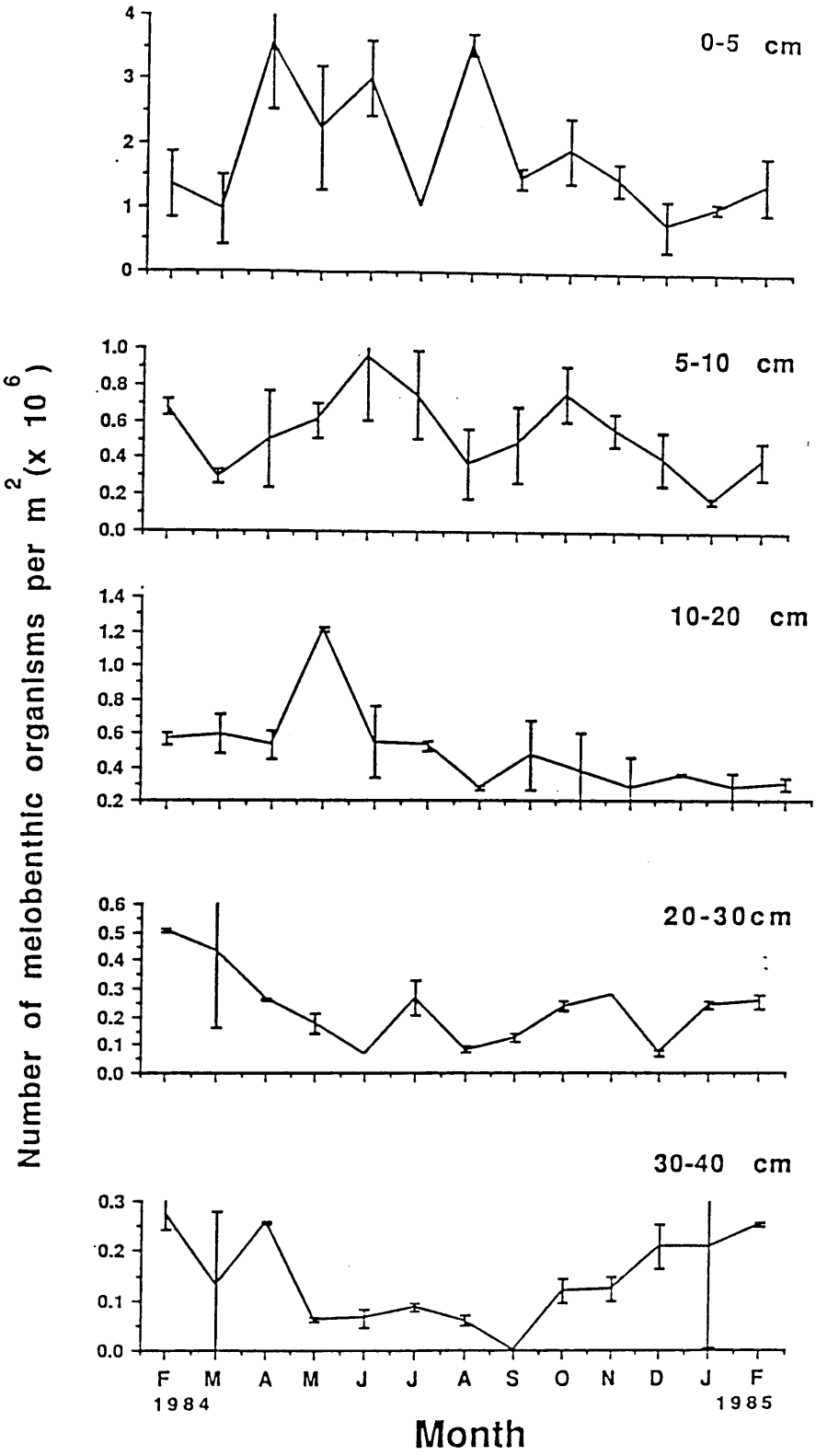


Figure (2.4)

Annual survey 1984-1985, Ardmore, low tide area. Means and standard deviations of the different groups of meiofauna at depths: 0-5cm, 5-10cm, 10-20cm, 20-30cm and 30-40cm of sediment. The mean and standard deviation were calculated from the two replicate cores given in table 2.1 page.

increasing depth. It is notable in certain months namely March, April, May 1984 and January 1985 that the number of meiofauna found at the 10-20cm depth was higher than the number found at the 5-10cm depth. The greatest abundance of meiofauna occurred in the 0-5cm depth (the mean between $0.9x10^6$ and $3.7x10^6$). At lower depths, it did not exceed $1.2x10^6$. The number of meiobenthic organisms fluctuated most in the uppermost depth of sediment (0-5cm). The results also show that the number of meiofauna is highest during the months of April, June and August, 1984 at all depths. The degree of fluctuation was less at the deeper depths.

II- Abundance of macrofauna

The number of macrofauna species found in replicate cores I and II are given in appendix 2, table 2. The number of macrofauna per m^2 of different species found at different depths of sediment is given in table 2.2. This data is derived from the appendix 2, table 2. In appendix 2, table 2 and the table 2.2, juvenile *Arenicola marina* and last stage *Hediste diversicolor* are defined as follows. The former is 2-3cm in length and the latter has the same features as the adult of *H.diversicolor* but not as well developed. The table shows the total number and the mean of the six species of macrofauna found at all depths. The table also shows that most species and the greatest number of organisms for each species were found in the top section of sediment i.e. 0-5cm. The mean of the total number of macrofauna per m^2 of samples I and II were plotted for each month of the survey (figure 2.5). The figure shows that in general, the total

Table (2.2)

Annual survey of macrobenthic organisms per m^2, Ardmore, Low tide area. February 1984 to February 1985. I, II: replicate of sediment cores.

Depth of sediment (cm)	Species	Number of organisms $.m^{-2}$ in month ---1984 February I	February II	March I	March II	April I	April II	May I	May II	June I	June II	July I	July II	August I	August II
0-5	*Pygospio elegans*	3691	3309	0	637	1018	5092	6110	6110	7765	6492	4837	1909	2291	6619
	Bathyporeia pilosa	127	127	0	1145	509	637	255	127	637	2546	2794	4837	1018	2801
	Eteone longa	0	0	0	0	127	127	255	127	0	382	127	382	127	255
	Hediste diversicolor	0	0	0	0	0	0	0	127	0	0	127	127	0	0
	Arenicola marina (Juvenile)	0	0	0	0	0	0	0	0	0	382	0	0	0	0
	Hediste diversicolor (Last stage)	0	0	0	0	0	0	382	255	127	0	0	0	0	0
5-10	*Pygospio elegans*	0	0	0	0	0	0	0	0	127	255	0	0	382	0
	Bathyporeia pilosa	255	127	255	127	255	127	0	0	0	255	0	0	0	0
	Eteone longa	255	255	0	0	0	0	0	0	0	0	0	127	0	255
	Scoloplos armiger	0	0	0	0	0	0	127	0	0	0	0	0	0	0
	Hediste diversicolor	0	0	127	0	0	0	0	0	0	0	0	0	0	0
10-20	*Hediste diversicolor*	0	0	0	0	0	0	0	0	0	127	0	0	0	0
	Arenicola marina counts	18	18	41	35	47	51	49	35	81	93	90	91	88	88
	Total number of animals	4346	3836	1060	2199	2210	6034	7178	6781	8737	10532	7975	7473	3906	10018
	Mean ± s.d.	4091 ± 360.6		1630 ± 805.4		4122 ± 2704		6980 ± 282.8		9635 ± 1269		7724 ± 355		6962 ± 4316	

Cont. table (2.2)

Depth of sediment (cm)	Species	Number of macrofauna .m^{-2} in month — 1985											
		September		October		November		December		January		February	
		I	II	I	II	I	II	I	II	I	II	I	II
0-5	*Pygospio elegans*	7383	3182	4964	1400	891	3437	1400	764	0	255	1782	1145
	Bathyporeia pilosa	255	1909	382	3819	509	1145	764	2037	1145	764	1145	382
	Eteone longa	255	127	255	382	0	0	0	0	0	255	0	127
	Scoloplos armiger	0	0	0	127	0	0	0	0	0	0	0	127
	Hediste diversicolor	0	0	0	0	0	0	0	0	0	0	0	127
	Arenicola marina (Juvenile)	0	0	127	0	0	0	127	0	0	0	127	637
5-10	*Pygospio elegans*	0	0	0	0	0	0	255	0	0	0	509	0
	Bathyporeia pilosa	0	0	0	0	0	382	637	891	0	0	0	0
	Eteone longa	255	0	0	0	255	127	127	255	127	0	0	0
	Scoloplos armiger	0	0	0	0	0	0	127	255	0	0	0	0
10-20	*Eteone Longa*	0	0	0	0	0	0	127	0	0	0	0	0
	Arenicola marina counts	52	48	51	57	38	66	22	37	24	24	37	39
	Total number of animals	8455	5521	5779	5785	1693	5157	3585	4876	1551	1934	3600	2584
	Mean ± s.d.	6988 ± 2075		5782 ± 4.243		3425 ± 2449		4230 ± 912.9		1742 ± 270.8		3092 ± 718.4	

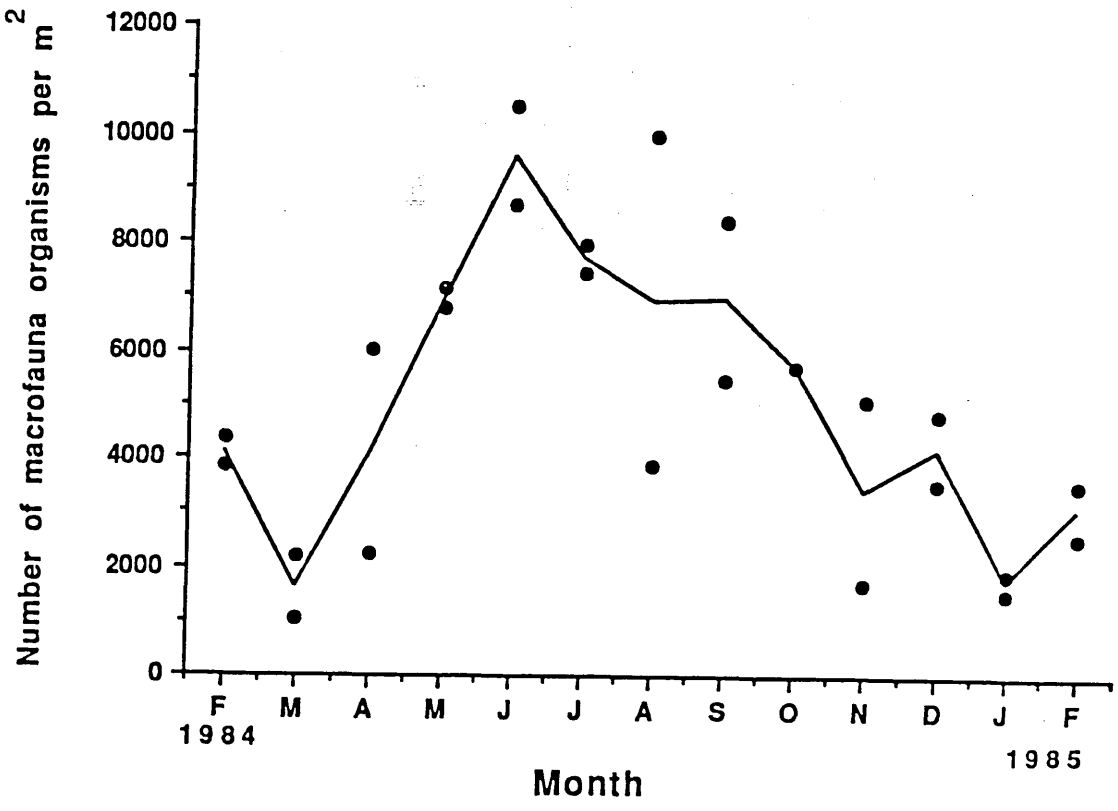


Figure (2.5)

Annual survey 1984-1985, Ardmore, low tide area. Total number of macrobenthic organisms of different species per m^2. The line joins the means of the total number of animals. The filled circles show the total number of animals in the two replicate cores.

number of macrofauna rises in spring, peaks in June, and then shows a steady decrease in autumn and winter. In the months of April, August, September and November there are considerable differences found between the two replicate samples I and II.

(III) Biomass of macrofauna

The biomass of different species of macrofauna including *Arenicola marina* is shown in table 2.3. The total dry weight (biomass) of different species determined from replicate cores I and II and the mean were plotted against different months (figure 2.6). The table and figure show that the biomass of macrofauna fluctuated. The highest biomass occurred in the month of June 1984 (91.22g $.m^{-2}$). Table 3 shows that *Arenicola marina* has the highest biomass of all the species in every month. The mean of the total biomass of different species was plotted against the mean of the total number of animals of different species (figure 2.7). The figure shows that there was no obvious correlation between the two factors (Correlation coefficient= +0.49 and P was $0.10<P<0.05$).

Table (2.3)

Annual survey 1984-1985, Ardmore, low tide area. Dry weight (g) of different species of macrofauna per m^2. I, II: replicate of sediment cores.

Depth of sediment (cm)	Species	Dry weight (g) of macrofauna $.m^{-2}$ -- 1984 -- February I	February II	March I	March II	April I	April II	May I	May II	June I	June II	July I	July II	August I	August II
0-5	*Pygospio elegans*	2.217	2.316	0	1.083	1.629	2.597	4.888	7.332	7.765	14.28	8.223	1.909	0.916	2.648
	Bathyporeia pilosa	2.121	1.207	0	4.237	0.764	1.083	1.173	0.521	0.637	1.782	1.337	0.967	0.713	2.406
	Eteone longa	0	0	0	0	0.927	0.838	1.020	1.067	0	0.497	0.648	0.497	0.826	0.714
	Hediste diversicolor	0	0	0	0	0	0	0	1.905	0	0	1.003	0.533	0	0
	Arenicola marina (Juvenile)	0	0	0	0	0	0	0	0	0	1.261	0	0	0	0
	Nereis diversicolor (Last stage)	0	0	0	0	0	0	1.490	0.995	0.533	0	0	0	0	0
5-10	*Pygospio elegans*	0	0	0	0	0	0	0	0	0.800	0.791	0	0	0.802	0
	Bathyporeia pilosa	0.765	0.521	1.658	0.673	0.536	0.622	0	0	0	0.791	0	0	0	0
	Eteone longa	3.600	4.565	0	0	0	0	0	0	0	0	0	0.572	0	0.893
	Scoloplos armiger	0	0	0	0	0	0	5.004	0	0	0	0	0	0	0
	Hediste diversicolor	0	0	1.880	0	0	0	0	0	0	0	0	0	0	0
10-20	*Hediste diversicolor*	0	0	0	0	0	0	0	0	0	6.998	0	0	0	0
	Arenicola marina	15.60	15.60	69.17	59.05	76.61	83.13	41.50	29.64	59.69	86.53	33.80	34.18	79.12	79.12
Total dry weights		24.30	24.21	72.71	65.04	80.47	88.27	55.08	41.46	69.53	112.9	45.01	38.66	82.38	85.78
Mean ± s.d.		24.26 ± 0.064		68.88 ± 5.424		84.37 ± 5.515		48.27 ± 9.631		91.22 ± 30.77		41.84 ± 4.49		84.08 ± 2.404	

cont. table (2.3)

Depth of sediment (cm)	Species	Dry weight (g) of macrofauna .m^{-2} 1985											
		September		October		November		December		January		February	
		I	II	I	II	I	II	I	II	I	II	I	II
0-5	*Pygospio elegans*	2.953	3.500	3.971	0.560	1.871	1.375	0.840	0.611	0	0.587	0.713	1.145
	Bathyporeia pilosa	0.689	3.436	1.031	1.910	0.662	0.687	0.993	1.426	0.802	0.688	2.061	0.535
	Eteone longa	1.658	8.077	1.173	1.070	0	0	0	0	0	0.944	0	2.172
	Scoloplos armiger	0	0	0	0.953	0	0	0	0	0	0	0	0.749
	Hediste diversicolor	0	0	0	0	0	0	0	0	0	0	0	2.121
	Arenicola marina (Juvenile)	0	0	0.292	0	0	0	0.292	0	0	0	0.381	1.210
5-10	*Pygospio elegans*	0	0	0	0	0	0	1.760	0	0	0	0.764	0
	Bathyporeia pilosa	0	0	0	0	0	0.573	0.701	0.980	0	0	0	0
	Eteone longa	0.765	0	0	0	0.765	0.483	0.826	1.046	0.533	0	0	0
	Scoloplos armiger	0	0	0	0	0	0	1.003	1.785	0	0	0	0
10-20	*Eteone Longa*	0	0	0	0	0	0	2.007	0	0	0	0	0
	Arenicola marina	41.17	38.01	26.60	29.73	14.99	26.03	20.71	34.82	10.64	10.46	16.26	17.14
Total dry weight		47.24	53.02	33.06	34.22	18.29	29.15	29.13	40.67	11.98	12.68	20.18	25.16
Mean ± s.d.		50.13 ± 4.087		33.64 ± 0.820		23.72 ± 7.679		34.90 ± 8.16		12.33 ± 0.495		22.67 ± 3.521	

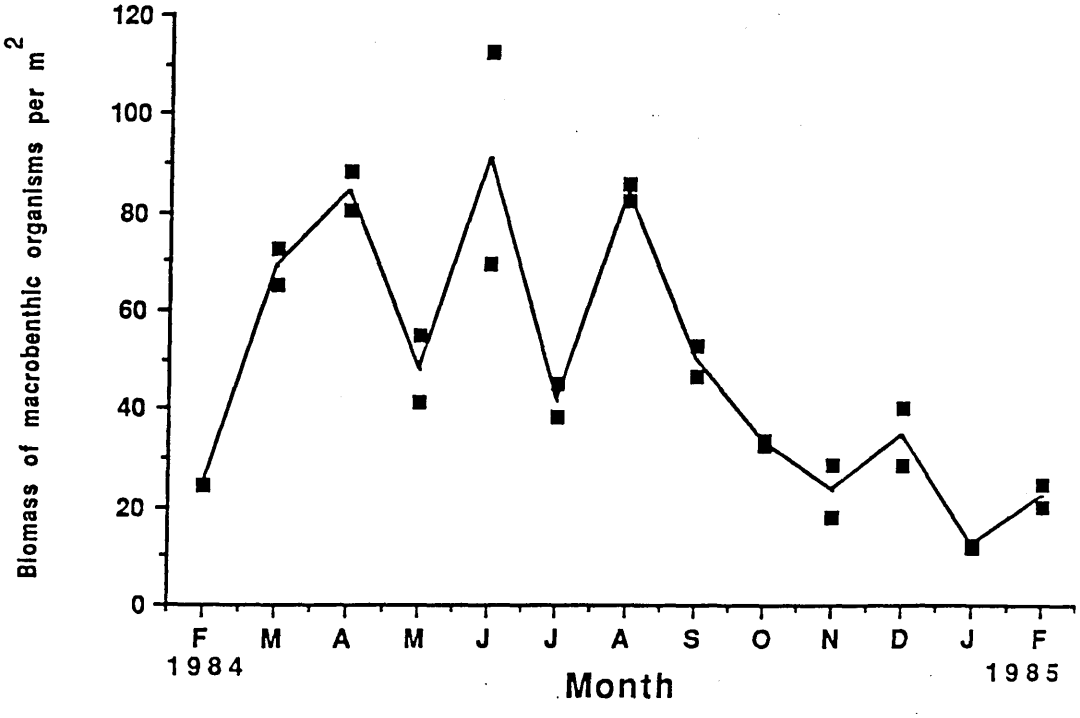


Figure (2.6)

Annual survey 1984-1985, Ardmore, low tide area. Total dry weight (biomass) of macrobenthic organisms of different species per m^2. The filled squares show the total dry weights of animals in the two replicate cores. The line joins their means.

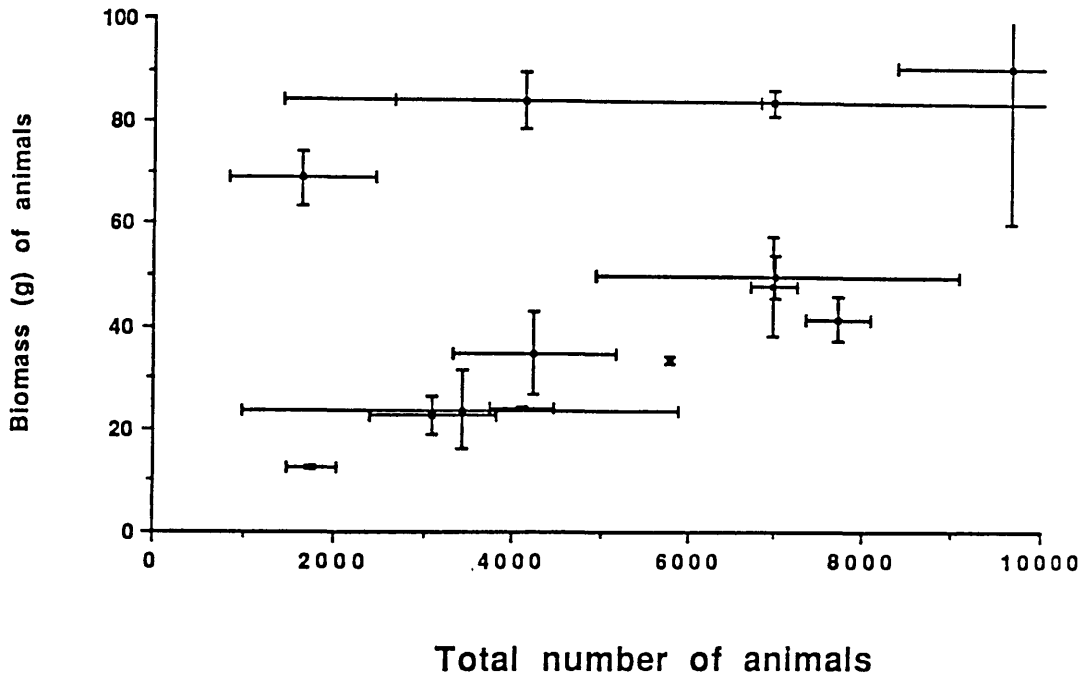


Figure (2.7)

Annual survey 1984-1985, Ardmore, low tide area. Relationship between the mean and standard deviation of the total number animals and the biomass. The horizontal bars show standard deviations of the total number of animals. The vertical bars show standard deviations of the biomass.

Section 2- Annual cycle of physical and chemical properties of sediment.

I- Field measurements.

1- Shear strength

The means and standard deviations of the peak and residual shear strength are given in tables 2.4A and 2.4B. This data was derived from the original data given in appendix 2, table 4. The means and standard deviations of peak and residual of shear strength were plotted against the different depth of sediment for each month (figure 2.8). The tables and figure show that shear strength generally increased with depth and there was little fluctuation in the lower depths. Near the surface of the sediment, the peak and residual readings were similar but at lower depths the range of differences between the two readings was wide. The lowest reading of peak and residual shear strength during the survey occurred in September 1984 throughout the different depths of sediment. The highest reading of peak and residual shear strength was recorded in the month of July 1984 at 100cm depth (peak= 162.2 $kN.m^{-2}$; residual= 74.03 $kN.m^{-2}$).

2- Permeability

The calculation of permeability ($m .sec^{-1}$) of sediment using the Hooghout and Ernst equations is given in table 2.5. The table shows the means and standard deviations of the permeability calculated for each month of the survey. The table shows that there were differences in the calculation of permeability using the two equations. The reason for these differences is not known. The table also shows that there was no difference in the permeability between

Table (2.4A)

Annual survey 1984-1985, Ardmore, low tide area. Means and standard deviations of the peak shear strength (kN $.m^{-2}$). S.d. = Standrd deviation.

Depth of sediment (cm)		Month												
		--1984										1985		
		Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Surface	Mean	4.038	1.346	3.029	1.346	4.711	2.019	2.154	0	2.692	1.683	2.692	4.038	6.057
	S.d.	0.952	0	0.476	0	0.952	2.855	2.665	0	3.807	0.476	0	1.904	0.952
5	Mean	8.749	8.278	5.048	7.740	11.44	8.749	8.211	6.057	6.394	7.403	11.78	8.076	11.44
	S.d.	2.855	3.522	0.476	3.331	0.952	4.759	0.761	0.952	2.379	0.952	2.379	0.952	4.759
10	Mean	17.50	11.17	9.086	13.80	18.51	12.79	10.77	10.77	8.749	9.759	16.83	9.422	16.83
	S.d.	5.711	0.952	1.428	4.283	0.476	8.566	0	0.952	0.952	2.379	0.952	1.904	0.952
15	Mean	16.89	15.82	14.13	14.50	22.21	14.81	14.81	15.48	12.45	10.77	14.81	10.43	16.69
	S.d.	6.567	0.476	0.952	4.283	7.614	5.711	1.927	0.952	2.379	1.904	1.904	0.476	2.665
20	Mean	17.03	16.96	18.17	15.82	26.92	22.41	15.14	15.48	15.14	15.82	21.87	20.19	14.81
	S.d.	4.473	1.142	0	3.331	0.952	15.90	1.428	0.952	2.379	0.476	4.283	9.518	1.904
25	Mean	24.16	18.17	18.84	26.92	22.21	32.30	23.30	16.15	20.53	22.88	20.86	22.88	31.30
	S.d.	0.095	3.807	0	0	0.952	3.807	6.186	0	1.428	3.807	12.37	1.904	9.994
30	Mean	27.86	25.57	29.61	26.58	29.61	35.33	30.96	21.54	24.90	28.27	36.34	24.23	36.68
	S.d.	2.475	0.952	7.614	4.283	2.855	5.235	1.903	7.614	2.855	1.904	9.518	3.807	3.331
35	Mean	36.48	39.37	25.57	39.71	35.47	30.96	24.90	25.91	28.27	32.30	43.41	24.90	37.69
	S.d.	7.805	11.90	2.855	7.614	6.948	1.904	15.23	6.187	9.518	3.807	19.51	18.08	0
40	Mean	42.82	33.65	34.99	30.29	57.88	46.77	49.13	22.88	31.97	35.33	40.72	30.96	35.13
	S.d.	3.426	5.711	3.807	6.662	18.08	13.80	0.952	5.711	14.75	0.476	8.090	13.33	19.23
45	Mean	72.68	36.88	43.75	44.76	32.30	58.22	56.20	20.86	44.08	48.12	51.15	30.29	52.83
	S.d.	18.65	16.94	2.855	12.85	19.04	8.090	9.994	10.47	1.428	11.90	0	29.51	7.138
50	Mean	59.69	43.75	47.45	66.63	30.29	74.03	67.97	24.23	53.84	61.58	69.66	44.42	69.32
	S.d.	8.280	0.952	5.235	7.614	2.855	10.47	0.952	3.807	3.807	32.84	7.138	9.518	6.662

Cont... table (2.4A)

Depth of sediment (cm)		Month												
		--1984											1985	
		Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
55	Mean	50.14	53.50	56.87	70.67	79.41	76.72	82.78	51.82	73.02	57.88	82.78	60.23	84.13
	S.d.	9.042	3.331	14.75	8.566	5.711	8.566	4.759	23.79	8.090	38.07	8.566	17.61	10.47
60	Mean	48.46	60.44	51.15	77.06	75.38	81.43	89.17	28.60	56.20	73.36	86.82	65.95	75.38
	S.d.	22.84	28.74	26.65	12.85	0	21.89	9.042	5.235	20.46	8.566	14.28	5.711	11.42
65	Mean	58.22	54.51	65.62	81.43	74.70	94.22	98.29	29.61	67.64	83.12	82.11	80.09	89.85
	S.d.	16.66	18.08	22.37	12.37	16.18	20.94	5.711	7.614	0.476	22.37	36.17	8.566	9.042
70	Mean	64.67	30.22	80.76	75.71	86.14	110.7	109.0	29.61	86.14	101.3	92.54	72.68	93.88
	S.d.	0.095	14.37	1.903	5.235	7.614	14.74	1.904	13.33	22.84	27.13	25.22	3.807	2.379
75	Mean	58.22	67.10	81.43	92.20	105.0	123.5	109.4	27.69	84.13	110.0	111.1	72.35	102.6
	S.d.	9.042	12.09	42.83	2.855	9.518	23.32	5.235	10.47	39.02	0	0	0.476	0.476
80	Mean	63.26	94.89	92.87	111.4	108.0	142.0	142.7	37.69	60.91	113.1	116.4	75.71	114.4
	S.d.	7.614	7/614	28.55	8.090	0.476	46.64	22.84	10.47	6.187	7.614	4.759	7.138	1.904
85	Mean	64.14	90.86	99.27	106.3	119.1	103.0	144.7	29.61	71.34	108.7	112.4	84.13	86.14
	S.d.	10.76	7.614	7.138	13.32	4.759	9.518	52.35	5.711	1.904	35.69	4.759	8.566	34.26
90	Mean	74.70	77.06	101.6	91.53	128.9	128.5	143.0	39.37	59.22	94.56	108.0	98.60	70.33
	S.d.	11.42	2.378	14.28	19.04	0.476	31.41	26.17	1.428	3.807	37.60	3.331	21.42	5.235
95	Mean	55.19	79.08	119.1	96.91	134.3	152.8	105.7	36.68	71.34	118.8	115.1	93.21	76.72
	S.d.	17.13	2.379	35.22	3.807	0.476	31.41	4.759	6.187	9.518	7.138	4.759	24.27	17.13
100	Mean	59.09	91.53	123.2	125.2	145.4	162.2	94.56	26.92	100.3	128.9	110.7	94.22	81.43
	S.d.	18.27	15.23	50.44	36.17	30.47	25.70	15.70	3.807	23.79	6.187	3.331	14.28	2.855

Table (2.4B)

Annual survey 1984-1985, Ardmore, low tide area. Means and standard deviations of the residual shear strength (kN $.m^{-2}$). S.d. = Standard deviation.

Depth of sediment (cm)		Month												
		--1984										1985		
		Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Surface	Mean	1.615	0.269	1.346	0.337	2.356	1.346	1.952	0	0	0	2.019	2.692	4.375
	S.d.	1.332	0.381	0.952	0.476	0.476	1.904	2.760	0	0	0	0.952	0	2.379
5	Mean	7.740	5.653	4.038	5.385	10.10	7.740	5.721	5.048	4.375	6.057	10.10	6.057	10.43
	S.d.	1.428	3.236	1.904	1.904	0	4.83	3.331	0.476	1.428	0.952	4.759	0.952	3.331
10	Mean	9.355	9.489	7.739	9.086	6.394	7.067	7.403	7.740	6.394	7.067	11.11	7.403	12.79
	S.d.	5.615	1.427	0.476	1.428	1.428	5.235	2.855	0.476	0.476	0.476	0.476	0.952	4.759
15	Mean	8.076	10.77	7.403	8.413	12.79	9.422	10.10	8.413	6.057	7.403	9.422	7.403	8.749
	S.d.	3.807	0	0.952	3.331	4.759	5.711	2.855	0.476	0.952	0.952	1.904	0.952	0.952
20	Mean	7.067	9.691	9.422	8.749	13.12	10.10	14.13	7.740	7.403	9.422	13.46	9.086	9.422
	S.d.	7.138	1.332	4.759	2.855	1.428	2.855	0.952	0.476	0.952	1.904	3.807	1.428	0
25	Mean	11.17	9.759	10.77	13.46	15.82	14.81	18.51	8.413	9.759	12.79	15.48	15.50	20.19
	S.d.	3.426	2.379	0	0	5.235	2.855	11.90	0.476	1.428	2.855	8.566	2.855	5.711
30	Mean	14.40	14.47	15.82	13.46	15.48	19.85	18.51	10.77	11.11	15.82	18.51	12.79	18.84
	S.d.	3.426	1.428	2.379	1.903	2.855	0.476	2.379	2.855	2.379	3.331	3.331	4.759	1.904
35	Mean	17.63	10.10	17.50	18.17	18.84	18.17	22.88	12.11	10.10	17.50	20.19	12.79	23.22
	S.d.	1.713	5.711	5.711	2.855	7.614	0.952	13.33	0	4.759	0	9.518	12.37	1.428
40	Mean	22.74	14.67	17.84	15.82	45.09	23.56	35.67	12.79	14.13	17.50	21.20	15.14	28.94
	S.d.	2.094	5.520	2.379	2.379	33.31	6.662	8.566	3.807	10.47	1.904	1.428	8.090	16.18
45	Mean	17.03	14.13	19.85	19.85	18.17	24.23	39.71	12.11	17.50	22.55	41.39	18.84	28.27
	S.d.	0.286	4.759	0.476	3.331	5.711	2.855	12.37	1.904	1.904	3.331	9.994	15.23	5.711
50	Mean	23.62	19.83	20.53	21.53	17.50	28.60	35.67	12.45	21.54	25.57	25.91	18.17	31.63
	S.d.	0.476	1.428	2.379	0	0	2.379	2.855	0.476	0	9.518	5.235	4.759	6.662

Cont... table (2.4B)

Depth of sediment (cm)		Month												
		--1984											1985	
		Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
55	Mean	24.16	20.86	24.90	26.92	32.30	32.98	41.05	20.19	27.26	24.23	36.68	26.92	45.43
	S.d.	1.808	0.952	0.952	1.903	3.807	2.855	2.855	5.711	3.331	11.42	9.994	12.37	4.283
60	Mean	24.23	20.86	18.84	27.26	27.59	32.98	45.09	16.15	23.89	31.30	35.67	32.30	42.40
	S.d.	3.807	2.855	5.711	0.476	0.952	2.855	2.855	0	0.476	1.428	2.855	3.807	4.759
65	Mean	24.29	23.56	26.58	31.63	31.63	34.07	43.75	16.83	28.27	32.30	35.00	32.98	38.70
	S.d.	2.951	4.759	4.283	6.662	4.759	5.711	2.855	4.759	0	0	12.37	6.662	2.379
70	Mean	26.25	16.15	28.94	27.93	32.30	42.40	53.84	14.47	29.61	37.69	40.04	34.32	47.78
	S.d.	4.759	3.807	0.952	3.331	3.807	0.952	0	1.428	0	3.807	10.95	0.952	0.952
75	Mean	26.58	26.11	33.99	30.62	41.39	41.05	62.93	20.53	34.99	43.41	71.34	35.67	47.78
	S.d.	0.476	2.094	9.994	5.235	6.187	0.952	1.428	12.85	8.566	8.090	41.88	10.47	0.952
80	Mean	28.33	28.60	33.99	39.71	39.03	42.06	60.91	20.53	28.27	45.43	49.13	35.33	43.41
	S.d.	3.712	3.331	9,994	4.759	3.807	9.994	9.994	2.379	1.904	6.187	0.952	0.476	6.186
85	Mean	30.96	27.93	36.68	41.39	41.73	37.35	43.75	21.20	32.64	48.79	47.11	44.42	45.09
	S.d.	4.759	5.235	2.379	3.331	7.614	10.95	10.47	4.283	3.331	4.283	5.711	5.711	8.566
90	Mean	36.01	28.93	35.33	38.03	45.09	43.07	60.57	22.20	31.97	47.78	55.52	49.13	39.03
	S.d.	1.428	6.662	0.476	4.283	7.614	19.04	2.855	0.952	0.476	12.37	1.428	17.13	5.711
95	Mean	31.97	29.61	46.44	37.69	41.73	53.17	52.49	24.90	28.27	49.47	53.84	45.76	41.05
	S.d.	11.90	1.904	2.855	0	1.904	8.566	5.711	0.952	1.904	1.428	0	19.04	8.566
100	Mean	36.21	29.61	45.76	52.16	50.81	72.01	42.74	19.52	37.35	53.17	61.92	42.74	41.39
	S.d.	5.901	3.807	3.807	7.138	14.75	42.83	0.476	1.903	6.186	6.662	7.614	4.283	9.042

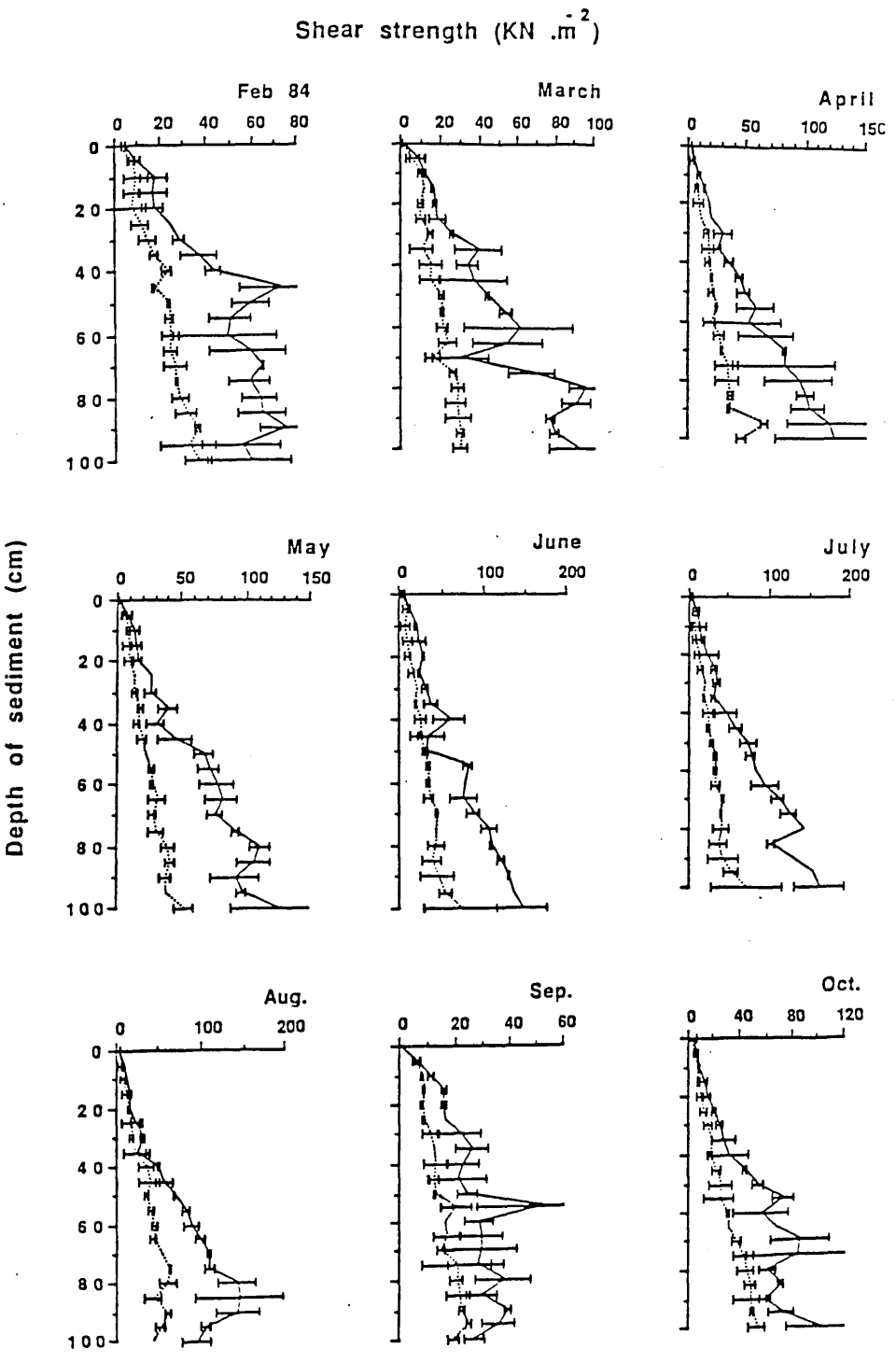
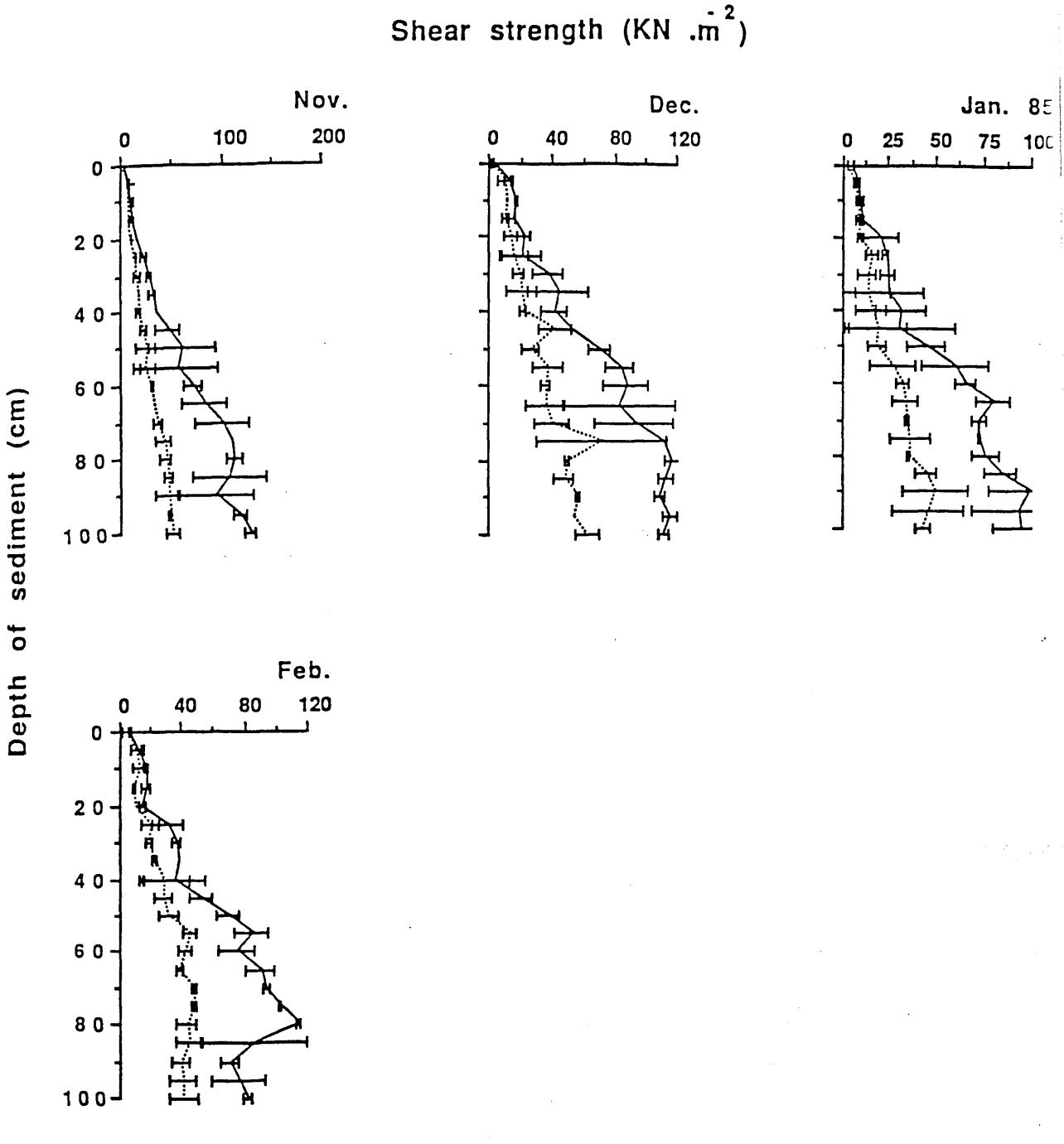


Figure (2.8)

Annual survey. February 1984 to February 1985. Ardmore, low tide area. Means and standard deviations of peak and residual shear strength (kN $.m^{-2}$) at different depth of sediment. The complete line shows the means of peak shear strength and the broken line gives the residual shear strength. The horizontal bars indicate standard deviations. Each mean and standard deviation is calculated from two replicate readings in tables 2.4A and 2.4B.



Cont. figure (2.8)

Table (2.5)

Annual survey 1984-1985. Ardmore, low tide area. Coefficient of permeabilty (m .sec^{-1}). Each mean and standard deviation is calculated from all the time intervals taken in each core as the water rose from the bottom of the core to the water table.

Month	Replicate readings	Hooghout Coefficient Mean ± s.d.	Ernst Coefficient Mean ± s.d.
February 1984	I	0.0001 ± 0.0001	0.0008 ± 0.00095
	II	0.0001 ± 0.0001	0.0008 ± 0.0009
March	I	0.00008 ± 0.00006	0.0006 ± 0.0005
	II	0.00008 ± 0.00006	0.0007 ± 0.0006
April	I	0.0001 ± 0.00005	0.0011 ± 0.0005
	II	0.00008 ± 0.00005	0.0007 ± 0.0004
May	I	0.0001 ± 0.00009	0.0014 ± 0.0007
	II	0.00008 ± 0.00006	0.0007 ± 0.0006
June	I	0.00009 ± 0.00007	0.0008 ± 0.0005
	II	0.00007 ± 0.00005	0.0006 ± 0.0004
July	I	0.00009 ± 0.00007	0.0008 ± 0.0005
	II	0.00009 ± 0.00005	0.0007 ± 0.0005
August	I	0.0001 ± 0.00005	0.0010 ± 0.0004
	II	0.00006 ± 0.00004	0.0006 ± 0.0004
September	I	0.00008 ± 0.00004	0.0007 ± 0.0004
	II	0.00007 ± 0.00004	0.0004 ± 0.0003
October	I	0.0001 ± 0.00006	0.0008 ± 0.0004
	II	0.0001 ± 0.00004	0.0009 ± 0.0003
November	I	0.0001 ± 0.00006	0.0010 ± 0.0005
	II	0.00009 ± 0.00006	0.0008 ± 0.0004
December	I	0.00006 ± 0.00005	0.0006 ± 0.0005
	II	0.00005 ± 0.00006	0.0006 ± 0.0006
January 1985	I	0.00009 ± 0.00007	0.0004 ± 0.0006
	II	0.00006 ± 0.00004	0.0005 ± 0.0003
February	I	0.00008 ± 0.00007	0.0008 ± 0.0006
	II	0.00007 ± 0.00005	0.0007 ± 0.0005

different months. The range of permeability (m .sec^{-1}) indicates that the type of soil is sand and the drainage properties are good (Smith 1981, page 41)

3- Redox potential (Eh)

The Eh (mV) values of the overlying and interstitial water from October 1984 to October 1985 are given in table 2.6. The table shows that there was a little difference between the overlying water and the interstitial water. The Eh of overlying water was always higher than the Eh of interstitial water.

The Eh (mV) of the different depths of sediment obtained during the survey is given table 2.7. The table shows the Eh readings I and II, and the means and standard deviations of these two readings. The means and standard deviations of Eh were plotted against different depths of sediment for each month of the survey (figure 2.9). The figure shows the Eh decreased from the surface of the sediment to 5cm depth, and then increased in the 10cm and 20cm depths in most months of the survey. The Eh then decreased in the 30cm depth but it has increased in two months of the survey (i.e. October 84 and March 85). The highest reading of Eh was recorded in the surface sediment in the month of November 1984 (+486 mV), and the lowest reading occurred at 5cm depth in September 1985 (-33 mV). The increase in Eh reading in the middle depths may be related to the biological effects of some animals e.g. *Arenicola marina*.

Table (2.6)

Annual survey 1984-1985. Ardmore, low tide area. Eh (mV) readings. I, II replicate readings.

Month	Replicate readings	Eh values (mV)	
		Interstitial water	Overlying water
October 1984	I	338	339
	II	328	347
November	I	333	349
	II	299	363
December	I	220	361
	II	223	365
January 1985	I	311	361
	II	296	364
February	I	389	404
	II	380	403
March	I	279	437
	II	281	406
April	I	424	425
	II	388	430
May	I	376	418
	II	389	393
June	I	407	451
	II	392	406
July	I	372	389
	II	373	424
August	I	380	408
	II	385	424
September	I	316	361
	II	302	335
October	I	440	480
	II	430	442

Table (2.7)

Annual survey 1984-1985. Ardmore, low tide area. Eh (mV) readings of different depths of sediment.

Month	Replicate readings	Depth (cm) Surface	5	10	20	30
October 1984	I	339	72	141	146	211
	II	327	69	134	169	189
Mean ± s.d.		333 ± 8.485	71 ± 2.121	138 ± 4.950	158 ± 16.26	200 ± 15.56
November	I	481	141	169	154	101
	II	491	119	199	81	114
Mean ± s.d.		486 ± 7.071	130 ± 15.56	184 ± 21.21	118 ± 51.62	108 ± 9.192
December	I	399	189	151	206	99
	II	376	162	176	157	86
Mean ± s.d.		388 ± 16.26	176 ± 19.09	164 ± 17.68	182 ± 34.65	93 ± 9.192
January 1985	I	418	129	91	78	52
	II	396	126	92	71	92
Mean ± s.d.		407 ± 15.56	128 ± 2.121	92 ± 0.707	75 ± 4.950	72 ± 28.28
February	I	388	189	325	432	57
	II	385	231	355	395	35
Mean ± s.d.		387 ± 2.12	210 ± 29.70	355 ± 17.32	414 ± 26.16	46 ± 15.56
March	I	367	78	123	210	204
	II	361	61	128	179	188
Mean ± s.d.		364 ± 4.24	70 ± 12.02	126 ± 3.54	195 ± 21.92	196 ± 11.31

Cont... table (2.7)

Month	Replicate readings	Depth (cm) Surface	5	10	20	30
April	I	427	127	204	202	151
	II	387	154	192	187	147
Mean ± s.d.		407 ± 28.28	141 ± 19.09	198 ± 8.48	195 ± 10.61	149 ± 2.828
May	I	397	277	341	362	322
	II	373	303	352	314	279
Mean ± s.d.		385 ± 16.97	290 ± 18.39	347 ± 7.78	338 ± 33.94	301 ± 30.41
June	I	425	112	128	229	154
	II	356	165	222	239	221
Mean ± s.d.		391 ± 48.79	139 ± 37.48	176 ± 67.88	234 ± 7.07	188 ± 47.38
July	I	361	321	291	294	137
	II	337	359	368	279	73
Mean ± s.d.		349 ± 16.97	340 ± 26.87	330 ± 54.44	287 ± 10.61	105 ± 54.25
August	I	294	229	209	200	74
	II	336	209	180	207	57
Mean ± s.d.		315 ± 29.70	219 ± 14.14	198 ± 15.56	204 ± 4.95	68 ± 12.02
September	I	279	-34	31	186	14
	II	261	-31	177	197	-1
Mean ± s.d.		270 ± 12.73	-33 ± 2.121	104 ± 103.2	192 ± 7.78	6.5 ± 10.61
October	I	402	192	177	142	99
	II	399	206	182	146	61
Mean ± s.d.		401 ± 2.12	199 ± 9.90	180 ± 3.54	144 ± 2.83	80 ± 26.87

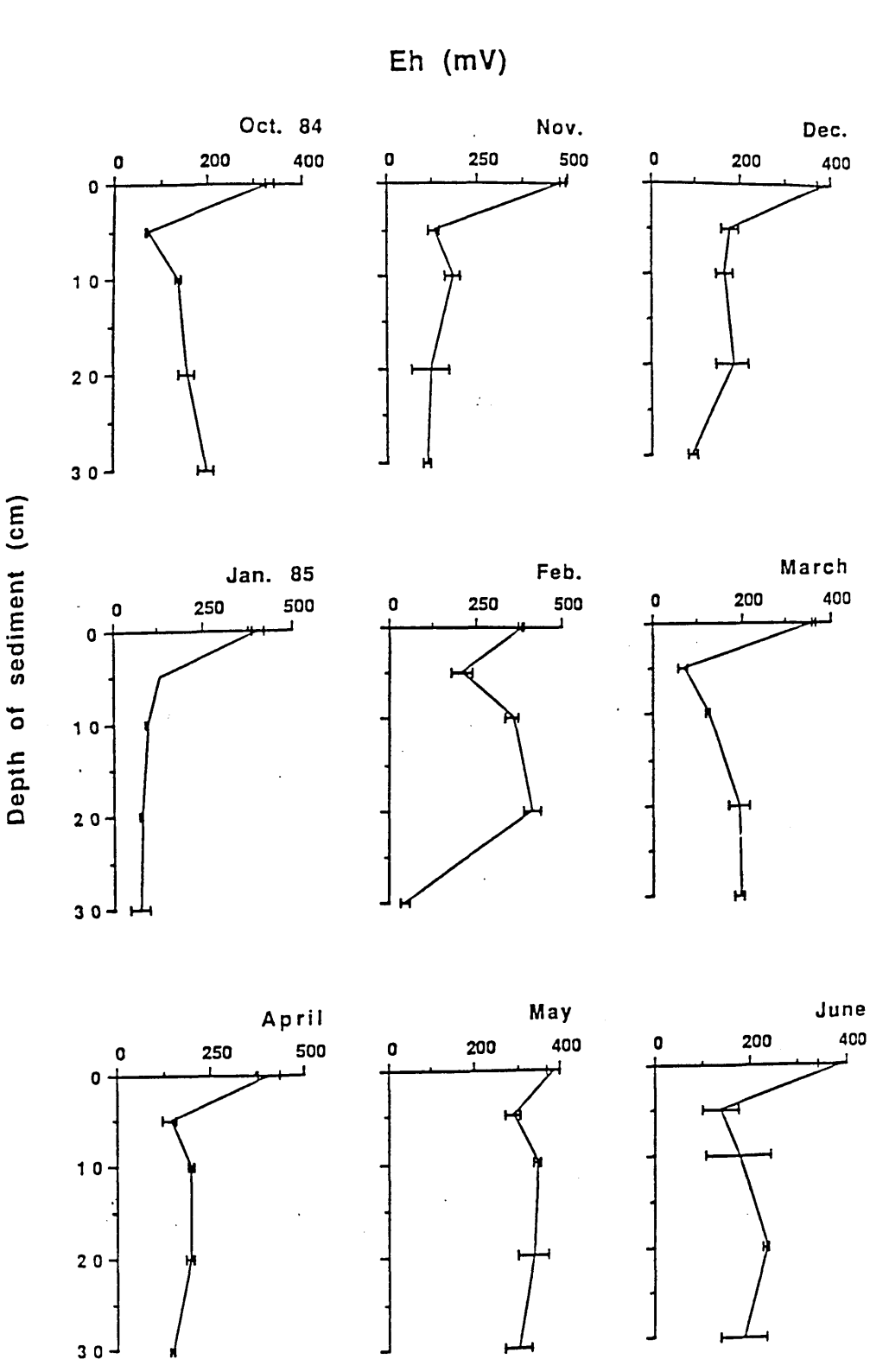
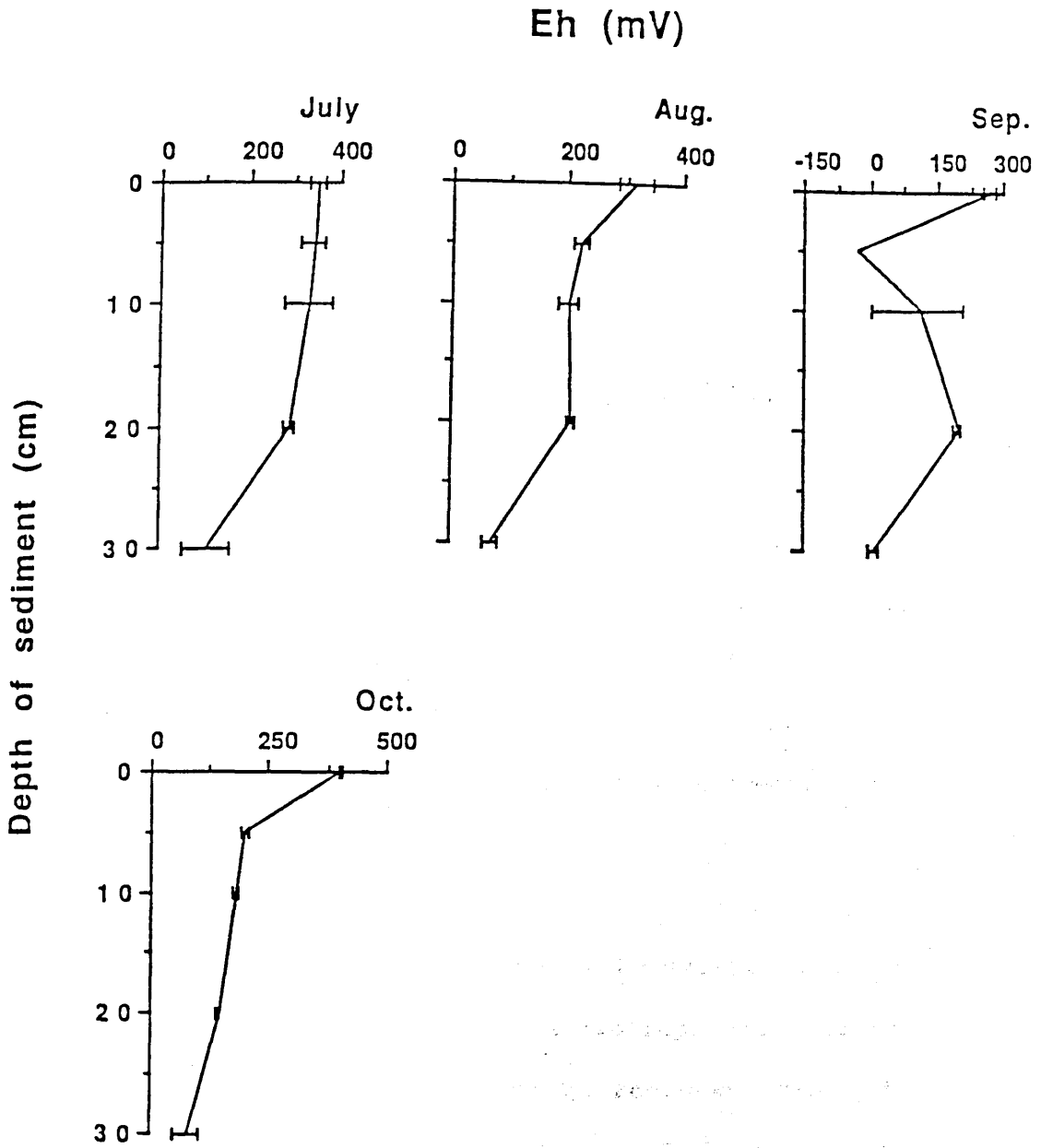


Figure (2.9)

Annual survey. October 1984 to October 1985. Ardmore, low tide area. Means and standard deviations of Eh (mV) at different depths of sediment. The line joins the means, horizontal bars shows the standard deviations. Each mean is calculated from the two replicate readings in table 2.7.



Cont. figure (2.9)

II- Laboratory measurements.

1- pH

The pH of the overlying and interstitial water of the low tide area of Ardmore point taken from October 1984 to October 1985 is given in table 2.8. The table shows there was no difference in the pH between different months for the overlying water and the interstitial water.

The pH of different depths of sediment is given in table 2.9. The table gives the values of pH of the two replicate readings taken in the low tide area of Ardmore point from October 1984 to October 1985. The table shows that there was no great difference between different months and also different depths of sediment.

2- Salinity

The salinity of overlying water and interstitial water is given in table 2.10. The table gives the two replicate readings of the salinity taken from February 1984 to February 1985 and also the rainfall measured in that period. The rainfall data was provided by the Meteorological Office, Edinburgh EH11 3XQ. The mean salinity of overlying and interstitial water was plotted against months in figure 2.10.

The table and figure show that the salinity of the overlying water and interstitial water increased from February 84 to March 84 and remained almost the same till September 84. It decreased again in October and November 1984, with a slight increase in December 84, decreasing again in January 85, finally increasing in February 1985. The figure also shows that the salinity in February 85 was

Table (2.8)

Annual survey 1984-1985. Ardmore, low tide area.

pH readings.

Month	Replicate readings	pH	
		Interstitial water	Overlying water
October 1984	I	6.30	6.50
	II	6.20	6.50
November	I	6.40	6.45
	II	6.45	6.40
December	I	6.40	6.60
	II	6.55	6.50
January 1985	I	6.60	6.87
	II	6.52	6.82
February	I	6.66	6.55
	II	6.68	6.87
March	I	6.57	6.60
	II	6.58	6.61
April	I	6.69	6.68
	II	6.66	6.66
May	I	6.32	7.12
	II	6.42	7.10
June	I	6.68	7.53
	II	6.83	7.64
July	I	7.00	8.09
	II	6.87	7.52
August	I	7.01	7.69
	II	6.91	7.38
September	I	6.68	7.43
	II	6.90	7.33
October	I	6.84	7.25
	II	6.87	7.15

Table (2.9)

Annual survey 1984-1985. Ardmore, low tide area. pH measurements of sediment.

Month	Replicate readings	Depth (cm) Surface	5	10	20	30
October 1984	I	6.80	6.85	6.82	6.87	6.86
	II	6.85	6.82	6.82	6.76	6.80
Mean ± s. d.		6.83 ± 0.035	6.84 ± 0.021	6.82 ± 0	6.82 ± 0.078	6.83 ± 0.04
November	I	6.65	6.80	7.15	6.93	7.18
	II	6.35	6.40	6.75	6.80	6.88
Mean ± s. d.		6.50 ± 0.212	6.60 ± 0.283	6.95 ± 0.283	6.87 ± 0.092	7.03 ± 0.21
December	I	6.88	7.34	7.23	7.36	7.61
	II	6.87	7.23	7.03	7.26	7.53
Mean ± s. d.		6.88 ± 0.007	7.29 ± 0.078	7.08 ± 0.064	7.31 ± 0.071	7.57 ± 0.05
January 1985	I	6.72	7.58	7.59	7.30	7.67
	II	6.75	7.58	7.60	7.50	7.66
Mean ± s. d.		6.74 ± 0.021	7.58 ± 0	7.60 ± 0.007	7.40 ± 0.028	7.67 ± 0.01
February	I	6.82	6.97	7.08	6.79	7.23
	II	6.73	6.95	6.69	6.63	7.13
Mean ± s. d.		6.78 ± 0.064	6.96 ± 0.014	7.02 ± 0.085	6.71 ± 0.113	7.18 ± 0.07
March	I	6.58	6.61	6.63	6.92	6.71
	II	6.66	6.63	6.65	6.66	6.69
Mean ± s. d.		6.62 ± 0.057	6.62 ± 0.014	6.64 ± 0.014	6.69 ± 0.184	6.70 ± 0.01

Cont... table (2.9)

Month	Replicate readings	Depth (cm) Surface	5	10	20	30
April	I	6.76	7.14	7.07	7.08	7.61
	II	6.75	7.12	7.05	6.93	7.48
Mean ± s. d.		6.76 ± 0.007	7.13 ± 0.014	7.06 ± 0.014	7.01 ± 0.106	7.55 ± 0.09
May	I	7.02	7.17	7.12	7.06	7.08
	II	6.92	7.14	7.08	7.11	7.22
Mean ± s. d.		6.99 ± 0.042	7.16 ± 0.021	7.10 ± 0.028	7.09 ± 0.035	7.15 ± 0.09
June	I	7.00	7.02	7.03	7.07	7.10
	II	6.91	7.10	6.78	6.94	7.05
Mean ± s. d.		6.70 ± 0.064	7.06 ± 0.057	6.91 ± 0.177	7.01 ± 0.092	7.08 ± 0.03
July	I	7.04	7.24	7.06	7.29	7.05
	II	7.03	7.20	7.29	7.12	7.26
Mean ± s. d.		7.04 ± 0.007	7.22 ± 0.028	7.13 ± 0.099	7.21 ± 0.120	7.16 ± 0.14
August	I	6.99	7.30	7.03	6.99	7.01
	II	7.02	7.25	6.89	6.95	6.99
Mean ± s. d.		7.01 ± 0.021	7.28 ± 0.035	6.96 ± 0.099	6.97 ± 0.028	7.00 ± 0.00
September	I	6.93	7.18	7.10	6.98	7.34
	II	6.90	7.13	7.06	7.07	7.38
Mean ± s. d.		6.92 ± 0.021	7.16 ± 0.035	7.08 ± 0.028	7.03 ± 0.064	7.36 ± 0.02
October	I	6.74	7.20	7.07	6.90	7.17
	II	6.78	7.26	7.14	6.96	7.13
Mean ± s. d.		6.67 ± 0.028	7.23 ± 0.042	7.11 ± 0.050	6.93 ± 0.042	7.15 ± 0.02

Table (2.10)

Annual survey 1984-1985. Ardmore, low tide area. Salinity ($^{o}/_{oo}$) of the interstitial and overlying water and the rainfall readings in mm obtained in the period of the survey.

Month	Replicate readings	Salinity $^{o}/_{oo}$ Interstitial water	Salinity $^{o}/_{oo}$ Overlying water	Rainfall readings (mm)
February 1984	I	20	20	131
	II	20	20	
March	I	30	32	48
	II	31	32	
April	I	32	31	44
	II	31	32	
May	I	32	33	19
	II	32	33	
June	I	32	31.5	17
	II	31	31.5	
July	I	32	32	10
	II	33	31	
August	I	32	32	61
	II	32	32	
September	I	33	33	163
	II	33	34	
October	I	28.5	30	228
	II	30	30	
November	I	18	17	218
	II	17	17	
December	I	25	19	Not
	II	25	19	available
January 1985	I	21	18	Not
	II	21	18	available
February	I	28	31	40
	II	28	31	

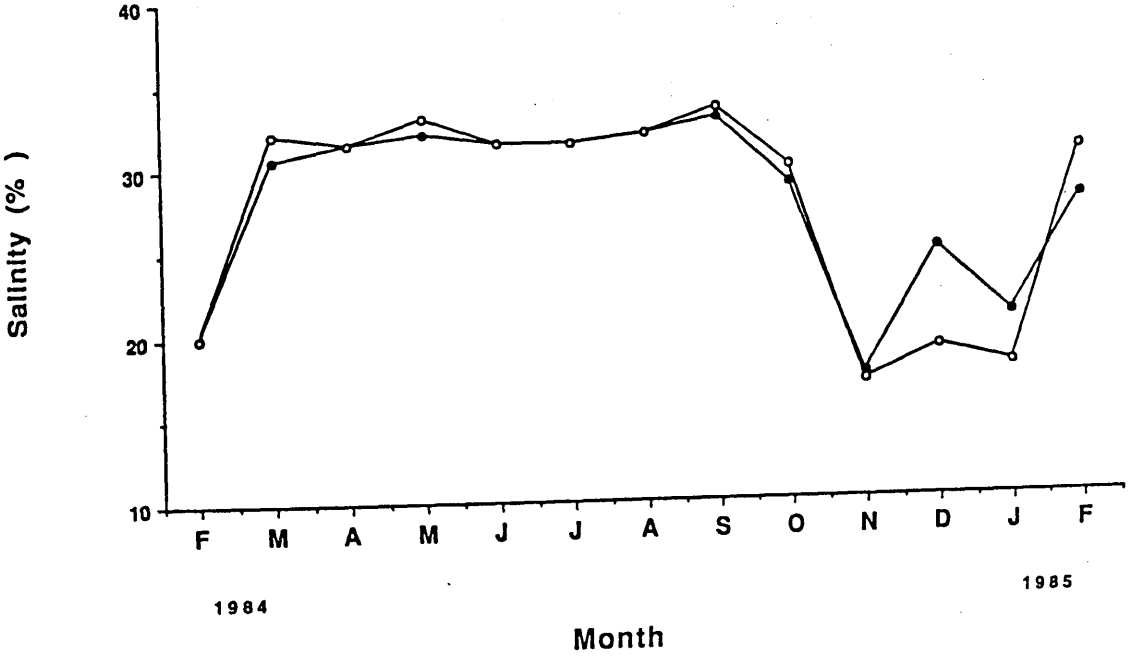


Figure (2.10)

Annual survey 1984-1985. Ardmore low tide area. Salinity (‰) of the overlying and interstitial water. Filled circles: salinity of the interstitial water; open circles: salinity of the overlying water. Each point represents the mean of the two replicate readings in table 2.10.

higher than the salinity in February 84. The reason for this difference is probably that in February 1984 the rainfall was 131mm but in February 1985 it was 40mm (see table 2.10).

