Mid to Late Holocene Changes in the Environment, Sedgemoor Valley, Somerset Levels, UK

Cathrine P. Eales

A thesis submitted in partial fulfilment of the requirements of the University of the West of England, Bristol for the degree of Doctor of Philosophy at Bath Spa University College

Quaternary Research Unit
Department of Geography
School of Science and the Environment, Bath Spa University College

February 2005

Acknowledgements

There are many people who have supported me throughout this research in different ways and to whom I am indebted. Firstly, my most sincere thanks go to my Director of Studies, Dr Simon Haslett. Simon has been a constant source of guidance and encouragement throughout this work and without his infectious enthusiasm and total support it would not have been completed. My second supervisor, Dr Paul Davies, has helped me both with fieldwork and in review of the work for which I am grateful and Dr Julie Jones kindly assisted with the plant macrofossils. I would also offer my thanks to all the landowners of the study sites who have allowed me access to their land.

Personally, I would like to acknowledge the love and support I have always received from my sister Jackie, for which I am forever grateful. I also send my love and thanks to my mum and dad for their support. Lastly, my thanks and love always, go to my husband Robert who has supported and encouraged me through the bad times when giving up would have been easy, he's even been seen with a soil auger in his hand, and now on completion he deserves a share of the recognition. Here's to many good times to come sweetheart!

Contents

Figures

Tables

Abstract

The mid to Late Holocene environmental development of the Sedgemoor Valley, Somerset Levels is examined using a multidisciplinary approach involving lithostratigraphy, biostratigraphy and radiocarbon dating. Three sites along a transect of the valley and one in the Bristol Channel are studied producing a temporal and spatial model of its palaeoenvironmental development.

A common red clay is seen in all three sites which has been interpreted as a palaeosol and its surface varies between –1.33 m OD and 6.2 m OD mantling the bedrock topography. Lithostratigraphic evidence indicates the red palaeosol was inundated by mid Holocene sea level rise as it is overlain by a blue clay that contains marine foraminifera. The surface of this blue marine clay varies in altitude between –1.14 m OD and 5.51 m OD, above which a peat deposit occurs demonstrating a marine regression and a change to freshwater conditions. Radiocarbon analysis has been carried out on five peat samples immediately above the clay-peat contact to date the marine regression. They vary from between 6920 and 6450 cal. yrs BP at a altitude of –0.87 m OD and 4795 and 4170 cal. yrs BP at 4.71 m OD. This study supports previous research suggesting that the peat began to form at a low altitude and subsequently extended vertically and laterally to cover the exhumed clay surface.

The peat deposit initially contains *Phragmities* and then becomes either detrital or *turfa* in nature up core. The detrital peat contains freshwater

molluscs indicating that large lake-like fringing waterbodies persisted in the valley for much of the late Holocene. Later the influence of humans is seen in the lithostratigraphy as drainage works become evident, marked by a change from organic to more minerogenic deposition. A saltmarsh at Stert is studied to examine the current intertidal area, and to calibrate and partially fill the gap in the stratigraphical record between the end of the peat samples in the valley and today.

Chapter 1 Introduction

Wetlands have long been the subject of research into Holocene palaeoenvironments as they are associated with deposits that can yield biostratigraphic, lithostratigraphic and archaeological evidence. This evidence may be used to reconstruct past environments (Godwin 1941, 1943, 1948, 1955; Birks 1986; Simmons 1981). The development of coastal wetlands, including saltmarshes in the temperate areas, are influenced by many factors, including the amount of sediment within the natural system, the tidal regime in which they occur and human agency (Allen, 2000a). They can be also be affected by relative sea level change, comprising eustasy, which is a change in absolute sea level and by vertical movements in the land surface, a phenomenon known as isostasy. During a glacial stage the oceans are depleted of water which is stored as continental ice resulting in `glacio-eustasy` (Dawson 1992, Lowe and Walker 1997). At the same time, this weight of ice on the land, may cause the land to isostatically subside i.e. `glacio-isostasy` (Walcott 1970; Gehrels *et al* 1996; Dawson and Smith 1998; Haslett 2000). Many authors consider relative sea level change to be the main influence in coastal wetland evolution throughout most of the Holocene (Knighton *et al* 1991, Pethick 1992) up until the historic period when human agency becomes an important determining factor (Allen 2000). For this reason, it is important to consider the Holocene relative sea level context of the Somerset Levels in southwest Britain.

Throughout the Holocene Epoch, which began around 10,000 years ago, land-levels have been subject to glacio-isostatic adjustments as the ice of the last glaciation (the Late Devensian in Britain) has receded (Lambeck 1995). In many areas these adjustments can still be seen occurring within coastal wetlands today (Shennan and Horton, 2002). Isostatic subsidence strongly influences the development of coastal wetlands as it enhances post glacial sea level rise, while isostatic uplift can counteract it leading to coastal uplift.

1.1 Models of Post Glacial Shorelines

Global models of isostatic rebound have been proposed to help in the understanding of historic coastlines (e.g. Shotton 1967, 1977a, 1977b; Boulton 1967, 1968, 1972a, 1974; Sissons 1966, 1967a, 1967b, 1972, 1974c, 1976, 1979b, 1981). Recently Lambeck (1993,1995) explained that by about 6000 yrs BP the majority of the deglaciation from the last glaciation had been completed and, with the exception of Greenland, the large ice sheets that had dominated the Northern hemisphere had disappeared. He considers that changes in sea level after this time are a consequence of the ongoing adjustments of the Earth to the redistribution of the ice and water loads, explained earlier as glacio-isostasy. Lambeck (1993,1995) estimates it would be unlikely that the ice thickness over Great Britain would have exceeded 1500m at the time of the Last Glacial Maximum (LGM) while over Fennoscandia an ice thickness of 2500m is estimated. Lambeck (1993,1995) concludes that his results are of a preliminary nature and they point to a need for improved observational data from key sites, for example, those that are more tectonically stable. The sea level curve for southwest Britain produced by Lambeck's (1993) model is included at Fig. 1.10.

A further model was created by Peltier (1998) who aimed to examine global postglacial variations and study the isostatic response to changes in the load.

The model involved equations to generate values for rigidity and viscosity and used sea level data from fossil shorelines as a constraint. Peltier (1998) examined radiocarbon dated histories of shoreline change and also the information of globally averaged sea level from oxygen isotope stratigraphies in deep sea sediment cores. He found that the viscous relaxation of the mantle and crust still continues and that this contributes to modern sea level change.

1.2 North West Europe

Since the LGM around 18,000 years ago the environment in northwest Europe has been re-adjusting to the atmospheric warming and the subsequent melting of the ice sheets. The raised shorelines of Fennoscandia have been widely researched to produce details of proposed past coastlines (Denton and Hughes 1981, Dawson 1992). The general shape of uplift for this area is elliptical therefore it is functioning separately from other known areas of uplift in northwest Europe (Dawson 1992). Morner (1979) estimated the total uplift for the Fennoscandian area was as much as 830 m since the last glacial maximum (Fig. 1.1). Scotland has an area of uplift that will be discussed in section 1.3.

Many other sites in Northwest Europe have been examined to establish land-sea changes through the Holocene period and these include studies in Belgium where Baeteman (1985, 2002) studied the sedimentary sequences of the Belgian coastal lowlands to establish the Holocene sea level history. Results have shown the rapid increase in sea level in the period before 7500 cal. yrs BP[1] and a progressive landward movement of the depositional environment (Baeteman

[1] Throughout this thesis uncalibrated will appear as ^{14}C yrs BP and calibrated dates as cal. yrs BP

2002). Psuty *et al* (2000) undertook a similar study examining the sediments of the Holocene in the Sado Estuary, Portugal. They found a high rate of relative sea level rise until around 2600 yrs BP, after which the rise continued but slowed in pace.

This figure has been removed from the digitized thesis for copyright reasons.

Fig. 1.1 The uplift cone of Fennoscandia surrounded by a subsidence trough (from Morner 1979)

Since the early 1970's, Morner has been working to develop regional eustatic information for northwest Europe and the North Sea area which he sees as `an immense sea level laboratory' in which different ideas and approaches may be experimented (Morner 1980). Morner (2000) argued that there is agreement and correlation between the eustatic records for southwest Sweden, northern Norway and northwest England. He goes on to say that prior to 6000 years BP the eustatic sea level rise was dominated by glacial eustatic rise but that after 5000 years BP the main ocean circulations become more important for the redistribution of water in the area.

Shennan (1983) examined the Holocene and Late Devensian sea level changes and crustal movements in the North Sea Region. The published sea level data and methods used of the time were reviewed and approaches to providing reliable correlation across regions were examined. He concluded the process of analysing regional sea level change is significantly enhanced by using sea level index points with known sea level tendency and indicative meaning. He proposed that further research would be necessary to combine all the relevant data into a data bank. This initial work was later developed further in Shennan (1989) and Shennan and Horton (2002) and is discussed in more detail in section 1.3.

1.3 The British Isles

The ice of the last glacial maximum in Britain is shown at Fig. 1.2. The areas of the country still undergoing uplift and subsidence in adjustment to the retreat of the Devensian ice sheets are shown at Fig. 1.3.

This figure has been removed from the digitized thesis for copyright reasons.

Fig. 1.2 Ice thickness at the LGM in Britain (from Lowe and Walker 1997)

This figure has been removed from the
digitized thesis for copyright reasons.

Fig. 1.3 Late Holocene land and sea-level changes (mm yr^{-1}). Positive values indicate relative land uplift or sea-level fall, negative values are relative land subsidence or sea-level rise. Contours are drawn by eye as a summary sketch of the spatial change (from Shennan and Horton 2002)

Shennan and Horton (2002) produced a new model of land and sea level changes in Great Britain (Fig. 1.3). This updated Shennan (1989) to include advances in the quality and quantity obtained in the intervening period. They analysed more that 1200 dated sea level index points that had been gathered into a data bank from 52 locations in Great Britain. Shennan and Horton (2002) argue that maximum relative land uplift occurs in central and western Scotland where land is rising by 1.6 mm yr^{-1}. Concurrently the maximum subsistence is in southwest England where land is subsiding by 1.2 mm yr^{-1}. Shennan and Horton (2002) went on to say that sediment consolidation from autocompaction in areas of thick Holocene sequences and where land drainage has occurred could increase subsidence in these areas by an average equivalent of an extra 0.2 mm yr^{-1}.

Many studies have been carried out in these areas of the British Isles to establish the rates and amount of change in the level of the land and the sea throughout the Holocene. Some of these studies are outlined here.

1.3.1 Areas of isostatic uplift throughout the Holocene

Most areas to the north of the country are characterised by a marine regression since the start of the Holocene as the area under the weight of the ice sheet began to uplift readjusting to its melting. Sissons (1983) examined the shoreline changes through isostatic effects throughout Scotland. He examined raised features that remained from late glacial shorelines and based on information from several locations dated the maximum of the marine regression to around 9000 yrs BP. This was followed by a period of marine transgression as the isostatic rebound became outpaced by eustatic rise. Sissons (1983) estimates this transgression culminated at 6850 ^{14}C yrs BP and since then the isostatic element has become more dominant with a fall to the level observed today.

Further studies in Scotland were undertaken by Shennan *et al* (1994) who carried out a multidisciplinary approach to examining relative sea level changes at Loch nan Eala, near Arisaig, northwest Scotland throughout the Late Devensian and the Holocene. They examined the sediments in isolation basins in an attempt to establish a precise history of northwest Scotland which they say differed from previous approaches that had focussed on raised morphological features (Sissons 1966, 1967, 1983; Sissons and Dawson 1981; Dawson 1980, 1984). Shennan *et al* (1994) argued that relative sea level fell continuously from 17.8 m OD at 11,800 ^{14}C yrs BP to 5.2 m OD at 10,100 ^{14}C yrs BP. The minimum sea level occurred between 10,000 and 9000 yrs BP and rose to 6.3 m OD at 8300 ^{14}C yrs BP. The maximum sea level occurred in the range of 6.6 m OD and 9.3 m OD in the period between 6600 and 4000 yrs BP. Shennan *et al* later went on to examine other isolation basins in the area (Shennan *et al* 1996).

In a further study in an area of uplift Lloyd *et al* (1999) examined Holocene relative sea level changes in the Inner Solway Firth. They examined biostratigraphy and lithostratigraphy at four sites along the estuary and established eleven new sea level index points. Their work showed a consistent pattern of rapid relative sea level rise in the early Holocene culminating in a mid Holocene sea level maximum and then a gradual fall to the present day. The analysis quantifies differential crustal movement between the north and south shores of the Solway Firth. The information obtained in the study is used by Lloyd *et al* (1999) to test the accuracy of the isostatic models of Lambeck (1993, 1995) and Peltier (1998), and the isobase model of Sissons (1983). Lloyd *et al* (1999) report a good agreement between the data recorded and the models. Comparison of the new data with the relative sea level predictions of the geophysical model of Lambeck (1993,1995) shows the model to be very accurate in amplitude for the northern Solway Firth, although the age of the mid Holocene relative sea level maximum is around 700 years too young. In the southern Solway Firth Lambeck's model (1993, 1995) is accurate during the early Holocene but becomes less accurate in the mid

Holocene. Peltier's (1998) global model also shows close agreement with the northern Solway Firth in the early Holocene but discrepancies occur from around 7000 yrs BP onwards. For the southern Solway Firth Peltier's (1998) model predicts a generally higher relative sea level than is recorded. The information from the Solway Firth also agreed with the predicted age of the Main Postglacial Shoreline of Sissons (1983).

Again in Scotland a more recent study by Smith *et al* (2003) examined the Holocene relative sea level change in the lower Nith valley and estuary where they undertook a detailed multidisciplinary study. They dated the main post glacial transgression in the area to between 7500 ^{14}C yrs BP (8350 cal. yrs BP) and 7800 ^{14}C yrs BP (8600 cal. yrs BP). They found widespread evidence for the Main Postglacial Shoreline in the lower Nith and dated this to 5900 ^{14}C yrs BP (6720 cal. yrs BP). After this time sea levels may have fluctuated but by 1760 ^{14}C yrs BP (1800 cal. yrs BP) had fallen to reach the current level. Smith *et al* (2003a) argued that this sequence was consistent with the Lloyd *et al* (1999) results from the northern shore of the Solway Firth.

It is only possible here to mention a few of the studies examining the change through the Holocene in the areas of Britain where uplift has been taking place. However, a common explanation of the changes can be seen with an early Holocene marine regression followed by a mid Holocene marine transgression and then a subsequent regression to the levels seen today.

1.3.2 Areas of isostatic subsidence throughout the Holocene

Many studies aiming to reconstruct Holocene environmental development have taken place in the southern parts of Great Britain. Isostatic subsidence in southern Britain is strongly influencing the development of coastal wetlands as it is enhancing post glacial sea level rise. As mentioned in section 1.3 Shennan and Horton (2002) have calculated that the subsidence in Southwest England to be around 1.2 mm yr^{-1}. The following examples illustrate the relationship between subsidence and sea level.

In Southeast England, Greensmith and Tucker (1973) examined the Holocene sea level changes on the Essex coast and the outer Thames Estuary. Their work suggests that Holocene sea level has not been uniform across the area that is known to have been subsiding since the end of the last ice age. They argue that through certain periods of time sea level may have either remained stable or even fallen. They record the initial Holocene submergence as commencing at about 8400 yrs BP with further episodes occurring at 7500, 4000, 2400, 1400 and 300 yrs BP. Greensmith and Tucker (1973) argue that variations in rates of sedimentation, subsidence, alternations of wet and dry phases and changes in wind direction may all have played a part. They conclude though that their evidence suggests most of the transgressions were the result of eustatic changes in sea level as the episodes correlate closely with similar events in the Low Countries and globally.

In a further study in the Southeast, Long and Innes (1993) investigated Holocene changes in Romney Marsh, Southeast England. They examined a pollen sequence from a peat bed that had accumulated under declining and then increasing marine influence. The radiocarbon information reported showed that the peat accumulation took place between 3700 – 2200 ^{14}C yrs BP (4050 – 2200 cal. yrs BP) and was encouraged by a slow rate of sea level rise and the development/ existence of a potential gravel barrier. Long and Innes (1993) argue that the time/altitude of the sea level index points from this area are comparable with other sites in East Sussex, suggesting regional rather than local processes dominate. They do however report variability in the age of the peat showing some local influences.

At the extreme tip of Southwest England, Healy (1995) examined a sedimentary sequence at Marazion Marsh in West Cornwall. A basal organic deposit was identified which is overlain by minerogenic materials. A multidisciplinary approach was undertaken to examine the sequence and it was identified that the lower organic unit accumulated between 5420 +/- 60 and 4380 +/- 55 ^{14}C yrs BP. A vegetational succession was seen in the unit from herb domination through to woodland and eventually fen carr and reed marsh development. Healy (1995) reports that diatom data also indicates an increasing salinity within the sequence. Based on a number of radiocarbon dates the main transgressive phase is dated to around 4500 ^{14}C yrs BP.

Midway between the isostatic divide and the south coast, Walker *et al* (1998) carried out a study into the mid to late Holocene buried peats of the Caldicot Levels in the Severn Estuary. They examined two peat sequences from beneath marine deposits. Radiocarbon dates for the regressive contacts at the base of the peat deposits are dated to 5740 +/-70 ^{14}C yrs BP (Beta 63595 cal. range 6356 – 6726 BP) and 5920 +/- 50 ^{14}C yrs BP (Beta 72511 cal. range 6659 – 6868 BP). Walker *et al* (1998) explained that a marine regression took place at around 5800 – 5900 yrs BP that they say conforms to evidence for coastal change from other parts of the Severn Levels. Smith and Morgan (1989) studied the Goldcliff area and dated this regression in two profiles to 5950 +/- 80 ^{14}C yrs BP and 5660 +/- 80 ^{14}C yrs BP and a further profile at Uskmouth power station was dated to 6260 +/- 90 ^{14}C yrs BP. Walker *et al* (1998) dated the later marine transgression to between 2470 +/- 60 ^{14}C yrs BP (Beta 63590: cal range 2347 –2745 BP) and 2900 +/- 60 ^{14}C yrs BP (Beta 72506: cal range 2859 – 3213 BP).

In a similar geographic context, Butler (1987) undertook a study at Kenn Moor, on the English side of the Severn Estuary where he examined the sediments in which a wooden stake was found and described by Gilbertson and Hawkins (1983). They found a “carefully fashioned” wooden stake of early Bronze Age or late Neolithic and Butler (1987) pointed out the similarities of the find and its setting with those found by the Somerset Levels Project (see section 1.4). His investigations revealed a complex sedimentary sequence that pointed to the existence of a variety of wetland environments, which he examined in relation to the presence of man and their potential influence. In pollen records he established that a woodland clearance was apparent at around 5000 yrs BP and a second phase between 4000 and 3500 yrs BP. Butler (1987) pointed out that the wooden stake was contemporary with the second phase of clearance. He went on to discuss the impact that woodland clearance can have on the increase in soil erosion through run off and that increased waterlogging and silt deposition is evident in the stratigraphy corresponding with the phases of clearance. He concluded by explaining that the local sedimentary sequence is in general agreement with Kidson and Heyworth (1976), but that human impact was also influencing local hydrology and sedimentation.

In eastern England, Van de Noort and Davies (1993) undertook an archaeological investigation of the Humber wetlands that highlighted the quality and quantity of archaeological and paleaoecological information contained in this area. The Humber wetlands project was supported by English Heritage in an expansion to projects undertaken in wetlands elsewhere in the country e.g. the Somerset Levels and the Fenlands. As part of the project they assessed the transgressive and regressive episodes of the area proposed by other authors. A major study examined was that of Gaunt and Tooley (1974) who demonstrated that a marine transgression occurred sometime around 6970 ±100 ^{14}C yrs BP (IGS-C14/99) and 6890 ±100 ^{14}C yrs BP (IGS-C14/100). Gaunt and Tooley (1974) went on to date a marine regression in the area to 6170 ^{14}C yrs BP although with several transgressive and regressive episodes this date may be inconclusive. Van de Noort and Davies (1993) concluded that the data required further research before an accurate history of the sea level of the area could be presented.

Again it has only been possible to highlight a few of the studies that have been carried out to examine Holocene environmental change in the southern parts of Great Britain. The common history evident is one of marine transgression with the rate of transgression changing from very quick in the early Holocene to a slower pace in the last few thousand years.

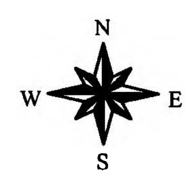
1.4 The Somerset Levels

The Somerset Levels are an extensive network of coastal wetlands situated in southwest England and comprise buried Pleistocene valleys infilled with interglacial sediment deposited during sea level highstands (Godwin 1948; Kisdon and Heyworth 1976). As the Levels are in the South of the country they are subject to subsidence of around 1.2 mm yr^{-1} (Shennan and Horton 2002). The infilling sediment is mostly Holocene in age, although some remnants of deposits from previous interglacials/stadials occur locally (Kidson *et al* 1978). The Levels comprise three generally east-west trending valley systems that merge westwards to form a coastal plain (Fig. 1.4). The most northerly valley is the Axe, which is bounded by the Mendip Hills to the north, and the Isle of Wedmore to the south. The Brue valley lies to the south of the Isle of Wedmore and to the north of the Polden Hills. The Sedgemoor valley complex lies to the south of the Poldens and is generally bounded to the south and east by the Mesozoic escarpments of Somerset and Dorset (Findlay *et al* 1984). The Sedgemoor valley complex covers an area of approximately 200 km^2 and has a surface altitude of 4 – 6 m OD. The complex includes King's Sedgemoor, West Sedgemoor and a number of smaller moor areas (Fig. 1.13). The geology of the Sedgemoor valley is shown at Figure 1.14.

One of the earliest researchers into the history of the Somerset Levels was Arthur Bullied who was born in 1862. At the age of 26 he began archaeological investigations in Somerset after learning about lake-dwellings in Switzerland and considered it was likely that the Somerset Levels would yield similar findings (Minnit and Coles 1996). In 1904 Bullied began excavating a lake village that he identified near to Godney in the Brue Valley (Fig. 1.5) and was joined by Harold St George Gray who at the time was curator of Somerset Archaeology and Natural History Society's museum in Taunton (Minnit and Coles 1996). The two men worked on the site until 1907 when they began work on the second and third villages at Meare Village West and Meare Village East (Fig. 1.5). They worked together at these sites until 1938 and unearthed some of Somerset's most important archaeological finds (Minnit and Coles 1996). In 1936, Harry Godwin (later Sir Harry) began working with Bullied and Gray, examining pollen sequences in the Meare lake village and later looked at other sites in the Brue valley (Godwin 1941; 1943; 1948; 1955). Godwin (1941) showed the presence of raised bogs in the Levels. On examining the deposits and archaeology, it was Godwin (1941) who suggested that, from the evidence that he had found, the maximum of the mid Holocene marine transgression had passed long before the Neolithic period. He compared this to evidence from East Anglia that showed that the equivalent transgression was considered to have been at its maximum in the late Neolithic or early Bronze Age. Godwin (1941) explained that the lithostratigraphy in the Somerset Levels and the Fens of East Anglia are very similar with the exception that raised bogs formed extensively in Somerset whereas true raised bogs developed above the Fenland peat in only one region of the Fens. He argued that the Somerset Levels and the Fens would have had in principle a very similar development. He later went on to explore the vegetational history in greater detail and established what he termed as a late Roman marine transgression of the Axe valley (Godwin 1955).

This figure has been removed from the digitized thesis for copyright reasons.

Fig. 1.4 The Somerset Levels



This figure has been removed from the digitized thesis for copyright reasons.

Fig 1.5 Sites of archaeological importance in the Brue Valley

Kidson and Heyworth (1973) investigated the Holocene sea level rise in the Bristol Channel. They examined and described the deposits as a basal forest peat, buried by a marine clay occurring at about OD. Overlying this clay was a series of peat bands intercalated with clays that they describe as being part of the normal process of coastal change rather than oscillations in sea level rise. They produced a sea level curve for the region taking some compaction of sediments into account and compared it to curves produced for the Netherlands and Sweden. They explain that some of the points used for this curve were taken from trackways within peat deposits rather than at lithostratigraphical boundaries. Kidson and Heyworth (1973) concluded that sedimentation has kept pace with sea level rise throughout the Holocene bringing about the infilling of the Somerset levels, and that they considered previous assumptions about the area being isostatically stable had been confirmed (Kidson & Heyworth 1978).

Kidson and Heyworth (1976) later reported on a study they had undertaken into the Quaternary deposits of the Somerset Levels. They examined intertidal exposures and also carried out an extensive borehole survey. They were able to include geotechnical site investigations that had taken place for the construction of the M5 motorway and water supply in the area. From the intertidal exposures they reported an upper series of horizontal peat bands and one basal peat that was present below –5.3 m OD. They proposed that the upper peat bands developed after the rate of sea level rise began to slow to a rate approximate to that of sedimentation in the mid Holocene. They showed that as they moved inland the series of interdigitated peats became thicker and merged with the lower basal peat. They reported that the present day land surface was higher at the coast than inland with a coastal ridge being a prominent feature of the levels. From the M5 information they reported that around the present day course of the River Parrett the basal peat was recovered at a depth of –20 m OD. Above it they reported the thick Holocene marine and estuarine clays up to approximately 0m OD.

Figure 1.6 has been removed from the digitized thesis for copyright reasons.

Fig 1.6 The extent of marine influence 9000 yrs ago from Kidson and Heyworth (1976)

Kidson and Heyworth (1976) explained the pre-Holocene evolution of the Somerset Levels by suggesting that during the Tertiary the now-buried valleys were cut by rivers following the courses of the Parrett, the Brue, and presumably the Axe. They argued that during the Pleistocene glaciations sea level fell to such an extent that considerable down cutting took place. At least one interglacial stage sea level highstand, most likely the last interglacial (Andrews *et al* 1984) exceeded present sea level to deposit marine and estuarine deposits known locally as the Burtle Beds (Kidson *et al* 1978). During the last glacial maximum, the Devensian glaciation, sea level fell to retreat beyond the present day Bristol Channel and downcutting in the valleys again took place to erode the valley bottoms to approximately –30 m OD (Kidson and Heyworth 1976). The Holocene has been a time of sedimentation in the Levels rather than erosion. Kidson and Heyworth (1976) argued that the valleys have been infilled during the period of rapid sea level rise, but not at a constant rate. In the early Holocene, between 9000 and 6500 years BP, there was rapid sea level rise during which time sufficient sediment was made available to the coastal system to enable sedimentation to keep pace with sea level rise (see also Haslett *et al* 2001b).

Figures 1.7 - 1.9 have been removed from the digitized thesis for copyright reasons.

Fig 1.7 Extent of marine influence 6000 yrs ago from Kidson and Heyworth (1976)

Kidson and Heyworth (1976) explained that at the end of the Devensian a birch forest colonised the valley floor that was later killed off and preserved by waterlogging and peat formation associated with the post-glacial rise of sea level. Kidson and Heyworth (1976) produce a series of maps (Figs. 1.6 - 1.9) showing the estimated marine extent (and consequently deposition of a lower blue clay) at differing time intervals through the Holocene. The maximum extent of marine transgression was attained approximately 6000 years BP, when the rate of sea level rise gradually slowed. The altitude of the upper surface of the silty-clay deposited by this early Holocene marine transgression lies approximately at 0m OD and appears to have been temporarily colonised by forests of oak and pine before again peat accumulation and poor drainage engulfed the trees. The amount of peat accumulation varied from location to location across the levels with raised bogs developing in some locations that grew vertically at a pace that outstripped sea level rise. At around 4000 years ago sea level attained its highest altitude resulting in a further inundation of marine silty-clay across many parts of the levels, but with some areas apparently escaping the second inundation.

Fig 1.8 Extent of marine influence 5000 yrs BP from Kidson and Heyworth (1976)

Fig 1.9 Extent of marine influence 4000 yrs BP from Kidson and Heyworth (1976)

Kidson and Heyworth (1976) proposed that by 3000 years ago the palaeogeography was very similar to that expected for the present day had not drainage works been introduced on the Somerset Levels. Kidson and Heyworth (1976) also considered the influence of compaction of sediment and its consequence. They recognised that the “OD peat”, as they termed it, rested on what would have been the horizontal marine clay surface. As it is now not horizontal subsequent consolidation must have taken place. They revisited the sea level curve produced in 1973 and added further corrections to allow for the compaction, which they again revisited in 1982 (Heyworth and Kidson 1982). They calculated a correction factor to account for the consolidation process and elevated some of their dated horizons by up to 1.3 m, some of these dates being taken from wooden structures within peat deposits. Heyworth and Kidson (1982) produced a revised sea level curve based on these corrected levels (Fig. 1.10). Figure 1.10 also shows the curve for Somerset produced by Lambeck (1993) and Hawkins (1971) for comparison.

Figure 1.10 has been removed from the digitized thesis for copyright reasons.

Fig. 1.10 Comparison of sea level curves for Somerset (from Long *et al* 2001)

The Somerset Levels Project began examining the archaeological history of the Somerset Levels in 1973 and was particularly dedicated to recording the wetland archaeology of the Brue valley (Somerset County Council website). In 1970 a local peat company discovered part of a wooden structure which it sent to John Coles (University of Cambridge) and a large scale investigation began in 1973 (Somerset County Council website). It became clear that the wooden structure was a prehistoric trackway and was dated as Neolithic. The trackway was named The Sweet Track after Mr R Sweet who discovered it (Fig. 1.5). The Sweet Track became the focus of the Somerset Levels Project and John Coles and his colleagues were able to discover a great deal about Somerset's ancient history. The project was able to attract funding from English Heritage and grew into a study spanning fifteen years (Somerset County Council website). Many researchers contributed to the project over this time including: B Coles (nee Orme), R Housley, A Caseldine and R Morgan amongst others and the project was able to cover a wide range of archaeological specialisms. For fifteen years the project examined the archaeology of the Brue valley (Fig. 1.7) and reported many important finds in annual Somerset Levels Papers. Improvements in legislation protecting wetland archaeology and the decline of the peat industry resulted in the project being scaled down in 1989.

Figure 1.11 has been removed from the digitized thesis for copyright reasons.

Fig. 1.11 Stratigraphy, approximate calendar year ages and relative major structures (mainly trackways) found in the Brue Valley (from Coles 1989).

Prof. John R. L. Allen (University of Reading) and co-workers have undertaken much research in recent years in and around the Severn Estuary and Levels. Allen and Fulford (1986) defined a Holocene lithostratigraphic division that they called the Wentlooge Formation. From investigations on the Welsh side of the Severn Estuary a lower silty-clay, a middle peat unit and an upper silty clay were identified. This formation was identified as being equivalent to the tripartite lithostratigraphy in the Somerset Levels described by Heyworth and Kidson (1976). Allen and Rae (1987) examined the late Flandrian (Holocene) shoreline changes in the Severn Estuary and described four morphostratigraphic salt marsh units in an upward and inward sequence, which were the upper Wentlooge, Rumney, Awre and Northwick formations. They proposed that the development of each of these formations is synchronous over the extent of the estuary. Allen and Rae (1987) explained that the upper Wentlooge Formation began to accumulate 2500 –3000 years ago and ceased to form in the Roman period or soon after. They argued that the Rumney Formation began to form from the early medieval to the early modern times. They proposed that evidence is seen in this formation of the medieval reclamation of the wetlands. The Awre formation is explained as beginning to accumulate in the 19th century and the Northwick formation after that. Campbell *et al* (1999) erected the Somerset Levels Formation for the Holocene sediments of the Somerset Levels that correspond to the Wentlooge Formation on the Welsh or north side of the estuary.