Figure 2.10 also shows that the salinity of the overlying water and the interstitial water were similar to each other in all months except December 84, and January and February 85.

The salinity of the overlying and the interstitial water was plotted against the amount of the rainfall (mm) in figure 2.11. The figure shows that there was a good negative correlation between the salinity and the amount of the rainfall. The salinity data and the rainfall data was fed into a minitab computer program to calculate the regression line and the correlation coefficient. Four salinity readings of the overlying and interstitial water (taken from the replicate readings I and II of each water) were entered against just one reading of rainfall obtained for each month. The statistical calculation is given in the following table.

Regression equation: Y = -8.50 X + 337
Correlation coefficient = - 0.562 P<0.001

Source	Ss	Ms	Df	F. ratio	Probability
Regression	83912	83912	1	19.39	P<0.001
Error	181760	4328	42		
Total	265672		43		

This table shows that there was a good correlation between rainfall and salinity. In other words, increased rainfall has a highly significant effect in lowering the salinity of the overlying and interstitial water at Ardmore.

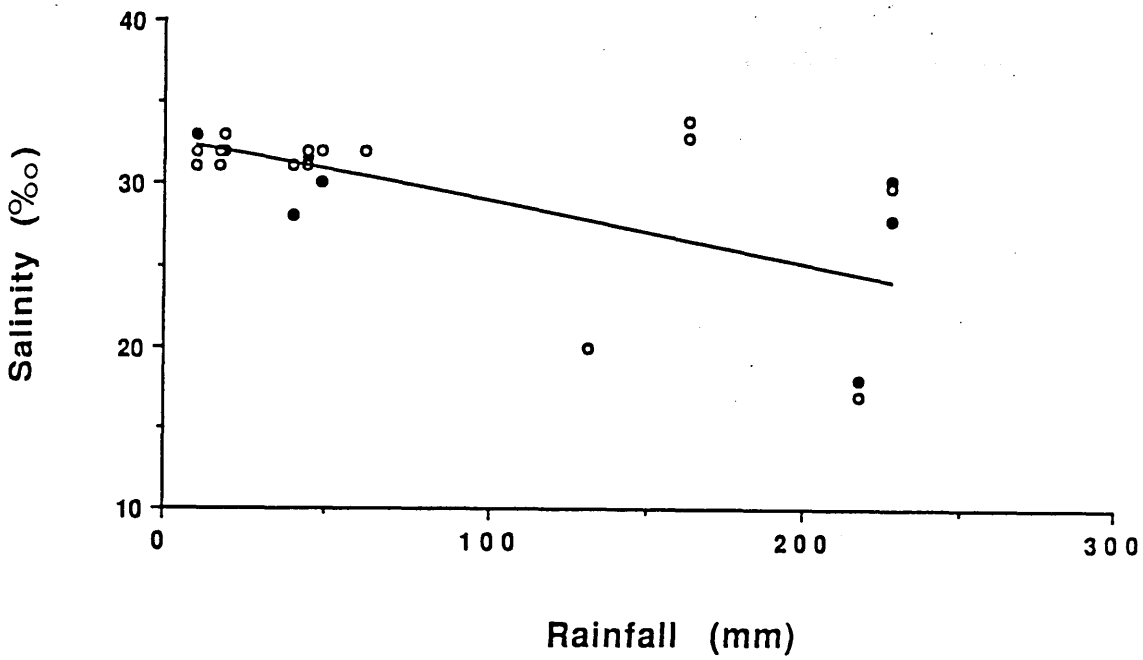


Figure (2.11)

Annual survey 1984-1985. Ardmore, low tide area. Relationship between rainfall and salinity of the overlying and interstitial water. Filled circles: relationship between rainfall and salinity of overlying water. Open circles: relationship between rainfall and salinity of interstitial water. Each point represents each replicate salinity reading in table 2.10 (y axis) with a single reading of rainfall (x axis)

3- Water content

The percentage water content of sediment determined at different depths of sediment in the survey is given in table 2.11. The table shows the means and standard deviations calculated from the replicate subsamples I, II and III of each depth during the survey. The table shows that the mean water content fluctuated between 22% and 30% i.e. about a quarter to a third of the weight of sediment in all samples.

4- Particles size distribution

The moment measurements: mean, standard deviation, skewness and kurtosis calculated from the sediment samples I and II of different depths throughout the survey were given in table 2.12.

Means and standard deviations

The mean of means and standard deviations of particles size were calculated and also expressed as a percentage compared with the mean of means and standard deviations of the 0-5cm depth of sediment (tables 2.13 and 2.14). The values of the mean of means and standard deviations of particle size were plotted against different depths of sediment for each month (figure 2.12). Tables 2.13 and 2.14 and figure 2.12 show that the mean particle size remained almost the same from the surface to a depth of 25cm for all months. Below 25cm the mean generally decreased. The standard deviations generally increased with depth.

The increases in mean particle size and standard deviation deeper in the sediment were clarified by plotting the mean of means standard deviations against depth as a percentage of their respective

Table (2.11)

The annual survey 1984-1985. Ardmore, low tide area. Percentage (%) water content.

Depth of sediment	Replicate subsamples	Month - 1984 Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	1985 Jan.	Feb.
0 - 5	I	23.89	23.39	24.37	23.00	24.16	24.69	25.37	23.98	27.09	24.90	23.89	24.76	24.27
	II	25.15	24.42	24.96	22.81	24.79	25.44	24.85	24.28	26.94	25.01	24.31	24.36	24.63
	III	24.74	25.75	24.81	24.16	24.69	25.29	25.03	24.67	26.97	24.85	23.40	24.94	24.74
Mean		24.59	24.52	24.71	23.32	24.55	25.14	25.08	24.31	27.00	24.92	23.87	24.69	24.54
Standard deviation		0.645	1.183	0.309	0.727	0.335	0.396	0.265	0.345	0.079	0.086	0.457	0.296	0.245
5 - 10	I	23.79	26.25	25.30	22.99	24.80	25.57	24.25	24.81	26.34	26.48	23.83	24.39	22.96
	II	22.09	25.44	25.48	25.48	24.13	25.01	24.72	25.10	26.77	26.36	22.65	24.12	23.99
	III	25.42	25.14	25.39	23.74	24.33	25.15	24.78	21.98	26.91	25.09	23.53	24.25	23.98
Mean		23.77	25.61	25.39	24.07	24.42	25.25	24.58	23.95	26.67	25.98	23.31	24.25	23.64
Standard deviation		1.665	0.574	0.009	1.277	0.344	0.293	0.289	1.724	0.297	0.771	0.664	0.136	0.594
10 - 15	I	28.50	24.06	25.25	25.15	24.54	24.58	25.61	25.92	26.39	25.64	24.23	24.40	24.18
	II	23.10	24.13	25.47	24.54	24.54	23.14	25.98	26.47	26.81	25.10	24.16	24.12	24.45
	III	24.18	24.51	24.80	25.11	24.73	24.24	25.37	25.95	26.75	26.76	23.92	24.23	24.46
Mean		25.26	24.24	25.17	24.93	24.61	23.99	25.65	26.12	26.65	25.83	24.10	24.25	24.78
Standard deviation		2.862	0.243	0.343	0.340	0.109	0.752	0.306	0.310	0.321	0.849	0.264	0.141	1.276
15 - 20	I	25.44	23.10	24.56	27.41	25.66	25.65	24.61	25.02	26.99	26.83	23.31	23.78	26.05
	II	26.10	22.63	23.95	25.65	25.24	25.39	24.92	24.16	27.70	24.60	22.79	25.93	24.79
	III	25.19	22.87	23.13	26.64	23.57	25.65	24.93	23.57	27.41	25.47	23.56	25.94	23.50
Mean		25.58	22.87	23.88	26.57	24.82	25.34	24.82	24.25	27.37	25.63	23.22	25.22	25.30
Standard deviation		0.471	0.233	0.714	0.882	1.108	0.336	0.178	0.729	0.357	1.128	0.392	1.243	0.771
20 - 25	I	24.45	25.54	25.64	25.33	26.19	25.78	24.57	26.34	26.88	25.36	24.76	25.97	25.93
	II	25.24	25.50	26.39	25.79	27.13	25.17	22.89	25.98	27.79	24.80	24.74	26.17	25.52
	III	27.00	23.83	24.85	26.46	26.27	25.77	26.01	25.80	26.58	25.15	25.41	26.27	24.44
Mean		25.56	24.96	25.63	25.86	26.53	25.58	24.49	26.04	27.08	25.10	24.97	26.14	25.09
Standard deviation		1.305	0.973	0.768	0.571	0.521	0.350	1.563	0.276	0.630	0.284	0.380	0.153	0.215

Cont... table (2.11)

Depth of sediment	Replicate subsamples	Month: Feb. (1984)	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan. (1985)	Feb.
25 - 30	I	33.70	24.71	26.37	25.69	23.64	25.01	25.78	23.84	27.46	26.92	24.56	24.50	25.03
	II	31.22	24.80	24.74	24.89	25.49	24.30	26.24	23.42	27.65	27.00	23.75	23.64	24.91
	III	23.29	25.26	23.95	25.03	24.87	26.36	24.98	24.09	26.87	27.43	24.80	26.27	25.32
Mean		29.40	24.93	25.02	25.20	24.67	25.22	25.67	23.79	27.33	27.12	24.37	24.81	25.62
Standard deviation		5.443	0.293	1.237	0.428	0.941	1.047	0.638	0.341	0.407	0.270	0.548	1.340	0.230
30 - 35	I	24.65	25.12	23.95	23.73	23.37	25.26	25.50	23.80	26.83	24.79	25.21	26.77	25.69
	II	24.66	24.82	25.05	24.22	24.77	25.33	24.19	23.11	27.09	25.66	25.49	25.55	25.36
	III	23.58	25.24	25.64	25.89	25.71	25.22	24.26	23.05	27.62	25.78	26.12	25.69	25.80
Mean		24.30	25.06	24.88	24.61	24.62	25.27	24.65	23.32	27.18	25.41	25.61	26.00	25.62
Standard deviation		0.619	0.213	0.856	1.131	1.176	0.055	0.736	0.416	0.403	0.543	0.457	0.665	0.230
35 - 40	I	22.96	22.08	23.83	24.80	22.93	23.67	25.96	23.53	28.12	25.50	24.12	27.52	24.71
	II	22.74	24.22	23.58	24.02	25.62	22.74	25.95	23.09	28.01	26.19	24.77	24.86	24.45
	III	22.31	24.21	22.24	24.81	25.52	21.64	26.25	20.59	28.37	27.57	24.76	25.54	23.85
Mean		22.67	23.50	23.22	24.54	24.69	22.69	26.05	22.40	28.17	26.42	24.55	25.97	24.33
Standard deviation		0.329	1.234	0.856	0.455	1.522	1.018	0.170	1.585	0.185	1.056	0.370	1.379	0.443
40 - 45	I	22.43	24.83	24.38	22.51	23.20	27.49	23.57	24.99	27.17	22.87	23.16	26.25	22.57
	II	21.87	26.83	25.84	23.11	25.38	24.99	19.52	24.55	26.24	25.34	23.13	25.45	23.84
	III	23.55	25.29	24.38	23.55	25.01	26.45	23.85	24.37	27.22	23.04	23.70	24.10	22.57
Mean		22.62	25.65	25.15	23.05	24.53	26.31	22.31	24.64	26.88	23.75	23.66	25.27	23.26
Standard deviation		0.851	1.047	0.730	0.524	1.166	1.255	2.424	0.321	0.552	1.382	0.567	1.085	0.642

Table (2.12)

Annual survey 1984-1985. Ardmore, low tide area. Particle size distribution (phi scale).

DEPTH OF SEDIMENT (cm)	MOMENT MEASUREMENTS	MONTH 1984 February I	February II	March I	March II	April I	April II	May I	May II	June I	June II	July I	July II	Augast I	Augast II
0-5	Mean	2.406	2.408	2.462	2.450	2.429	2.434	2.366	2.380	2.439	2.439	2.466	2.478	2.457	2.528
	Standard dev.	0.393	0.400	0.385	0.388	0.396	0.401	0.425	0.407	0.416	0.398	0.358	0.350	0.383	0.379
	Skewness	-0.668	-0.773	-0.401	-0.489	-0.444	-0.469	-0.581	-0.285	-0.338	-0.374	-0.356	-0.230	-0.395	-0.354
	Kurtosis	10.70	12.33	3.346	5.129	5.776	4.642	8.664	3.591	5.584	3.599	5.846	3.750	2.655	2.282
5-10	Mean	2.409	2.413	2.435	2.403	2.366	2.396	2.416	2.429	2.406	2.416	2.468	2.481	2.431	2.471
	Standard dev.	0.394	0.389	0.384	0.387	0.526	0.501	0.408	0.413	0.414	0.413	0.370	0.373	0.392	0.410
	Skewness	-0.628	-0.580	-0.408	-0.401	-1.553	-1.403	-0.342	-0.427	-0.480	-0.465	-0.279	-0.288	-0.366	-0.605
	Kurtosis	6.920	6.420	4.177	4.285	19.24	17.86	3.757	4.326	4.917	3.917	2.710	5.292	1.636	4.920
10-15	Mean	2.454	2.452	2.429	2.432	2.422	2.413	2.372	2.476	2.419	2.418	2.445	2.451	2.479	2.493
	Standard dev.	0.398	0.399	0.400	0.425	0.400	0.410	0.386	0.417	0.408	0.412	0.385	0.394	0.400	0.399
	Skewness	-0.383	-0.377	-0.513	-0.949	-0.416	-0.459	-0.184	-0.311	-0.439	-0.528	-0.375	-0.387	-0.396	-0.374
	Kurtosis	3.230	2.793	5.511	13.14	3.277	3.826	4.129	3.459	4.362	5.882	2.651	6.644	2.111	1.949
15-20	Mean	2.428	2.438	2.371	2.371	2.403	2.405	2.469	2.485	2.393	2.411	2.420	2.438	2.488	2.502
	Standard dev.	0.402	0.402	0.433	0.442	0.417	0.413	0.414	0.422	0.447	0.474	0.423	0.420	0.407	0.409
	Skewness	-0.445	-0.437	-0.710	-0.592	-0.402	-0.376	-0.389	-0.416	-0.777	-1.025	-0.474	-0.487	-0.513	-0.382
	Kurtosis	2.663	2.552	7.698	4.190	3.478	3.432	4.446	4.554	9.083	12.42	3.406	3.954	3.530	2.508
20-25	Mean	2.393	2.392	2.396	2.362	2.348	2.377	2.481	2.522	2.418	2.410	2.425	2.424	2.438	2.428
	Standard dev.	0.421	0.439	0.429	0.429	0.481	0.498	0.449	0.440	0.450	0.556	0.434	0.434	0.475	0.461
	Skewness	-0.670	-0.643	-0.523	-0.536	-1.118	-1.080	-0.927	-0.807	-0.668	-1.402	-0.496	-0.476	-0.895	-0.687
	Kurtosis	6.558	6.578	4.041	4.659	13.68	12.20	13.00	9.496	6.701	15.27	3.780	3.698	9.220	5.710
25-30	Mean	2.385	2.388	2.266	2.275	2.367	2.358	2.428	2.424	2.374	2.404	2.350	2.396	2.355	2.485
	Standard dev.	0.441	0.455	0.557	0.616	0.473	0.501	0.472	0.518	0.560	0.509	0.460	0.447	0.590	0.491
	Skewness	-0.535	-0.539	-1.133	-1.408	-0.738	-0.533	-0.682	-1.071	-0.953	-0.711	-0.587	-0.557	-1.291	-0.964
	Kurtosis	3.945	4.264	10.37	12.94	6.702	6.102	6.814	11.45	8.238	5.256	2.765	2.895	12.12	11.02
30-35	Mean	2.273	2.269	1.954	1.977	2.254	2.253	2.377	2.349	2.301	2.305	2.262	2.329	2.377	2.385
	Standard dev.	0.551	0.555	0.955	0.805	0.605	0.649	0.529	0.641	0.635	0.636	0.585	0.515	0.500	0.530
	Skewness	-0.876	-0.862	-0.999	-0.883	-0.894	-0.967	-0.976	-1.379	-0.798	-0.918	-1.126	-0.887	-0.602	-0.782
	Kurtosis	6.897	6.579	4.057	4.181	6.081	6.649	9.281	12.49	4.837	6.209	8.803	3.822	2.905	5.334
35-40	Mean	1.968	1.976	1.820	1.788	1.723	1.734	2.196	2.242	1.978	2.019	1.875	1.879	2.151	2.278
	Standard dev.	0.790	0.787	1.052	1.105	1.012	1.001	0.741	0.723	0.915	0.887	0.961	0.942	0.763	0.683
	Skewness	-0.873	-0.862	-0.833	-0.824	-0.445	-0.439	-1.162	-1.122	-0.606	-0.633	-0.589	-0.577	-1.002	-1.049
	Kurtosis	4.538	4.522	2.436	2.078	3.049	3.055	7.835	7.574	1.336	1.698	0.793	0.793	5.672	7.172
40-45	Mean	2.049	2.045	2.130	2.115	2.082	2.074	2.105	2.072	1.996	1.910	1.908	1.992	1.671	1.670
	Standard dev.	0.819	0.820	0.548	0.585	0.785	0.762	0.743	0.745	0.961	1.010	0.880	0.883	1.143	1.211
	Skewness	-0.959	-0.967	-0.811	-1.005	-1.004	-0.985	-0.818	-0.880	-0.523	-0.491	-0.792	-0.873	-0.536	-0.575
	Kurtosis	5.460	5.427	8.337	10.01	5.906	6.043	4.378	4.573	1.232	0.759	2.711	3.783	0.356	0.389

Cont... table (2.12)

DEPTH OF SEDIMENT (CM)	MOMENT MEASUREMENTS	Month											
		September		October		November		December		1985 January		February	
		I	II	I	II	I	II	I	II	I	II	I	II
0-5	Mean	2.433	2.491	2.501	2.481	2.501	2.488	2.477	2.467	2.475	2.463	2.497	2.480
	Standard dev.	0.385	0.375	0.368	0.367	0.351	0.354	0.383	0.396	0.373	0.373	0.364	0.369
	Skewness	-0.341	-0.321	-0.256	-0.338	-0.263	-0.304	-0.356	-0.387	-0.336	-0.368	-0.310	-0.327
	Kurtosis	1.935	1.912	2.308	2.083	1.133	1.183	2.019	2.468	1.978	1.812	2.258	1.848
5-10	Mean	2.430	2.462	2.471	2.439	2.440	2.450	2.444	2.467	2.417	2.415	2.449	2.462
	Standard dev.	0.408	0.398	0.400	0.411	0.391	0.390	0.427	0.421	0.402	0.421	0.399	0.391
	Skewness	-0.445	-0.399	-0.602	-0.637	-0.425	-0.413	-0.510	-0.519	-0.468	-0.785	-0.493	-0.550
	Kurtosis	2.314	2.279	4.856	4.664	2.304	2.368	2.570	3.049	2.517	8.007	2.799	3.243
10-15	Mean	2.439	2.455	2.415	2.438	2.471	2.437	2.464	2.485	2.421	2.431	2.439	2.436
	Standard dev.	0.403	0.408	0.493	0.415	0.378	0.390	0.432	0.418	0.406	0.419	0.413	0.397
	Skewness	-0.439	-0.451	-1.159	-0.574	-0.419	-0.457	-0.572	-0.540	-0.464	-0.286	-0.528	-0.436
	Kurtosis	2.136	2.583	11.45	3.629	2.415	2.270	3.464	3.492	2.162	3.599	2.921	1.372
15-20	Mean	2.452	2.497	2.419	2.403	2.435	2.424	2.488	2.470	2.451	2.422	2.428	2.448
	Standard dev.	0.420	0.424	0.481	0.435	0.413	0.457	0.439	0.448	0.401	0.414	0.428	0.462
	Skewness	-0.446	-0.441	-1.117	-0.573	-0.472	-1.083	-0.557	-0.587	-0.481	-0.475	-0.424	-0.383
	Kurtosis	2.066	2.698	10.88	2.879	2.562	13.00	3.021	3.029	2.201	2.209	1.973	5.247
20-25	Mean	2.463	2.462	2.378	2.383	2.407	2.362	2.450	2.370	2.434	2.463	2.466	2.436
	Standard dev.	0.450	0.452	0.516	0.447	0.449	0.473	0.469	0.546	0.432	0.415	0.437	0.462
	Skewness	-0.550	-0.566	-1.121	-0.511	-0.634	-0.615	-0.696	-0.542	-0.530	-0.511	-0.531	-0.554
	Kurtosis	3.221	3.186	10.97	2.329	3.393	3.188	4.098	1.509	2.736	2.733	2.849	2.353
25-30	Mean	2.416	2.448	2.421	2.385	2.372	2.360	2.387	2.402	2.414	2.415	2.448	2.416
	Standard dev.	0.537	0.506	0.442	0.488	0.540	0.567	0.537	0.520	0.420	0.424	0.498	0.556
	Skewness	-0.685	-0.890	-0.554	-0.768	-1.192	-1.294	-0.753	-0.662	-0.474	-0.486	-1.160	-1.452
	Kurtosis	3.222	7.179	3.183	5.480	11.24	12.43	4.330	2.838	2.138	2.120	13.33	18.81
30-35	Mean	2.373	2.372	2.410	2.373	2.274	2.325	2.354	2.367	2.352	2.323	2.412	2.420
	Standard dev.	0.531	0.684	0.447	0.505	0.562	0.549	0.562	0.547	0.709	0.739	0.490	0.485
	Skewness	-0.642	-1.272	-0.678	-0.798	-0.792	-0.786	-0.783	-0.773	-1.553	-1.834	-0.727	-0.871
	Kurtosis	2.760	10.29	4.961	5.874	4.812	5.314	3.492	4.376	13.03	12.09	5.199	4.939
35-40	Mean	2.271	2.303	2.049	2.160	1.991	1.986	2.257	2.216	2.283	2.261	2.199	2.122
	Standard dev.	0.605	0.587	0.866	0.736	0.781	0.812	0.651	0.748	0.626	0.677	0.736	0.801
	Skewness	-0.653	-0.680	-0.974	-0.941	-0.470	-0.580	-0.935	-1.106	-1.005	-0.884	-0.961	-1.049
	Kurtosis	2.393	2.921	4.358	4.744	0.722	1.440	5.826	7.001	7.045	2.773	5.398	5.239
40-45	Mean	2.011	2.025	2.030	1.932	1.752	1.726	2.159	2.149	1.879	1.896	1.799	1.792
	Standard dev.	1.070	1.102	0.783	0.868	1.045	1.044	0.774	0.794	0.986	0.983	1.137	1.256
	Skewness	-0.256	-0.282	-0.885	-0.827	-0.654	-0.636	-0.685	-0.728	-0.699	-0.688	-0.621	-0.659
	Kurtosis	0.622	0.767	4.533	3.336	1.174	1.009	2.646	2.770	1.771	1.732	0.682	0.843

Table (2.13)

Annual survey 1984-1985. Ardmore, low tide area. Mean particle size.

Mean = mean of two replicate means. % = mean as a percentage of the 0-5cm depth mean for each month.

Depth of sediment (cm)		month - 1984 Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	1985 Jan.	Feb.
0-5	Mean	2.407	2.456	2.432	2.373	2.439	2.472	2.493	2.492	2.491	2.495	2.472	2.469	2.489
	%	100	100	100	100	100	100	100	100	100	100	100	100	100
5-10	Mean	2.411	2.419	2.381	2.423	2.411	2.475	2.451	2.446	2.455	2.455	2.456	2.416	2.456
	%	100.2	98.49	97.90	102.1	98.85	100.1	98.32	99.35	98.56	98.40	99.33	97.85	98.65
10-15	Mean	2.453	2.431	2.418	2.424	2.419	2.448	2.486	2.447	2.427	2.427	2.475	2.426	2.438
	%	100.9	98.69	99.42	102.2	99.16	99.03	99.72	99.39	97.41	97.25	100.1	98.26	97.93
15-20	Mean	2.433	2.371	2.404	2.477	2.402	2.429	2.495	2.475	2.411	2.419	2.479	2.449	2.438
	%	101.8	96.54	98.85	104.4	98.48	98.26	100.1	100.5	96.79	96.95	100.3	99.17	97.95
20-25	Mean	2.393	2.379	2.363	2.502	2.414	2.425	2.433	2.463	2.381	2.385	2.410	2.449	2.436
	%	99.40	96.87	97.14	105.4	98.98	98.04	97.59	100	95.56	95.57	97.49	99.17	97.87
25-30	Mean	2.387	2.271	2.363	2.426	2.389	2.373	2.420	2.432	2.403	2.366	2.395	2.415	2.432
	%	99.15	92.45	97.14	102.2	97.95	96.00	97.07	98.78	96.47	94.83	96.87	97.79	97.71
30-35	Mean	2.271	1.966	2.254	2.363	2.303	2.396	2.381	2.373	2.392	2.300	2.361	2.338	2.416
	%	94.35	80.00	92.66	99.58	94.42	92.86	95.51	96.37	96.01	92.16	65.49	94.67	97.07
35-40	Mean	1.972	1.804	1.729	2.219	1.999	1.877	2.215	2.287	2.075	1.989	2.237	2.272	2.161
	%	81.19	73.45	71.07	93.51	81.94	75.93	88.83	92.89	83.30	79.70	90.47	92.02	86.80
40-45	Mean	2.047	2.123	2.078	2.089	1.953	1.950	1.671	2.018	1.842	1.739	2.154	1.888	1.796
	%	85.04	86.42	85.44	88.01	80.07	78.88	67.08	81.97	73.95	69.70	87.14	76.45	72.14

Table (2.14)

Annual survey 1984-1985. Ardmore, low tide area. Standard deviation of particle sizes.

Mean = mean of two replicate of standard deviations. % = mean as a percentage of the 0-5cm depth mean for each month.

Depth of sediment (cm)		month - 1984 Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan. 1985	Feb.
0-5	Mean	0.397	0.387	0.399	0.373	0.407	0.354	0.381	0.380	0.368	0.353	0.390	0.373	0.367
	%	100	100	100	100	100	100	100	100	100	100	100	100	100
5-10	Mean	0.392	0.386	0.514	0.411	0.414	0.372	0.401	0.403	0.406	0.391	0.424	0.412	0.395
	%	98.62	99.61	128.7	110.1	101.6	104.9	105.3	106.1	110.2	110.6	108.7	110.3	107.6
10-15	Mean	0.399	0.413	0.405	0.402	0.410	0.390	0.400	0.406	0.454	0.384	0.425	0.413	0.405
	%	100.4	106.6	101.5	107.6	100.7	110.0	104.9	106.7	123.4	108.8	109.0	110.6	110.4
15-20	Mean	0.402	0.438	0.415	0.418	0.461	0.422	0.408	0.422	0.458	0.435	0.444	0.408	0.445
	%	101.3	113.1	104.0	112.1	113.2	119.1	107.1	111.1	124.5	123.2	113.7	109.3	121.3
20-25	Mean	0.430	0.429	0.490	0.445	0.503	0.434	0.468	0.451	0.482	0.461	0.508	0.424	0.450
	%	108.3	110.9	122.7	119.2	123.6	122.6	122.8	118.7	130.8	130.6	130.1	113.5	122.5
25-30	Mean	0.448	0.587	0.487	0.495	0.535	0.454	0.541	0.522	0.465	0.554	0.529	0.422	0.527
	%	112.9	151.6	122.1	132.7	131.3	128.1	141.9	137.2	126.4	156.8	135.5	113.1	143.6
30-35	Mean	0.553	0.880	0.627	0.585	0.636	0.550	0.515	0.608	0.476	0.556	0.555	0.724	0.488
	%	139.3	227.4	157.1	156.8	156.1	155.4	135.2	159.9	129.4	157.4	142.2	194.1	132.8
35-40	Mean	0.789	1.079	1.007	0.732	0.901	0.952	0.723	0.596	0.801	0.797	0.700	0.602	0.819
	%	198.6	278.7	252.3	196.3	221.4	268.8	189.8	156.8	217.7	225.6	179.4	161.3	223.0
40-45	Mean	0.820	0.567	0.774	0.744	0.986	0.882	1.177	1.086	0.826	1.045	0.784	0.985	1.197
	%	206.4	146.4	193.9	199.5	242.1	249.0	308.9	285.8	224.3	295.9	201.0	263.9	326.0

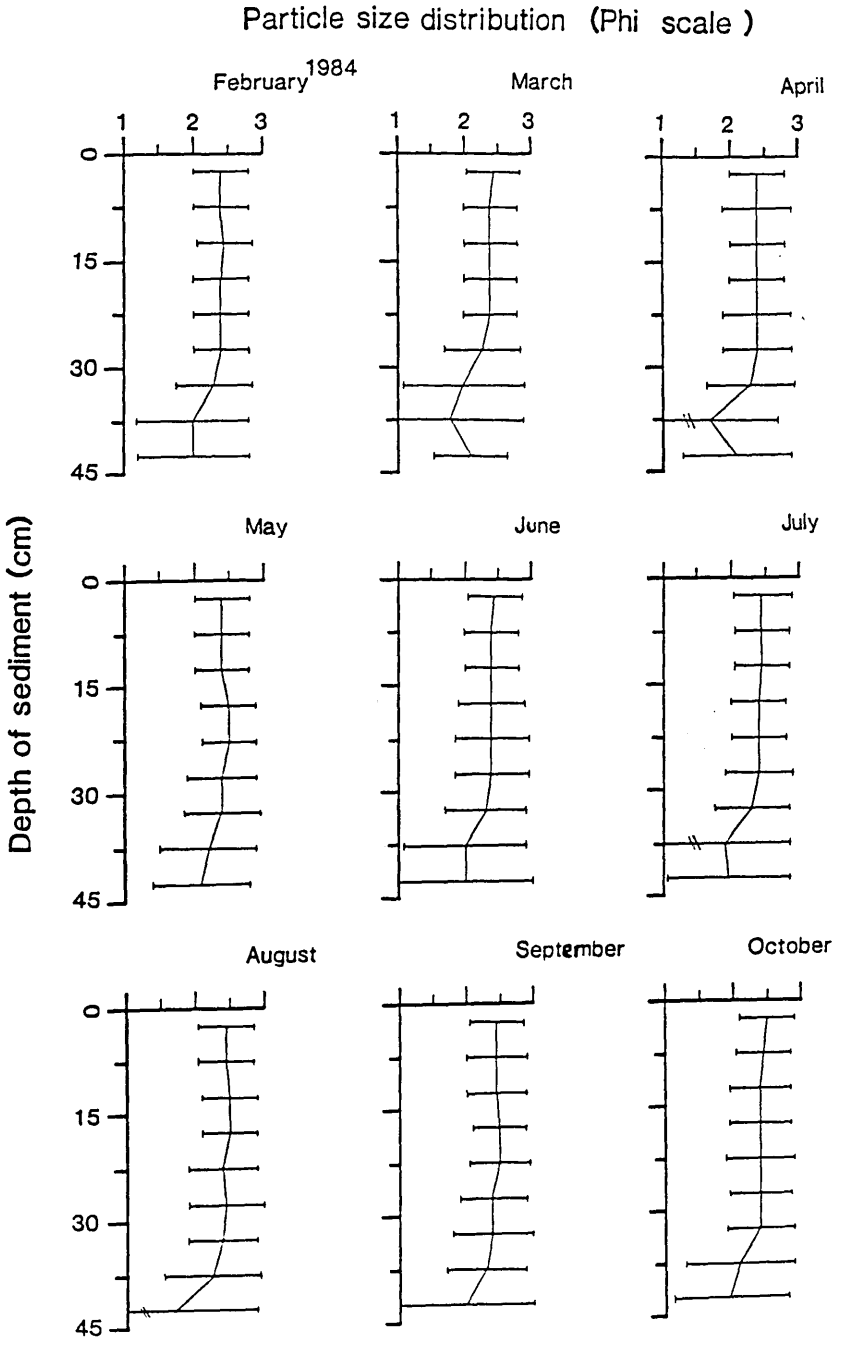
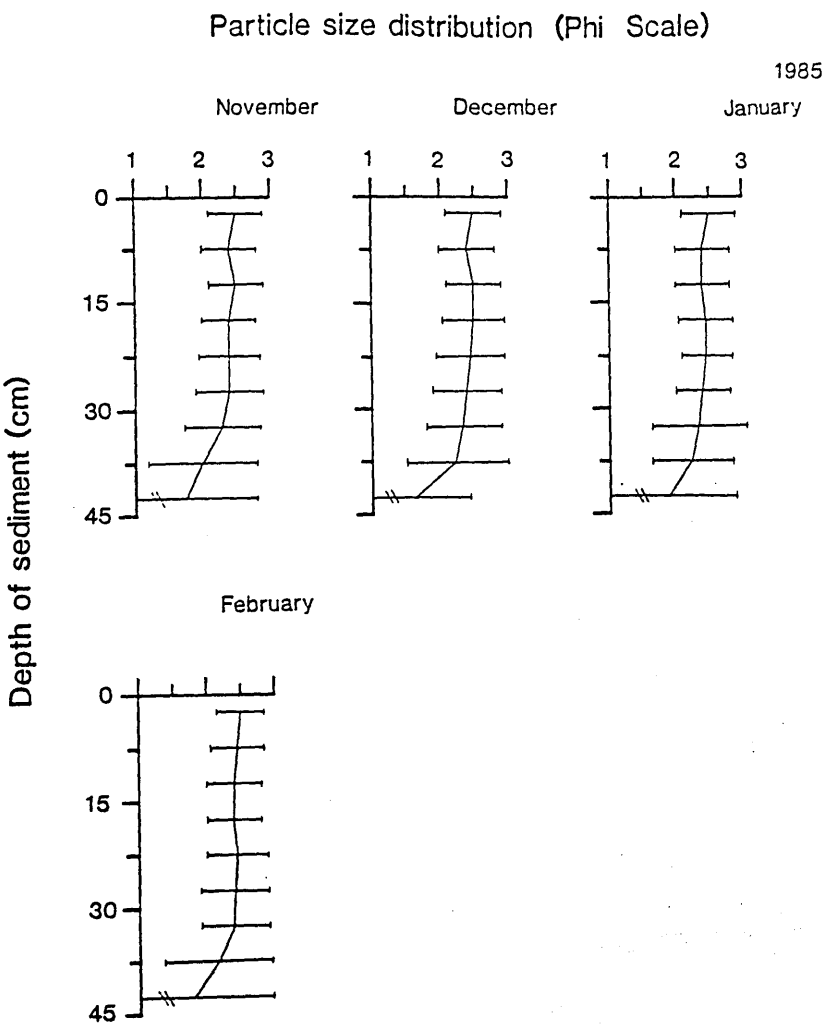


Figure (2.12)

Annual survey 1984-1985. Ardmore, low tide area. Means of the means and standard deviations of particle size of the different depths of sediment calculated in each month of the survey. The line joins the means of particle size, horizontal bars show the standard deviations of particle size. Each mean is calculated from the two replicate readings in table 2.11.



Cont. figure (2.12)

surface values (figure 2.13). The figure shows that the means remained the same until a depth of 30cm and then decreased. The standard deviations slowly increased from the surface to depth of 30cm and then increased more quickly.

Skewness and kurtosis

Table 2.12 shows that the skewness value for all samples was negative. This means that the curve departed from normality towards the left as follows. The tail of the curve was extended towards the left of the x axis where the negative phi values are (large particle sizes). The peak of the curve was towards the right of the curve where the positive phi values are (small particle sizes).

The kurtosis values were all positive, showing that most of the particles were very near the mean.

Inspection of the data in table 2.12 suggested that skewness and kurtosis were negatively correlated. To test this hypothesis the observed values of skewness were plotted against the observed values of kurtosis (figure 2.14). The figure shows that there was a strong negative correlation between the skewness and kurtosis which is given in the following table using the minitab statistical computer program.

Regression equation: Y = - 0.350 -0.0643 X
Correlation coefficient= -0.787 P<0.001

Source	Ss	Ms	Df	F. ratio	Probability
Regression	11.928	11.928	1	376.46	P<0.001
Error	7.351	0.032	232		
Total	19.278		233		

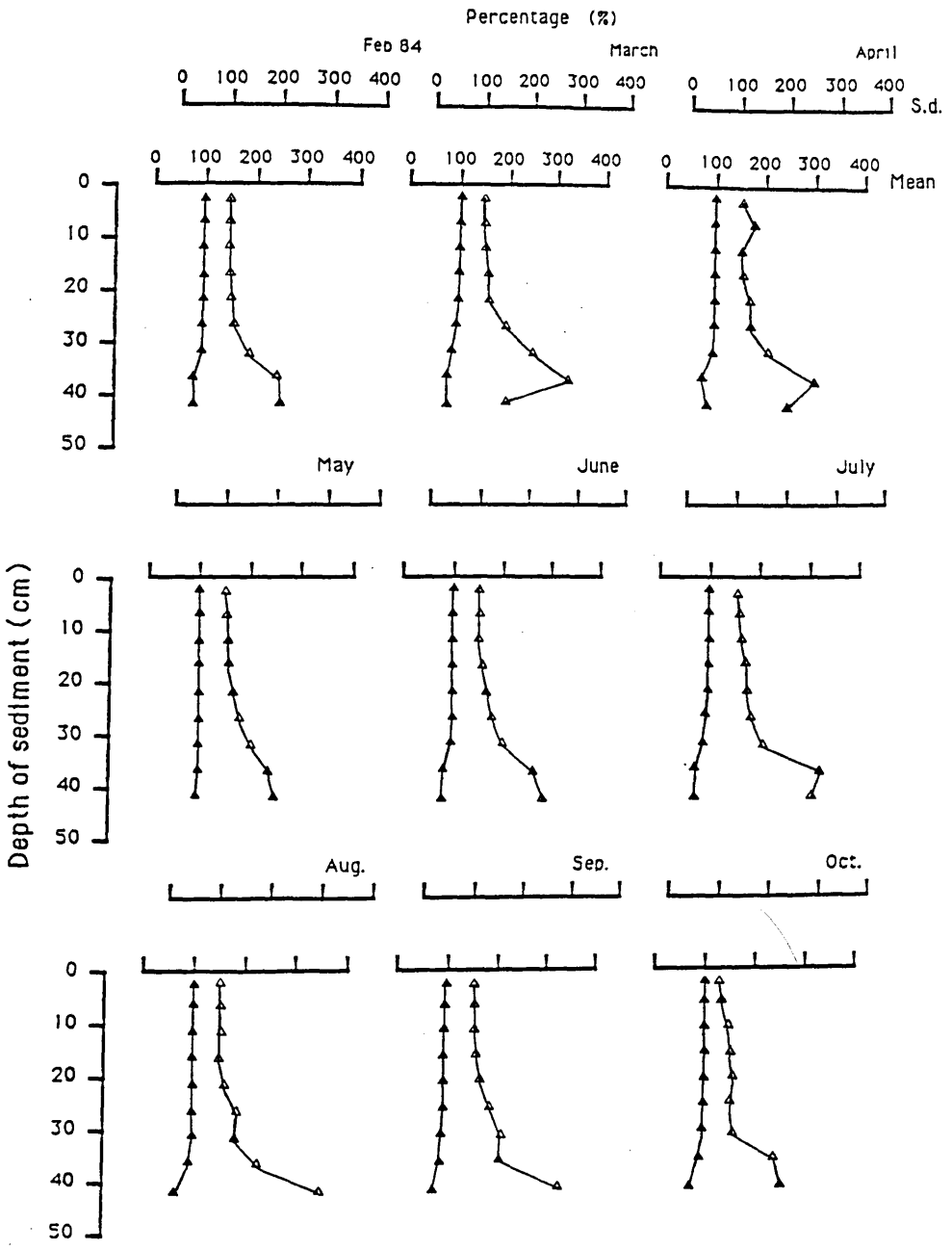
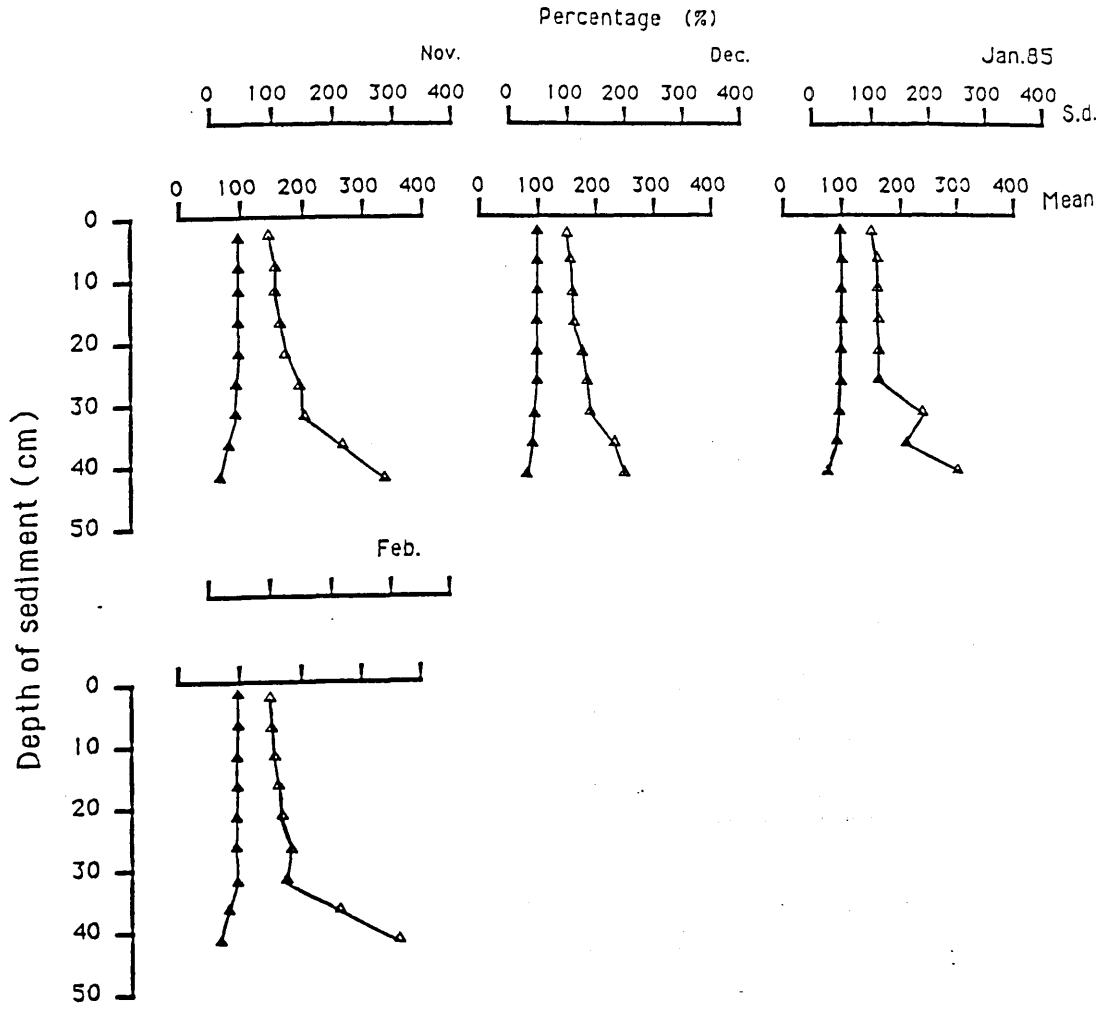


Figure (2.13)

Annual survey 1984-1985. Ardmore, low tide area. Percentage of means and standard deviations of particle size for different depths of sediment. The filled triangles gave the mean of the particle size means of two replicates and the open triangles show the mean of the particle size standard deviations of two replicates.



Cont. figure (2.13)

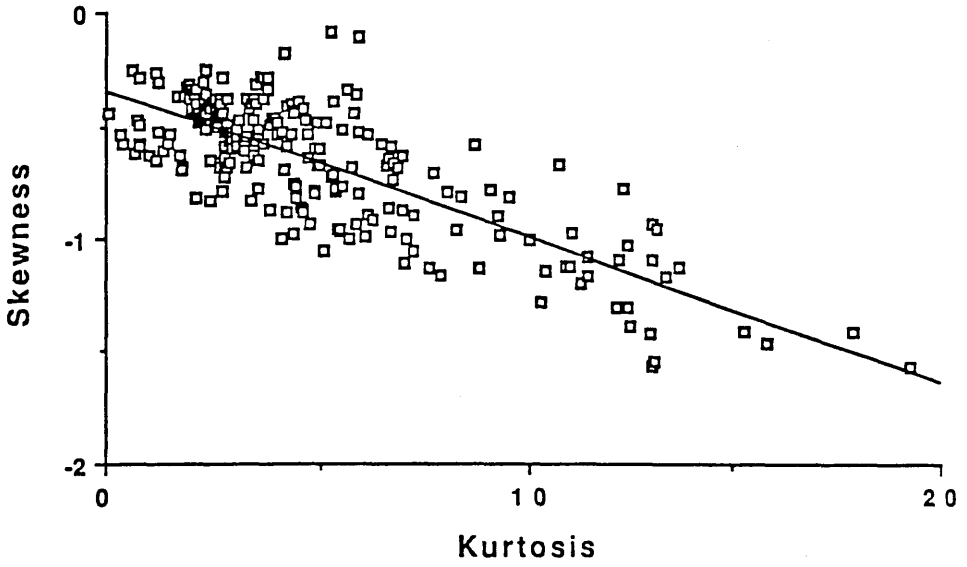


Figure (2.14)

Annual survey 1984-1985. Ardmore, low tide area. Relationship between the skewness and kurtosis of particle size distribution. Details of the regression line and the correlation coefficient are shown in the results part of this chapter.

This means that as the curve of the particle size become more skewed i.e. with a longer tail towards the left (large particles), the peak of the curve (kurtosis) becomes more closely packed around the finer particles at the right of the curve.

5- Organic carbon

The organic carbon content (mg C $.g^{-1}$) of the two replicates (subsamples I and II) are given in table 2.15. The means and standard deviations of the organic carbon were calculated and are shown in the same table. The mean and standard deviation were plotted against depths for each month (figure 2.15), and also in the form of histograms for each depth throughout the survey (figure 2.16). The table and figures show that organic carbon is low, being approximately 0.01-0.015% at all depths of sediment. This means that the sediment at low tide area is relatively clean and does not contain high levels of organic matter. Organic carbon increases at 40-45cm in September 1984 to approximately 0.044%. This may be because there was more detritus at that depth.

6- Specific gravity

The specific gravity of the sediment of the three replicates (subsamples I, II and III) is shown in table 2.16. The mean and standard deviations are also given. The results show that there was no difference in specific gravity between different depths throughout the survey. The specific gravity is always about 2.66, indicating that the sediment is quartz (BS1377, 1975; CRC, Handbook of chemistry and physics, 59th edition, 1978-1989, B224).

Table (2.15)

Annual survey 1984-1985. Ardmore, low tide area. Organic carbon (mg C. g^{-1} of dry sediment).

I and II: replicate subsamples.

Depth of	1984						Month							
sediment	February		March		April		May		June		July		August	
(cm)	I	II	I	II	I	II	I	II	I	II	I	II	I	II
0 - 5	1.045	1.030	1.120	1.101	1.051	1.081	0.911	0.933	1.040	1.072	1.026	1.089	1.094	1.100
Mean ± s.d.	1.037 ± 0.010		1.111 ± 0.013		1.066 ± 0.022		0.922 ± 0.016		1.056 ± 0.023		1.057 ± 0.044		1.097 ± 0.004	
5 - 10	0.991	1.039	1.149	1.119	1.036	1.037	0.958	0.988	1.081	1.092	0.991	0.965	1.031	1.081
Mean ± s.d.	1.015 ± 0.034		1.134 ± 0.022		1.036 ± 0.001		0.973 ± 0.021		1.086 ± 0.007		0.978 ± 0.018		1.056 ± 0.036	
10 - 15	1.101	1.102	1.283	1.096	1.072	1.055	0.988	0.981	1.090	1.175	1.009	0.943	1.079	1.1089
Mean ± s.d.	1.101 ± 0.001		1.190 ± 0.132		1.064 ± 0.012		0.985 ± 0.005		1.132 ± 0.060		0.976 ± 0.047		1.093 ± 0.020	
15 - 20	1.134	1.036	1.049	1.087	1.021	1.038	1.122	1.113	0.990	1.077	0.991	1.041	1.105	1.214
Mean ± s.d.	1.085 ± 0.069		1.068 ± 0.027		1.029 ± 0.012		1.117 ± 0.606		1.034 ± 0.062		1.016 ± 0.053		1.160 ± 0.077	
20 - 25	1.069	1.106	1.083	1.102	1.058	1.059	1.128	1.110	1.186	1.200	0.986	0.982	1.144	1.166
Mean ± s.d.	1.087 ± 0.027		1.092 ± 0.014		1.058 ± 0.001		1.119 ± 0.013		1.193 ± 0.010		0.994 ± 0.003		1.155 ± 0.016	
25 - 30	1.112	1.107	1.106	1.148	1.024	1.004	1.108	1.152	1.206	1.211	0.945	0.999	1.094	1.097
Mean ± s.d.	1.110 ± 0.004		1.127 ± 0.030		1.014 ± 0.014		1.130 ± 0.031		1.209 ± 0.004		0.972 ± 0.038		1.096 ± 0.002	
30 - 35	1.212	1.160	1.264	1.175	1.009	1.053	1.060	1.124	1.224	1.248	1.026	1.089	1.067	1.042
Mean ± s.d.	1.186 ± 0.036		1.220 ± 0.062		1.031 ± 0.031		1.092 ± 0.046		1.236 ± 0.017		1.057 ± 0.044		1.054 ± 0.017	
35 - 40	1.228	1.349	1.279	1.235	1.279	1.225	1.088	1.175	1.590	1.571	1.145	1.122	1.067	1.194
Mean ± s.d.	1.288 ± 0.085		1.257 ± 0.031		1.252 ± 0.038		1.132 ± 0.061		1.581 ± 0.013		1.133 ± 0.016		1.130 ± 0.090	
40 - 45	0.959	0.997	1.146	1.178	0.888	0.946	1.086	1.124	1.923	1.991	1.039	1.100	1.289	1.359
Mean ± s.d.	0.978 ± 0.027		1.162 ± 0.023		0.917 ± 0.040		1.105 ± 0.027		1.957 ± 0.048		1.070 ± 0.043		1.324 ± 0.050	

Cont... table (2.15)

Depth of sediment (cm)	Month 1985 September I	September II	October I	October II	November I	November II	December I	December II	January I	January II	February I	February II
0 - 5	1.042	1.110	0.954	0.927	0.964	0.830	0.971	0.940	1.048	1.057	0.979	0.972
Mean q s.d.	1.076 q 0.048		0.941 ± 0.019		0.897 ± 0.095		0.955 ± 0.022		1.053 ± 0.006		0.975 ± 0.005	
5 - 10	1.051	1.055	0.968	0.909	0.845	0.890	0.980	0.963	1.001	1.024	0.934	0.962
Mean q s.d.	1.053 q 0.003		0.938 ± 0.042		0.867 ± 0.032		0.972 ± 0.012		1.013 ± 0.016		0.948 ± 0.020	
10 - 15	0.991	1.059	0.944	1.013	0.872	0.916	1.027	1.042	0.982	0.951	0.942	0.963
Mean q s.d.	1.025 q 0.048		0.978 ± 0.049		0.894 ± 0.031		1.034 ± 0.011		0.966 ± 0.022		0.953 ± 0.015	
15 - 20	1.095	1.124	0.976	0.981	0.913	0.907	1.027	0.997	1.036	1.059	0.997	0.987
Mean q s.d.	1.109 q 0.020		0.979 ± 0.004		0.910 ± 0.004		1.012 ± 0.021		1.047 ± 0.017		0.992 ± 0.008	
20 - 25	1.113	1.154	1.044	1.030	0.940	0.969	1.057	1.080	1.104	1.231	1.052	1.082
Mean q s.d.	1.133 q 0.029		1.037 ± 0.010		0.955 ± 0.020		1.069 ± 0.016		1.167 ± 0.090		1.067 ± 0.021	
25 - 30	1.257	1.175	0.995	1.034	0.958	1.033	1.100	1.084	1.116	1.136	1.054	1.090
Mean q s.d.	1.216 q 0.058		1.015 ± 0.027		0.996 ± 0.053		1.092 ± 0.012		1.126 ± 0.014		1.072 ± 0.025	
30 - 35	1.167	1.117	0.986	1.010	0.899	0.932	1.050	1.077	1.088	1.111	1.083	1.122
Mean q s.d.	1.142 q 0.036		0.998 ± 0.017		0.915 ± 0.023		1.064 ± 0.019		1.100 ± 0.016		1.103 ± 0.028	
35 - 40	1.125	1.181	1.035	1.021	1.106	1.182	1.036	1.028	1.194	1.192	1.116	1.111
Mean q s.d.	1.153 q 0.040		1.028 ± 0.010		1.144 ± 0.054		1.032 ± 0.006		1.193 ± 0.001		1.114 ± 0.003	
40 - 45	4.605	4.167	1.033	1.038	1.065	1.093	1.218	1.201	1.077	1.158	1.372	1.190
Mean q s.d.	4.386 q 0.310		1.036 ± 0.004		1.079 ± 0.020		1.209 ± 0.012		1.117 ± 0.057		1.281 ± 0.129	

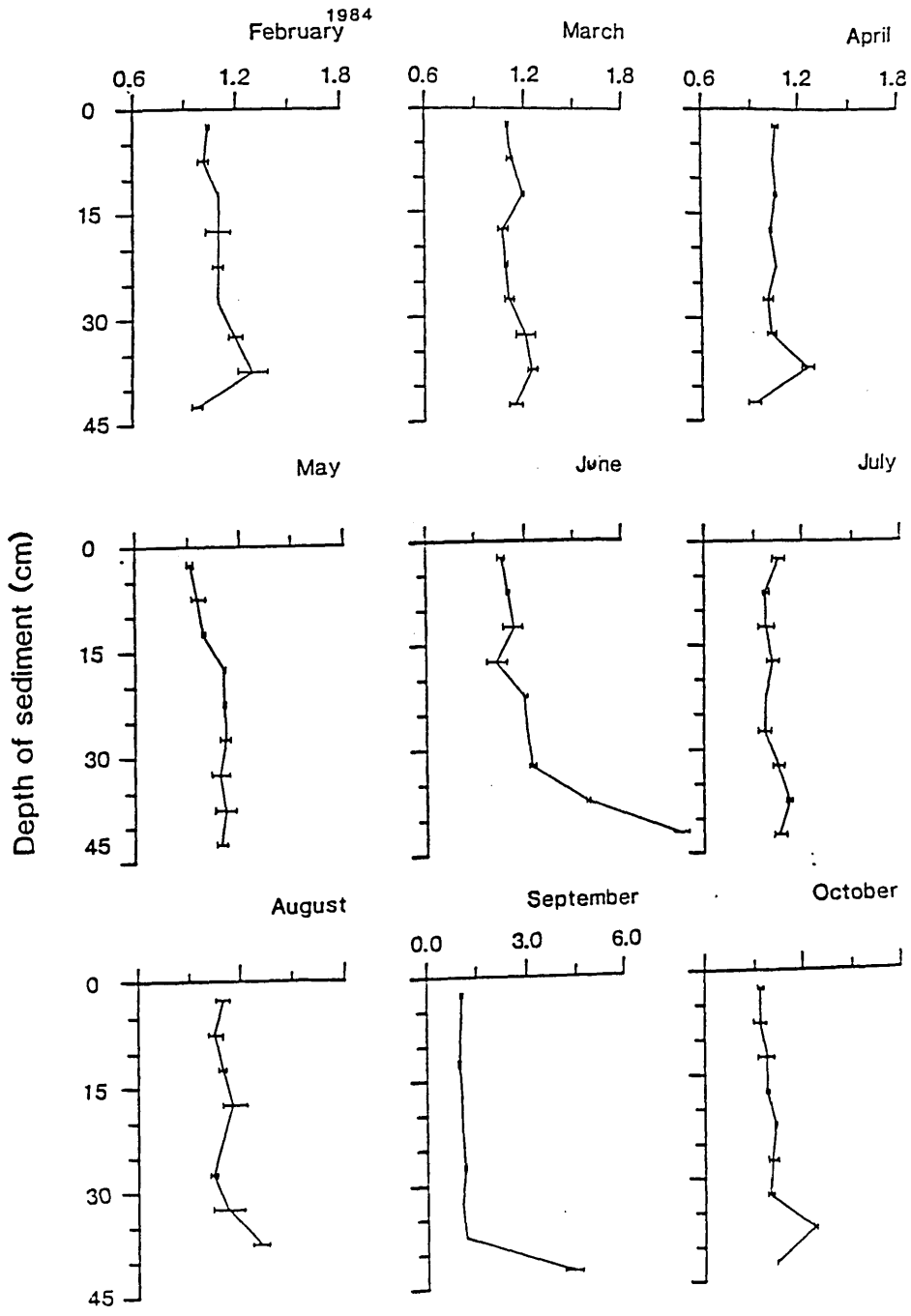
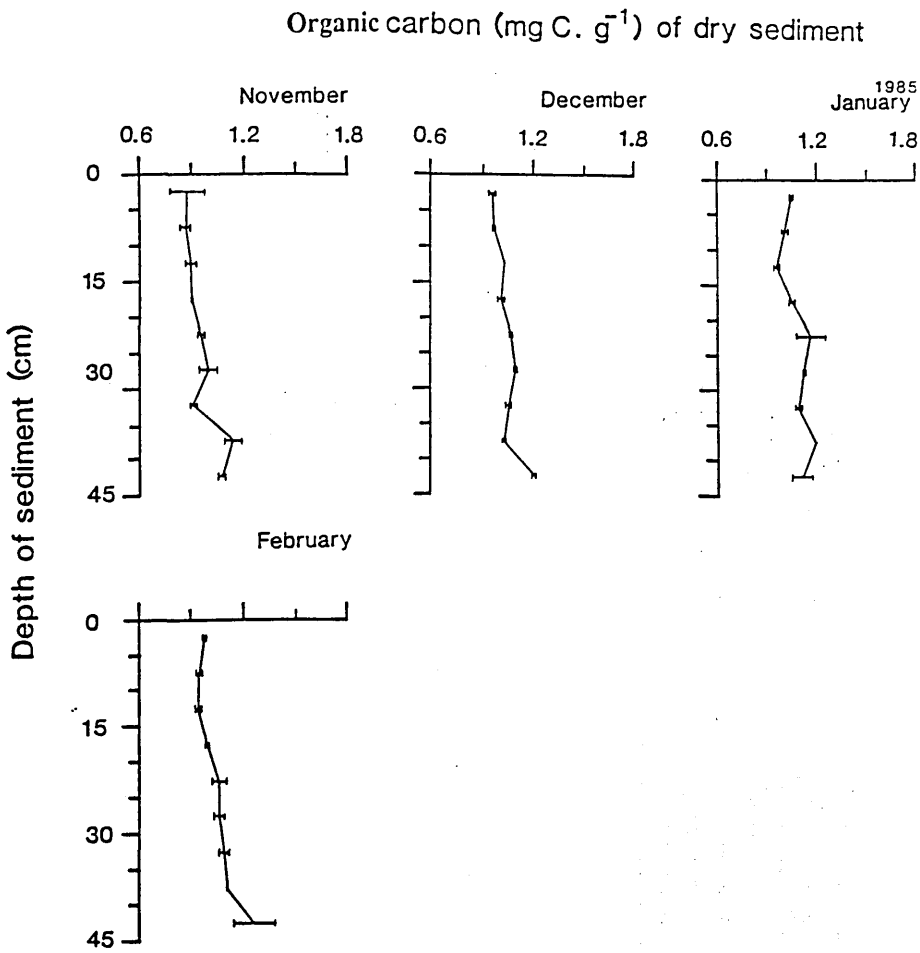


Figure (2.15)

Annual survey 1984-1985. Ardmore Point, low tide area. Means and standard deviations of organic carbon (mg C. g^{-1}) at different depths of sediment for each month of the survey. The lines join the mean, horizontal bars show the standard deviations. The means and standard deviations are calculated from the two replicate measurements in table 2.15.



Cont. figure (2.15)

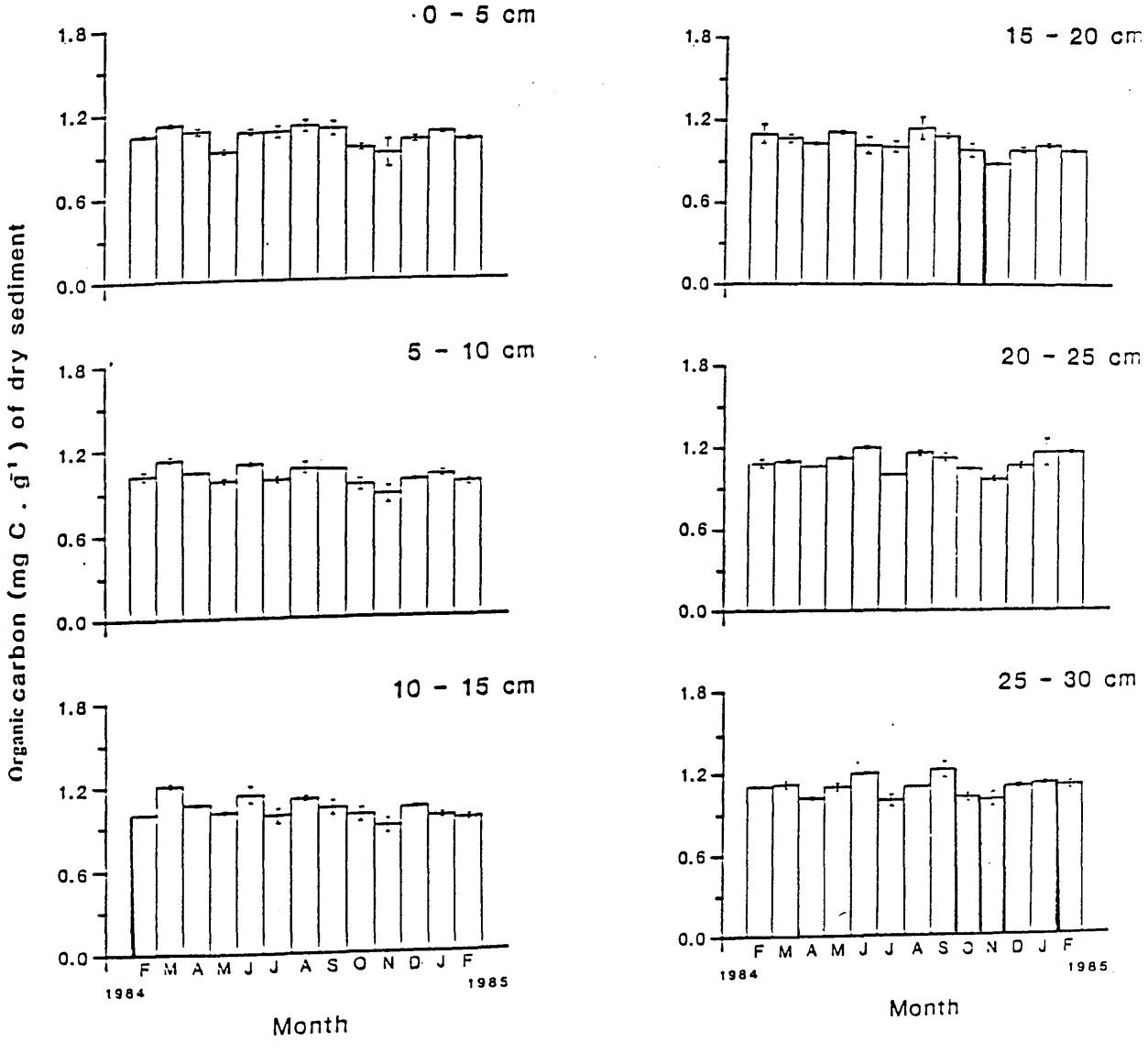
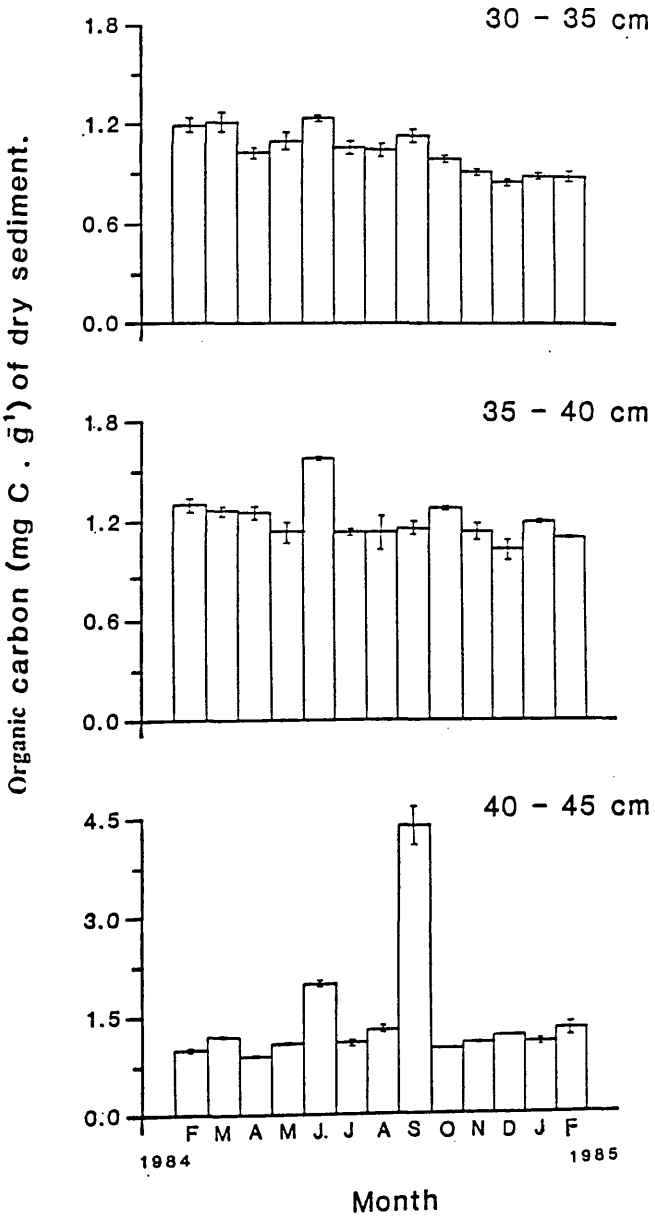


Figure (2.16)

Annual survey 1984-1985. Ardmore, low tide area. Histograms of the means and standard deviations of organic carbon (mg C $.g^{-1}$) throughout the survey for each section of sediment. The means and standard deviations are calculated from the two replicate readings in table 2.15.



Cont. figure (2.16)

Table (2.16)

Annual survey 1984-1985. Ardmore, low tide area. Specific gravity of sediment.

Month	Replicate subsamples	Specific gravity in depth (cm) 0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45
February 1984	I	2.665	2.658	2.672	2.661	2.663	2.663	2.672	2.641	2.657
	II	2.670	2.660	2.656	2.663	2.663	2.655	2.667	2.657	2.655
	III	2.667	2.656	2.655	2.657	2.683	2.662	2.664	2.645	2.665
Mean ± s.d.		2.667±0.004	2.658±0.002	2.660±0.010	2.660±0.003	2.670±0.012	2.660±0.004	2.668±0.004	2.640±0.017	2.659±0.005
March	I	2.682	2.675	2.682	2.670	2.663	2.669	2.655	2.649	2.644
	II	2.669	2.689	2.686	2.656	2.672	2.675	2.658	2.653	2.660
	III	2.693	2.662	2.668	2.663	2.670	2.666	2.643	2.668	2.665
Mean ± s.d.		2.681±0.012	2.678±0.001	2.679±0.010	2.663±0.007	2.668±0.005	2.670±0.005	2.652±0.008	2.657±0.010	2.656±0.011
April	I	2.674	2.665	2.661	2.667	2.646	2.667	2.658	2.678	2.671
	II	2.675	2.662	2.657	2.647	2.663	2.668	2.662	2.674	2.673
	III	2.678	2.665	2.665	2.659	2.674	2.667	2.666	2.668	2.667
Mean ± s.d.		2.676±0.002	2.664±0.002	2.661±0.004	2.658±0.010	2.661±0.001	2.667±0.001	2.662±0.004	2.673±0.005	2.670±0.003
May	I	2.665	2.654	2.647	2.650	2.654	2.663	2.665	2.662	2.662
	II	2.654	2.654	2.652	2.649	2.662	2.663	2.664	2.673	2.663
	III	2.659	2.663	2.651	2.661	2.663	2.663	2.666	2.664	2.649
Mean ± s.d.		2.659±0.006	2.657±0.005	2.650±0.003	2.653±0.00	2.660±0.005	2.663± 0	2.665±0.001	2.666±0.006	2.658±0.008
June	I	2.666	2.666	2.663	2.666	2.664	2.674	2.663	2.663	2.662
	II	2.670	2.662	2.662	2.665	2.676	2.666	2.667	2.649	2.663
	III	2.651	2.659	2.659	2.658	2.663	2.662	2.664	2.668	2.659
Mean ± s.d.		2.662±0.010	2.662±0.004	2.661±0.002	2.663±0.004	2.668±0.007	2.667±0.006	2.665±0.002	2.660±0.010	2.661±0.002
July	I	2.662	2.670	2.663	2.663	2.662	2.663	2.665	2.657	2.670
	II	2.666	2.670	2.664	2.662	2.663	2.661	2.660	2.664	2.670
	III	2.664	2.666	2.660	2.664	2.658	2.654	2.661	2.668	2.666
Mean ± s.d.		2.664±0.002	2.669±0.002	2.662±0.002	2.663±0.001	2.661±0.003	2.659±0.005	2.662±0.003	2.663±0.006	2.669±0.002
August	I	2.647	2.632	2.663	2.654	2.654	2.646	2.647	2.653	2.648
	II	2.651	2.632	2.665	2.660	2.660	2.644	2.650	2.646	2.645
	III	2.650	2.650	2.657	2.656	2.657	2.649	2.642	2.642	2.639
Mean ± s.d.		2.649±0.002	2.638±0.010	2.662±0.004	2.657±0.003	2.657±0.003	2.646±0.003	2.646±0.004	2.647±0.006	2.664±0.005

Cont... table (2.16)

Month	Replicate subsamples	Specific gravity values at depths (cm) 0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45
	I	2.663	2.662	2.659	2.665	2.658	2.668	2.674	2.662	2.671
September	II	2.655	2.658	2.658	2.657	2.663	2.662	2.670	2.672	2.656
	III	2.657	2.661	2.656	2.655	2.668	2.683	2.655	2.662	2.660
Mean ± s.d.		2.658±0.004	2.660±0.002	2.658±0.002	2.659±0.005	2.663±0.005	2.671±0.011	2.666±0.010	2.665±0.006	2.662±0.008
	I	2.661	2.666	2.666	2.644	2.658	2.646	2.667	2.664	2.656
October	II	2.666	2.679	2.672	2.651	2.654	2.646	2.662	2.663	2.661
	III	2.663	2.668	2.668	2.652	2.655	2.651	2.665	2.662	2.666
Mean ± s.d.		2.663±0.003	2.671±0.007	2.669±0.003	2.649±0.004	2.656±0.002	2.648±0.003	2.665±0.003	2.663±0.001	2.661±0.005
	I	2.663	2.674	2.664	2.661	2.659	2.661	2.651	2.666	2.660
November	II	2.669	2.666	2.661	2.665	2.659	2.663	2.660	2.657	2.665
	III	2.670	2.661	2.667	2.663	2.662	2.669	2.655	2.653	2.666
Mean ± s.d.		2.667±0.004	2.667±0.007	2.664±0.003	2.663±0.002	2.660±0.002	2.664±0.004	2.665±0.005	2.659±0.007	2.664±0.003
	I	2.670	2.671	2.662	2.613	2.618	2.638	2.668	2.665	2.659
December	II	2.672	2.665	2.659	2.626	2.628	2.646	2.669	2.659	2.658
	III	2.672	2.664	2.660	2.611	2.604	2.633	2.669	2.668	2.646
Mean ± s.d.		2.672±0.002	2.667±0.004	2.661±0.002	2.617±0.008	2.617±0.012	2.639±0.004	2.669±0.002	2.664±0.004	2.654±0.008
January	I	2.664	2.664	2.660	2.658	2.657	2.659	2.656	2.667	2.659
1985	II	2.665	2.660	2.663	2.659	2.659	2.664	2.660	2.658	2.660
	III	2.660	2.660	2.658	2.660	2.661	2.661	2.663	2.661	2.651
Mean ± s.d.		2.663±0.003	2.661±0.002	2.660±0.002	2.659±0.001	2.659±0.002	2.661±0.003	2.660±0.004	2.662±0.005	2.656±0.005
	I	2.670	2.673	2.663	2.654	2.664	2.667	2.662	2.672	2.653
February	II	2.670	2.671	2.666	2.658	2.657	2.673	2.662	2.666	2.662
	III	2.670	2.670	2.664	2.664	2.663	2.662	2.663	2.652	2.660
Mean ± s.d.		2.670± 0	2.671±0.002	2.664±0.002	2.659±0.005	2.662±0.004	2.667±0.005	2.662± 0	2.663±0.010	2.658±0.004

DISCUSSION

Estuaries are the unstable interfaces across which the fresh water drainage of the terrestrial world communicates with the open sea. Therefore, they are highly variable in physical, chemical and biological properties. This variability and the extremely low salinity have strong effects on both the composition and the dynamics of the biota (Levinton, 1982). Meadows and Campbell (1988) state that the intertidal estuarine environment is more difficult to live in than the open coast because of the variable salinity.

The monthly survey was carried out in the low tide area of Ardmore Point to study the biological, physical and chemical properties of sediments. The discussion, however, is divided into three sections, the biological aspects (section 1), physical properties of sediments (section 2), and chemical properties of sediments (section 3). Each section will be discussed separately.

Section 1- The biological aspects

This section is divided into two parts, containing abundance of meiofauna, and abundance and biomass of macrofauna.

I- Abundance of meiofauna

The number of meiofauna organisms per m^2 was counted each month during the survey in the period from February 1984 to February 1985. Three dominant taxonomic groups were found in the low tide area, nematodes, copepods, and ostracods (table 2.1). Nematodes were found in all depths of sediment, while copepods and ostracods only occurred

in the depths of 0-5cm and 5-10cm. Nematodes recorded the highest percentage of meiofauna in the low tide area of Ardmore, copepods recorded the second and ostracods the third. The average nematodes in 0-5cm depth fluctuated from month to month, and recorded high numbers in March, June and August 1984. The lowest average of nematodes occurred in December 1984. In lower depths, the degree of fluctuation decreased with depth and the average number of nematodes per m^2 decreased with depth (figure 2.1). The average of copepods per m^2 in the depth 0-5cm records the highest number in July and December 1984, while in the depth 5-10cm the highest number occurred in July and October 1984 (figure 2.2). The average number of ostracods per m^2 in 0-5cm records the highest number in June and December 1984, while in 5-10cm depth the highest number occurred in March and December 1984 (figure 2.3). The total number of meiofauna calculated from the low tide area shows that the number of meiofauna organisms fluctuated in the top 0-5cm depth of sediment (figure 2.4). The highest number of meiofauna was occurred in April, June and August 1984 (in spring and summer), and the lowest numbers occurred in December 1984 (winter). The degree of fluctuation decreased with increasing depth of sediment.

The changes in the abundance of meiofauna in different environments, such as the intertidal zone or subtidal zone, throughout the year has been studied by many investigators (Coull, 1970; Harris, 1972; Feller, 1980; Montagna et al., 1983; Bouwman et al., 1984; Coull et al., 1984; Fleeger, 1985). Most previous studies showed that the number of meiofauna fluctuate from month to month and increase mainly in summer and decreased in winter. The distribution of meiofauna is influenced by several factors such as temperature, salinity, light,

nutrients, grain size and water content (see McIntyre, 1969 for reviews). Montagna et al., (1983) stated that physical factors apparently influence meiofauna abundance. It is well known that meiofaunal community structure is dependent on sediment grain size (Decho et al., 1985) and other environmental factors (Hicks and Coull, 1983) as well as on biological interactions. Hulings and Gray (1976) showed in tidal beaches that sorting (standard deviation of particle size) was the most important factor in controlling the abundance of meiofauna followed by temperature and median diameter of particles. Gee and Warwick (1985) showed in experimental studies that the abundance of nematodes slightly decreased at high concentration of organic enrichment, while harpacticoid copepods increased significantly in abundance at low, medium and high concentrations of organic enrichment. My results showed similar trends in the abundance of meiofauna described by other workers and showed that physical factors may effect the abundance of meiofauna.

My study showed that meiofauna appeared in lower depths of sediment (to 40cm depth), but most meiofauna were found in the top 5cm of sediment. The vertical distribution of meiofauna may be effected by the type of sediments. In soft deposits meiofauna occur mainly to the upper few centimeters (McIntyre, 1969). In an intertidal mud flat the bulk of the fauna occurred in the top 1cm, and little life below the 3-4cm (Rees, 1940). Barnett (1968) showed that on a mud flat 95% of the harpacticoids were found in the top half centimetre, and occasional individuals occurred below the 1cm layer. Fenchel et al., 1967) showed in tideless beaches animals have been found down to a depth of 52cm below surface. Dye (1983) estimated that the maximum

depth of meiofauna penetration was on average 72cm at high tide level, 32cm at mid tide level and 23cm in low tide level. Ansari et al. (1984) found that most meiofauna were confined to the top 5cm of the sediment.

In my study nematodes recorded the dominated group in meiofauna in all depths of sediment, followed by harpacticoid copepods and ostracods which are found just in the top 10cm of sediment. Same trends were found in other studies. Perkins (1958a), and Wieser and Kanwisher (1961) showed that nematodes dominated the population throughout the year. Coull (1970) showed that nematodes gave the highest percentage in relation to the total number of meiofauna, followed by harpacticoid copepods in shallow water sediment. Dye (1983) found that nematodes gave 80% of the total number of meiofauna in Transkei, southern Africa. Ansari et al., (1984) studied the effect of domestic sewage on a sand beach meiofauna at Goa, India. They found that nematodes dominated the fauna, followed by harpacticoid copepods. Castel et al., (1989) found that nematodes represent more than 75% of the total abundance of meiofauna, followed in abundance by copepods in Arcachon Bay, south-west coast of France.

The appearance of nematodes in all depths of sediment may be related to the behavior of these animals which are sediment-dwelling animals (Jensen, 1984), and may be related to the presence of macrofauna animals such as *Arenicola marina* which pump water from the top layer of sediment to the lower layers during the feeding process (Reise, 1985). The restriction of copepods and ostracods to the upper layers of sediment may have been due to lack of oxygen, which may be absent at lower depths, but a more important cause may be the nature

of the bottom which became compact and sticky below the top 1/2cm (McIntyre, 1969).

II- Abundance and biomass of macrofauna

The dominant macrofauna species identified from the 1984-1985 survey are *Pygospio elegans, Bathyporeia pilosa, Eteone longa, Scoloplos armiger, Hediste diversicolor* and *Arenicola marina* (table 2.2). *P.elegans, B.pilosa* and *A.marina* were found throughout the year, while the other species were occasionally found in samples in some months and disappeared in other months. Most species were found in the top 5cm and few found in 5-10cm and 10-20cm depths of sediment, except *A.marina* which was found down to a depth of c. 40cm. The reason animals mostly appeared in the top layer of sediment (0-5cm) may be related to the decrease of oxygen level and microbial numbers with depth of sediment (Zobell a,b, 1946; Hayes, 1964; Meadows and Anderson, 1966, 1968; Fenchel, 1969; McLachan, 1978; Anderson et al., 1981; Meadows and Tait, 1985), since these two factors are very important for animal life. Oxygen is needed for respiration, and microorganisms are needed as food for deposit feeders. The reduction in species number with depth of sediment has also been noted by many other workers (e.g. Friedrich, 1969; Brown, 1982). *A.marina*, the deepest burrowing species, lives in 20 to 40cm deep burrows in tidal flats (Cadee, 1976). This species inhabits the deeper sediment avoids becoming anoxic by pumping water through its U-shaped burrows, thus maintaining an adequate oxygen supply (Green, 1968; Cadee, 1976).

The average abundance of macrofauna animals increased in spring and reached the highest level in the summer (June 1984) and then

1984, Tufail, Meadows and Mclaughlin, 1990). In general, organisms are not distributed uniformly over space (Valiela, 1984). The spatial distribution could be a uniform distribution (the variance less than the mean), a random distribution (the variance equal the mean) or an aggregated distribution (the variance greater than the mean) (Valiela, 1984).

In the following paragraphs I deal with each dominant species in turn, describing some factors affecting each particular species.

(i) *Pygospio elegans*

P.elegans was the most abundant species in the low tide area throughout the survey. The highest number occurred in May, June, August and September 1984. This polychaete species lives in tubes, formed by lining mucus with sand grains (Schäfer, 1972), in the tidal flats, which may explain the presence of this animal in the low tide area where the sediment contains clean sand (low organic content). The presence of this species in tidal flats varies from year to year. Wilson (1984) found that the population density of *P.elegans* varied between 57 and 1050 individuals per m^2 in river Blyth estuary, U.K. He found that the highest abundance of this species occurred in July in 1976, and in August in 1977.

(ii) *Bathyporeia pilosa*

B.pilosa was the only amphipod species found in the low tide area throughout the survey. The highest abundance of this species occurred in June, July, August and October 1984. The species shows great variation in the two replicate samples throughout the year. The

species is an amphipod and moves quickly in sediment (Rasmussen, 1973), and this may explain the greater variation occurring in the two replicate samples. The high abundance of this species which occurred in June and July may be related to the breeding period (Rasmussen, 1973).

(iii) *Arenicola marina*

A.marina was the second polychaete species found in the low tide area throughout the survey. This species shows less variation in the abundance between two replicate counts and recorded the highest biomass relative to the other macrofauna species. The highest abundance occurred in June, July and August 1984. This may be related to the breeding season of the species which occurs at that time. This may explain why the biomass in June and July was low because most of animals collected were small in size. The species avoids areas where *Ulva lactuca* is abundant (Baumfalk, 1979). The species burrows in sandy beaches and is absent from tidal flats which contain coarse clean sand and very soft mud (Cadee, 1976). The depth of sand over the substrata must be sufficient for the animal to develop its burrow (Meadows and Campbell, 1972).

Section 2: Physical properties of sediment

This section is divided into five parts, covering shear strength, permeability, particle size, water content and specific gravity.

A- Shear strength

In general, peak and residual shear strengths increased with increasing depth of sediments (tables 2.4A and 2.4B, and figure 2.8). Shear strength readings recorded differences from month to month. Increase in shear strength with sediment depth is well known and is caused by overburden pressure (Keller, 1974). Many studies of shear strength have been conducted in near shore or estuarine sediments (Moore, 1964; Rowe, 1974; Bokuniewicz, Gordon and Rhoads, 1975; Sherif et al., 1978), and also in the deep sea (Meadows and Tait, 1985). The differences in shear strength from month to month may be related to sediment water content. Inderbitzen (1970) shows that as the water content of sediment increases, the shear strength decreases. Animal activities in the intertidal zone can also affect shear strength. The burrows strengthen the sediment by aggregation of the particles in the burrow lining. Rowe (1974) reported that the shear strength of deep sea sediment was high when worm-tubes were present, and Meadows and Tait (1985) recorded a similar effect caused by burrow walls. Particle size in another factor which can affect shear strength. Bokunkniewiz, Gordon and Rhoads (1975) showed that shear strength increased with increasing sediment depth and with increases in the ratio of volume of sand to the volume of solids. McMaster (1967) showed a similar trend.

B- Permeability

The coefficient of permeability of sediment of the low tide area was calculated using Hooghout and Ernst equations (table 2.5). The results showed that the coefficient of permeability was 0.0001m $.s^{-1}$ for the Hooghout equation and 0.001m $.s^{-1}$ for the Ernst equation, and

there were no differences in permeability between months. The reason for the differences in results between Hooghout and Ernst is not known, but results showed that permeability of low tide area is in the range of sand permeability (Capper and Cassie, 1976). Similar results of permeability occurring throughout the year may be related to the particle size distribution which gives almost the same particle size (mean about 2.4phi about 180mm (fine sand)) (table 2.12). Particle size and sorting are important factors affecting permeability (Frazer, 1935; Webb, 1958; Green, 1968; Beard and Weyl, 1973). These authors showed that permeability became lower with decreasing particle size and poorer sorting. Sediment from low tide level has fine sand particles and is very well sorted.

C- Particle size

Particle size distribution of the low tide level sediment was calculated (table 2.12). The low tide sediment contains fine sand (mean about 2.4phi, about 0.180mm) and well sorted from surface to 35cm depth of sediment. The particle size was medium and fine sand and moderately well sorted below the 35cm depth. The negative skewness indicates that the bulk of particles were medium and fine sand. The large positive value of kurtosis indicates that the highest amount of particles occurred in the range from 0.250mm to 0.177mm. The mean particle size values (2.5phi to 1.9phi) I obtained are within the range of 7.0phi to -1.7phi observed by other authors (Duane, 1964; Dale, 1974; Anderson, Boonruang and Meadows 1981; Tufail, 1985).

Particle size is a very important parameter, since it affects many other parameters, such as permeability (Pillsbury and Appleman,

1950), shear strength (Holmes and Goodel, 1964), and water content (Trask and Rolston, 1950).

D- Water content

The water content of sediments is an important variable because it affects shear strength (Meadows and Tait, 1989) and is affected by particle size, porosity and biological activity (Trask and Rolston, 1950). The water content of sediment is dependent on at least three factors: period of exposure between tides, the distribution of particles, and the efficiency of packing (Rees, 1940). The effect of animal activity on sediment water content has been noted by Rhoads (1974). Construction of burrows, and constant irrigation of burrows results in a higher water content of sediment than would occur in the absence of bioturbation.

The water content at low tide level was generally higher at 0-35cm than deeper in the sediment throughout the survey. The percentage range of water water content found in low tide area (22% to 30%) is within that (11 to 64%) observed by a number of other authors (Rees, 1940, Mclusky, 1968; Meyer-Reil et al., 1978; Grant, 1981).

E- Specific gravity

In a soil sample it is useful to know the specific gravity of the material of the soil particles (Smith, 1981). Each element in the soil has its own specific gravity (Lambe and Whitman, 1979). The specific gravity of sediment at low tide area was (2.7) (specific gravity of quartz) throughout the survey (table 2.16).

Section 3- Chemical properties of sediment

A- Redox potential (Eh) and pH

(i) Eh

The Eh of overlying water and interstitial water was measured in the low tide area (table 2.6). The results showed no big differences between Eh of overlying water and Eh of interstitial water. Throughout the survey, Eh of overlying water gave higher values than Eh of interstitial water. The differences between Eh values of overlying water and interstitial water may be related to the consumption of oxygen by animals in the sediment.

The Eh of different depths of sediment was measured (table 2.7). Generally, the results showed that Eh decreased sharply from the surface to a depth of 5cm, and then increased slightly to a depth of 20cm, and then decreased again to a depth of 30cm. The decrease in Eh values just below the sediment surface (c. 5cm) may indicate the pressure of a redox potential discontinuity (RPD) layer which has been described as an area where significant changes in oxygen occur (McLachan, 1978). It is the layer where oxidising processes become displaced by reducing processes (Eagle, 1983). The slight increase in Eh values below 5cm depth may be related to the activity of burrowing animals such as *Arenicola marina* which increase the exchange between water and sediment. Anderson and Meadows (1978) showed that Eh of burrow-lining sediment was much higher than beside-burrow sediment.

The decrease in Eh with sediment depth is well known. Similar trends are known in the deep sea (Meadows and Tait, 1985), near-shore, and estuarine environments (Fenchel, 1969; Whitfield,

1969; Fenchel and Reidl, 1970; Anderson and Meadows, 1978). The decrease in Eh with sediment depth may be related to a number of factors such as oxygen concentration and particle size (Zobell, 1946b; McLachan, 1978).

The Eh range (6.5 to 480 mV) obtained from low tide level is within the range -200 to 550 mV obtained by other authors (Fenchel, 1969; McLachan, 1978; Meadows and Tait, 1985).

(ii) pH

The pH of overlying water and interstitial water was measured (table 2.8). The results showed that no differences occurred between the pH of overlying water and interstitial water.

The pH of different depths of sediment was taken (table 2.9). The results showed that in general pH increased slightly with depth throughout the survey.

pH values obtained from other authors showed that there are differences from author to author. For example, Zobell (1946b) records a range 6.4 to to 9.5, while Bägander and Niemistö (1978) record a range of 6.8 to 8.3. My results show a range of 6.50 to 7.50. Zobell (1946b) records a slight increase in pH with depth into the sediment, while Bägander and Niemistö (1978) stated that an increase of pH with depth into the sediment. My data generally appear to agree with Zobell's data.

B- Salinity

Results of the overlying water and interstitial water salinities showed that both were generally the same in most months except the

months of December 1984 and January 1985 in which salinity of the overlying water was lower than the salinity of the interstitial water. These differences in salinity between overlying water and interstitial water in these two months may be related to the amount of rainfall, a record of which was unfortunately not available from the Meteorological Office.

Salinity can be affected by several factors, such as tides, fresh water from run off, storms, winds, evaporation, and from local fluctuations in currents (Bowden, 1967; Man gelsdrof, 1967). The salinity in the low tide area at Ardmore was affected by the rainfall which gives a good negative correlation. When the salinity is high the rainfall is low and vice versa (figure, 2.11).

B- Organic carbon

The wet oxidation method provides a reliable estimate of total organic carbon, and the percentage recovery by this method varies according to the type of sediment (Buchanan, 1984).

The results of organic carbon showed that low tide area sediment contains low values of organic carbon (table 2.15).

The association between the type of sediment and organic carbon values is well known. Muddy sediment contains higher organic carbon, while sandy sediment contains lower organic carbon (Newell, 1965; Price, 1965; Longbottom, 1970; Hargrave, 1972; DeFaun and Meyer, 1983; Eagle, 1983). The organic carbon of low tide level sediment (0.10 to 0.015%) was lower than organic carbon determined by other workers (0.4 to 6.62%) (Waksman and Hotchkiss, 1938; McLachan, 1978; McLusky, 1968; Grant, 1981; Novitsky, 1983). Gadow and Schäfer (1973) found that the

highest organic carbon was obtained from the finer clay fractions of sediment.

Anderson, Boonruang and Meadows (1981) showed that organic carbon decreased with sediment depth. In my results the organic carbon increased slightly with depth in some months and decreased in other months (figure 2.15) throughout the survey.

SUMMARY

Monthly survey of biological aspects and physical and chemical properties of sediment were measured at low tide area of Ardmore Point.

I- Biological aspects.

A- Abundance of meiofauna

1- The abundance of three taxonomic groups, nematodes, copepods and ostracods, of meiofauna was determined.

2- Nematodes were found to be the most abundant group in sediment, followed by copepods and ostracods throughout the survey. Nematodes were found at deeper depths while copepods and ostracods were located in the top 10cm of sediment.

3- The highest number of total meiofauna occurred in the summer months and the lowest occurred in the winter months.

B- Abundance and biomass of macrofauna

1- Six species were recorded namely: *P.elegans, B.pilosa, E.longa, S.armiger, H.diversicolor and A.marina*.

2- Almost all the species were found in the top 5cm sediment, with the exception of *A.marina* which were found down to about 40cm sediment depth. The total number of macrofauna rises in spring, peaks in June, and then decreases in autumn and winter.

3- *P.elegans, B.pilosa* and *A.marina* were found throughout the survey, while the other species appeared in some months and disappeared in others. *P.elegans* and *B.pilosa* were the most abundant

species.

4- The total biomass of macrofauna fluctuated from month to month. The highest biomass occurred in June 1984. *A.marina* has the highest biomass relative to the other species throughout the survey.

5- There was no obvious correlation between the total number of macrofauna and the total biomass.

II- Physical properties of sediment

1- The physical properties of sediment measured were shear strength, permeability, water content, particle size, specific gravity.

2- Shear strength generally increased with increasing depth. The highest reading of shear strength occurred in the month of July 1984 at 100cm depth and the lowest reading of shear strength occurred in September 1984.

3- No differences were recorded in the permeability of sediment during the survey. The range of permeability determined indicates that the type of sediment is sand and that the drainage properties are good.

4- The percentage water content fluctuated between 22% to 30%. Water content decreased slightly with depth.

5- Mean particle size indicates that the low tide sediment was in the ranged of medium and fine sand and was well sorted. Mean particle size remained almost the same from the surface to 35cm depth for all months and then slightly increased below 35cm depth. The standard deviations (sorting) generally increased with depth.

6- Skewness of particle size of all samples was negative. Kurtosis of particle size of all samples was positive. A strong negative

correlation was shown between skewness and kurtosis.

7- There was no difference in specific gravity between different depths throughout the survey. The specific gravity always about 2.66, indicating that the type of low tide sediment is quartz.

III- Chemical properties

1- The chemical properties measured at low tide were redox potential (Eh), pH, salinity and organic carbon.

2- There was little difference in Eh between the overlying water and interstial water. The Eh of overlying water was always higher than the Eh of interstitial water.

2- The Eh decreased sharply from the sediment surface to 5cm depth. The Eh increased in the 10cm and 20cm depths, and then decreased in 30cm depth in most months of the survey.

3- There was no difference in the pH between the overlying water and interstitial water throughout the survey. pH values indicate that no difference occurred between different months and different depths of sediment.

4- Salinity of overlying water and interstitial water increased in spring and summer months of 1984 and generally decreased in autumn and winter months of 1984 and 1985. There was a strong negative correlation between the salinity and the rainfall.

5- The organic carbon of low tide sediment was low (0.01 to 0.015%) throughout the survey, except at a depth of 40-45cm in September 1984 when it was about 0.044%.

CHAPTER THREE

Effect of biological activities on the physical and chemical properties of sediment

INTRODUCTION

Organisms living in the top metre or so of sediments in the sea can have major effects on the physical and chemical properties of sediments in which they live. The presence of animals and their activities can cause sediment to become stabilised or destabilised, and plants and microorganisms can have similar effects (Meadows, 1986).

The effect of plants on sediment stability has been studied by many authors. Dense colonies of sea grasses or benthic macroalgae reduce the velocity of bottom currents (Ginsburg and Lowenstam, 1958; Frostick and McCave, 1979). Microalgae increase the adhesion between sediment particles and reduce resuspension of sediment by forming organic films on the sediment surface (Black, 1933; Bathurst, 1967; Frankel and Mead, 1973; Holland et al., 1974). Both macro- and microalgae produce filaments in the sediment which act as a rigid supporting skeleton (Scoffin, 1970; Neumann et al., 1970). Marine micro-organisms such as bacteria stabilise the sediment when they form polysaccharides and other substances during the degradation of biological remains (Sutherland, 1980). Webb (1969) showed that the activity of bacteria modifies the size, shape and adhesion of particles. Meadows and Tufail (1986) reported that the presence of micro-organisms in the surface of sediment, permeability was decreased.

Benthic invertebrates affect sediment stability by reworking sediment, and alter the physical and chemical properties of sediments during movement and feeding, and by burrow and tube building (Rhoads,

1974; Featherstone and Risk, 1977; Lee and Swartz, 1980; Meadows and Tufail, 1986). The feeding of animals affects sediment stability by disturbing the sediment surface (Dillon and Zimmerman, 1970). Extensive studies show that burrows and tubes influence the chemistry of marine sediments and alter the exchange of ions across the sediment water interface (Aller and Yingst, 1978; Day, 1978; Aller, 1978, 1980, 1983; Berner, 1980; McCaffery et al., 1980; Gust and Harrison, 1981; Waslenchuk, et al., 1983). The effects of tubes and burrows on the physical and chemical properties of sediments have also been studied (Rhoads et al., 1978; Eckman et al., 1981; Nowell et al., 1981; Aller, 1983; Luckenbach, 1986; Meadows and Tait, 1989).

Animal activities can stabilise or destabilise a sediment. But it is difficult to say whether a particular activity is responsible for destabilising or stabilising without conducting controlled experiments. This is because the effect of the activity on the sediment depends on the species responsible, its population density, the sediment composition, and the activities of co-inhabitants (Nowell et al., 1981). The effect of animals on sediment properties has received considerable attention recently (Fager, 1964; Dillon and Zimmerman, 1970; Yingst and Rhoads, 1978; Katz, 1980; Grant, 1981; Koike, and Mukai, 1983; Luckenbach, 1986; Meadows and Tait, 1985, 1989; Meadows, Tait and Hussain, 1990).

The destabilisation of sediment has been studied by various workers. Dillon and Zimmerman (1970) found that burrowing of crabs caused erosion of submarine canyons and resulted in collapse of the canyon walls. Ott et al. (1976) estimated that burrowing and the expulsion of sediment from the burrows of *Upogebia litoralis* caused

the sediment surface to be eroded by up to 0.5cm per year. Edwards and Fery (1977) found that extensive burrowing by the mud crab *Panopeus herbsti* caused subsidence of the creek banks in which it lived. Katz (1980) found that burrowing by the fiddler crab *Uca pugnax* caused considerable erosion of saltmarsh sediment. Eckman et al. (1981) found that tube building by the polychaete *Owenia fusiformis* in the laboratory decreased the critical erosion velocity of the sediment making it more easily eroded. The reduction in the stability of marine sediments by the activities of benthic invertebrates is reviewed by Hecker (1982).

Stabilisation of sediments by biological activity has also been investigated by a number of workers. Fager (1964) shows that a dense settlement of the tubicolous polychaete *Owenia fusiformis* stabilised a shifting sand against erosion. Young and Rhoads (1970) found that the faecal heaps of the holothurian *Molpadia oolitica* were stabilised by the tubes built in them by a small polychaete *Euchone incolor*. Neumann et al. (1970) reported that tubes and burrows of tanaids, polychaetes and harpacticoid copepods in subtidal sand algal mats increased the stability of the sediment. Luckenbach (1986) found that high densities of macrofauna increased the critical entrainment velocities for the natural cohesive sediments to about 46%, and the biological activities around *Diopatra cuprea* tubes are responsible for lowering the erosion of sediments. Meadows and Tait (1989) and Meadows, Tait and Hussain (1990) found the presence of two burrowing invertebrates *Hediste diversicolor* and *Corophium volutator* at different densities increased the stability of sediment.

The studies described above emphasise the importance of

biological activity in controlling marine sediment stability. Further studies are required to test the significance of the effect of other species in this respect, and their practical application. The practical importance of predicting and controlling sediment stability is of great significance both from the viewpoint of the engineer and the biologist.

The effect of animal activities on the physical and chemical properties of sediment is my main interest. Chapter two has provided an ecological background to the abundance of the bioturbating organisms and the physical and chemical parameters of the sediments during one annual cycle. With this background the present chapter considers the effects of two important infaunal species at Ardmore on the physical and chemical properties of sediments under controlled experimental conditions in the laboratory. The two species chosen were the polychaetes *Pygospio elegans* and *Fabricia sabella*. I chose these two species because they both built strong tubes, and because they are abundant in the intertidal zone at Ardmore shore. *P.elegans* is found at all tidal levels at Ardmore while *F.sabella* occurs only in the upper intertidal zone. The biology of the two species will be given first and then the background of the physical and chemical properties of sediment which were tested in the laboratory.

Morphology of the two species

Pygospio elegans

Phylum Annelida

Class Polychaeta

Family Spionidae

P.elegans is a spionid species living in the intertidal zone in tubes consolidated with sand grains. This is a common species in British estuarine sands and muds (Bassindale, 1938; Spooner and Moore, 1940; Beanland, 1940; Popham, 1966), and in marsh pools (Nicol, 1935). The species is also very common in the Clyde Sea Area (Clark, 1960). It occurs in White Bay sporadically from low tide to 20m, and in Balloch Bay it is abundant just below high water mark in brackish, fine sandy mud (Clark, 1960). It settles in dense populations so that the barely 1mm thick tube forms regular lawns; the individual tubes, however, do not touch each other. They extend 9cm into the sediment and are built of fine sand grains, cemented with mucus (Schafer, 1972). In the absence of sand, the tubes are made of lumps of mud, detritus, or plant remains. Grains are often missing in the wall of the tube deep in the sediment, and it consists only of mucus and is less hard. The upper section of tube has a brown stain from iron hydroxide which is lacking in the lower part (Schäfer, 1972). The body is 10-15 mm long, with 50 to 60 segments. The prostomium is faintly bilobed in front and pointed posteriorly. There are four to eight eyes arranged in an irregular pattern. The head is bluntly bifid, with a median ridge running backward to the second segment. The bronchia are fused to the dorsal lamellae. The two tentacles of the male are very long and attenuate. The female lacks tentacles. The

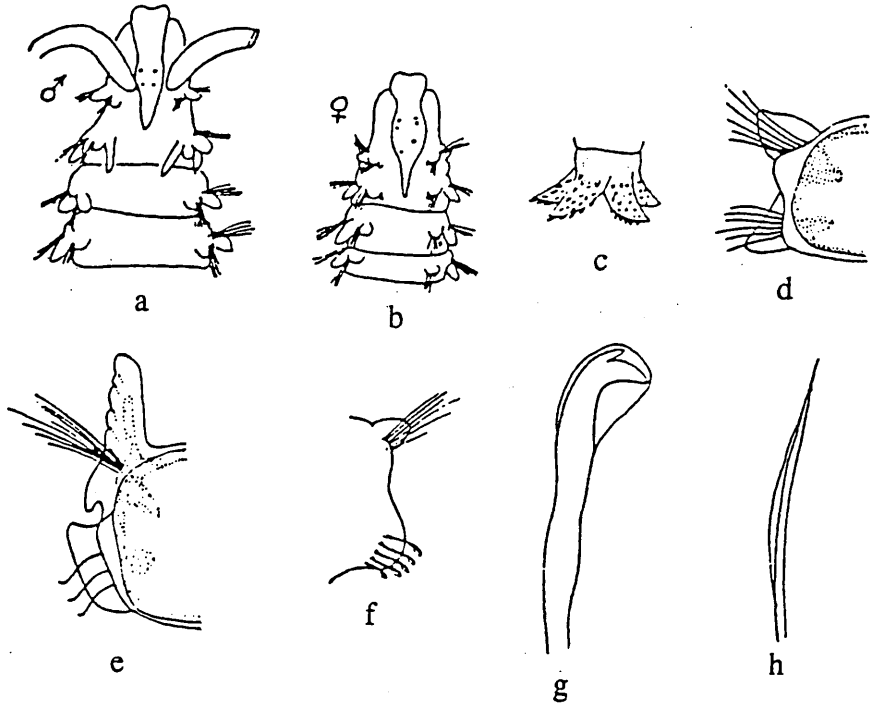


Figure (3.1.I)

Pygospio elegans. (a) Head of male. (b) Head of female. (c) Pygidium. (d) Anterior foot. (e) Branchiferous foot. (f) Posterior foot. (g) Hooded hook. (h) Limbée seta. (reprinted from Fauvel, 1923, and Day, 1967).

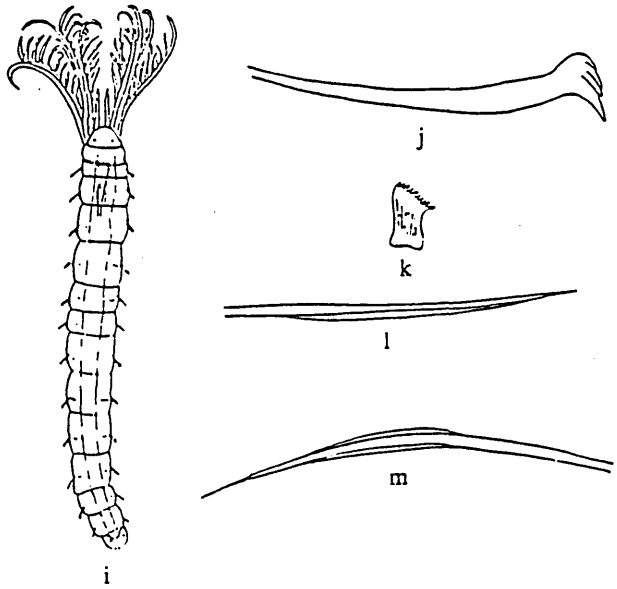


Figure (3.1.II)

Fabricia sabella. (i) Entire worm, dorsal view. (j) Thoracic hook (k) Uncinus. (l) Abdominal seta. (m) Thoracic seta. (reprinted from Fauvel, 1923).

pygidium has four glandular lobes (Figure 3.1.I, Fauvel, 1923; Day, 1967). The colour of the body is yellow or green with a brown intestine and red dorsal blood vessel (Eales, 1967).

The worm feeds predominantly as a deposit-feeder, using its two relatively short palps to gather detrital material (Wilson, 1983). *Pygospio* extends the anterior portion of its body from its tube and picks up sand grains directly with its mouth (Woodin, 1982). Small particles, including diatoms, are collected in the grooves and transported towards the head. The species sometimes occurs in enormous numbers in estuarine sands. Thamdrup (1935) found densities up to 20,300 per m^2 on the Danish coast (Green, 1968). Kaestner (1967) reported that *P.elegans* lives in U-Shaped burrows, in areas well supplied with diatoms, at densities of up to 20,000 animals per m^2. *P.elegans* penetrates to a salinity of $8^{o}/_{oo}$ in stable brackish water (Remane, 1958), and also it appears to be able to tolerate salinities as low as $2^{o}/_{oo}$ for a short period (Green, 1968). The life history pattern of and the sexual reproduction of *Pygospio* have been described by Hannerz (1956), Rasmussen (1973), and Gudmundsson (1985). The female of *P.elegans* may produce up to 16 egg capsules in the spring breeding season (Green, 1968). Each capsule is anchored to a sand grain by a thin thread. Each capsule contains about 50 eggs, but only 2 to 9 of these develop, the others serve as nurse cells which disintegrate and act as nourishment for the embryos (Green, 1968, Gudmundsson, 1985). The small number of embryos are hatched as a demersal or a pelagic larvae (Rasmussen, 1973).

Fabricia sabella

Phylum Annelida

Class Polychaeta

Family Sabellidae

Sub-family Fabriciinae

F.sabella is a small sabellid worm. The body of this species reaches 3-5mm long, 0.25mm wide, and contains 10 to 12 segments (Eales, 1967). Its branchial crown consists of six filaments which, when the worm is extended, are held out stiffly and widely separated. The worm uses its branchial crown to collect and sort suspended particles for feeding. Two eyes occur on the first segment and two eyes on the pygidium (Eales, 1967) (see figure 3.1.II, Fauvel, 1923). This worm lives in a non-calcareous tube, constructed on the surface of the sediment (Marshall and Williams, 1972; Schäfer, 1972).

Lewis (1968) describes the feeding mechanism of the species and how it builds its tube as follows. The pinnules borne on the three pairs of gill filaments possess three rows of cilia. The two rows of latero-frontal cilia move water through the crown and also trap particles from this current and deposit them on the frontal cilia. These transport the particles to ciliated grooves in the gill filaments, where a little preliminary sorting occurs as they move towards the centre of the crown. The final sorting occurs at the centre of the crown: large particles are rejected whilst the small ones are carried to the mouth. The medium-sized particles are mixed with mucus and incorporated into the tube. When the species constructs its tube, it crawls around, pygidium first, secreting mucus. As the animal moves forwards, the mucous glands of the pygidial region

secrete what becomes a cylinder of mucus. The rolling motion, especially of the pygidium, serves the function of transporting sand-grains and other particles towards the top surface of the newly formed temporary tube. After the worm has constructed its temporary tube, the pygidium is thrust into the substratum and with a revolving motion the animal burrows into it. The worm moves up and down the burrow, revolving and secreting mucus as it does so. When the burrow has been lined with mucus the branchial crown is pushed vertically upwards against the top of the temporary tube until it breaks, and the crown stands out from the burrow into the surrounding water. The actual particles used for the tube are medium-size ones. In calm water, the animal continues to add grains to its tube until it is about 2.5cm long and the branchial crown is thus well clear of the substratum (Lewis, 1968). This species lays its eggs throughout the year and several batches can be produced in a short time, particularly in summer. The eggs, which are laid in capsules along the inside of the tube, hatch in less than 14 days (Rasmussen, 1973). Lewis (1961) describes the reproduction of this species as being non-pelagic, the entire larval development taking place within the tube of the adult female.

Strelozov and Gurevich (1978) described the interaction of *Fabricia sabella* population with its environment by using the results of the logic analysis of the correlations and behavioral observations. They found that the existence of *Fabricia* depends directly on the presence and intensity of the processes of accumulation and erosion in the active layer of sandy sediment, suspension concentration in the near-bottom layer, sediment stability, the absence of the erosion of

the biosedimentative layer, moisture capacity of sediment, and the density of predators.

The species inhabits coastal waters ingesting sediment (Perkins, 1974), is locally abundant in the Clyde Sea Area (Clark, 1960). It is common on stones and in rock pools at Millport. Elmhirst (1932) found enormous numbers (6,000 to 8,000 per m^2) in mats of decaying *Zostera* roots in 1932 (Clark, 1960). It occurs in Balloch Bay just below high water mark in brackish water, fine sand, and sandy mud (Clark, 1960). The species also found in the Mediterranean, North Atlantic and North-east Pacific (Geroge and Geroge, 1979).

Some Physical and chemical properties of sediment

Permeability

Permeability is one of the important physical properties of sediment affected by animal activities. It is affected by burrowing invertebrates whose burrows may increase sediment permeability (Smith et al., 1944; Nowell et al., 1981; Weaver and Schulteiss, 1983; Meadows and Tufail, 1986; Meadows and Tait, 1989; Meadows, Tait and Hussain, 1990). Permeability also affects the distribution of intertidal burrowing invertebrates (Holme, 1949; Webb, 1958, 1969; Ruello, 1973) since many species are dependent on the water held between sediment particles during low tide.

Permeability is measured in the laboratory using two methods (Smith, 1981). The first method is called a constant-head Permeameter. Water under a constant head of pressure is allowed to percolate through a sample contained in a cylinder. The level of water is kept constant by the addition of water, in other words there is a constant

head of water pressure. The quantity of water passing through the sample in a certain time is collected in a measuring cylinder. A sand filter is sometimes incorporated above and below the sample to avoid the soil or sediment being disturbed by the water flow (Israelsen and Hansen, 1962; Cedergren, 1977; Hansen, et al., 1980; Smith, 1981; Das, 1985). The second method uses a variable-head or falling-head permeameter. This method is more suitable for fine-grained soils or sediments. The water is allowed to pass through the sample. However, the level of water does not remain constant because no water is added to the cylinder containing sediment. The time that water takes to fall a given distance in the cylinder is noted. The equations of these two methods are given in Smith (1981, page 42-45) and Capper and Cassie (1976, page 345-346).

In my study, I have used the second method with a little modification. This modified technique is given in detail in the Materials and Methods part of this chapter.

Shear strength

The shear strength of a soil may be defined as the maximum resistance of soil to shearing stress under any given condition (Smith, 1981). Shear strength is an important parameter to measure since it gives an indication of how easily a sediment may be eroded. The shear strength of sediment can be affected by many factors including water content, particle size, interparticle binding, gravity, cohesion, and friction between particles (Jumikis, 1962; Yong and Warkentin, 1966; Capper and Cassie, 1976; Bowles, 1978; Friedman and Sanders, 1978; Smith, 1981). Animal activities can affect sediment

shear strength dramatically (Rowe, 1974; Lee and Swartz, 1980; Letzsch and Frey, 1980; Eckman et al., 1981; Deans et al., 1982; Hecker, 1982). Shear strength can be measured in the laboratory using several tests. These tests are described in detail in Hansbo (1957), Capper and Cassie (1976) and Smith (1981). I used the fall cone test (Hansbo, 1957) to measure the effect of biological activity on sediment shear strength. Shear strength is calculated from the penetration depth of a steel cone dropped onto the sediment surface, and then expressed as kNm^{-2} (Smith, 1981). The test is described in detail in the Materials and Methods part of this chapter.

Chemical properties

Eh and pH parameters

Eh and pH are commonly interdependent in sedimentary environments (Friedman and Sanders, 1978). The description of these two parameters was given in detail in chapter 2. Eh and pH can be measured either colorimetrically or electrometrically (Langmuir, 1971; Zobell, 1946b). In my study I used the electrometrical method to measure Eh and pH at different depths in sediment, and also of the overlying water in the experiment carried out in the laboratory. The measurements of the two parameters are given in detail in the Materials and Methods part of this chapter.

MATERIALS AND METHODS

Two experiments were carried out for testing the effect of biological activity on the sediment stability using two Polychaete species *Pygospio elegans* and *Fabricia sabella*. The first experiment tested the effect of animals on the permeability of sediment, and the second one measured the effect of animals on the shear strength of sediment. A preliminary experiment was carried out to test the feasibility of the main experiment and to avoid any problems which might have arise. The main experiment was designed in the light of the experience obtained in the preliminary experiment.

The main experiment was in two parts. The first part involved the measurement of permeability, and the second the determination of shear strength. These parts were called the permeability experiment and the shear strength experiment, respectively.

I- Preparing samples.

Sediment samples were collected from the top 5cm of the sediment surface at the mid and high tide area on Ardmore Point which is where the two species are found. In the laboratory, the samples were wet sieved through a 0.5mm sieve to extract the two species in their tubes. The sieved sediment was then used to fill the cores. Each core of both shear strength and permeability experiments was carefully filled with sediment to a height of 10cm. The two species *P.elegans* and *F.sabella* with their tubes were placed in containers of sea water. A light was then placed at the front of the containers. This forced the animals from their tubes and away from the light source (Girling

1984). The two species were collected and put in separate receptacles containing sea water, and then aerated. The animals were then transferred from the receptacles to the cores at the appropriate densities.

Single species experiments and mixed species experiments were conducted in both the permeability and shear strength experiments. Three population densities of *P.elegans* and *F.sabella* were used in the cores: low density, medium density and high density. Three cores were prepared for each density. In the single species experiments, low, medium and high densities of the two species were tested in separate cores. In the mixed species experiments, cores contained either low, medium, or high densities of both species. The total number of cores prepared for the permeability and shear strength experiments was therefore as follows.

(i) Permeability experiment

	density			
	Low	Medium	High	Control
P.elegans species	3	3	3	3
F.sabella species	3	3	3	
Mixed species (*P.elegans&F.sabella*)	3	3	3	

Total number of cores = 30 cores

(ii) Shear strength experiment

As permeability experiment + 3 extra cores for measuring the shear strength, Eh and pH at the beginning of experiment.

The number of animals of each species for each density was

calculated as follows. Girling (1984) reported that in summer the density of *Pygospio elegans* at mid tide was about 7000 per m^2, and the density of *Fabricia sabella* at high tide was about 17000 per m^2. These two densities were taken as the medium density for each species respectively in both experiments.

The area of each of the 5cm diameter cores in the permeability experiment was 20.43cm^2 and of the 10.5cm diameter cores in the shear strength experiment was 95.03cm^2. Allowing for these areas, the numbers of animals added to each of the three replicate cores at each density in the single species experiments were 5 animals (low), 15 animals (medium) and 45 animals (high) *P.elegans*, and 11, 33 and 99 (*F.sabella*) (table 1A). The equivalent numbers for the shear strength experiment were 20, 60 and 180 (*P.elegans*), and 50, 150 and 450 (*F.sabella*) (table 1B). The numbers of *P.elegans* and *F.sabella* in the mixed species experiments of both the permeability and shear strength experiments are shown in table 3.1A and 3.1B.

II-Permeability experiment

A: Preparing containers.

A 5cm diameter core was used in this experiment. It was made of clear PVC. 30 cores 33cm in length were prepared. Each core was closed at the bottom with two layers of nylon mesh (mesh size 1mmx0.4mm) and then covered with a metal mesh (pore size 1.5mm). These layers allowed water to pass through the bottom of the core easily while at the same preventing sediment from escaping. On the external wall of the core, three triangular plastic supports (arrows in figure 3.2B) were fixed to allow the core to stand vertically in a tank during the experiment.

Table (3.1A)

Number of animals used in the permeability experiment.

Repl.	Single species cores						Mixed species cores						
	P.elegans			*F.sabella*			Low		Med.		High		Control
cores	Low	Med.	High	Low	Med.	High	P.e.:	F.s.	P.e.:	F.s.	P.e.:	F.s.	
Repl. I	5	15	45	11	33	99	5 :	11	15 :	33	45 :	99	0
Repl. II	5	15	45	11	33	99	5 :	11	15 :	33	45 :	99	0
Repl. III	5	15	45	11	33	99	5 :	11	15 :	33	45 :	99	0

Table (3.1B)

Number of animals used in the shear strength experiment.

Repl.	Single species cores						Mixed species cores						
	P.elegans			*F.sabella*			Low		Med.		High		Control
cores	Low	Med.	High	Low	Med.	High	P.e.:	F.s.	P.e.:	F.s.	P.e.:	F.s.	
Repl. I	20	60	180	50	150	450	20 :	50	60 :	150	180 :	450	0
Repl. II	20	60	180	50	150	450	20 :	50	60 :	150	180 :	450	0
Repl. III	20	60	180	50	150	450	20 :	50	60 :	150	180 :	450	0

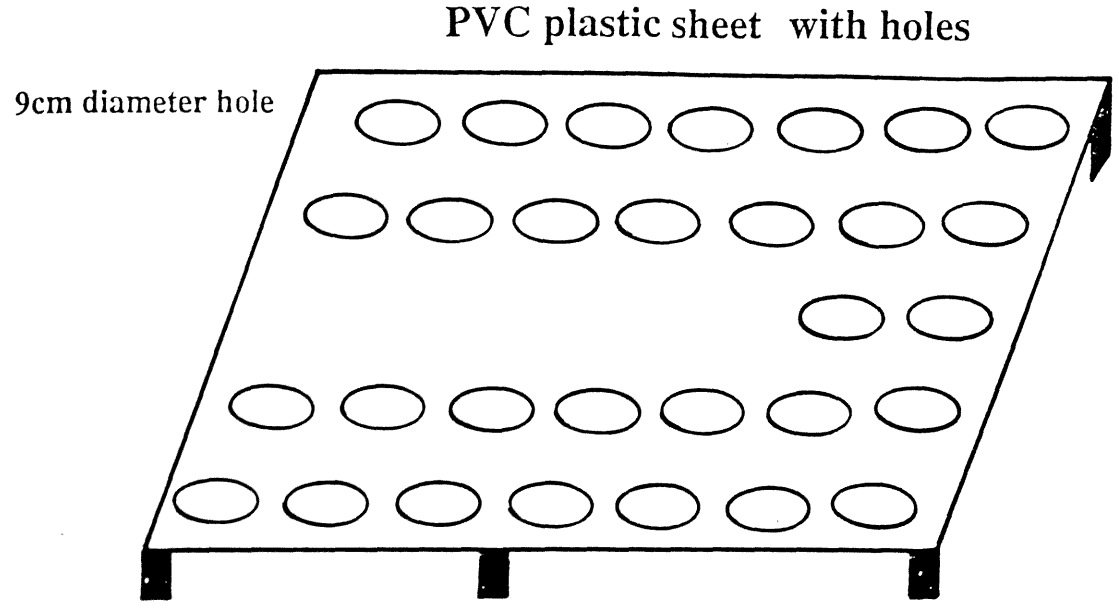


Figure (3.2A)

Stability experiment. The PVC plastic sheet with holes prepared for the permeability experiment cores.

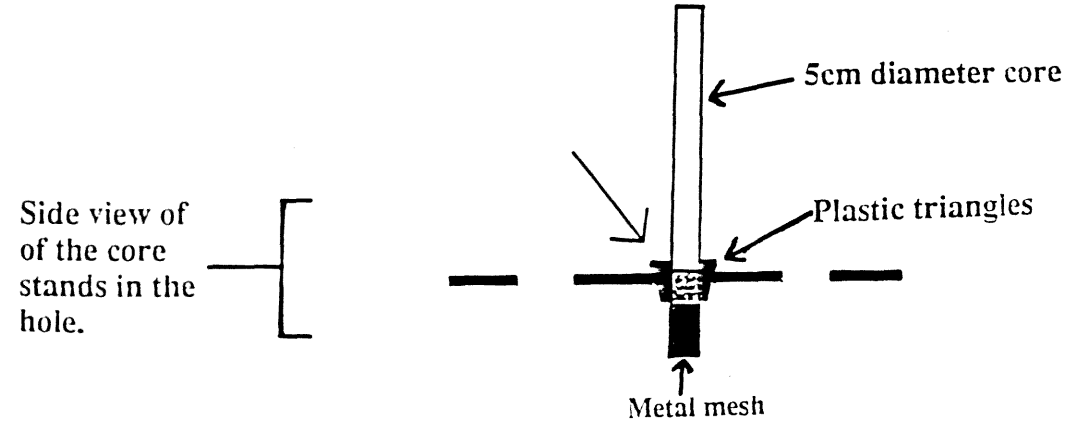


Figure (3.2B)

Stability experiment. Side view of the 5cm diameter core stands in the hole during the progress of permeability experiment.

A PVC sheet was cut to cover the bottom area of the tank (130cm long and 90cm width). Thirty holes of diameter 9cm were made in the sheet. The sheet was raised from the bottom of the tank to a height of about 15cm using six columns of PVC fixed to the sheet. This apparatus allowed the cores to be inserted easily and to stand vertically leaving a distance of about 3cm between the bottom of the core and the bottom of tank. It also allowed a free circulation of water around the cores during the progress of experiment. The general design of the experiment is shown in figure 3.2A, and details of the cores in figure 3.2B.

B: progress of experiment

The single and mixed species cores plus the control cores were put in a large tank containing slow running sea water at 15^{o} C. The tank was filled with sea water to a height of 60cm. Each core (33cm high) was slowly submerged and stood vertically in one of the 9cm diameter holes in the PVC sheet. All cores were left for six hours to allow the sediment to settle. The sea water was then drained from the tank until the top 5cm of the PVC plastic 33cm cores were exposed. This left about 18cm of water above the sediment surface in the cores. The animals for each treatment of both species were put into their label cores. No animals were added to the replicate control cores. The top of each core was then covered with a nylon mesh to prevent animals escaping from the core and to prevent anything entering the core from outside. When all cores were covered, the level of water was slowly raised to a height of 60cm from the bottom of the tank (24cm above the top of the PVC plastic cores) (plate 3.1), and the tank was then

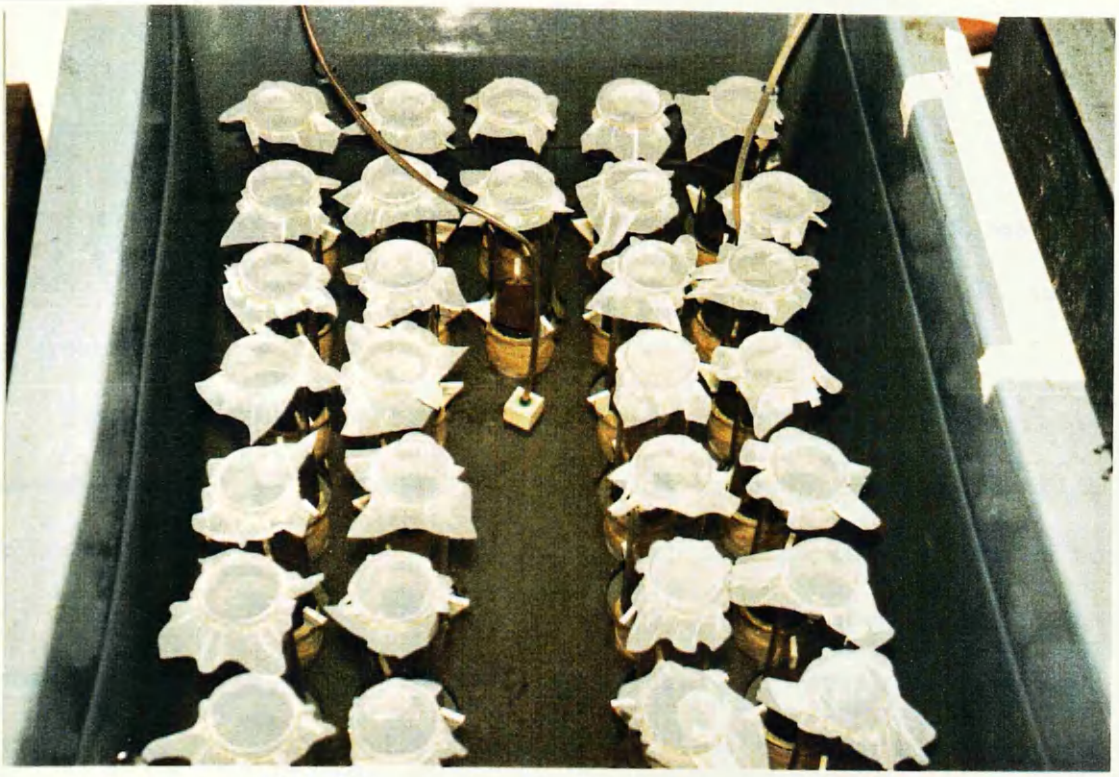


Plate (3.1)

Permeability experiment. Permeameter (cores with sediment and animals as appropriate) in tank with flowing sea water.

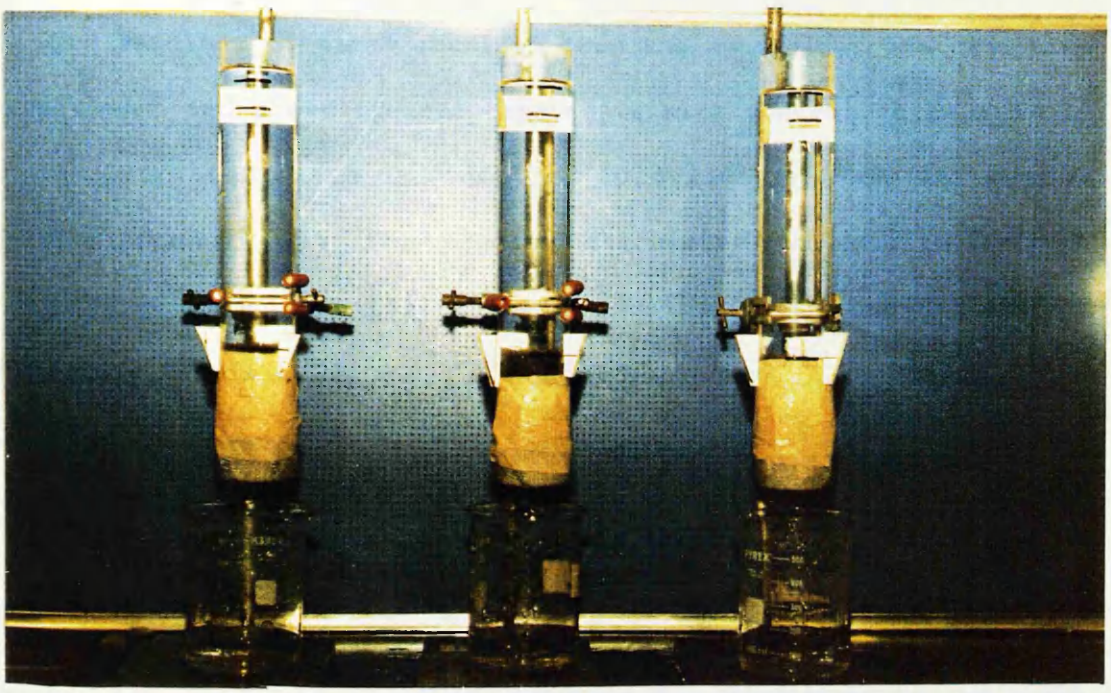


Plate (3.2)

Permeability experiment. Measurement of permeability using falling head permeameters.

aerated.

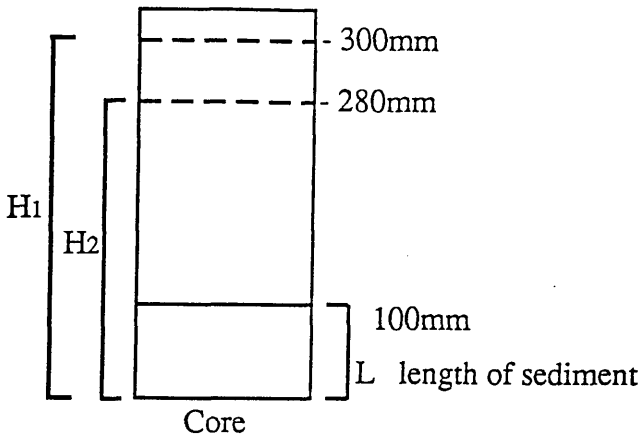
The permeability of all the cores was measured on day 5, day 10, and day 15. In addition, the permeability of the three control cores was measured on day 0.

Permeability was measured as follows. Each core was carefully removed from the tank and stood vertically using a metal screw clip fixed to a stand (plate 3.2). The time taken for the level of water to drop from a height of 30cm to a height of 28cm was recorded in seconds. The core was then refilled with sea water for the next reading. This was repeated fifteen times. After the last reading, the core was refilled once more and the top was covered with the nylon mesh and then removed from the stand. The core was then carefully replaced in the tank, avoiding disturbing the sediment.

The readings of times obtained from the control at the beginning of experiment and the different treatments with control at days 5, 10 and 15 were fed into a computer program written by myself (MH-PERM) (Appendix 3). The program calculated the coefficient of permeability using the falling-head equation. The coefficient of permeability (K) is:

$$K = \frac{L}{t} \times \ln \frac{H_1}{H_2}$$ (Smith 1980, page 41).

where L is the length of sediment column in mm. t is the time (seconds) taken for the level of water to drop from a height of 300mm to a height of 280mm. H_1 is the level of 300mm of water and H_2 is the level of 280mm of water from the bottom of the core (see figure below). Units of K are therefore mm $.s.^{-1}$



III- Shear strength experiment

A: Preparing containers.

10.5cm diameter PVC coring was used in this experiment. Its diameter was larger than the permeability experiment to allow 5 independent readings of shear strength to be taken on the surface of sediment. 30 cores 13cm in length were made. Each core was closed from the bottom using the same method used in the permeability experiment. Cores were put into a large tank leaving about 3cm between the bottom of the core and the bottom of the tank. As above, this allowed a free circulation of water around the core. This was done by putting long plastic bars (90cm long, 2cm width and 3cm height) fixed in the bottom of the tank.

B: Progress of experiment.

The single species and mixed species cores plus the control cores were put in a large tank containing slow running sea water at $15^{o}C$. The three extra cores to be used to measure the shear strength and Eh & pH profiles at the beginning of the experiment were put with

the other cores. The tank was filled with sea water to a height of 40cm from the bottom of the tank, (24cm above the PVC plastic cores), and the tank then aerated (plate 3.3). The cores were left for six hours to allow the sediment to settle. The water was then drained from the tank until the top 1.5cm of the cores was exposed. The animals of different densities of both single and mixed species of *P.elegans* and *F.sabella* were then transferred into their label cores. All cores were then covered with the nylon mesh to prevent animals escaping from the cores. The level of water in the tank was then slowly raised again to a height of 40cm and the tank aerated. The cores were then left for a further 6hrs to equilibrate and allow the animals to burrow.

The level of water in the tank was then reduced until the top of the cores was exposed. Shear strength, Eh and pH readings were taken from the extra three cores as follows.

The core was carefully removed from the tank and put into a plastic container (plate 3.4) containing sea water. Eh (mV) and pH readings of the overlying water were taken immediately as follows.

i-Eh reading

-Standardized the electrodes.

Two electrodes were used to take the reading of Eh. The first one was a black platinum electrode (E.I.L. 33-1213-400) and the second was a calomel reference electrode (E.I.L. 33-1370-210). These two electrodes were connected to a portable Corning pH meter 120, Serial No. 5272 (9V D.C. and 4mA). Before taken any reading, the two electrodes were standardized using the methods described in chapter

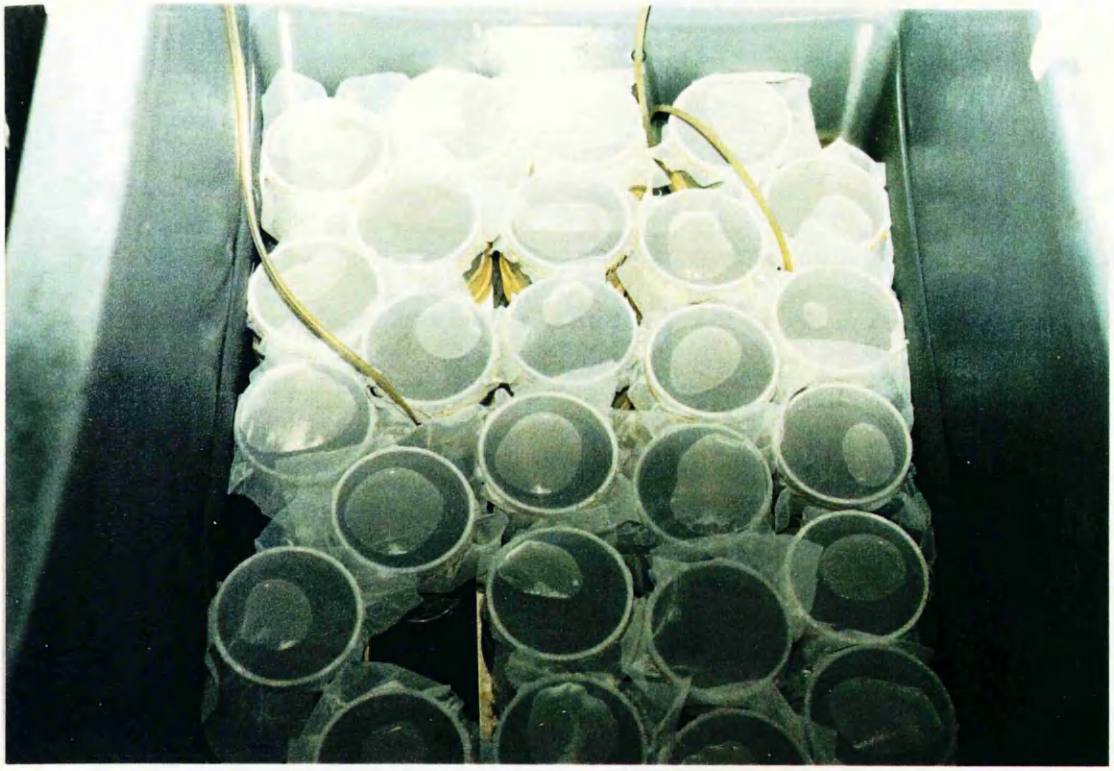


Plate (3.3)

Shear strength experiment. Cores with sediment and animals in tank with flowing sea water.

Plate (3.4)

Shear strength experiment. The core inside the outer container for taking shear strength readings. (Structures of animal tubes can be seen on the sediment surface)

two.

-Readings.

The Eh reading was taken by inserting the two electrodes into the overlying water and taking a reading after 5 seconds. One Eh reading was obtained from each core.

ii- pH reading

One reading of pH was obtained from the overlying water using a combination electrode (003 11 201N) connected to the Corning pH meter 120 as follows. The electrode was calibrated with pH7 buffer and then inserted into the water and a reading taken after 30 seconds.

iii- Shear strength of the sediment surface.