Allen (1990) examined salt marsh growth in the light of sea level change and proposed a model for the Severn Estuary. He concluded that the rate at which a marsh grows up is a factor of the minerogenic sedimentation, the organogenic sedimentation, the rate and tendency of relative sea level, and in the long term the amount of compaction in sedimentation. He argued that the amount of minerogenic sedimentation is determined by the tidal and fine sediment regimes and expected this to be a decreasing function of marsh elevation. This is because as the marsh builds up in the tidal frame it becomes flooded less frequently. Allen (1990) used these ideas to model salt marsh growth in the Severn Estuary and the model predicted that the elevation/time curve of salt marsh growth initially rises very steeply and then flattens very rapidly. He argued that a marsh that builds up during a period of rising sea level reaches an elevation that is constant in relation to the moving tidal frame, but lower than extreme tides. Against falling sea levels the marsh would rise above the tidal frame and would favour peat formation. Allen (1991) examined salt marsh accretion and sea level movement in the inner Severn Estuary. The rate of rise is shown to accelerate over the last two thousand years and he concluded that a minimum rise of relative sea level of 1.30 m has occurred since the Roman period in the inner Severn Estuary. The relationship between sea level change and the development of coastal surfaces has been explored by Allen (1990, 1994, 1995 1996). Allen (1994, 1996) described a model that assumes a horizontal salt marsh platform that is bounded to the landward side by a barrier. The model predicts that when the surface of the marsh is submerged the velocity of water travelling over it decreases landward, which has three implications: 1) that coarse sediment will be deposited at the front of the marsh and sediment size will decrease landward; 2) that rapid deposition of sediment on the marsh front causes a landward decrease in deposition rate; and 3) that the sediment concentration in the tidal water also decreases landward. This model allows sequences of sediments to be analysed when aiming to establish if shorelines were advancing or retreating at the time the sediments were deposited. Allen (1995) examined salt marsh growth against fluctuating sea level and discussed the implications of models of coastal stratigraphy and sea level curves based on peat. He concluded that when sea level is fluctuating a sedimentary sequence of intercalated peat and silty marsh sediments like that seen in the Severn Estuary result. He went on to explain that a lag was seen to exist between the fluctuation and the experimental marsh showing a response. He found that regressive contacts happen higher up the fluctuating component than transgressive ones. Because of these effects he proposed that uncertainties would exist in sea level curves constructed from radiocarbon dated peats. He argued that the ages of the conventional transgressive and regressive overlaps may poorly constrain the timings of the sea level fluctuations.

1.4.1. Drainage and reclamation of the Somerset Levels

During the later Holocene the natural processes already discussed have been frequently overwhelmed by human activity as people have attempted to control the natural systems. Several studies have examined this activity in the Somerset Levels. Evidence of Roman drainage of the Somerset Levels has been established. Rippon (1997) examined an area on the North Somerset Levels at Banwell and Puxton with the aim of identifying evidence of Roman reclamation. A Roman drainage system was identified which was seen to be at variance with the medieval landscape. Rippon (1997) suggests this is due to a period of abandonment before recolonisation in the Saxon period. Further investigations at the site by Rippon (1997) proposed that alluvial sequences, which represented tidal flooding of the area, would be the explanation for the abandonment.

Williams (1970) published a study on the later reclamation and draining of the Somerset Levels. The ‘islands’ of relatively higher ground that occur in the

Somerset Levels have, because of their isolation and solitude, become ideal locations for monasteries. In AD 878, Athelney Abbey was founded which was described by William of Malmesbury as being "so inaccessible on account of bogs and inundation of lakes that it cannot be approached but by a boat" (Williams 1970 p.19). The great ecclesiastical estates grew on the uplands and with them Saxon settlements. The area for a long time was used for fisheries and timber but pasture rights became an important part of the manorial economy. The settlements assumed a right to begin to utilise the moors close to them during the summer months for their stock for common pasturing. This situation was very difficult to control leading to illegal pasturing and there was the constant threat of flooding (Williams 1970). In an effort to balance the needs of the local population and protect the land from natural depredation reclamation began. In the 12th and 13th centuries the manorial control over the pasture land was lax leading to many illegal encroachments. The ecclesiastical estates were weakened by feuds that left them in financial troubles. Vigorous efforts were then made by the religious houses during the 13th century to stem the tide of leasehold and to recover and drain their lands. Williams (1970) argues that "the energy and enterprise of the religious houses in the thirteenth and early fourteenth centuries in recovering and reclaiming land were potent factors in the draining of the Levels" (p.40) leading to the character of the landscape that exists today.

Musgrove (1997) examined the medieval exploitation and reclamation of the inland peat moors in the Somerset Levels and during this study he looked at the peats of the lower Brue valley and King's Sedgemoor. He explained that the valleys are different with the Brue valley having been a raised bog and

Sedgemoor a fen carr but that both have a complex history of drainage. He used a site at Greinton Manor as a case study and reported on documentary evidence from as far back as the late 13th century. The first reference to meadow at Greinton are seen in the records of 1300's with the 1311 record showing that the reclamation underway was good enough to allow land use change as the areas formerly identified as meadow were by this time documented as being under arable cultivation. By the later years of the 14th century there is little evidence of further extension of the reclamation but there is evidence of a lot of effort in maintaining the existing system (Musgrove 1997). Musgrove (1997) explained that there is a recognisable pattern in the areas that he studied in that the earliest reclamations for meadow took place on the alluvial land at the upland edge as it provided the more freely draining soils. Later reclamation it seems built on the earlier reclamation by expanding along the edges of the high ground. Musgrove (1997) argues that throughout the medieval period there is little evidence of reclamation into the open peat moors on either side of the Poldens which would he said have been utilised as seasonal grazing and fishing.

1.5 The Bath Spa Project

Since 1996 the Quaternary Research Unit of Bath Spa University College has been carrying out research into the Holocene sea level and environmental change of the Somerset Levels. The work has addressed the themes of the International Geological Correlation Programme's (IGCP) projects relating to sea level change. IGCP Project number 437, which focused on the development of coasts during times of high interglacial sea level, ran between 1998 and 2003. This project is the latest in a line of projects that have examined sea level change and coastal evolution. IGCP 61 (1975-1982) was an early examination of sea level movement during the last deglacial hemicycle (Tooley 1982). It aimed to establish the trend of mean sea level during the Late Quaternary, continuing up to the present day, and based on sea level index points from all over the world (Tooley 1982). IGCP 200 (1983-1987) was the second project that examined `Late Quaternary sea level change: measurement, correlation and future applications` (Shennan 1989). Project IGCP 274 (1988-1993) was the third and was titled `Quaternary coastal evolution: case studies, models and patterns`. It focussed on the links between sea level and climate change and the need for accurate information regarding the response of sea level to a range of climate related regional processes (Shennan *et al* 1994). IGCP 367 ran between 1994 and 1999 and was titled `Late Quaternary coastal records of rapid change: applications to present and future conditions`. The work involved investigating several areas of study including rapid sea level change and response, and the human impacts on coastal systems (Shennan and Gehrels 1996; Shennan *et al* 1998). IGCP Project 437 aims to build on these previous projects by comparing and contrasting coastal evolution during the present interglacial. It also aims to document interglacial highstands, to quantify the magnitude of sea level variation evident and to develop new and existing technologies for the assessment of the age of coastal sedimentary succession. A further aim was to evaluate the impact of human induced environmental change in coastal environments. Work, including this study, that has been carried out at the Quaternary Research Unit at Bath Spa University College is contributing towards the aims of the project.

Early stratigraphic and palaeoenvironmental studies in the Somerset Levels were general in their nature, attempting to characterise the lithostratigraphy and sea level influence for the Somerset Levels as a whole (Godwin 1941, 1943, 1948, 1955, Kidson and Heyworth 1973, 1976), and as part of the wider regional context (Hawkins 1971a & b; Kidson and Heyworth 1978; Heyworth and Kidson 1982). Subsequently, there has been a narrowing of focus towards more in depth studies of the constituent parts of the Somerset Levels. The Somerset Levels Project (1979-1989) examined in detail the Holocene succession in the Brue Valley (Fig. 1.6) with particular emphasis on the associated archaeology. Also, the work of the Quaternary Research Unit at Bath Spa University College, until now, had investigated the Axe valley and the coastal plain of the Somerset Levels (Haslett *et al* 1998a, b; Haslett *et al* 2001a, b). The remaining areas that required attention included the relatively minor Lox-Yeo Valley (H. O. Williams, BSUC MPhil project, in progress) and Sedgemoor (this thesis). It was considered that investigations of these other relatively neglected areas of the Somerset Levels were essential for allowing a more complete insight into mid to late Holocene stratigraphy and history of environmental change of the Somerset Levels as a whole.

Haslett *et al* (1998a) examined the late Holocene relative sea level change in the Somerset Levels. They undertook a study at Nyland Hill in the Axe valley (Fig. 1.12) and evaluated the sea level model that was produced by Heyworth and Kidson (1982) and made several conclusions. Firstly, that sediment compaction significantly affects the altitude of the transgressive sea level index points where peat underlies clay. Secondly, they proposed that in estimating the amount of compaction a stratigraphic situation is required where sediment is traced onlapping non-deformable bedrock. Thirdly, that clay sedimentation rates are affected by the compaction of the underlying peat. Fourthly, that care should be taken when using sedimentation rates as indicators of sea level rise where the amount of compaction is unknown. The final conclusion is that the accuracy of Heyworth and Kidson's (1982) model was questioned as it proposed a stabilisation of sea level at around 3000 years BP, whereas Haslett *et al* (1998a) indicated that sea level continued to rise through the Roman Period. Haslett *et al* (1998a) argued that Heyworth and Kidson (1982) underestimated sediment compaction, failed to establish sea level tendency for their samples and placed undue emphasis on data derived from within raised bog sequences that have an unclear relationship to sea level. Haslett *et al* (1998a) proposed further studies be undertaken to reinvestigate the Holocene sea level change in the Somerset Levels. Haslett *et al* (2001b) examined the estuarine deposits of the Levels at the Nyland Hill site and for the first time provided an extended Holocene palaeo-environmental record. They proposed that during the early Holocene phase of rapid sea level rise the palaeo-intertidal surface occurred low within the tidal frame, equivalent to MHWNT-MHW. As the rate of rise decreases towards the mid Holocene allochthonous mineral deposition was out-paced by autochthonous organic sedimentation which led to elevation of intertidal surfaces above Highest Astronomical Tide (HAT), with subsequent mire emergence and peat formation. The dating evidence for the contact between the intertidal clay and the peat was dated to between 6855 – 6490 (lab code Beta 114969) and 3640 – 3330 (lab code Beta 101742) cal. yrs BP and they suggested that the indicative meaning of the contact was HAT. Haslett *et al* (2001b) also described a lagg deposit, which is

Figure 1.13 has been removed from the digitized thesis for copyright reasons.

Fig 1.13 The Somerset Levels project survey of Sedgemoor formed in a fringing water body, that was evident in the lithostratigraphy recovered at Nyland Hill, which migrated upslope with the growth of the terrestrial peat. It is similar to deposits reported in the Brue Valley by Coles *et al* (1980) who described fringing pools at the bog margin throughout.

Seaward of the Axe valley, Haslett *et al* (2001a) undertook a stratigraphic survey along a transect of the northern coastal plain (Fig 1.13). The lithostratigraphy recovered comprises the silty clays and peats of the Somerset Levels Formation (Campbell *et al* 1999) that directly correlates to the Lower Middle and Upper Wentlooge Formation of the Gwent Levels (Allen 1987). Haslett *et al* (2001a) erected Lower, Middle and Upper lithostratigraphic subdivisions of the Somerset Levels Formation. The Lower unit typesite is at North Yeo Farm and is termed the North Yeo Member (Haslett and Davies, 2002). It consists of 6m or more of blue/grey silty clay and is the lithostratigraphic equivalent of the Lower Wentlooge Formation (Allen, 1987). The Middle unit typesite is at Nyland Hill in the Axe valley and is termed the Nyland Hill Peat Member (Haslett and Davies, 2002). This unit is characterised by between 0.5m and 2m of thick peat. At the typesite it is found in one bed but nearer the coast it can be split with silty clay intercalations. This unit is the equivalent of the Middle Wentlooge Formation (Allen 1987). The Upper Somerset Levels Formation typesite is at Nyland Hill in the Axe Valley and is known as the Nyland Hill Clay member (Haslett and Davies, 2002). It is a deposit of <5m of thick minerogenic silty clay that is blue/grey in colour and marine in origin. It is equivalent to the Upper Wentlooge Formation of the Gwent Levels (Allen 1987). Haslett *et al* (2001a) stated that these clay-peat and peat-clay transitions at the base and top of the formation represents marine regression and transgression respectively. Radiocarbon dates for the marine regression at Nyland Hill dated to between 6285 – 5145 cal. yrs BP and the subsequent transgression to between 4090 – 4255 cal. yrs BP. The regressive contact is assigned an indicative meaning of Highest Astronomical Tide whilst the indicative meaning of the transgressive contact is given as Mean High Water Spring Tide (Haslett *et al* 2001a). As part of the investigations the model of Kidson and Heyworth (1976) was evaluated and found to be inaccurate in terms of the age and position of the palaeoshorelines (Haslett *et al* 2001a). The study went on to propose that there is a need for further research on the Holocene development of the Somerset Levels as a whole.

1.6 The Sedgemoor Valley

In 1982 the Somerset Levels Project undertook a reconnaissance survey of Sedgemoor. As previous studies by the project had concentrated on the Brue Valley it was suggested in 1982 that the Sedgemoor Valley became the focus of a "rapid survey" of the peats (Coles and Orme 1983). Coles and Orme (1983) sought to establish whether the peat of Sedgemoor would provide the same archaeological finds as the Brue valley. They stated that the initial findings of their survey suggested that Sedgemoor had undergone a different environmental history to the Brue Valley and that they had "discovered the aptness of the name Sedgemoor". Unlike in the Brue Valley they found little evidence of raised bog development in Sedgemoor and instead found that sedge peat dominated the investigated sequences. They assumed that the lack of raised bog and what they described as apparent episodes of desiccation would mean archaeological evidence was likely to be poorly preserved, although they suggest that the inflow of calcareous ground water may have been a factor. They described wooden structures in the vicinity of Greylake Fosse that became visible during a dry spell. They concluded that Sedgemoor, although it was not what they had expected, did preserve equivalent archaeological evidence at least equal to that of the Brue Valley and that the potential for archaeological and environmental investigations within the valley was good. The environmental results of the 1982 survey were presented in 1983 by A.M. Alderton who explained that a Hiller sampler was used for investigations at six sites throughout Sedgemoor. Figure 1.13 shows the sites of study in Sedgemoor by Alderton (1983). The first site was Somerton Drove (NGR SD1 ST4671 3130 and SD2 ST4673 3138). He described a thick peat deposit (480 cm) but also described the core as a continuous sequence of detritus muds that he interpreted as swamp mud deposits with considerable amounts of wood and fragments. At SD2 molluscan evidence was found that was indicative of water bodies larger than isolated ponds. Within SD1, a thick clay capped the peat deposit which was interpreted as slopewash. At Middlezoy three boreholes were investigated (MZ1 ST 3833 3460, MZ2 ST 3810 3440, MZ3 ST 3815 3452) situated adjacent to the Westonzoyland-Middlezoy Burtle Bed 'island', known to contain prehistoric finds. A consistent palaeoenvironmental history was suggested with an initial *Phragmites* (reed) deposit overlying the intertidal clay. This continued upwards into a fen sedge which dominated the remainder of the sequence. Alderton (1983) describes a fen carr deposit within the sedge fen and a clay top soil, and goes on to conclude that the site remained under the influence of a very high water table. He argued that this indicated a rise in water level keeping pace with sediment deposition. At Moor Drove (ST 3479 3626) one borehole was recovered in the area of the Burtle Beds in which Alderton (1983) aimed to locate a possible timber trackway identified by Norman (1980). At this location the lower blue estuarine clay was overlain by a *Phragmities* fen peat. The remaining lithostratigraphy consisted of overlying detritus muds with what appeared to be indications of brackish in-washings of fine clayey silts containing diatoms. Plant macrofossils from the muds showed a base rich water body being present with a sedge fen developing later. At the top of the sequence an alder fen carr is evident. The next study site was a series of four boreholes at a narrow point between the Chedzoy Burtle Bed 'island' and the spur of Sutton Hams (SH1 ST 3556 3711, SH2 ST 3554 3712, MCB1 ST 3522 3685, MCB2 ST 3535 3697). This site was chosen as it was considered likely that it may have been a prehistoric route between the two areas of high ground. The deposits below the peat deposit were examined at Mount Close Batch (MCB) and beneath the soft estuarine clay in MCB2 where Alderton (1983) found horizons of fine sand becoming more extensive with depth. At 954 cm depth a sharp boundary was recorded with a stiff yellow-brown clay containing many molluscs that indicate freshwater conditions and interpreted as a freshwater marl. At MCB1 considerable detrital mud horizons are present overlying the Burtle deposits with no estuarine clay. Alderton (1983) suggested that the sediments at Mount Close Batch indicate a considerable amount of surface water at the time of deposition. The SH1 and 2 boreholes again showed in-wash sediments, periodic wetting and a general trend towards fen wood. The next site studied was at Beer Wall where a section of 10 boreholes were studied over several 100m (ST 3879 3175 to ST 4024 3132). At this transect a *Phragmites* fen peat was present overlying the estuarine clays. This peat was succeeded by a sedge fen including plant macrofossils indicative of wet and base rich conditions. Alderton (1983) suggested that as the vegetation built up above water level a fen carr developed containing alder and sedges. Within one borehole (BW6) freshwater mollusc operculae and seeds are representative of a period of open pools, again with alder present close by. Alderton (1983) explained that the site as a whole appeared to dry out with the fen carr developing into fen wood. Overlying this peat, a stiff freshwater alluvial deposit was described that contained freshwater molluscs. The remaining site investigated was situated at West Moor where ditch dredgings had revealed raised bog species. Seventeen boreholes were investigated to determine the size of the deposit. The estuarine clay surface in the boreholes studied varied between –0.33 m OD and 0.8 m OD. Alderton (1983) reported a *Phragmites* fen peat overlying the estuarine clay. In some boreholes a succession was seen through to a fen peat, but the majority record sedge fen peat dominating with several horizons of *Sphagnum* peat. Such layers of bog deposits are located in several of the boreholes. In the eastern parts of West Moor the higher water table had resulted in thick detritus muds with frequent and diverse molluscan assemblages. The investigations at West Moor indicated that no single phase of raised bog development occurred, as *Sphagnum* horizons occur at different heights. Alderton (1983) proposed that renewed frequent flooding had counteracted the bog development. Alderton's (1983) study highlights the diverse nature of Holocene deposits of Sedgemoor and attempts to construct a preliminary environmental history. Overall he concluded that shell-detritus muds dominate the east and central parts of Sedgemoor, but in the south a succession occurs from *Phragmities* peat through fen carr and occasionally to fen wood.

The Somerset Levels have been the subject of research for many years as the sediments they hold allow the archaeological and environmental investigations that assist in the reconstruction of past environments. In contrast to the Brue and Axe valleys, Sedgemoor has received little environmental and archaeological research (Alderton 1983). The results from a study of the deposits in Sedgemoor would assist in broadening the mid to late Holocene history of the Somerset Levels.

Fig 1.14 - The Geology of the Sedgemoor Valley

1.7 Aims and Objectives

The aims of this study are to build on the work already undertaken by the Quaternary Research Unit at Bath Spa University College in the Somerset Levels by extending the study to the Sedgemoor Valley.

This study aims:

- To review and evaluate the existing information regarding the Sedgemoor Valley

- To acquire new stratigraphic, palaeoenvironmental and dating evidence through a programme of field work and laboratory analysis; and

- To develop a temporal and spatial model for the Holocene evolution of Sedgemoor, integrating both physical and human influences.

Chapter 2 Methodological approaches and techniques

While undertaking this study a variety of field and laboratory techniques were employed. This chapter will outline the processes used and the rationale behind the decisions to follow these procedures.

2.1 Site Selection

When planning this study careful thought was given to the sites to be examined. As explained in Chapter 1, a significant amount is known about the Holocene histories of the Brue and Axe valleys which were studied closely by Coles and Orme e*t al* in the Somerset Levels papers during the 1980s and the QRU at BSUC respectively, but comparatively little investigative work has been undertaken in the Sedgemoor Valley.

Generic criteria was devised in selecting the sites for study in Sedgemoor with the important factors being:

- **Bedrock** – At each of the sites concerned a transect of boreholes was taken which extend from a slope where it was clear that the sediment was still shallow enough to be supported by the underlying bedrock. It has been recognised that sediments in the Somerset Levels are subject to large amounts of compaction and that bedrock from slopes minimises the compaction experienced by overlying sediments (Haslett *et al* 1998a; Allen 1999, 2000b).

- **Spatial importance** – In selecting the sites for study in Sedgemoor it was decided to investigate equally spaced sites along the valley and to begin the Sedgemoor transect with an inland site and work towards the coast. Figure 2.1 shows a map of Sedgemoor with the three chosen sites highlighted.
- **Archaeological interest** – Sites were chosen where there was known archaeological interest. New information would then contribute and add to the known history of the Sedgemoor valley.

In selecting sites to survey, the known archaeological evidence was also considered, as new information from this study would contribute towards reconstructing the story of past environments building on what is known.

At Street Moor near Dundon Hayes, Bullied (1946) recorded oak piles, although as there was little alignment in them it seems unlikely that this was a trackway. Coles and Orme (1985a) located traces of a wooden structure near Henley Bridge which is also at the eastern part of King's Sedgemoor and has been dated to 3020 ± 60 yrs BP (HAR-4998). The site of Dundon Hayes was investigated in this study to build on this known information in providing a palaeoenvironmental context in the surrounding area (Chapter 4).

Gray (1926) recognised a series of oak piles, alder limbs and brushwood at Greylake on the Southside of King's Sedgemoor. This was later termed `Gray's Track' by Coles and Orme (1985a). Close to this site, Cole (1983) recorded a 6m long wooden structure 0.15m below the surface, which contained bone. Bullied (1946) reported what he considered were timbers from a northward extension of the structure recorded by Gray (1926). These works contributed to the selection of the site at Briarwood Farm and are considered further at Chapter 5.

Norman and Clements (1979) studied a further wooden structure in the western part of Sedgemoor extending westward from Sutton Hams. Norman (1980) located what was described as the westward extension of this `track` at the village of Chedzoy which was later dated by Coles and Orme (1985b). At the eastern end of Sedgemoor the Roman settlement of Crandon Bridge is recorded and a villa has been excavated in Bawdrip which is near to the field examined in this study at Chapter 6.

Before examining these sites a location in the modern day Bristol Channel was examined in order to set the scene for the site chapters that followed. This site is at the Steart Peninsula and is reported at Chapter 3. Each of the individual site chapters contains more specific details of the rationale behind the selection of each location.

Fig. 2.1 The selected sites in the Sedgemoor Valley

2.2 Lithostratigraphic Analysis

Lithological evidence can provide important insights into past environmental conditions and climatic regimes. Therefore, information on past events may be acquired from the detailed observations of the sedimentary record (Lowe and Walker 1997). Holocene sediments are usually unconsolidated and one of two general types. The first are inorganic deposits that consist of mineral particles which range in size from fine clays to gravel (Lowe and Walker 1997). The second sediment type are the biogenic deposits which form as a result of decaying plant and animal material (Lowe and Walker 1997). This type of sediment could be an organic substance like peat or could also be inorganic, for example a sediment made of molluscan shells (West 1977a).

2.2.1 Lithostratigraphy of the Somerset Levels

The Holocene lithostratigraphy of the Somerset Levels is the result of several changeable environments that have existed in the area during the Quaternary. The earliest Pleistocene deposits are known as the Burtle Beds, which are an interglacial sediment of sands and silt which have been shown to be marine or estuarine in nature (Kidson *et al* 1978). This deposit has been attributed to the Ipswichian (Oxygen isotope substage 5e) or perhaps earlier interglacials (Kidson *et al* 1978, Allen 2002). These Burtle Beds now only remain as `islands` of slightly higher ground in the Somerset Levels, having been dissected away by fluvial action, probably being eroded during the latest Devensian glacial stage (Oxygen isotope stages 5d-2).

Kidson and Heyworth (1976) showed that the sedimentary infilling of the Somerset Levels in the Holocene has been influenced by a rising sea level trend. The infill containing silty clays and peats has been termed the Somerset Levels Formation by Campbell *et al* (1999), divided into a lower silty clay unit, a middle peat section and an upper silty clay unit, formally defined by Haslett and Davies (2002) as the North Yeo Member, the Nyland Hill Peat Member and the Nyland Hill Clay Member respectively. Only limited work has been carried out on the sediments of the Sedgemoor valley (see section 1.6) and consequently this study aimed to record the sedimentary sequence there, and to consider its integration into this formal stratigraphic framework.

2.2.2 Retrieving and recording the Lithostratigraphy

The lithostratigraphical survey was carried out by retrieving Holocene sediments at selected locations in the Sedgemoor Valley (Fig. 2.1). The sediments for lithostratigraphical analysis were recovered using an Eijkelkamp gouge. The gouge recovered 1m sections of sediment and 1m extension rods were added as required to allow the gouge to recover deeper sediment. On recovery, sediment cores were measured in terms of depth from ground surface, and a full lithological description was made using the terminology of Haslett *et al* (1998a).

The samples that were to be analysed biostratigraphically, or to be dated by radiocarbon techniques, were retrieved with a Russian corer (examples of which are shown in Figs. 2.2 and 2.3). This type of corer minimises contamination, as the sediment sample is returned to the surface in a closed chamber. Biostratigraphical samples were removed from the corer using a clean pallet knife and were stored in labelled sample bags. Samples to be sent for radiocarbon dating were removed from the corer by turning the contents of the chamber into shaped 50 cm plastic pipe sections. These were labelled and wrapped in plastic-sheeting for protection. Following recovery, all samples were transported to the laboratory fridge and kept at a temperature of 2^{o}C.

Fig. 2.2 A Russian side sampling corer (from Lowe and Walker 1997)

Fig. 2.3 A Russian corer in use (from Lowe and Walker 1997)

2.2.3 Displaying the Lithostratigraphy

Microsoft Excel is used to display the lithostratigraphy and other results for the three sites (Figures 4.6, 5.5 and 6.5). The descriptions and altitude of the sediments recovered were entered onto Excel spreadsheets and area graphs prepared to graphically show the sediment stratigraphy.

2.3 Altitudinal Surveying

In order to calculate the altitude of lithostratigraphical changes in sediment at the locations examined in this study, sediment depths were related to Ordnance Datum Newlyn (OD). Ordnance Datum was determined from hourly observations at Newlyn, Cornwall, of the tide between 1915 and 1921 and serves as the map datum for Great Britain (Pugh 1987).

Ordnance Datum bench marks and Trigometric Points are widely distributed through Great Britain. These are points of known altitude marked on a permanent structure e.g. a Church. The altitude of the ground surface at each of the borehole sites in this study was established by measuring the ground level relative to OD by surveying from bench marks and trigonometric points using a Leica Total Station TC400. The Total Station is an apparatus that combines a theodolite, recording vertical and horizontal angular measurements and an Electromagnetic Distance Measurement for distance measure. The Total Station uses a laser to transmit an infra-red signal to a prism on a staff which returns the signal.

2.4 Foraminiferal Analysis

Foraminifera are marine protozoans of which around 4000 species can currently be found living in marine environments. Some of these species can be used as direct indicators of various different environmental factors including sea level, tide-level, intertidal environment, sediment provenance and depositional processes (Scott & Medioli 1978,1986; Gehrels *et al* 2002). There are many species that occupy narrowly defined niches that make them ideal for palaeoenvironmental analysis (Murray 1991). Foraminifera were chosen over diatoms as palaeoenvironmental indicators here as Haslett *et al* (1998a) established that diatoms are poorly preserved in the Holocene sediments of the Somerset Levels.

Foraminifera adopt a mode of life that is either planktonic or benthic (Murray 1991). It is the benthic forms that are of most use as biological indicators of marine processes and environments. The foraminifera shell or `test' consists of either mineral calcite or it is agglutinated from particulate matter. Both forms of foraminifera tests have been shown to successfully withstand routine laboratory methods (Scott & Medioli 1978; 1986).

The foraminiferal species that occupy the marsh environment have been shown to form certain assemblages that can be used to infer sea level (Scott and Medioli 1978; 1986). These assemblages have been shown to exist all over the world in very narrow vertical zones sometimes less than 10cm in range (Scott and Medioli 1986; Gehrels 1994). Other authors have since gone on to question this. For example, De Rijk (1995,1997) has carried out studies that have further examined the relationship between foraminiferal properties and environmental parameters. She has examined the influence of salinity, sediment characteristics, vegetation and food source on the species assemblages, and argues that salinity is a more important factor than altitude in determining foraminiferal distribution. However, while other factors may influence species distribution, the overriding evidence supports the view that elevation within the tidal frame is the main determining factor.

During this study both present day foraminifera and fossil foraminifera have been analysed. Modern distributional data provides a local reference that assists in calibrating fossil evidence collected via coring techniques.

2.4.1 Sampling of present day and fossil foraminifera

Present day samples were recovered from a saltmarsh near to the village of Steart in Bridgwater Bay, Somerset (NGR ST 265 456) (Figure 3.3). Samples of $10cm^2$ were recovered from the surface of the marsh at 10 m intervals along a shore transect extending from low marsh to high marsh covering 160m. These samples were recovered seasonally throughout 1997 and early 1998.

The samples to be analysed for fossil foraminifera were recovered using the Russian corer (Figure 2.2) as explained in section 2.1.2, which minimises contamination with present day material. The samples were then stored in a refrigerator at 2^oC.

2.4.2 Laboratory processing

A slightly different sample process was used for the present day and the fossil foraminifera samples. The main difference being that the present day samples were treated with Rose Bengal on the day of collection. Walton (1952) introduced the process of using Rose Bengal which stains foraminifera that were presumed to be alive at the time of sampling. Apart from this difference both the modern and fossil samples were processed in the following way.

The samples were soaked in tap water in order that the sediment begins to disaggregate. Rose Bengal was added to the modern foraminifera samples at this stage so that live individuals may be identified. After soaking the samples the sediment was washed through a 63µ (4 Phi) sieve to retain the fraction of the sample greater than this size which includes the foraminifera individuals. The retained portion of the sample was then dried in order that the individuals contained within it could be identified and counted.

2.4.3 Sample counting

The samples were studied with a bifocal microscope and while counting and recording foraminifera a total of at least 250 individuals was the aim. If less than 250 individuals were found in the sample the total population was recorded. Picked samples are archived in glass microslides at the Quaternary Research Unit (QRU) at Bath Spa University College.

2.4.4 Foraminifera Species identification

The reference text used during the identification of foraminiferal species undertaken in this study was Murray (1979). Additionally the reference collection held in the QRU at Bath Spa University College was utilised.

2.4.5 Foraminiferal assemblages

The use of foraminifera for sea level studies is well established and was introduced by Scott and Medioli (1978). Several authors have shown that foraminifera occur between specific vertical zones (e.g. Gehrels 1994). These zones can be related to modern day tide levels in order to infer the tide level of palaeo-saltmarsh samples. Gehrels (1994) recognised four faunal zones or assemblages. Zone A1 is represented by a monospecific assemblage of *Jadammina macrescens*. This is a very useful sea level indicator as it has been shown to represent the highest part of the tidal frame or Highest Astronomical Tide (HAT) (Scott & Medioli 1978; 1986, Gehrels 1994). The second zone is Zone 1B which consists of an assemblage dominated by *Jadammina macrescens, Tiphotrocha comprimata* and *Trochammina inflata* which represents the higher high marsh or Mean Highest High Water (MHHW). The third zone proposed by Gehrels (1994) is Zone 2A which is characterised by *Milammina fusca* and *Trochammina inflata* and represents the high marsh. Finally, the fourth zone, Zone 2B is dominated by *Milammina fusca* and calcareous species which represents the low marsh.