The overlying water was slowly sucked out using a water pump until the level of water reached the sediment surface. The level of water outside the core was kept at the same level as the height of sediment inside the core to ensure that the sediment remained fully saturated during the measurement of shear strength. The depth of cone penetration into the sediment in mm was taken using a fall-cone test apparatus (60.11gm, 60 degrees). Five readings of depth of penetration were obtained. One reading was obtained from the center of the core and four readings were taken from the periphery of the core (plate 3.5).

iv- Eh and pH readings of sediment.

Eh (mV) and pH readings were taken respectively from the sediment surface as follows. The Eh electrodes were inserted into the

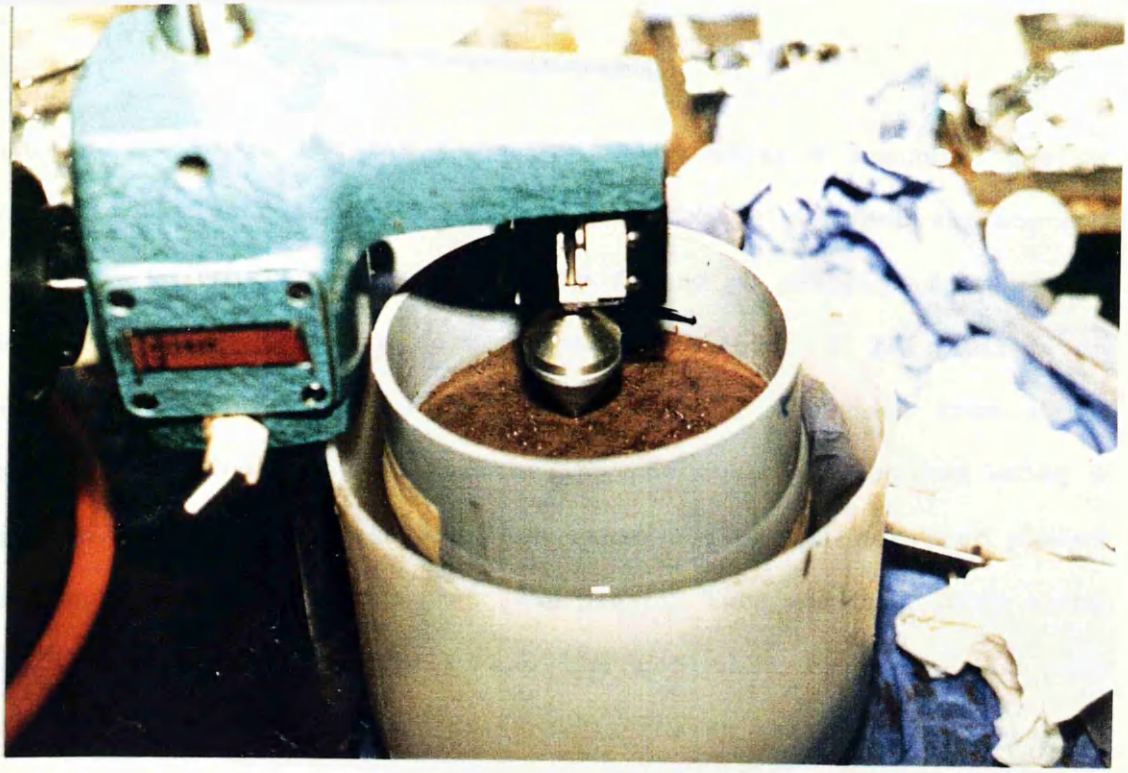


Plate (3.5)

Shear strength experiment. Measurement of shear strength of sediment surface using a Geonor falling cone.

Plate (3.6)

Shear strength experiment. Subcorer pushed into the sediment.

sediment to about 1cm and a reading taken after 5 seconds. The pH combination electrode was then inserted into the sediment surface and a reading taken after 30 seconds. The Eh and pH readings from depths 5cm and 9cm of sediment were taken as follows. A 2.6cm diameter plastic tube was pushed into the sediment in the core from above (plate 3.6). The sediment surrounding the tube was removed using a spatula. The plastic tube was then taken out of the core and placed horizontally on a plastic tray. The plastic tube was then split along its length using a scalpel, and the top half removed. When the sediment column was exposed (plate 3.7), the Eh readings were obtained at 5cm and 9cm (plate 3.8) by inserting the electrodes from above into the horizontal sediment core. The top half of the plastic tube was then replaced and the tube turned over. The new top half was then removed and the readings of pH taken in the same way. The water in the tank was increased again to 40cm and then aerated.

At day 5 and day 10, the shear strength of the sediment surface was taken using the same method described before, using the fall-cone test apparatus.

At the end of experiment (day 15), the measurements of shear strength and Eh and pH were obtained using the same methods.

The depths of penetration (mm) of the cone into the sediment obtained by using the fall-cone test apparatus were then fed into a computer program (MH-SSR) (Appendix 2, table 2) to calculate the shear strength ($kN\ .m^{-2}$) of the sediment in each of the experiments. The program used Hansbo's (1957, pages 22-25) equation.

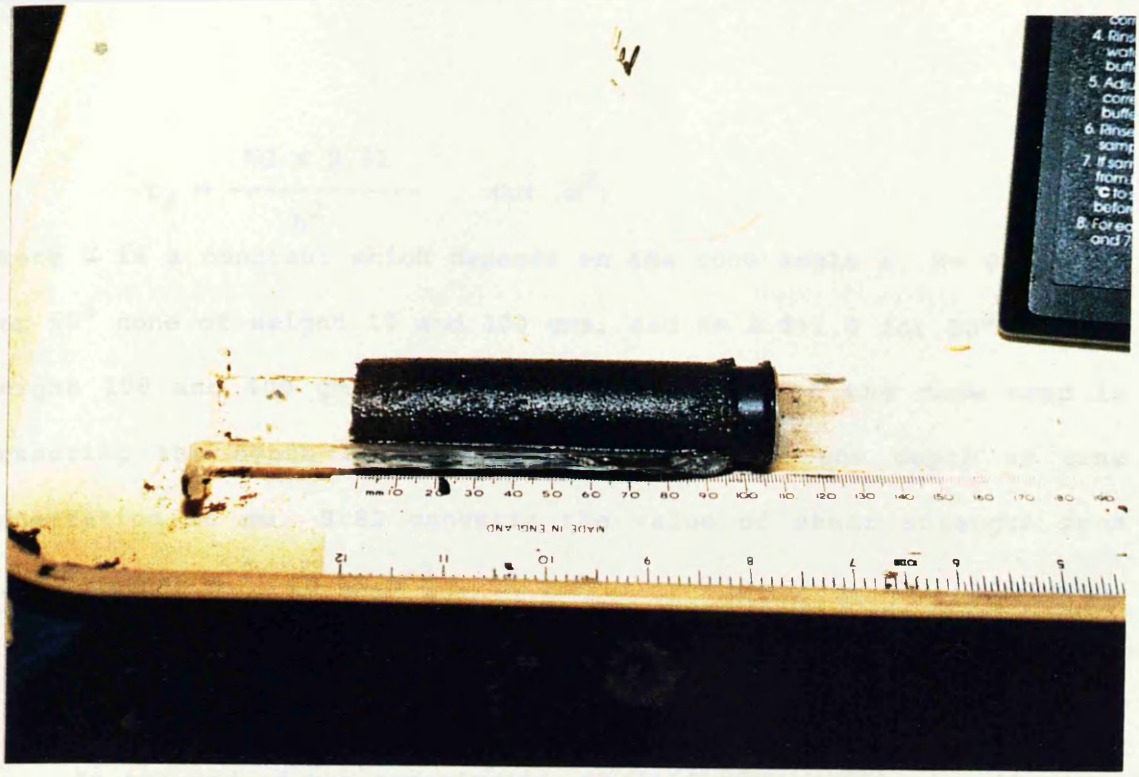


Plate (3.7)

The subcorer placed horizontally on a plastic tray and the top half was removed.

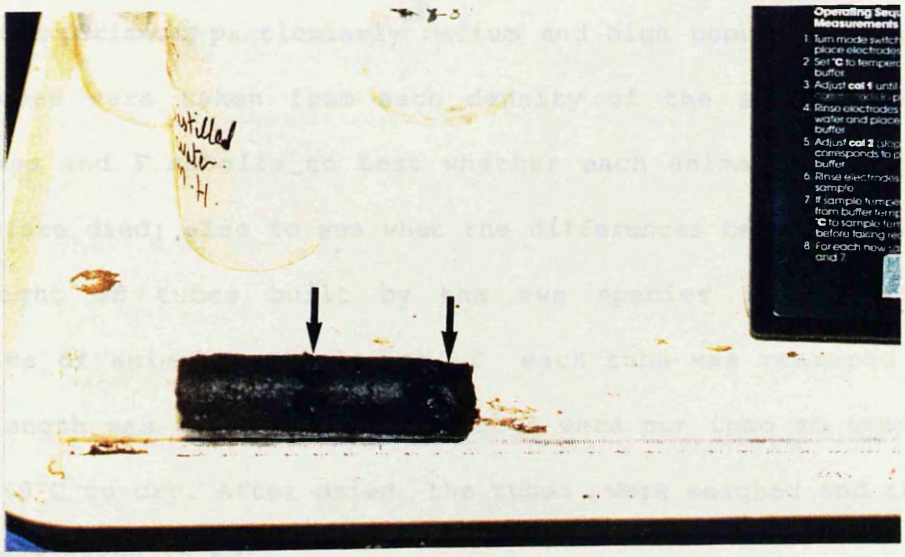


Plate (3.8)

The subcorer. Position of Eh and pH readings taken from the horizontal sediment core. (arrowed)

$$t_f = \frac{KQ \times 9.81}{h^2} \quad (kN \cdot m^2)$$

where K is a constant which depends on the cone angle a. K= 0.20-0.25 for 60^o cone of weight 10 and 100 gms, and K= 0.8-1.0 for 30^o cone of weight 100 and 400 gms. Q is the weight (gms) of the cone used in measuring the depth of cone penetration. h is the depth of cone penetration in mm. 9.81 converts the value of shear strength from $g.mm^{-2}$ ($tones.m^{-2}$) to $kN.m^{-2}$.

Measuring the mortality of animals and construction of tubes

At the end of the experiments, the sediment samples in all cores were sieved through a 0.5mm sieve to extract the animals. The number of surviving animals of *P.elegans* and *F.sabella* species were counted.

Because the high percentage in the mortality occurred at the end of both experiments particularly at medium and high population densities, five tubes were taken from each density of the single species of *P.elegans* and *F.sabella* to test whether each animal built it's own tube before died; also to see what the differences between the length and weight of tubes built by the two species in the different densities of animals. The length of each tube was measured and the total length was taken in mm. The tubes were put into an oven for 24 hrs at 60^oC to dry. After dried, the tubes were weighed and the total weight was taken in mg.

RESULTS

The results of the stability experiment were divided into four sections as follows.

Section 1- Permeability experiment

The results of the coefficient of permeability (mm/sec) are given in table 3.2. The means and standard deviations of permeability of single and mixed species (y axis) were plotted against the low, medium and high densities of animals on days 5, 10 and 15 (x axis) (figure 3.3) and also against days 5, 10 and 15 for control, low, medium and high densities of animals (figure 3.4).

Table 3.2 and figure 3.3 show that the permeability increased in *P.elegans* at different densities compared with the control readings. In *F.sabella*, the permeability decreased in the low and medium densities but increased in the high density. By comparison, permeability increased in the different densities of the mixed species. The table and figure also show that the higher readings of permeability occurred at day 5 and then generally decreased in all densities of *P.elegans*, in the high density of *F.sabella* and in all densities of mixed species. The permeability was low at day 5 in the low density of *F.sabella* and then increased. In the medium density of *F.sabella*, the permeability decreased from day 5 to day 10 and then increased slightly on day 15. The permeability decreased slightly in the control from day 0 to day 15. The table and figure show that there were no great differences in the standard deviations (vertical bars in the figure) for all different densities of the single and

Table (3.2)

Stability experiment. Coefficient of permeability (mm/sec). I, II and III replicate cores of sediment. n.a. = data not available.

	Replicate cores	Coefficient of permeability (mm/sec) at day 0	5	10	15
Control	I	0.0802	0.0734	0.0711	0.0679
	II	0.0877	0.0841	0.0844	0.0843
	III	0.0733	0.0724	0.0706	0.0705
Mean ± s.d.		0.080 ± 0.007	0.077 ± 0.007	0.075 ± 0.008	0.074 ± 0.009
P.elegans Low density	I	n.a.	0.0848	0.0815	0.0789
	II	n.a.	0.0990	0.0937	0.0874
	III	n.a.	0.1058	0.0944	0.0917
Mean ± s.d.			0.097 ± 0.011	0.090 ± 0.007	0.086 ± 0.007
P.elegans Medium density	I	n.a.	0.0889	0.0862	0.0849
	II	n.a.	0.1072	0.0991	0.0955
	III	n.a.	0.0979	0.0951	0.0973
Mean ± s.d.			0.098 ± 0.009	0.093 ± 0.007	0.093 ± 0.007
P.elegans High density	I	n.a.	0.1061	0.0942	0.0950
	II	n.a.	0.1113	0.1016	0.0999
	III	n.a.	0.1125	0.1003	0.1002
Mean ± s.d.			0.110 ± 0.003	0.099 ± 0.004	0.098 ± 0.003
F.sabella Low density	I	n.a.	0.0410	0.0405	0.0569
	II	n.a.	0.0346	0.0425	0.0434
	III	n.a.	0.0549	0.0688	0.0677
Mean ± s.d.			0.044 ± 0.010	0.051 ± 0.016	0.053 ± 0.013
F.sabella Medium density	I	n.a.	0.0519	0.0508	0.0528
	II	n.a.	0.0694	0.0603	0.0591
	III	n.a.	0.0836	0.0781	0.0779
Mean ± s.d.			0.068 ± 0.016	0.063 ± 0.014	0.063 ± 0.013
F.sabella High density	I	n.a.	0.0935	0.0874	0.0864
	II	n.a.	0.0893	0.0870	0.0848
	III	n.a.	0.0909	0.0838	0.0807
Mean ± s.d.			0.091 ± 0.002	0.086 ± 0.002	0.084 ± 0.003

Cont. table (3.2)

	Replicate cores	Coefficient of permeability (mm/sec) at day 0	5	10	15
Mixed species	I	n.a.	0.0971	0.0990	0.0892
P.e. and F.s.	II	n.a.	0.0971	0.0952	0.0843
Low density	III	n.a.	0.0880	0.0938	0.0794
Mean ± s.d.			0.094 ± 0.005	0.096 ± 0.003	0.084 ± 0.005
Mixed species	I	n.a.	0.0938	0.0937	0.0895
P.e. and F.s.	II	n.a.	0.0897	0.0900	0.0894
Medium density	III	n.a.	0.0928	0.0897	0.0908
Mean ± s.d.			0.092 ± 0.002	0.091 ± 0.002	0.090 ± 0.001
Mixed species	I	n.a.	0.1043	0.0997	0.0982
P.e. and F.s.	II	n.a.	0.1125	0.1053	0.1034
High density	III	n.a.	0.1068	0.1006	0.0921
Mean ± s.d.			0.108 ± 0.004	0.102 ± 0.003	0.098 ± 0.006

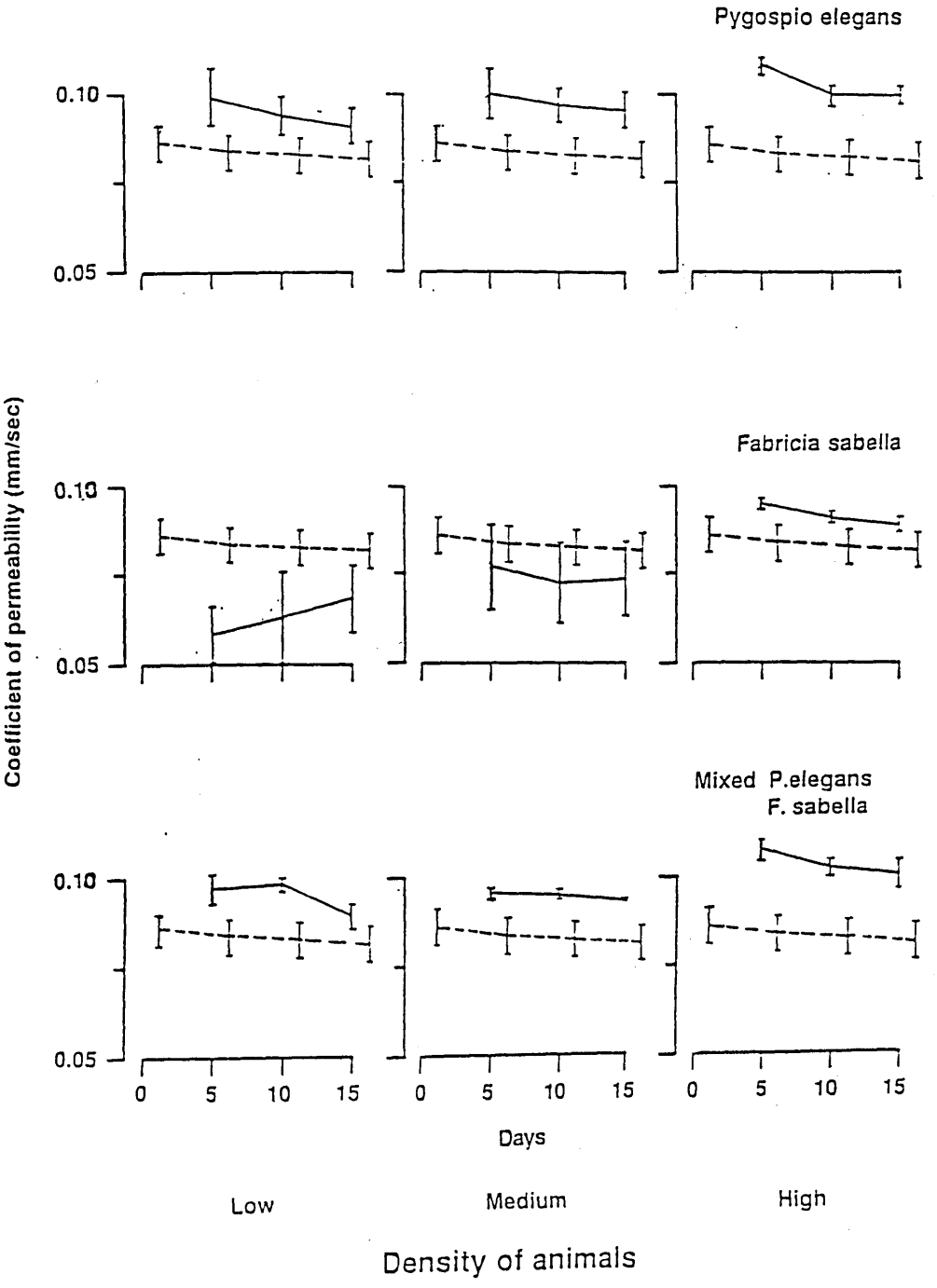


Figure (3.3)

Stability experiment. Means (continued lines) and standard deviations (vertical bars) of the coefficient of permeability (mm/sec) measured in the single and mixed species cores. The broken lines show the readings of the control cores.

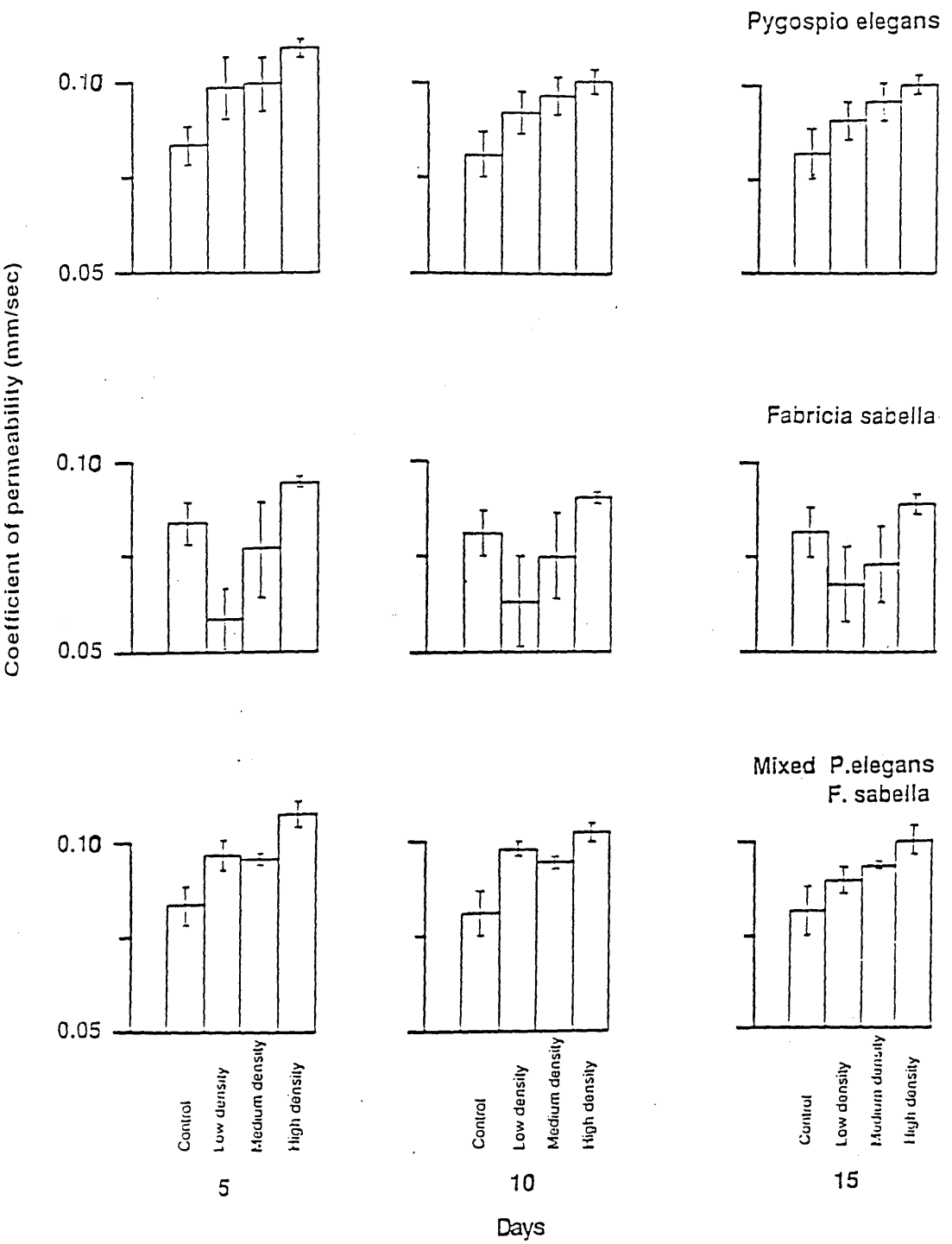


Figure (3.4)

Stability experiment. Histograms of the Means and standard deviations (vertical bars) of the coefficient of permeability (mm/sec) measured in the single and mixed species cores and the control cores.

mixed species except the low and medium densities of *F.sabella*.

Table 3.2 and figure 3.4 show that the permeability increased with increasing density of animals of *P.elegans* and *F.sabella* on days 5, 10 and 15. In the mixed species at days 5 and 10, the readings of permeability in the low density were higher than in the medium density, but this pattern changed on day 15.

The coefficient of permeability obtained from single and mixed species at days 5, 10 and 15 were tested statistically using two way analyses of variance (table 3.3). The table shows that the interaction was not significant. Therefore, the F.ratio of the two factors A and B can be used. Factor A (species) was highly significant but factor B (days) was only marginally so. The permeabilities obtained from the single and mixed species on each day were also tested statistically using one way analyses of variance (table 3.4). The table shows that on days 5, 10 and 15 the readings of permeability gave highly significant differences between the single and mixed species. The differences in permeability on day 15 were further tested statistically using students t tests (table 3.5). The table shows that 20/45 ($P>0.10$) t tests were not significant, 12/45 were neither significant nor not significant ($0.10>P>0.05$), 11/45 were significant ($0.05>P>0.02$), and 2/45 were highly significant ($0.02>P>0.001$).

These tests show that most of the significant differences occurred when the medium and high densities of animals, particularly *P.elegans*, were compared with the other densities. This means that the increased number of animals causes marked increases in permeability of sediment.

Table (3.3)

Stability experiment. Two way analysis of variance on permeability ($mm.sec^{-1}$). Factor A: single and mixed species experiments.

Factor B: days (5, 10 and 15).

Factor	Sum of square	Mean of square	Degrees of freedom	F. ratio	Probability
A (species)	0.0228	0.0025	9	40.87	P<0.001
B (days)	0.0004	0.0002	2	3.289	0.05>P>0.025
Interaction	0.0009	0.0001	18	0.760	P>0.75
Error	0.0037	0.0001	60		
Total	0.0278		89		

Table (3.4)

Stability experiment. Three one way analyses of variance of the permeability experiment, testing the differences between the single and mixed species experiments at days 5, 10 and 15. Each analysis was a 1 X 10 one way anovar. The 10 levels in each of the three one way analyses of variance were control of experiment, low, medium and high densities of *P.elegans*, low, medium and high densities of *F.sabella*, low, medium and high densities of mixed species.

Source	Sum of square	Mean of square	Degrees of freedom	F. ratio	Probability
Day 5	0.0108	0.0012	9	18.07	P< 0.001
Error	0.0011	0.0001	20		****
Total	0.0065		29		
Day 10	0.0054	0.0006	9	12.94	P< 0.001
Error	0.0011	0.0001	20		****
Total	0.0065		29		
Day 15	0.0054	0.0006	9	10.78	P< 0.001
Error	0.0011	0.0001	20		****
Total	0.0065		29		

* Degree of significant.

	Control	*P.elegans* (L.D.)	*P.elegans* (M.D.)	*P.elegans* (H.D.)	*F.sabella* (L.D.)	*F.sabella* (M.D.)	*F.sabella* (H.D.)	Mixed spec. P.e.&F.s.	Mixed spec. P.e.&F.s.	Mixed spec P.e.&F.s.
Control	-	NS	?	*	?	NS	NS	NS	?	*
P.elegans (L.D.)	- 1.86	-	NS	?	?	NS	NS	NS	NS	?
P.elegans (M.D.)	- 2.87	- 1.22	-	NS	*	?	NS	NS	NS	NS
P.elegans (H.D.)	- 4.50	- 3.00	- 1.37	-	*	*	***	*	*	NS
F.sabella (L.D.)	2.36	3.94	4.69	5.86	-	NS	?	?	*	*
F.sabella (M.D.)	1.21	2.70	3.46	4.54	- 0.99	-	NS	NS	?	?
F.sabella (H.D.)	- 1.81	0.49	2.04	6.02	- 4.03	- 2.68	-	NS	?	*
Mixed species P.e.&F.s.(L.D.)	- 1.73	0.36	1.72	4.27	- 3.91	- 2.61	- 0.10	-	NS	?
Mixed species P.e.&F.s.(M.D.)	- 3.07	- 1.03	0.68	4.85	- 4.90	- 3.53	- 3.38	- 1.95	-	NS
Mixed species P.e.&F.s.(H.D.)	- 3.91	2.39	- 1.05	0.13	- 5.48	- 4.22	- 3.79	- 3.15	- 2.43	-

Table (3.5)

Stability experiment. T test on coefficients of permeability (mm/sec). Symbols:

NS = not significant. (P>0.10)

? = neither significant nor not significant. (0.10>P>0.05)

* = significant. (0.05>P>0.02)

** and *** = highly significant. (0.02>P>0.001)

**** = very high significance. (P<0.001)

Section 2: Shear strength experiment

The shear strength (kN/m^2) readings are given in table 3.6. The means and standard deviations of shear strength (y axis) were first plotted against different days (x axis) for each density of animals (figure 3.5), and second against control, *P.elegans*, *F.sabella* and mixed species (x axis) for each day of low, medium and high densities of animals (figure 3.6).

The table 3.6 and figure 3.5 show that the shear strength increased with increasing density of animals for single and mixed species. As time passed, the shear strength increased. The figure shows that there was no great difference in the shear strength between the low densities single species and the control, but in the mixed species there was a difference. The pattern of variation remained generally the same on days 5, 10 and 15.

Table 3.6 and figure 3.6 show that the highest reading of shear strength occurred in the mixed species. At low and medium densities, the shear strength readings of *F.sabella* were higher than the readings of *P.elegans*, but in the high density the readings of shear strength of *P.elegans* were higher than the readings of *F.sabella*.

The data of shear strength obtained from the control and different densities of the single and mixed species at days 5, 10 and 15 were tested statistically using two way analysis of variance (table 3.7). The table shows that there was a highly significant interaction. Therefore, nothing can be said about the significance of the two factors A (species) and B (days).

The data of shear strength were therefore statistically analysed using one way analyses of variance (table 3.8). The table

Table (3.6)

Stability experiment. Shear strength readings (kN /m^2). I, II and III replicate cores of sediment. n.a. = data not available.

Treatment	Replicate cores	Shear stength values (kN/m^2) at day 0	5	10	15
Control	I	1.0128	1.3530	1.1053	1.1909
	II	0.9856	1.2969	1.3094	1.5831
	III	0.9967	1.0224	1.1667	1.2280
Mean ± s.d.		0.998 ± 0.014	1.291 ± 0.065	1.194 ± 0.105	1.334 ± 0.217
P.elegans	I	n.a.	1.2892	1.0872	1.5337
	II	n.a.	1.2917	1.5281	1.5710
Low density	III	n.a.	1.1492	1.2833	1.3881
Mean ± s.d.			1.243 ± 0.082	1.300 ± 0.221	1.478 ± 0.097
P.elegans	I	n.a	1.7447	1.5880	2.0291
	II	n.a.	1.3304	1.4365	1.6689
Medium density	III	n.a.	1.3653	1.5086	1.7733
Mean ± s.d.			1.480 ± 0.230	1.511 ± 0.076	1.824 ± 0.185
P.elegans	I	n.a.	2.0355	2.1742	2.6547
	II	n.a.	1.5034	2.1527	1.8692
High density	III	n.a.	1.5958	2.1519	2.0321
Mean ± s.d.			1.712 ± 0.284	2.160 ± 0.013	2.185 ± 0.415
F.sabella	I	n.a.	0.9825	1.1230	1.6005
	II	n.a.	1.3644	1.3647	1.5483
Low density	III	n.a.	1.7572	1.8125	2.2967
Mean ± s.d.			1.368 ± 0.387	1.433 ± 0.350	1.815 ± 0.418
F.sabella	I	n.a.	2.1228	1.9387	2.4673
	II	n.a.	1.3620	1.4647	1.8397
Medium density	III	n.a.	2.0933	2.4232	1.9562
Mean ± s.d.			1.859 ± 0.431	1.942 ± 0.479	2.088 ± 0.334
F.sabella	I	n.a.	1.3646	1.6115	2.0656
	II	n.a.	1.3405	1.6105	1.9088
High density	III	n.a.	1.5281	1.8870	2.1926
Mean ± s.d.			1.411 ± 0.102	1.703 ± 0.159	2.056 ± 0.142

Cont. table (3.6)

Treatment	Replicate cores	Shear stength values (kN/m^2) at day 0	5	10	15
Mixed species	I	n.a.	1.8120	1.9310	2.7895
P.e. and F.s.	II	n.a.	2.1742	1.9562	3.0065
Low density	III	n.a.	2.0334	1.7800	2.1926
Mean ± s.d.			2.007 ± 0.183	1.892 ± 0.099	2.688 ± 0.380
Mixed species	I	n.a.	1.7882	2.0657	3.2443
P.e. and F.s.	II	n.a.	1.4949	1.8747	2.8629
Medium density	III	n.a.	2.2710	1.9786	3.1872
Mean ± s.d.			1.851 ± 0.392	1.973 ± 0.096	3.098 ± 0.206
Mixed species	I	n.a.	1.9485	3.6396	6.0541
P.e. and F.s.	II	n.a.	1.6154	3.1512	5.9953
High density	III	n.a.	1.6005	2.3668	5.9614
Mean ± s.d.			1.722 ± 0.197	3.053 ± 0.642	6.004 ± 0.047

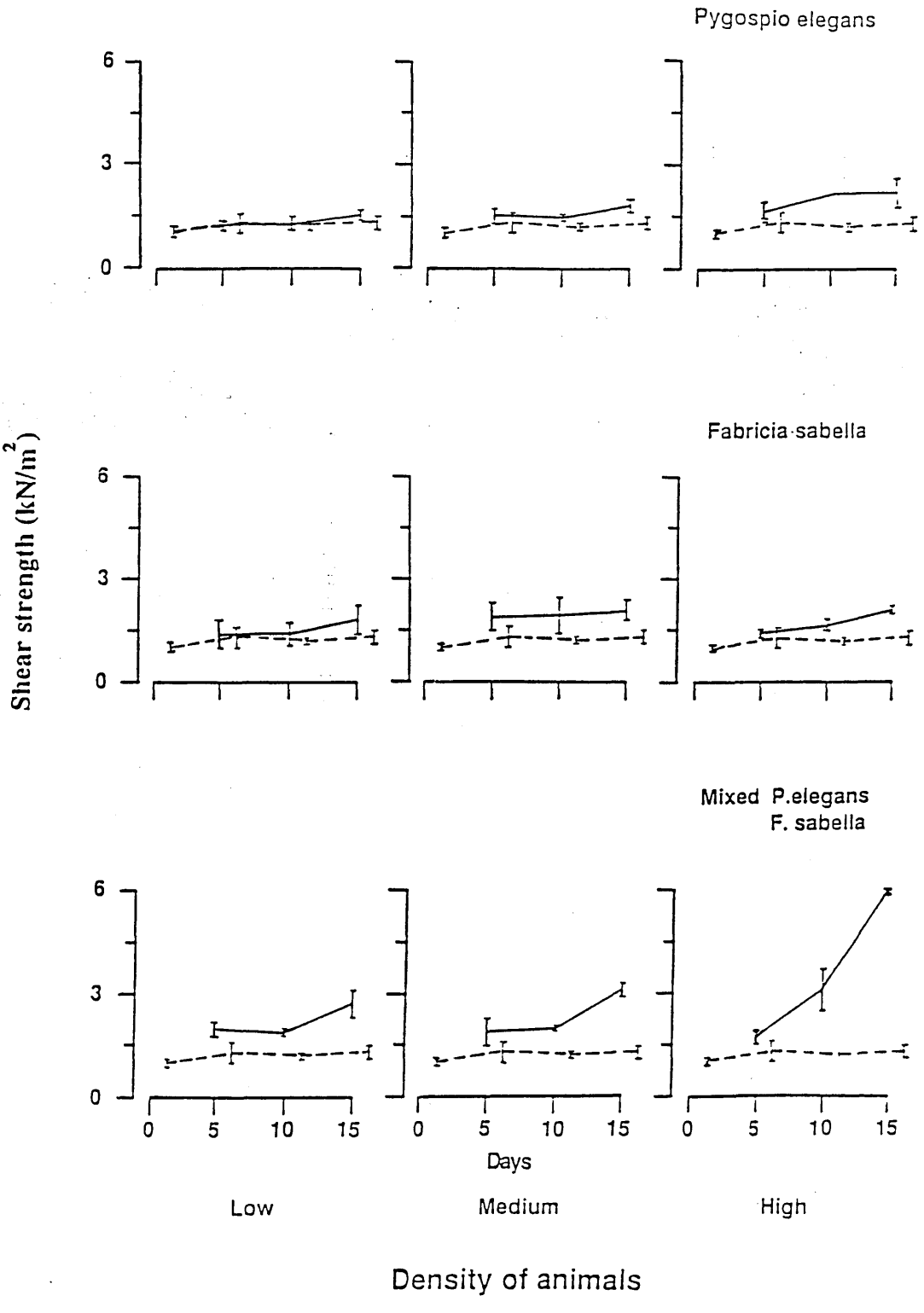


Figure (3.5)

Stability experiment. Means (continued lines) and standard deviations (vertical bars) of the shear strength (kN/m^2) measured in the single and mixed species cores. The broken lines show the readings of the control cores.

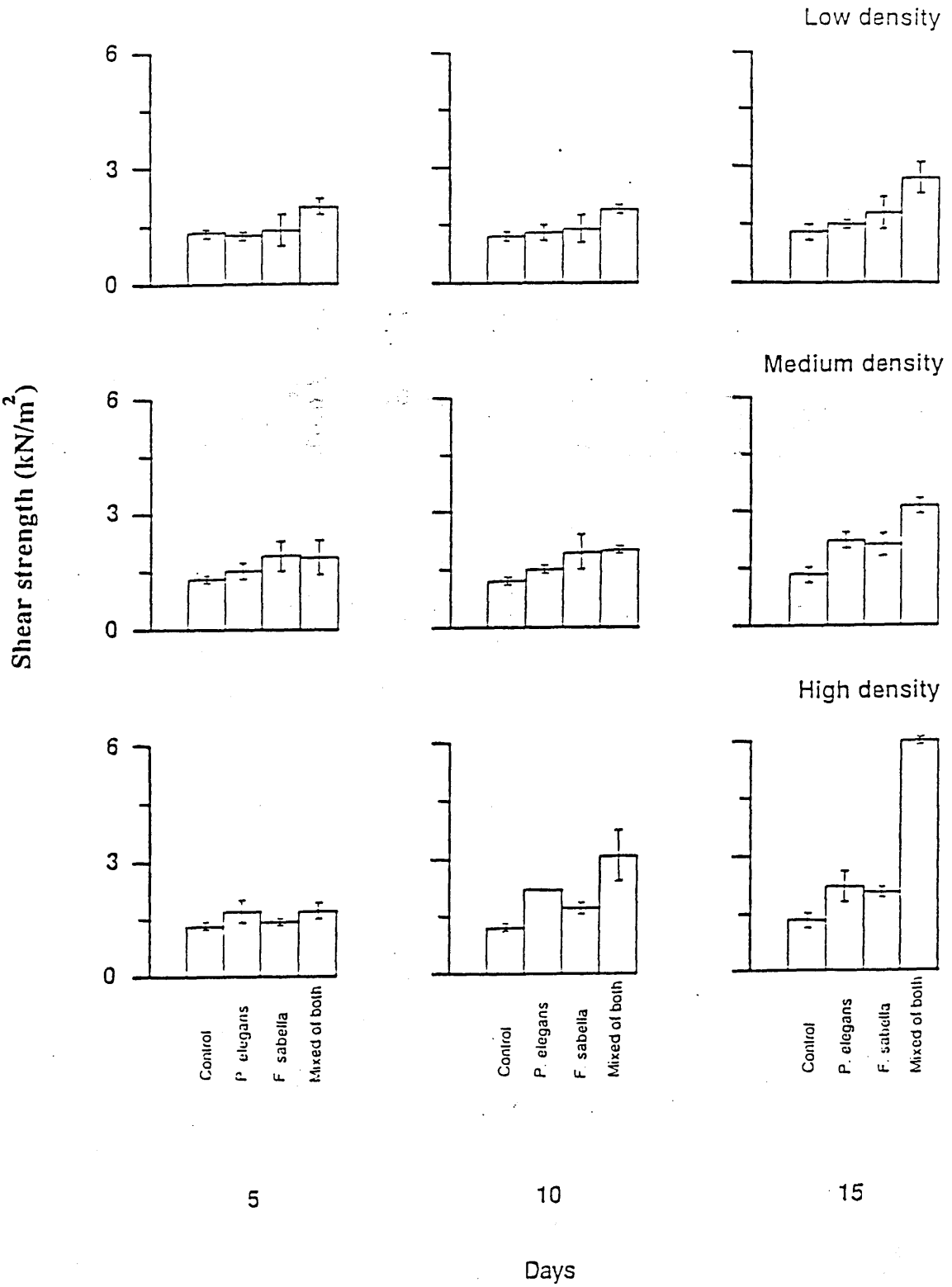


Figure (3.6)

Stability experiment. Histograms of the means and standard deviations (vertical bars) of the shear strength (kN/m^2) measured in the single and mixed species cores and the control cores.

Table (3.7)

Stability experiment. Two way analyses of variance on the shear strength (kN $.m^{-2}$) experiment.

Factor A: single and mixed species experiments.

Factor B: days (5, 10 and 15).

Factor	Sum of square	Mean of square	Degrees of freedom	F. ratio	Probability
A (species)	36.639	4.071	9	12.924	
B (days)	12.100	6.050	2	19.206	
Interaction	22.310	1.239	18	3.9333	P>0.001
Error	18.906	0.315	60		
Total	89.955		89		

Table (3.8)

Stability experiment. Three one way analyses of variance of the shear strength experiment, testing the differences between the single and mixed species experiments at days 5, 10 and 15. Each analysis was a 1 X 10 one way anovar. The 10 levels in each of the three one way analyses of variance were control of experiment, low medium and high densities of *P.elegans*, low, medium and high densities of *F.sabella*, low medium and high densities of mixed species.

Source	Sum of square	Mean of square	Degrees of freedom	F. ratio	Probability
Day 5	2.0761	0.2307	9	3.10	0.2>P>0.10
Error	1.4882	0.0744	20		
Total	3.5643		29		
Day 10	7.7970	0.8663	9	9.92	P< 0.0001
Error	1.7473	0.0874	20		****
Totl	9.5444		29		
Day 15	49.093	5.455	9	6.96	P< 0.0001
Error	15.667	0.783	20		****
Total	64.760		29		

* degree of significant.

	Control	*P.elegans* (L.D.)	*P.elegans* (M.D.)	*P.elegans* (H.D.)	*F.sabella* (L.D.)	*F.sabella* (M.D.)	*F.sabella* (H.D.)	Mixed spec. P.e.&F.s. (L.D.)	Mixed spec. P.e.&F.s. (M.D.)	Mixed spec. P.e.&F.s. (H.D.)
Control	-	NS	?	?	NS	*	**	**	***	****
P.elegans (L.D.)	- 1.20	-	?	NS	NS	?	**	**	***	****
P.elegans (M.D.)	- 2.98	- 2.70	-	NS	NS	NS	NS	?	***	****
P.elegans (H.D.)	- 3.15	- 2.78	- 1.38	-	NS	NS	NS	NS	?	***
F.sabella (L.D.)	- 1.77	- 1.28	0.03	1.09	-	NS	NS	?	**	***
F.sabella (M.D.)	- 3.28	- 2.94	- 1.20	0.32	- 0.88	-	NS	NS	*	***
F.sabella (H.D.)	- 4.83	- 5.62	- 1.72	0.51	- 0.94	0.15	-	NS	***	****
Mixed species P.e.&F.s.(L.D.)	- 4.86	- 4.67	- 3.16	- 1.40	- 2.47	- 1.85	- 2.36	-	NS	***
Mixed species P.e.&F.s.(M.D.)	- 10.23	- 12.20	- 7.97	- 3.42	- 4.77	- 4.46	- 7.22	- 1.61	-	***
Mixed species P.e.&F.s. (H.D.)	- 36.51	- 72.65	- 37.87	- 15.85	- 17.25	- 20.12	- 45.68	- 13.64	- 23.85	-

Table (3.9)

Stabilty experiment. T test on shear strength ($kN.m^{-2}$).

Symbols:

NS = not significant. (P>0.10)

? = neither significant nor not significant. (0.10>P>0.05)

* = significant. (0.05>P>0.02)

** and *** = highly significant. (0.02>P>0.001)

**** = very high significance. (P<0.001)

shows that there was no significant difference between the readings of shear strength on day 5, but that there were highly significant differences on days 10 and 15. The data for day 15 were then analysed further using students t tests (table 3.9). The table shows that 18/45 t tests were not significant ($P>0.10$), 7/45 were neither significant nor not significant ($0.10>P>0.05$). 2/45 were significant ($0.05>P>0.02$), 14/45 were highly significant ($0.02>P>0.001$))and 4/45 were very high significant ($P<0.001$). Most of the high and very high significant differences occurred when the high density of mixed species were compared with the control and the other densities of both *P.elegans* and *F.sabella* species. This means that shear strength of sediment surface is dramatically increased with increase of the population densities of the mixed species more than the increase population densities of the single species.

Section 3: Eh and pH measurements

Eh measurement

The Eh readings are given in table 3.10. The means and standard deviations were calculated and shown in the same table.

The means and standard deviations of Eh were plotted against depths of sediment for each density of animals of single and mixed species (figure 3.7).

Table 3.10 and figure 3.7 show that the Eh decreased with depths in the single and mixed species. Eh was high at the surface of the sediment, and decreased with depth. Eh obtained from different densities of single and mixed species was less than the control at depths 5cm and 9cm.

Table (3.10)

Stability experiment. Eh (mV) measurements. I, II and III replicate cores of sediment.

Treatment	Replicate cores	Depth of sediment: Overlying water	Surface	5cm	9cm
Control at beginning of experiment	I	+ 469	+ 215	+ 181	+ 134
	II	+ 426	+ 240	+ 174	+ 144
	III	+ 437	+ 221	+ 141	+ 109
Mean ± s.d.		444 ± 22.34	225 ± 13.05	165 ± 21.36	129 ± 18.03
Control at the end of experiment	I	+ 523	+ 449	+ 204	+ 156
	II	+ 524	+ 377	+ 139	+ 37
	III	+ 510	+ 325	+ 119	+ 117
Mean ± s.d.		519 ± 7.81	383 ± 62.27	154 ± 44.44	103 ± 60.67
P.elegans Low density	I	+ 552	+ 509	+ 174	+ 129
	II	+ 531	+ 529	+ 172	+ 74
	III	+ 539	+ 537	+ 104	+ 99
Mean ± s.d.		541 ± 10.60	525 ± 14.42	150 ± 39.85	101 ± 27.54
P.elegans Medium density	I	+ 559	+ 544	+ 124	+ 99
	II	+ 519	+ 502	+ 127	+ 115
	III	+ 538	+ 494	+ 172	+ 145
Mean ± s.d.		539 ± 20.01	513 ± 26.86	141 ± 26.89	120 ± 23.35
P.elegans High density	I	+ 580	+ 525	+ 309	+ 97
	II	+ 515	+ 394	+ 119	+ 114
	III	+ 516	+ 489	+ 202	+ 92
Mean ± s.d.		537 ± 37.24	469 ± 67.69	210 ± 95.25	101 ± 11.53
F.sabella Low density	I	+ 544	+ 469	+ 203	+ 158
	II	+ 519	+ 324	+ 124	+ 109
	III	+ 539	+ 324	+ 144	+ 139
Mean ± s.d.		534 ± 13.23	372 ± 83.72	157 ± 41.07	135 ± 24.71
F.sabella Medium density	I	+ 544	+ 512	+ 189	+ 117
	II	+ 513	+ 461	+ 219	+ 97
	III	+ 527	+ 509	+ 154	+ 142
Mean ± s.d.		528 ± 15.52	494 ± 28.62	187 ± 32.53	119 ± 22.55

Cont. table (3.10)

Treatment	Replicate cores	Depth of sediment: Overlying water	Surface	5cm	9cm
F.sabella	I	+ 512	+ 377	+ 194	+ 146
	II	+ 49	+ 473	+ 99	+ 85
High density	III	+ 526	+ 443	+ 210	+ 172
Mean ± s.d.		512 ± 13.50	418 ± 71.45	168 ± 60.00	134 ± 44.61
Mixed species	I	+ 515	+ 490	+ 238	+ 94
P.e. and F.s.	II	+ 499	+ 471	+ 147	+ 42
Low density	III	+ 438	+ 427	+ 49	- 17
Mean ± s.d.		484 ± 40.63	463 ± 32.32	145 ± 94.52	40 ± 55.54
Mixed species	I	+ 445	+ 399	+ 275	+ 9
P.e. and F.s.	II	+ 451	+ 423	+ 55	0
Medium density	III	+ 402	+ 404	+ 59	+ 47
Mean ± s.d.		433 ± 26.73	409 ± 12.66	130 ± 125.9	19 ± 24.95
Mixed species	I	+ 382	+ 379	+ 79	+ 29
P.e. and F.s.	II	+ 418	+ 399	+ 142	+ 52
High density	III	+ 464	+ 371	+ 101	+ 83
Mean ± s.d.		421 ± 41.10	383 ± 14.4	107 ± 31.97	55 ± 27.10

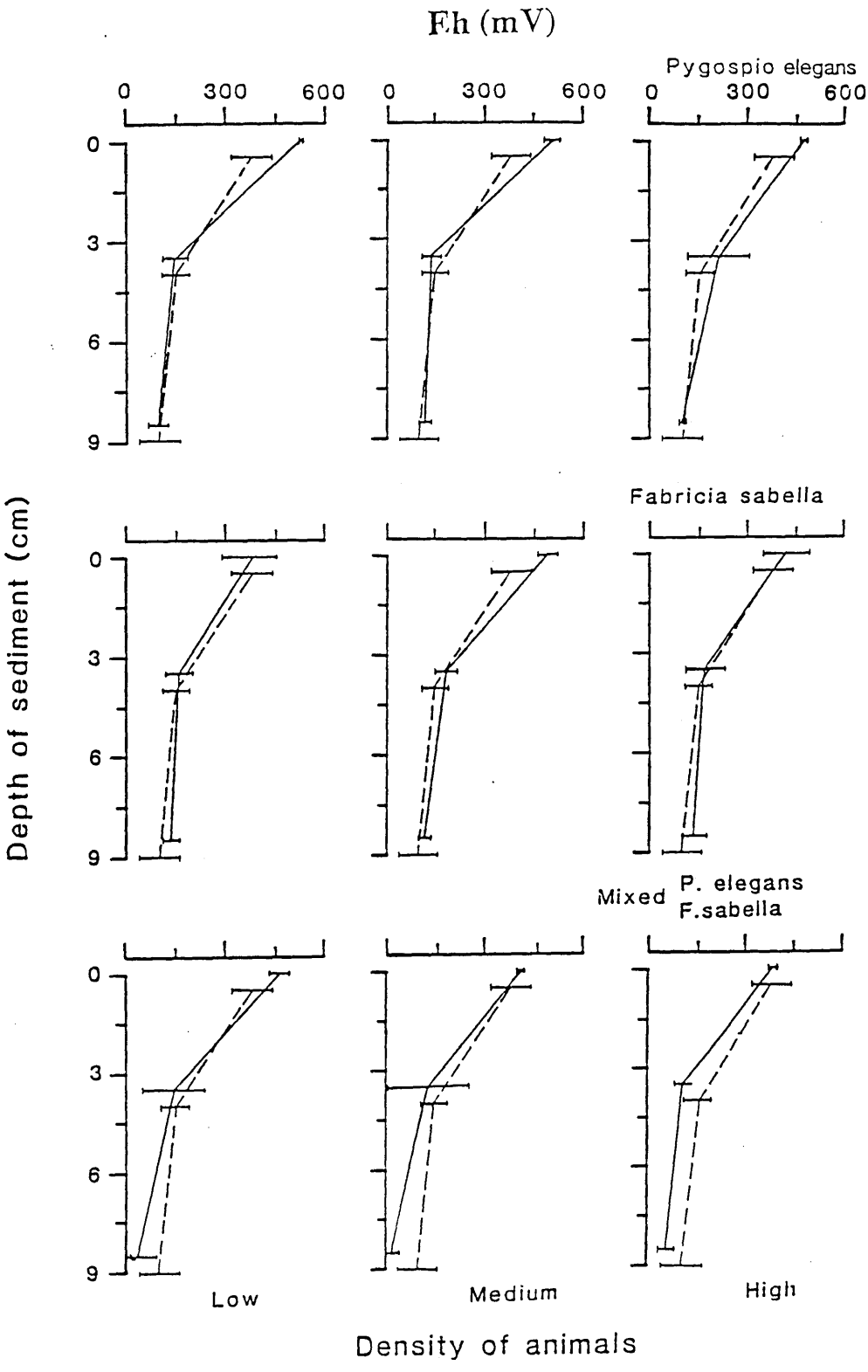


Figure (3.7)

Stability experiment. Means (continued lines) and standard deviations (horizontal bars) of the Eh (mV) readings measured in the single and mixed species cores. The broken lines show the readings of the control cores.

The differences in Eh between the control, and single and mixed species at the end of experiment were tested statistically using one way analyses of variance. This was done for the overlying water, the sediment surface, and the 5cm and the 9cm depths (table 3.11). The table shows that there were only significant differences in the overlying water data, the sediment surface data and the 9cm depth. These effects are not obvious in figure 3.7 but can be clearly seen in the histograms of Eh data of different animal species and densities for different layers (figure 3.8).

The significant differences in Eh data were further tested using students t tests (table 3.12). The table shows that in the overlying water, the significant differences occurred in the medium and high densities of mixed species when compared with control and other densities of single species. At depth 5cm, highly significant differences were found in the medium and high densities of mixed species when compared with low and medium densities of *P.elegans*. The table also shows that at depth 5cm, significant differences occurred in the medium and high densities of mixed species when compared with medium density of *F.sabella*. At depth 9cm, most of significant differences occurred when the medium density of mixed species compared with the different densities of *P.elegans* and *F.sabella* species.

Table 3.10, figures 3.7 and 3.8 and the statistical analyses show that the Eh readings were low in the different densities of mixed species comparing with control and different densities of single species.

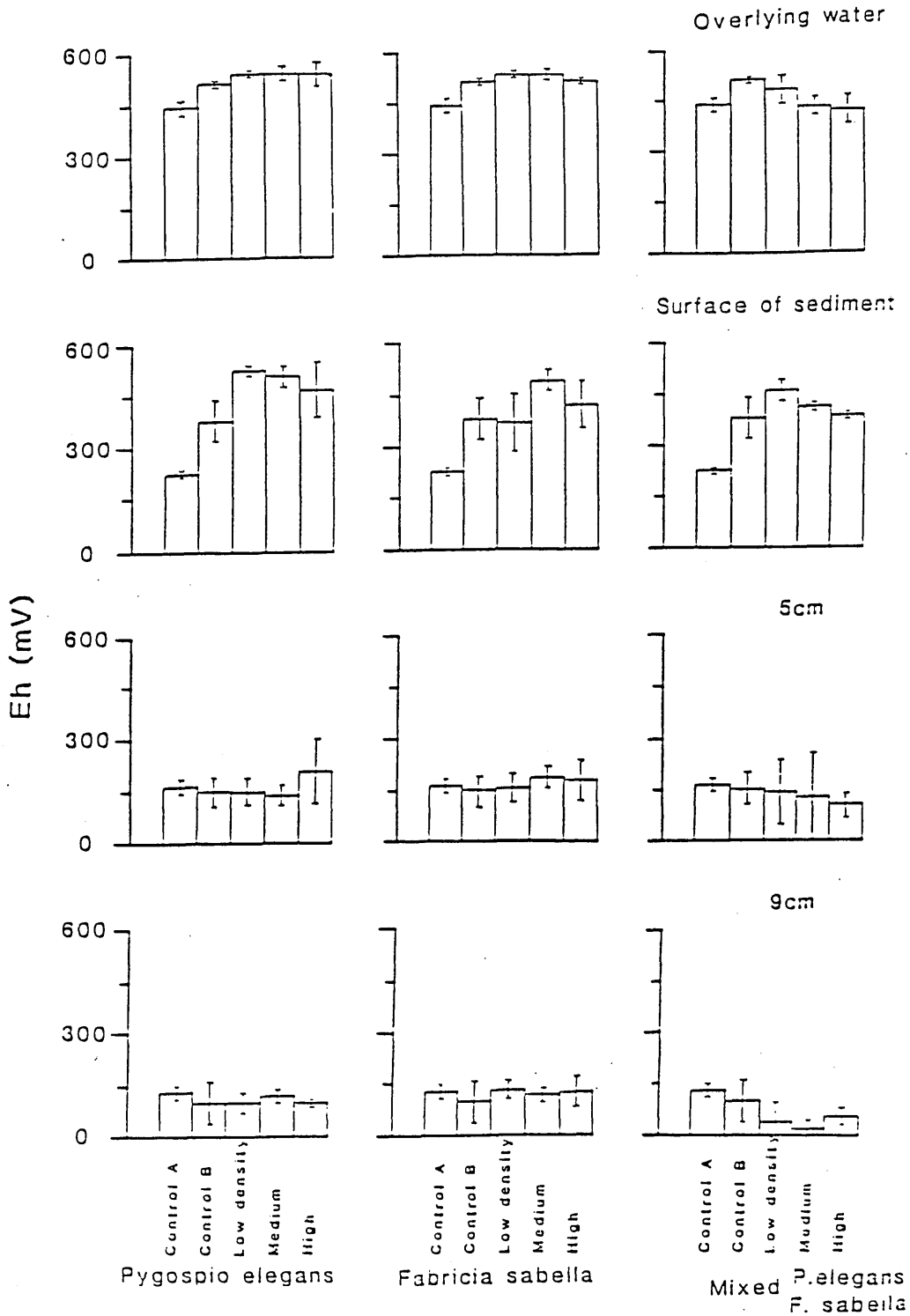


Figure (3.8)

Stability experiment. Histograms of the means and standard deviations (horizontal bars) of the Eh (mV) readings measured in the single and mixed species cores and the control cores.

Table (3.11)

Stability experiment. Four one way analyses of variance of Eh readings taken from the overlying water and different layers of sediment (surface, 5cm and 9cm), testing the differences between single and mixed species experiments. Each analysis was a 1 X 10 way anovar. The 10 levels in each of the four one way analyses of variance were control of experiment, low, medium and high densities of *P.elegans*, low, medium and high densities of *F.sabella*, low, medium and high densities of mixed species.

Layers	Source	Sum of square	Mean square	Degrees of freedom	F. ratio	Probability
Overlying water	Between species	53166	5907	9	8.93	P< 0.001
	Error	13227	661	20		****
	Total	66393		29		
Surface	Between species	86920	9658	9	4.08	0.005>P>0.001
	Error	47315	2366	20		***
	Total	134235		29		
5cm	Between species	22432	2492	9	0.55	P> 0.75
	Error	91013	4551	20		
	Total	113445		29		
9cm	Between species	43098	4789	9	3.57	0.01>P>0.005
	Error	26845	1342	20		**
	Total	69943		29		

* Degree of significance.

		Control	*P.elegans* (L.D.)	*P.elegans* (M.D.)	*P.elegans* (H.D.)	*F.sabella* (L.D.)	*F.sabella* (M.D.)	*F.sabella* (H.D.)	Mixed spec. P.e.&F.s. (L.D.)	Mixed spec. P.e.&F.s. (M.D.)	Mixed spe P.e.&F.s. (H.D.)
Control	(OW)	-	?	NS	NS	NS	NS	NS	NS	*	?
	(0)	-	*	?	NS	NS	NS	NS	NS	NS	NS
	(9)	-	NS	NS	NS	NS	NS	NS	NS	NS	NS
P.elegans	(OW)	2.85	-	NS	NS	NS	NS	?	NS	**	*
(L.D.)	(0)	3.83	-	NS	NS	?	NS	?	?	***	****
	(9)	0.09	-	NS	NS	NS	NS	NS	NS	*	NS
P.elegans	(OW)	1.59	0.15	-	NS	NS	NS	NS	NS	**	*
(M.D.)	(0)	3.31	0.66	-	NS	NS	NS	?	NS	*	***
	(9)	0.40	0.91	-	NS	NS	NS	NS	NS	*	?
P.elegans	(OW)	0.85	0.16	0.07	-	NS	NS	NS	NS	*	*
(H.D.)	(0)	1.61	1.39	1.05	-	NS	NS	NS	NS	NS	NS
	(9)	0.09	0.02	1.24	-	NS	NS	NS	NS	*	NS
F.sabella	(OW)	1.69	0.68	0.34	0.13	-	NS	NS	NS	*	*
(L.D.)	(0)	0.19	3.11	2.78	1.56	-	NS	NS	NS	NS	NS
	(9)	0.80	1.62	0.80	2.18	-	NS	NS	NS	*	*
F.sabella	(OW)	1.27	1.11	0.63	0.31	0.38	-	NS	NS	*	*
(M.D.)	(0)	2.79	1.68	0.85	0.58	2.38	-	NS	NS	*	*
	(9)	0.38	0.88	0.05	1.21	0.86	-	NS	NS	*	?
F.sabella	(OW)	0.78	2.76	1.89	1.11	1.96	1.64	-	NS	NS	NS
(H.D.)	(0)	1.03	3.18	2.55	0.79	1.05	1.92	-	NS	NS	NS
	(9)	0.68	1.11	0.50	1.25	0.03	0.54	-	NS	*	?
Mixed species	(OW)	1.47	2.34	2.09	1.67	2.03	1.87	1.09	-	NS	NS
P.e.&F.s.(L.D.)	(0)	1.95	3.05	2.09	0.15	1.74	1.26	0.93	-	NS	?
	(9)	1.35	1.70	2.30	1.87	2.73	2.28	2.30	-	NS	NS
Mixed species	(OW)	5.37	6.51	5.50	3.94	5.89	5.69	4.44	1.83	-	NS
P.e.&F.s.(M.D.)	(0)	0.68	10.50	6.11	1.53	0.74	4.72	0.76	2.69	-	NS
	(9)	2.22	3.82	5.12	5.19	5.76	5.15	3.92	0.60	-	NS
Mixed species	(OW)	4.04	4.87	4.45	3.61	4.52	4.37	3.56	1.88	3.40	-
P.e.&F.s.(H.D.)	(0)	0.02	12.06	7.41	2.16	0.22	6.00	1.62	3.90	2.32	-
	(9)	1.27	2.06	3.15	2.72	3.81	3.14	2.64	0.42	1.69	-

Table (3.12)
Stability experiment. T test on Eh (mV) readings.
Symbols:
NS = not significant. (P>0.10)
? = neither significant nor not significant. (0.10>P>0.05)
* = significant. (0.05>P>0.02)
** and *** = highly significant. (0.02>P>0.001)
**** = very high significance. (P<0.001)
(OW) = Overlying water, (0) = Sediment surface, and (9) = Depth of 9cm

pH measurements

The pH readings are given in table 3.13. The mean and standard deviation were calculated and are also shown in the table. The means and standard deviations of pH were then plotted against different depths of sediment (figure 3.9). The table and figure show that the pH increased with increasing depths, and that readings of the different densities of single and mixed species were higher than the controls.

The pH data were tested statistically using one way analyses of variance. These analyses firstly tested differences between the control and the different animal species and densities, for the overlying water, the sediment surface, and the 5cm and 9cm depths. A second set of analyses tested differences in pH between the different depths of sediment. The results of the first set of analyses of variance are shown in table 3.14. The table shows that there were significant differences in the overlying water data, the 5cm data and the 9cm data. These effects are not obvious in figure 3.9 but can be clearly seen in the histograms of pH data of different animal species and densities for different layers (figure 3.10).

The significant differences shown in table 3.14 was further tested statistically using students t tests (table 3.15). The table shows that in the overlying water, the high significant differences occurred in the low density of *P.elegans* when compared with the control, the high density of *P.elegans*, the high density of *F.sabella* and the low and medium densities of mixed species. High significant differences also occurred in the depth of 9cm when the control data and compared with the low and medium densities of *P.elegans* and *F.sabella*. It is not immediately obvious why there should be these significant

Table (3.13)

Stability experiment. pH measurments. I, II and III replicate cores of sediment.

Species	Replicate cores	Depth of sediment			
		Overlying water	Surface	5cm	9cm
Control at beginning of experiment	I	7.73	7.46	7.59	7.68
	II	7.45	7.47	7.70	7.69
	III	7.29	7.54	7.68	7.76
Mean ± s.d.		7.49 ± 0.22	7.49 ± 0.04	7.66 ± 0.06	7.71 ± 0.04
Control at the end of experiment	I	7.35	7.04	7.55	7.56
	II	7.30	7.06	7.45	7.47
	III	7.32	7.09	7.44	7.48
Mean ± s.d.		7.32 ± 0.03	7.06 ± 0.03	7.48 ± 0.06	7.50 ± 0.05
P.elegans Low density	I	7.52	6.90	7.66	7.72
	II	7.48	7.07	7.70	7.72
	III	7.55	7.01	7.61	7.71
Mean ± s.d.		7.52 ± 0.04	6.99 ± 0.09	7.66 ± 0.05	7.72 ± 0.01
P.elegans Medium density	I	7.45	7.21	7.76	7.81
	II	7.40	7.17	7.74	7.71
	III	7.35	7.28	7.67	7.82
Mean ± s.d.		7.40 ± 0.05	7.22 ± 0.06	7.72 ± 0.05	7.78 ± 0.06
P.elegans High density	I	7.34	7.20	7.62	7.60
	II	7.36	7.18	7.71	7.73
	III	7.30	7.14	7.76	7.78
Mean ± s.d.		7.33 ± 0.03	7.17 ± 0.03	7.70 ± 0.07	7.70 ± 0.09
F.sabella Low density	I	7.54	7.06	7.71	7.82
	II	7.35	7.06	7.63	7.76
	III	7.43	6.95	7.68	7.81
Mean ± s.d.		7.44 ± 0.10	7.02 ± 0.06	7.67 ± 0.04	7.80 ± 0.03
F.sabella Medium density	I	7.44	7.01	7.67	7.78
	II	7.30	7.81	7.67	7.72
	III	7.35	7.18	7.66	7.71
Mean ± s.d.		7.36 ± 0.07	7.12 ± 0.10	7.67 ± 0.01	7.74 ± 0.04

Cont. table (3.13)

Species	Replicate cores	Depth of sediment			
		Overlying water	Surface	5cm	9cm
F.sabella	I	7.30	7.05	7.68	7.73
	II	7.29	7.42	8.03	8.06
High density	III	7.25	6.99	7.63	7.66
Mean ± s.d.		7.28 ± 0.03	7.15 ± 0.23	7.78 ± 0.22	7.82 ± 0.21
Mixed species	I	7.35	7.17	7.58	7.65
P.e. and F.s.	II	7.28	7.24	7.70	7.72
Low density	III	7.30	7.14	7.44	7.42
Mean ± s.d.		7.31 ± 0.04	7.18 ± 0.05	7.57 ± 0.13	7.60 ± 0.16
Mixed species	I	7.24	7.05	7.32	7.36
P.e. and F.s.	II	7.25	7.09	7.54	7.67
Medium density	III	7.26	7.11	7.50	7.60
Mean ± s.d.		7.25 ± 0.01	7.08 ± 0.03	7.45 ± 0.12	7.54 ± 0.16
Mixed species	I	7.35	7.14	7.66	7.72
P.e. and F.s.	II	7.32	7.08	7.87	7.92
High density	III	7.54	7.18	7.55	7.69
Mean ± s.d.		7.40 ± 0.12	7.13 ± 0.05	7.69 ± 0.16	7.78 ± 0.13

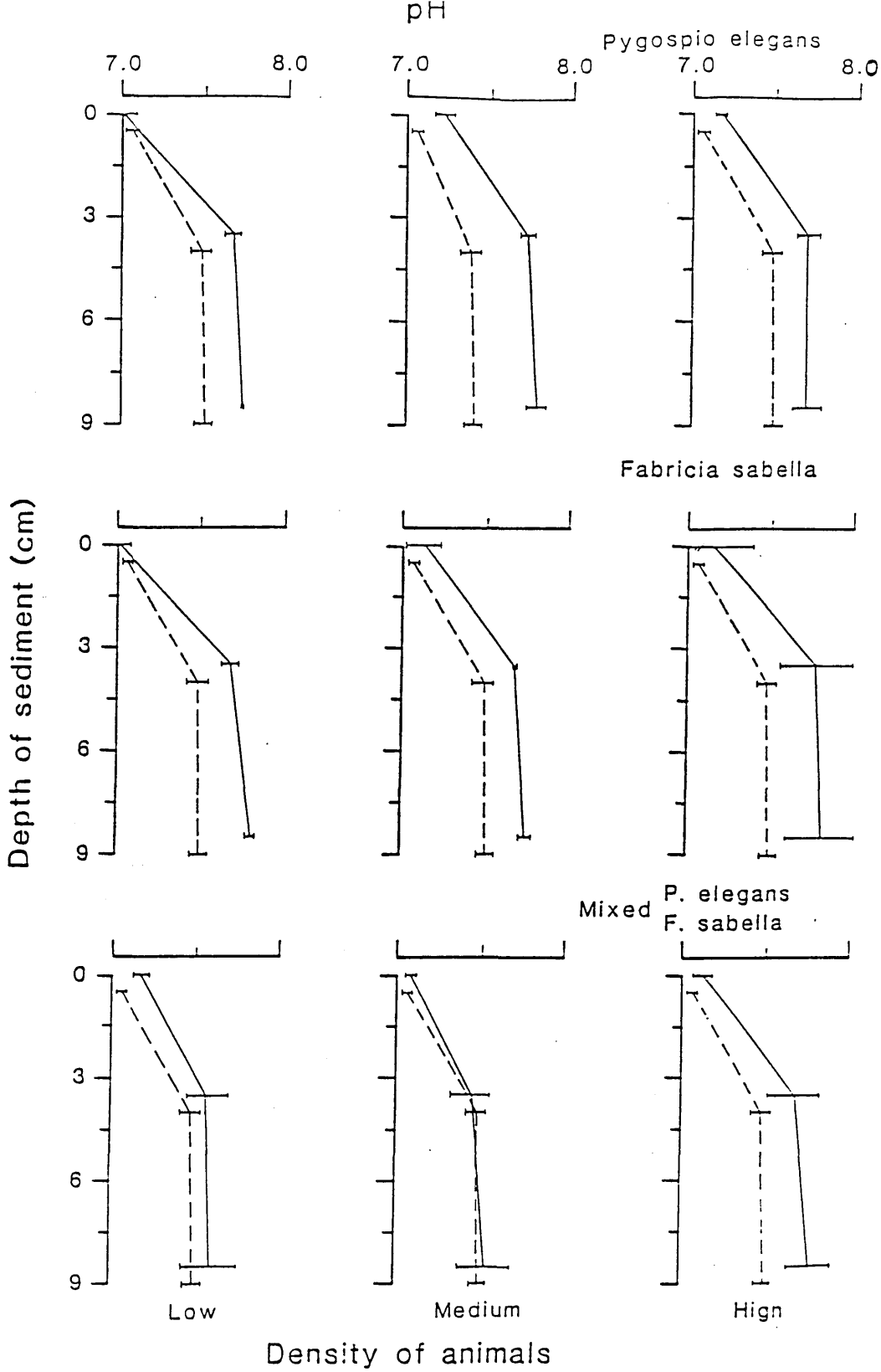


Figure (3.9)

Stability experiment. Means (continued lines) and standard deviations (horizontal bars) of the pH readings measured in the single and mixed species cores. The broken lines show the readings of the control cores.

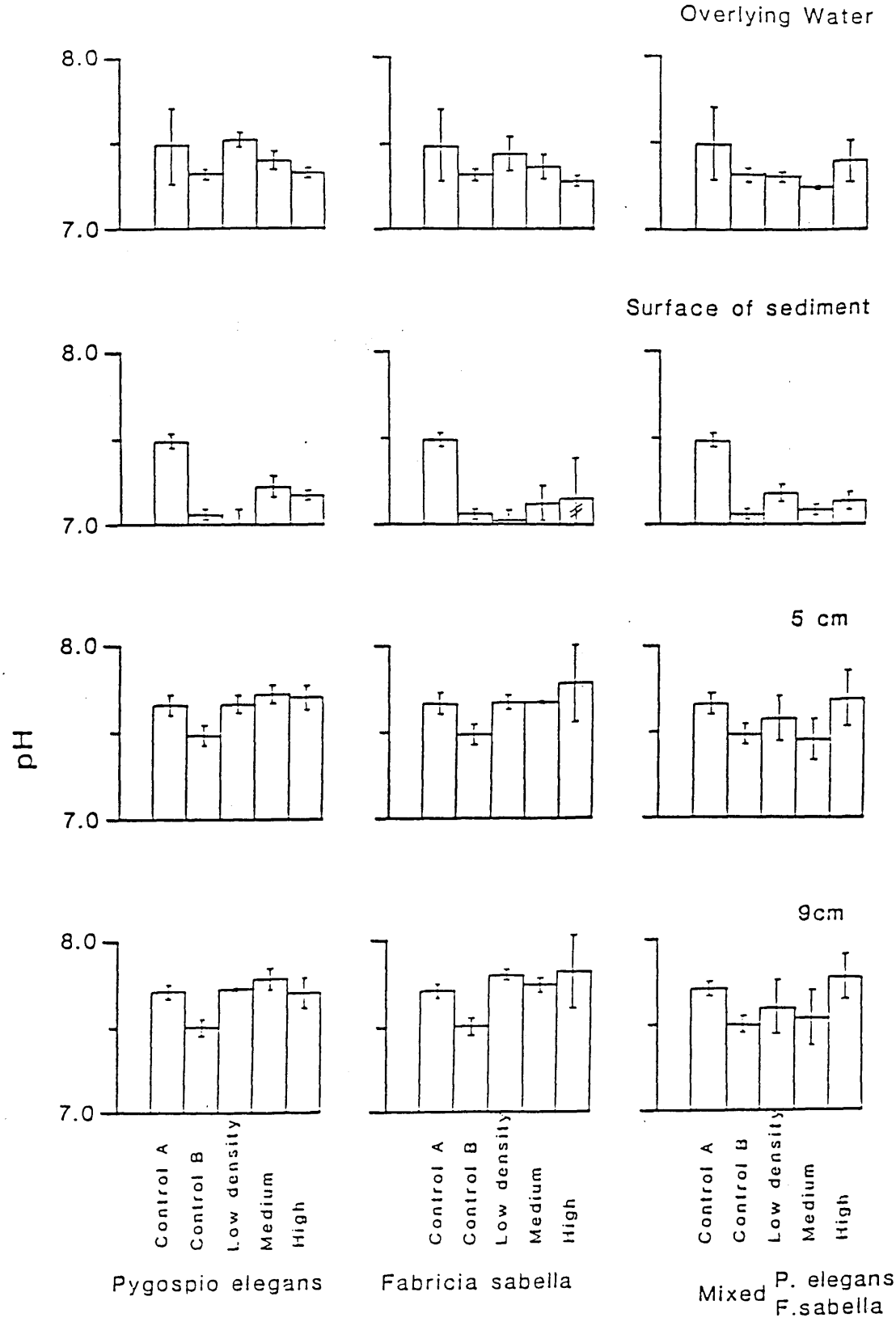


Figure (3.10)

Stability experiment. Histograms of the means and standard deviations (horizontal bars) of the pH readings measured in the single and mixed species cores and the control cores.

Table (3.14)

Stability experiment. Four one way analyses of variance of pH readings taken from The overlying water and different layers of sediment (surface, 5cm and 9cm), testing differences between different single and mixed species experiments. Each analysis was a 1 X 10 one way anovar. The 10 levels in each of the four one way analyses of variance were control of experiment, low, medium and high densities of *P.elegans*, low, medium and high densities of *F.sabella*, low, medium and high densities of mixed species.

Layers	Factor	Sum of square	Mean square	Degrees of freedom	F.ratio	Probability
Overlying water	Between experiments	0.1724	0.0192	9	5.35	P< 0.001
	Error	0.0715	0.0036	20		****
	Total	0.2439		29		
Surface	Between experiments	0.1436	0.0160	9	1.85	0.25>P>0.1
	Error	0.1722	0.0086	20		
	Total	0.3158		29		
5cm	Between experiments	0.2988	0.0332	9	2.78	0.05>P>0.025
	Error	0.2385	0.0119	20		**
	Total	0.5373		29		
9cm	Between experiments	0.3320	0.0369	9	2.85	0.025>P>0.01
	Error	0.2592	0.0130	20		***
	Total	0.5912		29		

* Degree of significance.

	Control	*P.elegans* (L.D.)	*P.elegans* (M.D.)	*P.elegans* (H.D.)	*F.sabella* (L.D.)	*F.sabella* (M.D.)	*F.sabella* (H.D.)	Mixed spec. P.e.&F.s. (L.D.)	Mixed spec. P.e.&F.s. (M.D.)	Mixed spec. P.e.&F.s. (H.D.)
Control	(OW) -	***	NS	NS	NS	NS	NS	NS	*	NS
	(5) -	*	*	*	*	*	NS	NS	NS	NS
	(9) -	**	***	*	***	***	NS	NS	NS	?
P.elegans	(OW) 7.75	-	*	***	NS	?	***	***	***	NS
(L.D.)	(5) 4.04	-	NS	NS	NS	NS	NS	NS	NS	NS
	(9) 7.44	-	NS	NS	?	NS	NS	NS	NS	NS
P.elegans	(OW) 2.37	3.31	-	NS	NS	NS	*	?	*	NS
(M.D.)	(5) 5.47	1.77	-	NS	NS	NS	NS	NS	?	NS
	(9) 6.12	1.80	-	NS	NS	NS	NS	NS	NS	NS
P.elegans	(OW) 0.44	6.82	1.97	-	NS	NS	NS	NS	*	NS
(H.D.)	(5) 4.02	0.82	0.54	-	NS	NS	NS	NS	?	NS
	(9) 3.29	0.25	0.42	-	NS	NS	NS	NS	NS	NS
F.sabella	(OW) 2.05	1.31	1.97	1.84	-	NS	NS	NS	?	NS
(L.D.)	(5) 4.59	0.48	1.39	0.49	-	NS	NS	NS	?	NS
	(9) 8.63	4.24	0.42	1.64	-	NS	NS	NS	NS	NS
F.sabella	(OW) 0.92	3.35	0.64	0.67	1.12	-	NS	NS	NS	NS
(M.D.)	(5) 5.29	0.38	2.06	0.73	0.28	-	NS	NS	?	NS
	(9) 6.50	0.90	1.05	0.58	2.09	-	NS	NS	NS	NS
F.sabella	(OW) 2.06	9.32	0.73	2.29	2.80	1.91	-	NS	NS	NS
(H.D.)	(5) 2.30	0.96	0.44	0.63	0.83	0.90	-	NS	NS	NS
	(9) 2.59	0.79	0.22	0.82	0.09	0.61	-	NS	NS	NS
Mixed species	(OW) 0.53	7.11	3.67	0.86	2.21	1.16	1.16	-	NS	NS
P.e.&F.s.(L.D.)	(5) 1.13	1.05	1.88	1.44	1.27	1.24	1.41	-	NS	NS
	(9) 0.98	1.32	1.89	1.01	2.16	1.50	1.45	-	NS	NS
Mixed species	(OW) 4.69	12.65	2.53	4.49	3.43	2.74	1.84	2.78	-	NS
P.e.&F.s.(M.D.)	(5) 0.35	2.80	3.70	3.08	3.07	3.15	2.29	1.19	-	NS
	(9) 0.41	1.85	2.36	1.48	2.65	0.61	1.79	0.41	-	NS
Mixed species	(OW) 1.14	1.58	5.10	0.98	0.42	0.50	1.75	1.30	2.32	-
P.e.&F.s.(H.D.)	(5) 2.13	0.38	0.31	0.03	0.21	0.28	0.55	1.00	2.07	-
	(9) 3.52	0.83	0.04	0.82	0.27	2.01	2.22	1.55	1.97	-

Table (3.15)
Stability experiment. T test on pH readings.
Symbols:
NS = not significant. (P>0.10)
? = neither significant nor not significant. (0.10>P>0.05)
* = significant. (0.05>P>0.02)
** and *** = highly significant. (0.02>P>0.001)
**** = very high significance. (P<0.001)
(OW) = Overlying water, (5) = Depth of 5cm, and (9) = Depth of 9cm.

differences in pH.

The results of the second test are shown in table 3.16. The table shows that significant differences occurred between in the pH readings obtained from different depths of sediment for the control and the different densities of single and mixed species except the medium density of *F.sabella*.

It was noted that when the value of Eh was high, the value of pH was low. This is shown in figure 3.11 which shows a negative relationship between Eh and pH. The overlying and the surface readings were scattered at the top of the figure and the readings of 5cm and 9cm at the bottom.

Section 4: Measuring the mortality and construction of tubes

The number of animals of both *P.elegans* and *F.sabella* counted at the end of the permeability and shear strength experiments are given in table 3.17. The table shows that there was a high mortality rate particularly in the high densities of animals of single and mixed species. This data was tested statistically using chi square to test the significance of mortality in the different densities of *P.elegans* and *F.sabella*. (table 3.18). The table shows that, in permeability experiment, there was no significant difference in the low and medium densities of *P.elegans* in single and mixed species experiments. There was a significant difference in the number of animals counted in the high density of *P.elegans* and the low, medium and high densities of *F.sabella* of both single and mixed species experiments. The table also shows that, in shear strength experiment, there was a significant difference in different population densities of *Pygospio* and *Fabricia*

Table (3.16)

Stability experiment. Ten one way analysesd of variance of the pH readings, testing the differences between the depths of sediment for the the control, single and mixed species of *P.elegans* and *F.sabella* in different densities. The 3 levels in each of the three one way analyses of variance were sediment surface, the 5cm and 9cm depths of sediment.

Layers	Factor	Sum of square	Mean square	Degrees of freedom	F.ratio	Probability
Control	Between depths	0.3678	0.1839	2	81.52	P< 0.0001
	Error	0.0135	0.0023	6		*****
	Total	0.3813		8		
P.elegans Low dens.	Between depths	0.9668	0.4834	2	152.66	P<0.0001
	Error	0.0190	0.0032	6		*****
	Total	0.9858		8		
P.elegans Medium dens.	Between depths	0.5702	0.2851	2	94.68	P<0.0001
	Error	0.0181	0.0030	6		*****
	Total	0.5882		8		
P.elegans High dens.	Between depths	0.5548	0.2774	2	57.00	P<0.0001
	Error	0.0292	0.0049	6		*****
	Total	0.5840		8		
F.sabella Low dens.	Between depths	1.0358	0.5179	2	231.89	P< 0.0001
	Error	0.0134	0.0022	6		*****
	Total	1.0492		8		
F.sabella Medium dens.	Between depths	0.2787	0.1393	2	2.33	0.2>P>0.1
	Error	0.3582	0.0597	6		
	Total	0.6369		8		
F.sabella High dens.	Between depths	0.8341	0.4170	2	8.49	0.025>P>0.01
	Error	0.2947	0.0491	6		**
	Total	1.1288		8		
Mixed species P.e.&F.s. Low dens.	Between depths	0.3235	0.1617	2	10.89	P = 0.01
	Error	0.0884	0.0147	6		**
	Total	0.4119		8		
Mixed species P.e.&F.s. Medium dens.	Between depths	0.3566	0.1783	2	13.01	0.01>P>0.005
	Error	0.0822	0.0137	6		***
	Total	0.4388		8		
Mixed species P.e/&F.s. High dens.	Between depths	0.7344	0.3672	2	24.70	P<0.001
	Error	0.0892	0.0149	6		****
	Total	0.8236		8		

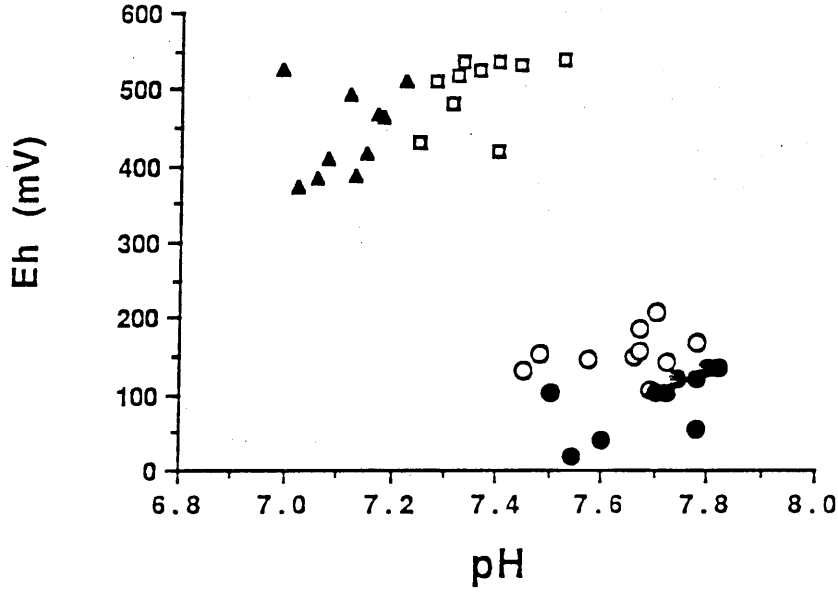


Figure (3.11)

Stability experiment. Relationship between Eh values and pH values.

□ - Gives the readings of the overlying water.

▲ - Gives the readings of the sediment surface.

○ - Gives the readings of the depth of 5cm.

● - Gives the readings of the depth of 9cm.

Table (3.17)

Stability experiment. Number of animals of *Pygospio elegans* and *Fabricia sabella* found at the end of the shear strength and permeability experiments.

Species	Replicate cores	Number of animals	
		Shear strength experiment	Permeability experiment
		Beginning : End	Beginning : End
Pygospio elegans	I	20 : 15	5 : 3
	II	20 : 11	5 : 4
Low density	III	20 : 15	5 : 5
Pygospio elegans	I	60 : 20	15 : 11
	II	60 : 28	15 : 14
Medium density	III	60 : 19	15 : 10
Pygospio elegans	I	180 : 105	45 : 2
	II	180 : 103	45 : 8
High density	III	180 : 94	45 : 4
Fabricia sabella	I	50 : 33	11 : 3
	II	50 : 42	11 : 7
Low density	III	50 : 33	11 : 10
Fabricia sabella	I	150 : 103	33 : 19
	II	150 : 49	33 : 11
Medium density	III	150 : 114	33 : 7
Fabricia sabella	I	450 : 188	99 : 28
	II	450 : 203	99 : 74
High density	III	450 : 131	99 : 74
Mixed species	I	20 & 50 :14 & 36	5 & 11 : 5 & 9
P.e. & F.s.	II	20 & 50 :12 & 33	5 & 11 : 4 & 5
Low density	III	20 & 50 :14 & 38	5 & 11 : 4 & 5
Mixed species	I	60 & 150 :46 & 107	15 & 33 : 15 & 2
P.e. & F.s.	II	60 & 150 :35 & 81	15 & 33 : 15 & 4
Medium density	III	60 & 150 :48 & 98	15 & 33 : 7 & 0
Mixed species	I	180 & 450 :106 & 237	45 & 99 : 1 & 0
P.e. & F.s.	II	180 & 450 : 47 & 88	45 & 99 : 7 & 0
High density	III	180 & 450 :114 & 293	45 & 99 : 0 & 0

Table (3.18)

Stability experiment. Chi squared of the mortality occurred in the permeability and shear strength experiments.

Treatment	Experiment	X^2	Degrees of freedom	Probability
Pygospio elegans (Low density)	Permeability	1.000	2	0.70>P>0.50
	Shear strength	6.550	2	0.05>P>0.02*
Pygospio elegans (Medium density)	Permeability	2.800	2	0.30>P>0.20
	Shear strength	71.75	2	P<0.001****
Pygpspio elegans (High density)	Permeability	108.9	2	P<0.001****
	Shear sterngth	105.3	2	P<0.001****
Fabricia sabella (Low density)	Permeability	7.364	2	0.05>P>0.02*
	Shear strength	12.84	2	0.01>P>0.001***
Fabricia sabella (Medium density)	Permeability	41.09	2	P<0.001****
	Shear strength	91.37	2	P<0.001****
Fabricia sabella (High density)	Permeability	63.55	2	P<0.001****
	Shear strength	514.2	2	P<0.001****
Mixed species (low dens.) *P.elegans*	Permeability	0.400	2	0.90>P>0.80
	Shear strength	6.800	2	0.05>P>0.02*
F.sabella	Permeability	6.909	2	0.05>P>0.02*
	Shear strength	12.88	2	0.01>P>0.001***
Mixed species (Medium dens.) *P.elegans*	Permeability	4.267	2	0.30>P>0.20
	Shear strength	16.08	2	P<0.001****
F.sabella	Permeability	87.61	2	P<0.001****
	Shear strength	62.09	2	P<0.001****
Mixed species (High dens.) *P.elegans*	Permeability	120.1	2	P<0.001****
	Shear strength	152.9	2	P<0.001****
F.sabella	Permeability	0	0	0
	Shear strength	446.8	2	P<0.001****

* Degree of significant.

species of both single and mixed species experiments. The significant difference increased with increasing density of animals.

The results of measurements of the total length and weight of the five tubes of *P.elegans* and *F.sabella* built at different densities are given in table 3.19 (columns 3 and 4). The table shows the weight of tube per unit of length (column 5), and the total lengths and weights of tubes produced by the animals in each density (columns 6 and 7). The table also shows the expected length and weight of tube produced by one animal in each density (columns 8 and 9). The means and standard deviations of the length and weight of tube produced by one animal of *P.elegans* and *F.sabella* were plotted against number of animals in each density (figures 3.12 and 3.13, respectively).

Figure 3.12 shows that length of tube built by *F.sabella* was longer than the length of tube produced by *P.elegans* in the low density of animals, but in the medium and high densities, the length of tube produced by *P.elegans* was longer than the length of tube produced by *F.sabella*. The length of tube was reduced in the medium density of animals and remained the same in the high density of *F.sabella*. The length of tube of the medium density of *P.elegans* was longer than the length of tube of the low density. This length was reduced in the high density.

Figure 3.13 shows that the tube produced by *P.elegans* has more weight than the weight of tube produced by *F.sabella* at the different densities of animals. The weight of tube produced by *P.elegans* in the low density was less than the weight of tube in the medium density. This weight was decreased in the high density. The figure shows that the weight of tube produced by *F.sabella* was decreased from the low

Table (3.19)

Stability experiments. Measurement of tubes produced by *P.e.elegans* and *F.sabella* in the single and mixed species experiments.

Species	Replicate	Total length of five tubes L (mm)	Total weight of five tubes W (mg)	Weight per unit length	Total length and weight of tubes produced at each density		Length and weight of tube produced by one animal at each density	
					Length (mm)	Weight (mg)	Length (mm)	Weight (mg)
P.elegans Low dens.	I	122	40.75	0.3340	962.13	321.35	48.11	16.07
	II	81	29.60	0.3654	349.95	957.72	47.81	17.50
	III	92	34.40	0.3739	502.50	1343.94	67.20	25.13
P.elegans Med. dens.	I	82	28.25	0.3445	3863.43	1330.95	64.39	22.18
	II	83	25.50	0.3072	3839.52	1179.50	60.66	19.66
	III	94	33.35	0.3548	3154.17	1119.10	52.57	18.52
P.elegans High dens.	I	69	26.70	0.3870	6376.74	2467.80	35.43	13.71
	II	74	23.05	0.3115	7717.02	2403.85	42.87	13.36
	III	88	27.40	0.3114	8549.62	2662.35	47.50	14.79
F.sabella Low dens.	I	49	2.55	0.0520	5193.27	270.05	103.90	5.40
	II	52	2.65	0.0510	4175.49	212.95	83.50	4.26
	III	45	2.40	0.0533	4003.75	213.40	80.10	4.27
F.sabella Med. dens.	I	45	4.40	0.0978	6859.41	670.85	45.70	4.47
	II	49	6.30	0.1286	4015.16	516.35	26.80	3.44
	III	41	3.50	0.0854	4892.86	417.85	32.60	2.79
F.sabella High dens.	I	42	3.35	0.0798	14894.10	1188.55	33.10	2.64
	II	54	6.60	0.1222	12529.46	1531.10	27.80	3.40
	III	40	3.20	0.0800	14316.25	1145.30	31.80	2.55

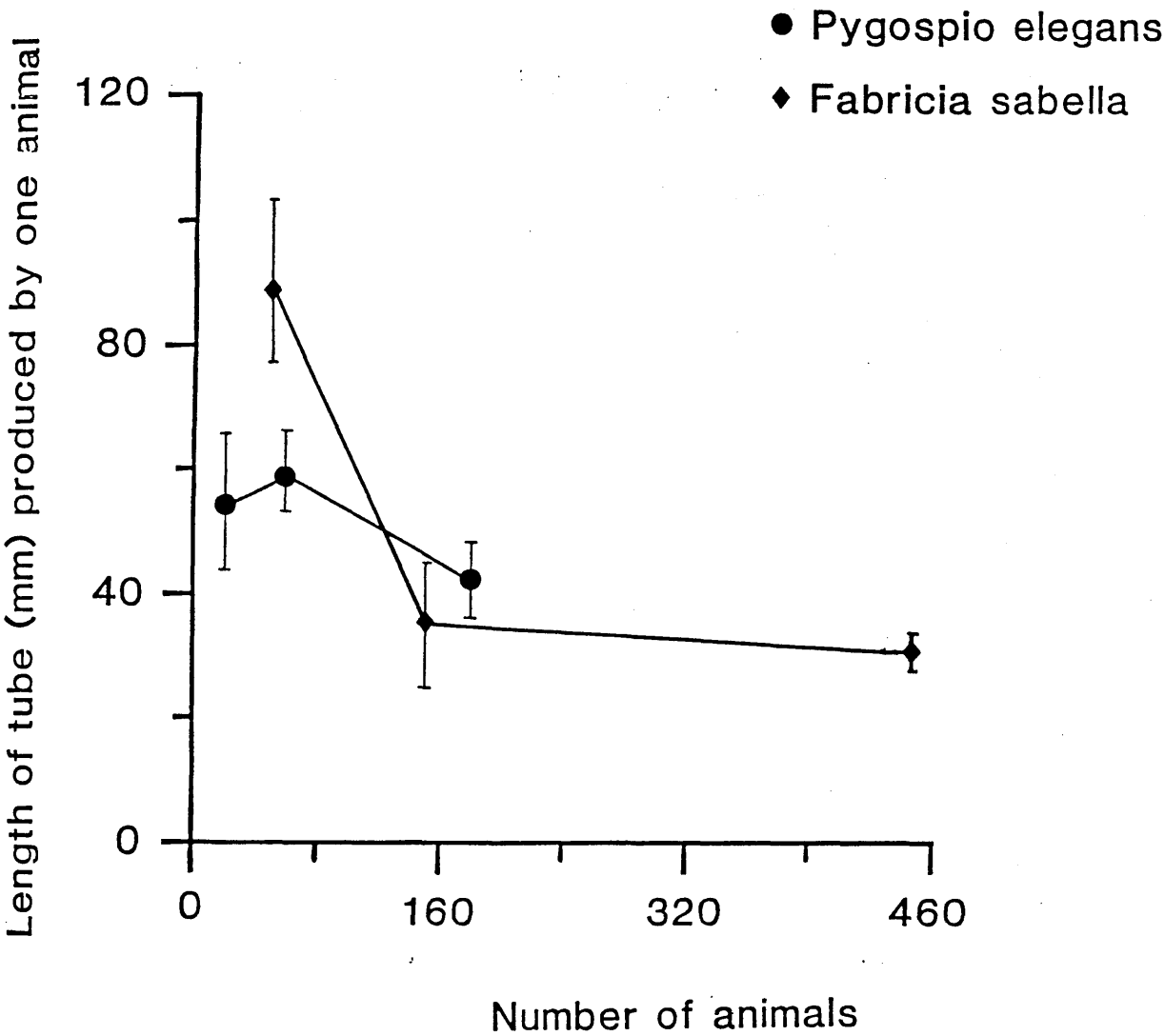


Figure (3.12)

Stability experiment. Means length (mm) of one tube produced by *pygospio elegans* and *Fabricia sabella* at different densities of animals. (Vertical bars gave the Standard deviations).

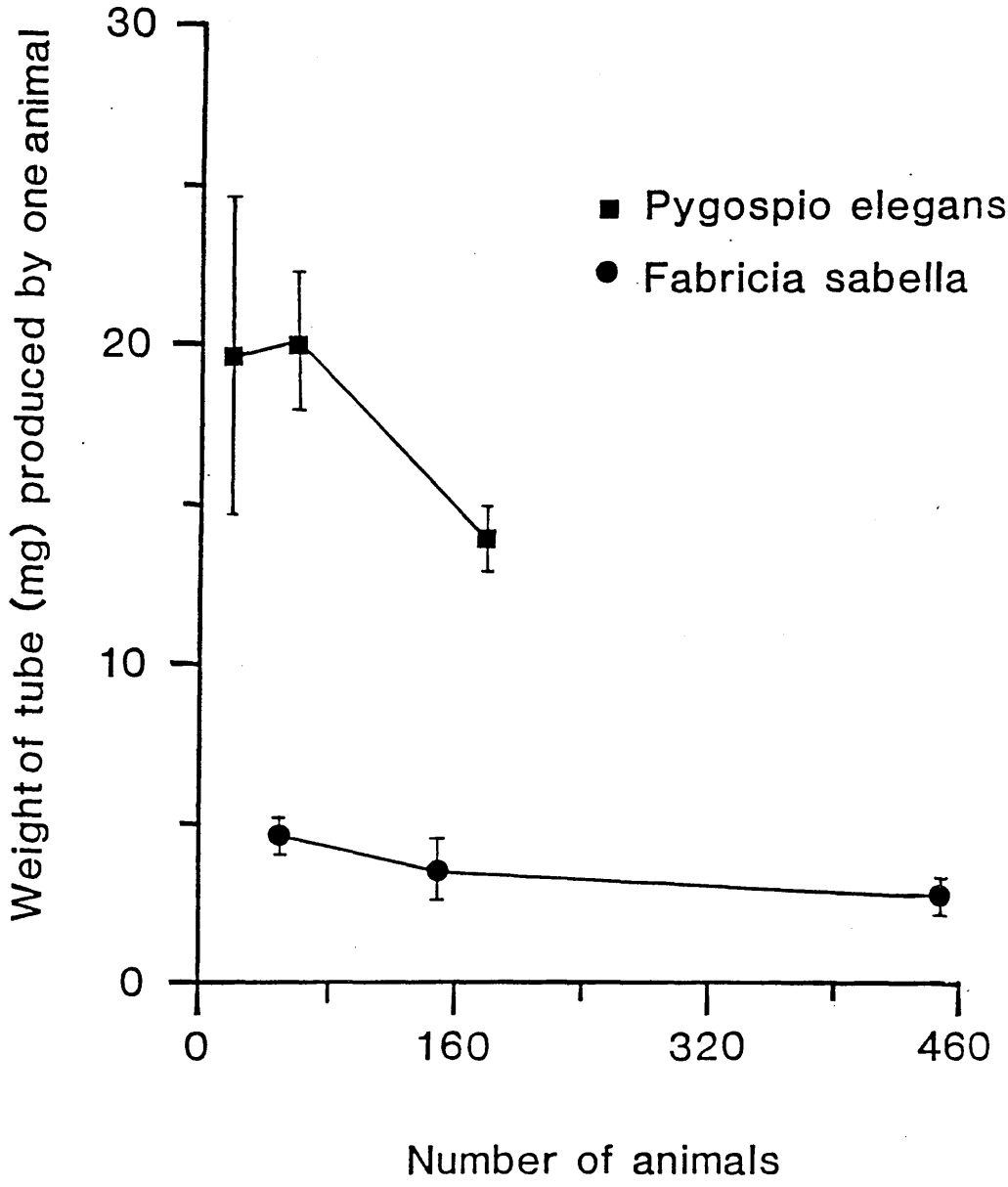


Figure (3.13)

Stability experiment. Means weight (mg) of one tube produced by *Pygospio elegans* and *Fabricia sabella* at different densities of animals. (Vertical bars gave the Standard deviations).

density to the medium and remained the same in the high density.

The data of length and weight of tube produced by *P.elegans* and *F.sabella* was tested statistically using one way analysis of variance and students t tests (tables 3.20, 3.21 and 3.22, respectively).

Table 3.20 shows the two one way analyses of variance applied to each species testing the differences between weight (mg) of tube per unit length (mm) produced at different densities. The table shows there was no significant difference between the weight per unit length in *P.elegans* species produced at different densities, but that there was a significant difference between the weight per unit length of *F.sabella* species produced at different densities.

Table 3.21 shows students t tests conducted on the length and weight of tubes produced by each species at different densities of animals. The table shows that there was a significant difference in the length and weight of tubes produced by *P.elegans* and *F.sabella* at the medium density compared with the high density. The table also shows that there was a significant difference between the length of tubes produced at medium density compared with the low density.

Table 3.22 shows the results of the students t tests applied to the weight and length of tubes produced by one animal of *P.elegans* and *F.sabella* at different densities. The table shows that there were a highly significant differences in the weight of tubes between the two species in the different densities. There was little significant difference in the length of tubes between the two species at the different densities. The table finally shows that there were a high significant difference in weight per unit length between the two species at different densities.

Table (3.20)

Stability experiments. Two one way analyses of variance of *Pygospio elegans* and *Fabricia sabella* species, testing differences between weight of tube per unit length produced at different densities. Each analysis was a 1 X 3 one way anovar. The 3 levels in each of the two one way analyses of variance were low, medium and high densities of animals.

Species	Factor	Sum of squares	Mean square	Degrees of freedom	F.ratio	Probabilty
Pygospio elegans	Between density	0.0009	0.0005	2	0.4764	0.75>P>0.50
	Residual	0.0059	0.0010	6		
	Total	0.0069		8		
Fabricia sabella	Between density	0.0045	0.0023	2	6.2345	0.05>P>0.025
	Residual	0.0022	0.0004	6		*
	Total	0.0067		8		

Table (3.21)

Student t test of the weight (W) and length (L) of tubes produced by *P.elegans* and *F.sabella* in the stability experiment.

	Weight (W) and length (L) of *Pygospio elegans* tube			Weight (W) and length (L) of *Fabricia sabella* tube		
	Low	Medium	High	Low	Medium	High
Low	-	(W) NS	(W) NS	-	(W) NS	(W) NS
	-	(L) NS	(L) NS	-	(L) ***	(L) NS
Medium	(W) 0.1837	-	(W) ***	(W) 1.7412	-	(W) **
	(L) 0.6594	-	(L) **	(L) 5.8212	-	(L) ***
High	(W) 1.9631	(W) 5.2988	-	(W) 3.8315	(W) 1.2594	-
	(L) 1.7072	(L) 3.4876	-	(L) 7.6657	(L) 0.7110	-

Table (3. 22)

Stability experiments. T test on the weight and length of tubes produced by one animal of *Pygospio elegans* and *Fabricia sabella*. Different densities (Low, medium and high) were tested.

Parameter	Comparison	t. test	Degrees of freedom	Probability
Weight (mg)	*P.elegans* (Low) Vs *F.sabella* (Low)	5.2594	4	0.01>P>0.001 ***
	P.elegans (Medium) Vs *F.sabella* (Medium)	13.9483	4	P<0.001 ****
	P.elegans (High) Vs *F.sabella* (High)	21.8381	4	P<0.001 ****
Length (mm)	*P.elegans* (Low) Vs *F.sabella* (Low)	3.5443	4	0.05>P>0.02 *
	P.elegans (Medium) Vs *F.sabella* (Medium)	3.6686	4	0.05>P>0.02 *
	P.elegans (High) Vs *F.sabella* (High)	2.8580	4	0.05>P>0.02 *
Weight per unit length	*P.elegans* (Low) Vs *F.sabella* (Low)	25.1530	4	P<0.001 ****
	P.elegans (Medium) Vs *F.sabella* (Medium)	11.9742	4	P<0.001 ****
	P.elegans (High) Vs *F.sabella* (High)	7.1386	4	0.01>P>0.001 ***

DISCUSSION

Marine organisms affect the stability of fine-grained sediments in one of two ways. They can stabilise sediments by binding individual sediment particles together thus reducing erosion by tidal currents (Yingst and Rhoads, 1978), or they can destabilise sediment by thus leading to erosion (Dillon and Zimmerman, 1970).

Stabilising effects caused by marine animals have been described by a number of investigators (Bock and Moore, 1968; Pamatmat, 1968; Neumann et al., 1970; Young and Rhoads, 1971; Riemann and Schrage, 1978; Meadows and Tait, 1989). Destabilising effects caused by marine animals have been described by many workers (Dillon and Zimmerman, 1970; Rhoads and Young, 1970; Rhoads, 1973; Allen and Curren, 1974; Katz, 1980; Eckman et al., 1981). However, it is difficult to say which animal activities in particular are responsible for stabilising and destabilising sediments since the effect of bioturbation on sediment stability is influenced by factors such as population density, kind of species, sediment composition, and other inhabitants of the sediment (Nowell et al., 1981). The point is borne out by studies made by Fager (1964) and Eckmann et al., (1981). Fager (1964) found that the tubes of *Owenia fusiformis* and a small anemone *Zaolutus actius* can act together to stabilise the sediment surface against the movement by wave surge. Eckman et al., (1981), in later studies, found that high densities of *Owenia* tubes destabilised sediment, and isolated tubes caused localised scour resulting in erosion of the sediment-water interface. Rhoads and Young (1970), and Young and Southard (1978) reported in field and laboratory studies that the

bioturbation structures cause erosion of the sediment-water interface by altering bed water flow and causing turbulence.

Most of the above work is based on field work and there is less quantitative research on the effect of marine animals on specific sediment properties in the laboratory (Meadows and Tait, 1989; Meadows, Tait and Hussain, 1990). This chapter, which follows naturally from the field work in chapter two, describes laboratory studies of this sort. The results described in this chapter are discussed as follows:

1- Experimental design.

2- The effect of animals on permeability.

3- The effect of animals on shear strength.

4- The effect of animals on redox potential (Eh) and pH, and the relationship between the Eh and pH.

5- The effect of population density on mortality and tubes construction.

6- Environment implication and future work.

1- Experimental design

In designing an experiment to test the effect of animals population density on specific factors, two alternatives can be used by the investigators. The first one is a continuous range of densities, e.g. ten densities can be used with a difference of one animal between each density. If a density effect occurs, the limits of effect can be pin-pointed to an accuracy of one animal. This is an accurate method to use but has one main disadvantage. The experimenter

must be able to predict with confidence, the density range over which the effect may be expected to occur. This is rarely the case in density experiments. The second one is to test several densities, the interval between each density being made large enough to ensure that, if present, a density effect will be spotted. If an effect is detected, the experimenter can repeat the experiment with selected densities near to that which caused the effect. In this way, the relevant densities can be found accurately (Bailey, 1984; Bishop, 1985).

In the experiments in this chapter, the second alternative was adopted. Three population densities (Low, medium and high) were tested for each species. Medium density represented the field density of each species which was counted in the summer by Girling (1984). For *Pygospio elegans* this was 7000 animals m^{-2} and for *Fabricia sabella* 17,000 animals m^{-2}. By setting the low and high densities to represent one-third and three times field density it was thought that if present, a density effect would be detected. Three replicate permeameters were used for each population density. The preliminary experiment shows that when using three densities, a maximum of three replicates could be handled efficiently. Three replicates were also suitable for statistical analysis. The two big experiments (permeability experiment and shear strength experiment) were carried out separately, because I feel that measuring shear strength during the progress of experiment will effect the reading of permeability if both parameters are measured together in one experiment. The Eh and pH measurements were conducted at the beginning of the shear experiment using extra cores, and at the end of experiment after having taken all

shear strength readings of sediment surface. A subcore was taken from each replicate core of single and mixed species and the control to measured Eh and pH for different depths of sediment. The method of taking these subcores is a new one and proved excellent for obtaining undisturbed columns of sediment to measure Eh and pH parameters (see plates 3.6 to 3.8).

2- The effect of animals on permeability

i- *Pygospio elegans*

In the single species experiment, permeability was first measured five days after adding the animals. The mean permeability had increased in all densities relative to the mean control permeability. The average permeability had increased about 26%, 28%, and 44% for low, medium and high population densities respectively comparative to the average control permeability (table 3.2 and figure 3.4). The permeability of high density is increased much higher than the permeability of low and medium densities which are approximately the same. Subsequent measurements taken at intervals (i.e. days 10 and 15) showed that at these densities and control there was a decrease in permeability which occurred after day 5 (Figure 3.3). This reduction in permeability occurred more rapidly in the high density, particularly in day 10, than in the low and medium densities and the control.

The increase permeability found at all *Pygospio* population densities may be related to the following interpretation. When animals are put on the sediment at different densities, they burrow into sediment and established their tubes in a matter of a minute (Wilson, 1983). The entrances to these were often visible as structures on the

sediment surface, particularly in high densities. Schäfer (1972) described that the tube of this species goes to 9cm deep into sediment, and the tube remains open from the top to pass water into it during the feeding process. This process would enable water to pass through sediments containing these tubes at an increased rate relative to unburrowed sediment. Weaver and Schultheiss (1983) have calculated that burrows in deep-sea sediments may change permeability from the equivalent of clay to that of a coarse sand. Meadows and Tait (1989) described that the permeability increased with increasing densities of *Hediste diversicolor*.

ii- *Fabricia sabella*

In the single species experiment permeability was first measured five days after adding the animals. The average permeability of the low and medium population densities sediment had decreased by about 43% and 11% respectively relative to the average of control permeability, while the average of permeability of the high density sediment has increased by about 19% relative to the average of control permeability (table 3.2 and figure 3.4). Further measurements showed that the permeability of the low density changed with time. It's permeability increased after five days (table 3.2 and figure 3.3), but was still below the control permeability. The permeability of the medium and high densities sediment had decreased slightly after five days (figure 3.3).

The reduction in permeability of the sediment containing the low and medium population densities, and the increase permeability in the high density relative to the control permeability in day five may be

related to the following reasons.

(a) Lewis (1968) described that each worm establishes first a temporary tube on the surface of sediment using mucus to bind particles. The worms then commence to burrow, a few tubes are placed on the sediment surface, before their permanent tubes are formed in the sediment. These temporary tubes placed on the sediment surface would tend to decrease sediment void size thereby reducing permeability.

(b) At low and medium population densities, space in which to burrow is enough and so there is free space in which worms could establish many tubes in sediment surface. Through this process worms form an adherent layer of mucus lined with particles, before they burrow their permanent tubes into the sediment, which reduces the permeability. This reason may be accepted because it is obvious that permeability of the low density is lower than the permeability of the medium density where the layer may have caused reduction in permeability. Meadow and Tait (1989) described that permeability decreased in medium and high population densities of *Corophium volutator*. They related this reduction in this species to the physical barrier of its U-shape burrows in the upper 2 to 5cm of the sediment.

(c) At high population density, space in which worms tend to form tubes on sediment surface is limited, therefore, they burrow their permanent tubes into the sediment. This means that more tubes are built into the sediment which increases the area of exchange between water and lower sediment thereby increasing the permeability.

(d) As time passes, worms continue to add to their tubes until they become longer. Lewis (1968) recorded that in calm water, e.g. in

the aquarium, worms continue to add to their tubes until they are about 2.5cm long. This procedure would increase the permeability which is noted in the low population density after day five. In the medium and high densities, slightly decreased permeability after day 5 might be due to microbial growth because high mortality occurs in these two densities of this species (table 3.17) which would allow microorganisms to grow on the sediment surface.

iii- Mixed population of *Pygospio elegans* and *Fabricia sabella*

In the mixed species experiment permeability was measured five days, ten days, and fifteen days after adding the animals, the average permeability of all population densities sediment had increased relative to the average control permeability (table 3.2 and figure 3.4).

Subsequent measurements taken at 5 day intervals showed that, at the different densities and the control, further slight changes in permeability occurred after day 5 (table 3.2 and figure 3.3). the permeability slightly increased at day 10 and then decreased at day 15. The permeability of medium and high population densities had decreased after day 5. The results showed that the *Pygospio* population has influenced permeability more than the *Fabricia* population particularly in the low and medium population densities. However the effect of *Pygospio* species on permeability in mixed populations was reduced compared to the effects found at similar population densities in single species experiment. This means that there is may be an interaction between the two species. Nowell et al. (1981) described that the effect of bioturbation on sediment stability is influenced by

the other animals species present, and interaction effects have also been noted between *Corophium volutator* and *Hediste diversicolor* by Meadows and Tait (1989).

3- The effect of animals on shear strength

i- Single species experiments

In the single species experiment, shear strength was measured 5 days, 10 days and 15 days after adding the animals of *Pygospio elegans* and *Fabricia sabella*. The results showed that shear strength of all population densities of both species sediment had changed relative to the control shear strength (table 3.6 and figure 3.5). The shear strength increased in the medium and high population densities of *Pygospio* species, and in different population densities of *Fabricia* species at day 5. The shear strength slightly decreased in the low density of *Pygospio* species at day 5. At days 10 and 15 (end of experiment), shear strength of sediment surface increased in all population densities of both species relative to the control shear strength (table 3.6 and figure 3.6).

The average shear strength of low, medium and high population densities of *Pygospio* species increased about 11%, 37% and 64% respectively relative to the control shear strength at day 15. The average shear strength of low, medium and high population densities of *Fabricia* species increased about 36%, 57% and 54% respectively relative to the control shear strength at day 15. Shear strength of the control sediment (no animals) slightly decreased at day 10 and then increased at day 15. These changes in the control sediment may be due to the production of microorganisms (Meadows and Tufail 1986) or

the compaction of sediment during the progress of experiment.

The increase in shear strength in all population densities of both species at the end of the experiment (day 15) is probably due to the following factors, some of which may also affect permeability.

a- Many tubes strengthened by mucus lining will tend to compact the sediment laterally like re-inforcing rods, causing an increase in shear strength. Powell (1977) found that the burrows of the holothurian *Leptosynapta tenuis* increased the stability of sediment by increasing the packing of the sediment between burrows. Brenchely (1982) noted that animal tubes and burrows increased the hardness of the sediment and made it more difficult to burrow into. Meadows and Tait (1989) found that shear strength is increased with an increased number of animals of *Corophium volutator* and *Hediste diversicolor*.

b- Animals on the sediment surface will tend to compact sediment vertically increasing its shear strength.

c- The scraping of detritus from the sediment surface into the burrows, described by Meadows and Reid (1966), will remove part of the soft detrital layer present on the sediment surface after loading the permeameters. The removal of this soft layer will tend to increase the shear strength of sediment.

Shear strength was increased to a greater range by *Fabricia* species than by *Pygospio* species at equivalent densities (low and medium). The main reason for this would appear to be that *Pygospio* dig more deeply into sediment than *Fabricia*. *Fabricia* also formed tubes on the sediment surface which were mucus lined, so the sediment surface containing this species may be harder than the surface of sediment containing *Pygospio*. Lewis (1968) noted that *Fabricia* formed

temporary tubes on the surface of sediment before building their permanent tubes into the sediment. Wilson (1983) noted that *Pygospio* burrowed and built its tube in sediment in a matter of minutes, and dug to about 10cm deep.

The effect of other polychaete species on sediment stability has been noted by other investigators. Fager (1964) found that dense colonies of *Owenia fusiformis* tubes and a small anemone *Zaolutus actius* increased sediment stability. Woodin (1976) found that dense tube builders such as *Ampelisca* and *Streblospio* increase sediment stability and caused deposition of fine particles. Meadow and Tait (1989) and Meadows, Tait and Hussain (1990) described that increased density of *Corophium* and *Hediste* increased the shear strength of the sediment surface.

ii- Mixed populations of *Pygospio elegans* and *Fabricia sabella*

Shear strength of the sediment surface is measured at days 5, 10 and 15 after adding animals of both species in different densities of population. The results showed that shear strength of sediment surface had dramatically increased with increasing population densities in mixed species relative to shear strength of the control at day 15 (end of experiment) (table 3.6 and figure 3.5). The average shear strength of low, medium and high densities is increased about 101%, 132% and 350% respectively relative to shear strength of sediment surface of the control at day 15.

This finding may be due to the building of tubes by both species where they act together to adhere sediments.

Several investigators have found that shear strength

measurements made on highly bioturbated sediment tend to show a high degree of variation (Hagerty, 1974; Rowe, 1974; Adams and Weatherly, 1981). Rowe (1974) found that shear strength of sediment adjacent to a *Cerianthus* burrow was almost two times greater than sediment further away from the burrow. Adams and Weatherly (1981) found that the benthic boundary layer responds to a stabilising suspended-sediment of concentration gradients by a reduction of about 45% in the bottom stress and by decrease in the slope of the velocity profile.

4- The effect of animals on redox potential and pH, and the relationship between the Eh and pH.

A- Redox potential (Eh)

i- *Pygospio elegans*

The redox potential (Eh) of different population densities of *Pygospio* was measured at the end of single species experiment (shear strength experiment). Eh was measured from the overlying water of each population density, surface of sediment, 5cm and 9cm depths of sediment (table 3.10). Eh results showed that the overlying water of different population densities had slightly increased relative to Eh of the control. Eh of sediment surface of low, medium and high densities had increased about 37%, 34%, and 23% relative to the Eh of sediment surface of control. Eh of 5cm depth of sediment of low and medium densities are generally same relative to the Eh of control in that depth, but it is increased in high population density. There is no difference in Eh of 9cm depth of sediment of the different population densities comparing with the Eh of control, except the

medium density which Eh slightly increased.

The increased Eh at the surface of the sediment and other depths of the different densities may be due to burrow activities of animals into sediment in which their activities increase gas exchange between overlying water and sediment. Anderson and Meadows (1978) measured Eh of *Hediste diversicolor* burrows. They measured the Eh in burrow-lining sediment, surface sediment, and sediment from beside a burrow. They showed that burrow-lining sediment was much more closely related to the surface sediment than the beside-burrow sediment. Meadows and Tait (1985) found similar effects of biological activities on Eh in deep sea sediment. The burrows, therefore, appear to be an exten tion of sediment-water interface thus oxygenating the deeper sediment.

ii- ***Fabricia sabella***

Eh was measured in sediments containing different population densities of *Fabricia* at the end of single species experiment (shear strength experiment). The results showed that Eh of the sediment surface of the medium and high population densities had increased relative to Eh of sediment surface of the control, while it is decreased in the low population density relative to the control (table 3.10). Similar trends of reduction in Eh with increasing depths of sediment are found in this species as in *Pygospio* species. No great changes (either plus or minus) of the Eh occurred in the overlying water of different densities relative to the Eh of overlying water of the control.

The reduction of Eh in the low population density may be due to the structure of temporary tubes formed on the sediment surface or the

activities of microorganisms.

iii- Mixed of *Pygospio elegans* and *Fabricia sabella*

In the mixed species experiment, Eh was measured in sediment at different population densities at the end of experiment (shear strength experiment). The results showed that the average of Eh in the overlying water of different population densities had decreased relative to the average of Eh in the control. and it decreased further with increased densities (table 3.10). Average of Eh of surface sediment increased in the low and medium population densities, and slightly decreased in the high density relative to the average of Eh of the control. The mean Eh at depth 5cm was lower in the different densities relative to the average of Eh of the same layer in the control, and this reduction increased with increased densities. The average Eh sharply decreased at a depth of 9cm in all densities of mixed species relative to the Eh of the same layer in the control.

The reduction of Eh in the overlying water of different population densities may be related to the consumption of oxygen by animals. This reduction may also be affected by the concentration of oxygen in the lower layers of sediment (i.e. 5cm and 9cm) where the lowest Eh values were recorded.

The results showed that Eh decreased from the overlying water to the lower depth of sediment in all population densities of the single and mixed species and also in the control (table 3.10, and figure 3.7). The decrease of Eh with sediment depths is well known in near-shore and estuarine environments (Whitfield, 1969; Fenchel and Reidl, 1970; Anderson and Meadows, 1978; Pearson and Stanley, 1979),

and in the deep sea (Meadows and Tait, 1985). The decrease in Eh with sediment depth may be related to a number of factors, such as microbial activity, oxygen concentration and particle size. Mclachalan (1978) showed that the decrease in Eh readings is accompanied by a decrease in oxygen concentration. Zobell (1946b) has noted that coarser sediment and those deficient in organic matter are generally less reducing.

The results also showed that Eh of the overlying water and surface of sediment of the control (no animals) at the end of experiment are higher than the Eh of the same layers of the control at the beginning of experiment. Inverse results are found below sediment surface where Eh of 5cm and 9cm sediment depths are lower than the Eh of the same depths of the control taken at the beginning of experiment. The increase of Eh in the overlying water and sediment surface of the control may be due to the activities of photosynthetic microorganisms such as diatoms which increase the oxygen concentration, and may be due to the activity of meiofauna in the sediment surface. The reduction of Eh below sediment surface between the beginning and the end of experiment may be due to the lack of oxygen because of the increase in the amount of H_2S.

B- pH

pH of low, medium and high population densities of the single species of *Pygospio* and *Fabricia* and the mixed species are measured at the end the of experiment (shear strength experiment). The readings of pH were taken from the overlying water, the sediment surface, and at a depth of 5cm and 9cm in the sediment. The results showed that the pH

of all population densities in the single and mixed species experiments and even in the control increased with the increasing of sediment depths (table 3.13 and figure 3.9).

The average pH of sediment surface was lower than the average pH of overlying water in different densities of single and mixed species and also of the control at the end of experiment, while no difference occurred between the overlying water and sediment surface of the control at the beginning of experiment. The reason for these differences are not obvious.

Recorded values of the pH of sediment in the literature appear to be rather varied. ZoBell (1946b), for example, records a range of 6.4 to 9.5, and Bägander and Niemistö (1978) record a range of 6.9 to 8.3. My data of pH in the laboratory experiment records a range of 6.99 to 7.82. ZoBell (1946b) records a slight increase in pH with depth into the sediment, while Bägander and Niemistö (1978) state an increase in pH with depth into sediment. My own studies show an increase of pH with depth into sediment and therefore my results appear to agree with ZoBell's data.

C- The relationship between the Eh and pH

The data of Eh and pH taken from the single and mixed species of *Pygospio* and *Fabricia* and the control was used to determine the relationship between them.

The results shows that there is a negative relationship between Eh and pH (when the value of Eh was high, the value of pH was low). The results show a distinct picture where the overlying and the surface readings were scattered at the top of the figure and the

readings of 5cm and 9cm at the bottom.

The relationship between Eh and pH in natural systems has been studied by Bass Becking, Kaplan and Moore (1960) and Krauskopf (1979). Meadows and Campbell (1988) show diagrams of the relationship between Eh data (y axis) and pH data (x axis) obtained from a number of natural systems. For example, sea water is generally more basic and may have a considerably lower Eh than fresh water. Continental shelf and abyssal sediments have a slightly more restricted pH range than coastal inshore sediments but a slightly greater Eh range.

5- The effect of population density on mortality and construction of tubes

i- Mortality

The surviving animals of both *Pygospio elegans* and *Fabricia sabella* species were counted at the end of permeability and shear strength experiments to measure the degree of mortality (table 3.17). In the permeability experiment, the mortality occurred in high population density of *Pygospio*, and at low, medium and high densities of *Fabricia*. In the shear strength experiment, mortality occurred in all population densities of both *Pygospio* and *Fabricia* (tables 3.17 and 3.18). It is possible that mortality occurred due to the reduction of oxygen in the seawater overlying the sediment. Mortality increased with an increased density of animals. The high mortality occurrence in the medium and high population densities may be related to the lack of food (both *Pygospio* and *Fabricia* species feed on microorganisms) and the lack of oxygen (needed for respiration). The lack of oxygen may be

an accepted reason because, at medium and high densities, the average values of Eh of the overlying water are lower than the average of Eh in low density of both species. The reduction of Eh (an indication to the amount of oxygen) is more obvious in low, medium and high densities of mixed species containers compared with the Eh of the control.

ii- Tubes construction

a- *Pygospio elegans*

The average length of tube produced /animal slightly increased from low density to medium density and then decreased at the high density (table 3.19 and figure 3.11). It was 54.37mm in low density, 59.21mm in medium density, and 41.64mm in high density.

Similar trends occurred in the average weight of tube produced /animal (table 3.19 and figure 3.13). It was 19.57mg in low density, 20.12mg in medium density, and 13.95mg in high density.

b- *Fabricia sabella*

The average length of tube produced /animal sharply decreased from low density to medium density and then slightly decreased from medium density to high density (table 3.19 and figure 3.11). It was 89.17mm in low density, 35.03mm in medium density, and 30.9mm in high density.

The average weight of tube produced by one animal decreased with increased population density (table 3.19 figure 3.12). It was 4.64mg in low density, 3.57mg in medium density, and 2.85mg in high density.

The large length of tube produced per animal in the low density

cores may be due to the calm flow of water (e.g. an aquarium) in which each animal extends its tube length. Lewis (1968) noted that in calm flow of water, like the aquarium, *Fabricia* extends its tube length to 2.5cm above the sediment surface. The reduction in length of tube produced by one animal with increased density of animals may be due to the high mortality occurring in the medium and high density which does not allow the animal to extend its tube length.

The difference between the weight of tube produced per animal of *Pygospio* and *Fabricia* may be related to the thickness of tube. *Pygospio* forms a 1mm thick tube (Schäfer, 1972), while *Fabricia* forms a 0.25mm thick tube (related to the worm width) (Eales, 1967). This is substantiated by the weight per unit length taken in both species (table 3.19 column 5). The average weight per unit length taken by *Pygospio* tubes in different population densities was about 0.343, while the average weight per unit length of *Fabricia* tubes in different densities was about 0.0833.

6- Environmental implication and future experiments

The results reported in this chapter suggest that *Pygospio elegans* and *Fabricia sabella* have a significant effect on the stability of natural estuarine sediment. Both species significantly affect permeability, shear strength and redox potential (Eh) in the laboratory at population densities equivalent to or lower than natural densities.

Pygospio and *Fabricia* are both tube building polychaete species and common macrofauna in estuaries. Where they occur in high numbers, such as the Clyde estuary, they may reduce erosion of sediment by

increasing its shear strength or critical erosion.

The compactness of estuarine and marine sediments changes seasonally, and it is thought to be related to factors such as temperature and biological activity (McMaster 1962, 1967; Anderson et al., 1981). In the winter, sediment transport in estuaries is high due to strong currents and run-off from the land. Erosion may in part be increased due to a significant reduction in the number of burrowing animals present. The activity of the animals present will be reduced due to low water temperatures.

The effect of both species tubes may be important for the distribution of pollutants in sediments. Tubes and burrows are known to have a significant effect on the input of dissolved substances to the water column from sediments (Lee and Swartz, 1980; Aller, 1983; Waslenchuk et al., 1983; Officer and Lynch 1989 ; Riedel et al., 1987, 1989). The amount of exchange dissolved substances between the sediment and the water column depends on factors such as the surface area of the sediment, thickness of the oxidized top layer, water movement across the surface (Dworschak, 1981). Burrows can greatly increase the surface area of the sediment (Anderson and Meadows, 1978; Katz, 1980; Atkinson et al., 1982; Meadows, 1986) and so would affect exchange in this way. My research has shown that tubes affect sediment permeability and this effect factor would also affect exchange of dissolved substances across the sediment-water interface.

The dumping of radioactive waste at sea is one area where burrows may be important in this aspect. Benninger et al., (1979) and Cochran and Aller (1979) found that burrowing animals were important for determining the depth distribution of radioisotopes in marine

sediments. *Pygospio* and *Fabricia* and other burrowing animals may be important for distributing radio isotopes in the Clyde estuary. Swan et al., (1982) described that the distribution of radioisotopes of Casesium and Lead in a Clyde Sea Loch was influenced significantly by bioturbation.

The effect of these two species on sediment stability needs further investigation such as comparative studies between field and laboratory (flume tank experiments in the laboratory), and measurements to determine the critical erosion of sediment around their tubes. This will give a clearer picture of their effects on natural sediment stability.

However, this is only a beginning. Even at Ardmore where the species diversity is relatively low, there are a number of other macrofaunal organisms and also a large meiofaunal community that require investigation. Very little is known experimentally about the effects of these other species on sediment properties, either individually or in multi-species experiments. Clearly before we can understand in detail the effects of these diverse infaunal communities on the physical and chemical properties of the sedimentary ecosystem, a great deal of further integrated field and laboratory investigation is required.

SUMMARY

1- The effect of *Pygospio elegans* on sediment permeability, shear strength, and redox potential (Eh) and pH at specific population densities was studied over a fifteen day experimental period. Low, medium and high densities of *Pygospio* (2,333, 7,000 and 21,000 animals m^{-2} respectively) increased permeability, shear strength, and redox potential (sediment surface). Permeability slightly decreased after 5 days. Shear strength increased after day 5 even in low population density which is slightly lower than the control at day 5.

2- The effect of *Fabricia sabella* on sediment permeability, shear strength, and Eh and pH at specific population densities was studied over a fifteen day experimental period. Low of *Fabricia* (5,667 animals m^{-2}) decreased permeability, increased shear strength, and decreased Eh. Medium density of *Fabricia* (17,000 animals m^{-2}) decreased permeability, increased shear strength and Eh. High density of *Fabricia* (51,000 animals m^{-2}) increased permeability, shear strength and Eh. In low and medium densities, permeability increased after 5 days but was still below the control, while in the high density, permeability slightly decreased after 5 days. In general, shear strength increased with time. In general, pH slightly changed at the end of experiment.

3- The effect of mixed population of *Pygospio* and *Fabricia* on sediment permeability, shear strength and Eh and pH was studied over a 15 day experimental period. Low, medium and high densities of both

species increased permeability, shear strength and Eh. Permeability slightly decreased after 5 days, while shear strength increased after 5 days particularly in high density of mixed species.

4- A negative relationship was found between the Eh and pH for control and single and mixed species of *Pygospio* and *Fabricia*.

5- The mortality of *Pygospio elegans* at different population densities was studied at the end of the single species and mixed species experiments. In general, mortality occurred at the high population density in the permeability experiment (45 animals/core = 21,000 animals m^{-2}) and in all population densities in the shear strength experiment. The mortality increased with increasing population density.

6- Mortality of *Fabricia sabella* of low, medium and high population densities was studied at the end of single and mixed species experiments. Mortality occurred in all population densities of *Fabricia* for single and mixed species in the permeability and shear strength experiments.

7- Length and weight of tubes of *Pygospio elegans* of low, medium and high population densities were studied at the end of single species experiments. In general, length and weight of tubes decreased with increasing density.

8- Length and weight of tubes of *Fabricia sabella* of different population densities were studied at the end of single species experiments. Length and weight of tubes decreased with increasing density.

CHAPTER FOUR

Assessment of bioturbation

INTRODUCTION

Bioturbation, that is the burrowing activities of infaunal invertebrates, mixes the surface layers of sediments (Berner, 1980). The process of bioturbation in marine sediments is very important, and it is well known that animal activity and burrowing in sediments can have major effects on the physical and chemical properties of the sediment (Rhoads, 1974; Aller, 1980; Berner, 1980; Valiela, 1984; Meadows and Campbell, 1988). Bioturbation occurs in several different ways (Berner, 1980). Some organisms, such as crabs and snails, mix surface sediment by crawling or plowing through it. Other organisms, specially Polychaete worms and bivalves, burrow into sediment and ingest the sediment particles, and some burrows can extend to a few metres into sediment. Animals live in burrows flush the burrows with seawater. This process increases the amount of water below the sediment surface and extends the interface between the overlying water and the sediment (Berner, 1980).

Assessment of bioturbation is described by several investigators using different mathematical approaches (Berger and Heath, 1968; Ruddiman and Glover, 1972; Fisher et al. 1980; Officer and Lynch, 1989).

The main purpose of my research was to study the effect of animal burrows on sediment properties. The present chapter is concerned with developing quantitative approaches that will give an assessment of bioturbation using the measurement of tube diameters.

MATERIALS AND METHODS

Quantitative approaches to the assessment of bioturbation

Different types of sediment contain different species of burrowing animals, some of which produce more bioturbation than others. These differences in bioturbation may consist of differences in the total number of burrows at different depths because some species burrow deeper than others. There may also be differences in the diameter of burrows produced by the different species. Furthermore, the angle of the burrows to the vertical will also have an effect. For example, over a given vertical distance, a burrow running at an angle will have a greater length and hence greater surface area than one running vertically.

These differences suggest that a quantitative estimate of bioturbation may be obtained by assessing:

(i) The number of burrows at each depth

(ii) The diameter of each burrow

(iii) The angle of burrows to vertical.

Item (i) will give a quantitative assessment of the reduction of bioturbation according to the depth in the sediment. Item (ii) may lead to an indication of the number of species at each level. Items (ii) and (iii) will lead to accurate assessment of the total burrow perimeter at given level and also to the total burrow surface area over a range of depths.

A model of bioturbation was therefore constructed, mimicking a natural sediment on which parameters (i), (ii) and (iii) could be measured.

The model (figure 4.1) consisted of horizontal cross sections of sediment at depths 0cm, 5cm, 10cm, 20cm, 30cm and 50cm. Each cross section contained different diameters of burrows, some of which were not circular.

The following measurements were taken at each cross section:

- The total number of burrows
- The diameter of each burrow in mm
- The major and minor axes of those burrows which were not circular.

These data are given in table 4.1 and used in the subsequent quantitative assessment of bioturbation.

(i) Changes in number of burrows with depth.

Table 4.1 shows that the number of burrows decreases with increasing depth. Figure 4.2 shows that the decrease is not linear. To quantify the decrease it is therefore necessary to transform the data of the total number of burrows at each depth, applying several transformations and picking the one that gives the best linear relationship between numbers of burrows and sediment depth. I have used the following transformations: ln, square root and $\log_{10}$.

The details of these transformations are given in appendix 4.I, table 1 and figure 1. The best transformations were ln and $\log_{10}$. This can be seen by comparing the correlation coefficients of the linear regressions given in appendix 4.I, table 2. In this example the ln and $\log_{10}$ transformations happened to be the best transformations because they had the highest correlation coefficients. However, each set of data is likely to be different. Therefore, the

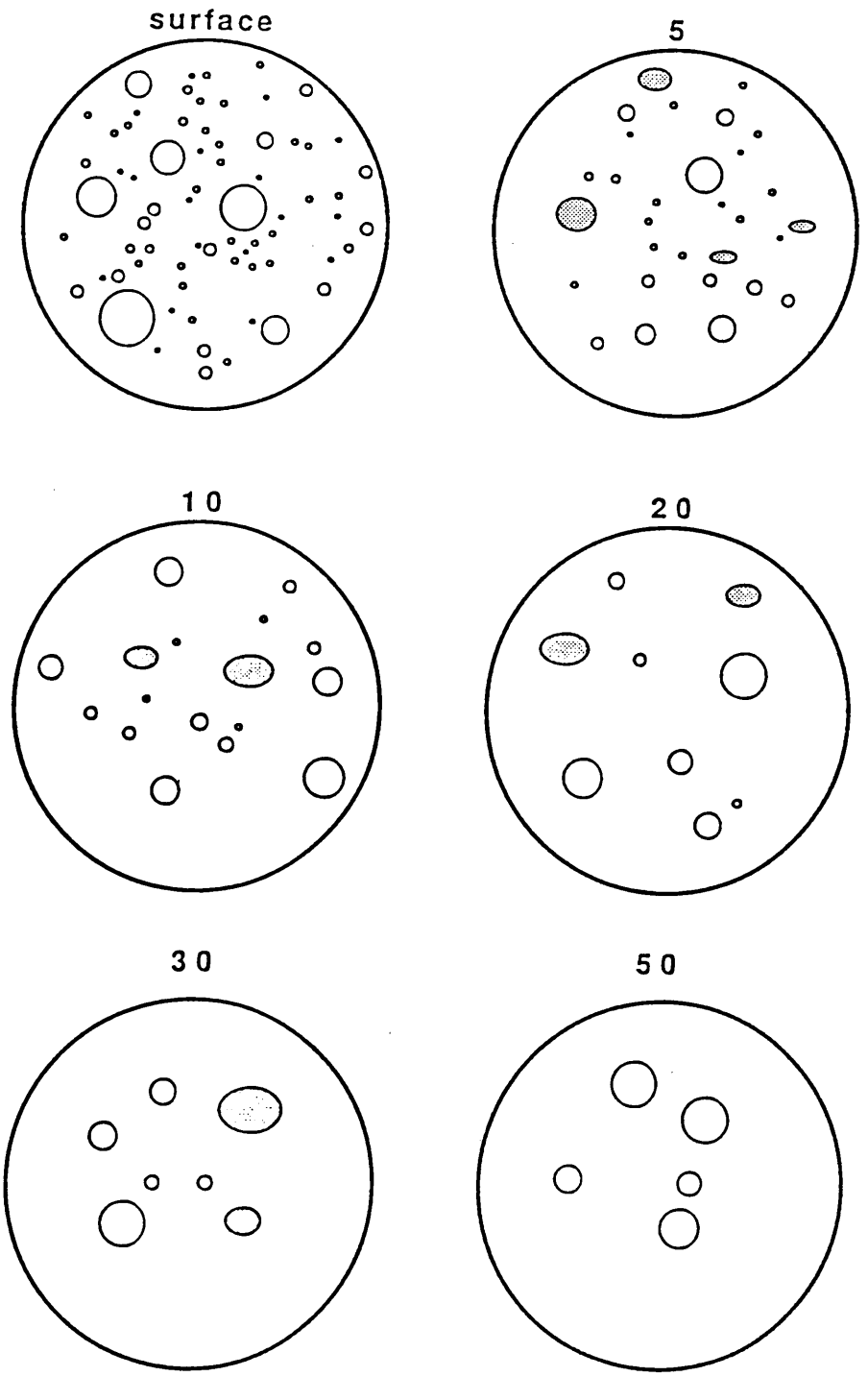


Figure (4.1)

The model constructed for the horizontal cross section of animal burrows in different depths of sediment (surface, 5cm, 10cm, 20cm, 30cm and 50cm).