Haslett *et al* (1998a) examined fossil foraminifera samples from cores taken in the Axe Valley of the Somerset Levels. They identified Zone 1B assemblages

(Scott and Medioli 1978,1986) and inferred a Mean High Water Spring Tide (MHWST) indicative meaning, and Zone 1A was identified as a barren zone which they proposed represented Highest Astronomical Tide (HAT) (Haslett *et al* 1998b). Subsequently, Haslett *et al* (1998b; 2001b) have undertaken studies of modern salt marsh surface samples and recent historic samples from the inner Severn Estuary. King and Haslett (1998) reported initial findings from research carried out on the salt marsh at Stert which is considered further in this study in Chapter 3.

Foraminifera were used as a biological indicator of sea level when Allen and Haslett (2002) carried out a study examining buried salt-marsh edges and tide-cycles in the mid Holocene on the Caldicot level in Gwent. In this study they propose that in the mid Holocene the Severn Estuary was subject to gross geomorphological changes indicated by silt and peat bands but also subtle and local changes. They also point out that autocompaction of sediments is an important influence when considering Holocene sequences.

2.4.6 Presentation of sample results

The Tilia computer package has been used to display the information from the core analysis. Other results are presented using Excel.

2.4.7 The statistical methods used

Cluster analysis was undertaken to create the Dendrograms shown in the Tilia diagrams. These dendrograms were used to identify the zonation throughout the samples. Detrended correspondence analysis (DCA) was used to explore the ecological relationships in the data which is presented in scatter graphs. The full statistical results are included at the Appendices for reference.

2.5 Molluscan Analysis

Mollusca are a common group of fossils found in Quaternary freshwater deposits (Sparks 1961). They are commonly found in tufas, calcareous muds and fens, chalk and marls (Lozek 1986). However, they are preserved in a full range of sediments providing there is sufficient calcium carbonate present to build and preserve their shells. Freshwater molluscs were first used in reconstructing past environments when in the late nineteenth and early twentieth centuries they were used as indicators of palaeoclimate (Kennard and Woodward 1917). Later they were also used to date geological events (Kerney 1977a). However, it has since been found that they are less suitable for these purposes than other biological indicators. With regard to climate it has been found that molluscs migrate very slowly and consequently there is a time lag between a climatic change and a change in the molluscan community (Lowe and Walker 1997). Radiocarbon dating has been an issue because of the difficulty in obtaining suitable material from the delicate shells of freshwater molluscs and, therefore, dates from surrounding sediments have been relied upon (Lowe and Walker 1997).

Despite these limitations, it is appreciated that Mollusca are very useful in characterising local depositional environments. Sparks (1961) outlined that different species have differing environmental requirements and this is examined further in section 2.5.5. By recovering fossil Molluscan assemblages a picture can be reconstructed outlining the broad environmental conditions that existed at various stages of the depositional sequence (Lozek 1986).

2.5.1 Sampling

Lozek (1986) proposed that sampling of well-stratified sediment is appropriate for quantitative analysis of mollusca and sampling of all sites within this study was undertaken so that changes of Molluscan assemblage may be recorded. The sediment containing the molluscs was recovered using a Russian corer (Fig. 2.2) to minimise sample contamination. Each sample taken was carefully contained in a well documented sample bag.

2.5.2 Laboratory work

Following recovery the samples were treated to remove the fossil shells from the deposit. The samples were initially placed in a bowl of water and stirred until the sediment was saturated and began to break down. At this stage the slaked sediment was washed through a 500µm mesh sieve to retain the proportion of the sample greater than 500µm in size (Losek 1986). The retained washed sample was then gently dried. Following the drying process the samples were studied with a bifocal microscope and all shells and shell fragments were carefully removed. The shells and fragments were retained for sorting, identification and counting.

2.5.3 Sample counting

Fossil shell assemblages contain mixtures of complete shells and fragments. Sparks (1961) stated that with regard to shell fragments "counting is best done on apical fragments" (p. 73). This is because it is possible that duplication could occur during the counting process. To avoid this, only shells and fragments with an apex were identified and recorded. Picked samples were archived in glass tubes at the Quaternary Research Unit laboratory at Bath Spa University College.

2.5.4 Species identification

A number of guides to freshwater molluscan identification are available for reference material while identifying individuals. During this study identification was carried out with reference to Macan (1960) and the reference collection at the QRU Bath Spa University College.

2.5.5 Molluscan palaeoecological groups

During this study the results obtained from the molluscan analysis were collated according to the groups proposed by Sparks (1961). These groups characterise certain environmental conditions preferred by the species included in it. The first group are known as the `Slum group`, a term originally used by Boycott (1936) includes individuals with a tolerance of, or a preference for poor, water conditions. It represents small bodies of water that regularly fluctuate in temperature, stagnate or dry out (Sparks 1961). The second group is known as the `Catholic group` and represents the freshwater mollusca which tolerate a wide range of habitats except the slum environment (Sparks 1961). The third group is known as the `Ditch group` and included are species found in ditches with slow moving but clean water (Sparks 1961). The fourth and final group is known as the`Moving water group`. The species included within this group are commonly found in larger bodies of water that can be stirred by currents and wind (Sparks 1961).

As well as the size of the water body, authors have looked at other physical and chemical factors which influence the local freshwater environment. These could be substrate, pH, temperature, water quality or oxygen levels. Keen *et al* (1984) showed the importance of water quality to the molluscan population on a study of a kettle-hole in Kildale, Yorkshire. Kerney (1999) explained that certain species like “good clear-water conditions” and went on to show the species that preferred the vegetated shallow water around the lake margins.

Few fossil molluscan sequences have been examined from the deposits of Somerset as the acidic nature of the raised bogs limited preservation of individuals. A few sites have been reported, Alderton (1983) found molluscs present in cores taken at Somerton Drove and West Moor in Sedgemoor, which probably survived due to the limited amount of raised bog within Sedgemoor (Coles and Orme 1983). Fossil molluscs have been found in the Axe valley in palaeochannel fill (Haslett *et al* 2001b) but were of low to moderate diversity.

2.5.6 Presentation of sample results

Results are included in Chapters 4, 5 and 6 and are displayed using the Tilia computer package.

2.5.7 The statistical methods used

Cluster analysis was again undertaken to create the Dendrograms shown in the Tilia diagrams. The dendrograms were used to identify the zonation throughout the samples. Detrended correspondence analysis (DCA) was used to explore the ecological relationships in the data which is presented in scatter graphs (Dale and Dale 2002). The full statistical results are included in the Appendices for reference.

2.6 Radiocarbon dating

Radiocarbon dating methods are based upon the decay of ^{14}C from carbon material. The content of the isotope will decrease by a certain fraction per unit of time (Olsson 1986). Radiocarbon age determination was introduced in the 1940's by Willard Libby and is still one of the most widely used techniques for dating material. It can only be used for dating organic materials. Carbon exists in several forms ^{12}C, ^{13}C and ^{14}C, but only ^{14}C is radioactive. ^{14}C oxidises to CO_2 in the atmosphere and circulates as part of the global carbon cycle. When organisms die, they no longer exchange ^{14}C and, therefore, the amount declines (Mannion 1999).

The half-life of ^{14}C is the rate at which it decays to half of that originally present. Libby showed that the half-life was 5568 ± 30 years, which has now been corrected to 5730 ± 40 years, but in order to be consistent with earlier dates Libby's half-life is still used.

The age of a sample is calculated by comparing the remaining ^{14}C with that of a modern day sample. The measurement can be achieved in two ways. Conventional ^{14}C age determination involves the counting of beta particle emissions which are measured when ^{14}C is released from the samples as a gas. The second measurement is the Accelerator-Mass Spectrometry (AMS) age which involves the direct measurement of ^{14}C atoms by passing charged particles through a magnetic field at high speeds (Mannion 1999).

Each sample is given a Conventional ^{14}C Age which is the result after applying $^{13}C/^{12}C$ corrections to the measured age and is the most appropriate radiocarbon age (Beta Analytic guidance notes). Radiocarbon dates are then calibrated to convert before present (BP) dates to calendar years. The parameters used for these corrections have come from analysis of dated tree rings and corals and are available for samples of up to 19,000 years BP. As a mean is used to estimate the radiocarbon age the distribution of results need to be known, therefore, each sample is also given a standard deviation from the mean that is a measure of the standard error and can be seen as a estimation of confidence in the result.

There are several problems associated with age determination by ^{14}C. The date is the result of many influences on the sample. It is affected by the samples deposition, its collection, its relation to an event e.g. bioturbation, the accuracy of measurement of isotope activity and also an interpretation of the result (Olsson 1986). All of these factors will influence the final result of the radiocarbon date and consequently all possible steps should be taken to avoid circumstances that could affect the sample being given a true radiocarbon date.

2.6.1 Sample Collection

Collecting a sample for ^{14}C dating should be undertaken with care to avoid contamination with present day material. During this study samples were recovered with a Russian Corer in order to minimise sample contamination or deterioration.

2.6.2 Sample Storage

Following collection of the samples to be submitted for radiocarbon dating techniques, care was taken to avoid any degradation of the sediment. All samples to be radiocarbon dated were refrigerated at 2°C on the day of collection and remained refrigerated until sent to a laboratory for analysis.

2.6.3 Sample Analysis

Samples for radiocarbon dating were sent to the Beta Analytic Incorporated laboratory (4985 SW 74 Court, Miami, Florida, 331155 USA). Samples can usually be measured by the radiometric techniques and are analysed by synthesising the sample carbon to benzene, measuring the ^{14}C content in a scintillation spectrometer and then calculating for radiocarbon age. In some smaller samples extended counting is required. Accelerator-mass-spectrometer (AMS) methods can also be used which involves reducing the carbon content to graphite and sending this for ^{14}C measurement.

2.6.4 Pre-treatment of samples

Pre-treatment of the sample eliminates errors associated with secondary carbon components being present within the sample. Examples of these secondary sources are shells, roots and carbonate concentrations (Olsson 1986). Without the elimination of these components the result could be erroneous.

The pre-treatment of the sample reduces the sediment to a single component. The full pre-treatment method is that of a sequence of acid, alkali and finally acid washes. The sample is first crushed in water and then given hot HCL washes to remove carbonates and alkali washes (NaOH) to remove secondary organic acids. Each sample requires a unique combination of treatment e.g. repetitions, length of exposure and chemical concentrations, and is assessed by staff at Beta Analytic (Inc).

Additional acid washes may be required. This involves HCL being applied repeatedly to the sample to remove carbonate. This process is typical of organic sediment pre-treatment, including some peats and small wood or charcoal. The process is used when, for a number of reasons the sample could not be subject to alkali washes. An example of this is that the primary carbon is soluble in the alkali. The method of pre-treatment of each sample dated in this study is included in the results.

2.6.5 The Radiocarbon Age and Calibration

The Conventional ^{14}C Age is the result after applying $^{13}C/^{12}C$ corrections to the measured age and is considered the most appropriate radiocarbon age. Calibration has been carried out by using INTCAL98 (Stuiver *et al* 1998).

2.7 Chemostratigraphy

Sediments can be tested for heavy metal enrichment as a method to derive a date of deposition. Analysis can be undertaken for Pb, Zn, Cu and Ni using flame atomic absorption spectrophotometry. Burton and Liss (1976) showed that trace metal elements are readily absorbed onto the surfaces of fine sediment particles. Dominik *et al* (1978) and Clifton and Hamilton (1979) both showed how sediments have retained an historical record of these trace metals over time.

2.7.1 Chemostratigraphy in Somerset

Dating sediments by this method has been undertaken at several sites in the region. Stenner (1978) retrieved samples from the cave in Wookey Hole and used the heavy metal pollution in the sediment to date the samples. In 1982 Leech and Leach were able to identify the increase in lead in samples that could be correlated to the production of the oldest known lead ingots in the Mendip Hills by the Romans. Haslett *et al* (1998a) went on to show that samples retrieved from the Axe Valley could be tested to show the onset of Roman lead mining (Haslett *et al* 2001a & 2001b; French *et al* 1993). In aiming to date later sediments, Allen and Rae (1986) have examined salt-marshes in the Severn

Estuary. They analysed samples for the heavy metals that would have been produced during the industrial revolution in the region and created three chemozones relating to different periods (Fig. 2.4).

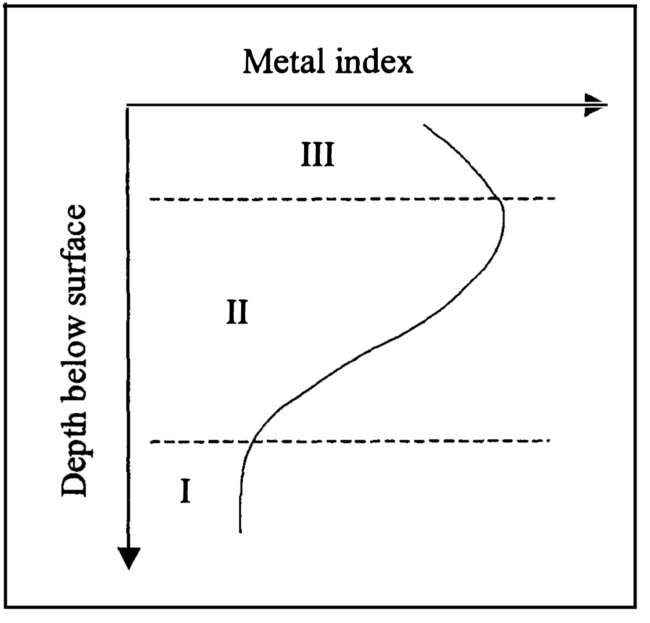


Fig. 2.4 Representation of the chemozones of Allen and Rae (1986)

Chemozone 1 represents what Allen and Rae (1986) describe as background levels of the chemicals studied and all levels are comparatively low. Chemozone 2 represents the deposits of the industrial revolution and an increase is seen in the chemical levels from deposits of this age. Chemozone 3 is dated to the period after the industrial revolution when levels of chemicals are seen to fall. The change from Zone I to Zone II is estimated to be between AD 1840 and 1850 and the Zone II to Zone III change at AD 1951 ± 4 yrs (Allen and Rae 1986). French (1996) undertook further investigations on the sediments of the Severn Estuary in an attempt to correlate radiometric dating techniques with heavy metal profiles in salt marsh sections. French (1996) demonstrated with his study how the measurement of metal pollution profiles can be used to infer detail about depositional history.

2.7.2 Laboratory analysis

The samples were air dried and weighed and were then soaked until the sediment began to break down. They were then washed through a 200µm sieve to obtain the <200µm fraction. The sediments were then dissolved by treating them with concentrated HCL and HNO_3 at a concentration of 3 to1 respectively (Forstner and Wittmann 1979). The sample was then analysed using flame atomic absorption spectrophotometry.

2.7.3 Reference material

The results obtained from the samples were compared with the values of the Global Shale Standard proposed by Forstner and Wittmann (1979). This reference data expresses metal concentrations that can be considered as `background' in the environment.

2.8 Particle size analysis

Soil particle size can be linked to the energy of the depositional environment. Crude particle size analysis was carried out on the lower clays recovered from the three main sites and on the core recovered at Stert.

The method involved passing the sediments through a series of differing sized sieves (-1 to 4 phi) which retain the appropriate portion for measurement. The silt and clay fractions (5 phi and above) were not examined as part of this analysis as it represents the fraction used for chemostratigraphic analysis.

Friedman and Sanders (1978) describe the –1 phi grade as being very fine pebbles while 0 phi sediment is very coarse to coarse sand. 2 phi, 3 phi and 4 phi represent the medium, fine and very fine sands.

These data are displayed using Excel area graphs, rather than cumulative frequency curves as this method is not easily applied to consecutive down-core samples.

Chapter 3 Stert

3.1 Site Details

As outlined in Chapter 2, while selecting sites for study in Sedgemoor a transect from the East to West in the valley was identified. In order to set the scene for the findings in the rest of the study the first site outlined is within the modern day estuary. A salt marsh on the Steart peninsula was selected for this purpose. The investigation at Steart[1] was twofold, (1) The surface of the salt marsh at Stert flats was examined seasonally over a year and sampled for microsfossils to provide a calibration for palaeoenvironmental datasets anticipated from older Holocene marine sediments in Sedgemoor, and (2) a 1m core was investigated with the aim of establishing salt marsh dynamics within the recent historical period in the modern Bristol Channel/Severn Estuary.

3.1.1 Site Location

The Steart peninsula is located in the Bristol Channel at the mouth of the River Parrett. The Bristol Channel is funnel shaped and has a tidal range in excess of 14m (Haslett 2000) and Stert flats is in an open coastal position being fully exposed to this the second largest tidal range in the world.

The village of Steart is on the peninsula and forms part of Otterhampton Parish which Somerset County Council estimated in 2002 had 910 residents. These residents of the parish are spread over a wide area of mainly rural land. The Steart peninsula is thought to be under threat from rising sea levels and the area has been subject to much study by consultants employed by the Environment

Agency. A Stolford to Combwich coastal defence strategy was published by the Agency in 2001 which examined the existing defences the area has and began looking towards sustainable options for the next 50 years or more. From this was developed the Steart Peninsula Project, which is currently examining the way ahead for the residents of Steart and the important natural habitat found there.

[1] The peninsula at Stert is known as the Steart Peninsula and the village located there is Steart. However the spelling of the Stert Flats where this research took place is correct as Stert.

Fig. 3.1 The saltmarsh studied at the Steart peninsula

Fig. 3.2 A northwest view along the modern day transect towards the Bristol Channel

Fig. 3.3 The foreshore of the marsh at Stert showing evidence of erosion and landward movement of the marsh

3.1.2 Topography

The salt marsh faces north west and slopes gently towards the shoreline. Fig. 3.4 shows the surface profile of the salt marsh along the transect studied. The sharp rise inland indicates where the marsh backs on to a gabion basket coastal defence.

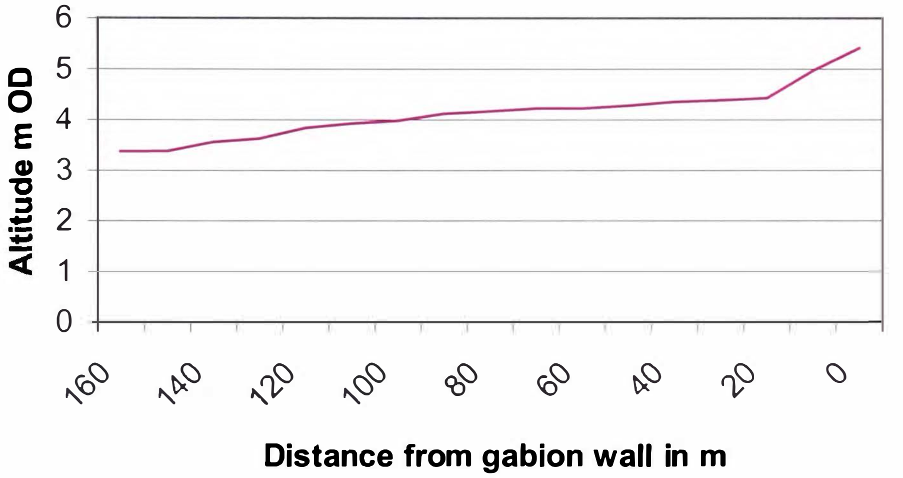


Fig. 3.4 Profile of the salt marsh surface at Stert (from King and Haslett 1998)

The salt marsh is in an exposed position in the estuary and forms an `Open-coast marsh` as described by French (1997) who suggested seven distinct marsh types that depended on the topographical conditions in which they have formed.

The site at Stert represents only part of the tidal range in the area as Mean High Water Spring tides occur at around 7 m OD which conditions the surface of the marsh would be completely inundated as the surface. Mean High Water Neap tides occur at around 3.7 m OD showing parts of the marsh are frequently affected by tide.

3.1.3 Fieldwork

Fig. 3.5 Sample sites along the Stert salt marsh

As outlined in Chapter 2, two differing sampling methods were used at Stert. A series of 17 surface samples at 10 m intervals were analysed seasonally between autumn 1997 and 1998. The locations of these samples are shown as the modern transect in Fig. 3.5 and the grid references shown in Table 3.1.

Sample Distance from gabion wall (m)	Grid Reference
0	ST 26599 45615
10	ST 26593 45620
20	ST 26587 45629
30	ST 26580 45637
40	ST 26572 45645
50	ST 26566 45653
60	ST 26560 45661
70	ST 26554 45669
80	ST 26546 45677
90	ST 26540 45684
100	ST 26535 45692
110	ST 26528 45700
120	ST 26522 45707
130	ST 26517 45714
140	ST 26511 45722
150	ST 26505 45732
160	ST 26499 45738

Table 3.1 Surface sample grid references at Stert

These sample sites were visited four times between October 1997 and October 1998 and the samples analysed for biostratigraphical evidence which is presented in section 3.2. In addition to the modern transect a one metre core of the salt marsh was analysed for biostratigraphical and particle size information. The location of the core is shown as ST1 in Fig. 3.5. The National Grid reference for the borehole site (ST1) is ST 26516 45668.

3.2 Results

3.2.1 Biostratigraphy

The sediments recovered from the Stert salt marsh were analysed for biological indicators that can be used to infer the environment in which they were deposited. As it is an intertidal area both the modern day and core samples were examined for foraminifera.

3.2.1.1 Modern analysis

Four modern surveys were undertaken at October 1997, February 1998, June 1998 and October 1998. Each time the seventeen samples retrieved were processed with Rose Bengal to distinguish between the foraminifera that were alive and those that were dead at the time of sampling (Walton 1952). Samples were then sieved to 63 μm and allowed to dry. Counts of living, dead and total populations were recorded for each of the four surveys. Tables 3.2 to 3.5 show the foraminiferal results of the four surveys. Each species column contains three results. The first column is the number of individuals alive at the time of sampling, the second column those dead and the third column in bold is the total count. For statistical analysis these tables were also examined as percentage counts which are included as total counts from Table 3.7 to 3.9. These tables are included at Appendix IV for reference. All statistical analysis is included at Appendix V

Dist. From Gabion (m)	*Jadammina macrescens*			*Trochammina inflata*			*Elphidium williamsoni*			*Quinqueloculina seminulum*			*Cyclogyra balkwilli*			*Cyclogyra involvens*			*Ammonia beccarii*			*Nonion germanica*			*Ammonia batavas*			*Elphidium crispum*		
0	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	0	0	0	**0**
10	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	0	0	0	**0**
20	1	53	**54**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	0	0	0	**0**
30	9	51	**60**	1	4	**5**	0	4	**4**	0	0	**0**	0	0	**0**	0	0	**0**	0	6	**6**	0	1	**1**	0	0	0	0	0	**0**
40	15	75	**90**	6	13	**19**	0	2	**2**	0	0	**0**	0	0	**0**	0	0	**0**	2	8	**10**	2	2	**4**	0	0	0	0	0	**0**
50	12	56	**68**	25	23	**48**	4	17	**21**	0	3	**3**	0	0	**0**	0	0	**0**	4	6	**10**	1	2	**3**	0	0	0	0	0	**0**
60	11	15	**26**	4	7	**11**	2	56	**58**	2	12	**14**	0	0	**0**	0	0	**0**	10	42	**52**	6	12	**18**	0	0	0	0	1	**1**
70	7	11	**18**	8	6	**14**	0	13	**13**	6	2	**8**	0	0	**0**	1	0	**1**	14	34	**48**	5	8	**13**	0	0	0	0	0	**0**
80	0	1	**1**	3	10	**13**	0	14	**14**	0	4	**4**	0	0	**0**	0	0	**0**	12	34	**46**	0	7	**7**	0	0	0	0	0	**0**
90	0	0	**0**	5	1	**6**	0	5	**5**	5	3	**8**	1	0	**1**	0	0	**0**	12	21	**33**	3	3	**6**	0	0	0	0	0	**0**
100	0	5	**5**	13	4	**17**	0	6	**6**	44	18	**62**	1	0	**1**	1	0	**1**	12	65	**77**	8	17	**25**	0	0	0	0	0	**0**
110	0	3	**3**	22	3	**25**	0	5	**5**	18	2	**20**	3	0	**3**	13	2	**15**	17	18	**35**	5	8	**13**	0	0	0	0	0	**0**
120	0	2	**2**	21	20	**41**	5	17	**22**	13	3	**16**	4	0	**4**	9	4	**13**	9	35	**44**	2	3	**5**	0	0	0	0	0	**0**
130	0	0	**0**	5	7	**12**	1	6	**7**	23	4	**27**	0	0	**0**	0	0	**0**	47	48	**94**	6	4	**10**	0	0	0	0	0	**0**
140	0	0	**0**	7	4	**11**	8	28	**36**	17	5	**22**	0	0	**0**	0	0	**0**	50	68	**118**	10	12	**22**	0	0	0	0	0	**0**
150	0	0	**0**	4	4	**8**	5	10	**15**	3	0	**3**	0	0	**0**	0	0	**0**	75	35	**110**	4	17	**21**	0	0	0	0	0	**0**
160	0	0	**0**	0	0	**0**	20	4	**24**	3	1	**4**	0	0	**0**	0	0	**0**	25	20	**45**	10	8	**18**	0	0	0	0	0	**0**

Table 3.2 Raw count results of the first survey (October 1997) at Stert. Total individuals in bold.

Dist. From Gabion (m)	*Jadammina macrescens*			*Trochammina Inflata*			*Elphidium williamsoni*			*Quinqueloculina seminulum*			*Cyclogyra balkwilli*			*Cyclogyra involvens*			*Ammonia beccarii*			*Nonion germanica*			*Ammonia batavas*			*Elphidium crispum*		
0	0	6	**6**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	0	0	0	0
10	6	31	**37**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	0	0	0	0
20	7	65	**72**	0	0	**0**	0	3	**3**	0	0	**0**	0	0	**0**	0	0	**0**	1	2	**3**	0	0	**0**	0	0	0	0	0	0
30	3	62	**65**	0	0	**0**	0	11	**11**	0	2	**2**	0	0	**0**	0	0	**0**	3	11	**14**	0	5	**5**	0	0	0	0	0	0
40	3	21	**24**	0	0	**0**	0	11	**11**	0	4	**4**	0	0	**0**	0	0	**0**	0	10	**10**	0	3	**3**	0	0	0	0	0	0
50	0	8	**8**	0	0	**0**	0	6	**6**	7	16	**23**	0	0	**0**	0	0	**0**	13	45	**58**	6	4	**10**	0	0	0	0	0	0
60	0	5	**5**	0	0	**0**	0	7	**7**	4	13	**17**	0	0	**0**	0	2	**2**	4	47	**51**	0	6	**6**	0	0	0	0	0	0
70	5	26	**31**	0	0	**0**	1	3	**4**	23	18	**40**	0	0	**0**	0	0	**0**	20	41	**61**	3	7	**10**	0	0	0	0	0	0
80	6	29	**35**	0	1	**1**	2	7	**9**	0	2	**2**	0	0	**0**	1	0	**1**	22	53	**75**	12	9	**21**	0	0	0	0	0	0
90	0	0	**0**	0	1	**1**	1	3	**4**	0	0	**0**	0	0	**0**	4	0	**4**	5	54	**59**	5	24	**29**	0	0	0	0	0	0
100	1	18	**19**	12	25	**37**		3	**3**	5	10	**15**	0	0	**0**	86	13	**99**	0	80	**80**	1	8	**9**	0	0	0	0	0	0
110	1	1	**2**	9	4	**13**	2	5	**7**	7	13	**20**	0	0	**0**	21	2	**23**	7	96	**103**	3	8	**11**	0	0	0	0	0	0
120	1	6	**7**	0	0	**0**	7	27	**34**	5	9	**14**	0	0	**0**	8	4	**12**	6	51	**57**	8	10	**18**	0	0	0	0	0	0
130	0	3	**3**	0	0	**0**	2	10	**12**	19	25	**44**	0	0	**0**	35	12	**47**	5	27	**32**	2	0	**2**	0	0	0	0	0	0
140	1	2	**3**	0	0	**0**	1	19	**20**	5	10	**15**	0	0	**0**	18	11	**29**	5	40	**45**	7	6	**13**	0	0	0	0	0	0
150	0	0	**0**	0	0	**0**	4	3	**7**	0	0	**0**	0	0	**0**		0	**0**	7	10	**17**	7	2	**9**	0	0	0	0	0	0
160	0	1	**1**	2	4	**6**	5	2	**7**	0	0	**0**	0	0	**0**	1	0	**1**	9	18	**27**	20	8	**28**	0	0	0	0	0	0

Table 3.3 The raw count results of the second modern transect (February 1998) at Stert

Dist. From Gabion (m)	*Jadammina macrescens*			*Trochammina inflata*			*Elphidium williamsoni*			*Quinqueloculina seminulum*			*Cyclogyra balkwilli*			*Cyclogyra involvens*			*Ammonia beccarii*			*Nonion germanica*			*Ammonia batavas*			*Elphidium crispum*		
0	0	29	**29**	3	36	**39**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	0	**0**	0	0
10	2	25	**27**	0	4	**4**	1	3	**4**	0	0	**0**	0	0	**0**	0	0	**0**	0	3	**3**	0	0	**0**	0	0	0	0	0	0
20	4	54	**58**	0	3	**3**	18	60	**78**	0	0	**0**	0	0	**0**	0	0	**0**	1	18	**19**	7	12	**19**	0	0	0	0	0	0
30	3	4	**7**	0	5	**5**	3	4	**7**	7	2	**9**	0	0	**0**	0	0	**0**	3	12	**15**	2	12	**14**	0	0	0	0	0	0
40	1	8	**9**	0	0	**0**	1	8	**9**	0	0	**0**	0	0	**0**	0	0	**0**	2	22	**24**	0	0	**0**	0	0	0	0	0	0
50	2	7	**9**	0	0	**0**	1	4	**5**	4	7	**11**	0	0	**0**	0	1	**1**	1	27	**28**	1	8	**9**	0	0	0	0	0	0
60	0	0	**0**	0	3	**3**	3	1	**4**	0	0	**0**	0	0	**0**	0	0	**0**	2	22	**24**	5	19	**24**	0	0	0	0	0	0
70	0	1	1	0	4	**4**	0	2	**2**	0	0	**0**	0	0	**0**	0	0	**0**	4	16	**20**	3	14	**17**	0	0	0	0	0	0
80	0	5	**5**	4	41	**45**	0	2	**2**	10	9	**19**	0	0	**0**	0	0	**0**	9	58	**67**	2	3	**5**	0	0	0	0	0	0
90	0	0	**0**	0	1	1	0	1	**1**	3	8	**11**	0	0	**0**	0	0	**0**	11	43	**54**	1	19	**20**	0	0	0	0	0	0
100	0	0	**0**	0	0	**0**	0	1	**1**	1	1	**2**	0	0	**0**	0	0	**0**	20	79	**99**	0	21	**21**	0	0	0	0	0	0
110	0	0	**0**	0	0	**0**	1	7	**8**	19	20	**39**	0	0	**0**	0	3	**3**	2	6	**8**	0	2	**2**	0	0	0	0	0	0
120	0	0	**0**	0	0	**0**	2	0	**2**	1	0	**1**	0	0	**0**	0	1	**1**	12	47	**59**	0	8	**8**	0	0	0	0	0	0
130	0	0	**0**	0	0	**0**	4	10	**14**	12	2	**14**	0	0	**0**	10	8	**18**	0	13	**13**	3	12	**15**	0	0	0	0	0	0
140	0	0	**1**	1	0	**0**	11	20	**31**	6	1	**7**	0	0	**0**	0	1	1	7	54	**61**	3	15	**18**	0	0	0	0	0	0
150	0	0	**0**	0	0	**0**	0	0	**0**	0	2	**2**	0	0	**0**	0	0	**0**	5	19	**24**	1	2	**3**	0	0	0	0	1	1
160	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	**0**	0	0	**0**	4	7	**11**	0	0	**0**	0	0	0	0	0	0

Table 3.4 The raw count results of the third modern transect (June 1998) at Stert.