Table (4.1)

The diameter of each burrow (mm) measured at each depth of sediment. The major and minor axes of non-circular burrows are shown in figure 1 as 7:4.5 for example and are asterisked.

Depth of sediment (cm)	Burrow number	Diameter of burrow (mm)	Burrow number	Diameter of burrow (mm)
	1	1	35	7
	2	1	36	2
	3	6	37	8
	4	1	38	2
	5	1.5	39	0.5
	6	0.5	40	1
	7	0.5	41	0.75
	8	0.5	42	0.5
	9	0.5	43	0.5
	10	1	44	1
	11	1	45	2
	12	1.5	46	1.5
	13	3	47	1.5
	14	1	48	0.5
	15	1	49	1
	16	1	50	0.5
Surface	17	0.5	51	0.75
	18	1	52	1
	19	7	53	0.5
	20	0.5	54	1
	21	1	55	1
	22	1	56	2
	23	1.5	57	1
	24	1.5	58	1
	25	0.5	59	1
	26	0.75	60	2
	27	0.75	61	2
	28	1	62	2
	29	1	63	4.5
	30	0.5	64	10
	31	1	65	2
	32	2	66	1
	33	1	67	1
	34	1	68	2
Total number of burrows			68	

Table 4.1 Continued,

Depth of sediment (cm)	Burrow number	Diameter of burrow (mm)	Burrow number	Diameter of burrow (mm)
5	1	1	16	0.5
	2	6 | 4 *	17	4.5| 2 *
	3	3.5	18	1
	4	1	19	3
	5	2.5	20	2
	6	1	21	2
	7	0.5	22	1.5
	8	0.75	23	3
	9	7 | 6 *	24	2
	10	1	25	2
	11	0.5	26	1.5
	12	1	27	1
	13	1	28	6.5
	14	4.5| 2 *	29	4.5
	15	1	30	1
Total number of burrows			30	
10	1	5	10	1
	2	2	11	2
	3	1	12	3
	4	2.5	13	1
	5	1	14	2
	6	6 | 4 *	15	7
	7	4	16	5
	8	5	17	2
	9	9 | 5.5 *		
Total number of burrows			17	
20	1	4	6	3
	2	5 | 3.5 *	7	1
	3	2	8	4.5
	4	8	9	7
	5	8 | 5*		
Total number of burrows			9	

Table 4.1 Continued,

Depth of sediment (cm)	Burrow number	Diameter of burrow (mm)	Burrow number	Diameter of burrow (mm)
	1	11 | 8 *	5	2.5
	2	4.5	6	6 | 5 *
30	3	5	7	8
	4	2.5		
Total number of burrows			7	
	1	8	4	7
50	2	8	5	4
	3	5		
Total number of burrows			5	
Grand number of burrows in all sections			136	

best transformation, in other words the transformation which gives the closest fit to a straight line (highest correlation coefficient), should be assessed in each case.

(ii) The differences in the diameter of burrows.

Figure 4.1 and table 4.1 columns 3 & 5 show that different diameters of burrows occurred in the upper depths of sediment, and that these differences decreased with increasing depth. For example, small diameter burrows were found in the upper depths, but were absent at the lower depths. This may mean that there were more species occurring in the upper depths.

The differences in diameters at each depth and between depths, were analysed statistically as follows. The burrow diameters were used to calculate the means, standard deviations, coefficients of variation (%), skewnesses and kurtoses of the perimeter and surface area of the burrows at each depth. The means give an indication of the most abundant values of the perimeter and surface area of the burrow at each depth. The standard deviations and coefficients of variation give estimates of scatter about the means.

Skewness and kurtosis measure the departures of the curve from the normal distribution (appendix 4.II, figures 2a and 2b). A positive skewness means that there are a large number of small burrows all within a narrow size range, and a small number of large burrows scattered throughout the larger size ranges. A negative skewness indicates that there are a large number of large burrows all within a narrow size range, and a small number of smaller burrows scattered throughout the small size ranges. A positive kurtosis (a leptokurtic

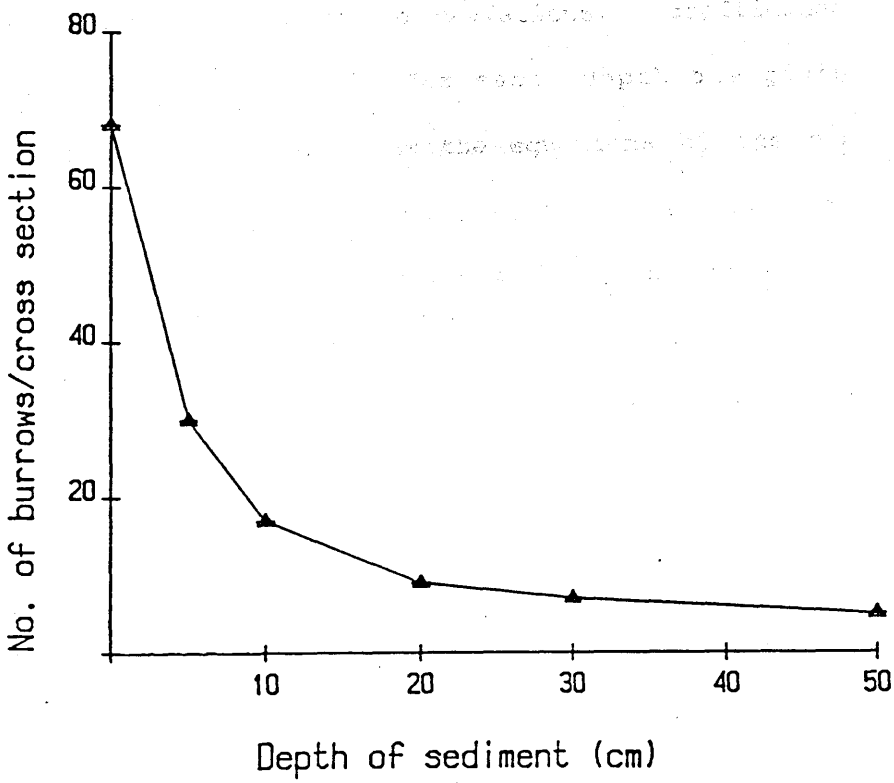


Figure (4.2)

Total number of burrows / cross section at different depths of sediment.

curve) means that there are more values of the perimeter or surface area of burrows at or near the mean, and fewer values at the extremes of the curve. A negative kurtosis (a platykurtic curve) means that there are fewer values of the perimeter and surface area of burrows at or near the mean, and more values at the extremes of the curve.

The details of the equations of the perimeter and the surface area and their statistical measurements are given in appendix 4.II.

Computer programs calculating the perimeter and surface area of each burrow, and their means, standard deviations, coefficient of variations, skewnesses and kurtoses for each depth are given in appendix 4.III. The appendix shows how the equations of the burrow perimeter and surface area and their statistical measurements (mean, standard deviation, coefficient of variation, skewness and kurtosis) were calculated.

(iii) The angle of burrows to the vertical

The model (figure 4.1 and table 4.1) shows that most of the burrows are circular but some are not (stippled in figure 4.1 and * data in table 4.1). Burrows that run into the sediment vertically have a circular cross section in the horizontal plane. Burrows that run at an angle to the vertical have an elliptical cross section. This point is very important because it will affect the calculation of the burrow perimeter and surface area of non-vertical burrows at a given level in the sediment. It will also have an effect on the interaction between the sediment and water interface because the length of burrow running at an angle between two depths, and hence its surface area, will be larger than that of a burrow running

vertically. This is described in detail in appendix table 4.IV. The appendix indicates that when the angle to the vertical increases (i.e. angle to the horizontal decreases), the cross section of the burrows change to an elliptical shape (appendix 4.IV, figure 1). It is important to note that in this process the minor axis remains the same and equal to the diameter of an equivalent vertical burrow. Appendix 4.IV, table 1 (columns 1 & 5) shows that as the ratio of the major axis to the minor axis increases, the angle to the horizontal decreases. Figure 4.3 shows that the increase is not linear. Therefore, to pick the best straight line fit, the data of the ratio of major and minor axes and the angles were transformed using ln, square root and $\log_{10}$ transformations (appendix 4.IV, table 1. The best transformation was ln, and this can be seen by comparing the correlation coefficients of the linear regressions given in appendix 4.IV, table 2 and graphs given in appendix 4.IV, figure 2.

Items i, ii and iii (above headings) are closely related, because the perimeter and surface area of burrows cannot be determined without measuring the perimeter of burrows. If the cross section of the burrow is circular, only the diameter of the burrow needs to be measured. But if the cross section of the burrow is an ellipse, it is necessary to measure the major and minor axes.

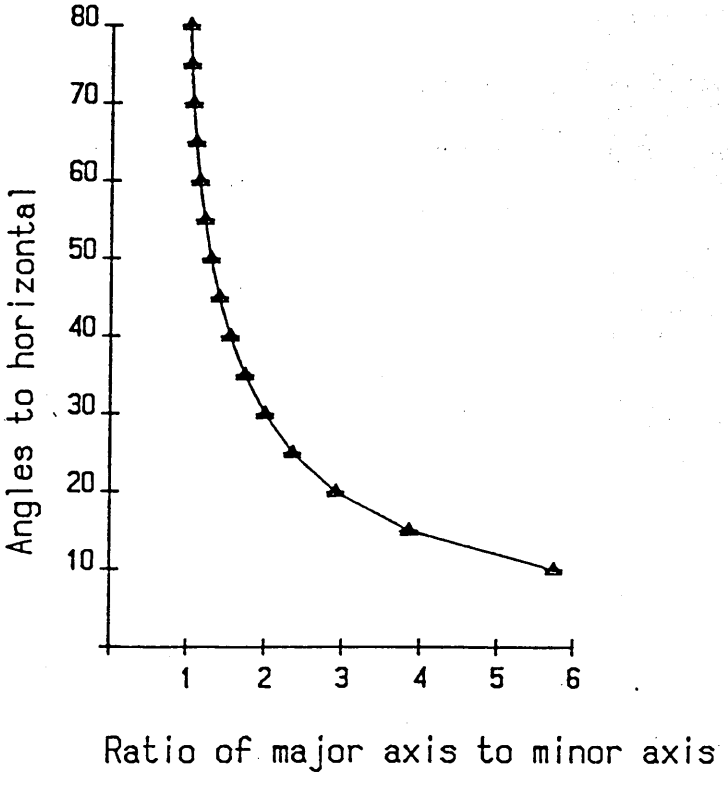


Figure (4.3)

The ratio of the major axis to the minor axis for different angles to the horizontal.

RESULTS

The data of the burrow measurements of the model (table 4.1) were fed into the computer to calculate the perimeter and surface area of each burrow, the total number of burrows and the total burrow perimeter and surface area. The program then calculated the statistical measurements of the burrow perimeter and surface area. The results of the data of the model are described as follows.

Table 4.2 and figure 4.4a show that as the total number of burrows decreased with increasing sediment depth, the total perimeter and surface area of the burrows decreased, while the means of perimeter and surface area of the burrows increased. Table 4.2 and figure 4.4b show that the standard deviations of the perimeter and surface area of burrows fluctuated, while the coefficients of variation (%), skewness and kurtosis decreased with increasing depth. The values of skewness and kurtosis decreased from positive values at the upper depths to negative values at the lower depths.

The statistical significance of the observed skewness and kurtosis of burrow perimeter and surface area compared with the normal curve were tested using the student's t test (table 4.3). The table shows that there were significant differences in the skewness and kurtosis for the perimeter and surface area of burrows at the surface, 5cm and 10cm depths of sediment (asterisked in the table), but not at the 30 and 50cm depths.

Table (4.2)

The total number of burrows, the total burrow perimeter and total surface area and their statistical measurements, calculated at each depth of sediment for the model page 3.

Depth of sediment (cm)	Total number of burrows	Parameters	Total	statistical measurements				
				Mean	Standard deviation	coeff. of var. (%)	Skewness	Kurtosis
Surface	68	Perimeter	350.29	5.1513	5.8292	113	2.9568	8.7532
		Area	324.76	4.7759	13.012	314	4.0684	17.819
5	30	Perimeter	202.77	6.7590	5.2961	78	1.3639	1.2239
		Area	168.71	5.6238	8.7443	156	2.3743	5.2887
10	17	Perimeter	175.74	10.395	6.7650	65	0.7010	-0.5505
		Area	195.37	12.026	13.837	115	1.4632	1.6123
20	9	Perimeter	126.91	14.224	7.3304	52	0.0121	-0.9652
		Area	173.38	19.902	17.063	86	0.7270	-0.6436
30	7	Perimeter	118.07	16.830	8.2480	49	0.5447	-0.7129
		Area	188.30	27.180	24.599	91	1.1250	0.6229
50	5	Perimeter	100.53	20.106	5.7070	28	-0.5671	-2.2309
		Area	171.22	34.243	17.426	51	-0.3938	-2.5989

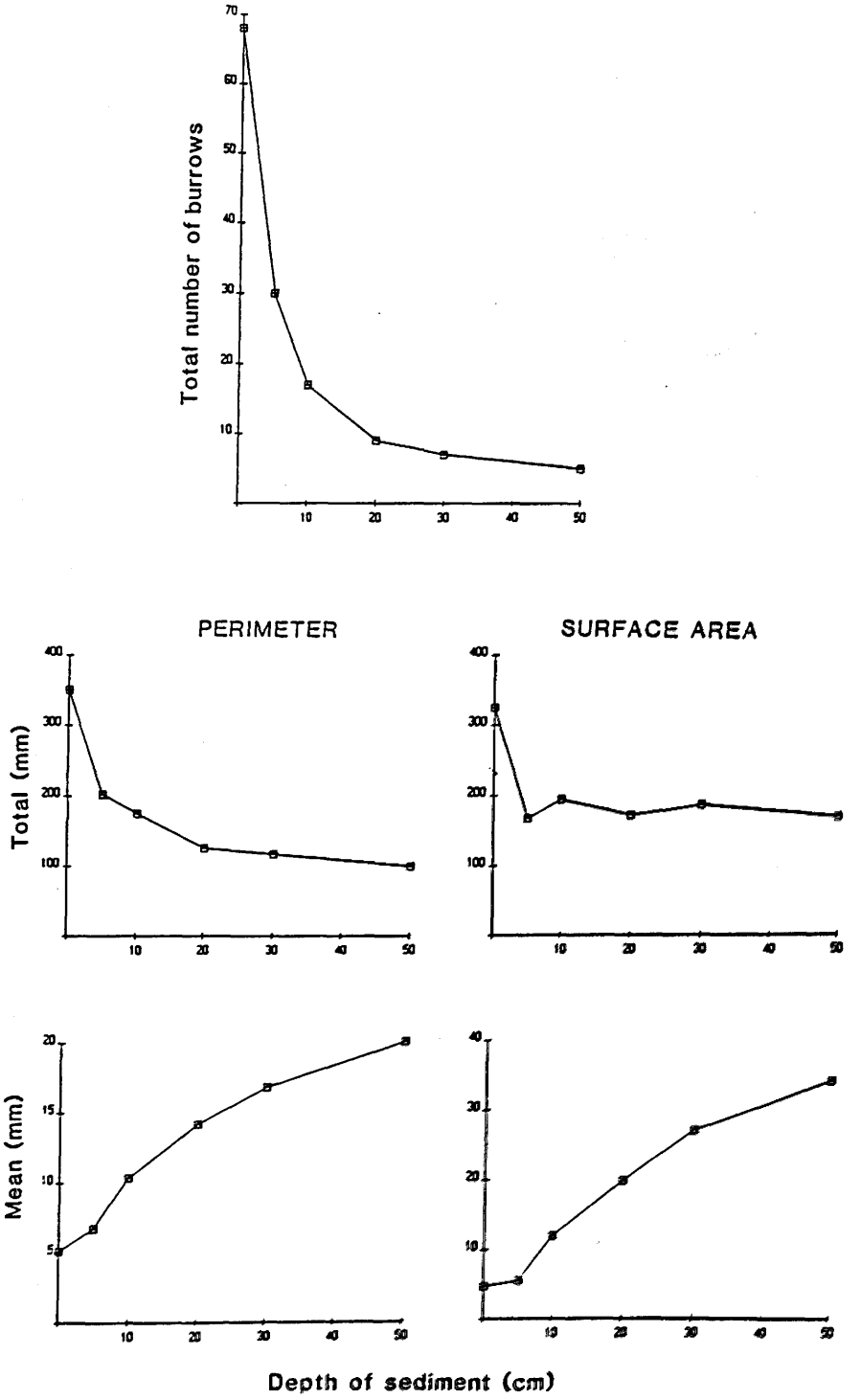


Figure (4.4a)

Plot of the total number of burrows, total of perimeter and surface area of burrows and the means of perimetér and surface area of burrows against the different depths of sediment (surface, 5cm, 10cm, 20cm, 30cm and 50cm).

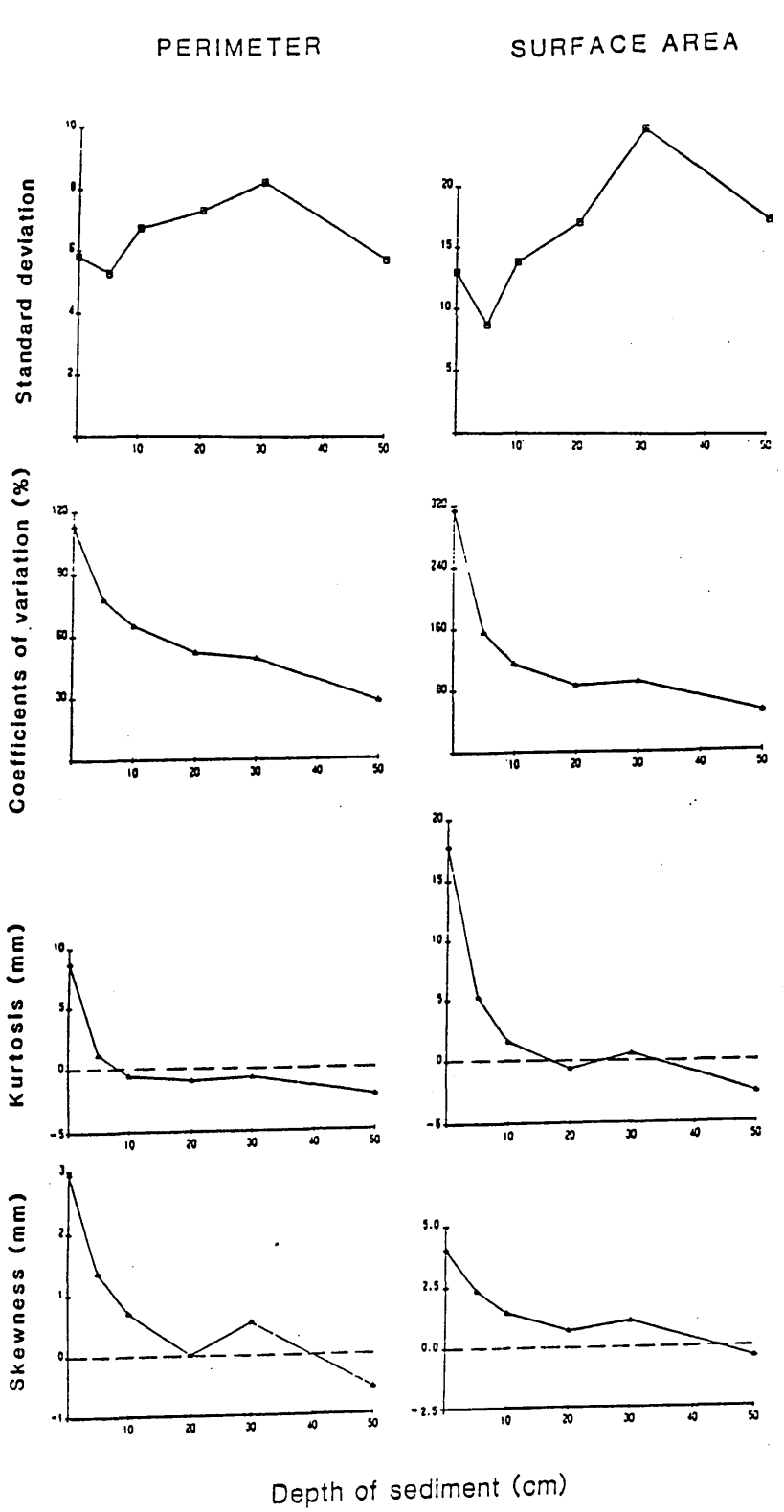


Figure (4.4b)

Plot of the statistical measurements (standard deviation, coefficient of variation (%), skewness and kurtosis) against the depth of sediments (surface, 5cm, 10cm, 20cm, 30cm and 50cm). Horizontal dash line indicates zero skewness and kurtosis.

Table (4.3)

Student's t of the skewness and kurtosis of the burrows perimeter and surface area. (* statistical significance)

Depth of sediment (cm)	Burrows parameter	Student's t		Probability	
		Skewness	Kurtosis	Skewness	Kurtosis
Surface	Perimeter	10.169	15.249	P<0.001***	P<0.001***
	Area	13.992	31.043	P<0.001***	P<0.001***
5	Perimeter	3.3173	1.0982	P<0.001***	P>0.05
	Area	4.8646	4.1793	P<0.001***	P<0.001***
10	Perimeter	1.2751	0.5177	P>0.05	P>0.05
	Area	2.6615	1.5165	0.01>P>0.001***	P>0.05
30	Perimeter	0.6863	0.4491	P>0.05	P>0.05
	Area	1.4174	0.1656	P>0.05	P>0.05
50	Perimeter	0.6213	1.1155	P>0.05	P>0.05
	Area	0.4313	1.2995	P>0.05	P>0.05

The positive skewness of the perimeter and surface area of the burrows from the surface to 30cm (table 4.2 and figure 4.4b) mean that at these depths there were a large number of small perimeter and surface area of burrows, and with only a small number of large perimeter and surface area of burrows. The negative skewness calculated at depth 50cm shows that there was a large number of large perimeter and surface area of burrows, and with a small number of perimeter and surface area of burrows.

The positive kurtosis calculated at the surface and the depth of 5cm of sediment for the perimeter and surface area of burrows means that there were more values of perimeter and surface area of burrows at or near the mean of the curve and less values at the extremes of the curve. The negative kurtoses of the perimeter of burrows calculated at depths 10cm, 20cm, 30cm and 50cm mean that there were less values near the mean and more values at the extremes of the curve.

APPENDIX ONE

Appendix 1, table (1)

The number of meiobenthic organisms per 2ml of sediment of different groups counted from each concentration using the Ludox solution. Three washes were conducted for replicates A and B of sediment. (i and ii indicate to the upper and lower layers, respectively)

Number of washes	Meiobenthos Group	Concentration of solution %																			
		100				75				50				25				12.5			
		A		B		A		B		A		B		A		B		A		B	
		i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii
First	Nematodes	144	47	120	40	50	10	40	13	14	4	4	4	-	1	-	-	3	1	1	3
	Copepods	6	-	8	1	5	3	3	4	1	1	1	1	-	1	-	-	-	-	-	-
	Polychaetes	2	1	4	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
	Eggs	6	10	5	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	158	67	137	49	55	13	43	17	15	5	5	5	-	2	-	-	4	1	1	3
Second	Nematodes	16	5	18	2	6	4	3	5	-	1	-	1	-	1	-	-	-	-	-	-
	Copepods	2	-	2	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1
	Total	21	5	21	3	6	4	3	6	-	1	-	1	-	1	-	-	-	-	-	1
Third	Nematodes	-	1	4	1	5	1	1	-	6	1	1	-	-	-	-	-	-	-	-	-
	Copepods	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
	Total	-	1	4	1	7	1	1	-	6	2	1	-	-	-	-	-	-	-	-	-
Total of organisms of all washes	Nematodes	160	53	142	43	61	15	44	18	14	6	5	6	-	2	-	1	3	1	1	3
	Copepods	8	-	10	1	5	3	5	1	1	2	1	1	-	1	-	-	-	-	-	1
	Polychaetes	2	1	4	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
	Total number of organs. of all groups	179	64	162	52	68	18	49	19	15	13	6	7	-	3	-	1	4	1	1	4
Grand total of organisms.		243		211		86		68		28		13		3		1		5		5	

Appendix 1, table (2).

The number of meiobenthic organisms per 2ml of sediment of different groups counted from each concentration using the Agar solution. Three washes were conducted for replicates A and B of sediment. (i and ii indicate to the upper and lower layers, respectively)

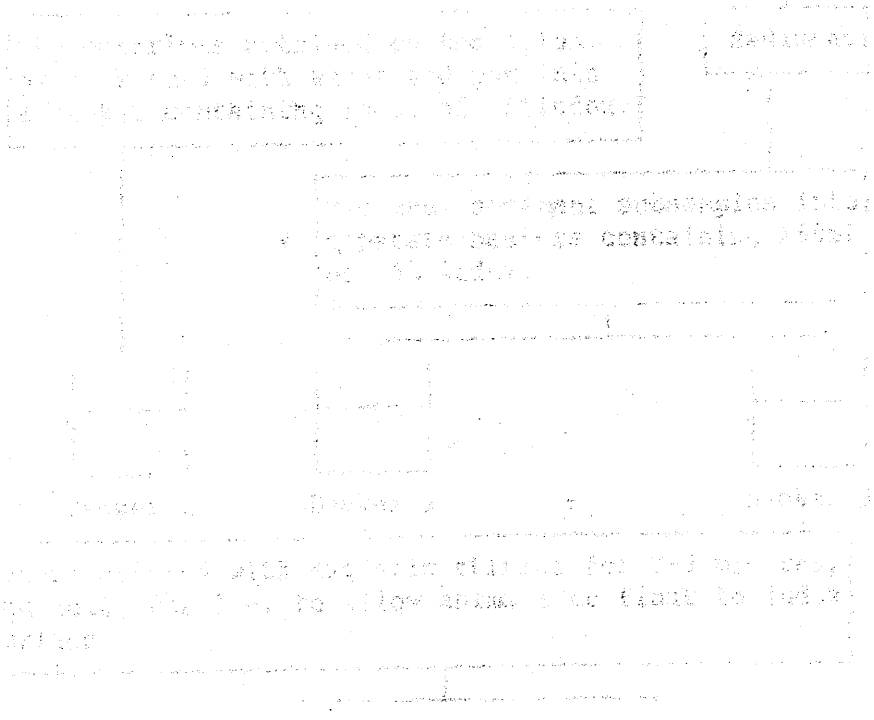
Number of washes	Meiobenthos Group	Concentration of solution %																			
		100				75				50				25				12.5			
		A		B		A		B		A		B		A		B		A		B	
		i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii
First	Nematodes	18	53	3	33	9	50	17	44	24	64	4	49	6	31	52	35	8	5	13	14
	Copepods	2	9	1	2	1	3	4	3	2	4	1	3	1	7	1	2	-	2	1	1
	Polychaetes	2	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
	Eggs	4	5	5	3	2	5	4	3	-	-	1	5	2	3	-	2	-	-	4	5
	Total	26	67	9	38	12	58	25	50	26	68	6	57	9	42	53	39	8	7	18	20
Second	Nematodes	30	15	21	18	8	10	15	5	7	18	8	15	-	10	-	3	-	4	-	-
	Copepods	-	2	1	-	2	5	-	-	-	1	-	1	-	3	-	-	-	-	-	-
	Polychaetes	1	-	-	-	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-
	Eggs	5	2	5	-	3	3	-	2	-	-	1	-	-	-	-	-	-	-	-	-
	Total	36	19	27	18	14	19	16	8	7	19	9	16	-	13	-	3	-	4	-	-
Third	Nematodes	-	2	-	6	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
	Copepods	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	-	3	-	6	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
The total in the three washes	Nematodes	48	70	24	57	17	60	32	50	31	82	12	64	6	41	52	38	8	9	13	14
	Copepods	2	12	2	2	3	8	4	3	2	5	1	4	1	10	1	2	-	2	1	1
	Polychaetes	3	-	-	-	1	1	1	1	-	-	-	-	-	1	-	-	-	-	-	-
	Eggs	8	7	10	3	5	8	4	5	-	-	2	5	2	3	-	2	-	-	4	5
Total number of organs. for all groups		61	89	36	62	35	77	41	59	33	87	15	73	9	55	53	42	8	11	18	20
Grand total of organs.		150		98		122		100		120		80		64		95		19		38	

Appendix 1, table (3)

The number of meiobenthic organisms per 2ml of sediment of different groups counted from each concentration using the Sucrose solution. Three washes were conducted for replicates A and B of sediment. (i and ii indicate to the upper and lower layers, respectively)

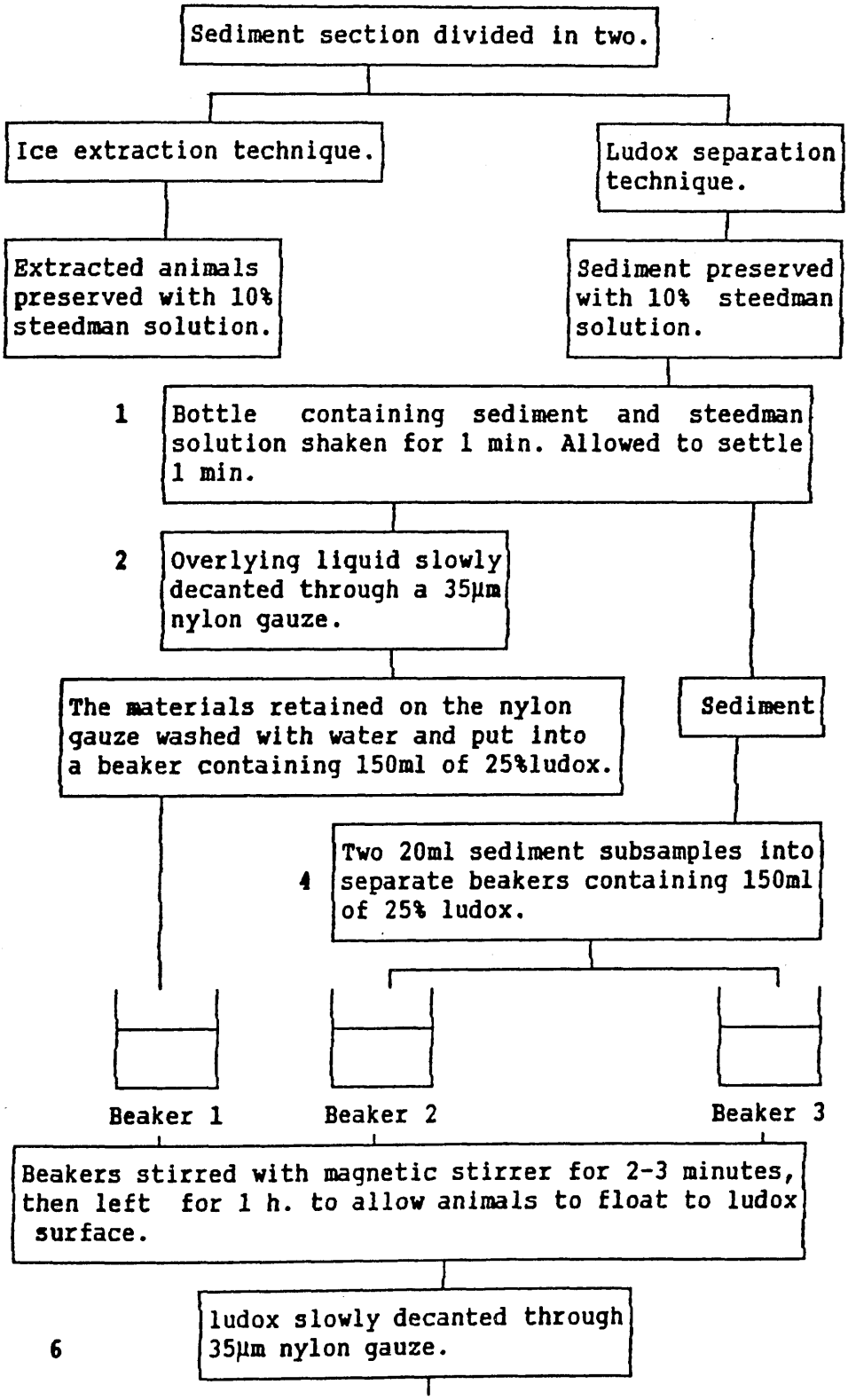
Number of washes	Meiobenthic group	Concentration of solution %																	
		100				75				50				25		12.5			
		A		B		A		B		A		B		A		A		B	
		i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii	i	ii
First	Nematodes	8	8	12	13	16	6	26	30	1	2	-	2	-	4	-	-	-	2	-	-
	Copepods	1	1	1	1	1	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-
	Polychaetes	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Total	10	9	13	14	17	6	27	31	2	2	-	2	-	4	-	-	-	2	-	-
Second	Nematodes	-	-	-	-	10	22	3	6	-	-	-	-	-	-	1	-	-	-	-	-
	Copepods	-	-	-	-	-	1	-	2	-	-	-	-	-	-	-	-	-	-	-	-
	Total	-	-	-	-	10	23	3	8	-	-	-	-	-	-	1	-	-	-	-	-
Third	Nematodes	-	-	-	-	-	4	-	-	-	-	-	1	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	4	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Total no. in three washes	Nematodes	8	8	12	13	26	32	29	36	1	2	-	3	-	4	1	-	-	-	-	-
	Copepods	1	1	1	1	1	1	1	3	1	-	1	-	-	-	-	-	-	-	-	-
	Polychaetes	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Total number of organs. for all groups		10	9	13	14	27	33	30	40	2	2	1	3	-	4	1	-	-	-	-	-
Grand total number		19		27		60		70		4		4		4		1		-		-	

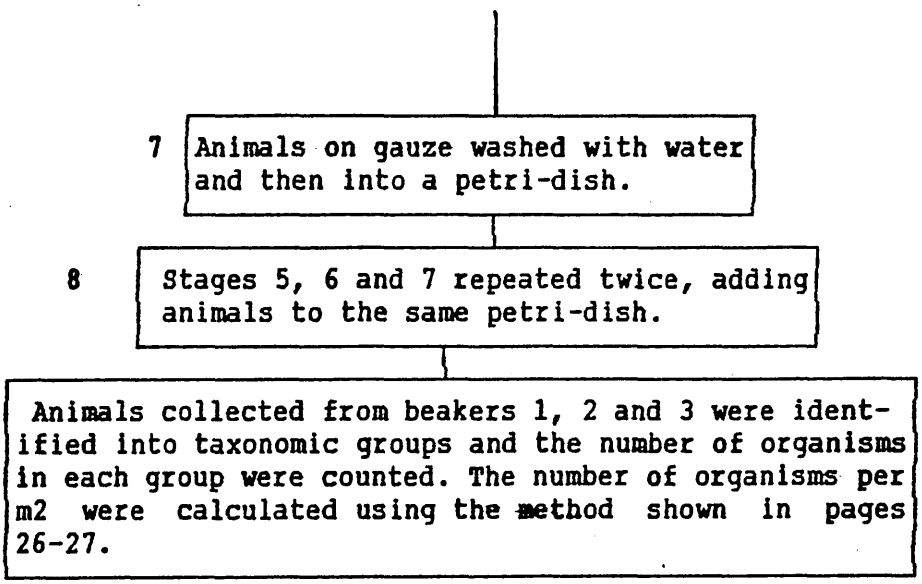
APPENDIX TWO



Appendix 2, figure (1)

A flow diagram of the procedure followed to treat the sediment samples for extraction meiofauna during the survey.




7
Animals on gauze washed with water and then into a petri-dish.
8
Stages 5, 6 and 7 repeated twice, adding animals to the same petri-dish.
Animals collected from beakers 1, 2 and 3 were identified into taxonomic groups and the number of organisms in each group were counted. The number of organisms per m2 were calculated using the method shown in pages 26-27.

Appendix 2, table (1).

Number of meiobenthic organisms extracted from the two 20ml subsamples (A and B) of sediment. Two samples of sediment (I and II) were taken from each depth.

MONTH	GROUP	Depth of sediment (cm) (0 - 5) I A	B	Overlying liquid	II A	B	Overlying liquid	(5 - 10) I A	B	Overlying liquid	II A	B	Overlying liquid
1984 February	Nematodes	309	315	949	407	385	2642	192	169	1030	168	158	917
	Copepods	2	1	4	-	1	11	1	-	-	-	-	-
	Ostracods	1	-	6	-	-	1	-	-	-	-	-	-
March	Nematodes	174	216	270	397	400	1358	105	82	197	112	104	305
	Copepods	3	-	1	2	1	8	-	-	-	-	-	-
	Ostracods	1	-	3	-	-	10	-	-	3	2	-	-
April	Nematodes	1380	1333	4370	800	877	2405	230	251	383	100	89	295
	Copepods	-	6	25	1	2	10	-	-	1	-	-	-
	Ostracods	-	-	10	1	-	20	-	-	-	-	-	-
May	Nematodes	895	975	2510	320	230	2725	172	168	985	149	143	670
	Copepods	-	-	5	5	-	35	-	1	-	-	-	-
	Ostracods	15	-	5	5	-	30	-	1	-	-	-	-
June	Nematodes	550	810	6640	890	695	1910	215	279	2450	112	163	1565
	Copepods	-	10	120	45	85	120	2	2	10	-	-	5
	Ostracods	-	5	35	5	10	30	-	-	5	-	-	-
July	Nematodes	215	150	1065	190	169	1915	250	238	1195	104	119	1165
	Copepods	15	55	420	30	16	495	-	2	-	-	-	-
	Ostracods	-	-	25	-	1	15	-	-	-	-	-	-
August	Nematodes	835	665	4680	1020	950	3860	161	143	525	83	76	255
	Copepods	10	30	25	25	10	35	1	-	-	-	-	-
	Ostracods	-	-	20	5	-	5	-	-	-	-	-	-
September	Nematodes	360	320	1890	580	480	1090	127	170	970	102	104	355
	Copepods	-	-	50	-	5	5	-	-	-	-	-	-
	Ostracods	-	-	25	10	10	5	-	1	-	-	-	-
October	Nematodes	125	150	1790	87	67	3645	30	22	800	84	38	1015
	Copepods	5	5	90	-	2	75	-	-	15	-	-	15
	Ostracods	-	-	25	-	-	40	-	-	-	-	-	-
November	Nematodes	325	325	1685	450	410	1990	100	127	1190	95	75	915
	Copepods	10	5	40	10	10	45	-	-	-	-	-	-
	Ostracods	-	-	5	10	5	35	-	-	-	-	-	-
December	Nematodes	205	175	710	109	125	535	99	87	295	163	164	400
	Copepods	-	25	25	10	10	80	-	-	-	1	-	-
	Ostracods	10	5	15	3	20	10	-	1	-	1	-	-
1985 January	Nematodes	90	107	2870	130	270	1390	30	22	350	19	24	470
	Copepods	5	3	35	6	10	70	-	-	5	-	-	-
	Ostracods	-	3	75	3	-	35	-	-	-	-	-	-
February	Nematodes	240	190	1900	445	220	3305	78	52	1120	34	62	850
	Copepods	5	-	45	-	-	5	-	-	-	-	-	-
	Ostracods	-	-	10	-	-	15	-	-	-	-	-	-

Cont... Appendix 2, table (1)

MONTH	GROUP	Depth of sediment (cm)																	
		(10 - 20)						(20 - 30)						(30 - 40)					
		I			II			I			II			I			II		
		A	B	Overlying liquid	A	B	Overlying liquid	A	B	Overlying liquid	A	B	Overlying liquid	A	B	Overlying liquid	A	B	Overlying liquid
1984 February	Nematodes	40	71	100	74	87	310	44	50	70	47	49	300	10	5	20	8	6	35
	Copepods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ostracods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
March	Nematodes	97	100	140	134	131	71	48	40	152	128	118	105	6	4	18	45	48	23
	Copepods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ostracods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
April	Nematodes	103	60	501	107	100	560	35	56	263	48	38	343	41	48	288	43	49	210
	Copepods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ostracods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
May	Nematodes	150	167	3345	144	183	2960	21	20	375	27	32	450	11	8	92	10	13	64
	Copepods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ostracods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
June	Nematodes	108	94	1470	48	61	925	9	6	225	10	9	125	7	8	305	4	9	150
	Copepos	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ostracods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
July	Nematodes	71	54	1830	60	82	1175	31	27	1295	29	32	535	11	9	320	9	11	240
	Copepods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ostracods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
August	Nematodes	44	26	665	50	32	595	7	8	340	12	13	210	11	10	120	9	8	65
	Copepods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ostracods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
September	Nematodes	39	52	720	90	91	1265	15	15	325	11	29	290	6	3	44			
	Copepods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
	Ostracods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
October	Nematodes	29	36	430	61	98	1065	42	40	370	37	36	315	32	10	260	17	14	205
	Copepods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ostracods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
November	Nematodes	37	16	1065	40	30	895	27	38	895	46	31	690	10	12	665	13	9	390
	Copepods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ostracods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
December	Nematodes	36	49	1025	41	46	1100	6	12	135	13	8	210	14	27	1080	20	19	595
	Copepods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ostracods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1985 January	Nematodes	41	37	1110	28	22	730	23	27	845	31	40	565	29	37	710	24	18	430
	Copepods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ostracods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
February	Nematodes	39	49	805	29	40	770	35	26	645	39	37	635	38	30	645	30	40	650
	Copepods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ostracods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix 2, table (2)

Annual survey 1984-1985. Abundance of macrobenthos organisms per core I and II.

Depth of sediment (cm)	Species	1984 February I	II	March I	II	April I	II	May I	II	June I	II	July I	II	August I	II	September I	II	October I	II	November I	II	December I	II	1985 January I	II	February I	II
0-5	*Pygospio elegans*	29	26	0	5	8	40	48	48	61	51	38	15	18	52	57	25	39	11	7	27	11	6	0	2	14	9
	Bathyporeia pilosa	1	1	0	9	4	5	2	1	5	20	22	38	8	22	2	15	3	30	4	9	6	16	9	6	9	3
	Etione longa	0	0	0	0	1	1	2	1	0	3	1	3	1	2	2	1	2	3	0	0	0	0	0	2	0	1
	Scoloplos armiger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
	Hediste diversicolor	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Arenicola marina (Juvenile)	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	5
	Hediste diversicolor (Last stage)	0	0	0	0	0	0	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-10	*Pygospio elegans*	0	0	0	0	0	0	0	0	0	2	0	0	3	0	0	0	0	0	0	0	2	0	0	0	4	0
	Bathyporeia pilosa	2	1	2	1	2	1	0	0	0	2	0	0	0	0	0	0	0	0	0	3	5	7	0	0	0	0
	Etione longa	2	2	0	0	0	0	0	0	0	0	0	1	0	2	2	0	0	0	2	1	1	2	1	0	0	0
	Scoloplos armiger	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0
	Hediste diversicolor	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10-20	*Etion longa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Hediste diversicolor	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 2, table (3)

The List of program to calculate the shear strength of sediment using BBC computer.

```
 10 *TV0,1
 20 MODE6
 30 PRINT"THIS PROGRAM CALCULATES THE"
 40 PRINT"SHEAR STRENGTH OF THE SEDIMENT"
 50 PRINT"USING THE CONE EQUATION AND THE VANE TESTER."
 60 PRINT"M.HARIRI,1985"
 70 DIM H(100),T(100)
 80 DIM P1(100),R2(100)
 90 DIM P(100),R1(100)
100 CLS
110 PRINT:PRINT
120 PRINT TAB(0,4);"DO YOU WISH TO CALCULATE THE  SHEAR"
130 PRINT TAB(0,6);"STRENGTH OF SEDIMENT USING THE CONE"
140  PRINT TAB(0,8);"OR THE VANE TESTER ? (PRESS C FOR THE"
150 PRINT TAB(0,10);"CONE OR V FOR THE VANE).  ";
160 A$=GET$
170 PRINT A$
180 CLS
190 IF A$="C"THEN GOTO 240 ELSE 1050
200 PRINT"THIS CALCULATION OF SHEAR STRENGT BY USING THE CONE ECUATION"
210 PRINT"(HANSBO,1957)"
220 PRINT :PRINT:PRINT
230 CLS
240 PRINT :PRINT
250 PRINT TAB(5);"*********************************"
260 PRINT TAB(5);"*   SHEAR STRENGTH OF SEDIMENT  *"
270 PRINT TAB(5);"*         USING  A CONE         *"
280 PRINT TAB(5);"*********************************"
290 PRINT:PRINT:PRINT:PRINT
300 INPUT"ENTER CONE ANGLE ? "B
310 PRINT:PRINT
320 INPUT"WHAT IS THE WEIGHT OF THE CONE(gm) ? "Q
330 PRINT:PRINT
340 PRINT"ENTER THE CONE CONSTANT (HANSBO,1957."
350 PRINT"p.22-25: k= Between 0.20-0.25 FOR 10"
360 PRINT"and 100 gms OF THE 60 degree CONES. "
370 PRINT"k= between 0.8-1.0 FOR 100,400 gms OF"
380 INPUT"THE 30 DEGREE CONES.)  > "K
390 CLS
400 PRINT:PRINT:PRINT:PRINT
410 INPUT "NAME OF SITE > "W$
420 PRINT
430 INPUT "DATE > "D$
440 PRINT
450 INPUT"ENTER NUMBER OF SAMPLES          > "N
460 VDU2
470 PRINT TAB(25);"*********************************"
480 PRINT TAB(25);"*   SHEAR STRENGTH OF SEDIMENT  *"
490 PRINT TAB(25);"*         USING A CONE          *"
500 PRINT TAB(25);"*********************************"
510 PRINT:PRINT:PRINT:PRINT
520 PRINT TAB(5);"NAME OF SITE = ";W$, TAB(50)"DATE = ";D$
530 PRINT
540 PRINT TAB(5);"NUMBER OF SAMPLES  = ";N
550 PRINT:PRINT
560 VDU3
570 CLS
580 FOR X=1 TO N
590 PRINT:PRINT:PRINT:PRINT:PRINT
600 INPUT TAB(5);" TITLE    > "S$
610 VDU2
620 PRINT TAB(5);" TITLE  = "S$
630 PRINT
640 VDU3
650 CLS
660 MODE6
670 INPUT TAB(0,4);"ENTER NUMBER OF READINGS OF THE DEPTH OF PENETRATION   >"U
680 PRINT
690 CLS
700 PRINT TAB(0,4);"TO CALCULATE THE SHEAR STRENGTH, PUT"
710 PRINT TAB(0,6);"THE DEPTH OF PENETRATION(mm) OF THE "
720 PRINT TAB(0,8);"CONE IN TURN."
730 E=0:B=0
740 FOR V=1 TO U
750 INPUT H(V)
760 L=H(V)^2
770 T(V)=((K)*(Q)*9.81)/(L)
780 E=E+T(V)
790 B=B+T(V)^2
800 NEXTV
810 VDU2
820 PRINT TAB(5);"DEPTH OF PENETRATION(mm)", TAB(40)"SHEAR STRENGTH VALUE(N.m
^-2)"
830 PRINT
```

```
 840 FOR V=1 TO U
 850 PRINT TAB(14);H(V) ,TAB(45);T(V)
 860 NEXT V:VDU 3
 870 ME=E/U
 880 SD=SQR((1/(U-1))*(B-(1/U)*E^2))
 890 PRINT
 900 VDU2
 910 PRINT
 920 PRINT TAB(5);"MEAN (KN.m^-2) = "ME
 930 PRINT TAB(5);"S.D. (KN.m^-2) = "SD
 940 PRINT:PRINT:PRINT:PRINT:PRINT
 950 VDU3
 960 CLS
 970 NEXTX
 980 GOTO2240
 990 CLS
1000 PRINT:PRINT:PRINT
1010 PRINT"THIS CALCULATION OF SHEAR STRENGTH OF THE SEDIMENT USED THE DIRECT"
1020 PRINT"READING HAND VANE TESTER FOR A QUICK AND AN ACCURATE DETERMINATION."
1030 PRINT"(PILCON ENGINEERING LIMITED. BROOK HOUSE,ALENCON LINK, BASINGSTOKE,"
1040 PRINT"HANTS.RG21 1QX.025656367)"
1050 CLS
1060 PRINT TAB(5);"*****************************"
1070 PRINT TAB(5);"*  SHEAR STRENGTH USING     *"
1080 PRINT TAB(5);"*      THE VANE TESTER      *"
1090 PRINT TAB(5);"*****************************"
1100 PRINT:PRINT:PRINT:PRINT
1110 INPUT "NAME OF SITE      > "W$
1120 PRINT:PRINT
1130 INPUT "DATE    >  "D$
1140 PRINT:PRINT
1150 INPUT "NUMBER OF SAMPLES > "N
1160 VDU2
1170 PRINT:PRINT:PRINT
1180 PRINT TAB(25);"***********************************"
1190 PRINT TAB(25);"*   SHEAR STRENGTH OF SEDIMENT    *"
1200 PRINT TAB(25);"*      USING THE VANE TESTER      *"
1210 PRINT TAB(25);"***********************************"
1220 PRINT:PRINT:PRINT:PRINT:PRINT
1230 PRINT TAB(5);"NAME OF SITE = ";W$, TAB(50)"DATE = ";D$
1240 PRINT
1250 PRINT TAB(5);"NUMBER OF SAMPLES   = ";N
1260 PRINT:PRINT:PRINT:PRINT
1270 VDU3
1280 CLS
1290 PRINT TAB(0,4);"WHAT IS THE DIAMETER OF VANE"
1300 INPUT TAB(0,6);"YOU USED(mm) ? "R
1310 CLS
1320 PRINT:PRINT:PRINT
1330 PRINT TAB(0,4);"ENTER THE CORRECTION FACTOR TO CONVARET"
1340 PRINT TAB(0,6);"READINGS FROM KPa TO KN.m^-2."
1350 PRINT TAB(0,8);"( K=1.346 FOR THE DIAMETER 19mm  VANE.  AND K=1.145 FOR TH
E DIAMETER 33mm VANE)."
1360 INPUT TAB(0,12);"  K    X"K
1370 CLS
1380 PRINT "DO YOU WISH TO CALCULATE MEAN AND"
1390 PRINT"STANDARD DEVIATION (Y/N)":INPUT A$ :IF A$="Y" THEN 1400 ELSE 1920
1400 FOR X=1 TO N
1410 CLS
1420 PRINT:PRINT:PRINT:PRINT:PRINT
1430 INPUT TAB(5);" TITLE  > "S$
1440 VDU2
1450 PRINT TAB(5);" TITLE  > "S$
1460 PRINT:PRINT
1470 PRINT TAB(5);"DEPTH(cm)", TAB(30)"PEAK(KN.m^-2)", TAB(60)"RESIDUAL(KN.m^-2
)"
1480 PRINT TAB(5);"_________", TAB(30)"_____________", TAB(60)"________________
_"
1490 VDU3
1500 CLS
1510 PRINT:PRINT:PRINT
1520 PRINT TAB(0,4);"ENTER NUMBER OF DEPTHS OF SEDIMENT"
1530 INPUT TAB(0,6);"FOR EACH SAMPLE ? "H1
1540 PRINT:PRINT:PRINT
1550 PRINT TAB(0,4);"ENTER NUMBER OF READINGS OF PEAK  "
1560 INPUT TAB(0,6);"AND RESIDUAL VALUES FOR EACH DEPTH > "H2
1570 CLS
1580 FOR O=1 TO H1
1590 PRINT TAB(0,4);"PUT THE DEPTH OF SEDIMENT(cm), THE PEAK"
1600 PRINT TAB(0,6);"AND THE RESIDUAL VALUES RECORDED FROM "
1610 PRINT TAB(0,8);"THE VANE, RESPECTIVELY.PUT COMMA AFTER"
1620 PRINT TAB(0,10);"EACH ONE"
1630 PRINT
1640 E=0:I=0:B=0:W=0
1650 PRINT"DEPTH,PEAK,RESIDUAL"
1660 FOR Z=1 TO H2
1670 INPUT H(O),P(Z),R1(Z)
1680 P1(Z)= P(Z) * (K)
1690 R2(Z)= R1(Z)* (K)
1700 E=E+P1(Z)
1710 I=I+R2(Z)
1720 B=B+P1(Z) ^2
1730 W=W+R2(Z) ^2
1740 NEXTZ
1750 VDU2
```

```
 1760 PRINT
 1770 FOR Z=1 TO H2
 1780 PRINT TAB(8);H(O) , TAB(34);P1(Z) , TAB(64);R2(Z)
 1790 NEXTZ
 1800 PRINT
 1810 M1= E/(H2)
 1820 M2=I/(H2)
 1830 SD=SQR((B-E^2/H2)/(H2-1))
 1840 SD1=SQR((W-I^2/H2)/(H2-1))
 1850 PRINT TAB(30);"MEAN="M1 , TAB(60);"MEAN="M2
 1860 PRINT TAB(30);"S.D.="SD , TAB(60);"S.D.="SD1
 1870 VDU3
 1880 CLS
 1890 NEXTO
 1900 NEXTX
 1910 GOTO2240
 1920 FOR X=1 TO N
 1930 CLS
 1940 PRINT:PRINT:PRINT:PRINT:PRINT
 1950 INPUT TAB(5);" TITLE  > "S$
 1960 VDU2
 1970 PRINT TAB(5);" TITLE > "S$
 1980 PRINT:PRINT
 1990 PRINT TAB(5);"DEPTH(cm)", TAB(30)"PEAK(KN.m^-2)", TAB(60)"RESIDUAL(KN.m^-2
)"
 2000 PRINT
 2010 VDU3
 2020 CLS
 2030 PRINT TAB(0,4);"ENTER NUMBER OF DEPTHS OF THE SEDIMENT"
 2040 INPUT TAB(0,6);"FOR EACH MONTH RECORDED ? "H1
 2050 CLS
 2060 PRINT TAB(0,4);"PUT THE DEPTH OF SEDIMENT(cm), THE PEAK"
 2070 PRINT TAB(0,6);"AND THE RESIDUAL VALUES RECORDED FROM "
 2080 PRINT TAB(0,8);"THE VANE, RESPECTIVELY.PUT COMMA AFTER"
 2090 PRINT TAB(0,10);"EACH ONE"
 2100 PRINT"DEPTH,PEAK,RESIDUAL"
 2110 FOR O=1 TO H1
 2120 INPUT H(O),P(O),R1(O)
 2130 P1(O)= P(O) * (K)
 2140 R2(O)= R1(O)* (K)
 2150 NEXTO
 2160 VDU2
 2170 FOR O= 1 TO H1
 2180 PRINT TAB(8);H(O) , TAB(34);P1(O) , TAB(64);R2(O)
 2190 NEXTO
 2200 PRINT:PRINT:PRINT:PRINT
 2210 VDU3
 2220 NEXTX
 2230 CLS
 2240 PRINT"DO YOU WANT TO CONTINUE(Y/N)":INPUT F$:IF F$="Y" THEN 100 ELSE
 2250 CLS
 2260 END
>
```

Appendix 2, Table (4). Original shear strength data taken from low tide area, Ardmore Point.

February 1984				March		
DEPTH(cm)	PEAK(KN.m^-2)	RESIDUAL(KN.m^-2)	PEAK-RESIDUAL(KN.M^2)	PEAK(KN.m^-2)	RESIDUAL(KN.m^-2)	PEAK-RESIDUAL(KN.M^2)
0	4.711	2.6574	2.0536	1.046	0	1.046
0	3.365	0.673	2.692	1.046	0.2684	0.8076
MEAN=	4.038	1.6152	2.4228	1.046	0.2692	1.0768
S.D.=	0.951765733	1.33247202	0.380706287	0	0.380706291	0.38076629
5	6.73	6.73	0	10.768	7.9414	2.8266
5	10.768	8.749	2.019	5.7878	3.365	2.4228
MEAN=	8.749	7.7395	1.0095	8.2779	5.6532	2.6247
S.D.=	2.85529718	1.42764859	1.42764859	3.52215532	3.22600348	0.295557702
10	13.46	5.384	8.076	11.8448	8.4798	3.365
10	21.536	13.3254	8.2106	10.4988	10.4988	0
MEAN=	17.498	9.3547	8.1453	11.1718	9.4893	1.6825
S.D.=	5.71059437	5.6154178	9.51760238E-2	0.951765748	1.42764856	2.37941432
15	12.2486	5.384	6.8646	16.152	10.768	5.384
15	21.536	10.768	10.768	15.479	10.768	4.711
MEAN=	16.8923	8.076	8.8163	15.8155	10.768	5.0475
S.D.=	6.5671835	3.80706291	2.7601206	0.475882624	0	0.475882874
20	13.8638	2.019	11.8448	17.7672	8.749	9.0182
20	20.19	12.114	8.076	16.152	10.6334	5.5186
MEAN=	17.0269	7.0665	9.9604	16.9596	9.6912	7.2684
S.D.=	4.47329891	7.13824296	2.66494405	1.14211886	1.33247203	2.47459499
25	24.0934	8.749	15.3444	20.863	11.441	9.422
25	24.228	13.5946	10.6334	15.479	8.076	7.403
MEAN=	24.1607	11.1718	12.9889	18.171	9.7585	8.4125
S.D.=	9.51760238E-2	3.42635663	3.33118003	3.80706293	2.37941433	1.4276426
30	26.1124	11.9794	14.133	24.901	15.479	9.422
30	29.612	16.825	12.787	26.247	13.46	12.787
MEAN=	27.8622	14.4022	13.46	25.574	14.4695	11.1045
S.D.=	2.47459078	3.42635662	0.951765748	0.951765748	1.42764858	2.37941432
35	41.9952	18.844	23.1512	20.958	14.133	16.825
35	30.958	16.4212	14.5368	47.783	6.057	41.726
MEAN=	36.4766	17.6326	18.844	29.3705	10.095	29.2725
S.D.=	7.80447898	1.71317824	6.09130065	11.8970715	5.71059436	17.607666
40	45.2256	24.228	20.9976	37.688	18.5748	19.1132
40	40.38	21.2668	19.1132	29.612	10.768	18.844
MEAN=	42.8028	22.7474	20.0554	33.65	14.6714	18.9786
S.D.=	3.42635676	2.09388471	1.33247212	5.71059441	5.52024122	0.1903222
45	59.4972	16.825	42.6682	48.8578	17.498	31.3618
45	85.8748	17.2288	68.646	24.901	10.768	14.133
MEAN=	72.686	17.0269	55.6571	36.8804	14.133	22.7474
S.D.=	18.6546983	0.285329324	18.3690785	16.94143	4.75882864	12.1826013
50	65.3502	23.9588	41.3914	43.072	20.863	22.209
50	53.94	23.2858	30.6542	44.418	18.844	25.574
MEAN=	59.6451	23.6223	36.0728	43.745	19.8535	23.8915
S.D.=	8.28026172	0.475882624	7.80447885	0.951764249	1.42764846	2.37941432
55	56.532	25.4394	31.0926	55.859	21.536	34.322
55	45.745	22.882	20.863	51.148	20.19	30.958
MEAN=	50.1385	24.1607	25.9778	53.5035	20.863	32.6405
S.D.=	9.04177433	1.80835487	7.22341957	3.33117994	0.951765748	2.37941432
60	64.608	26.92	37.688	40.1108	18.844	21.2668
60	32.304	21.536	10.768	80.76	22.882	57.878
MEAN=	48.456	24.228	24.228	60.4354	20.863	39.5724
S.D.=	22.8425774	3.80706293	19.0355146	28.743325	2.85529716	25.8880278
65	69.992	26.3816	43.6104	41.726	20.19	21.536
65	46.437	22.209	24.228	67.3	26.92	40.38
MEAN=	58.2145	24.2953	33.9192	54.513	23.555	30.959
S.D.=	16.6559002	2.95047371	13.7054264	18.0835488	4.75882859	13.3247202
70	64.7426	29.612	35.1306	20.0554	15.46	6.5954
70	64.608	22.882	41.726	40.38	18.844	21.536
MEAN=	64.6753	26.247	38.4283	30.2177	16.152	14.0657
S.D.=	9.51634978E-2	4.75882859	4.663652	14.3716625	3.80706293	10.5645996
75	51.021	26.92	24.901	50.551	24.6318	25.9192
75	64.608	26.247	38.361	75.6452	27.595	48.0502
MEAN=	58.2145	26.5835	31.631	67.0991	26.1124	40.9867
S.D.=	9.04177444	0.475882624	9.51765731	12.087425	2.09388459	9.99736011
80	57.878	25.7086	32.1694	89.509	26.247	63.262
80	68.646	30.958	37.688	100.277	30.958	69.319
MEAN=	63.262	28.3333	34.9287	94.893	28.6025	66.2905
S.D.=	7.61412574	3.71188625	3.90222952	7.61412599	3.33118008	4.28294617
85	56.532	27.593	28.979	96.259	24.228	72.011
85	71.7418	34.323	37.4188	85.471	31.631	53.84
MEAN=	64.1369	30.958	33.1709	90.855	27.9295	62.9255
S.D.=	10.7549528	4.75882864	5.99612405	7.61412349	5.23471155	12.0488774
90	66.627	24.996	41.631	78.741	24.228	54.513
90	82.779	37.015	45.764	75.376	33.65	41.726
MEAN=	74.703	31.0055	43.6975	77.0585	28.939	48.1195
S.D.=	11.471189	1.42764854	9.99754016	2.37941432	6.6623601	9.04177444
95	45.072	23.555	19.517	77.395	28.266	49.129
95	67.3	40.38	26.92	80.76	30.958	49.802
MEAN=	55.186	31.9675	23.2185	79.0775	29.612	49.4655
S.D.=	17.1317831	11.8970716	5.23471146	2.37941432	1.9035315	0.475883625
100	72.011	40.38	31.631	80.76	32.304	48.456
100	46.1678	32.0348	14.133	102.296	26.92	75.376
MEAN=	59.0894	36.2074	22.882	91.528	29.612	61.916
S.D.=	18.2739019	5.90194757	12.3729549	15.2282517	3.80706299	19.0353146

Cont. appendix 2, table (4)

		April			May		
DEPTH(cm)		PEAK(KN.m^-2)	RESIDUAL(KN.m^-2)	PEAK-RESIDUAL(KN.M^2)	PEAK(KN.m^-2)	RESIDUAL(KN.m^-2)	PEAK-RESIDUAL(KN.M^2)
0		2.692	2.019	0.672999999	1.346	0.673	0.673
0		3.365	0.673	2.692	1.346	0	1.346
	MEAN=	3.0285	1.346	1.6825	1.346	0.3365	1.009
	S.D.=	0.475882864	0.951765727	1.42764859	0	0.475882864	0.475882864
5		4.711	2.692	2.019	10.095	6.73	3.365
5		5.384	5.384	0	5.384	4.038	1.346
	MEAN=	5.0475	4.038	1.0095	7.7395	5.384	2.3555
	S.D.=	0.475882859	1.90353145	1.42764859	3.33118005	1.90353145	1.42764859
10		10.095	7.403	2.692	16.825	10.095	6.73
10		8.076	8.076	0	10.768	8.076	2.692
	MEAN=	9.0855	7.7395	1.346	13.7965	9.0855	4.711
	S.D.=	1.42764862	0.475882906	1.90353145	4.28294577	1.42764862	2.85529718
15		13.46	8.076	5.384	17.498	10.768	6.73
15		14.806	6.73	8.076	11.441	6.057	5.384
	MEAN=	14.133	7.403	6.73	14.4695	8.4125	6.057
	S.D.=	0.951765748	0.951765748	1.90353146	4.28294577	3.33118006	0.951765733
20		18.171	6.057	12.114	18.171	10.768	7.403
20		18.171	12.787	5.384	13.46	6.73	6.73
	MEAN=	18.171	9.422	8.74899999	15.8155	8.749	7.0665
	S.D.=	0	4.75882863	4.75882864	3.33118005	2.85529718	0.475882843
25		18.844	10.768	8.076	26.92	13.46	13.46
25		18.844	10.768	8.076	26.92	13.46	13.46
	MEAN=	18.844	10.768	8.076	26.92	13.46	13.46
	S.D.=	0	0	0	0	0	0
30		24.228	14.133	10.095	25.555	12.114	11.441
30		24.996	17.498	7.498	29.612	14.806	14.806
	MEAN=	29.612	15.8155	13.7965	26.2035	13.46	12.7435
	S.D.=	7.61412583	2.37941432	5.22471149	4.28294578	1.90353315	2.37941463
35		27.593	21.556	6.057	34.333	16.152	18.171
35		23.555	13.46	10.095	45.091	20.19	24.901
	MEAN=	25.574	17.498	8.076	39.707	18.171	21.536
	S.D.=	2.85529725	5.71059437	2.85529718	7.61412574	2.85529725	4.75882867
40		37.688	19.517	18.171	25.574	14.133	11.441
40		32.304	16.152	16.152	34.996	17.498	17.498
	MEAN=	34.996	17.8345	17.1615	30.285	15.8155	14.4695
	S.D.=	3.80706274	2.37941427	1.42764862	6.66226006	2.37941432	4.28294577
45		41.726	19.517	22.209	35.669	17.498	18.171
45		45.764	20.19	25.574	53.84	22.209	31.631
	MEAN=	43.745	19.8535	23.8915	44.7545	19.8535	24.901
	S.D.=	2.85529741	0.475882373	2.37941422	12.8488374	3.33117998	9.51765723
50		43.745	18.844	24.901	61.243	21.536	39.707
50		51.148	22.209	28.939	72.011	21.536	50.475
	MEAN=	47.4465	20.5265	26.92	66.627	21.536	45.091
	S.D.=	5.2347115	2.37941442	2.85529725	7.61412599	0	7.61412586
55		67.3	25.574	41.726	76.722	28.266	48.456
55		46.437	24.228	22.209	64.608	25.574	39.034
	MEAN=	56.8685	24.901	31.9675	70.665	26.92	43.745
	S.D.=	14.7523688	0.951765498	13.800603	8.5658919	1.90353315	6.66225995
60		69.997	22.882	47.11	67.973	26.92	41.053
60		32.304	14.806	17.498	86.144	27.593	58.551
	MEAN=	51.148	18.844	32.304	77.0585	27.2565	49.802
	S.D.=	26.6494404	5.71059437	20.938846	12.8488373	0.475882624	12.3729544
65		81.433	29.612	51.821	72.684	26.92	45.764
65		49.802	23.555	26.247	90.182	36.342	53.84
	MEAN=	65.6175	26.5835	39.034	81.433	31.631	49.802
	S.D.=	22.0664945	4.28294578	18.0853489	12.3729544	6.66226601	5.71059432
70		82.106	29.612	52.494	79.414	30.285	49.127
70		79.414	28.266	51.148	72.011	25.574	46.437
	MEAN=	80.76	28.939	51.821	75.7125	27.9295	47.783
	S.D.=	1.90353049	0.951765748	0.951765247	5.22471152	3.33118001	1.9053315
75		111.718	41.053	70.665	94.22	34.333	59.887
75		51.148	26.92	24.228	90.182	26.92	63.262
	MEAN=	81.433	33.9865	47.4465	92.201	30.6215	61.5795
	S.D.=	42.8294577	9.99334016	32.8359176	2.85529641	5.23471155	3.17941452
80		113.064	41.053	72.011	117.102	43.072	74.03
80		72.684	26.92	45.764	105.661	36.342	69.319
	MEAN=	92.874	33.9865	58.8875	111.3815	39.707	71.6745
	S.D.=	28.5529718	9.99334016	18.5594318	8.09099926	4.75882854	3.32118051
85		104.315	34.996	69.319	96.912	43.745	53.167
85		94.22	28.261	65.959	115.756	39.034	76.722
	MEAN=	99.2675	26.6785	62.589	106.334	41.3895	64.9445
	S.D.=	7.1382425	2.37941412	9.51765728	13.3247201	3.33118008	16.8259992
90		91.520	34.996	56.372	78.048	34.996	43.052
90		111.718	25.669	76.049	104.998	41.053	63.945
	MEAN=	101.619	35.3325	66.2705	91.228	38.0245	53.1035
	S.D.=	14.2764861	0.475882626	13.8094803	19.0253146	4.28294584	14.7223587
95		144.022	44.418	99.604	94.22	37.688	56.532
95		94.22	48.456	45.764	99.604	37.688	61.916
	MEAN=	119.121	46.437	72.684	96.912	37.688	59.224
	S.D.=	35.2153319	2.85529741	28.0706292	3.80706299	0	3.80706299
100		158.828	48.456	110.372	150.752	57.505	93.247
100		87.49	43.072	44.418	99.604	47.11	52.494
	MEAN=	123.159	45.764	77.395	125.178	52.1575	73.0205
	S.D.=	50.4435835	3.80706299	46.6365206	36.1670976	7.13824289	29.0288567