Dist. From Gabion (m)	*Jadammina macrescens*			*Trochammina inflata*			*Elphidium williamsoni*			*Quinqueloculina seminulum*			*Cyclogyra balkwilli*			*Cyclogyra involvens*			*Ammonia beccarii*			*Nonion germanica*			*Ammonia batavas*			*Elphidium crispum*		
0	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	0	0	0	0
10	0	4	**4**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	0	0	0	0
20	0	17	**17**	0	14	**14**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	0	0	0	0
30	0	10	**10**	0	2	**2**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	0	0	0	0
40	0	3	**3**	0	0	**0**	0	2	**2**	0	0	**0**	0	0	**0**	0	0	**0**	0	1	**1**	0	0	**0**	0	0	0	0	0	0
50	1	4	**5**	0	1	**1**	0	11	**11**	0	1	**1**	0	0	**0**	0	0	**0**	0	35	**35**	0	10	**10**	0	0	0	0	0	0
60	0	0	**0**	0	0	**0**	1	18	**19**	0	1	**1**	0	0	**0**	0	0	**0**	1	4	**5**	1	11	**12**	0	0	0	0	0	0
70	0	5	**5**	1	57	**58**	0	0	**0**	0	9	**9**	0	0	**0**	0	0	**0**	1	18	**19**	0	4	**4**	0	0	0	0	0	0
80	0	1	**1**	0	0	**0**	0	2	**2**	0	1	**1**	0	0	**0**	0	0	**0**	4	28	**32**	1	12	**13**	0	0	0	0	0	0
90	0	1	**1**	0	1	**1**	0	0	**0**	0	6	**6**	0	0	**0**	0	0	**0**	0	9	**9**	0	2	**2**	0	0	0	0	0	0
100	0	4	**4**	0	7	**7**	0	7	**7**	0	18	**18**	0	0	**0**	1	5	**6**	0	15	**15**	0	2	**2**	0	0	0	0	0	0
110	0	5	**5**	0	5	**5**	0	5	**5**	1	23	**25**	0	0	**0**	8	13	**21**	0	16	**16**	0	8	**8**	0	0	0	0	0	0
120	0	3	**3**	0	3	**3**	1	3	**4**	2	4	**6**	0	0	**0**	5	1	**6**	0	4	**4**	0	2	**2**	0	0	0	0	0	0
130	0	14	**14**	1	24	**25**	0	3	**3**	4	5	**9**	0	0	**0**	3	2	**5**	0	4	**4**	0	1	**1**	0	0	0	0	0	0
140	1	7	**8**	1	13	**14**	1	21	**22**	8	8	**16**	0	0	**0**	0	9	**9**	19	38	**57**	0	27	**27**	0	0	0	0	0	0
150	0	4	**4**	0	4	**4**	0	18	**18**	3	2	**5**	0	0	**0**	5	8	**13**	0	6	**6**	1	4	**5**	0	0	0	0	0	0
160	0	21	**21**	2	21	**23**	0	40	**40**	5	18	**23**	0	0	**0**	8	44	**52**	0	9	**9**	0	7	**7**	0	0	0	0	0	0

Table 3.5 The results of the forth modern transect (October 1998) at Stert

Altitude M OD	Distance from gabion (m)	*J. macrescens*	*T. inflata*	*E. williamsoni*	*Q. seminulum*	*C. balkwilli*	*C.involvens*	*A. beccarii*	*N. germanica*	*A. batavus*	*E. crispum*
5.415	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.968	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.427	20	98.18	0.00	0.00	0.00	0.00	0.00	0.00	1.82	0.00	0.00
4.386	30	78.95	6.58	5.26	0.00	0.00	0.00	7.89	1.32	0.00	0.00
4.352	40	72.00	15.20	1.60	0.00	0.00	0.00	8.00	3.20	0.00	0.00
4.282	50	44.44	31.37	13.73	1.96	0.00	0.00	6.54	1.96	0.00	0.00
4.226	60	14.44	6.11	32.22	7.78	0.00	0.00	28.89	10.00	0.00	0.56
4.221	70	15.65	12.17	11.30	6.96	0.00	0.87	41.74	11.30	0.00	0.00
4.17	80	1.18	15.29	16.47	4.71	0.00	0.00	54.12	8.24	0.00	0.00
4.117	90	0.00	10.00	8.33	13.33	1.67	1.67	55.00	10.00	0.00	0.00
3.984	100	2.40	8.17	2.88	29.81	0.48	7.21	37.02	12.02	0.00	0.00
3.924	110	2.80	23.36	4.67	18.69	2.80	12.15	23.36	12.15	0.00	0.00
3.837	120	1.49	30.60	16.42	11.94	2.99	0.00	32.84	3.73	0.00	0.00
3.629	130	0.00	7.95	4.64	17.88	0.00	0.00	62.91	6.62	0.00	0.00
3.559	140	0.00	5.26	17.22	10.53	0.00	0.00	56.46	10.53	0.00	0.00
3.377	150	0.00	5.10	9.55	1.91	0.00	0.00	70.06	13.38	0.00	0.00
3.374	160	0.00	0.00	26.37	4.40	0.00	0.00	49.45	19.78	0.00	0.00

Table 3.6 Total foraminiferal results from the first survey (Oct 97) expressed as percentages

Altitude M OD	Distance from gabion (m)	*J. macrescens*	*T. inflata*	*E. williamsoni*	*Q. seminulum*	*C. balkwilli*	*C.involvens*	*A. beccarii*	*N. germanica*	*A. batavus*	*E. crispum*
5.415	0	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.968	10	97.37	0.00	2.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.427	20	92.31	0.00	3.85	0.00	0.00	0.00	3.85	0.00	0.00	0.00
4.386	30	67.01	0.00	11.34	2.06	0.00	0.00	14.43	5.15	0.00	0.00
4.352	40	46.15	0.00	21.15	7.69	0.00	0.00	19.23	5.77	0.00	0.00
4.282	50	7.62	0.00	5.71	21.90	0.00	0.00	55.24	9.52	0.00	0.00
4.226	60	5.68	0.00	7.95	19.32	0.00	2.27	57.95	6.82	0.00	0.00
4.221	70	21.23	0.00	2.74	27.40	0.00	0.00	41.78	6.85	0.00	0.00
4.17	80	24.31	0.69	6.25	1.39	0.00	0.69	52.08	14.58	0.00	0.00
4.117	90	0.00	1.03	4.12	0.00	0.00	4.12	60.82	29.90	0.00	0.00
3.984	100	7.25	14.12	1.15	5.73	0.00	37.79	30.53	3.44	0.00	0.00
3.924	110	1.09	7.10	3.83	10.93	0.00	12.57	56.28	6.01	2.19	0.00
3.837	120	4.90	0.00	23.78	9.79	0.00	8.39	39.86	12.59	0.70	0.00
3.629	130	2.11	0.00	8.45	30.99	0.00	33.10	22.54	1.41	1.41	0.00
3.559	140	2.38	0.00	15.87	11.90	0.00	23.02	35.71	10.32	0.79	0.00
3.377	150	0.00	0.00	21.21	0.00	0.00	0.00	51.52	27.27	0.00	0.00
3.374	160	0.00	0.00	41.46	0.00	0.00	0.00	31.71	26.83	0.00	0.00

Table 3.7 Total foraminiferal results from second survey (Feb 98) expressed as percentages

Altitude m OD	Distance from gabion (m)	J. macrescens	T. inflata	E. williamsoni	Q. seminulum	C. balkwilli	C.involvens	A. beccarii	N. germanica	A. batavus	E. crispum
5.415	0	42.65	57.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.968	10	71.05	10.53	10.53	0.00	0.00	0.00	7.89	0.00	0.00	0.00
4.427	20	32.77	1.69	44.07	0.00	0.00	0.00	10.73	10.73	0.00	0.00
4.386	30	12.28	8.77	12.28	15.79	0.00	0.00	26.32	24.56	0.00	0.00
4.352	40	19.51	0.00	21.95	0.00	0.00	0.00	58.54	0.00	0.00	0.00
4.282	50	14.29	0.00	7.94	17.46	0.00	1.59	44.44	14.29	0.00	0.00
4.226	60	0.00	5.45	7.27	0.00	0.00	0.00	43.64	43.64	0.00	0.00
4.221	70	2.27	9.09	4.55	0.00	0.00	0.00	45.45	38.64	0.00	0.00
4.17	80	3.50	31.47	1.40	13.29	0.00	0.00	46.85	3.50	0.00	0.00
4.117	90	0.00	1.15	1.15	12.64	0.00	0.00	62.07	22.99	0.00	0.00
3.984	100	0.00	0.00	0.81	1.63	0.00	0.00	80.49	17.07	0.00	0.00
3.924	110	0.00	0.00	13.33	65.00	0.00	5.00	13.33	3.33	0.00	0.00
3.837	120	0.00	0.00	2.82	1.41	0.00	1.41	83.10	11.27	0.00	0.00
3.629	130	0.00	0.00	18.92	18.92	0.00	24.32	17.57	20.27	0.00	0.00
3.559	140	0.84	0.00	26.05	5.88	0.00	0.84	51.26	15.13	0.00	0.00
3.377	150	0.00	0.00	0.00	6.67	0.00	0.00	80.00	10.00	0.00	3.33
3.374	160	0.00	0.00	8.33	0.00	0.00	0.00	91.67	0.00	0.00	0.00

Table 3.8 Total foraminiferal results from the third survey (June 98) expressed as percentage

Altitude m OD	Distance from gabion (m)	J. macrescens	T. inflata	E. williamsoni	Q. seminulum	C. balkwilli	C.involvens	A. beccarii	N. germanica	A. batavus	E. crispum
5.415	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.968	10	80.00	0.00	0.00	0.00	0.00	0.00	0.00	20.00	0.00	0.00
4.427	20	54.84	45.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.386	30	83.33	16.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.352	40	60.00	0.00	40.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.282	50	7.94	1.59	17.46	1.59	0.00	0.00	55.56	15.87	0.00	0.00
4.226	60	0.00	0.00	51.35	2.70	0.00	0.00	13.51	32.43	0.00	0.00
4.221	70	5.26	61.05	0.00	9.47	0.00	0.00	20.00	4.21	0.00	0.00
4.17	80	2.04	0.00	4.08	2.04	0.00	0.00	65.31	26.53	0.00	0.00
4.117	90	5.26	5.26	0.00	31.58	0.00	0.00	47.37	10.53	0.00	0.00
3.984	100	6.78	11.86	11.86	30.51	0.00	10.17	25.42	3.39	0.00	0.00
3.924	110	5.95	5.95	5.95	28.57	0.00	25.00	19.05	9.52	0.00	0.00
3.837	120	10.71	10.71	14.29	21.43	0.00	21.43	14.29	7.14	0.00	0.00
3.629	130	24.56	43.86	5.26	8.77	0.00	8.77	7.02	1.75	0.00	0.00
3.559	140	5.23	9.15	14.38	10.46	0.00	5.88	37.25	17.65	0.00	0.00
3.377	150	7.27	7.27	32.73	9.09	0.00	23.64	10.91	9.09	0.00	0.00
3.374	160	12.00	13.14	22.86	13.14	0.00	29.71	5.14	4.00	0.00	0.00

Table 3.9 Total foraminferal results from the fourth survey (Oct 98) expressed as percentages

Abundance in the samples was usually high with nine species being identified. These were of both agglutinating and calcareous forms and were mainly those considered to be common to the salt marsh environment.

Fig. 3.6 shows the percentage of *Ammonia beccarii* (non *batavus*) over the four transects. The species is seen to be present in high numbers in the low and middle marsh as would be expected (Scott and Medioli 1978, Murray 1991,Gehrels 1994).

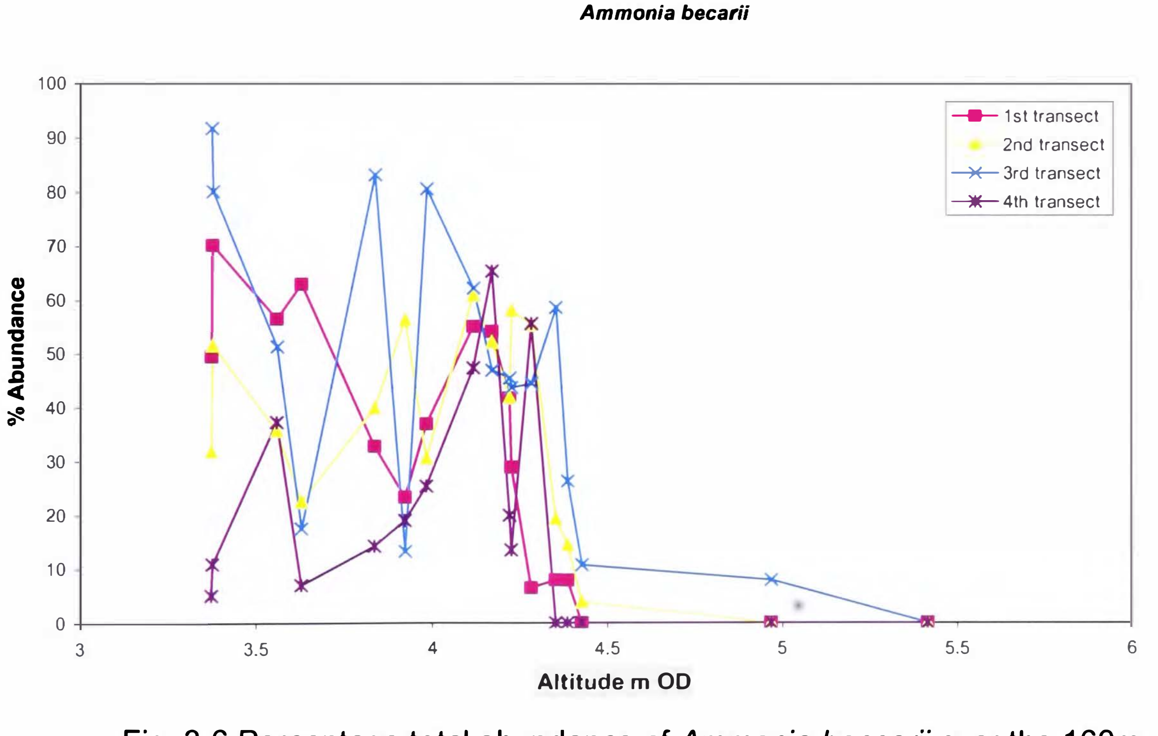


Fig. 3.6 Percentage total abundance of *Ammonia beccarii* over the 160m transect

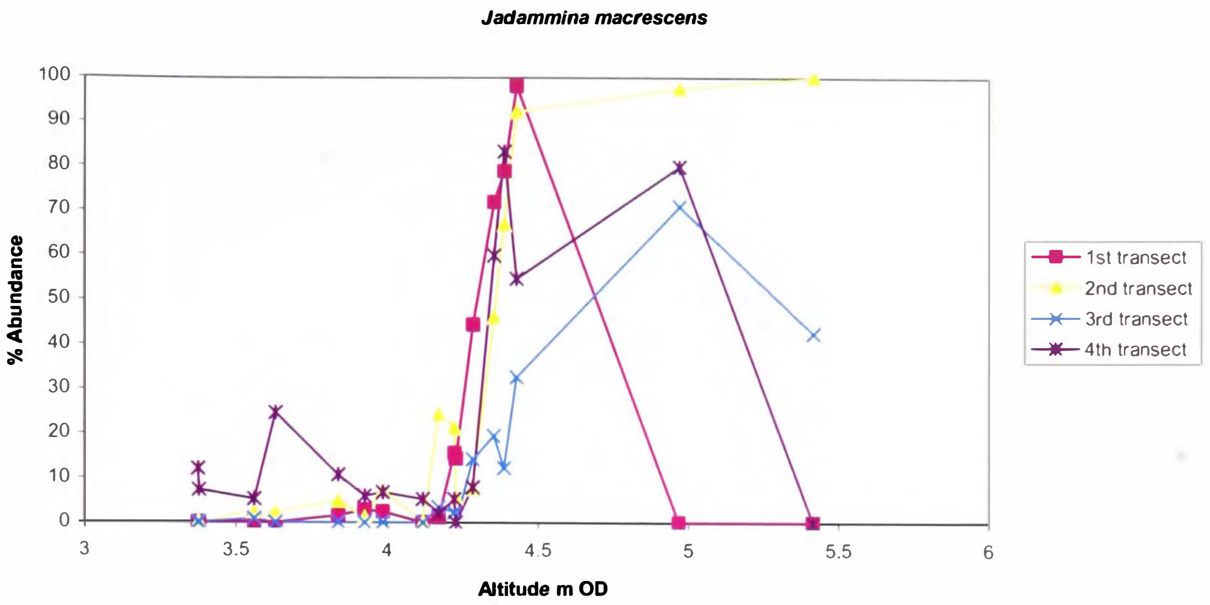


Fig. 3.7 Percentage total abundance of *Jadammina macrescens* over the 160m transect

Jadammina macrescens and *Trochammina inflata* are known to be species found in the high marsh environment (Scott and Medioli 1978, Murray 1991, Gehrels 1994). The result for *Jadammina macrescens* at Stert (Fig. 3.7) clearly demonstrate the species dominating the high marsh environment.

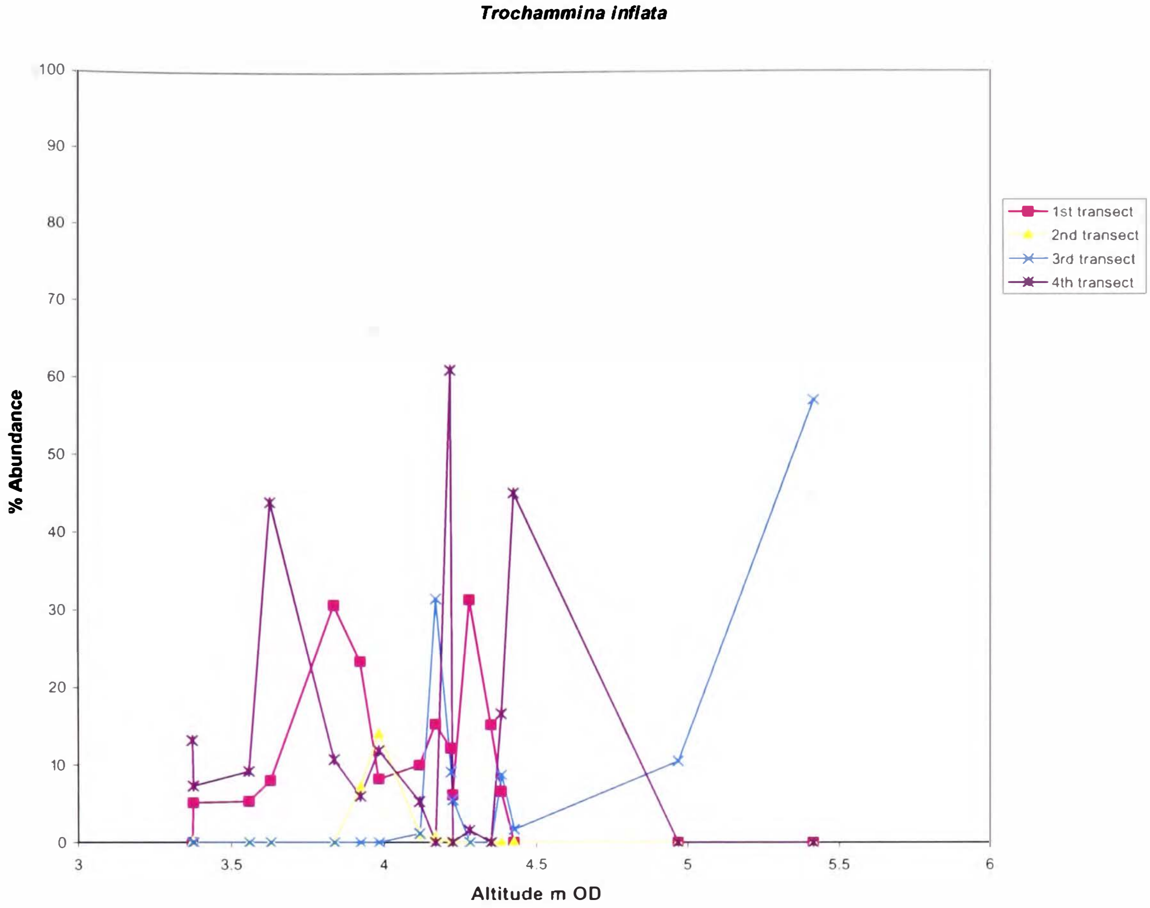


Fig. 3.8 Percentage total abundance of *Trochammina inflata* over the 160m transect

The results for *Trochammina inflata* at Stert (Fig. 3.8) are however more complicated with a less clear distinction between high and low marsh being evident.

Elphidium williamsoni are seen to decrease with altitude at Stert (Fig. 3.9) as would be expected with the species having been described as a low to mid marsh species (Scott and Medioli 1978, Murray 1991, Gehrels 1994).

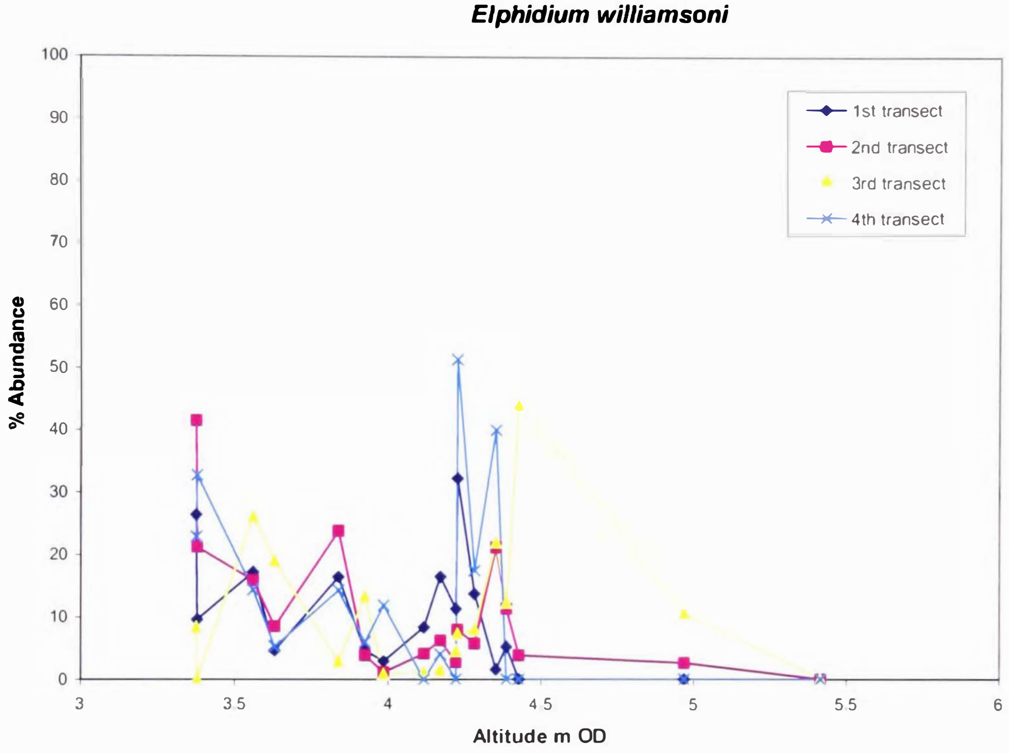


Fig. 3.9 Percentage total abundance of *Elphidium williamsoni* over the 160m transect

An unexpectedly high number of *Quinqueloculina seminulum* and *Cyclogyra involvens* have been identified at Stert. These species are usually considered to be a continental shelf species and surprisingly they have often been stained as being alive at the time of sampling. A possible explanation for the presence of *Quinqueloculina seminulum* at such high numbers is the open nature of the estuary environment in which the salt marsh at Stert is found. The high numbers may also be due to the high levels of salinity in the estuary as this marsh would be frequently inundated by the tides relatively undiluted by fresh river discharge. Fig. 3.10 shows that the *Quinqueloculina seminulum* are commonly found in the low and mid marsh but are absent from the high marsh environment at Stert.

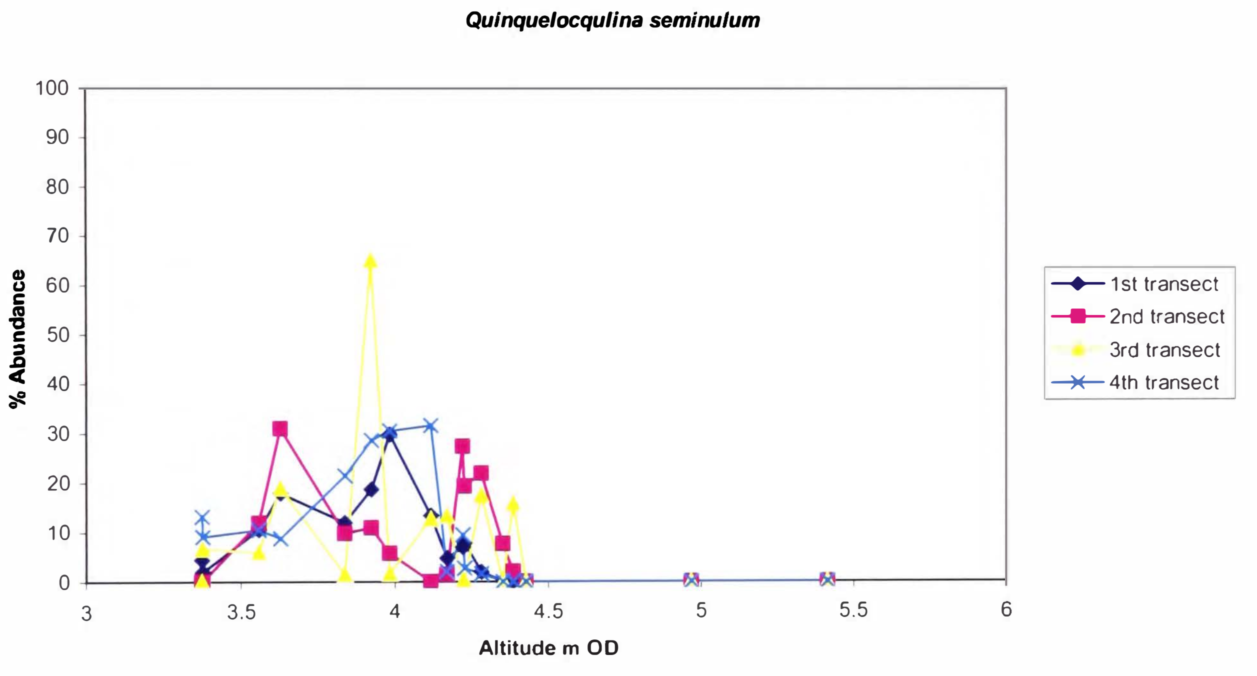


Fig. 3.10 Percentage total abundance of *Quinqueloculina seminulum* over the 160 transect at Stert

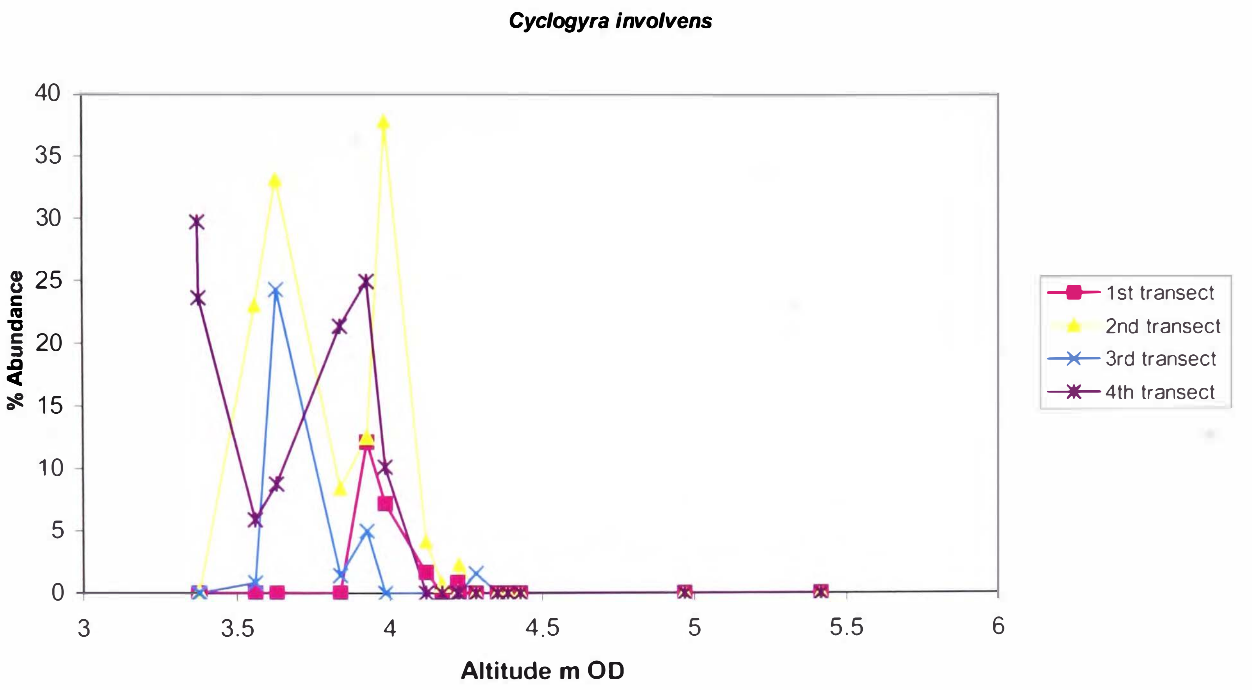


Fig. 3.11 Percentage total abundance of *Cyclogyra involvens* over the 160 m transect

Fig. 3.11 above shows the abundance of *Cyclogyra involvens* that was recorded during the four transects at Stert. *Cyclogyra involvens* is also considered to be a continental shelf species and again is probably present due to the open nature or high salinity of the estuary at Stert.

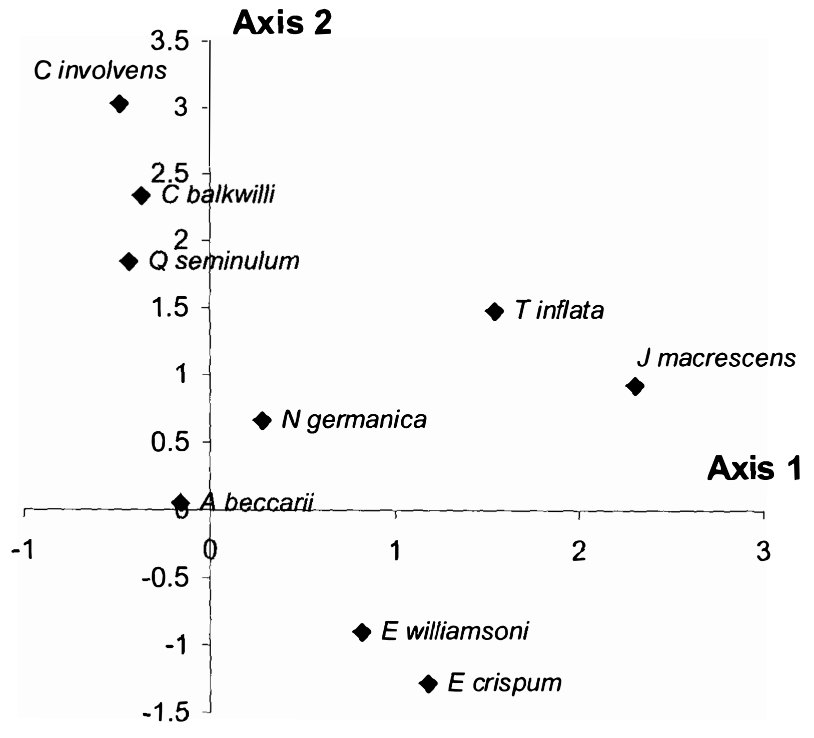


Fig. 3.12 Axis 1 and Axis 2 DCA results of the raw count foraminifera from the 1st transect

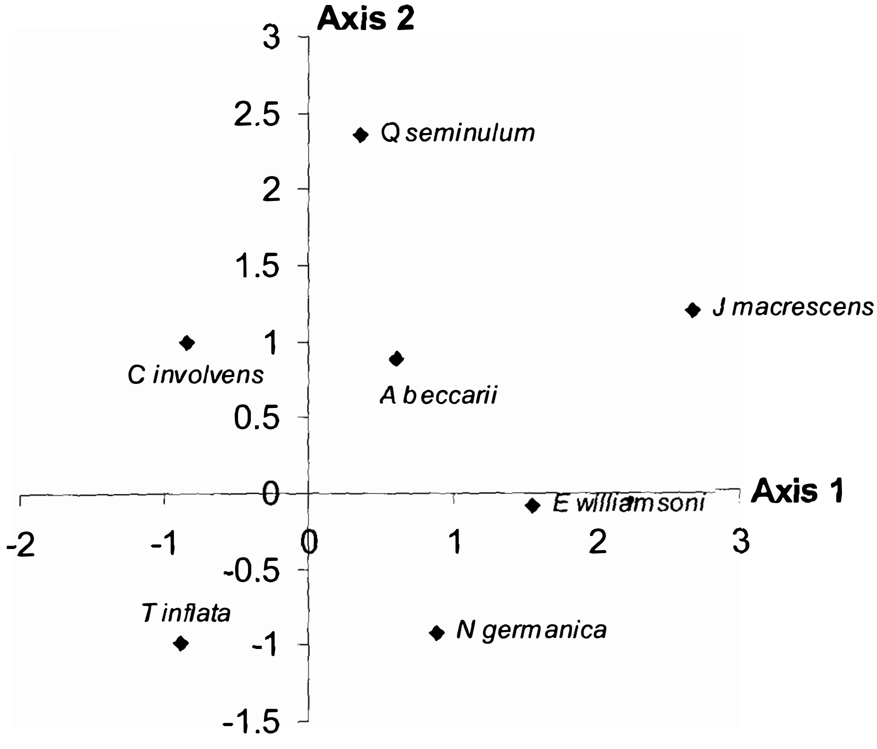


Fig. 3.13 Axis 1 and Axis 2 DCA results of the raw count foraminifera from the 2nd transect

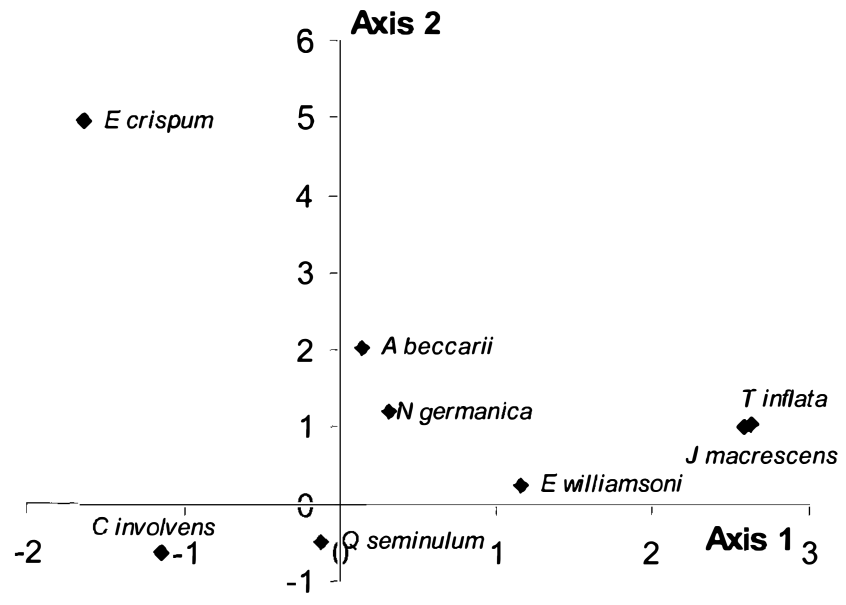


Fig. 3.14 Axis 1 and Axis 2 DCA results of the raw count foraminifera from the 3rd transect

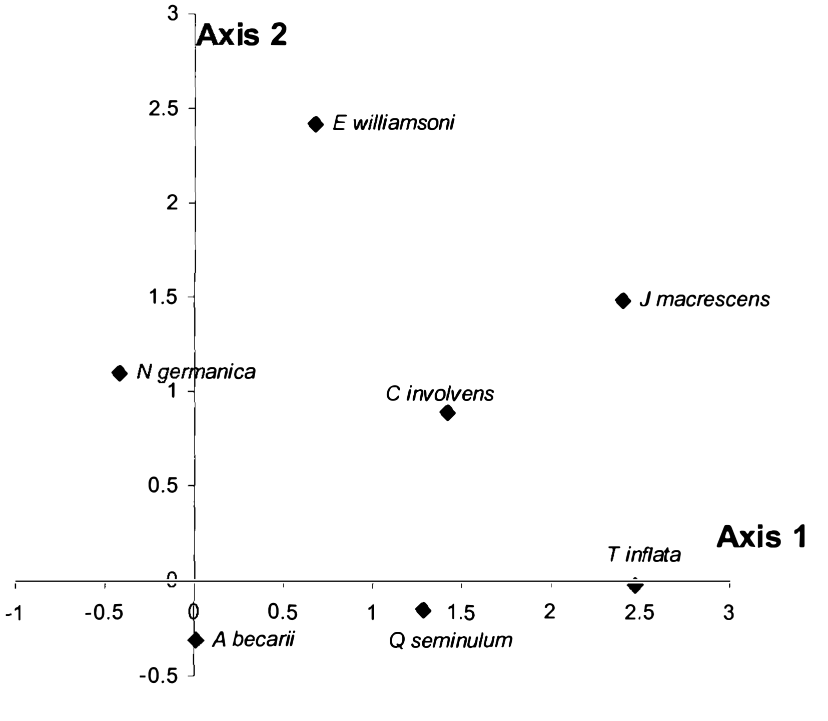


Fig. 3.15 Axis 1 and Axis 2 DCA results of the raw count foraminifera from the 4th transect

DCA analysis has been carried out on the foraminiferal results from Stert (Dale and Dale 2002) and the results shown in Figures 3.12 to 3.15. *T inflata* and *J macrescens* (both high marsh) can be seen to closely relate in three out of the four transects with only the second transect not showing a clear relationship. *N germanica* and *A beccarii* (both low to middle marsh species) are also seen to closely relate in the Stert modern transects. *C involvens* and *Q seminulum* (continental shelf species) also display a close relationship in the results.

3.2.1.2 Foraminiferal results from a core of the marsh at Stert

At the location identified in Fig. 3.5 a 1 m sediment core was recovered and analysed for foraminifera.

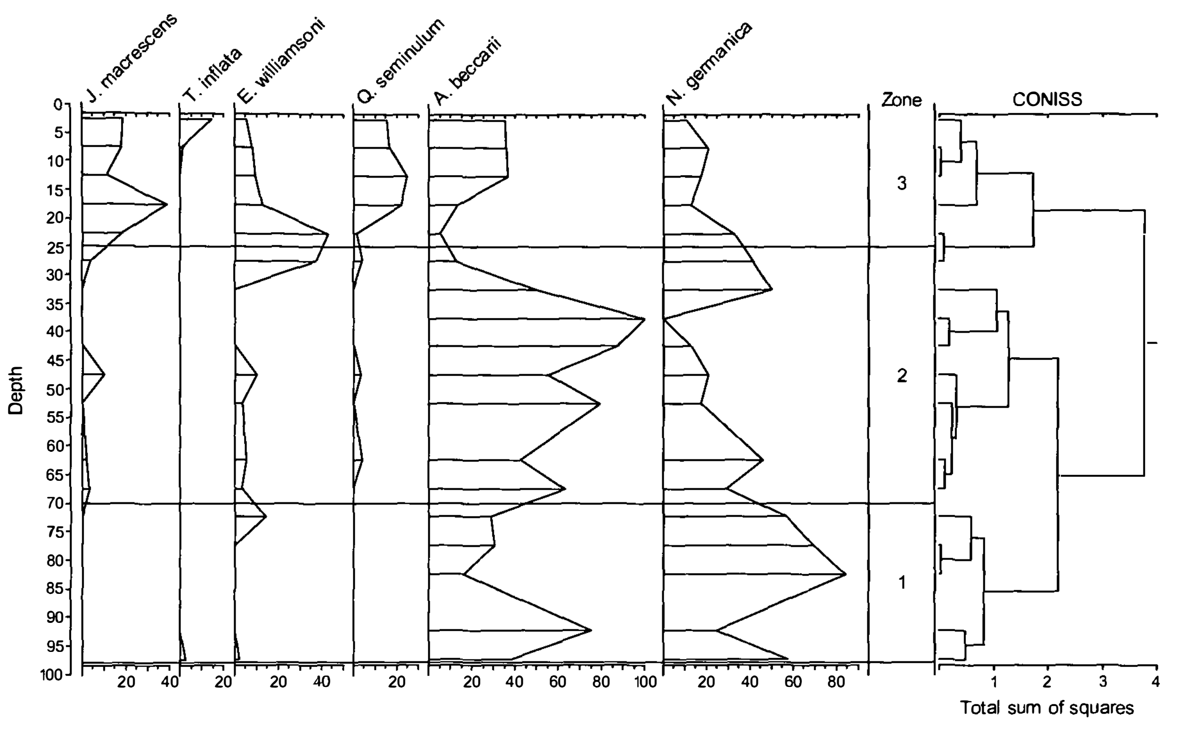


Fig 3.16 Percentage foraminiferal results for the core at Stert

Six species were recovered from the core at Stert and numbers of individuals were relatively high with some samples containing more than 150 individual specimens. The percentage data has been explored using cluster analysis and shows three zones represented by the dendrogram (Fig. 3.16) full details of the DCA analysis are included at Appendix IV and V. A lower zone (Zone 1) is dominated by *Nonion germanica* and *Ammonia beccarii,* which are species that have been shown to inhabit the mid to low marsh environment (Scott and Medioli 1978, Murray 1991 Gehrels 1994). This Zone covers the depth between

1m and 0.7m below the marsh surface. The second zone (Zone 2) is again dominated by *Nonion germanica* and *Ammonia beccarii* but also includes additional species with *Jadammina macrescens, Quinqueloculina seminulum* and *Elphidium williamsoni* being present in the samples. Care should be taken when considering the % abundance of *Nonion germanica* and *Ammonia beccarii* in this zone as it contains lower numbers of individuals thereby over emphasising the dominance. Abundance of *Ammonia beccarii* and *Nonion germanica* are seen to fall at the end of this zone. This zone spans 0.45 m between 0.7m and 0.25m in the core depth. It indicates a varied habitat at ST1 during this phase, foraminifera known to inhabit the both the inner continental shelf and the high marsh were found. The third zone evident from the statistical analysis (Zone 3) of the foraminiferal data covers the top 0.25m of the core at ST1. All six species are found within this zone with *Jadammina macrescens* becoming more abundant along with *Quinqueloculina seminulum. Ammonia beccarii* are also seen to recover in abundance after the decline at the end of Zone 2. Table 3.10 shows the foraminiferal data from the core as raw counts.

Depth (cm)	*J. macrescens*	*T. inflata*	*E. williamsoni*	*Q. Seminulum*	*A. beccarli*	*N. germanica*
0 – 5	35	28	11	29	66	20
5 – 10	13	1	6	12	26	15
10 – 15	6	0	5	13	19	9
15 – 20	9	0	3	5	3	3
20 – 25	30	0	72	2	9	55
25 – 30	1	0	9	1	3	10
30 – 35	0	0	0	0	1	1
35 – 40	0	0	0	0	7	0
40 – 45	0	0	0	0	7	1
45 – 50	3	0	3	1	16	6
50 – 55	0	0	1	0	23	5
55 – 60	1	0	3	2	22	24
65 – 70	2	0	2	0	36	17
70 – 75	0	0	1	0	2	4
75 – 80	0	0	0	0	7	16
80 – 85	0	0	0	0	4	21
90 – 95	0	0	0	0	33	11
95 – 100	0	1	1	0	17	26

Table 3.10 Raw foraminiferal results from the Stert core

3.2.2 Chemostratigraphy

The samples retrieved from the core at ST1 were analysed for levels of Zinc (Zn), Lead (Pb), Copper (Cu) and Nickel (Ni), as a method of dating the sediment sequence. The results are given in Table 3.11 and shown in figure 3.17.

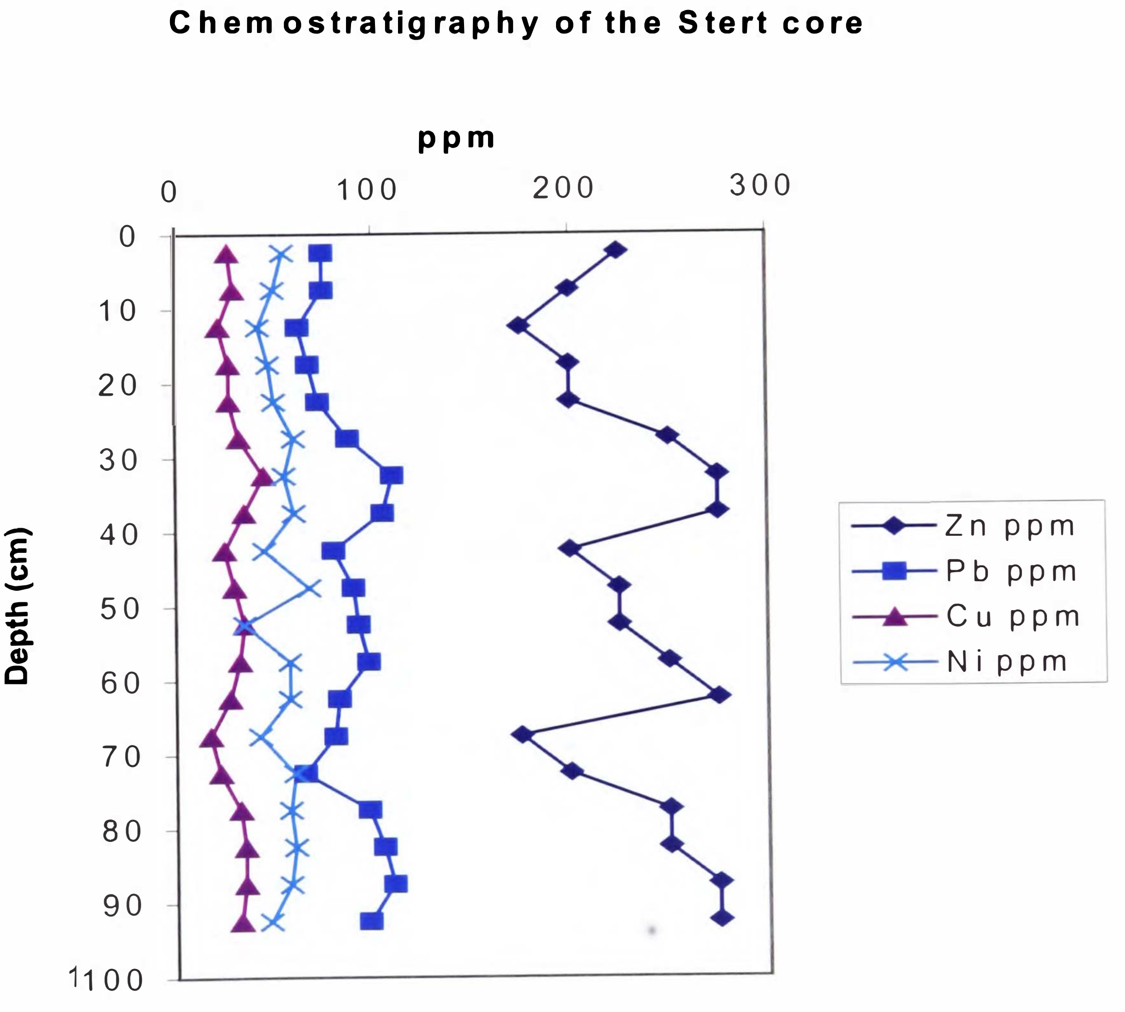


Fig 3.17 Chemostratigraphical results from the core ST1 at Stert

Allen and Rae (1986) examined the time sequence of metal pollution in the Severn estuary and produced the model at Fig 2.4 which defines chemozones aimed at assisting in the dating of sedimentary sequences. Chemozone I represents the background levels, Chemozone II the high levels of the industrial revolution and Chemozone III the post industrial falls in levels. The change from Zone I to Zone II is estimated to be between 1840 and 1850 and the Zone II to Zone III change at 1951 +/- 4 yrs (Allen and Rae 1986). French (1996) undertook further investigations on the sediments of the Severn Estuary in an attempt to correlate radiometric dating techniques with heavy metal profiles in salt marsh sections. French (1996) demonstrated with his study how the measurement of metal pollution profiles can be used to infer detail about depositional history.

Sample/depth (cm)	Zn (ppm)	Pb (ppm)	Cu (ppm)	Ni (ppm)
0-5	225	75.00	27.50	55.00
5-10	200	75.00	30.00	50.00
10-15	175	62.50	22.50	42.50
15-20	200	67.50	27.50	47.50
20-25	200	72.50	27.50	50.00
25-30	250	87.50	32.50	60.00
30-35	275	110.00	45.00	55.00
35-40	275	105.00	35.00	60.00
40-45	200	80.00	25.00	45.00
45-50	225	90.00	30.00	67.50
50-55	225	92.50	35.00	35.00
55-60	250	97.50	32.50	57.50
60-65	275	82.50	27.50	57.50
65-70	175	80.50	17.50	42.50
70-75	200	65.00	22.50	60.00
75-80	250	97.50	32.50	57.50
80-85	250	105.00	35.00	60.00
85-90	275	110.00	35.00	57.50
90-95	275	97.50	32.50	47.50

Table 3.11 Geochemical results from the Stert core

The geochemical results at Stert record higher than background levels for all of the metals analysed. The results for Zinc show the most variance with two clear peaks being visible. The results will be discussed at section 3.3.

3.2.3 Particle size analysis

Particle size analysis was carried out on samples retrieved from the core at Stert. The silt and clay fraction (5 phi and above) was not examined as part of the particle size analysis as this sediment fraction was used for the geochemical analysis.

Fig 3.18 shows the results of the particle size analysis for the sediments in the –1 to 4 phi range and full details are included at Appendix VII for reference. The –1 phi sediment equates to very fine pebbles on the Freidman and Sanders (1978) scale and at Stert this grade of particle shows a decline with some fluctuation down core. The 0 phi sediment or very coarse to coarse sand is also seen to decrease down core. The results for the 1 phi particles which are the coarse and medium sands show a consistent percentage throughout the core, while a change is seen in the 2 phi, 3 phi and 4 phi sediments. These sediments are the medium, fine and very fine sands and all of these categories increase down core to comprise a larger percentage of total sediment in the lower samples.

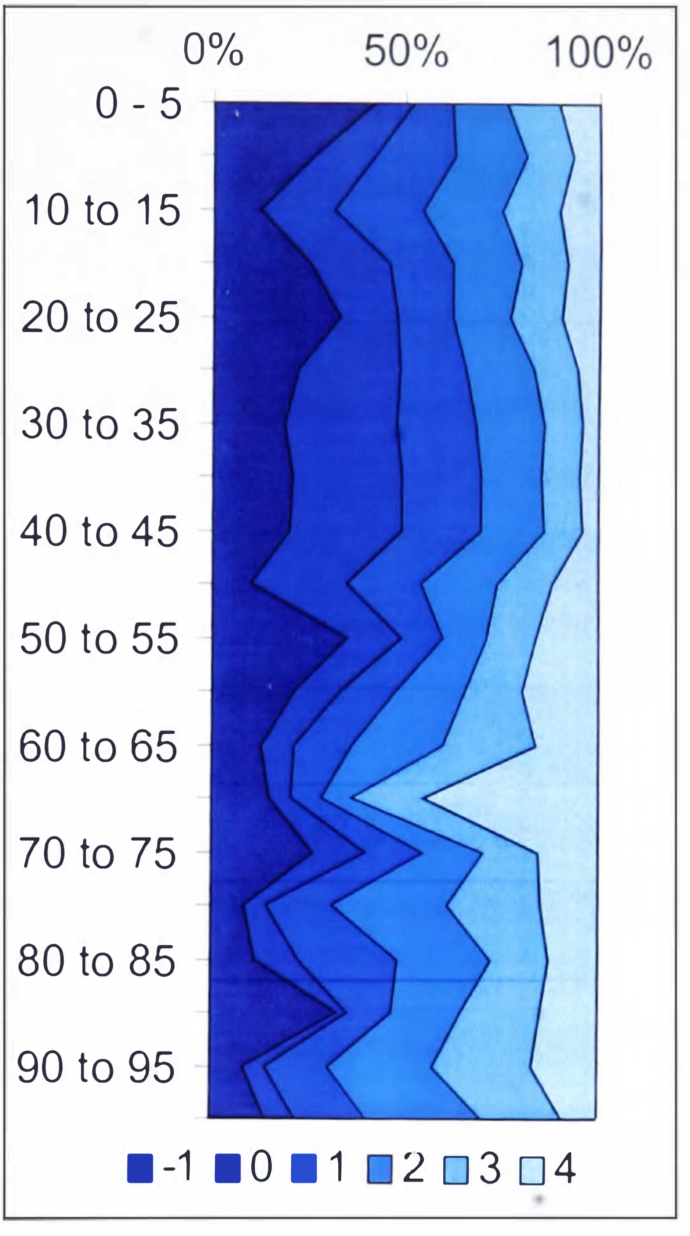


Fig 3.18 Particle size analysis from the core at Stert

3.3 The modern estuary: a study of the Steart Peninsula

The coastline that includes the Steart peninsular has seen rapid coastal retreat since the early twentieth century leading to a programme of defence strategies (Long *et al* 2001). This began early in 1928 and 1929 when the coastal protection authorities put in place a gravel bank and planted *Spartina anglica* in the hope that it would trap fine sediments and create a saltmarsh (Long *et al* 2001). Ranwell (1964) showed how for thirty years the marsh prograded seaward before beginning to retreat. The retreat has resulted in the new strategies currently being examined by the Environment Agency for the future of the Steart peninsula. Fig. 3.3 shows evidence that remnants of the marsh can now be seen in the mudflat which supports the accepted theory that sea level in the Severn Estuary is rising and the coast transgressing.

This study examined the salt marsh at Stert with the aim of partially filling the hiatus that exists between the information gathered in the inner levels until around 2000 years ago, and today. Modern biostratigraphical evidence shows saltmarsh foraminifera being present in high numbers on the marsh. An interesting feature is the abundant nature of two continental shelf species on the marsh. This is most likely the result of the open nature of the marsh itself and its position in an estuary with the second largest tidal range in the world. As mentioned earlier a further possibility could be the highly saline nature of the Severn Estuary which would frequently inundate this marsh.

In order to establish the local response of the salt marsh to sea-level rise a core was taken. Reed (1990) questioned the assumption that vertical saltmarsh accretion takes place in equilibrium with sea level rise. Other factors such as sediment supply and vegetation are also important and Reed (1990) suggested that in order to assess the reaction of a marsh to various sea level scenarios all the physical processes should be incorporated. Reed (1995) went on to show that net vertical accretion is a result of interactions between tidal imports, vegetation and depositional processes. Haslett *et al* (2001c) examined vertical salt marsh accretion in the Severn Estuary and suggested a model for three scenarios of foraminiferal sequence. The first scenario is for a Quasi-equilibrium foraminifera sequence where a salt marsh surface is accreting in equilibrium with sea level rise and, therefore, the marsh surface stays in a similar position in the tidal frame. The foraminifera recovered from a fixed point would show similar results through a core. The second scenario is the submergent foraminiferal sequence. In this scenario the accretion and subsequent elevation lags behind the rate of sea level rise (leading to drowning). The foraminifera recovered from a fixed point would show a progressive change from higher through to lower marsh species. The third zone is the emergent foraminifera sequence. In this marsh accretion and elevation overtake the rate of sea level rise and produce a sequence of foraminifera that change from low marsh to high marsh species. The results from Stert support this model proposed by Haslett *et al* (2001c) and suggests that the rate of accretion of the marsh at Stert is high. As a result of the advance of the sea and marsh retreat we would expect that the near shore foraminiferal species would become more abundant up core in the sediments. The foraminiferal results from the core at Stert however represent a relative sea level fall throughout the period of deposition. This sequence can be explained by also considering the amount and rate of sediment accretion at the marsh. These results support the work of Reed (1990, 1995) and implies that local factors including the sediment supply and vegetation are influencing the accretion of the saltmarsh at Stert in addition to the sea level rise occurring.

The chemostratigraphical results from the core at Stert indicate that all of the 1m of sediment is relatively recently deposited which again supports the theory that the rate of accretion is high. When compared to the Chemozones of Allen and Rae (1987) it appears that the whole of the sequence examined at Stert was deposited during the 20th century. Allen and Rae (1987) went on to examine the geomorphological and stratigraphical response of the Severn Estuary to shoreline oscillations and the chemostratigraphical content of the sediments they recovered. Their results for Zinc content show two peaks seen in many of the sequences of the Northwick Formation, which as explained in Chapter 1 is the youngest lithostratigraphical unit found in the Severn Estuary and to which the salt marsh at Stert is assigned. French (1996) undertook further investigations and from the results he reported it would suggest that the deposits examined at Stert are post 1958.

Particle size analysis was also carried out on the sediment recovered from the core at Stert. The results show that the fraction of coarser sediments increase up core while the finer fraction concurrently decreases upcore. Allen (1996) proposed that as a shoreline retreats and the sea advances the sediment sequence changes to reflect the conditions as sediment size decreases landward on a saltmarsh. In a core this would result in particle size increasing up core. This is further evidence that the marsh at Stert is retreating.

All of the results from investigations of the Stert salt marsh reported here show that the Steart peninsula is within a highly dynamic estuarine system and is currently responding to rising sea levels. The Stert study has only contributed to the final 100 years of the Holocene history of the Sedgemoor valley and the hiatus of the intervening 1900 years cannot be conclusively commented upon here beyond supporting that proposed by other authors (Haslett *et al* 1998a, Allen 1991) that it appears sea level has continued to rise throughout this period. As discussed in Chapter 1 this has been occurring against glacio-isostatic subsidence which has emphasised the relative rise. Haslett (1997) discussed the difficulties that will be faced in the low lying parts of Somerset as global warming continues bringing with it higher sea levels, more storminess and higher rainfall. The site at Stert has enabled this investigation of the mid to Late Holocene environmental history of the Sedgemoor Valley to be brought to the present day which will be discussed further in Chapter 7.

Chapter 4 Dundon Hayes

As stated in Chapter 2, following the initial investigation in the modern estuary, the strategy for sites for investigation in Sedgemoor required the study begin the Sedgemoor transect with an inland site and work towards the coast. Sedgemoor is an enclosed basin comprising part of the Rivers Parrett and Cary. Dundon Hayes was selected as the first site because it was at the head of the valley, close to a hill minimising sediment compaction and archaeological evidence shows it was an area that has a history of human occupation. Compton Dundon Hill Fort over looks the site (SHER 53760 – Somerset Historic Environment Record number) and Cunliffe (1982) explained that this major hill fort was occupied from late Bronze or early Iron Age. Bullied (1946) recorded oak piles near to Dundon Hayes consisting of some sharpened posts with mortice holes. Coles and Orme (1983) recovered traces of a wooden structure near Henley Bridge which was later dated in Coles and Orme (1985b) as 3020 ± 60 BP (HAR – 4998). At Lower Hayes Farm, Compton Dundon (ST 468 315) a Roman burial was discovered that suggested a Roman settlement on the site (Leech 1977). He found earthworks and vegetational marks on the site that suggested sub-surface building remains comprising of two rectangular structures with miscellaneous short linear features (SHER 53775).

4.1 Site Location

Dundon Hayes is located at the easternmost part of Sedgemoor near the town of Compton Dundon (Fig. 4.1). The site examined is located in a field on the northerly foot slope of a ridge that attains an altitude of 90mOD, upon which the Iron Age hill fort is situated. Dundon Hayes today is a village (Fig. 4.2) integrated with Compton Dundon. Parish records from 2001 show that the population of nearby Compton Dundon was recorded as 720 people and the area is mainly agricultural with large areas of pasture land (Fig. 4.3)

Fig. 4.1 The site studied at Dundon Hayes

Fig. 4.2 A westward view along Hayes Lane. Field of study to the right.

Fig. 4.3 A northward view across the basin towards Walton Hill

Fig. 4.4 A south east view from the top of Walton Hill across to Dundon Hayes.

4.1.2 Topography, Geology and soils

Dundon Hayes lies on the northerly foot slope of a ridge that rises to a height of 90 m OD. It is a sheltered basin surrounded and semi-enclosed by high ground to the South, East and North. To the North and East are the Polden Hills which reach a maximum of 119 m OD at Great Breach Wood (ST 50100 32200). These hills above Dundon Hayes are formed of Triassic rocks referred to as the Mercia Mudstone Group (Fig. 1.14). The Mercia Mudstone Group was previously known as the Keuper Marls, deposited in an arid environment. The hills around Dundon Hayes were formed by escarpment retreat since the opening of the Bristol Channel during the Tertiary (Gibbard & Lewin 2003). At nearby Compton Dundon a boring of 158 m took place in search of coal measures but failed to reach the base of the Keuper Marl (Woodward 1906). Woodward (1906) points out that the soils that form on this deposit yield a good fertile soil. Findlay *et al* (1984) classified the soil at Dundon Hayes as the Midelney Association. This soil type is confined to lowland areas and consists of clayey river alluvium overlying peat (Findlay *et al* 1984). Investigations here identified a heavy red clay that covers a depth of 1.37 m at some boreholes examined in this study (e.g. DH6). There is a gentle slope present in the field studied with the soil surface being recorded 8.07 m OD and falling away to 6.88 m OD over 140m of transect distance.

4.1.3 Fieldwork

Fig. 4.5 Borehole locations at Dundon Hayes

Seven boreholes were recovered at Dundon Hayes which were named DH1 to DH7 and are shown in Fig. 4.5. Table 4.1 gives the National Grid references for the boreholes. Borehole DH1 is located furthest from the foot slope of the ridge to the South of Dundon Hayes, and 140m from DH2 which is the closest to the Hill. The boreholes were taken at 20m intervals along the transect except between DH7 and DH1 where there is an intervening distance of 40m.