June

DEPTH(cm)		PEAK(KN.m^-2)	RESIDUAL(KN.m^-2)	PEAK-RESIDUAL(KN.m^2)
0		5.784	2.692	2.692
0		4.038	2.019	2.019
	MEAN=	4.711	2.3555	2.3555
	S.D.=	0.951765717	0.475882859	0.475882859
5		12.114	10.095	2.019
5		10.768	10.095	0.673
	MEAN=	11.441	10.095	1.346
	S.D.=	0.951765748	0	0.951765728
10		18.844	5.784	13.46
10		18.171	7.403	10.768
	MEAN=	18.5075	6.5935	12.114
	S.D.=	0.475882624	1.42764859	1.90353147
15		27.593	16.152	11.441
15		16.825	9.422	7.403
	MEAN=	22.209	12.787	9.42199999
	S.D.=	7.61412582	4.75882864	2.85529717
20		26.92	14.133	12.787
20		25.574	12.114	13.46
	MEAN=	26.247	13.1235	13.1235
	S.D.=	0.951765498	1.42764854	0.475882874
25		21.576	12.114	9.422
25		22.882	19.517	3.365
	MEAN=	22.209	15.8155	6.3935
	S.D.=	0.951765748	5.23471149	4.28294577
30		31.631	17.498	14.133
30		27.593	13.46	14.133
	MEAN=	29.612	15.479	14.133
	S.D.=	2.85529725	2.85529718	3.45264983E-4
35		40.38	24.228	16.152
35		30.5542	13.46	17.0942
	MEAN=	35.4671	18.844	16.6221
	S.D.=	6.94788985	7.61412583	0.666235745
40		70.665	68.646	2.018999999
40		45.091	21.536	23.555
	MEAN=	57.878	45.091	12.787
	S.D.=	18.0833488	33.3118004	15.2282516
45		18.844	14.133	4.711
45		45.764	22.209	23.555
	MEAN=	32.304	18.171	14.133
	S.D.=	19.0353145	5.71059437	13.3247202
50		28.266	17.498	10.768
50		32.304	17.498	14.806
	MEAN=	30.285	17.498	12.787
	S.D.=	2.85529699	0	2.85529772
55		75.376	29.612	45.764
55		83.452	34.996	48.456
	MEAN=	79.414	32.304	47.11
	S.D.=	5.71059382	3.80706299	1.905531
60		75.376	28.266	47.11
60		75.376	26.92	48.456
	MEAN=	75.376	27.593	47.783
	S.D.=	0	0.951765748	0.951766249
65		62.262	28.266	34.996
65		86.144	34.996	51.148
	MEAN=	74.703	31.631	43.072
	S.D.=	16.1900175	4.75882864	11.4211886
70		91.328	29.612	61.716
70		80.76	34.996	45.764
	MEAN=	86.144	32.304	53.86
	S.D.=	7.61412574	3.80706299	11.4211888
75		111.718	45.764	65.954
75		98.228	37.015	61.243
	MEAN=	104.988	41.2895	63.5705
	S.D.=	9.51765688	6.18647719	3.33117965
80		107.68	36.342	71.338
80		108.353	41.726	66.627
	MEAN=	108.0165	39.034	68.9825
	S.D.=	0.475889638	3.80706299	3.33117994
85		115.756	47.11	68.646
85		122.484	36.342	86.144
	MEAN=	119.121	41.726	77.395
	S.D.=	4.75882904	7.61412586	12.7279544
90		128.543	39.707	88.836
90		129.216	50.475	78.741
	MEAN=	128.8795	45.091	83.7885
	S.D.=	0.475889638	7.61412574	7.13024276
95		177.927	45.072	90.855
95		134.6	40.38	94.22
	MEAN=	134.2635	41.726	92.5375
	S.D.=	0.475873606	1.9035315	2.37941452
100		122.032	40.38	81.652
100		166.904	61.263	105.641
	MEAN=	145.268	50.8115	94.5565
	S.D.=	30.4565034	14.7523688	15.7041346

July

PEAK(KN.m^-2)	RESIDUAL(KN.m^-2)	PEAK-RESIDUAL(KN.m^2)
0	0	0
4.038	2.692	1.346
2.019	1.346	0.673
2.05529718	1.90353145	0.951765728
5.784	4.711	0.673
12.114	10.768	1.346
8.749	7.7395	1.0095
4.75882863	4.28294577	0.475882864
6.73	3.365	3.365
18.844	10.768	8.076
12.787	7.0665	5.7205
8.56589155	5.2347115	3.33118004
10.768	5.784	5.784
18.844	13.46	5.784
14.806	9.422	5.784
5.71059437	5.71059436	0
11.1718	8.076	3.0958
33.65	12.114	21.536
22.4109	10.095	12.3159
15.8944876	2.85529717	13.0391905
29.612	12.787	16.825
34.996	16.825	18.171
32.304	14.806	17.498
3.80706299	2.85529716	0.951765623
39.034	20.19	18.844
31.631	19.517	12.114
33.3325	19.8535	13.479
5.2347115	0.475882373	4.75882864
32.304	18.844	13.46
29.612	17.498	12.114
30.958	18.171	12.787
1.90353162	0.951765748	0.951765748
56.532	28.266	28.266
37.015	18.844	18.171
46.7735	23.555	23.2185
13.8006603	6.66226006	7.15024276
63.975	26.247	37.688
52.494	22.209	30.285
58.2345	24.228	33.9965
8.09000879	2.85529716	5.23471141
66.627	26.92	39.707
81.433	30.285	51.148
74.03	28.6025	45.4275
10.4669423	2.37941432	8.09000879
70.665	30.958	39.707
82.779	34.996	47.783
76.722	32.977	43.745
8.5658919	2.85529725	5.71059441
65.954	28.266	37.688
96.912	37.688	59.224
81.433	32.977	48.456
21.8996118	6.6623601	15.2282516
79.414	30.958	48.456
109.026	39.034	69.992
94.22	34.996	59.224
20.9388458	5.71059441	15.2282516
121.14	43.072	78.068
100.277	41.726	58.551
110.7085	42.399	68.3095
14.7527685	0.951764746	13.8993603
129.984	41.726	88.259
107.007	40.38	66.627
125.4955	41.053	82.4425
23.7182603	0.951764751	22.7644945
174.98	49.129	125.851
109.026	34.996	74.03
142.003	42.0625	99.94075
46.6363208	9.9935402	56.6429805
109.699	45.091	64.608
96.259	29.612	66.627
102.979	37.3515	65.6275
9.51765688	10.9457059	1.02764887
150.755	56.572	94.22
106.336	27.612	78.722
128.545	41.072	87.471
31.4082691	19.0353145	12.3729546
174.98	59.224	115.756
120.562	47.11	73.452
152.771	53.167	99.604
31.4082691	8.56589157	22.8423775
180.264	102.296	78.068
144.022	41.726	102.296
162.197	72.011	90.187
25.6976744	42.8294577	17.1317829

Cont. appendix 2, table (4)

August

DEPTH(cm)	PEAK(KN.m^-2)	RESIDUAL(KN.m^-2)	PEAK-RESIDUAL(KN.M^2)
0	0.2692	0	0.2692
0	4.038	3.9034	0.1346
MEAN=	2.1536	1.9517	0.2019
S.D.=	2.86494404	2.76012061	9.51765733E-2
5	7.6722	3.365	4.3072
5	8.749	8.076	0.672999997
MEAN=	8.2106	5.7205	2.4901
S.D.=	0.761412535	3.33118005	2.56976747
10	10.768	5.384	5.384
10	10.768	9.422	1.346
MEAN=	10.768	7.403	3.365
S.D.=	0	2.85529718	2.85529718
15	16.152	8.076	8.076
15	13.46	12.114	1.346
MEAN=	14.806	10.095	4.711
S.D.=	1.9035315	2.85529717	4.75882864
20	14.152	13.46	0.673
20	16.152	14.806	1.346
MEAN=	15.1425	14.133	1.0095
S.D.=	1.4276485	0.951765748	0.475882867
25	18.844	10.095	8.749
25	27.593	26.92	0.673
MEAN=	23.2185	18.5075	4.711
S.D.=	6.18647723	11.8970716	5.71059436
30	32.304	16.825	15.479
30	29.612	20.19	9.422
MEAN=	30.958	18.5075	12.4505
S.D.=	1.90353162	2.37941422	4.28294578
35	33.669	32.304	3.36499999
35	14.153	13.46	0.673
MEAN=	24.991	22.882	2.019
S.D.=	15.2282516	13.2247202	1.90353145
40	49.802	41.726	8.076
40	48.456	29.612	18.844
MEAN=	49.129	35.669	13.46
S.D.=	0.951767252	8.56589152	7.61412282
45	49.129	30.958	18.171
45	63.262	48.456	14.806
MEAN=	56.1955	39.707	16.4885
S.D.=	9.99354002	12.3729544	2.37941437
50	67.3	37.688	29.612
50	68.646	33.65	34.996
MEAN=	67.973	35.669	32.304
S.D.=	0.951765267	2.85529741	3.80706287
55	86.144	43.072	43.072
55	79.414	39.034	40.38
MEAN=	82.779	41.053	41.726
S.D.=	4.75882824	2.85529741	1.9035315
60	82.779	43.072	39.707
60	95.566	47.11	48.456
MEAN=	89.1725	45.091	44.0815
S.D.=	9.04177444	2.85529708	6.18647735
65	102.296	45.764	56.532
65	96.22	41.726	52.494
MEAN=	99.258	43.745	54.513
S.D.=	4.29059482	2.85529741	2.85529741
70	107.68	52.84	52.84
70	110.372	53.84	56.532
MEAN=	109.026	53.84	55.186
S.D.=	1.90353049	0	1.9035315
75	115.064	61.716	51.148
75	105.661	63.935	41.726
MEAN=	110.3625	62.9255	46.437
S.D.=	6.65471094	1.42764887	6.66276003
80	158.828	67.773	90.055
80	126.229	55.84	70.389
MEAN=	142.676	61.9065	81.7695
S.D.=	22.8423773	8.99354011	12.8488376
85	107.68	76.242	31.438
85	181.71	51.148	130.562
MEAN=	144.695	63.745	100.75
S.D.=	52.3471115	10.469423	41.877692
90	124.595	59.551	65.044
90	161.52	62.209	99.311
MEAN=	143.0575	60.87	82.4425
S.D.=	26.1775578	2.05529674	23.2182644
95	102.276	56.222	45.754
95	109.026	48.456	60.57
MEAN=	105.651	52.494	53.167
S.D.=	4.75882904	5.71059416	10.469423
100	105.661	42.399	63.262
100	83.452	43.072	40.38
MEAN=	94.5565	42.7355	51.821
S.D.=	15.7041346	0.475884628	16.1049173

September

PEAK(KN.m^-2)	RESIDUAL(KN.m^-2)	PEAK-RESIDUAL(KN.M^2)
0	0	0
0	0	0
0	0	0
0	0	0
6.73	5.384	1.346
5.384	4.711	0.673
6.057	5.0475	1.0095
0.951765733	0.475882859	0.475882864
11.441	7.403	4.038
10.095	8.076	2.019
10.768	7.7555	3.0285
0.951765717	0.475882906	1.42764859
14.806	8.749	6.057
16.152	8.076	8.076
15.479	8.4125	7.0665
0.951765811	0.475882937	1.42764859
14.806	7.403	7.403
16.152	8.076	8.076
15.479	7.7395	7.7395
0.951765811	0.475882906	0.475882906
16.152	8.749	7.403
16.152	8.076	8.076
16.152	8.4125	7.7395
0	0.475882937	0.475882843
26.92	12.787	14.133
16.152	8.749	7.403
21.536	10.768	10.768
7.61412282	2.85529718	4.75882863
30.305	12.114	18.171
21.536	12.114	9.422
25.9105	12.114	17.2765
6.18647723	0	6.18647723
26.92	15.479	11.441
18.044	10.095	8.749
22.882	12.787	10.095
5.71059437	3.80706292	1.90353148
28.266	13.46	14.806
13.46	10.768	3.692
20.863	12.114	8.749
10.469423	1.90353147	8.56509153
21.536	12.787	8.749
26.92	12.114	14.806
24.228	12.4505	11.7775
3.80706293	0.475882749	4.28294377
48.646	24.228	44.418
34.996	16.152	18.844
51.821	29.19	21.631
23.7941432	5.71059436	18.0835488
24.901	16.152	8.749
32.304	16.152	16.152
28.6025	16.152	12.4505
5.23471153	0	5.23471149
24.996	20.19	14.806
29.228	13.46	10.768
27.612	16.822	12.787
7.61412283	4.75882867	2.85529718
20.19	13.46	6.73
29.034	15.479	22.555
29.612	14.4495	15.1425
13.3247202	1.42764858	11.8970716
20.19	11.441	8.749
34.996	29.612	5.384
27.593	20.2255	7.3665
10.469423	12.0498373	2.37941432
30.305	18.844	11.441
45.091	22.209	22.882
27.688	29.2255	17.1615
10.469423	3.37941442	8.08900867
25.574	18.171	7.403
33.65	24.228	9.42199999
29.612	21.1995	9.4125
5.71059432	4.28294576	1.42764859
30.261	22.882	15.479
40.38	21.536	18.844
29.2705	22.209	17.1615
1.42764854	0.951765748	8.08900867
22.216	24.228	0.6725
41.053	25.574	15.479
26.6785	24.901	11.7775
6.18647712	0.951765498	5.2247115
29.612	18.171	11.441
24.228	20.863	3.365
26.92	19.517	7.403
5.80706299	1.9035315	5.71059476

Cont. appendix 2, table (4)

	October			November		
DEPTH(cm)	PEAK(KN.m^-2)	RESIDUAL(KN.m^-2)	PEAK-RESIDUAL(KN.m^2)	PEAK(KN.m^-2)	RESIDUAL(KN.m^-2)	PEAK-RESIDUAL(KN.m^2)
0	5.384	0	5.384	1.346	0	1.346
0	0	0	0	2.019	0	2.019
MEAN=	2.692	0	2.692	1.6825	0	1.6825
S.D.=	3.80706291	0	3.80706291	0.475882862	0	0.475882862
5	8.076	5.384	2.692	6.73	6.73	0
5	4.711	3.365	1.346	8.076	5.384	2.692
MEAN=	6.3935	4.3745	2.019	7.403	6.057	1.346
S.D.=	2.37941432	1.42764859	0.951765731	0.951765748	0.951765733	1.90353146
10	9.422	6.73	2.692	11.441	7.403	4.038
10	8.076	6.057	2.019	8.076	6.73	1.346
MEAN=	8.749	6.3935	2.3555	9.7585	7.0665	2.692
S.D.=	0.951765686	0.475882906	0.475882062	2.37941433	0.475882874	1.90353145
15	10.768	5.384	5.384	12.114	6.73	5.384
15	14.133	6.73	7.403	9.422	8.076	1.346
MEAN=	12.4505	6.057	6.3935	10.768	7.403	3.365
S.D.=	2.3794143	0.951765733	1.42764859	1.90353147	0.951765748	2.85529718
20	13.46	6.73	6.73	15.479	8.076	7.403
20	16.025	9.076	8.74899999	16.152	10.768	5.384
MEAN=	15.1425	7.403	7.7795	15.8155	9.422	6.3935
S.D.=	2.37941435	0.951765748	1.42764861	0.475882624	1.90353143	1.42764859
25	19.517	8.749	10.768	25.574	14.806	10.768
25	21.536	10.768	10.768	20.19	10.768	9.422
MEAN=	20.5265	9.7585	10.768	22.882	12.787	10.095
S.D.=	1.42764871	1.4276486	0	3.80706293	2.85529718	0.951765686
30	22.882	9.422	13.46	29.612	18.171	11.441
30	26.92	12.787	14.133	26.92	13.46	13.46
MEAN=	24.901	11.1045	13.7965	28.266	15.8155	12.4505
S.D.=	2.85529708	2.37941432	0.475882999	1.9035315	3.33118005	1.42764854
35	34.996	13.46	21.536	34.996	17.498	17.498
35	21.536	6.73	14.806	29.612	17.498	12.114
MEAN=	28.266	10.095	18.171	32.304	17.498	14.806
S.D.=	9.51765728	4.75882863	4.75882862	3.80706299	0	3.80706292
40	42.399	21.536	20.863	34.996	18.844	16.152
40	21.536	6.73	14.806	35.669	16.152	19.517
MEAN=	31.9675	14.133	17.8345	35.3325	17.498	17.8345
S.D.=	14.7525688	10.469423	4.28294578	0.475883626	1.90353137	2.37941437
45	43.072	18.844	24.228	39.707	20.19	19.517
45	45.091	16.152	28.939	56.532	24.901	31.631
MEAN=	44.0815	17.498	26.5835	48.1195	22.5455	25.574
S.D.=	1.42764854	1.90353137	3.33118016	11.8970716	3.33118005	8.56589157
50	51.148	21.536	29.612	38.261	18.844	19.517
50	56.532	21.536	34.996	84.798	32.304	52.494
MEAN=	53.84	21.536	32.304	61.5295	25.574	35.9555
S.D.=	3.80706299	0	3.80706287	32.8359176	9.51765728	23.3182603
55	78.741	24.901	53.84	30.958	16.152	14.806
55	67.3	29.612	37.688	84.798	32.304	52.494
MEAN=	73.0205	27.2565	45.764	57.878	24.228	33.65
S.D.=	8.09000902	3.33118008	11.4211887	38.0706291	11.4211887	26.6494404
60	70.665	23.555	47.11	67.3	30.285	37.015
60	41.726	24.228	17.498	79.414	32.304	47.11
MEAN=	56.1955	23.8915	32.304	73.357	31.2945	42.0625
S.D.=	20.4629631	0.475882624	20.978846	8.56589146	1.42764854	7.1382431
65	67.973	28.266	39.707	98.931	32.304	66.627
65	67.3	28.266	39.034	67.3	32.304	34.996
MEAN=	67.6365	28.266	39.3705	83.1155	32.304	50.8115
S.D.=	0.47588563	0	0.475882624	22.3644945	0	22.3644946
70	69.992	29.612	40.38	120.467	40.38	80.087
70	102.296	29.612	72.684	82.106	34.996	47.11
MEAN=	86.144	29.612	56.532	101.2865	37.688	63.5985
S.D.=	22.8423775	0	22.8423775	27.1333232	3.80706287	23.3182603
75	56.532	28.939	27.593	110.372	37.688	72.684
75	111.718	41.053	70.665	110.372	49.129	61.243
MEAN=	84.125	34.996	49.129	110.372	43.4085	66.9635
S.D.=	39.0223948	8.56589152	30.4565033	0	8.09000861	8.09000879
80	56.532	26.92	29.612	107.68	41.053	66.627
80	83.281	29.612	53.669	118.448	49.802	68.646
MEAN=	69.9065	28.266	41.6405	113.064	45.4275	67.6365
S.D.=	8.18647896	1.9035315	4.28294573	7.61412599	6.18647742	1.42764887
85	72.684	30.285	42.399	83.452	45.764	37.688
85	69.992	34.996	34.996	133.927	51.821	82.106
MEAN=	71.338	32.6405	38.6975	108.6895	48.7925	59.897
S.D.=	1.9035325	3.33118008	5.2547115	35.6912147	4.28294573	31.4078269
90	61.916	31.631	30.285	67.995	39.034	28.959
90	56.532	32.304	24.228	121.14	56.532	64.608
MEAN=	59.224	31.9675	27.2565	94.5585	47.783	46.7775
S.D.=	3.80706299	0.475883125	4.28294584	37.5947462	12.5729545	25.2217917
95	64.608	26.92	37.688	115.357	48.456	66.901
95	70.068	29.612	40.456	123.832	50.475	73.357
MEAN=	71.338	28.266	43.072	119.5945	49.4655	69.719
S.D.=	9.51765708	1.9035315	7.6141258	7.12824303	1.42764887	5.71059482
100	117.102	41.226	75.876	133.224	48.456	84.768
100	83.452	32.977	50.475	124.503	37.878	86.627
MEAN=	100.277	37.1015	62.9755	128.8635	43.167	75.7175
S.D.=	23.7941433	6.18647727	17.8076659	6.18647896	8.66226003	12.8488573

Cont. appendix 2, table (4)

December

DEPTH(cm)		PEAK(KN.m^-2)	RESIDUAL(KN.m^-2)	PEAK-RESIDUAL(KN.M^2)
0		2.692	1.346	1.346
0		2.692	2.692	0
	MEAN=	2.692	2.019	0.673
	S.D.=	0	0.951765727	0.951765727
5		10.095	6.73	3.365
5		13.46	13.46	0
	MEAN=	11.7775	10.095	1.6825
	S.D.=	2.3794143	4.75882863	2.37941432
10		17.498	11.441	6.057
10		16.152	10.768	5.384
	MEAN=	16.825	11.1045	5.7205
	S.D.=	0.951765874	0.475882874	0.475882874
15		16.152	8.076	8.076
15		13.46	10.768	2.692
	MEAN=	14.806	9.422	5.384
	S.D.=	1.90353315	1.90353143	3.80706291
20		24.901	16.152	8.749
20		18.844	10.768	8.076
	MEAN=	21.8725	13.46	8.4125
	S.D.=	4.28294581	3.8070629	0.475882874
25		12.114	9.422	2.692
25		29.612	21.536	8.076
	MEAN=	20.863	15.479	5.384
	S.D.=	12.3729545	8.56589154	3.80706291
30		43.072	20.863	22.209
30		29.612	16.152	13.46
	MEAN=	36.342	18.5075	17.8345
	S.D.=	9.51765728	3.33118001	6.18647725
35		57.205	26.92	30.285
35		29.612	13.46	16.152
	MEAN=	43.4085	20.19	23.2185
	S.D.=	19.5111974	9.51765726	9.99354013
40		46.437	22.209	24.228
40		34.996	20.19	14.806
	MEAN=	40.7165	21.1995	19.517
	S.D.=	8.09000861	1.42764846	6.66226008
45		51.148	34.323	16.825
45		51.148	48.456	2.692
	MEAN=	51.148	41.3895	9.7505
	S.D.=	0	9.99354011	9.99354013
50		74.703	22.209	52.494
50		64.608	29.612	34.996
	MEAN=	69.6555	25.9105	43.745
	S.D.=	7.13824276	5.2347115	12.3729545
55		88.836	43.745	45.091
55		76.722	29.612	47.11
	MEAN=	82.779	36.6785	46.1005
	S.D.=	8.56589123	9.99354011	1.42764887
60		96.912	37.688	59.224
60		76.722	33.65	43.072
	MEAN=	86.817	35.669	51.148
	S.D.=	14.2764861	2.85529741	11.4211886
65		107.68	43.745	63.935
65		56.532	26.247	30.285
	MEAN=	82.106	34.996	47.11
	S.D.=	36.1670977	12.3729545	23.7941432
70		110.372	47.783	62.589
70		74.703	32.304	42.399
	MEAN=	92.5375	40.0435	52.494
	S.D.=	25.2217917	10.9453059	14.2764859
75		111.045	100.95	10.095
75		111.045	41.726	69.319
	MEAN=	111.045	71.338	39.707
	S.D.=	0	41.8776919	41.877692
80		119.794	48.456	71.338
80		113.064	49.802	63.262
	MEAN=	116.429	49.129	67.3
	S.D.=	4.75882824	0.951767252	3.71059482
85		115.756	43.072	72.684
85		109.026	51.148	57.878
	MEAN=	112.391	47.11	65.281
	S.D.=	4.75882744	5.71059432	10.469423
90		110.372	56.532	53.84
90		105.661	54.513	51.148
	MEAN=	108.0165	55.5225	52.494
	S.D.=	3.33118051	1.4276482	1.903551
95		118.448	53.84	64.608
95		111.718	53.84	57.878
	MEAN=	115.083	53.84	61.243
	S.D.=	4.75882904	0	4.75882844
100		113.064	67.3	45.764
100		108.353	56.532	51.821
	MEAN=	110.7085	61.916	48.7925
	S.D.=	3.33117822	7.61412561	4.20294573

January 1985

DEPTH(cm)		PEAK(KN.m^-2)	RESIDUAL(KN.m^-2)	PEAK-RESIDUAL(KN.M^2)
0		5.384	2.692	2.692
0		2.692	2.692	0
	MEAN=	4.038	2.692	1.346
	S.D.=	1.90353145	0	1.90353145
5		7.403	5.384	2.019
5		8.749	6.73	2.019
	MEAN=	8.076	6.057	2.019
	S.D.=	0.951765748	0.951765725	0
10		10.768	6.73	4.038
10		8.076	8.076	0
	MEAN=	9.422	7.403	2.019
	S.D.=	1.90353143	0.951765748	2.85529718
15		10.768	8.076	2.692
15		10.095	6.73	3.365
	MEAN=	10.4315	7.403	3.0285
	S.D.=	0.475882874	0.951765748	0.475882866
20		13.46	8.076	5.384
20		26.925	10.095	16.825
	MEAN=	20.1975	9.0855	11.1045
	S.D.=	9.51657275	1.42764291	8.0900086
25		21.536	17.498	4.038
25		24.228	13.46	10.768
	MEAN=	22.882	15.479	7.403
	S.D.=	1.9035315	2.85529718	4.75882864
30		21.536	9.422	12.114
30		26.92	16.152	10.768
	MEAN=	24.228	12.787	11.441
	S.D.=	3.80706293	4.75882864	0.951765748
35		12.114	4.038	8.076
35		37.688	21.536	16.152
	MEAN=	24.901	12.787	12.114
	S.D.=	18.0835488	12.3729545	5.71059437
40		21.536	9.422	12.114
40		40.38	20.863	19.517
	MEAN=	30.958	15.1425	15.8155
	S.D.=	13.3247202	8.09000869	5.23471149
45		9.422	8.076	1.346
45		51.148	29.612	21.536
	MEAN=	30.285	18.844	11.441
	S.D.=	29.5047375	15.2282316	14.2764859
50		37.688	14.806	22.882
50		51.148	21.536	29.612
	MEAN=	44.418	18.171	26.247
	S.D.=	9.51765728	4.75882864	4.75882864
55		47.783	18.171	29.612
55		72.684	35.669	37.015
	MEAN=	60.2335	26.92	33.3135
	S.D.=	17.6076459	12.3729545	5.2347115
60		61.916	29.612	32.304
60		69.992	34.996	34.996
	MEAN=	65.954	32.304	33.65
	S.D.=	5.71059449	3.80706299	1.90353175
65		96.144	28.266	57.878
65		74.03	37.688	36.342
	MEAN=	80.087	32.977	47.11
	S.D.=	8.56589168	6.66223601	15.2282517
70		75.376	34.996	40.38
70		69.992	33.65	36.342
	MEAN=	72.684	34.323	38.761
	S.D.=	3.80706299	0.951765247	2.85529741
75		72.684	28.266	44.418
75		72.011	43.072	28.939
	MEAN=	72.3475	35.669	36.6785
	S.D.=	0.47588563	10.469423	10.9453058
80		90.76	35.669	45.091
80		70.663	34.996	35.669
	MEAN=	75.7125	35.3325	40.38
	S.D.=	7.1382425	0.47588563	6.66223601
85		78.069	40.38	37.688
85		90.182	48.456	41.726
	MEAN=	84.125	44.418	39.707
	S.D.=	8.5638919	5.71059449	2.85529725
90		83.452	37.015	46.437
90		113.737	61.243	52.494
	MEAN=	98.5945	49.129	49.4655
	S.D.=	21.4147291	17.1317852	4.28294595
95		76.049	32.304	43.745
95		110.372	59.224	51.148
	MEAN=	93.2105	45.764	47.4465
	S.D.=	24.2700262	19.0353144	5.2347115
100		84.125	39.707	44.418
100		104.315	45.764	58.551
	MEAN=	94.22	42.7355	51.4845
	S.D.=	14.2764858	4.28294595	9.99354002

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DEPTH (cm)		PEAK (KN.m^-2)	RESIDUAL (KN.m^-2)	PEAK-RESIDUAL (KN.M^2)
0		5.384	2.692	2.692
0		6.73	6.057	0.672999999
	MEAN=	6.057	4.3745	1.6825
	S.D.=	0.951765733	2.37941432	1.42764859
5		8.076	8.076	0
5		14.806	12.787	2.019
	MEAN=	11.441	10.4315	1.0095
	S.D.=	4.75882864	3.33118005	1.42764859
10		16.152	9.422	6.73
10		17.498	16.152	1.34599999
	MEAN=	16.825	12.787	4.038
	S.D.=	0.951765874	4.75882864	3.80706292
15		14.806	8.076	6.73
15		18.5748	9.422	9.1528
	MEAN=	16.6904	8.749	7.9414
	S.D.=	2.66494405	0.951765686	1.71317832
20		16.152	9.422	6.73
20		13.46	9.422	4.038
	MEAN=	14.806	9.422	5.384
	S.D.=	1.90353315	0	1.90353146
25		38.361	24.228	14.133
25		24.228	16.152	8.076
	MEAN=	31.2945	20.19	11.1045
	S.D.=	9.99354011	5.71059434	4.28294578
30		34.323	17.498	16.825
30		39.034	20.19	18.844
	MEAN=	36.6785	18.844	17.8345
	S.D.=	3.33117994	1.90353143	1.42764854
35		37.688	22.209	15.479
35		37.688	24.228	13.46
	MEAN=	37.688	23.2185	14.4695
	S.D.=	0	1.42764871	1.42764854
40		21.536	17.498	4.038
40		48.7252	40.38	8.3452
	MEAN=	35.1306	28.939	6.1916
	S.D.=	19.2256677	16.1800174	3.04565033
45		47.783	24.228	23.555
45		57.878	32.304	25.574
	MEAN=	52.8305	28.266	24.5645
	S.D.=	7.13824289	5.71059437	1.42764854
50		74.03	36.342	37.688
50		64.608	26.92	37.688
	MEAN=	69.319	31.631	37.688
	S.D.=	6.66235988	6.6623601	0
55		91.528	42.399	49.129
55		76.722	48.456	28.266
	MEAN=	84.125	45.4275	38.6975
	S.D.=	10.4694228	4.28294595	14.7523687
60		83.452	39.034	44.418
60		67.3	45.764	21.536
	MEAN=	75.376	42.399	32.977
	S.D.=	11.4211888	4.75882844	16.1800174
65		96.239	37.015	59.224
65		83.452	40.38	43.072
	MEAN=	89.8455	38.6975	51.148
	S.D.=	9.04177444	2.37941412	11.4211887
70		92.201	47.11	45.091
70		95.566	48.456	47.11
	MEAN=	93.8835	47.783	46.1005
	S.D.=	2.37941452	0.951765247	1.42764754
75		102.969	47.11	55.859
75		102.296	48.456	53.84
	MEAN=	102.6325	47.783	54.8495
	S.D.=	0.475881622	0.951765247	1.42764887
80		113.064	47.783	65.281
80		115.756	39.034	76.722
	MEAN=	114.41	43.4085	71.0015
	S.D.=	1.90353049	6.18647712	8.09000879
85		61.916	39.034	22.882
85		110.272	51.148	59.224
	MEAN=	86.144	45.091	41.053
	S.D.=	34.2675661	8.56589146	25.6976746
90		66.627	34.996	31.631
90		74.03	43.072	30.958
	MEAN=	70.3285	39.034	31.2945
	S.D.=	5.23471168	5.71059441	0.475883125
95		64.608	34.996	29.612
95		88.036	47.11	41.726
	MEAN=	76.722	41.053	35.669
	S.D.=	17.1317831	8.56589168	8.56589146
100		83.452	47.783	35.669
100		79.414	34.996	44.418
	MEAN=	81.433	41.3895	40.0435
	S.D.=	2.85529708	9.04177439	6.18647727

APPENDIX THREE

Appendix 3, table (1)

The list of program to calculate the coefficient of permeability using IBM computer.

```
10 REM"THIS PROGRAM CALCULATES THE COEFFICIENT OF PERMEABILITY OF SEDIMENT USING
 THE FULLINGHEAD EQUATION (SMITH 1981, PAGE  ); M.S.HARIRI, 1989"
20 PRINT"THIS PROGRAM CALCULATES THE COEFFICIENT OF PERMEABILITY OF SEDIMENT USI
NG THE   FULLINGHEAD EQUATION (SMITH 1981, PAGE  ); M.S.HARIRI, 1989."
30 PRINT:PRINT
40 DIM K(100), T(100)
50 INPUT"NAME OF TREATMENT OR SAMPLE:", W1$
60 INPUT"DATE :",W$
70 INPUT"NUMBER OF REPLICATE SAMPLES:",N
80 INPUT"INPUT THE TOP HEIGHT OF WATER IN mm (THIS MEASURES FROM THE BOTTOM OF S
EDIMENT TO THE TOP LEVEL OF WATER) =",H1
90 INPUT"INPUT THE SECOND HEIGHT OF WATER IN mm (THIS MEASURES FROM THE BOTTOM O
F SEDIMENT  TO THE SECOND LEVEL OF WATER) =",H2
100 LPRINT:LPRINT
110 LPRINT TAB(5)"NAME OF TREATMENT OR SAMPLE:";W1$
120 LPRINT TAB(5)"DATE :";W$
130 LPRINT TAB(5)"NUMBER OF REPLICATE SAMPLES:";N
140 LPRINT
150 CLS
160 FOR S= 1 TO N
170 PRINT"REPLICATE SAMPLE :",S
180 LPRINT TAB(5)"REPLICATE SAMPLE :";S
190 PRINT
200 LPRINT
210 INPUT"LENGTH OF SEDIMENT COLUMN (L) in (mm) =",L
220 INPUT"NUMBER OF TIME READINGS IN SECONDS =",Z
230 PRINT:PRINT
240 PRINT"ARE YOU SURE? Y OR N"
250 INPUT Y$: IF Y$="Y" GOTO 280 ELSE 260
255 INPUT"PLEASE INTER THE CORRECT LENGTH OF SEDIMENT COLUMN in mm =",L
260 INPUT"PLEASE INTER THE CORRECT NUMBER OF TIME READINGS :" ,Z
270 GOTO 240
280 PRINT"TO CALCULATE THE COEFFICIENT OF PERMEABILITY, PLEASE INPUT THE READING
 OF TIME IN TURN, PRESS INTER AFTER EACH TIME READING."
290 LPRINT TAB(5);"COEFFICIENT OF PERMEABILITY (mm/s)"
300 LPRINT
310 E=0:R=0
320 A=LOG (H1/H2)
330 FOR X= 1 TO Z
340 INPUT T(X)
350 NEXT X
360 GOSUB 590
370 FOR X= 1 TO Z
380 K(X)=(L/T(X))*(A)
390 E=E+K(X)
400 R=R+K(X)^2
410 NEXT X
420 ME=E/Z
430 S1=SQR ((R-(E^2/Z))/(Z-1))
440 FOR X= 1 TO Z
450 PRINT TAB(10),K(X)
460 LPRINT TAB(10),K(X)
470 NEXT X
480 PRINT TAB(5)"MEAN (mm/s) =";ME
490 LPRINT
500 LPRINT TAB(5)"MEAN (mm/s) =";ME
510 PRINT TAB(5)"STANDARD DEVIATION =";S1
520 LPRINT TAB(5)"STANDARD DEVIATION =";S1
530 LPRINT:LPRINT:LPRINT
540 CLS
550 NEXT S
560 CLS
570 PRINT"DO YOU WISH TO CALCULATE THE COEFFICIENT OF PERMEABILITY FOR MORE SAMP
LES? YES   OR  NO": INPUT F$: IF F$ ="YES" THEN GOTO 50 ELSE END
580 END
590 CLS
600 PRINT TAB(5)"READING", TAB(20)"TIME IN SECOND"
610 FOR X= 1 TO Z
620 PRINT TAB(8);X, TAB(25);T(X)
630 NEXT X
640 PRINT"DO YOU WISH TO CORRECT YOUR DATA? Y OR N"
650 INPUT Q$: IF Q$="Y" GOTO 670
660 RETURN
670 PRINT"INPUT ROW,NEW READING OF TIME, SEPARATED BY A COMMA"
680 INPUT RR,VV
690 T(RR)=VV
700 GOTO 590
```

APPENDIX FOUR

APPENDIX 4.I

The reduction in the total number of burrows with increasing depth is described as follows:

The data (table 4.1) of the total number of burrows were plotted against depth intervals (figure 4.2). It can be seen that the decrease is not linear. Therefore, to get the best fit line, the data of the total number of burrows at each depth were transformed to ln, $\log_{10}$ and square root, respectively (appendix 4.I, table 1). The transformed data were plotted against depth (appendix 4.I, figure 1). The transformed data of ln and $\log_{10}$ gave better correlations than the normal and the square root (appendix 4.I, table 2).

Appendix 4.I, table (1)

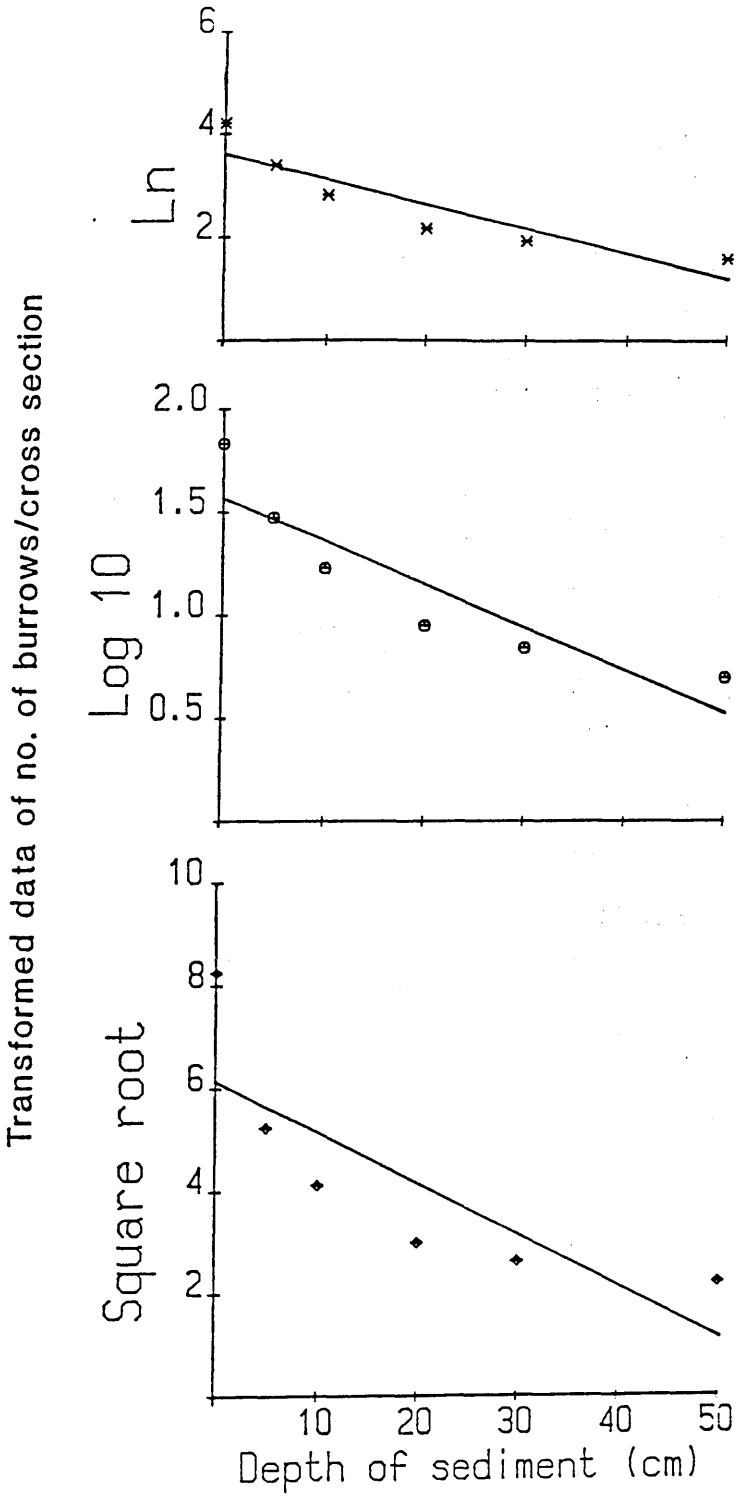
Untransformed and transformed (Ln, log_{10} and square root transformations) data of the total number of burrows in each depth of sediment.

The total number of burrows		Depth of sediment (cm) Surface	5	10	20	30	50
Untransformed data		68	30	17	9	7	5
Transformed data	Ln	4.2195	3.4012	2.8332	2.1972	1.9459	1.6094
	Log_{10}	1.8325	1.4771	1.2305	0.9542	0.8451	0.6990
	Square root	8.2462	5.2462	4.1231	3	2.6458	2.2361

Appendix 4.I, table (2)

The correlation coefficient equations and the regression of the number of burrows using different transformations.

The total number of burrows		Regression equation	Correlation coefficient
Untransformed data		Y = -0.9569 X + 41.0073	- 0.7390
Transformed data	Ln	Y = -0.0479 X + 3.6199	- 0.9049
	Log_{10}	Y = -0.0208 X + 1.5721	- 0.9049
	Square root	Y = -0.1007 X + 6.2186	- 0.8246



Appendix 4.I, figure (1)

Plot of the transformed total number of burrows counted at each depth against different depths of sediment using (ln, $\log_{10}$ and square root transformations).

Appendix 4.II

This appendix is divided into two parts. The first part describes the equations of burrow perimeter and surface area. The second describes the moment measurement equations.

A- Perimeter and surface area equations

The burrow perimeter and surface area depend on the shape of a horizontal cross section of the burrow.

Circular cross section.

If the burrow is circular in cross-section, the formula for the burrow perimeter and surface area are the formulae for a circle:

Perimeter = $2 \pi r$

Surface area = πr^2

Where r is the radius of the circle.

Elliptical cross section.

If the cross section of the burrow is an ellipse, the formulae of the perimeter and surface area are as follows:

(i) Perimeter

The following calculation of the perimeter of the ellipse was taken from Adams (1983. pp 382-383).

The formula of an ellipse is:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

where a is the semimajor axis and b is the semiminor axis.

The perimeter (s) of an ellipse is:

$$s = 4 \int_0^a \frac{\sqrt{a - \frac{a^2 - b^2}{a^2} x^2}}{\sqrt{a^2 - x^2}} \cdot dx \qquad (1)$$

Now, let $x = a \sin t$, and $dx = a \cos t \, dt$,

(Adams 1983, pp 383). Then:

$$s = 4 \int_0^{\pi/2} \sqrt{a^2 - (a^2 - b^2) \sin^2 t} \cdot dt \qquad (2)$$

$$s = 4 \int_0^{\pi/2} \sqrt{a^2(1 - ((a^2 - b^2)/a^2) \sin^2 t} \cdot dt \qquad (3)$$

$$s = 4 \int_0^{\pi/2} a \sqrt{1 - ((a^2 - b^2)/a^2) \sin^2 t} \cdot dt \qquad (4)$$

$$s = 4 a \int_0^{\pi/2} \sqrt{1 - ((a^2 - b^2)/a^2) \sin^2 t} \cdot dt \qquad (5)$$

$$s = 4 a \int_0^{\pi/2} \sqrt{1 - \varepsilon^2 \sin^2 t} \cdot dt \qquad (6)$$

Where $\varepsilon^2 = (a^2 - b^2)/ a^2$

(ε is termed the eccentricity of the ellipse)

This can be written as

$$s = 4 a E(\varepsilon) \qquad (7)$$

Where $E(\varepsilon)$ is defined as the complete elliptic integral and is given by the integral on the right hand side of the above equation, that is:

$$E(\varepsilon) = \int_0^{\pi/2} \sqrt{1 - \varepsilon^2 \sin^2 t} \cdot dt \qquad (8)$$

where $\varepsilon = \sqrt{(a^2 - b^2)/a^2}$ is the eccentricity of the ellipse. The function $E(\varepsilon)$ defined by the integral in equation (8) is called a complete elliptic integral. It can not be evaluated by elementary techniques for general ε, but tables of values (as a function of ε) are given in Abramowitz and Stegun 1972, (page 609).

At the top of the table on page 609 of Abramowitz and Stegun (1972) E(m) is given by:

$$E(m) = \int_0^{\pi/2} (1 - m \sin^2 \theta)^{1/2} \, d\theta \qquad (9)$$

(For more details see the same reference pp 590).

Now, Adams (1983) shows (pp 383) that

$$E(\varepsilon) = \int_0^{\pi/2} (1 - \varepsilon^2 \sin^2 t)^{1/2} \, dt \qquad (10)$$

Where $t = \theta$

Hence $E(m) = E(\varepsilon)$ (11)

Therefore,

$$m = \varepsilon^2 = a^2 - b^2/a^2 \qquad (12)$$

In Abramowitz and Stegun's table when $0 \leq m \leq 0.50$ (where $m = \varepsilon 2$), the value of E(m) (as $E(\varepsilon)$) is found from columns 1 and 3. When $0.50 \leq m \leq 1.00$, the value of E(m) is found from columns 4 and 5.

$E(\varepsilon)$ obtained in this way, is then substituted into equation 8, and 8 into 6, to give s, the perimeter of the ellipse.

Note that if a = b, then $\varepsilon = 0$, and the formula of the perimeter of the ellipse becomes the formula for the perimeter of a circle (Adams 1983, pp 383):

$s = 4a(\pi/2) = 2\pi a$

(ii) Surface area

The surface area of an ellipse is:

$$\pi a b$$

Where a is the semimajor axis and b is the semiminor axis.

B- Statistical measurements

The mean is the first moment. The variance is the second moment. Departures from a normal curve called skewness and kurtosis are the third and the fourth moments. The variance is defined as the average value of the squared deviation of each observation from the arithmetic mean. Skewness and kurtosis are defined as the average value of the cube and fourth power deviation of each observation from the arithmetic mean. The coefficient of variation (%) estimates the amount of variation about the mean (Snedecor and Cochran 1982, page 37).

The following equations are given by Sokal and Rohlf (1984, pp. 41-45, 114-116) and Snedecor and Cochran (1982, page 37).

(1) Mean (arithmetic mean)

The mean is calculated by summing all the individual observations or items of the sample and dividing this by the number of items in the sample. The formula of the mean is:

$$\bar{Y} = \Sigma Y/n$$

Where ΣY is the sum of individual items, and n is the number of items in the sample.

(2) Variance and Standard deviation

The variance is defined as the mean of the squares of the deviations about the mean, which is given by:

$$V = \Sigma (Y - \bar{Y})^2/n-1$$
$$V^2 = (\Sigma Y^2 - (\Sigma Y)^2/n)/n-1$$

Where ΣY^2 is the square of the individual items.

The denominator is n-1 rather than n for statistical reasons (Cohen and Holliday 1982; Hamburg 1974; Snedecor and Cochran 1981; Sokal and Rohlf 1984)

The standard deviation is the square root of the variance (V),

$$s = \sqrt{v}$$

(3) The coefficient of variation (%)

The coefficient of variation describes the amount of variation in the population (Snedecor and Cochran 1982, page 37). The coefficient of variation is calculated as:

$$cv = \sigma / \bar{x} \quad \text{or} \quad cv = 100\ (\sigma)/ \bar{x} \quad (\%).$$

where σ is the standard deviation and $(\bar{x})$ is the mean.

The standard deviation is expressed as a proportion or a percentage (%) of the mean (Cohen and Holliday 1983, page 47; and Snedecor and Cochran 1982, page 37).

(4) Skewness

The third moment about the mean is called skewness. This measures the displacement of the curve from a theoretical symmetrical curve, either to the right or left. The coefficient of skewness is given by:

$$g_1 = \frac{\Sigma(Y - \bar{Y})^3}{n \cdot s^3}$$

Where $\frac{\Sigma(Y - \bar{Y})^3}{n} = \frac{n\,\Sigma Y^3 - 3\,(\Sigma Y)\,(\Sigma Y^2) + 2\,(\Sigma Y)^2/n}{(n-1)(n-2)}$

So, $$g_1 = \frac{(n\,\Sigma Y^3 - 3\,(\Sigma Y)\,(\Sigma Y^2) + 2\,(\Sigma Y)^2/n)}{(n-1)\,(n-2)\,s^3}$$

Where ΣY^3 is the cube of the individual observations, and s^3 is the cube of the standard deviation.

A negative value of skewness means the tail is towards the left of the curve and the median is greater than the mean. A positive value of skewness means the tail is towards the right of the curve and the median is less than the mean (appendix 4.II figure 1a).

(4) Kurtosis

Kurtosis is an estimate of the peakedness of the curve, and is the fourth power about the mean. Kurtosis equals zero in the normal curve. When the value of kurtosis is greater than zero, the curve is called leptokurtic. Here, the distribution has a higher central peak than the normal curve and has longer tails. When the value of kurtosis is less than zero, the curve is called platykurtic. Here, the distribution has a lower central peak than the normal curve and is flat topped with little or no tails (appendix 4.II, figure 1b). The formula for kurtosis is:

$$g_2 = \frac{\Sigma(Y - \bar{Y})^4}{n \cdot s^4} - 3$$

Where s^4 is the fourth power of the standard deviation. In this equation,

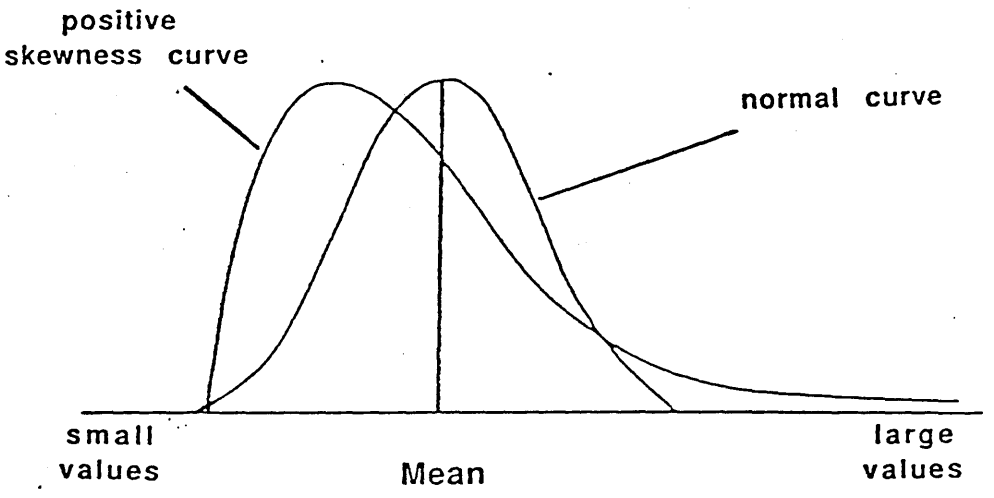
$$\frac{\Sigma(Y - \bar{Y})^4}{n} = \frac{(n-1)\{n\Sigma Y^4 - 4(\Sigma Y)(\Sigma Y^3) + [6(\Sigma Y)^2(\Sigma Y^2)/n] - 3(\Sigma Y)^4/n^2\}}{(n-1)(n-2)(n-3)}$$

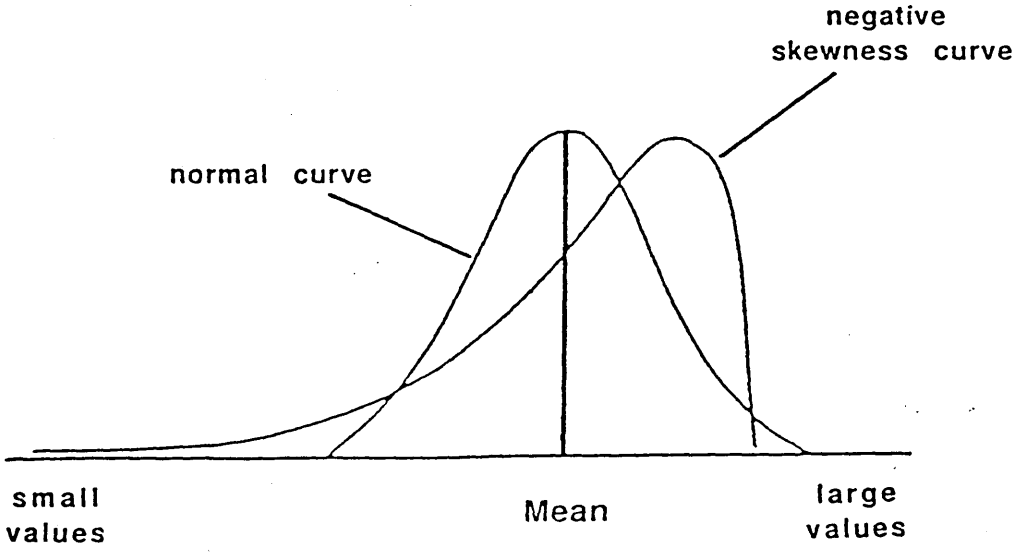
So,

$$g_2 = \frac{(n+1)\{n\Sigma Y^4 - 4(\Sigma Y)(\Sigma Y^3) + [6(\Sigma Y)^2(\Sigma Y^2)/n] - 3(\Sigma Y)^4/n^2\}}{(n-1)\,(n-2)\,(n-3)\,s^4} - \frac{3(n-1)^2}{(n-2)(n-3)}$$

ΣY^4 is the sum of the fourth power of the individual items.

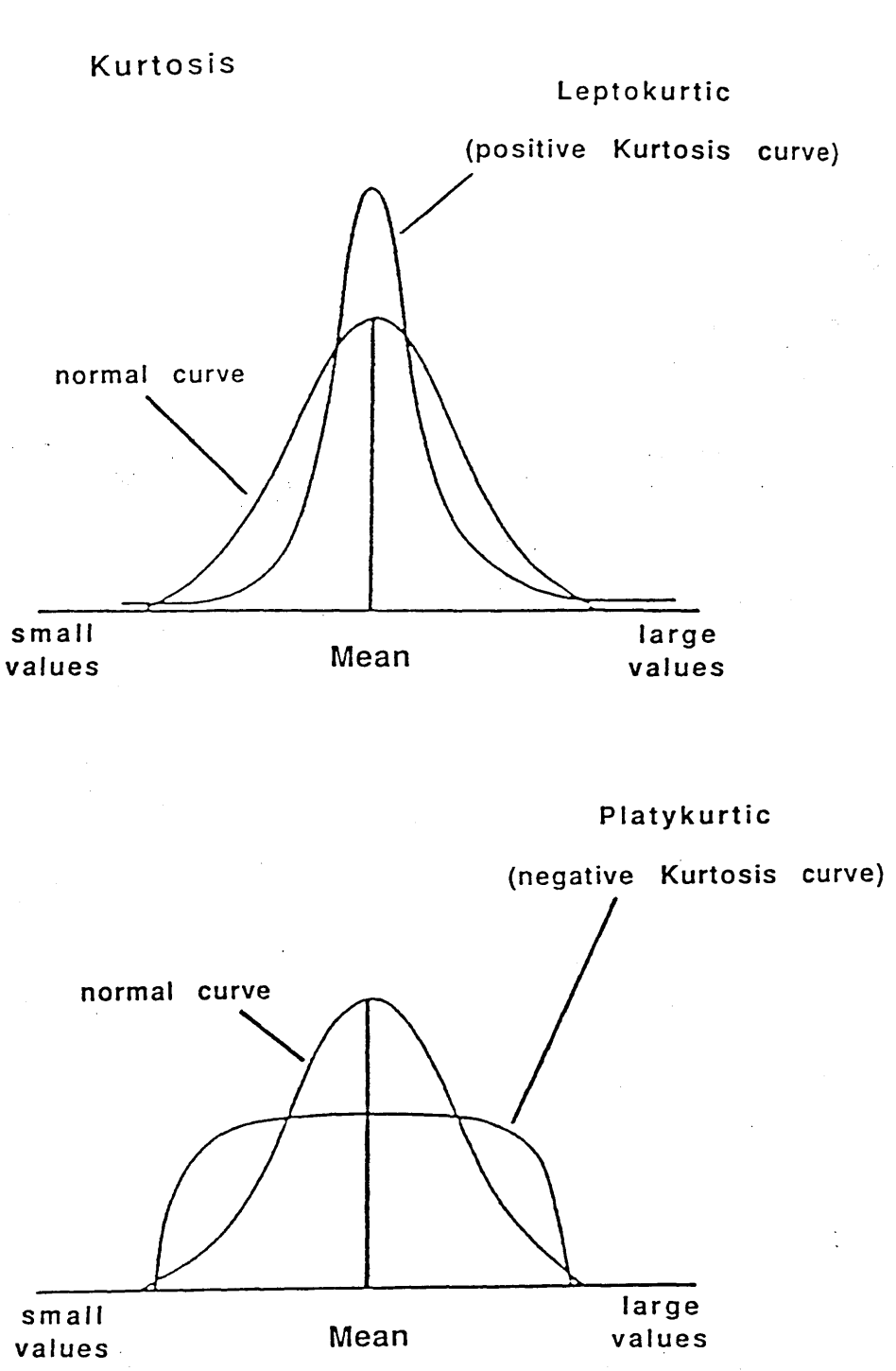
Skewness





Appendix 4.II, figure (1a).

The Positive and negative skewness curves compared with the normal curve.



Appendix 4.II, figure (1b)

The positive and negative kurtosis curves compared with the normal curve.

(5) Testing the significance of the skewness and kurtosis

The observed values of skewness and kurtosis can be tested using student's t. This test compares the observed skewness and kurtosis with the skewness and kurtosis of the normal curve which are both zero. The formula for student's t is given by Snedecor and Cochran (1982, pp 79-80 and pp 492) and Sokal and Rohlf (1981, box 7.4 pp 114-117, box 7.1 pp 139, 174-175 and text pp 170).

Student's t for skewness = $g_1 - \Gamma_1 / Sg_1$

Student's t for kurtosis = $g_2 - \Gamma_2 / Sg_2$

Where,

Sg_1 is the standard error of skewness which is:

$$=\sqrt{6n\ (n-1)/(n-2)(n+1)(n+3)}$$

Sg_2 is the standard error of kurtosis which is given by:

$$\sqrt{24n\ (n-1)^2/(n-3)(n-2)(n+3)(n+5)}$$

$\Gamma 1$ and $\Gamma 2$ = zero for the normal distribution (Snedecor and Cochran 1982 pp xv, and Sokal and Rohlf 1981 pp 114-117).

Computer program

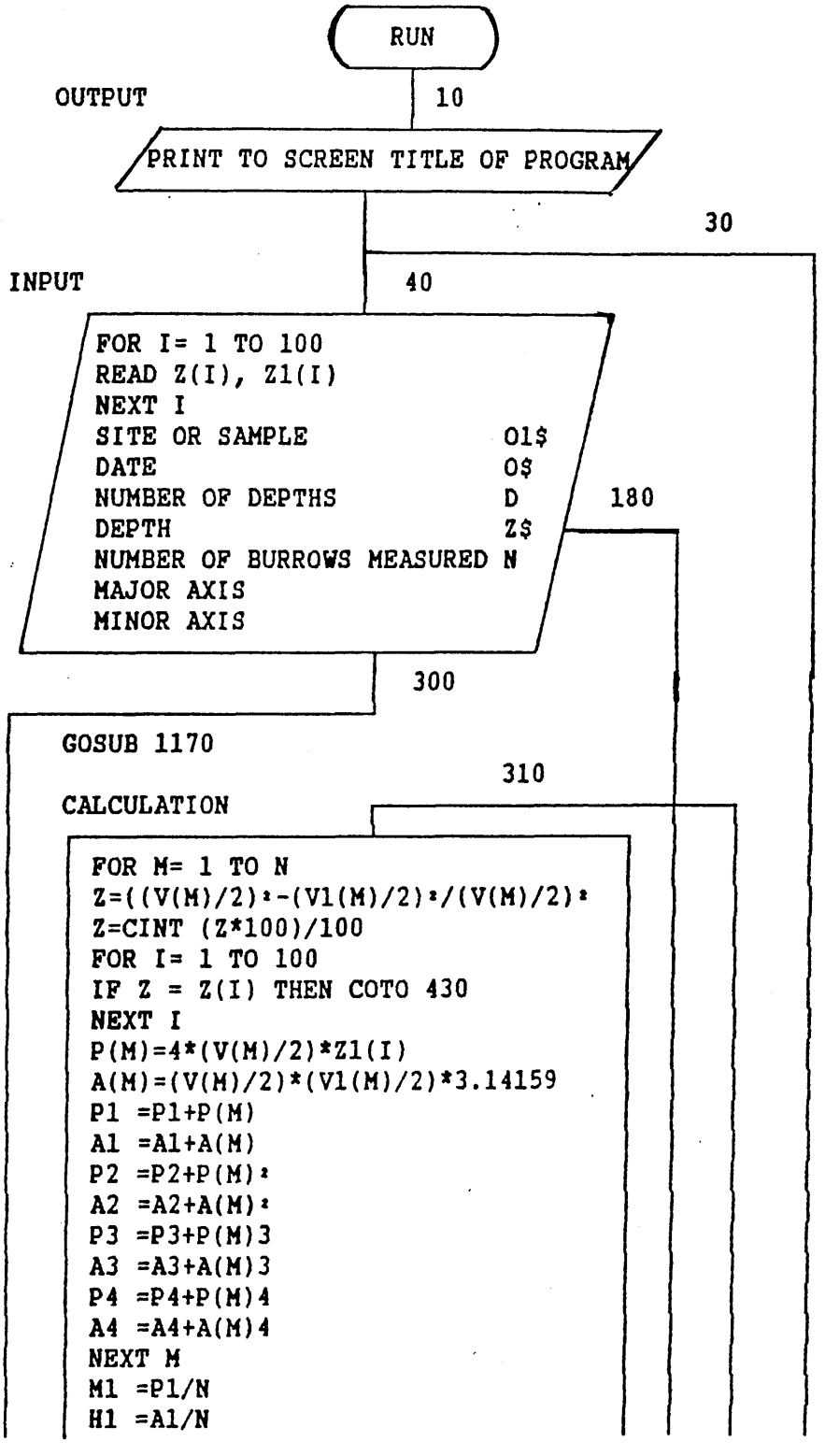
I have developed a computer program (MH-BIOT) to determine the burrow perimeter and surface area and their statistical measurements (Mean, Standard deviation, coefficients of variation (%), Skewness and Kurtosis) using Basic, Mbasic and P-basic languages in the BBC, COMART and IBM computers, respectively. My reason for using three computers in writing the program is because it is part of my training. The program calculates the perimeter and surface area of each burrow using major and minor axes measurements (for more details about the major and minor axes see appendix 4.IV), and the total burrow perimeter and surface area and then the moment measurements of both. The flow diagram of the program, the list of the programs using the BBC, COMART and IBM computers are given in appendix 4.III, figure 1, and appendix 4.III, tables 1,2 and 3). The run of the program is given in appendix 4.III, table 4.

When the burrow is an ellipse, there is a difficulty in the calculation of the perimeter of the burrow. This problem has been solved as follows:

The values of m and E(m) from the table given by Abramowitz and Stegun 1972 (page 609) were stored in the computer program (as Z(I) and Z1(I), respectively). The calculation of m (Which is Z in the program) is given in the program at Line 370 in the BBC, line 380 in the COMART.

Appendix figure (4.III.1)

Flow diagram of the computer program for calculation of burrow perimeter and surface area and their statistical measurements (mean, standard deviation, coefficient of variation, skewness and kurtosis).