Borehole number	**Distance along transect (m)**	**Grid Reference**
DH1	140	ST 47977 32924
DH2	0	ST 48069 32765
DH3	40	ST 48068 32804
DH4	20	ST 48067 32784
DH5	60	ST 48068 32822
DH6	80	ST 48069 32843
DH7	100	ST 48069 32864

Table 4.1 Dundon Hayes borehole grid references

Borehole number and depth (m)	**Sample altitude (m OD)**	**Description**
DH1		
0 – 0.94	6.88 – 5.94	Red clay becoming paler with depth and snails at 86cm
0.94 - 1.14	5.94 – 5,74	Bluish grey clay organic at base
1.14 – 4.54	5.74 – 2.34	Peat, mainly Turfa with wood at base and phragmites
4.54 – 5.19	2.34 – 1.69	Blue/grey clay, wood at 499cm and grit at 510cm
5.19 – 5.22	1.69 – 1.66	Red clay, stopped coring in basal red clay
DH2		
0 – 0.95	8.07 – 7.12	Red clay becoming paler with depth
0.95 – 1.12	7.12 – 6.95	Pale grey (pinky) clay
1.12 – 1.26	6.95 – 6.81	Dark brown organic rich clay

1.26 – 1.29	6.81 – 6.78	Orangy coloured clay
1.29 – 1.37	6.78 – 6.70	Light brown clay
1.37 – 1.72	6.70 – 6.35	Buff/reddish clay with limestone (lst) fragments
1.72 – 1.87	6.35 – 6.20	Grey clay, quite organic
1.87 – 2.49	6.20 – 5.58	Red clay with lst and wood at 240cm
2.49 – 2.72	5.58 – 5.35	Red sand
2.72 – 2.84	5.35 – 5.23	Red clay with wood stopped coring in basal red clay
DH3		
0 – 0.97	7.80 – 6.83	Red clay becoming paler with depth
0.97 – 1.07	6.83 – 6.73	Bluish grey clay
1.07 – 1.17	6.73 – 6.63	Buff/reddish clay with molluscs
1.17 – 1.26	6.63 – 6.54	Yellowish clay with organic material
1.26 – 1.37	6.54 -- 6.43	Detrital peat with molluscs
1.37 – 1.48	6.43 – 6.32	Buff clay with molluscs
1.48 – 1.56	6.32 – 6.24	Light brown clay
1.56 – 1.86	6.24 – 5.94	Dark brown clay
1.86 – 2.00	5.94 – 5.80	Transition from brown clay to peat
2.10	5.70	Peat
2.10 – 2.15	5.70 – 5.65	Light coloured clay with molluscs
2.15 – 3.08	5.65 – 4.72	Clayey peat with wood
3.08 – 3.51	4.72 – 4.29	Blue/grey clay with wood at top
3.51 – 3.58	4.29 – 4.22	Red clay
3.58 – 3.74	4.22 – 4.06	Purplish/grey clay
3.74	4.06	Red clay
3.80	4.00	Stopped coring in basal red clay
DH4		
0 – 0.97	7.86 – 6.89	Red clay becoming paler with depth and snails at 65cm
0.97 – 1.07	6.89 – 6.79	Clayey peat
1.07 – 1.18	6.79 – 6.68	Grey pinky clay

1.18 – 1.51	6.68 – 6.35	Grey/brown clay with some oxidization between 125 - 130 cm
1.51 – 1.63	6.35 – 6.23	Bluish grey clay with organic staining
1.63 – 1.95	6.23 – 5.91	Brown/grey clay with oxidization spots and wood at 190cm
1.95 – 2.10	5.91 – 5.76	Red clay with wood
2.10 – 2.35	5.76 – 5.51	Organic rich peaty clay
2.35 – 2.40	5.51 – 5.46	Peaty clay with blue tinge
2.40	5.46	Red clay
2.94	4.92	Stopped coring in basal red clay
DH5		
0 – 1.08	7.46 – 6.38	Red clay topsoil stones at 40cm
1.08 – 1.11	6.38 – 6.35	Transition of clay to soil
1.11 – 1.15	6.35 – 6.31	Grey clay
1.15 – 1.21	6.31 – 6.25	Light brown macerated detrital organic clay synonomous with colluvium
1.21 – 1.50	6.25 – 5.96	Dark brown peat with light woody bits
1.50 – 2.00	5.96 – 5.46	Colluvium, brown detrital with roots
2.00 – 3.65	5.46 – 3.81	Woody dark peat
3.65 – 3.90	3.81 – 3.56	Blue grey clay, organic layer
3.90	3.56	Blue grey clay contact
3.97	3.49	Slight red tinge in clay
4.40	3,06	Blue clay layer
4.45	3.01	Contact with red clay
4.50	2.96	Hole abandoned in basal clay
DH6		
0 – 1.32	7.43 – 6.11	Red clay topsoil
1.32 – 1.37	6.11 – 6.06	Transition from red clay to red soil
1.37 –1.43	6.06 – 6.00	Bluish grey clay
1.43 – 2.42	6.00 – 5.01	Brown colluvium deposit

2.42	5.01	Peat contact
4.91	2.52	Clay to peat transition
4.96	2.47	Organic blue grey clay layer
5.03	2.40	Brown bluish clay getting bluer with depth
5.63	1.80	Transition to red basal clay with lumps of wood
5.73	1.70	Hole abandoned
DH7		
0 – 1.20	7.35 – 6.15	Red clay topsoil
1.20 – 1.25	6.15 – 6.10	Clay to soil transition
1.25 – 1.31	6.10 – 6.04	Bluish grey clay
1.31 – 2.30	6.04 – 5.05	Colluvium deposit
2.30 – 4.91	5.05 – 2.44	Peat – wood between 3.8 and 3.89
4.91 – 4.93	2.44 – 2.42	Transition peat to blue clay
4.93	2.42	Blue grey clay
5.38	1.97	Woody peat layer with clay intrusions
5.57 – 5.73	1.78 – 1.62	Blue grey clay layer
5.73	1.62	Contact with red basal clay
5.74	1,61	Hole abandoned

Table 4.2 Core descriptions summarised from field notes

4.2 Results

4.2.1 Lithostratigraphy

The lithostratigraphy at Dundon Hayes possesses elements of the classic clay-peat-clay sequence common to much of the Somerset Levels (Kidson and Heyworth 1976), described as the Somerset Levels Formation by Campbell *et al* (1999) and Haslett *et al* (2001). The Dundon Hayes lithostratigraphy however differs from the classic sequence, the main difference being that a true upper blue clay is absent at this site. Instead a colluvium deposit indicating a long history of slopewash is recorded.

A basal red clay overlies the basement which is 20cm in depth at some boreholes but up to a metre in borehole DH2. The altitude along the surface of this palaeosol varies from 1.65 m OD at DH1, and 6.20 m OD at DH2. A lower blue/grey clay unit overlies the red clay. It is found at its maximum thickness of 0.8m at DH7. Traces of the clay are seen at DH4 where it reaches an altitude of 5.506 m OD. The clay is overlain by peat that reaches a maximum thickness of 3.4 m at DH1. The surface altitude varies between 5.01 m OD and 6.20 m OD along the transect. The peat is initially a *Phragmities* peat which becomes a woody *Turfa* peat. Up sequence some detrital peat is evident and contains fresh water molluscs.

With the exception of DH1, the sediments recovered from the other boreholes show a series of clay or mud bands overlaying the peat. In field notes these bands were described as brown, buff and red clays that occasionally contained clastic material (DH2) and freshwater molluscs (DH3 and DH4). This evidence suggests this lithostratigraphical unit is a colluvial deposit representing in-wash from the nearby ridge to the South. The colluvial deposit attains a maximum thickness of 1.13 m at DH4, becoming thinner with distance from the base of the foot-slope, disappearing towards borehole DH1 (most distant from the foot-slope) where it is absent. The altitude of the colluvium surface varies between 7.122 m OD (DH2) and 6.04 m OD (DH7).

A thin bluish grey clay overlies the colluvium deposit which attains a maximum thickness of 0.2 m at DH1. The altitude of the clay surface varies between 6.886 m OD at DH4 and 5.944 m OD at DH1. Above this clay, the modern soil occurs which is red and clayey in nature. Findlay *et al* (1984) has classified this as the Midelney Association. The depth of this soil unit is 1.37 at its maximum which is found at borehole DH6. Its surface varies in altitude between 8.07 m OD at DH2 and 6.88 m OD at DH1.

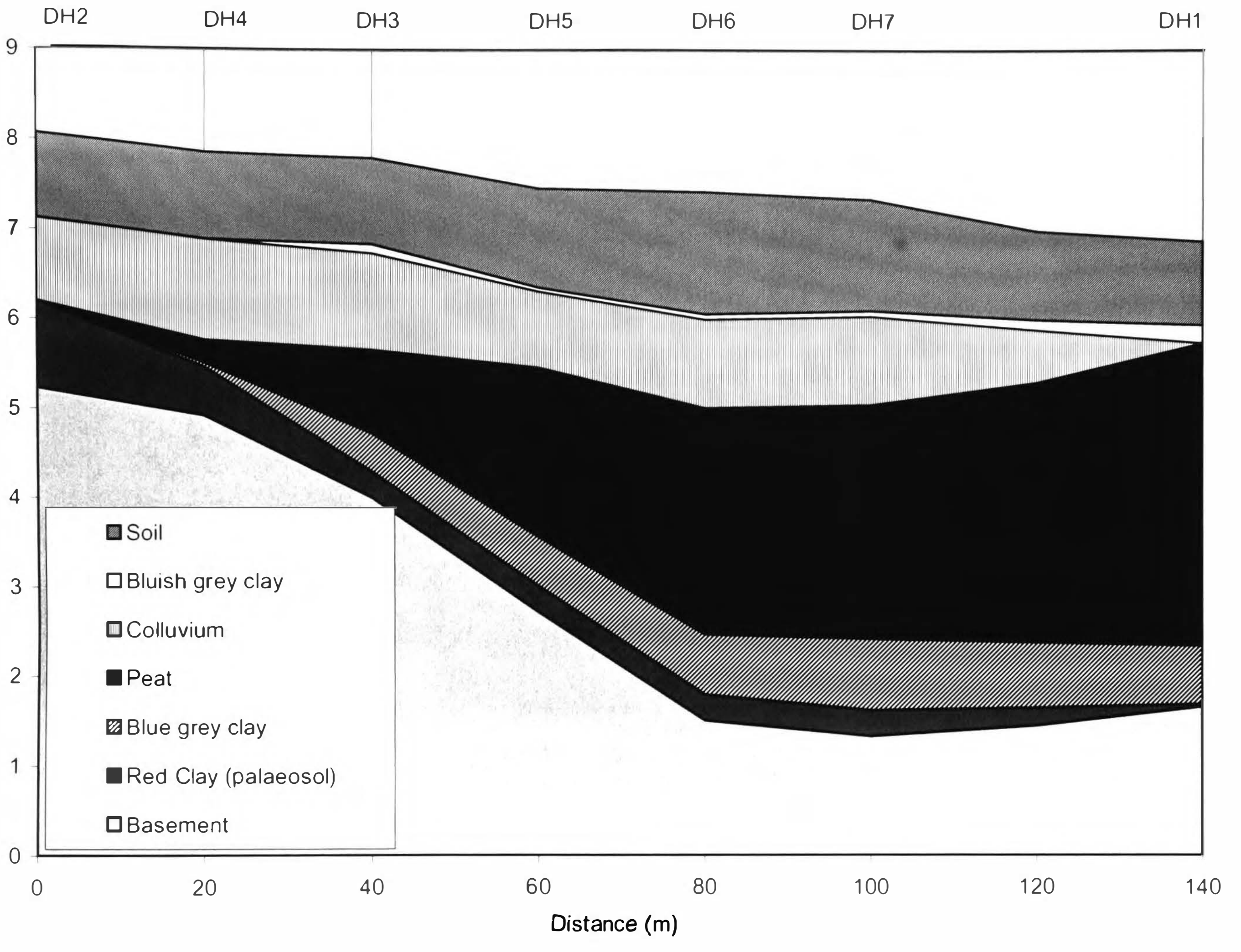


Fig. 4.6 Lithostratigraphy along Dundon Hayes transect (see Fig 4.5 and Table 4.1)

4.2.2 Biostratigraphy

The sediments recovered from Dundon Hayes were analysed for biological indicators that can be used to infer the environment in which they were deposited. The clays were analysed for foraminifera to establish whether they are of marine origin, and molluscan analysis was performed due to the abundant nature of molluscan remains in part of the sequence.

4.2.2.1 Foraminiferal results

Foraminifera, although low in numbers, were present in the lower blue clay indicating that the clay is a marine deposit. Table 4.3 contains the details of foraminifera present in a sequence of samples (DH1 454 – 522 depth) which were recovered from the blue clay at borehole DH1. The species of foraminifera present in the samples are those found in modern salt marsh inter-tidal environment. The grouping solely of *Trochammina inflata* and *Jadammina macrescens* has been shown to be indicative of Mean High Water Spring Tide (MHWST) in the Severn Estuary (Haslett *et al* 1998a).

4.2.2.2 Freshwater molluscs

A sequence of freshwater molluscs was recovered from the peat deposit in borehole DH5 (220 – 266 depth) and was analysed to establish species abundance. The results are shown as percentage data in Fig. 4.7 and as raw data in Fig. 4.8. The molluscan sequence recovered from DH5 represents an environment that was dominated by freshwater conditions. Mollusc species have been grouped into those of Sparks (1951), `Moving water`, `Ditch`, `Catholic' and `Slum` species. Some specimens of terrestrial species were found at Dundon Hayes and they are included on the raw count diagram.

The results show a diverse molluscan assemblage with high numbers of individuals (>300) in many samples. The number of molluscs present indicates that the preservation of the samples was very good . The overall assemblage is dominated by *Gyraulus crista* and *Lymnaea peregra* which are present in high numbers. These species form part of the `Catholic' group which are tolerant of many habitats from lakes through to habitats prone to seasonal drying. *Lymnaea peregra* is known as an early coloniser of habitats and is seen at Dundon Hayes as one of the species to dominate the early establishment of the freshwater environment. The `Slum' group make a larger percentage of the assemblage in this early phase of the sequence. These species can tolerate periods of drying and imply that some areas around Dundon Hayes were not always wet throughout this period. The one species of the `moving water' group that is most prominent during this early phase is *Gyraulus laevis,* which is interesting in that it is one of the few species tolerant of brackish conditions. It may have been present around

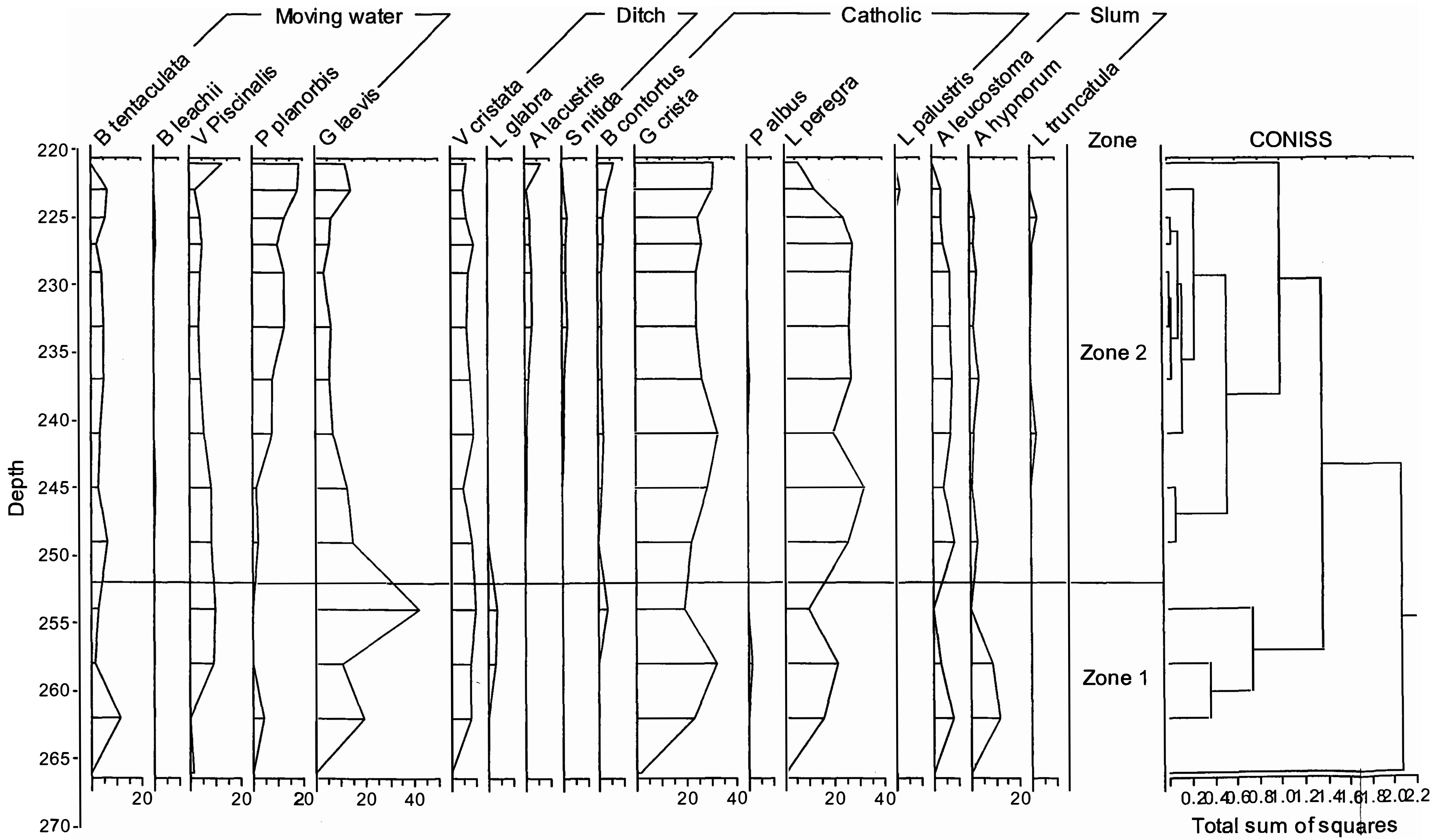


Fig. 4.7 Molluscan results from DH5 shown as percentage counts against depth (cm)

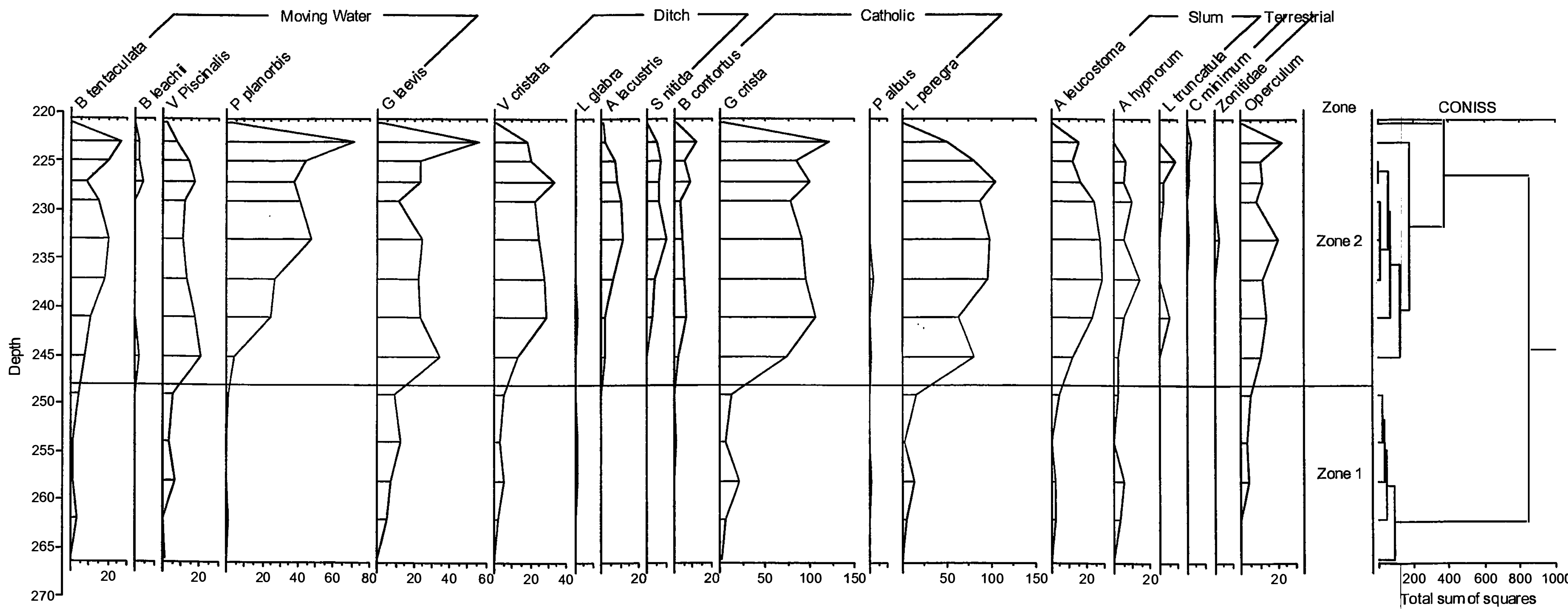


Fig. 4.8 Molluscan results from DH5 shown as raw counts against depth (cm)

the fringes of the previous intertidal area and therefore was one of the first colonisers.

Up sequence, at depth 253 cm, abundance and species diversity increases. The `Moving water' species become more evident with *Planorbis planorbis* numbers being high. *Planorbis planorbis* is found in many types of freshwater aquatic habitats but is particularly related to well vegetated areas. Other species confirm the presence of vegetation; *Valvata cristata* strongly prefer richly vegetated areas and the presence of *Ancylus lacustris*, *Lymnaea truncatula* and *Carychium minimum* further up the sequence all support the evidence for a well vegetated water body. *Bithynia tentaculata* is also constantly present up sequence indicating that the water body at Dundon Hayes was large and well oxygenated at this stage. Several of the species found in the sequence suggest that the water body would have had a muddy substrate. For example, *Bithynia tentaculata*, *Valvata piscinalis* and *Valvata cristata* are all species that are abundant throughout the sequence and which thrive in habitats with a muddy substrate. A retrograde succession is seen at the top of the sequence (220 cm) where a sharp decline in numbers brings the molluscan sequence to a close.

Detrended Correspondence Analysis (DCA) has been used on both the percentage data and the raw data to explore the ecological relationships of the species seen at Dundon Hayes. The results are presented as scatter graphs of Axis 1 against Axis 2 at Figures 4.9 and 4.10 (Dale and Dale 2002).

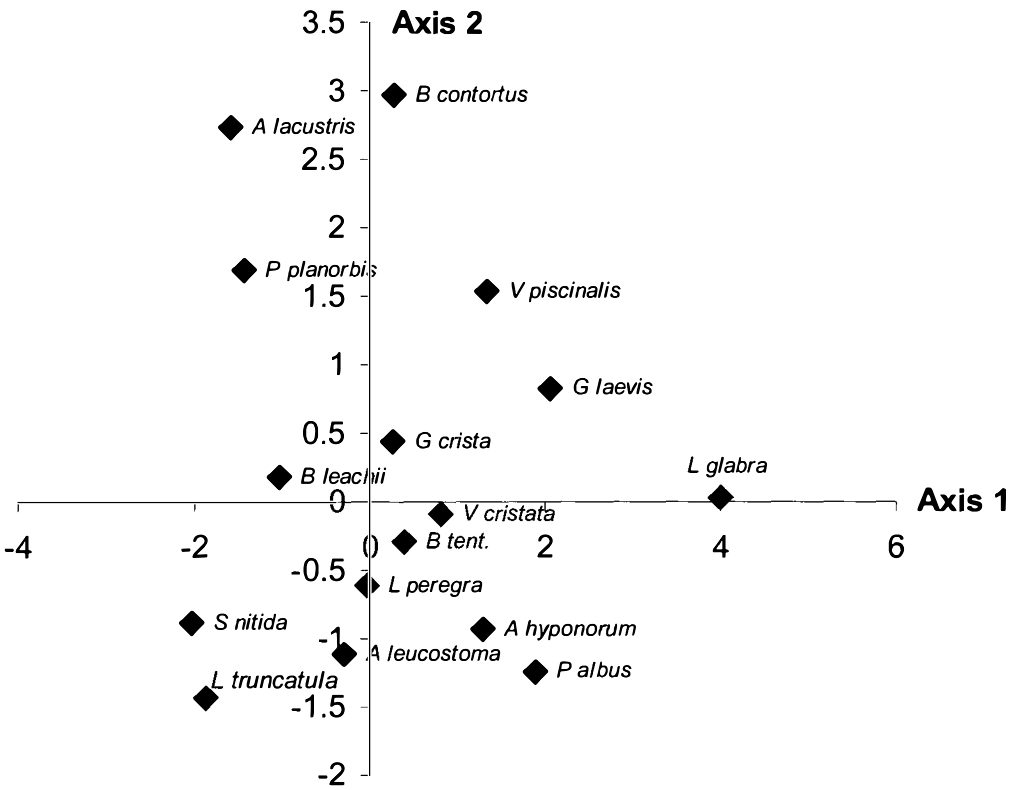


Fig. 4.9 Axis 1and Axis 2 results from the DCA of the percentage molluscan data at Dundon Hayes

The results shown in Fig. 4.9 are not straightforward. However, evidence for the groups proposed by Sparks (1951) can be seen along Axis 1 results from the raw count data (Fig. 4.10) with *B Leachii, G laevis, P planorbis* and *B tentaculata* (from the moving water group) being at a similar point along the axis. *V cristata* and *A lacustris* (ditch species)are also at the same area along Axis 1 although *S nitida* is higher up the Axis.

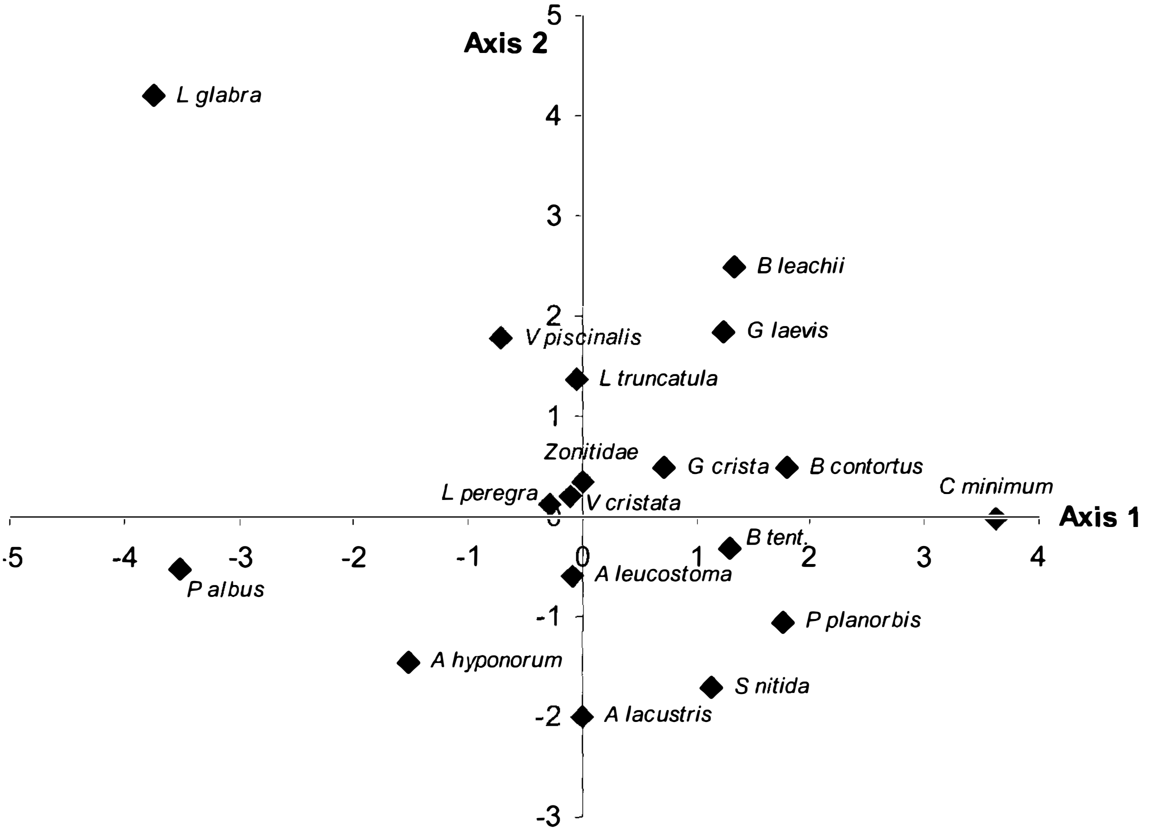


Fig. 4.10 Axis 1 and Axis 2 results from the DCA of the raw molluscan data at Dundon Hayes

Cluster analysis of the molluscan percentage and raw data has been carried out to produce dendrograms identifying clusters of statistically significant information. These results confirm that in both the percentage and the raw counts at Dundon Hayes there are two zones evident. Zone 1 in the raw data begins with the first sample analysed at Dundon Hayes from a depth of 267 cm and continues until depth 248 cm. In the percentage data Zone 1 is seen to finish slightly lower at 252 cm depth. Zone 1 represents the initial phase of habitat development when \`Catholic\` and \`Ditch\` species are the main representatives. This indicates a phase of initial environment colonisation that may have included drier periods. This would not have affected the \`Catholic\` species, which are more tolerant to changes in environmental conditions. The Ditch species are able to thrive in slowly moving or still waters. There is an indication, suggested by some of the \`Moving water\` species in Zone 1, that there were periods of time when the water body at Dundon Hayes was large enough to be classed as lake-like with currents.

The change to Zone 2 is particularly evident in Fig. 4.8, showing the raw mollusc data with its lower boundary at 248 cm where abundance is seen to increase markedly. The data in Fig. 4.7 shows the lower boundary of Zone 2 at 252cm with all four groups well represented from the outset, continuing throughout the Zone. This zone represents a period when the larger water body dominated, but where the other environments were likely to be present around the fringes. The molluscan information gathered outlines a period of ecological succession. The early colonisers found in most environmental conditions, through to a period when those that would be expected to be found in more established large water bodies are higher in numbers. Full details of the DCA and the cluster analysis is shown at Appendix I for reference.

4.2.3 Radiocarbon Dates

Five samples retrieved from Dundon Hayes were selected and submitted for radiocarbon analysis and the results are given in Table 4.4. The initial samples chosen for dating were those between the lower blue clay and the peat so that the date of the marine transgression could be established. Samples were from DH3 at a depth of 298-308 cms and from DH1 at 445 – 454cm. The sample from DH1 at an altitude of 2.34 m OD was dated to between 6160 and 5920 cal. yrs BP. The same contact between the lower clay and the peat was dated at borehole DH3 as between 4795 and 4170 cal. yrs BP. The altitude from which this sample was recovered was 4.71 m OD. The results from these samples indicate that the altitudinally lower contacts are older possibly suggesting that peat development began at the lower altitudes and grew up over the exposed blue clay surface. This supports evidence proposed by Haslett *et al* (2001b) who found a similar altitudinal – chronostratigraphic relationship at Nyland Hill in the Axe Valley.

The samples selected to date the upper peat and clay boundary were retrieved from DH5 at a depth of 120 – 125cm and DH7 at 131-141cms. The radiocarbon date of the samples from DH5 is between 1050 and 780 cal. yrs BP and is from an altitude of 6.31 m OD. The DH7 sample was assigned a radiocarbon date of between 940 and 670 cal. yrs BP and was recovered from 6.04 m OD.

A further sample (DH5 267 – 271 cm) was analysed to clarify the date at the beginning of the snail sequences in the detrital peat. The Radiocarbon date of this sample is between 3820 and 3490 cal. yrs BP and was recovered from an altitude of 4.79 m OD.

Lab Code	Sample (cm)	Context	Altitude m OD	Conventional ^{14}C age BP	2 Sigma calibrated Calendar yrs BP	2 Sigma cal. results yrs BC/AD	Calibrated intercept age Calendar yrs BP
Beta – 131494	DH3 298-308	Clay-Peat boundary	4.71	3970+/- 80	4795 to 4770 4620 to 4215 4210 to 4170	2845 to 2820 2670 to 2265 2260 to 2220 BC	4425
Beta – 131493	DH1 445-454	Clay-Peat boundary	2.34	5200+/- 40	6160 to 6145 6110 to 6050 6035 to 5920	4210 to 4195 4160 to 4100 4085 to 3970 BC	5985
Beta – 148754	DH5 120-125	Peat-Clay boundary	6.31	1010+/- 60	1050 to 780	900 to 1170 AD	930
Beta – 148755	DH7 131-141	Peat-Clay boundary	6.04	880+/- 70	940 to 670	1010 to 1280 AD	780
Beta – 153513	DH5 267-271	Peat-snail boundary	4.79	3400+/- 50	3820 to 3780 3730 to 3490	1870 to 1840 1780 to 1540 BC	3640

Table 4.4 Radiocarbon dates recorded at Dundon Hayes

4.2.4 Particle size analysis

Crude particle size analysis was carried out on the lower clay samples retrieved from Dundon Hayes (DH1) as a way of further understanding the depositional environment. Particle size is linked to energy and in salt marshes decreases with distance from the salt marsh shore (Allen, 1994, 1996). The results from Dundon Hayes are shown in Fig. 4.11 and are outlined in full at Appendix VII for reference.

The < 63μm fraction of the samples were lost during the sieving for biostratigraphical analysis. The remaining fraction that has been analysed here is the sediments that make up the sand – grade component of the sediment size spectrum. The lowest samples in the core possess a greater proportion of the finer size fraction inferring that the initial phase of deposition was under relatively low energy conditions. Particle size increases abruptly at 500 – 511 cms depth possibly representing a change to a higher energy environment.

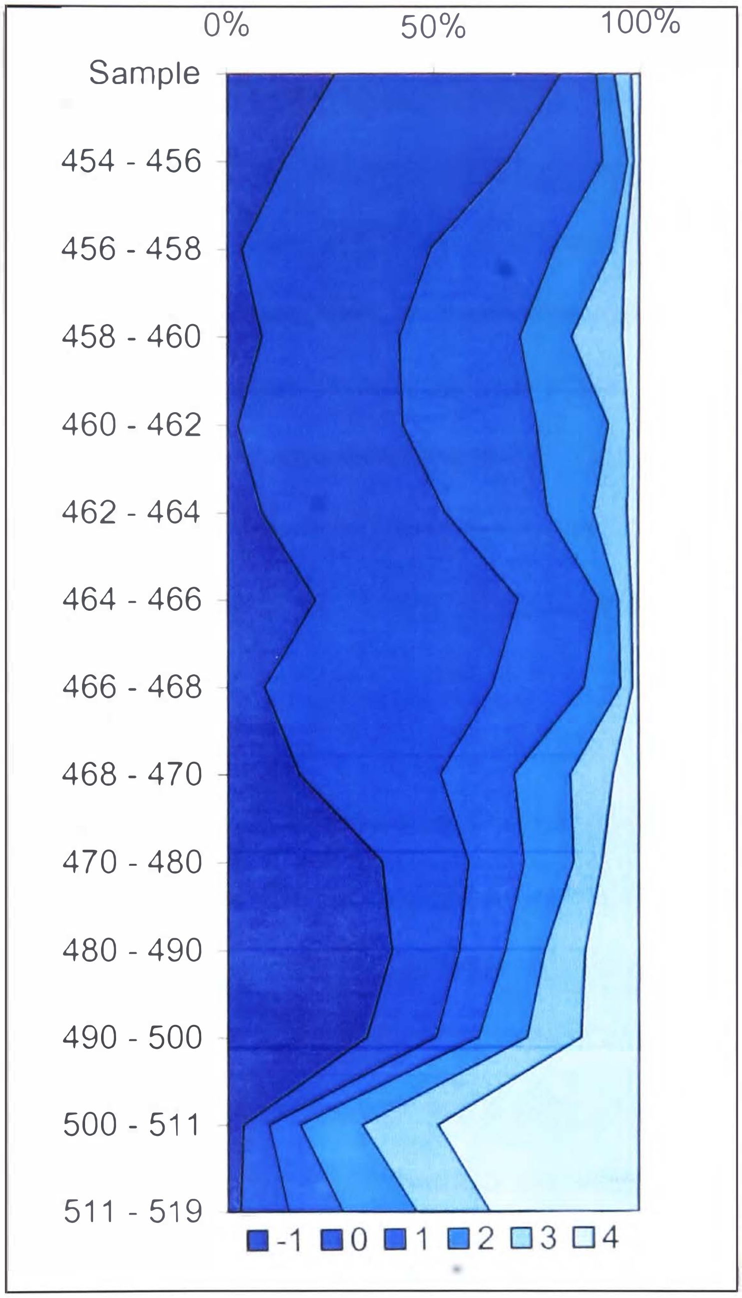


Fig. 4.11 Particle size results from lower clay at Dundon Hayes (DH1)

4.3 The mid to late Holocene environmental history of Dundon Hayes

Lithostratigraphic investigations recorded here at Dundon Hayes have shown that around 7000 years ago a red soil, not unlike the modern topsoil, covered the area. Soil cores also recorded wood and limestone fragments in this deposit and so it is likely that the area was wooded. Haslett e*t al* (1998a) interpreted this soil as a palaeosol or head deposit (Green & Welch 1965) as it was not found to contain any aquatic microfossils. This palaeosol has been measured at Dundon Hayes to cover a maximum of 0.97cm deep and so it might be inferred that this environment persisted for a considerable period of time.

Some time before 6000 yrs BP the environment around Dundon Hill became intertidal as a consequence of marine transgression into the Somerset Levels palaeo-valleys. During this period a blue-grey clay was deposited on top of the basal red palaeosol that had existed (Kidson and Heyworth 1976, Alderton 1983). Foraminiferal analysis on this deposit at Dundon Hayes has confirmed the lower blue – grey clay as marine. It is recorded here that this deposit reaches an altitude of 5.506 m OD at Dundon Hayes which is significant as it is the highest recorded altitude that this deposit has reached in the Somerset Levels. Previously the highest level it has been found is at 3.64 m OD at Nyland Hill in the Axe valley (Haslett e*t al* 1998a).

The lithological sequence suggests a subsequent dramatic change of environmental conditions indicated by a sedimentary sequence shift from clay to peat. The change from clay to peat is explained by the results as a change from an intertidal to an environment dominated by fresh water. Radiocarbon date information indicates that this change to fresh water first affected the lower palaeo-land surfaces of Dundon Hayes. This change is recorded as occurring at between 6160 and 5920 cal. yrs BP at an altitude of 2.344 m OD and higher up the slope at between 4795 and 4170 cal. yrs BP at 4.719m OD. The results here indicate that the peat began forming at the lowest altitudes and grew up over the exhumed clay surface. This supports evidence shown by Haslett *et al* (2001b) which outlined the same process occurring in the Axe valley. The peat at Dundon Hayes initially contains *Phragmites* and becomes *turfa* peat up sequence. The deposit then changes to detrital peat containing fresh water molluscs. The evidence from the soil cores implies this early freshwater environment would have been a water-logged habitat with some trees as the sediments recorded are *turfa* peats with wood fragments. This would suggest peat formed under terrestrial conditions and the dating evidence indicates that this environment persisted at Dundon Hayes until between 3820 and 3490 cal. yrs BP.

The overlying detrital peat provides evidence that points to the environment becoming wetter, supporting a large population of freshwater molluscs. The molluscs recovered at Dundon Hayes indicate an ecological succession with early colonisers being those species that are able to adapt to a variety of habitats. The evidence then indicates the establishment of a well vegetated water body with a muddy substrate that soon became large enough to support several of the `moving water' category of mollusc (Sparks 1951). Recorded in the snail sequence at Dundon Hayes is an abrupt retrograde succession when the species abruptly decline. It is not possible here to identify why this could have occurred but a change of environmental conditions is a likely candidate.

It appears that the environment at Dundon Hayes remained wet for a protracted period and the area was repeatedly affected by slope wash from the nearby hill. There are many horizons of muddy clay deposits throughout the upper sequence which have been grouped together as colluvium, and this deposit is capped at Dundon Hayes by a bluish-grey clay. The sediment just below this clay was dated to between 1050 and 780 cal. yrs BP at DH 5 (6.31 mOD) and between 940 and 670 cal. yrs BP at DH7 (6.04 mOD). The upper clay has been analysed for foraminifera to establish its origin. It is barren of foraminifera and therefore is unlikely to be a marine deposit. The dates of the underlying sediment would also support the argument that this clay is not a marine deposit. It may represent a considerable freshwater flood that affected the area, depositing this clay. Williams (1970) discusses the extensive flooding which the Somerset Levels is subject to. A return to a red clay soil follows this bluish clay and this is the present day topsoil of the Midelney Association.

The environmental history that has been reconstructed at Dundon Hayes integrates into the wider palaeogeography that has ben previously established for the Somerset Levels. The mid Holocene marine transgression is represented as is the regression that followed. The transgression attains an altitude of 5.506 m OD at Dundon Hayes, which is the highest altitude for the lower blue clay and, therefore, transgressive limits, recorded in the Somerset Levels.

The Somerset Levels Formation (Campbell *et al* 1999) includes a second marine transgression occurring around 4000 yrs BP which is not recorded at Dundon Hayes although it is a time when Dundon Hayes was changing to a wetter freshwater environment as the sediment from DH5 below the freshwater snail deposit was dated to between 3820 and 3490 cal. yrs BP. It is possible that more freshwater was held in the Sedgemoor valley due to impeded discharge during marine transgression at the coast. This will be examined later in Chapter 7.

Chapter 5 Briarwood Farm

As explained in chapter 2, in selecting a second site of study an area was chosen approximately mid way along the axis of the Sedgemoor valley. The site chosen at Briarwood Farm is approximately at the mid point along the longitudinal transect and is close to areas where there has been archaeological investigations in the past. For example, Gray (1926) found oak piles projecting from the ground surface with evidence of mortice holes and sharpened points. At nearby Greylake (NGR ST 3880 3360) Coles and Campbell (1982), later carried out further investigations on Gray's work, recorded what they termed as Gray's trackway at the site. Clark (1933) and Wainwright (1960) have provided evidence for Mesolithic occupation of Sedgemoor, based on material obtained at Greylake. It would seem the area around Greylake has been a centre for human activity over an extended period of prehistory. As with other sites investigated, the site chosen at Briarwood Farm (Fig. 5.1) comprised a field on a south facing slope of the Polden Hills reflecting the underlying geology and therefore, minimising the effect of sediment compaction. Briarwood Farm therefore, met the field criteria required for its inclusion in this investigation.

5.1 Site Location

Briarwood Farm (NGR 4050 3500) is located close to the small villages of Greinton and Greylake (Fig. 5.1). It is approximately 13 km from the sea therefore, around the mid point along the longitudinal transect of the Sedgemoor valley. The site lies alongside the A361, which is also known as Greylake Fosse, a corridor of raised ground that has functioned as a route between the higher ground of Middlezoy to the south and the Polden Hills to the north.

Fig. 5.1 The study site at Briarwood Farm.

The field indicated contains the transect, for general location of this site in the Sedgemoor Valley see Figure 2.1.

Greinton is a small agricultural village (Figs. 5.2 and 5.3), which recorded 70 residents in the Parish records of 2001.

Fig. 5.2 A westward view at Briarwood Farm. The southern flank of the Poldens is to the right.

Fig. 5.3 The footslopes of the Polden Hills at Briarwood Farm.

5.1.2 Topography, Geology and soils

The field in which the coring transect was undertaken (Fig. 5.4) lies adjacent to the A361 and slopes gently from north-east to south-west. Over a 60m coring transect the altitude falls from 6.739 m OD to 4.983 m OD. The Polden Hills rise to the North of the study site and are formed of strata of the Triassic Mercia Mudstone Group (Fig. 1.10). The hills have been formed as part of general erosion of the Mesozoic cover with escarpment retreat from the west since the opening of the Bristol Channel during the Tertiary (Gibbard & Lewin 2003). Findlay *et al* (1984) identified the Midelney Association to be the soil type at Briarwood Farm. This association consists of clayey alluvium overlying peat deposits.

5.1.3 Fieldwork

Figure 5.4 shows the locations of the study boreholes at Briarwood Farm.

Fig. 5.4 Location of the boreholes studied at Briarwood Farm (BF).

Borehole number	Distance along transect (m)	Grid Reference
BF4	0	ST 401136 348209
BF8	10	ST 401028 348187
BF7	20	ST 400912 348173
BF9	30	ST 400790 348166
BF6	40	ST 400681 348130
BF5	60	ST 400558 348115

Table 5.1 Grid references of boreholes studied at Briarwood Farm

A series of 6 boreholes were made over a transect distance of 60m and are numbered BF 4 to BF 9, with BF1 to 3 being holes abandoned in the search for an appropriate site of study. The stratigraphy of the abandoned boreholes is listed in the Appendix VI. The locations of the boreholes investigated are shown at Fig. 5.4 and the grid references of the boreholes given in table at Table 5.1. Table 5.2 gives the full core descriptions taken from field notes and is shown graphically in Fig. 5.5

Borehole number and depth (m)	Sample altitude (m OD)	Description
BF4		
0-0.30	6.74 – 6.44	Topsoil
0.30-2.12	6.44 – 4.62	Peat (very woody layer 102-116)
2.12-2.52	4.62 – 4.22	Blue clay with wood fragment
2.52	4.22	Hole abandoned
BF5		
0-0.24	4.98 – 4.74	Topsoil
0.24 –1.24	4.74 – 3.24	*Turfa* peat
1.24 – 4.10	3.24 – 0.88	Detrital peat. Mollusc horizon at 320, charcoal recovered at 338
4.10	0.88	Clay contact. Blue with colour variation from grey to brown containing fragments of *Phragmites* and charcoal
5.00	-0.02	Hole abandoned
BF6		
0-0.50	5.23 – 4.73	Topsoil
0.50-3.97	4.73 – 1.26	Peat (molluscs present from 162)
3.97-4.55	1.26 – 0.68	Blue clay
4.55-4.65	0.68 – 0.58	Transition into red clay
465-4.90	0.58 – 0.33	Red clay.
4.90-5.04	0.33 – 0.19	Sandy blue clay band
5.04	0.19	Red clay
5.08	0.15	Stopped in red clay
BF7		
0-0.52	5.67 – 5.15	Topsoil
0.52-3.18	5.15 – 2.49	Peat (High snail molluscan presence 115 – 318 and

		very woody)
3.18-3.24	2.49 – 2.43	Transition into grey clay
3.24-3.54	2.43 – 2.13	Red clay
3.54-3.61	2.13 – 2.06	Grey clay
3.61-3.87	2.06 – 1.80	Red clay with gravel
		Stopped coring in red clay
BF8		
0-0.50	6.06 – 5.56	Topsoil
0.50-1.17	5.56 – 4.89	Peat
1.17-2.50	4.89 – 3.56	Woody molluscan peat
2.50-2.85	3.56 – 3.21	Blue clay
2.85-2.90	3.21 – 3.16	Red clay
2.90	3.16	Stopped coring in red clay
BF9		
0-0.52	5.51 – 4.99	Topsoil
0.52-4.26	4.99 – 1.25	Peat. 297-299 mollusc band, 358-390 molluscan
4.26-4.32	1.25 – 1.19	woody peat.
4.32-4.42	1.19 – 1.09	Blue-brown clay
4.42-4.48	1.09 – 1.03	Red clay
		Grey-red clay contains charcoal

Table 5.2 Core descriptions at Briarwood Farm summarised from field notes.

5.2 Results

5.2.1 Lithostratigraphy

A basal red clay or palaeosol was recovered at Briarwood Farm that reaches its maximum observed thickness at borehole BF9 where it is recorded as 26 cm thick, however, no attempt was made to penetrate the full thickness of this unit to reach bedrock. The surface of this basal red clay attains its highest altitude of 3.21 m OD in borehole BF8 and is seen to slope to the south, probably mantling the underlying bedrock. At BF 7, the red clay contained angular clasts of gravel at a depth of 2.06 m OD. Also, at BF6 a layer of sandy clay 14cm thick was encountered with the basal red clay unit.

A thin layer of blue-grey clay overlies the basal red clay at all sites where the full sequence was cored. Of the boreholes studied at Briarwood Farm, this layer of blue-grey clay is found at a maximum thickness of 14 cm at BF6, where it is described in field notes as being a very sandy band sandwiched in the red clay. The surface of this deposit attains a maximum altitude of 2.13 m OD in BF7. Overlying this sandy clay band a further red clay deposit is recorded. The maximum thickness of this deposit is 35 cm in borehole BF6 and its surface altitude reaches 2.23 m OD in borehole BF7.

The lithostratigraphic sequence recovered at Briarwood Farm is dominated by a peat unit that is 3.8m thick at BF5. All of the boreholes studied here display a very woody detrital peat that contains many freshwater molluscs. At BF4 a particularly woody layer was recorded between 1.02 and 1.16 m in depth, which relates to an altitude of between 5.719 and 5.579 m OD. BF 5 is the furthest from the slope and therefore, occurs at the lowest altitude. In this core, the detrital peat contains charcoal and upsequence changes from a detrital to a *turfa* peat, with plant roots in growth position.

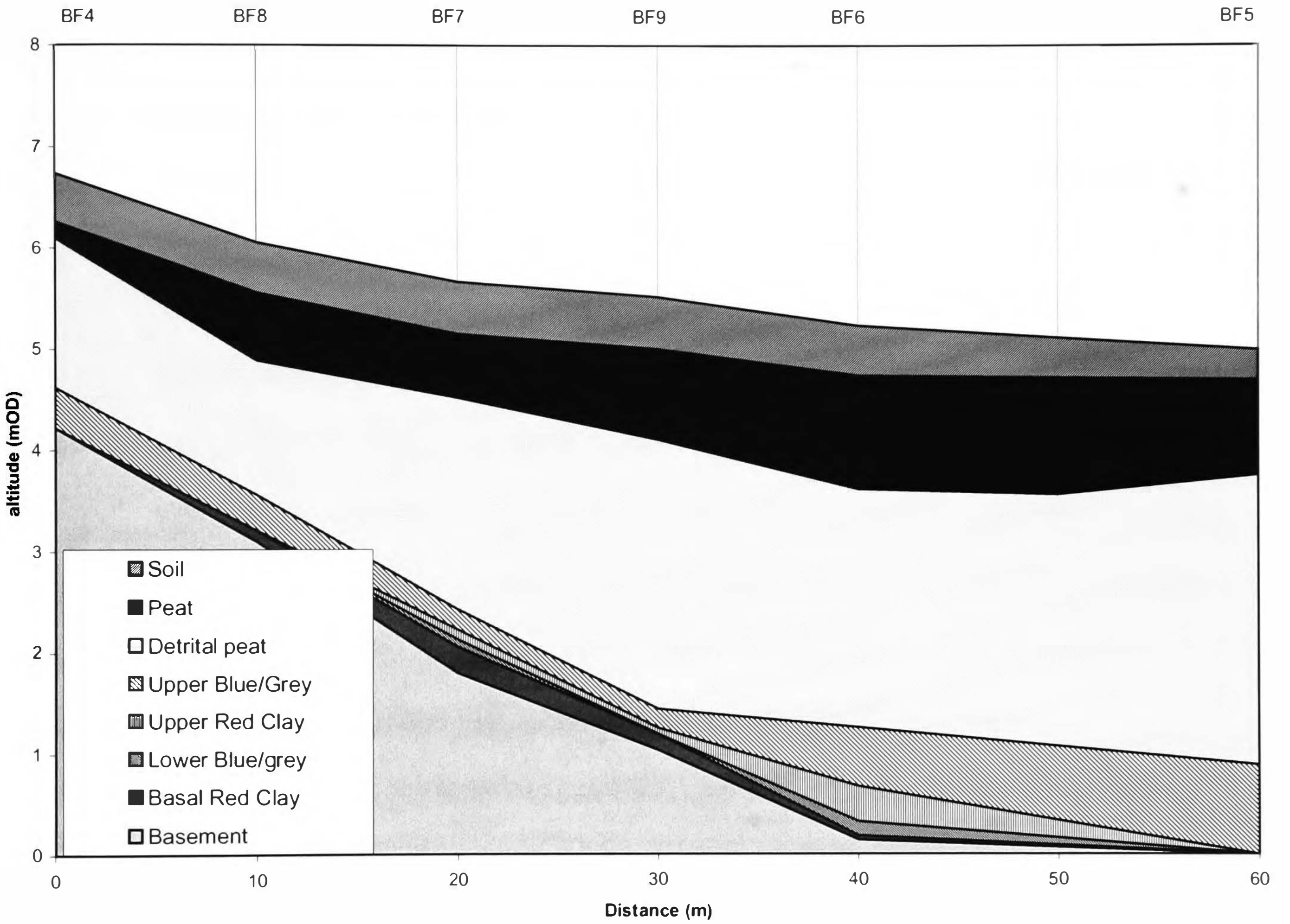


Fig. 5.5 Lithostratigraphy along the Briarwood Farm (BF) transect (see Figure 5.2 for borehole location).

5.2.2 Biostratigraphy

The sediments recovered from Briarwood Farm were analysed for biological indicators that can be used to infer the environment in which they were deposited (Berglund 1986; and Haslett, 2002).

5.2.2.1 Foraminiferal analysis

Analysis of the upper blue clay at borehole BF6 was undertaken to determine the presence of foraminifera. Foraminifera were present in the clay confirming that it is marine in origin. The general species assemblage includes *Trochammina inflata*, *Jadammina macrescens*, *Nonion germanica*, *Quinqueloculina seminulum* and *Elphidium williamsoni*. Most of these species are found in all the samples containing foraminifera examined from in borehole BF6 until below a depth of 435 – 445 cm where all the samples analysed were barren of forамininfera. Numbers of individuals within the samples were high with over 200 in all the samples containing foraminifera and the results are presented in Table 5.3.

The lowest sample (420 – 430 cm depth) containing foraminifera at BF6 was recovered from an altitude of between 1.025 and 0.925 m OD. It contained high numbers of *Trochammina inflata* and *Jadammina macresens* but also *Quinqueloculina seminulum.* This assemblage may be representative of a mid salt marsh environment (Charman *et al* 1998; Haslett *et al* 1998a, 2001b; Gehrels 2002). The overlying sample (410 – 420 cm depth) contains a more diverse population including *Ammonia beccarii, Nonion germanica, Quinqueloculina seminulum* and *Elphidum williamsoni*. This assemblage can also be seen to represent the mid marsh environment (Murray 1979, Haslett *et al* 1998b). Further up the foraminiferal sequence the numbers of *Ammonia beccarii* are seen to increase. The highest sample (397 – 405 cm depth) contains high numbers of *Ammonia beccarii*, which is a species common to the low marsh environment (Murray 1979, Haslett *et al* 1998b). This is a point of interest as the lithostratigraphic survey shows that at 397 cm depth (1.255 m OD) the sediment in borehole BF6 changes from the blue clay to peat that represents a marine regression and a change to an environment dominated by freshwater. The presence of high numbers of *Ammonia beccarii* is unexpected, as it would be usual to find high marsh species dominating the assemblage in a sample directly below a peat. High marsh species *Trochammina inflata* and *Jadammina macrescens* are present in the sample, but at lower numbers.

BF6 Depth (cm)	**Lithostratigraphy**	***A beccarii***	***E williamsoni***	***N germanica***	***J macrescens***	***T inflata***	***Q seminulum***
397 – 405	Blue clay	344	0	0	2	1	0
405 – 410	Blue clay	184	0	0	34	9	6
410 – 420	Blue clay	125	1	4	59	30	22
420 – 430	Blue clay	5	0	0	150	191	36
435 – 445	Blue clay	0	0	0	0	0	0
445 – 455	Blue clay	0	0	0	0	0	0
455 – 465	Red clay	0	0	0	0	0	0
465 – 475	Red clay	0	0	0	0	0	0
475 – 480	Red clay	0	0	0	0	0	0
490 – 495	Sandy blue grey clay band	0	0	0	0	0	0

Table 5.3 Foraminifera results as raw counts from borehole BF6

5.2.2.2 Freshwater molluscs

A sequence of freshwater molluscs spanning 1.85 m was recovered from the peat deposit in borehole BF7 (115 – 300 cm depth) and was analysed to establish species composition and abundance variation. The results are shown as percentage data in Figure 5.6 and raw data in Figure 5.7. These data were subjected to Cluster Analysis and resulting dendrograms (CONISS) displayed on Figures 5.6. and 5.7 were used to subdivide the sequence into defined molluscan zones. Full details of the statistical analysis are included at Appendix II. Overall, the molluscan sequence represents an environment that was dominated by freshwater. The species recovered have been categorised by Sparks (1951) and assigned to groups of ecologically-related species, these groups include `Moving water` species, `Ditch` species, `Catholic' species and `Slum` species. These grouping categories are used in the construction of the figures (Figure 5.6 and 5.7). One species of terrestrial mollusca was also recovered from the peat sequence at Briarwood Farm, and is included in the results plotted in raw count diagram (Figure 5.7).

The molluscan sequence from borehole BF7 at Briarwood Farm yielded quite low numbers of individuals with only four of the nineteen samples analysed bearing more than 100 molluscs. The sample yielding the most abundant specimens was recovered from 200 –210 cm depth (altitude 3.67 – 3.57 m OD) and contained 223 individuals. In all of the samples analysed preservation of the molluscs was good. The overall assemblage of the sequence is dominated by *Bithynia tentaculata, Valvata piscinalis, Valvata cristata* and *Gyraulus crista*. Fig. 5.7 presents the molluscan data, displayed as raw counts. It shows that in the lower part of the

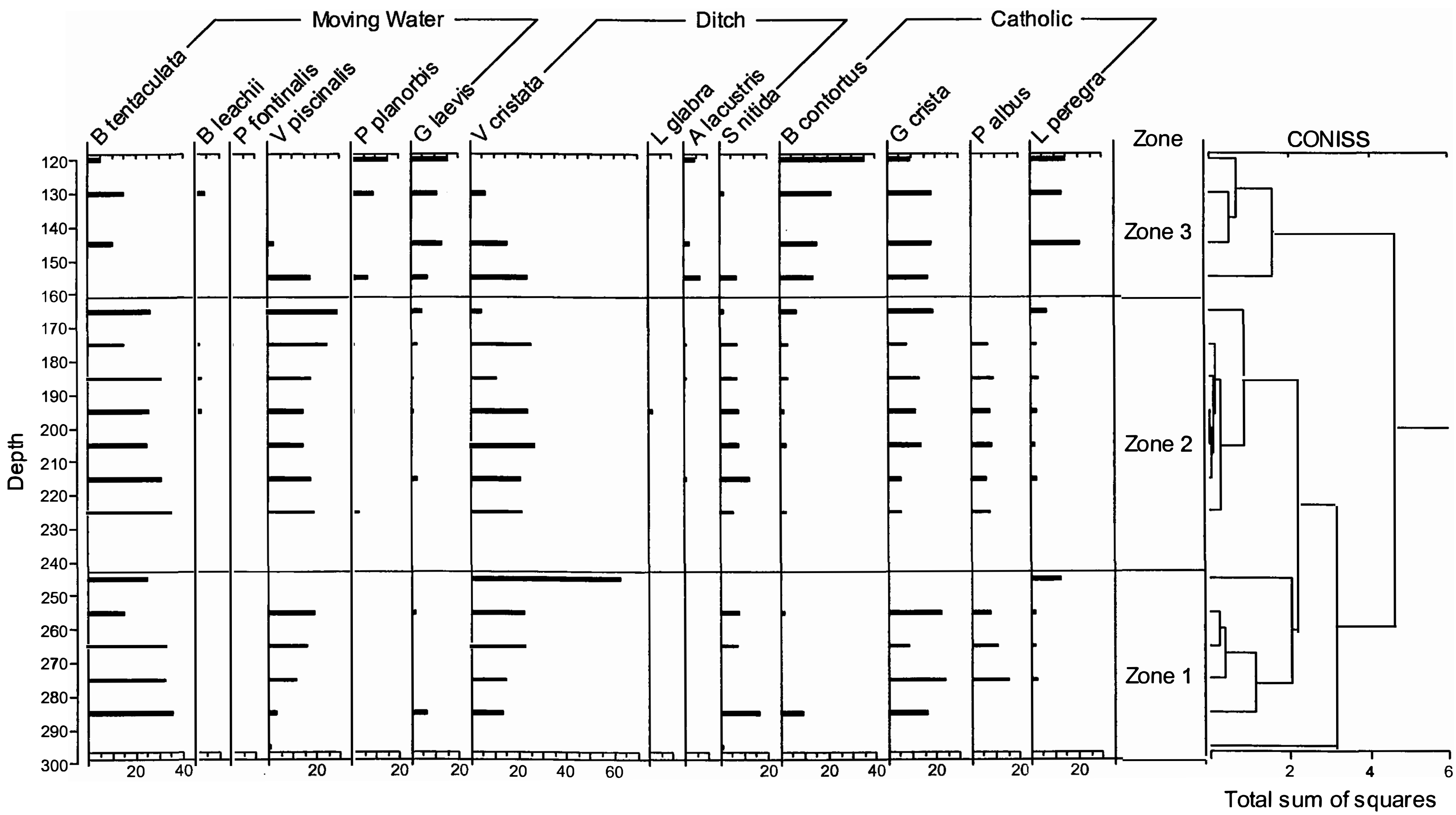


Fig. 5.6 Molluscan results from BF7 shown as percentage counts against depth (cm)

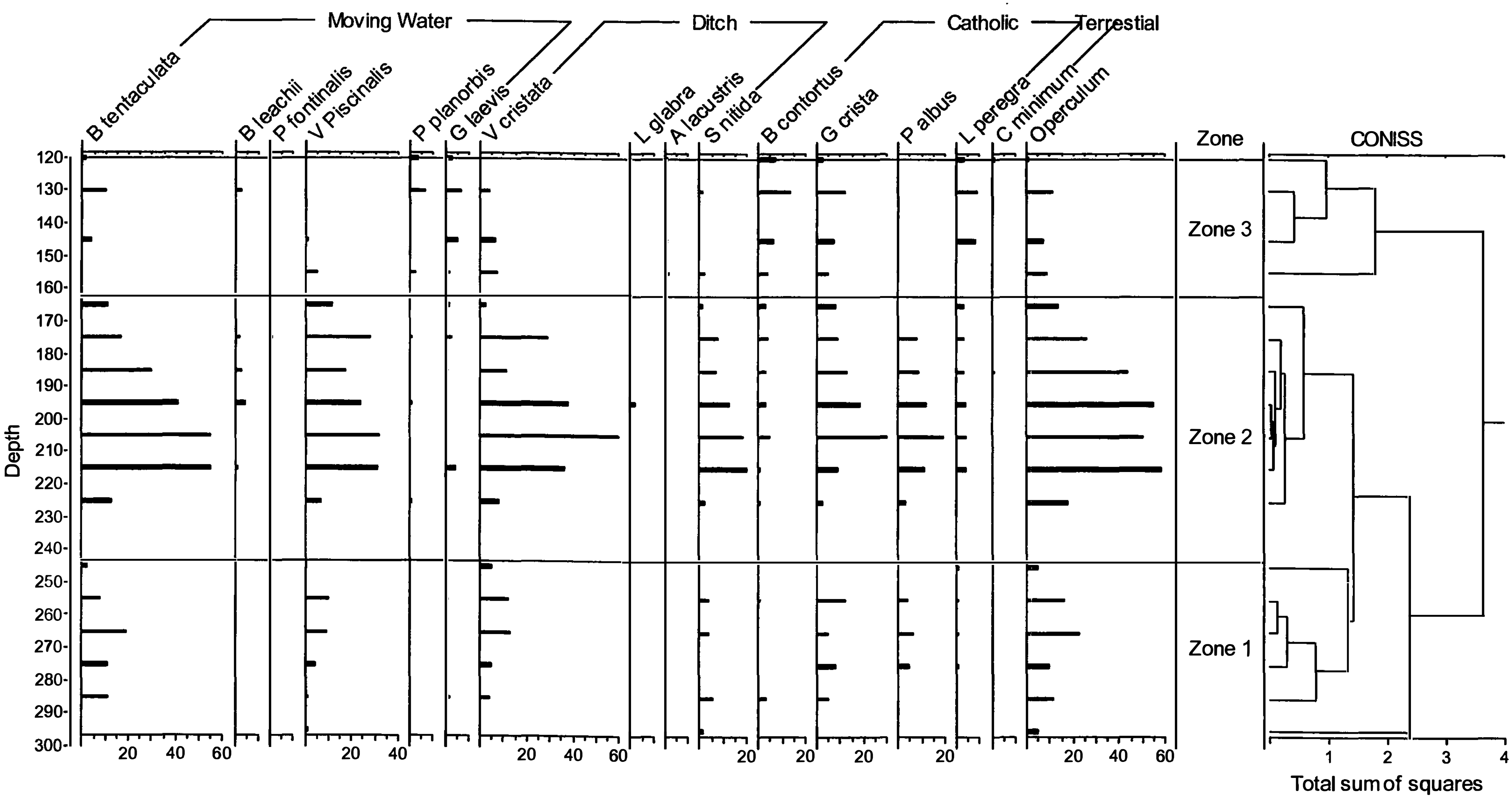


Fig. 5.7 Molluscan results from BF7 shown as raw counts against depth (cm)

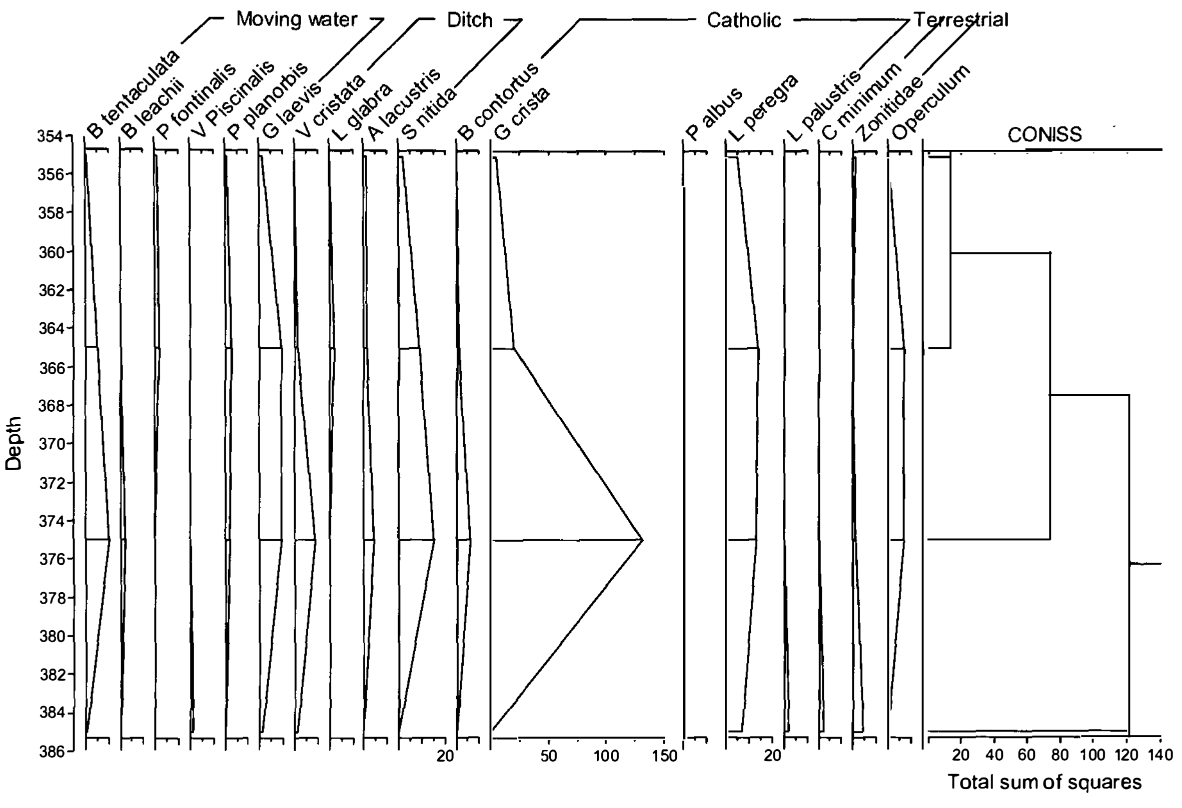


Fig. 5.8 Molluscan results from BF9 as raw data against depth (cm)

molluscan sequence (zone 1), the `Catholic` species, those most adaptable to differing environments, are the predominant group. These probably represent early colonisation of the emerging freshwater habitat. Specimen abundance declines upsequence culminating with the only barren sample in the sequence (230 to 240 cm). Following this barren sample, numbers of individuals increase and represent a second phase in the molluscan sequence (zone 2). Throughout this second phase, the `Moving water' species become established; *Bithynia tentaculata*, *Valvata piscinalis* and *Valvata cristata*, and dominate this phase of the sequence. These species are indicative of a larger open water body and good water quality. It can also be inferred that the substrate of the water body was likely to be muddy as these species also have a preference for muddy substrates (Kerney 1999).