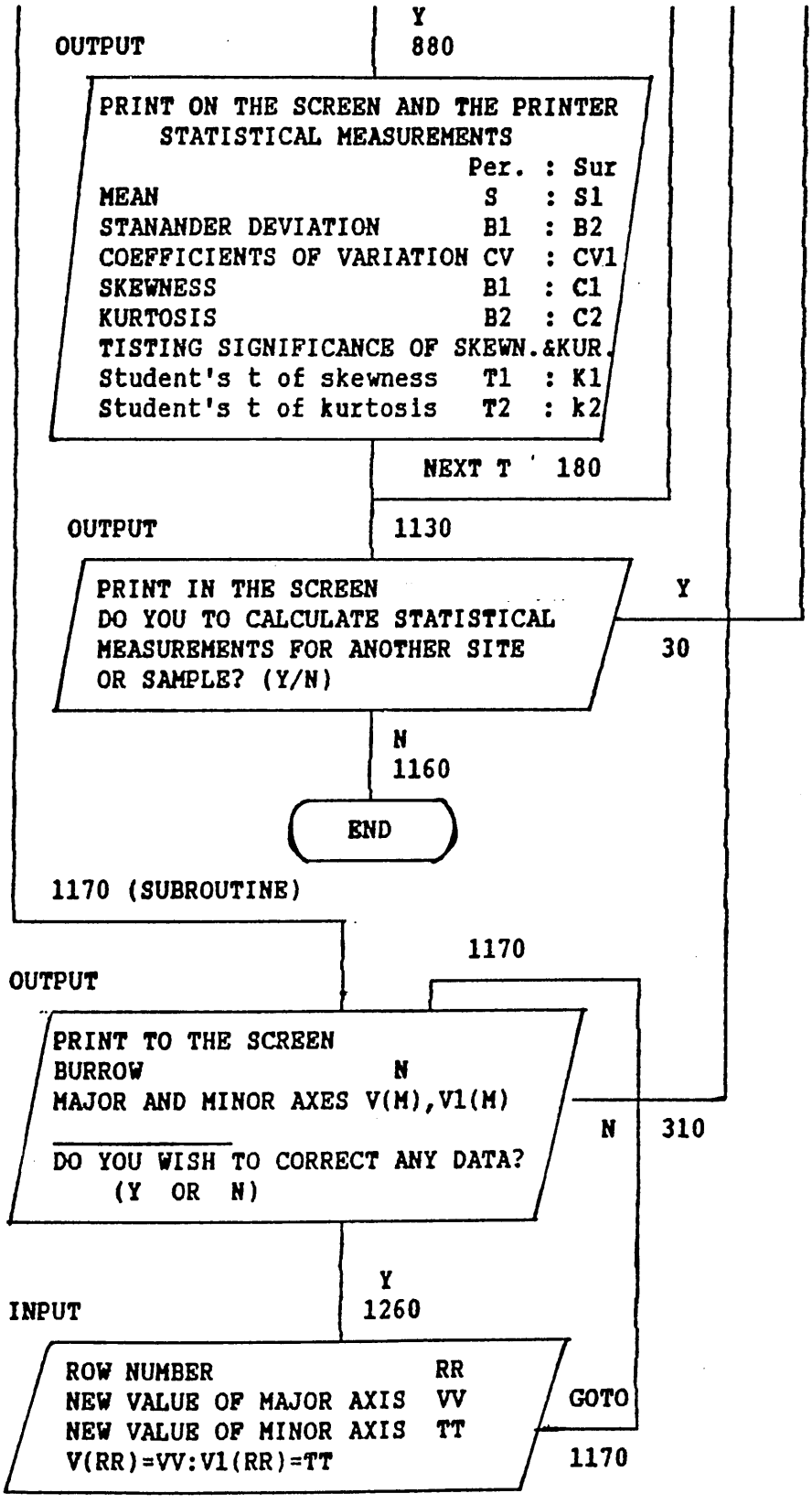
```
M2 =(P2-(P1²/N)/N-1
H2 =(A2-(A1²/N)/N-1
S  =SQR (M2)
S1 =SQR (H2)
CV =(S*100)/M1
CV1=(S1*100)/M1
M3 =
 (N*P3-3*P1*P2+2(P13)/N/(N-1)*(N-2)
H3 =
 (N*A3-3*A1*A2+2(A13)/N/(N-1)*(N-2)
G =N*P4-4*P1*P3
E =N*A4-4*A1*A3
G1=6*(P1²)*P2/N
E1=6*(A1²)*A2/N
G2=3*(P14)/N²
E2=3*(A14)/N²
G3=3*(N-1)²/(N-2)*(N-3)
E3=3*(N-1)²/(N-2)*(N-3)
M4=
 (N+1)*(G+G1-G2)/(N-1)*(N-2)*(N-3)
H4=
 (N+1)*(E+E1-E2)/(N-1)*(N-2)*(N-3)
B1=M3/S3
C1=H3/S13
B2=(M4/S4)-G3
C2=(H4/S14)-E3
W1=SQR(6*N*(N-1))/(N-2)*(N+1)*(N+3)
W2=SQR(24*N*(N-1)²)/(N-3)*(N-2)*
                              *(N+5)
T1=B1/W1
T2=B2/W2
K1=C1/W1
K2=C2/W2
```

OUTPUT | 760

```
PRINT TO THE SCREEN AND THE PRINTER
DEPTH                          Z$
BURROWS NUMBER                 M
MAJOR AXIS                     V(M)
MINOR AXIS                     V1(M)
PERIMETER OF BURROW(mm)        P(M)
SURFACE AREA OF BURROW(mm)     A(M)
TOTAL NUMBER OF BURROWS        N
TOTAL PERIMETER OF BURROWS     P1
TOTAL SURFACE AREA OF BURROWS  A1
```

OUTPUT | 860

```
PRINT TO THE SCREEN
Do you wish to calculate the stat-
istical measurements of perimeter
and surface area of burrows? YorN
```


Y
OUTPUT
880
PRINT ON THE SCREEN AND THE PRINTER
STATISTICAL MEASUREMENTS
Per. : Sur
MEAN S : S1
STANANDER DEVIATION B1 : B2
COEFFICIENTS OF VARIATION CV : CV1
SKEWNESS B1 : C1
KURTOSIS B2 : C2
TISTING SIGNIFICANCE OF SKEWN.&KUR.
Student's t of skewness T1 : K1
Student's t of kurtosis T2 : k2
NEXT T 180
OUTPUT
1130
PRINT IN THE SCREEN
DO YOU TO CALCULATE STATISTICAL
MEASUREMENTS FOR ANOTHER SITE
OR SAMPLE? (Y/N)
Y
30
N
1160
END
1170 (SUBROUTINE)
1170
OUTPUT
PRINT TO THE SCREEN
BURROW N
MAJOR AND MINOR AXES V(M),V1(M)
DO YOU WISH TO CORRECT ANY DATA?
(Y OR N)
N
310
Y
INPUT
1260
ROW NUMBER RR
NEW VALUE OF MAJOR AXIS VV
NEW VALUE OF MINOR AXIS TT
V(RR)=VV:V1(RR)=TT
GOTO
1170

Appendix 4.III, table (1)

The list of program to calculate the perimeter and surface area of burrows and their moments using the BBC computer.

```
   10 MODE3
   20 PRINT:PRINT:PRINT
   30 PRINT"      THIS PROGRAM CALCULATES THE MOMENT MEASUREMENTS (MEAN,
D DEVIATION,SKEWNESS AND KURTOSIS) OF SEVERAL PARAMETERS (e.g. Perimeter
face area of animals burrows ). (M. S. HARIRI, 1988, ZOOLOGY DEPARTMENT)
   40 PRINT
   50  PRINT TAB(5)"(THIS PROGRAM DOES NOT TAKE LESS THAN FOUR MEASUREME
URROWS)"
   60 DIM V(50),V1(50),P(50),A(50),Z(100),Z1(100)
   70 FOR I= 1 TO 100
   80 READ Z(I),Z1(I)
   90 NEXT I
  100 PRINT:PRINT:PRINT:PRINT
  110 INPUT"SITE OR SAMPLE = "O1$
  120 INPUT"DATE : "O$
  130 VDU2:PRINT TAB(5);"SITE OR SAMPLE ="O1$
  140 PRINT
  150 PRINT TAB(5);"DATE : "O$
  160 PRINT"-------------------------------------------------------------
---------"
  170 VDU3
  180 CLS
  190 PRINT TAB(5);"SITE OR SAMPLE ="O1$
  200 PRINT:PRINT:PRINT
  210 INPUT"ENTER NUMBER OF DEPTHS OF SEDIMENT WHICH YOU MEASURED THE BUR
D
  220 FOR T= 1 TO D
  230 PRINT:PRINT"ENTER YOUR DEPTH "T
  240 INPUT"DEPTH  = "Z$
  250 PRINT: INPUT"HOW MANY BURROWS HAVE YOU MEASURED AT THIS DEPTH = "N
  260 PRINT:PRINT"ENTER THE MAJOR AND MINOR AXES OF EACH BURROW, RESPECTI
  270 PRINT "(If the major and minor axer are the same, ENTER the same va
both axes)"
  280 FOR M= 1 TO N
  290 PRINT"BURROW "M
  300 INPUT "MAJOR AXIS(mm): "V(M)
  310 INPUT "MINOR AXIS(mm): "V1(M)
  320 NEXT M
  330 GOSUB 1620
  340 P1=0:A1=0:P2=0:A2=0:P3=0:A3=0:P4=0:A4=0
  350 H1=0:H2=0:H3=0:H4=0:M1=0:M2=0:M3=0:M4=0
  360 FOR M=1 TO N
  370  Z=(((V(M)/2)^2-(V1(M)/2)^2)/((V(M)/2)^2))
  380 X$=STR$(Z)
  390 X$=LEFT$(X$,4)
  400 Z=VAL(X$)
  410 FOR I=1 TO 100
  420 IF Z(I)=Z THEN GOTO 440
  430 NEXT I
  440 P(M)=4*(V(M)/2)*Z1(I)
  450 A(M)=(V(M)/2)*(V1(M)/2)*3.141593
  460 P1=P1+P(M)
  470 A1=A1+A(M)
  480 P2=P2+P(M)^2
  490 A2=A2+A(M)^2
  500 P3=P3+P(M)^3
  510 A3=A3+A(M)^3
  520 P4=P4+P(M)^4
  530 A4=A4+A(M)^4
  540 NEXT M
  550 M1=P1/N
  560 H1=A1/N
```

```
  570 M2=(P2-(P1^2/N))/(N-1)
  580 H2=(A2-(A1^2/N))/(N-1)
  590 S=SQR (M2)
  600 S1=SQR (H2)
  610 CV=(S*100)/M1
  620 CV1=(S1*100)/H1
  630 M3=(N*P3-3*P1*P2+2*((P1^3)/N))/((N-1)*(N-2))
  640 H3=(N*A3-3*A1*A2+2*((A1^3)/N))/((N-1)*(N-2))
  650 G=N*P4-4*P1*P3
  660 E=N*A4-4*A1*A3
  670 G1=6*(P1^2)*P2/N
  680 E1=6*(A1^2)*A2/N
  690 G2=3*(P1^4)/N^2
  700 E2=3*(A1^4)/N^2
  710 G3=3*(N-1)*(N-1)/((N-2)*(N-3))
  720 E3=3*(N-1)*(N-1)/((N-2)*(N-3))
  730 M4=(N+1)*(G+G1-G2)/((N-1)*(N-2)*(N-3))
  740 H4=(N+1)*(E+E1-E2)/((N-1)*(N-2)*(N-3))
  750 B1=M3/S^3
  760 C1=H3/S1^3
  770 B2=(M4/S^4)-G3
  780 C2=(H4/S1^4)-E3
  790 W= ((6*N*(N-1))/((N-2)*(N+1)*(N+3)))
  800 W1=SQR W
  810 W2= ((24*N*(N-1)*(N-1))/((N-3)*(N-2)*(N+3)*(N+5)))
  820 W3=SQR W2
  830 T1=B1/W1
  840 T2=B2/W3
  850 K1=C1/W1
  860 K2=C2/W2
  870 X$=STR$(M1)
  880 X$=LEFT$(X$,8)
  890 M1=VAL(X$)
  900 X$=STR$(H1)
  910 X$=LEFT$(X$,8)
  920 H1=VAL(X$)
  930 X$=STR$(S)
  940 X$=LEFT$(X$,8)
  950 S=VAL(X$)
  960 X$=STR$(S1)
  970 X$=LEFT$(X$,8)
  980 S1=VAL(X$)
  990 X$=STR$(CV)
 1000 X$=LEFT$(X$,8)
 1010 CV=VAL(X$)
 1020 X$=STR$(CV1)
 1030 X$=LEFT$(X$,8)
 1040 CV1=VAL(X$)
 1050 X$=STR$(B1)
 1060 X$=LEFT$(X$,8)
 1070 B1=VAL(X$)
 1080 X$=STR$(B2)
 1090X$=LEFT$(X$,8)
 1100 B2=VAL(X$)
 1110 X$=STR$(C1)
 1120 X$=LEFT$(X$,8)
 1130 C1=VAL(X$)
 1131 X$=STR$(C2)
 1132 X$=LEFT$(X$,8)
 1133 C2=VAL(X$)
 1140 VDU2
 1150 PRINT:PRINTTAB(5)"DEPTH ="Z$
```

```
1160 PRINT:PRINT
1170 PRINT TAB(5);"BURROW";TAB(15);"MAJOR AXIS(mm)";TAB(30);"MINOR AXIS(mm)";
 5);"PERIMETER(mm)";TAB(59);"SURFACE AREA(mm^2)"
1180 PRINT:VDU3
1190FOR M=1 TO N
1200 VDU2:PRINT TAB(7);M, TAB(20);V(M),TAB(35);V1(M),TAB(47);P(M),TAB(62);A(M

1210 NEXT M
1220 PRINT:PRINTTAB(5);"_____"; TAB(45);"_____"; TAB(60);"_____

1230 PRINT "TOTAL:";TAB(7);N, TAB(47);P1, TAB(64);A1
1240 PRINT:PRINT
1250 VDU3
1260 PRINT"Do you wish to calculate the statistical measurements of perimeter
 surface area  of burrows ? Y/N"
1270 INPUT F$ : IF F$="Y" THEN 1280 ELSE END
1280 VDU2
1290 PRINT:PRINT"STATISTICAL MEASUREMENTS OF PERIMETER (mm) AND SURFACE AREA
 )"
1300 PRINT
1310 PRINT TAB(10);"MEAN";TAB(20);"STAN. DEV.";TAB(35);"COEFF. OF VAR.(%)";TA
 ;"SKEWNESS";TAB(70);"KURTOSIS"
1320 PRINT
1330 PRINT "(PERIM.)";  TAB(10);M1; TAB(20);S; TAB(35);CV; TAB(55);B1; TAB(70

1340 PRINT "(AREA)"; TAB(10);H1; TAB(20);S1; TAB(35);CV1; TAB(55);C1; TAB(70)

1350 PRINT:PRINT
1360 PRINT TAB(10)"TESTING SIGNIFICANCE OF SKEWNESS AND KURTOSIS"
1370 PRINT TAB(5)"Student's t test comparing observed skewness and kurtosis w

1380 PRINT TAB(5)"the skewness and kurtosis of a normal curve which are both z

1390 PRINT TAB(5)"(Sokal & Rohlf 1981, 2nd edition, Box 7.4 p 174,175; text p
 "
1400 PRINT TAB(5)"Box 7.1 p 139.)"
1410 PRINT:PRINT TAB(10)"Student's t of skewness of perimeter = "T1
1420PRINT:PRINT TAB(10)"Student's t of kurtosis of perimeter = "T2
1430 PRINT:PRINT TAB(10)"Student's t of skewness of surface area = "K1
1440 PRINT:PRINT TAB(10)"Student's t of kurtosis of surface area = "K2
1450 PRINT:PRINT
1460 PRINT TAB(3)"5%, 1% and 0.1% critical values of student's t with d.f.=in
 :y:"
1470 PRINT:PRINT TAB(3)"Student's t   :     1.960       2.576       3.291"
1480 PRINT TAB(3)"Probability   :      0.05        0.01        0.001"
1490 PRINT
1500 PRINT TAB(3)"The statistical significance of the observed skewness & kur
 ;"
1510 PRINT TAB(3)"can also be tested using Snedecor & Cochran's (1967, 7th ed
 ,"
1520 PRINT TAB(3)"pp 79-80, and table A20 i,ii p492) method."
1530 PRINT:PRINT"-------------------------------------------------------------
 ------------"
1540 PRINT:PRINT
1550 VDU3
1560 CLS:NEXT T
1570 CLS:CLEAR
1580 PRINT:PRINT:PRINT
1590 PRINT"DO YOU WISH TO CALCULATE MOMENT MEASUREMENTS FOR ANOTHER SITE OR S
 ? (Y/N)"
1600 INPUT Y$ : IF Y$="Y" GOTO 60 ELSE END
1610 END
1620 CLS
1630 PRINT TAB(5);"BURROW";TAB(10);"MAJOR AXIS(mm)"; TAB(25);"MINOR AXIS(mm)"
```

```
 1640 PRINT: FOR M=1 TO N
 1650 PRINT TAB(7);M, TAB(15);V(M), TAB(30);V1(M)
 1660NEXT M
 1670 PRINTTAB(5);"_____"; TAB(12);"_________" ;TAB(28);"_________"
 1680 PRINT:PRINT"DO YOU WISH TO CORRECT YOUR DATA  Y OR N"
 1690 INPUT Q$: IF Q$="Y" GOTO 1710
 1700 RETURN
 1710 PRINT"INPUT ROW,NEW VALUE OF MAJOR AND MINOR AXES, SEPARATE VALUE BY A COM
MA"
 1720 INPUT RR,VV,TT
 1730  V(RR)=VV:V1(RR)=TT
 1740 GOTO 1630
 1750 @%=10
 1760 DATA 0.00,1.57080
 1770 DATA 0.01,1.56686
 1780 DATA 0.02,1.56291
 1790 DATA 0.03,1.55895
 1800 DATA 0.04,1.55497
 1810 DATA 0.05,1.55097
 1820 DATA 0.06,1.54696
 1830 DATA 0.07,1.54293
 1840 DATA 0.08,1.53889
 1850 DATA 0.09,1.53483
 1860 DATA 0.10,1.53076
 1870 DATA 0.11,1.52667
 1880 DATA 0.12,1.52256
 1890 DATA 0.13,1.51843
 1900 DATA 0.14,1.51428
 1910 DATA 0.15,1.51012
 1920 DATA 0.16,1.50594
 1930 DATA 0.17,1.50174
 1940 DATA 0.18,1.49753
 1950 DATA 0.19,1.49329
 1960 DATA 0.20,1.48904
 1970 DATA 0.21,1.48476
 1980 DATA 0.22,1.48047
 1990 DATA 0.23,1.47615
 2000 DATA 0.24,1.47182
 2010 DATA 0.25,1.46746
 2020 DATA 0.26,1.46309
 2030 DATA 0.27,1.45869
 2040 DATA 0.28,1.45427
 2050 DATA 0.29,1.44983
 2060 DATA 0.30,1.44536
 2070 DATA 0.31,1.44088
 2080 DATA 0.32,1.43636
 2090 DATA 0.33,1.43183
 2100 DATA 0.34,1.42727
 2110 DATA 0.35,1.42269
 2120 DATA 0.36,1.41808
 2130 DATA 0.37,1.41345
 2140 DATA 0.38,1.40879
 2150 DATA 0.39,1.40411
 2160 DATA 0.40,1.39939
 2170 DATA 0.41,1.39465
 2180 DATA 0.42,1.38988
 2190 DATA 0.43,1.38509
 2200 DATA 0.44,1.38026
 2210 DATA 0.45,1.37540
 2220 DATA 0.46,1.37052
 2230 DATA 0.47,1.36560
 2240 DATA 0.48,1.36065
 2250 DATA 0.49,1.35566
 2260 DATA 0.50,1.35064
 2270 DATA 0.51,1.34559
 2280 DATA 0.52,1.34051
 2290 DATA 0.53,1.33538
 2300 DATA 0.54,1.33022
 2310 DATA 0.55,1.32503
 2320 DATA 0.56,1.31979
 2330 DATA 0.57,1.31451
 2340 DATA 0.58,1.30919
 2350 DATA 0.59,1.30383
 2360 DATA 0.60,1.29843
 2370 DATA 0.61,1.29298
 2380 DATA 0.62,1.28748
 2390 DATA 0.63,1.28194
 2400 DATA 0.64,1.27635
 2410 DATA 0.65,1.27071
 2420 DATA 0.66,1.26501
 2430 DATA 0.67,1.25926
 2440 DATA 0.68,1.25346
 2450 DATA 0.69,1.24760
 2460 DATA 0.70,1.24167
 2470 DATA 0.71,1.23568
 2480 DATA 0.72,1.22963
 2490 DATA 0.73,1.22351
 2500 DATA 0.74,1.21732
 2510 DATA 0.75,1.21106
 2520 DATA 0.76,1.20471
 2530 DATA 0.77,1.19829
 2540 DATA 0.78,1.19178
 2550 DATA 0.79,1.18518
 2560 DATA 0.80,1.17849
 2570 DATA 0.81,1.17170
 2580 DATA 0.82,1.16480
 2590 DATA 0.83,1.15779
 2600 DATA 0.84,1.15065
 2610 DATA 0.85,1.14340
 2620 DATA 0.86,1.13600
 2630 DATA 0.87,1.12845
 2640 DATA 0.88,1.12074
 2650 DATA 0.89,1.11285
 2660 DATA 0.90,1.10478
 2670 DATA 0.91,1.09648
 2680 DATA 0.92,1.08794
 2690 DATA 0.93,1.07912
 2700 DATA 0.94,1.06999
 2710 DATA 0.95,1.06047
 2720 DATA 0.96,1.05050
 2730 DATA 0.97,1.03995
 2740 DATA 0.98,1.02860
 2750 DATA 0.99,1.01599
 2760 DATA 1.00,1.00000
```

Appendix 4.III, table (2)

The list of program to calculate the perimeter and surface area of burrows and their moments using the COMART computer.

```
10 REM****PERIMETER AND SURFACE AREA MOMENT MEUSUREMENT****
20 REM***M.S.HARIRI***
30 CS$=CHR$(126)+CHR$(28)
40 PRINT CS$
50 PRINT"THIS PROGRAM CALCULATES THE MOMENT MEASUREMENTS (MEAM, STANDARD DEVIAT
ON, SKEWNESS AND KURTOSIS) OF SEVERAL PARAMETERS (e.
g. Perimeter and Surface area of animals burrows). (M.S.HARIRI, 1988, ZOOLOGY D
PARTMENT)"
60 PRINT:PRINT TAB(5)"(THIS PROGRAM DOES NOT TAKE LESS THAN FOUR READINGS OF DI
METER)"
70 DIM V(1000), V1(1000), P(1000), A(1000),Z(100),Z1(100)
80 FOR I=1 TO 100
90 READ Z(I),Z1(I)
100 NEXT I
110 PRINT:PRINT:PRINT:PRINT
120 INPUT"SITE OR SAMPLE = ",O1$
130 PRINT:INPUT"DATE : ",O$
140 LPRINT"SITE OR SAMPLE = "O1$
150 LPRINT:LPRINT"DATE : "O$
160 LPRINT"------------------------------------------------------------------
--------"
170 PRINT CS$
180 PRINT TAB(5);"SITE OR SAMPLE = "O1$
190 PRINT:PRINT:PRINT
200 INPUT"ENTER NUMBER OF DEPTHS OF SEDIMENT AT WHICH YOU MEASURED THE BURROW :
,D
210 FOR T= 1 TO D
220 PRINT:PRINT:PRINT"INTER YOUR DEPTH  "T
230 INPUT "DEPTH = ",Z$
240 PRINT:INPUT"HOW MANY BURROW YOU MEASURED AT THIS DEPTH = ",N
250 PRINT:PRINT"ENTER the major and minor axes, respectivelly. Press return aft
r each entery."
260 PRINT"(If the major axis equal the minor axis. PUT the same value in both a
es"
270 FOR M= 1 TO N
280 PRINT
290 PRINT TAB(3),M
300 INPUT"THE MAJOR AXIS :",V(M)
310 INPUT"THE MINOR AXIS :",V1(M)
320 NEXT M
330 GOSUB 1200
340 P1=0:A1=0:P2=0:A2=0:P3=0:A3=0:P4=0:A4=0
350 H1=0:H2=0:H3=0:H4=0:M2=0:M3=0:M4=0
360 B1=0:B2=0:C1=0:C2=0:S=0:S1=0
370 FOR M= 1 TO N
380 Z=(((V(M)/2)^2-(V1(M)/2)^2)/((V(M)/2)^2))
390 Z=CINT(Z*100)/100
400 FOR I=1 TO 100
410 IF Z=Z(I) THEN GOTO 430
420 NEXT I
430 P(M)=4*(V(M)/2)*Z1(I)
440 A(M)=(V(M)/2)*(V1(M)/2)*3.14159
450 P1=P1+P(M)
460 A1=A1+A(M)
470 P2=P2+P(M)^2
480 A2=A2+A(M)^2
490 P3=P3+P(M)^3
500 A3=A3+A(M)^3
510 P4=P4+P(M)^4
```

```
520 A4=A4+A(M)^4
530 NEXT M
540 H1=P1/N
550 M1=A1/N
560 M2=(P2-(P1^2/N))/(N-1)
570 H2=(A2-(A1^2/N))/(N-1)
580 S=SQR (M2)
590 S1=SQR (H2)
592 CV=(S*100)/H1
594 CV1=(S1*100)/M1
600 M3=((N*P3)-(3*P1*P2)+(2*(P1^3/N)))/((N-1)*(N-2))
610 H3=((N*A3)-(3*A1*A2)+(2*(A1^3/N)))/((N-1)*(N-2))
620 G=(N*P4)-(4*P1*P3)
630 E=(N*A4)-(4*A1*A3)
640 G1=6*(P1^2)*P2/N
650 E1=6*(A1^2)*A2/N
660 G2=3*(P1^4)/(N^2)
670 E2=3*(A1^4)/(N^2)
680 G3=3*(N-1)*(N-1)/((N-2)*(N-3))
690 E3=3*(N-1)*(N-1)/((N-2)*(N-3))
700 M4=(N+1)*(G+G1-G2)/((N-1)*(N-2)*(N-3))
710 H4=(N+1)*(E+E1-E2)/((N-1)*(N-2)*(N-3))
720 B1=M3/(S^3)
730 C1=H3/(S1^3)
740 B2=(M4/S^4)-G3
750 C2=(H4/S1^4)-E3
760 W1=SQR ((6*N*(N-1))/((N-2)*(N+1)*(N+3)))
770 W2=SQR ((24*N*(N-1)*(N-1))/((N-3)*(N-2)*(N+3)*(N+5)))
780 T1=B1/W1
790 T2=B2/W2
800 K1=C1/W1
810 K2=C2/W2
820 LPRINT:LPRINT TAB(5)"DEPTH = "Z$
830 LPRINT:LPRINT
840 LPRINT TAB(5);"BURROW"; TAB(15);"MAJOR AXIS(mm);" TAB(30);"MINOR AXIS(mm)";
TAB(45);"PERIMETER(mm)"; TAB(60);"SURFACE AREA(mm^2)
"
850 LPRINT:FOR M= 1 TO N
860 LPRINT TAB(7);M, TAB(20);V(M), TAB(35);V1(M), TAB(47);P(M); TAB(62);A(M)
870 NEXT M
880 LPRINT:LPRINT TAB(5);"------"; TAB(18);"-------"; TAB(33);"-------"; TAB(45
;"-----------"; TAB(60);"-------------"
890 LPRINT"TOTAL:"; TAB(7);N, TAB(47);P1, TAB(62);A1
900 LPRINT:LPRINT
910 PRINT CS$
920 PRINT"Do you wish to calculate the statistic measurements of both perimeter
and "
930 PRINT"surface area? Y or N"
940 INPUT F$: IF F$="Y" THEN 950 ELSE END
950 LPRINT:LPRINT"STATISTIC MEASUREMENTS OF PERIMETER (mm) AND SURFACE AREA (mm
2)"
960 LPRINT:LPRINT TAB(10);"MEAN"; TAB(20);"STAN. DEV."; TAB(35);"COEFF. OF VAR.
%)"; TAB(55);"SKEWNESS"; TAB(70);"KURTOSIS"
970 LPRINT
980 LPRINT "(PERIM.)"; TAB(10);H1; TAB(20);S; TAB(35);CV; TAB(55);S1; TAB(70);E2
990 LPRINT"(AREA)"; TAB(10);M1; TAB(20);S1; TAB(35);CV1; TAB(55);C1; TAB(70);C2
1000 LPRINT:LPRINT TAB(10);"TESTING SIGNIFICANCE OF SKEWNESS AND KURTOSIS"
1010 LPRINT:LPRINT TAB(10);"t of skewness of perimeter ="T1
1020 LPRINT TAB(10);"t of kurtosis of perimeter ="T2
1030 LPRINT TAB(10);"t of skewness of surface area ="K1
```

```
1040 LPRINT TAB(10);"t of kurtosis of surface area ="K2
1050 LPRINT:LPRINT
1060 LPRINT TAB(5);"The critical values of t with degree of freedom v=infinity:"
1070 LPRINT:LPRINT TAB(3);"t 0.05=196  t 0.01=2.576 t 0.001=3.291 (Sokal and Rol
hlf 1981 pp 175)"
1080 LPRINT TAB(5);"You can find out where your calculated values of t with the
above critical"
1090 LPRINT TAB(5);"values to give the significance of probability"
1100 LPRINT:LPRINT TAB(5);"Another alternative of testing the significance of sk
ewness and kurtosis"
1110 LPRINT TAB(5);"by using the Snedecor and Cochran method."
1120 LPRINT TAB(5);"(Statistical method, seventh edition 1982) (table 20A page 4
92)"
1130 LPRINT:LPRINT:LPRINT"-------------------------------------------------------
-----------------------"
1140 LPRINT:LPRINT
1150 NEXT T
1160 PRINT CS$:CLEAR
1170 PRINT"DO YOU WISH TO CALCULATE MOMENT MEASUREMENTS FOR ANOTHER SITE OR SAMP
LE? (Y/N)
1180 INPUT Y$: IF Y$="Y" GOTO 70 ELSE END
1190 END
1200 PRINT CS$
1210 PRINT TAB(5);"BURROW"; TAB(15);"MAJOR AXIS(mm)"; TAB(40);"MINOR AXIS(mm)"
1220 PRINT: FOR M =1 TO N
1230 PRINT TAB(7);M; TAB(20);V(M); TAB(45);V1(M)
1240 NEXT M
1250 PRINT TAB(5);"------"; TAB(18);"-------"; TAB(42);"--------"
1260 PRINT:PRINT"DO YOU WISH TO CORRECT YOUR DATA ? Y OR N
1270 INPUT Q$ : IF Q$="Y" GOTO 1290
1280 RETURN
1290 PRINT:PRINT"INPUT ROW, VALUE OF MAJOR AND MONOR AXES, SEPARATE VALUES BY A
COMMA"
1300 INPUT RR,VV,TT
1310 V(RR)=VV:V1(RR)=TT
1320 GOTO 1210
1330 DATA 0.00,1.57080:DATA 0.01,1.56686:DATA 0.02,1.56291:DATA 0.03,1.55895:DAT
A 0.04,1.55497:DATA 0.05,1.55097:DATA 0.06,1.54696:D
ATA 0.07,1.54294:DATA 0.08,1.53889:DATA 0.09,1.53483
1340 DATA 0.10,1.53076:DATA 0.11,1.52667:DATA 0.12,1.52256:DATA 0.13,1.51828:DAT
A 0.14,1.51428:DATA 0.15,1.51012:DATA 0.16,1.50594:D
ATA 0.17,1.50174:DATA 0.18,1.49753:DATA 0.19,1.49329
1350 DATA 0.20,1.48904:DATA 0.21,1.48476:DATA 0.22,1.48047:DATA 0.23,1.47615:DAT
A 0.24,1.47182:DATA 0.25,1.46746:DATA 0.26,1.46309:D
ATA 0.27,1.45869:DATA 0.28,1.45427:DATA 0.29,1.44983
1360 DATA 0.30,1.44536:DATA 0.31,1.44088:DATA 0.32,1.43637:DATA 0.33,1.43183:DAT
A 0.34,1.42727:DATA 0.35,1.42269:DATA 0.36,1.41808:D
ATA 0.37,1.41345:DATA 0.38,1.40879:DATA 0.39,1.40411
1370 DATA 0.40,1.39939:DATA 0.41,1.39465:DATA 0.42,1.38988:DATA 0.43,1.38509:DAT
A 0.44,1.38026:DATA 0.45,1.37540:DATA 0.46,1.37052:D
ATA 0.47,1.36560:DATA 0.48,1.36065:DATA 0.49,1.35566:DATA 0.50,1.35064
1380 DATA 0.51,1.34560:DATA 0.52,1.34052:DATA 0.53,1.33538:DATA 0.54,1.33022:DAT
A 0.55,1.32503:DATA 0.56,1.31979:DATA 0.57,1.31451:D
ATA 0.58,1.30919:DATA 0.59,1.30383:DATA 0.60,1.29843
1390 DATA 0.61,1.29299:DATA 0.62,1.28748:DATA 0.63,1.28194:DATA 0.64,1.27635:DAT
A 0.65,1.27071:DATA 0.66,1.26501:DATA 0.67,1.25926:D
ATA 0.68,1.25346:DATA 0.69,1.24760:DATA 0.70,1.24167
1400 DATA 0.71,1.23568:DATA 0.72,1.22963:DATA 0.73,1.22351:DATA 0.74,1.21732:DAT
A 0.75,1.21106:DATA 0.76,1.20471:DATA 0.77,1.19829:D
ATA 0.78,1.19178:DATA 0.79,1.18518:DATA 0.80,1.17849
1410 DATA 0.81,1.17170:DATA 0.82,1.16480:DATA 0.83,1.15779:DATA 0.84,1.15065:DAT
A 0.85,1.14340:DATA 0.86,1.13600:DATA 0.87,1.12845:D
ATA 0.88,1.12074:DATA 0.89,1.11285:DATA 0.90,1.10478
1420 DATA 0.91,1.09648:DATA 0.92,1.08794:DATA 0.93,1.07912:DATA 0.94,1.06999:DAT
A 0.95,1.06047:DATA 0.96,1.05050:DATA 0.97,1.03995:D
ATA 1.98,1.02850:DATA 0.99,1.01599:DATA 1.00,1.0000
```

Appendix 4.III, table (3)

listing of programme calculating the perimeter and surface area of burrows and their moments using the IBM computer.

```
10 PRINT"THIS PROGRAM CALCULATES THE MOMENT MEASUREMENTS (MEAN, STANDARD DEVIATI
ON, SKEWNESS AND KURTOSIS) OF SEVERAL PARAMETER (e.g. Perimeter and surface are
 of animals burrow). (M.S. HARIRI, 1988, ZOOLOGY DEPARTMENT)"
20 PRINT: PRINT "(THIS PROGRAM DOES NOT TAKE LESS THAN FOUR MEASUREMENTS OF THE
BURROWS"
30 DIM V(2000),V1(2000),P(2000),A(2000),Z(100),Z1(100)
40 FOR I= 1 TO 100
50 READ Z(I),Z1(I)
60 NEXT I
70 PRINT:PRINT:PRINT
80 INPUT"SITE OR SAMPLE :",O1$
90 INPUT"DATE  :",O$
100 LPRINT TAB(5);"SITE OR SAMPLE :"O1$
110 LPRINT TAB(5);"DATE  : "O$
120 LPRINT ;"_____
        "
130 CLS
140 PRINT TAB(5),"SITE OR SAMPLE  : "O1$
150 PRINT:PRINT:PRINT
160 INPUT"ENTER NUMBER OF DEPTHS OF SEDIMENT WHICH YOU MEASURED THE BURROWS =",D

170 FOR T=1 TO D
180 PRINT:PRINT"ENTER YOUR DEPTH  "T
190 INPUT"DEPTH  = ",Z$
200 PRINT:INPUT"HOW MANY BURROWS HAVE YOU MEASURED AT THIS DEPTH = ",N
210 PRINT:PRINT"ENTER the major and minor axes, respectivelly. press INTER afte
each value."
220 PRINT TAB(5);"If the major axis equal the minor axis, PUT the same value in
both"
230 PRINT
240 FOR M= 1 TO N
250 PRINT
260 PRINT"BURROW ";M
270 INPUT"MAJOR AXIS :",V(M)
280 INPUT"MINOR AXIS :",V1(M)
290 NEXT M
300 GOSUB 1170
310 P=0:P1=0:P2=0:P3=0:P4=0:A=0:A1=0:A2=0:A3=0:A4=0:H1=0:H2=0:H3=0:H4=0:M1=0:M2=
0:M3=0:M4=0:S=0
320 FOR M= 1 TO N
330 Z=((V(M)/2)^2-(V1(M)/2)^2)/((V(M)/2)^2)
340 Z=CINT(100*Z)/100
350 FOR I=1 TO 100
360 IF Z=Z(I)  THEN GOTO 380
370 NEXT I
380 P(M)=4*(V(M)/2)*Z1(I)
390 A(M)=(V(M)/2)*(V1(M)/2)*3.141593
400 P1=P1+P(M)
410 A1=A1+A(M)
420 P2=P2+P(M)^2
430 A2=A2+A(M)^2
440 P3=P3+P(M)^3
450 A3=A3+A(M)^3
460 P4=P4+P(M)^4
470 A4=A4+A(M)^4
480 NEXT M
490 M1=P1/N
500 H1=A1/N
510 M2=(P2-(P1^2/N))/(N-1)
```

```
520 H2=(A2-(A1^2/N))/(N-1)
530 S=SQR (M2)
540 S1=SQR (H2)
542 CV=(S*100)/M1
544 CV1= (S1*100)/H1
550 M3=(N*P3-3*P1*P2+2*((P1^3)/N))/((N-1)*(N-2))
560 H3=(N*A3-3*A1*A2+2*((A1^3)/N))/((N-1)*(N-2))
570 G=N*P4-4*P1*P3
580 E=N*A4-4*A1*A3
590 G1=6*(P1^2)*P2/N
600 E1=6*(A1^2)*A2/N
610 G2=3*(P1^4)/N^2
620 E2=3*(A1^4)/N^2
630 E3=(3*(N-1)*(N-1))/((N-2)*(N-3))
640 M4=(N+1)*(G+G1-G2)/((N-1)*(N-2)*(N-3))
650 H4=(N+1)*(E+E1-E2)/((N-1)*(N-2)*(N-3))
660 B1=M3/S^3
670 C1=H3/S1^3
680 B2=(M4/S^4)-E3
690 C2=(H4/S1^4)-E3
700 W1=SQR ((6*N*(N-1))/((N-2)*(N+1)*(N+3)))
710 W2=SQR ((24*N*(N-1)*(N-1))/((N-3)*(N-2)*(N+3)*(N+5)))
720 T1=B1/W1
730 T2=B2/W2
740 K1=C1/W1
750 K2=C2/W2
760 LPRINT:LPRINT TAB(5);"DEPTH  = "Z$
770 LPRINT:LPRINT
780 LPRINT TAB(5);"BURROW";TAB(15);"MAJOR AXIS(mm)";TAB(30);"MINOR AXIS(mm)";TAB
(45);"PERIMETER(mm)";TAB(60);"SURFACE AREA (mm^2)"
790 LPRINT
800 FOR M=1 TO N
810 LPRINT TAB(7);M; TAB(20);V(M); TAB(35);V1(M); TAB(47);P(M); TAB(64);A(M)
820 NEXT M
830 LPRINT:LPRINT TAB(5);"_____"; TAB(45);"_____"; TAB(60);"_____
_____"
840 LPRINT"TOTAL:" TAB(7);N; TAB(47);P1; TAB(64);A1
850 LPRINT:LPRINT
860 PRINT"Do you wish to calculate the statistical measurements of perimeter and
 surface area  of burrow? Y OR N "
870 INPUT F$:IF F$="Y" THEN 880 ELSE END
880 LPRINT"STATISTICAL MEASUREMENTS OF PERIMETER(mm) AND SURFACE AREA (mm^2)"
890 LPRINT
900 LPRINT TAB(10);"MEAN"; TAB(20);"STAN. DEV."; TAB(35);"COEFF. OF VAR.(%)"; TA
B(55);"SKEWNESS"; TAB(70); "KURTOSIS"
910 LPRINT:LPRINT "(PERIM.)"; TAB(10);M1; TAB(20);S; TAB(35);CV; TAB(55);B1; TAB
(70);B2
920 LPRINT "(AREA)"; TAB(10);H1; TAB(20);S1; TAB(35);CV1; TAB(55);C1; TAB(70);C2

930 PRINT:LPRINT
940 LPRINT TAB(10);"TESTING SIGNIFICANCE OF SKEWNESS AND KURTOSIS"
950 LPRINT TAB(5);"Student's t test comparing observed skewness and kurtosis wit
h"
960 LPRINT TAB(5);"the skewness and kurtosis of a normal curve which are both ze
ro"
970 LPRINT TAB(5);"(Sokal and Rohlf 1981, 2nd edition, box 7.4 p174,175; text p1
70."
980 LPRINT TAB(5);"Box 7.1 p139.)"
990 LPRINT:LPRINT TAB(10);"Student's t of skewness of perimeter = "T1
1000 LPRINT:LPRINT TAB(10);"Student's t of kurtosis of perimeter = "T2
1010 LPRINT:LPRINT TAB(10);"Student's t of skewness of surface area = "K1
```

```
1020 LPRINT:LPRINT TAB(10);"Student's t of kurtosis of surface area = "K2
1030 LPRINT:LPRINT
1040 LPRINT TAB(30);"5%, 1% and 0.1% critical values of student's t with d.f.=in
finity:"
1050 LPRINT:LPRINT TAB(3);"Student's  t :     1.960      2.576      3.291"
1060 LPRINT;TAB(3);"Probability  :      0.05       0.01       0.001"
1070 LPRINT:LPRINT TAB(3);"The statistical significance of the observed skewness
 & kurtosis "
1080 LPRINT TAB(3);"can also be tested using Sendecor & Cochran's (1982, 7th edi
tion,"
1090 LPRINT TAB(3);"pp 78-80, and table A20 i,ii p492) method."
1100 LPRINT"_____________________________________________________________________
_______"
1110 CLS
1120 NEXT T
1130 CLS :CLEAR
1140 PRINT:PRINT:PRINT"DO YOU WISH TO CALCULATE STATISTICAL MEASURMENTS FOR ANOT
HER SITE OR SAMPLE ? Y/N"
1150 INPUT Y$: IF Y$="Y" GOTO  30   ELSE END
1160 END
1170 CLS
1180 PRINT TAB(5);"BURROW",TAB(15);"MAJOR AXIS", TAB(30);"MINOR AXIS"
1190 PRINT: FOR M=1 TO N
1200 PRINT TAB(7);M, TAB(20);V(M), TAB(35);V1(M)
1210 NEXT M
1220 PRINT TAB(5);"______", TAB(17);"_______" , TAB(32);"______"
1230 PRINT:PRINT "DO YOU WISH TO CORRECT YOUR DATA Y OR N"
1240 INPUT Q$ :IF Q$ ="Y" GOTO 1260
1250 RETURN
1260 PRINT"INPUT ROW,NEW VALUE OF THE MAJOR AND MINOR AXES, SEPARATE VALUES BY A
 COMMA"
1270 INPUT RR,VV,TT
1280 V(RR)=VV:V1(RR)=TT
1290 GOTO 1170
1300 DATA 0.00,1.57080:DATA 0.01,1.56686:DATA 0.02,1.56291:DATA 0.03,1.55895:DAT
A 0.04,1.55497:DATA 0.05,1.55097:DATA 0.06,1.54696:DATA 0.07,1.54294:DATA 0.08,1
.53889:DATA 0.09,1.53483
1310 DATA 0.10,1.53076:DATA 0.11,1.52667:DATA 0.12,1.52256:DATA 0.13,1.51828:DAT
A 0.14,1.51429:DATA 0.15,1.51012:DATA 0.16,1.50594:DATA 0.17,1.50174:DATA 0.18,1
.49753:DATA 0.19,1.49329
1320 DATA 0.20,1.48904:DATA 0.21,1.48476:DATA 0.22,1.48047:DATA 0.23,1.47615:DAT
A 0.24,1.47182:DATA 0.25,1.46746:DATA 0.26,1.46309:DATA 0.27,1.45869:DATA 0.28,1
.45427:DATA 0.29,1.44983
1330 DATA 0.30,1.44536:DATA 0.31,1.44088:DATA 0.32,1.43637:DATA 0.33,1.43183:DAT
A 0.34,1.42727:DATA 0.35,1.42269:DATA 0.36,1.41808:DATA 0.37,1.41345:DATA 0.38,1
.40879:DATA 0.39,1.40411
1340 DATA 0.40,1.39939:DATA 0.41,1.39465:DATA 0.42,1.38988:DATA 0.43,1.38509:DAT
A 0.44,1.38026:DATA 0.45,1.37540:DATA 0.46,1.37052:DATA 0.47,1.36560:DATA 0.48,1
.36065:DATA 0.49,1.35566:DATA 0.50,1.35064
1350 DATA 0.51,1.34559:DATA 0.52,1.34051:DATA 0.53,1.33538:DATA 0.54,1.33022:DAT
A 0.55,1.32503:DATA 0.56,1.31979:DAT 0.57,1.31451:DATA 0.58,1.30919:DATA 0.59,1.
30383:DATA 0.60,1.29843
1360 DATA 0.61,1.29298:DATA 0.62,1.28748:DATA 0.63,1.28194:DATA 0.64,1.27635:DAT
A 0.65,1.27071:DATA 0.66,1.26501:DATA 0.67,1.25926:DATA 0.68,1.25346:DATA 0.69,1
.24760:DATA 0.70,1.24167
1370 DATA 0.71,1.23568:DATA 0.72,1.22963:DATA 0.73,1.22351:DATA 0.74,1.21732:DAT
A 0.75,1.21106:DATA 0.76,1.20471:DATA 0.77,1.19829:DATA 0.78,1.19178:DATA 0.79,1
.18518:DATA 0.80,1.17849
1380 DATA 0.81,1.17170:DATA 0.82,1.16480:DATA 0.83,1.15779:DATA 0.84,1.15065:DAT
A 0.85,1.14340:DATA 0.86,1.13600:DATA 0.87,1.12845:DATA 0.88,1.12074:DATA 0.89,1
.11285:DATA 0.90,1.10478
1390 DATA 0.91,1.09648:DATA 0.92,1.08794:DATA 0.93,1.07912:DATA 0.94,1.06999:DAT
A 0.95,1.06047:DATA 0.96,1.05050:DATA 0.97,1.03995:DATA 0.98,1.02859:DATA 0.99,1
.01599:DATA 1.00,1.00000
```

Appendix 4.III, table (4)

Run of computer programme calculating the perimeter and surface area of burrows and their statistical measurements.

SITE OR SAMPLE :MODEL
DATE : 3-11-88

DEPTH = 5CM

BURROW	MAJOR AXIS(mm)	MINOR AXIS(mm)	PERIMETER(mm)	SURFACE AREA (mm^2)
1	1	1	3.1416	.7853983
2	6	4	15.83748	18.84956
3	3.5	3.5	10.9956	9.621128
4	1	1	3.1416	.7853983
5	2.5	2.5	7.854	4.908739
6	1	1	3.1416	.7853983
7	.5	.5	1.5708	.1963496
8	.75	.75	2.3562	.4417866
9	7	6	20.42166	32.98673
10	1	1	3.1416	.7853983
11	.5	.5	1.5708	.1963496
12	1	1	3.1416	.7853983
13	1	1	3.1416	.7853983
14	4.5	2	10.60641	7.068585
15	1	1	3.1416	.7853983
16	.5	.5	1.5708	.1963496
17	4.5	2	10.60641	7.068585
18	1	1	3.1416	.7853983
19	3	3	9.4248	7.068585
20	2	2	6.2832	3.141593
21	2	2	6.2832	3.141593
22	1.5	1.5	4.7124	1.767146
23	3	3	9.4248	7.068585
24	2	2	6.2832	3.141593
25	2	2	6.2832	3.141593
26	1.5	1.5	4.7124	1.767146
27	1	1	3.1416	.7853983
28	6.5	6.5	20.4204	33.18308
29	4.5	4.5	14.1372	15.90431
30	1	1	3.1416	.7853983
TOTAL: 30			202.771	168.7134

STATISTICAL MEASUREMENTS OF PERIMETER(mm) AND SURFACE AREA (mm^2)

	MEAN	STAN. DEV.	COEFF. OF VAR.(%)	SKEWNESS	KURTOSIS
(PERIM.)	6.759032	5.296063	78.35534	1.363912	1.223947
(AREA)	5.623779	8.744282	155.4877	2.374281	5.288746

TESTING SIGNIFICANCE OF SKEWNESS AND KURTOSIS

Student's t test comparing observed skewness and kurtosis with the skewness and kurtosis of a normal curve which are both zero (Sokal and Rohlf 1981, 2nd edition, box 7.4 p174,175; text p170. Box 7.1 p139.)

Student's t of skewness of perimeter = 3.194979

Student's t of kurtosis of perimeter = 1.469773

Student's t of skewness of surface area = 5.561779

Student's t of kurtosis of surface area = 6.350975

5%, 1% and 0.1% critical values of student's t with d.f.=infinity:

Student's t :	1.960	2.576	3.291
Probability :	0.05	0.01	0.001

The statistical significance of the observed skewness & kurtosis can also be tested using Sendecor & Cochran's (1982, 7th edition, pp 78-80, and table A20 i,ii p492) method.

As shown in the table the value of m is given to two significant figures after the decimal point. However, the calculation of m using the computer gives more than two significant figures after the decimal point. Three different functions can be used to round the value of m to two significant figures - CINT,INT and STR$.

I chose the CINT function in the COMART and IBM computers (line 390-420 and 340-370, respectively), and the INT function in the BBC computer (line 375-410) for picking up the value of m (which is Z(I) in the program). The reason for using these two functions without using the STR$ function is because the space taken by these two functions is less than the space taken by the STR$ function. Also the reason for using different functions in the three computers is because the CINT function is not available in the BBC computer. The use of these functions in the program is as follows.

1- CINT function

This function rounds the value of x to obtain an integer. For example, if x = 3.556532.

Then using CINT x = 4

But we do not want our value to be the integer value because the value of m has two decimal places. The value of m was therefore multiplied by 100 to obtain a percentage. This percentage was integered using CINT and then divided by 100 to convert it back to the required value of m having two significant figures after the decimal point.

For example, if m = 0.555642, then the following procedure was used:

```
m = 0.555642
m = CINT (m*100)/100
m = 0.56
```

2- INT function

This function converts the real number to the lower integer without rounding the value, thus:

```
If x = 2.55635. Then using INT command.
  x = 2
```

Here, the same method was used as the CINT function but adding 0.005 to the actual value of m before using the function. This statement will add one to the second decimal place if the number in the third decimal place is more than 5. As previously, if m= 0.555642, then:

```
m = 0.555642
m = m + 0.005
m = INT (m*100)/100
m = 0.56
```

3- STR$ function

This function is used to convert the numeric value to a string value and then pick up the desired value of m. The value of m converts firstly to a string value and then pick up only two decimal places by using the LEFT (A$,4) function. This function allows the computer to pick up only two decimal places of the value of m. Then the string value of m converts to a numeric value using VAL function.

For example, if m = 0.555642, then.

```
  m = 0.555642
A$ = STR$ (m)
A$ = LEFT (A$,4)
  m = VAL (A$)
  m = 0.55
```

This incorrect, m should be 0.56 not 0.55. Therefore, the same method used with the INT function, of adding 0.005 to the value of m before using the function, also used:

```
m = 0.556542
m = m + 0.005
A$ = STR$ (m)
A$ = LEFT (A$,4)
m = VAL (A$)
m = 0.56
```

Adding 0.005 caused a problem if the value of m=0. The computer will give the value of m = 4.99 when it converts this figure to the string value, thus:

```
m = 0
m = 0 + 0.005
m = 0.005
A$ = STR$(m)
m = 4.99
```

This value is not the correct value of the actual m. Another statement was therefore added to allow the computer to jump the line of adding 0.005, if the value of m = 0 as follows:

```
20  m = m + 0.005
30 If m=0 then goto 50 else 40
40 m = m + 0.005
50 A$= STR$ (m)
60 A$= LEFT (A$,4)
70 m = VAL (A$)
```

==========

The equations for the calculation of the burrow perimeter and surface area are given in lines 420-430 in the BBC, lines 430-440 in the COMART and lines 380-390 in the IBM. The equations calculate the perimeter and the surface area of the burrow using major and minor axes measurements.

The computer then calculates the moment measurements of the burrow perimeter and surface area from lines 440 to 800 in the BBC, lines 450-810 in the COMART and lines 400-750 in the IBM.

A student's t test is also calculated in the program for the skewness and kurtosis of the burrow perimeter and surface area. This test is given in lines 1030-1190 in the BBC, lines 1000-1120 in the COMART and lines 940-1090 in the IBM.

The following tables show the variables of the program and the standard notations of the burrow perimeter and surface area and their statistical measurements with the equivalent notations used in the three computers.

Appendix 4.III, table (5)

Variables of different parameters.

Variables	Standard notation	Computer notation
Total number of burrows	n	N
Major and minor axes of each burrow.	A1,A2	V(M),V1(M)*
Perimeter of each burrow	P=4*(A1/2)*E(ε)	P(M)=4*(V(M)/2)*Z1(I)
Surface area of burrow	S= π*(A1/2)*(A2/2)	A(M)=(V(M)/2)*(V1(M)* π
Sum of individual items	ΣY	Perim.= P1= P1+P(M) Area = A1= A1+A(M)
Sum of squares of individual items	ΣY^2	Perim.=P2=P2+P(M)² Area =A2=A2+A(M)²
Sum of cube of individual items	ΣY^3	Perim.=P3=P3+P(M)^3 Area =A3=A3+A(M)^3
Sum of fourth power of individual items	ΣY^4	Perim.=P4=P4+P(M)^4 Area =A4=A4+A(M)^4

* This means that the burrow diameters are stored in columns and rows. Note that in the list of the program in the BBC computer (pp 45) at line 60, there is a dimension statement for the array V; I have allowed for a maximum of 70 observations. Most programs commonly use either X(I) or X(J) to mean Xi or Xj, but I have used V(M),that is Vm, which performs the same function as X(I) or X(J). i, j and m are integer counters.

Appendix 4.III, table (6)

The standard and computer notations of the moment measurements.

Variables	Standard notation	Computer notation
Mean	$Y = \Sigma Y/n$	Perim.= M1= P1/N Area = H2= A1/N
Variance	$S^2 = \frac{\Sigma Y^2 - (\Sigma Y)^2/n}{(n-1)}$	Perim.= M2=(P2)(P1)²/N)/(N-1) Area = H2=(A2)(A1)²/N)/(N-1)
Standard deviation	$s = \sqrt{v}$	Perim. = S= SQR (M2) Area = S1 = SQR (H2)
Coefficient of variation (%)	cv= s(100)/Y	Perim.= CV= (S*100)/M1 Area =CV1= (S1*100)/H1
Skewness	$g_1 = \Sigma(Y - Y)^3 / n\, s^3$	Perim.=M3=(N*P3)3*P1*P2+(2*(P1)3/N)/(N-1)(N-2) =B1= M3/ S3 Area=H3=(N*A3)3*A1*A2+(2*(A1)3/N)/(N-1)(N-2) =C1= H3/ S13
Kurtosis	$g_2=\Sigma(Y\ Y)^4/n\, s^4 -3$	Perim.= M4=(N+1)*(G+G1)G2)/(N-1)(N-2)(N-3) Where, G=(N*P4))(4*P1*P3) G1=(6*(P1)²*(P2/N)) G2=(3*(P1)4/N² B2=(M4/S4) -G3 Where, G3=3*(N-1)²/(N-2)(N-3) Area=H4=(N+1)*(E+E1+E2)/(N-1)(N-2)(N-3) Where, E=(N*A4))(4*P1*P3) E1=(6*(A1)²*(A2/N)) E2=(3*(P1)4/N² C2=(H4/ S4))E3 Where E3=3*(n-1)²/(n-2)(n-3)
Testing significance of skewness and kurtosis.		
Student's t of skewness = $\frac{g_1 - \Gamma_1}{Sg_1}$ Where, $Sg_1 = \sqrt{6n\,(n-1)/(n-2)(n+1)(n+3)}$		Student's t of skewness Perimeter T1= B1 /W1 Area K1= C1 /W1 Where, W1 = Sg_1
Student's t of kurtosis = $\frac{g_2 - \Gamma_2}{Sg_2}$ Where, $Sg_2 = \sqrt{24n\,(n-1)^2/(n-3)(n-2)(n+3)(n+5)}$ W2 = Sg_2 Γ_1 and Γ_2 = 0 for the normal distribution.		Student's t of kurtosis Perimeter T2= B2/ W2 Area K2= C2/W2 Where,

Appendix 4.III, table (7)

The commands of different variables used in the three computers.

Variables	Commands		
	BBC	COMART	IBM
Clear the screen	CLS	CHR$=CHR$(126)+CHR$(28) *1 PRINT CS$	CLS
Send the data to print in the printer	VDU2	LPRINT	LPRINT
Print the data on the screen	PRINT	PRINT	PRINT
Stop printing the data in the printer	VDU3	-	-

*1 This line has the function of clearing the screen of characters. This helps to clarify the sequence of instructions on the screen, since the next set of characters begins at the top of the screen.

VDU2 is a command which allows the printer to print any thing after that line. To stop printing, command VDU3 will stop sending items to the printer.

LPRINT, PRINT These two commands send a message to print the structures written to the printer and the screen, respectively. These commands do not need another command to stop the printing because the order will stop automatically at the end of the line. This only occurs in the Comart and IBM computers.

Appendix 4.III, table (8)

The following commands used in the design of the program for reading the stored values of the E(m) to calculate the perimeter of burrows using the three computers.

Items	Commands	
	FOR I=1 TO 100	
1	READ Z(I),Z1(I)	
	NEXT I	
	Z2=(V(m)/2-v1(m)/2)/(v(m)/2)^2	For BBC computer
2	Z2=CINT(Z2*100)/100	Z2=Z2 + 0.005
		Z2=INT(Z2*100)/100
	FOR I=1 TO 100	
3	IF Z(I)=Z2 THEN GOTO	
	P(M)=4*(V(M)/2)*Z1(I)	

1- This command allows the computer to read the stored data ofm (as Z(I)) and E(m) (as Z1(I)) and put both into the memory.

2- This conversion functions as previously described.

3- This allows the computer to pick up the value of Z(I) related to the calculation of the value Z2. The computer will then read the opposite value of Z1(I) related to the value of Z(I) and put it in the calculation of the burrow perimeter.

APPENDIX 4.IV

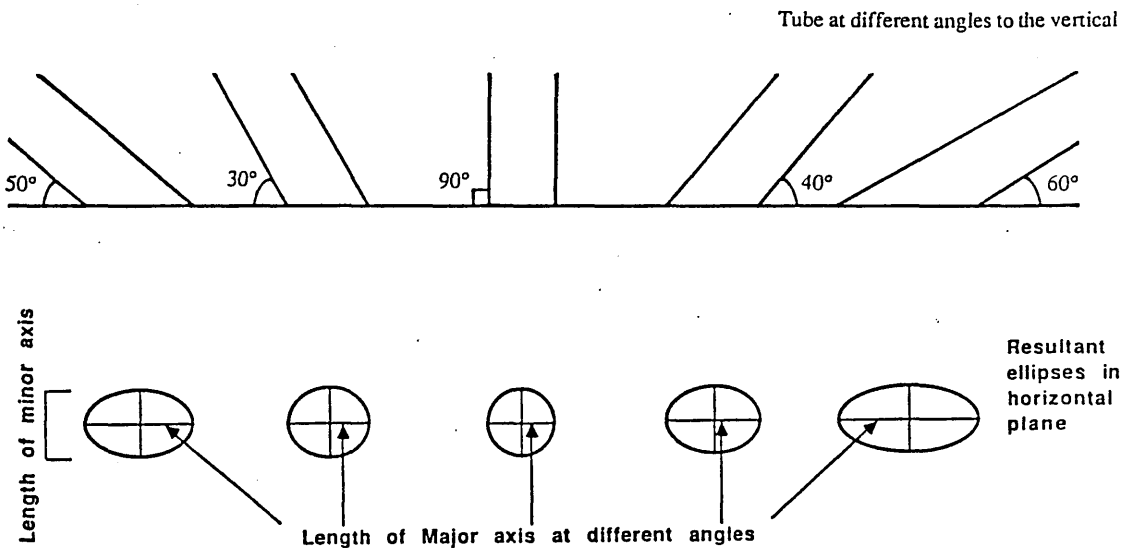
The model constructed of the bioturbation at different sediment depths (figure 4.1) shows that some of the burrows were elliptical rather than circular. This posed the question: what is the relationship between the horizontal cross-section and the angle of burrows running through the sediment? The following description answers this question.

If a tube is standing vertically, its horizontal cross- section will be circular. On the otherhand, when the tube is not standing vertically, different elliptical shapes will be obtained (appendix 4.IV, figure 1).

To obtain the relationship between the angle of a burrow running non-vertically in the sediment and its horizontal cross-section, three diagrams were drawn (appendix 4.IV, figure 2). These diagrams were drawn as tubes of the same diameter (3cm) put at different angles to the horizontal cross section (40°, 60° and 80°, respectively). From these diagrams, the major and minor axes were found as follows.

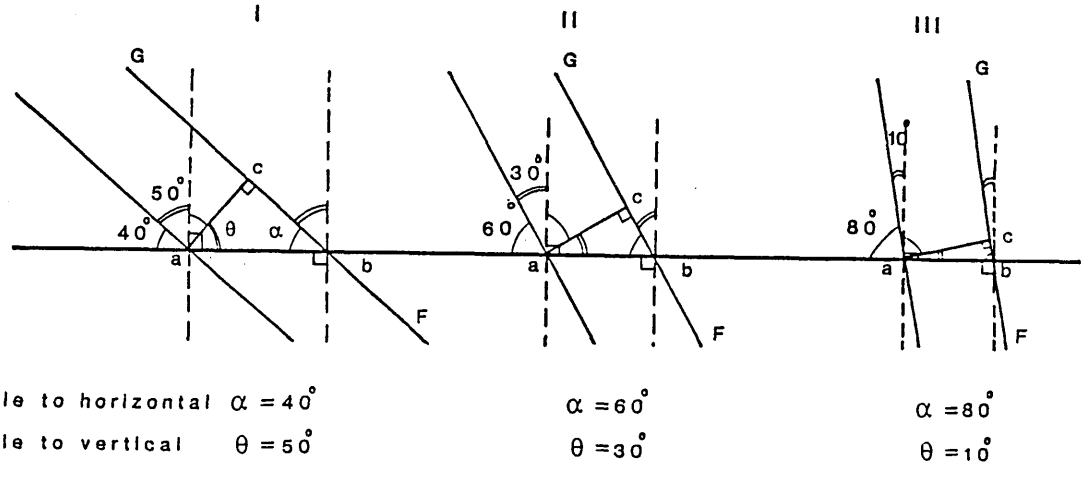
The line (ac) was drawn from point (a) perpendicular onto the line (FG) to point c in appendix 4.IV, figure 2 (I, II and III). This line equals the diameter of the tubes (3cm). Three right triangles (abc) were hence obtained with different angles of θ and α.

The diameter of tube is known (3cm). This is the minor axis of the ellipse. The angles to the horizontal (α) are 40° ,60° and 80°, and hence the angles to the vertical (θ)



Appendix 4.IV, figure (1)

Cross section showing form of burrows cut at different angles to the horizontal.



Appendix 4.IV, figure (2)

Three diagrams (I, II and III) of burrows with the same diameters standing at different angles (80°, 60° and 40°) to the horizontal. Angle to horizontal = 90° - angle to vertical.

are 50°, 30° and 10°. The hypotenuses (ab), which are the major axes of the ellipses, were then determined using the cos and sin equations. For example, in appendix 4.IV, figure 1 diagram I,

The angle of α = 40° and ac = 3cm

$$\sin \alpha = ac / ab$$
$$ab = 3 / \sin 40$$

Then ab = The major axis = 4.66cm

These calculations of the major and minor axes are essential because the calculation of the surface area and the perimeter of a horizontal cross-section of a non-vertical burrow depend on knowing them.

The ratios of major axis to the minor axis were calculated (appendix 4.IV, table 1). The appendix table shows that as the angles to the horizontal axis decreased (column 5), the ratios of the major axis to the minor axis increase (column 1), . This relation is not linear (figure 4.3). Therefore, the ratios of major axis to the minor axis and the angles, were transformed using ln, log10 and square root transformations (appendix 4.IV, table 1) to obtain the best fit straight line. The best transfomation was ln. This can be seen by comparing the correlation coefficients of linear regressions given in appendix 4.IV, table 2 and graphs given in appendix 4.IV, figure 2.

Appendix 4.IV, table (1)

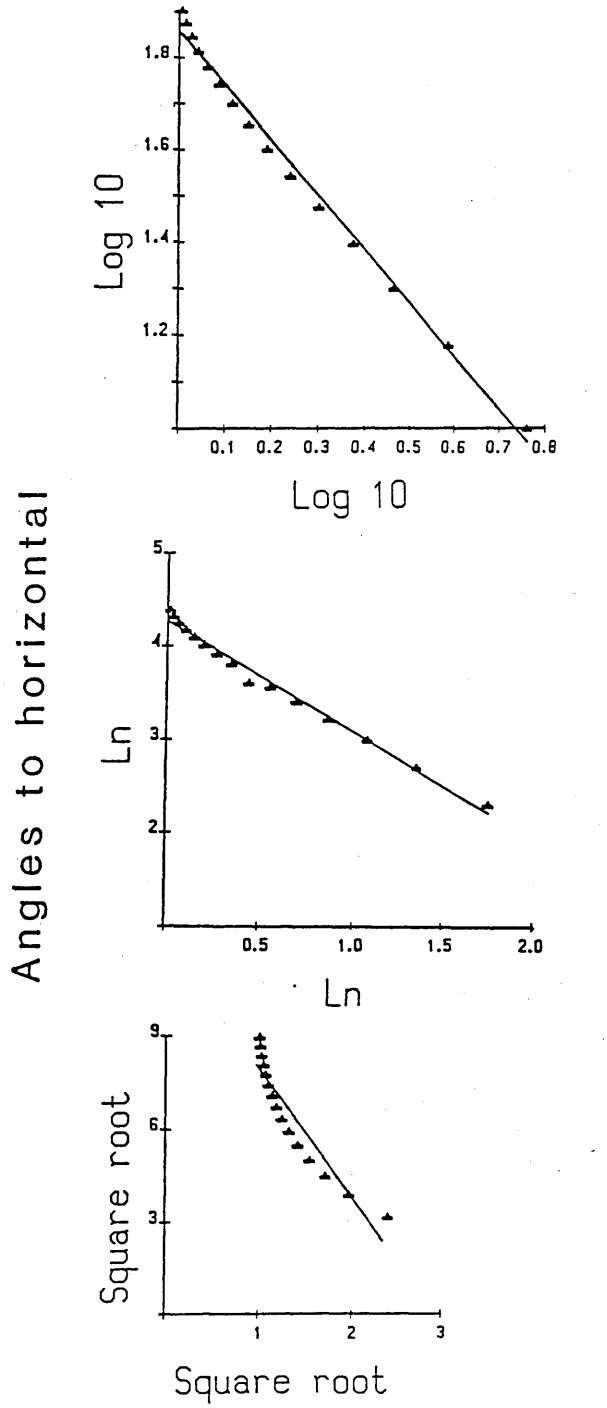
The untransformed and transformed (log_{10}, ln and square root (SR)) data of the ratios of the major axis to the minor axis (x) with the untransformed and transformed data of different angles (y) to the horizontal.

Ratio of major to minor axis (x)				Angle to horizontal (y)			
x	$Log_{10}(x)$	Ln(x)	SR(x)	y	$Log_{10}(y)$	Ln(y)	SR(y)
1.0154	0.0066	0.0153	1.0077	80	1.9031	4.3820	8.9443
1.0353	0.0151	0.0347	1.0175	75	1.8751	4.3175	8.6603
1.0642	0.0270	0.0622	1.0316	70	1.8451	4.2485	8.3666
1.1034	0.0427	0.0984	1.0504	65	1.8129	4.1743	8.0623
1.1547	0.0625	0.1438	1.0746	60	1.7782	4.0944	7.7460
1.2208	0.0866	0.1995	1.1049	55	1.7404	4.0073	7.4162
1.3054	0.1157	0.2665	1.1425	50	1.6990	3.9120	7.0711
1.4142	0.1505	0.3466	1.1892	45	1.6532	3.8067	6.7082
1.5557	0.1919	0.4419	1.2473	40	1.6021	3.6021	6.3246
1.7435	0.2414	0.5559	1.3204	35	1.5441	3.5554	5.9161
2.0000	0.3010	0.6931	1.4142	30	1.4771	3.4012	5.4773
2.3662	0.3741	0.8613	1.5383	25	1.3979	3.2189	5.0000
2.9238	0.4659	1.0729	1.7099	20	1.3010	2.9957	4.4721
3.8637	0.5870	1.3516	1.9656	15	1.1761	2.7081	3.8729
5.7588	0.7603	1.7507	2.3998	10	1.0000	2.3026	3.1623

Appendix 4.IV, table (2)

The correlation coefficient equations and the regression of the ratios of the major to the minor axis compared with the different angles to the horizontal using different transformations.

Comparison of ratio and angle		Regression equation	Correlation coefficient
Untransformed data		Y= -13.9133 X + 72.386	- 0.8242
Transformed data	ln	Y= -1.2449 X + 4.2945	- 0.9961
	$\log_{10}$	Y= -1.1760 X + 1.8558	- 0.9949
	Square root	Y= -4.1579 X + 12.0832	- 0.9355



Appendix 4.III, figure (3)

Plot of transformed data of the ratios of the major to the minor axis against the transformed different angles to the horizontal using ($\log_{10}$, ln and square root transformations).

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