A third and final phase of the molluscan sequence (zone 3) begins with sample 150 to 160 cm. This final phase shows a change of environmental conditions with the waterbody being smaller and prone to drier periods. The `Catholic' species, which withstand varying environmental conditions, return to dominate this phase in the sequence. None of the species included in the `Slum` category are found throughout the entire molluscan sequence, which indicates that the environment was not prone to complete drying out and had relatively good water quality throughout. Overall it seems that the molluscan sequence from Briarwood Farm suggests that during peat deposition it was a large open water body that was well vegetated, as the species encountered possess a strong preference for this habitat type.

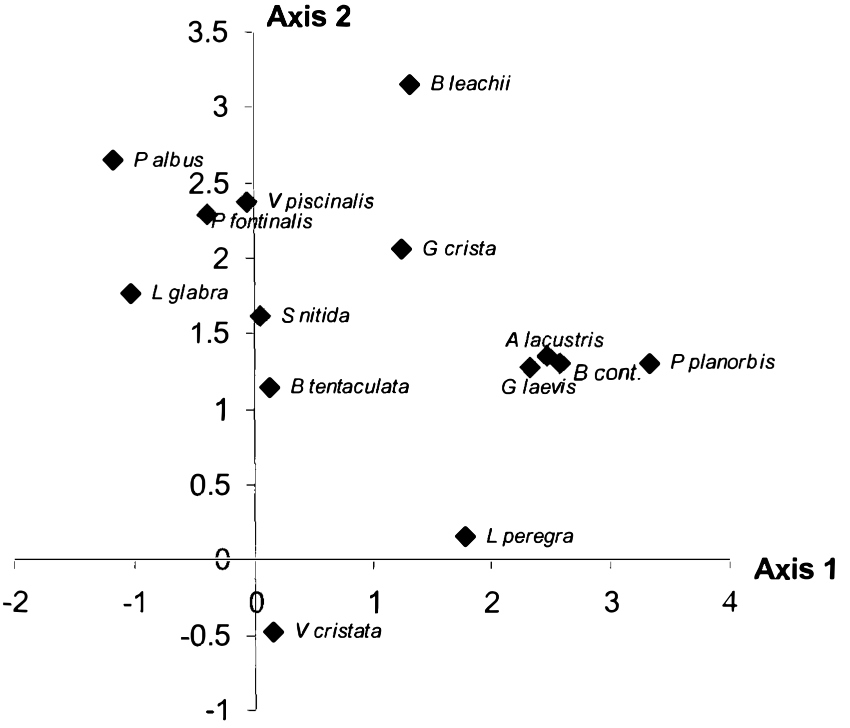


Fig. 5.9 Axis 1 and Axis 2 results from the DCA of the percentage molluscan data at BF7

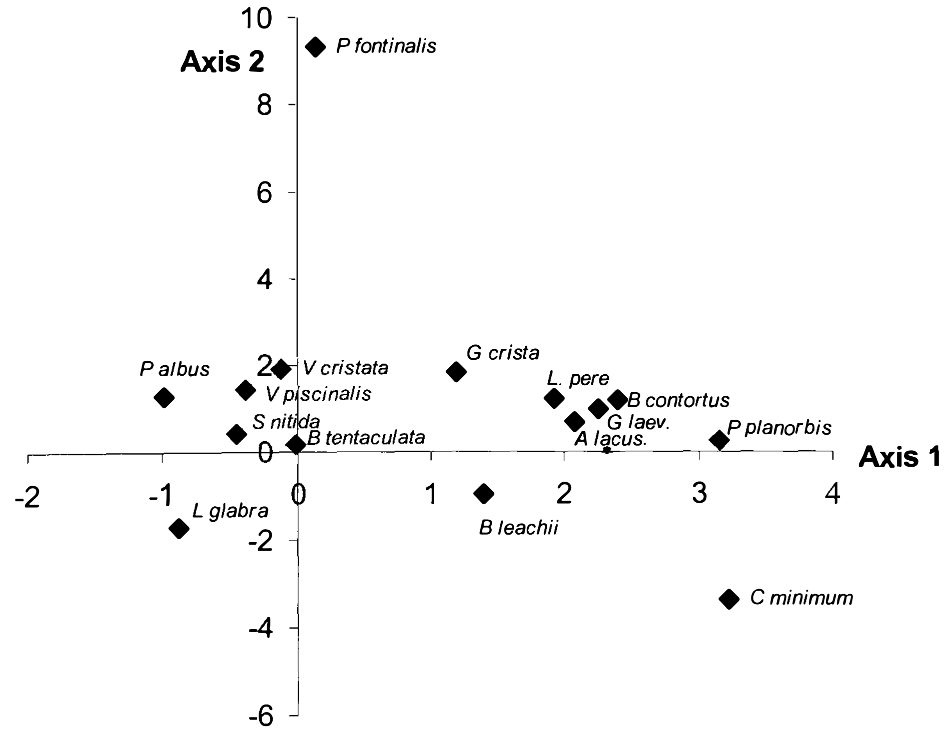


Fig. 5.10 Axis 1 and Axis 2 results of the DCA of raw molluscan data from BF7

Figures 5.9 and 5.10 show the Axis 1 and Axis 2 DCA results from the molluscs at Briarwood Farm (Dale and Dale 2002). No clear patterns are evident in these results. The full details of all the statistical analysis is included at Appendix II for reference.

A second sequence from borehole BF9 (samples 350-390cms) was also analysed for molluscs and was recovered from the peat immediately above the clay-peat transition. The results are shown as raw data in Fig. 5.8. This is a short molluscan sequence with the Cluster Analysis showing no clear zonation. However, a similar picture to the one found at BF7 can be seen. The same species are present and a period of colonisation is seen before the succession reverses. Similar to the sequence at BF7 in the early phase of the BF9 sequence there are high numbers of *Gyraulus crista* a \`Catholic\` species. \`Moving water\` species are present in the BF9 sequence, but do not appear in as high numbers as the \`Ditch\` and \`Catholic\` species. It would seem that the sequence at BF9 represents a smaller fringing waterbody that was present as the peat grew up over the exposed clay surface.

5.2.3 Radiocarbon Dates

Four samples retrieved from Briarwood Farm were submitted for Radiocarbon analysis and the results shown in Table 5.4. The initial samples chosen for dating were those at the contact between the lower blue-grey clay and the peat. Two samples of this contact were examined from BF6 (390 –397 cm), a contact altitude of 1.25 m OD and BF7 (115 –135 cm) at 2.45 m OD. The lower altitude sample from BF6 was dated to between 6760 and 6275 cal. yrs BP and the higher sample from BF7 was dated to between 6450 and 6180 cal. yrs BP.

A sample was analysed from borehole BF7 to date the termination of a sequence of freshwater molluscs (discussed in sec 5.2.2.2) located within the peat deposit at an altitude of 4.32 m OD, yielding a date of between 4529 and 4170 cal. yrs BP. A fourth sample was selected from the Briarwood Farm transect to date the end of the peat deposition. A sample from BF 9 at 52-67 cm and an altitude of 4.84 m OD was dated to between 2469 and 2320 cal. yrs BP.

Lab Code	Sample	Context	Altitude m OD	Conventional ^{14}C Age BP	2 Sigma cal. calendar yrs BP	2 Sigma cal. results BC/AD	Calibrated Intercept Age calendar Yrs BP
Beta – 131491	BF6 390-397	Clay-peat boundary	1.25	5700+/- 130 BP	6760 to 6275	4810 to 4325 BC	6475
Beta – 131492	BF7 310-324	Clay-peat boundary	2.43	5520+/- 80 BP	6450 to 6180	4500 to 4230 BC	6300
Beta – 169233	BF7 115-135	At top of mollusc sequence	4.32	3930+/- 60 BP	4520 to 4220 4210 to 4170	2580 to 2270 2260 to 2220 BC	4410
Beta – 169234	BF9 52-67	Upper peat sample	4.84	2340+/- 50 BP	2460 to 2320	400 BC	2350

Table 5.4 Radiocarbon dates from Briarwood Farm.

5.2.4 Particle size analysis

Particle size analysis was carried out on the lower clay samples retrieved from Briarwood Farm as a way of further understanding the environment in which the deposits were laid down. The results are shown at Fig. 5.11 and are outlined in full at Appendix VII. The silt-clay fraction, that below 63μm, was lost during sample processing for biostratigraphical analysis. The remaining >63μm fraction has been analysed (see methods) so that the sediments that make up the sand-grade part of the sediment size spectrum can be investigated.

The lowest samples are dominated by the finer sand-grades. Between 480 and 490 cm an increase in particle size is evident that coincides with the occurrence of a sandy layer noted in the lithostratigraphical descriptions (Table 5.2). Finer sand-grade sediment then dominates between samples 470 cm to 430 cms. At 430 cm an abrupt change occurs marked by a steep increase in the coarser sediment fractions and a fall in the finer grades. The highest samples in the sequence show that between 390 and 420 cm the coarsest particle size fractions decrease while the finer-grade sediments increase. Overall the uppermost samples remain dominated by the coarser sediment fractions, however, a clear change nevertheless takes place at the top of the sequence.

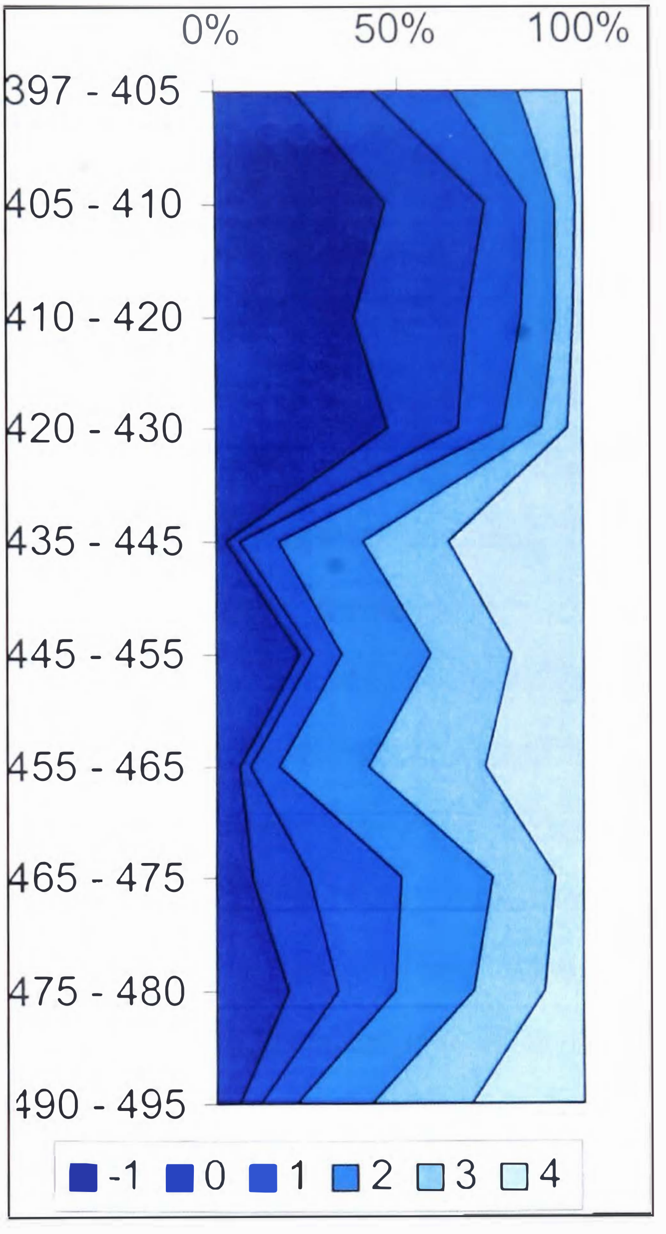


Fig. 5.11 Particle size results from the lower clays at BF6.

5.3 The mid to late Holocene environmental history of Briarwood Farm

Similar to other sites in Somerset, a basal red clay unit underlies the Holocene sequence at Briarwood Farm. At Nyland Hill in the Axe Valley, Haslett *et al.* (1998a) interpret this basal red clay unit as representing a palaeosol or head deposit (Green & Welch, 1965). From the radiocarbon dating and lithostratigraphy reported here it may be also be interpreted that this basal unit is a palaeosol, representing the ground-surface some 7000 years ago. It is clear from the work of Clark (1933) and Wainwright (1960) that there was likely to have been human occupation in the area during the Mesolithic, based on evidence they obtained at nearby Greylake. At BF7 the red soil is seen to contain gravels and, therefore, it may also be described as a head deposit (Green & Welch 1965; Haslett *et al* 1998a) which may contain the frost shattered evidence of late Pleistocene periglacial activity. Within this red clay at Briarwood Farm a sandy blue clay deposit is recorded which is at its maximum of 14cm thick at BF6. The particle size analysis undertaken on these clays does show an increase in the coarser fractions in these samples showing that they could possible have been deposited in a relatively high energy environment or during a high energy event, such as a flood. The sandy•layer has been analysed for foraminifera, which were not found to be present, therefore, it appears that this deposit is unlikely to be of marine origin. It is possible that the sandy layer represents a freshwater inundation of the site, although again this cannot be confirmed. Overlying this sandy clay horizon, another deposit of red clay occurs that reaches a maximum thickness of 35cm at borehole BF6. The particle size analysis shows that this deposit consists mainly of finer-grades of sediment. Again, this deposit was analysed for foraminifera, but they were not found.

Following the basal red palaeosol, the Briarwood Farm stratigraphic sequence records an abrupt change with a blue-grey clay seen to overly the red palaeosol. This blue-grey clay has been analysed for the presence of foraminifera, which were found to be present in four of the six samples studied from borehole BF6. The lowest samples however, were barren of foraminifera and it may be that these samples represent the barren zone as described by Haslett *et al* (1998a), being deposited high in the intertidal zone approximately between the tidal levels of HAT and MHWST. Indeed, it would be expected that this tidal zone would transgress the palaeosol surface as the post-glacial rise in sea-level occurred. The foraminifera present in the upper samples are salt marsh species that represent a various tide level intervals, although one would expect to record lower numbers of the lower marsh species *Ammonia beccarii* in the sample at the top of the sequence when a return to high marsh conditions would be expected. This could be indicative of a high energy tidal event occurring or the abrupt exclusion of tidal waters by the formation of a barrier, for example, across the mouth of the Parrett Estuary (e.g. Kidson and Heyworth 1976) or more likely local erosion of the blue clay prior to peat deposition. This blue-grey clay is, therefore, of marine origin and attains a maximum thickness at BF5, where ≥88cm were recovered before the borehole was abandoned without reaching the underlying basal red palaeosol or bedrock. The blue clay is recorded here as reaching an altitude of 4.619 m OD in borehole BF4. The particle size analysis of this clay deposit indicates that this clay is dominated by coarse particles up until the top of the sequence when the finer grade sediment components increase. This supports Allen (1996) who states that grain size deposited at a specific point on a salt marsh surface will vary in relation to the position of the marsh shoreline, so that as a marsh shoreline retreats landward/advances seaward the sediment deposited at the specific point becomes coarser/finer respectively. Evidence from the particle size analysis indicates that towards the top of this sequence the marsh may have been advancing seaward (i.e. sea level regressing).

Lithostratgraphical evidence shows that overlying the blue clay is a peat deposit measuring up to 3.8 m on depth. Radiocarbon dating evidence suggests that as elsewhere in the Somerset Levels (*e.g.* Haslett *et al* 2001b) this lithological change occurred earlier at lower altitudes with peat growing upwards and laterally over a palaeosurface exhumed by marine regression. Here the date at BF6 (1.25 m OD) is between 6760 and 6275 cal. yrs BP and at BF7 (2.43 m OD) between 6450 and 6180 cal. yrs BP, although it should be noted that those dates do overlap at in the 2σ range.

Following the lithological transition from blue-grey clay to peat, the environment at Briarwood Farm became one dominated by freshwater. The early freshwater environment appears to be a waterlogged terrestrial habitat with trees and reeds (cf. fenwood). Fragments of wood are seen at the base of borehole BF9 and boreholes BF7 and BF5 contained fragments of *Phragmites* in the lower peat samples.

Overlying this initial peat development evidence suggests that the environment became wetter at Briarwood Farm, supporting a large population of freshwater molluscs. The molluscs indicate that the waterbody present at Briarwood Farm developed into an area substantial enough to support those species that prefer well oxygenated environments with some current activity. The evidence also suggests that this waterbody would have been richly vegetated and probably have a muddy substrate. There is one sample (230-240) in the sequence at BF7 that is barren of molluscs, but it is not clear from the evidence here why this should be. One possibility is a bog burst of a nearby raised bog area which could have introduced a pulse of acidic water into the freshwater environment accounting for a sharp decline (McEwen and Withers 1989) however, the lack of evidence for raised bog in Sedgemoor makes this unlikely. The molluscan data shows the `Catholic` species being dominant in the upper parts of the sequence inferring a change to a relatively drier environment. The top of the molluscan sequence in BF7 at Briarwood Farm has been dated to between 4520 and 4170 cal. yrs BP, and with the sequence of molluscs at BF7 spanning 2.85m, it is clear that this habitat dominated the area for approximately 2000 years.

Above the molluscan sequence, the appearance of *turfa* peat indicates a reversion to a terrestrial depositional environment and continues upsequence to form part of the modern profile of the Midelney Soil Association. A radiocarbon date taken from borehole BF9 (52-67 cm) dates the upper contact of the peat (within the soil profile) to between 2460 and 2329 cal. yrs BP.

From at least Mesolithic times onwards, people appear to have lived in and around the area, and most recently have been able to influence and control the natural systems through drainage and reclamation. The history of the area surrounding Briarwood Farm seems closely tied to human activity, a topic that will be examined in greater depth in Chapter 7.

Chapter 6 Bawdrip

Continuing the seaward longitudinal transect along the Sedgemoor valley the third site selected for investigation in the valley is located near Bawdrip (Figure 6.1). The area around Bawdrip has a long history of archaeological importance. Norman and Clements (1979) described a wooden structure that extends westward from the high ground at Sutton Hams. Norman (1980) later also recorded further wooden structures that he considered to represent a westward extension to the earlier described 'Sutton Hams Trackway'. Coles and Orme (1985b) obtained two radiocarbon dates from this structure (HAR-4375: 4690 +/- 90 BP; HAR-4374: 4510 +/- 80 BP) placing them within the later Neolithic or Bronze Age. There is evidence that later, Romans settled in and around Bawdrip, with a settlement recorded at Crandon Bridge (ST 3279 4036 SHER 44739). Excavations took place at Bawdrip while the King's Sedgemoor Drain was being widened in 1939, where a concentration of finds indicated a large area of Roman settlement. Historical references show a possible Roman villa in the field opposite the study site at Bawdrip, being first mentioned in 1689 (SHER 10041). In 1827, Strandling recorded finds of flue tiles, pottery and a Roman bead at Bawdrip and in 1956 Miles and Smith located the foundations of two buildings. One of the buildings overlaid an Iron Age hut containing pottery dated 48 – 80 AD, with one of the finds being a Durotrigian ribbed bowl suggesting prolonged occupation of the site (SHER 10041). Coins and pottery found suggested occupation from the first to the fourth centuries AD. It is clear that Bawdrip has considerable interest from an archaeological viewpoint and so was considered an appropriate location for the third study site reported here.

6.1 Site Location

The field chosen for study at Bawdrip is shown in Figure 6.1. Bawdrip is a small agricultural village (Fig. 6.3), which recorded 467 residents in the Parish records of 2001.

Fig. 6.1 The study site at Bawdrip

Fig. 6.2 Field of study at Bawdrip to the right of the picture with the rise to the Poldens on the left.

Fig. 6.3 The slope above the field of study at Bawdrip, looking northwest. Transect across the field from right to left.

6.1.2 Topography, Geology and soils

The field studied (Figs. 6.1 and 6.3) is part of King's Farm and slopes gently from northeast to southwest. The surface altitude of the field studied varied between 5.27 m OD at its highest and 4.03 m OD in the lowest borehole. Bawdrip is at the western part of the Sedgemoor valley and the Polden Hills rise to the north of the site. The geology of the Polden Hills at this point is a Triassic succession comprising the Blue Anchor Formation overlying the Mercia Mudstone Group (Fig. 1.10). The Blue Anchor Formation is predominantly characterised by grey and green mudstones, silty mudstones and siltstones, which are partly calcareous. The base of the formation is marked by the top of the highest prominent red mudstone in the Mercia Mudstone Group (Whittaker and Green 1983). Findlay *et al* (1984) identified the soils at Bawdrip as belonging to the Downholland 1 Association which are clayey and silty calcareous alluvial soils.

6.1.3 Fieldwork

Figure 6.4 shows the locations of the boreholes at Bawdrip.

Fig. 6.4 Borehole locations at Bawdrip (BAW).

Borehole number	Distance along transect (m)	Grid Reference
BAW1	30	ST 35255 39411
BAW2	0	ST 35260 39439
BAW3	60	ST 35248 39383
BAW4	90	ST 35237 39359
BAW5	150	ST 35220 39299

Table 6.1 Grid references of boreholes studied at Bawdrip

A series of 5 boreholes were made over a transect distance of 150m and are numbered BAW1 to BAW5 with 30m between all, except BAW4 and BAW5 where the boreholes are separated by an interval of 60m.

Borehole ref. And depth (m)	Sample altitude (m OD)	Description
BAW1		
0-0.30	4.66 – 4.36	Topsoil
0.30 - 0.60	4.36 – 4.06	Buff Brown clay with molluscs
0.60 – 0.86	4.06 – 3.80	Bluish grey clay with peat inclusions turning brown with depth
0.86 – 0.89	3.80 – 3.77	Rich in molluscs, light coloured marl/tufa slight organic layer at base
0.89 – 0.92	3.77 – 3.74	Brown/grey clay
0.92 – 1.00	3.74 – 3.66	Brown brown clay/peat
1.00 –1.20	3.66 – 3.46	Well humified peat
1.20 – 1.27	3.46 – 3.39	Pale detrital peat/marl
1.27 – 1.28	3.39 – 3.38	*Sphagnum* peat (moss)

1.28 – 1.29	3.38 – 3.37	Well humified dark detrital peat
1.29 – 1.80	3.37 – 2.86	Light coloured detrital peat/marl rich in molluscs
1.80 – 2.22	2.86 – 2.44	Woody fen peat with a few molluscs
2.22 – 2.25	2.44 – 2.41	Light coloured detrital peat with molluscs
2.25 – 3.05	2.41 – 1.61	Woody fen peat with a few molluscs
3.05 – 3.29	1.61 – 1.37	Blue grey clay
3.29 – 3.42	1.37 – 1.24	Red clay – hole abandoned in red clay at 3.42
BAW2		
0 - 0.30	5.27 – 4.97	Topsoil
0.30 – 0.80	4.97 – 4.47	Buff orangey clay with mottles of blue. Molluscan rich
0.80 – 1.10	4.47 – 4.17	Bluish grey clay with black streaks
1.10 – 1.35	4.17 – 3.92	Brown organic peaty clay with some orange mottling
1.35 – 2.12	3.92 – 3.15	*Turfa* peat, lighter at top. Contains wood, but no molluscs
2.12 – 2.48	3.15 – 2.79	Detrital peat. Contains wood, molluscs and charcoal
2.48 – 2.77	2.79 – 2.50	Blue grey clay
2.77 – 3.12	2.50 – 2.15	Red clay – hole abandoned at 312
BAW3		
0 – 0.30	4.51 – 4.21	Topsoil
0.30 – 0.42	4.21 – 4.09	Brown orangey clay
0.42 – 0.63	4.09 – 3.88	Bluish grey clay with orange and black mottling
0.63 – 0.90	3.88 – 3.61	Organic peaty clay
0.91 – 0.98	3.61 – 3.53	Well humified detrital peat
0.98 – 1.15	3.53 – 3.36	Grey brown detrital peat with molluscs
1.15 – 1.18	3.36 – 3.33	Dark brown humified detrital peat
1.18 – 1.26	3.33 – 3.25	Light coloured detrital peat/marl, abundant molluscs
1.26 – 1.97	3.25 – 2.54	Variable shaded light brown detrital peat, abundant molluscs
1.97 – 2.64	2.54 – 1.87	Dark woody fen peat, but no molluscs (except occasional fragments)
2.64 – 3.09	1.87 – 1.42	Light brown detrital peat with molluscs
3.09 – 3.22	1.42 – 1.29	Woody detrital peat with snails

3.22 – 3.35	1.29 – 1.16	Light brown detrital peat with molluscs
3.35 – 3.75	1.16 – 0.76	Fen peat with wood, *turfa* roots and charcoal
3.75 – 4.05	0.76 – 0.46	Blue grey clay
4.05 – 4.19	0.46 – 0.32	Red clay – stopped in red clay at 419
BAW4		
0 - 0.24	4.33 – 4.09	Topsoil
0.24 – 0.45	4.09 – 3.88	Buff orange clay
0.45 – 0.58	3.88 – 3.75	Bluish grey clay
0.58 – 0.62	3.75 – 3.71	Pale coloured (marl), mollusc-rich layer
0.62 – 0.64	3.71 – 3.69	Brown organic clay
0.64 – 0.66	3.69 – 3.67	Light brown mollusc-rich clayey marl
0.66 – 0.95	3.67 – 3.38	Brown organic peaty clay
0.95 – 1.05	3.38 – 3.28	Dark humified detrital peat
1.05 – 1.18	3.28 – 3.15	Light tan detrital peat with molluscs
1.18 – 1.25	3.15 – 3.08	Creamy beige detrital peat with molluscs
1.25 – 1.31	3.08 – 3.02	Dark brown humified detrital peat with wood
1.31 – 1.34	3.02 – 2.99	Detrital peat – very pale white molluscan marl
1.34 - 1.35	2.99 – 2.98	Dark brown detrital peat with molluscs
1.35 – 1.40	2.98 – 2.93	Beige detrital peat with molluscs
1.40 – 1.41	2.93 – 2.92	Thin bluish clay layer
1.41 – 4.19	2.92 – 0.14	Light brown detrital peat, molluscan-rich – wood between 210-236 and 310 – 334. 337 chunk of wood
4.19 – 4.38	0.14 - -0.15	Fen peat (wood, roots)
4.38 – 4.59	-0.15 - -0.26	Brown grey organic clay possibly transition
4.59 – 4.80	-0.26 - -0.47	Blue grey clay
4.80 – 5.18	-0.47 - -0.85	Red clay – stopped coring at 518
BAW5		
0 – 0.30	4.03 – 3.73	Topsoil
0.30 – 0.37	3.73 – 3.66	Buff coloured clay
0.37 – 0.45	3.66 – 3.58	Bluish grey clay

0.45 – 0.69	3.58 – 3.34	Brown peaty clay
0.69 – 0.74	3.34 – 3.29	Pale molluscan-rich marl/detrital peat
0.74 – 0.93	3.29 – 3.10	Dark detrital peat
0.93 – 1.00	3.10 – 3.03	Tan coloured detrital peat with mollsucs
1.00 – 1.01	3.03 – 3.02	Bluish grey clay
1.01 – 1.02	3.02 – 3.01	Pale detrital peat
1.02 – 1.10	3.01 – 2.93	Tan coloured detrital peat
1.10 – 1.19	2.93 – 2.84	Dark humified detrital peat with wood
1.19 – 1.42	2.84 – 2.61	Pale brown detrital peat with molluscs
1.42 – 2.10	2.61 – 1.93	Brown detrital peat with molluscs and *Phragmites*
2.10 – 2.19	1.93 – 1.84	Pale detrital peat with molluscs
2.19 – 3.49	1.84 – 0.54	Brown detrital peat with molluscs, wood and *Phragmites*
3.49 – 3.61	0.54 – 0.42	Pale brown detrital peat with molluscs
3.61 – 5.08	0.42 - -1.05	Well humifed peat with molluscs (436 – 450 lots of wood). No *turfa* peat in this sequence.
5.08 – 5.17	-1.05 - -1.14	Brown organic clay possible transition
5.17 – 5.36	-1.14 - -1.33	Blue grey clay
5.36 – 5.40	-1.33 - -1.37	Red clay – stopped coring in red clay

Table 6.2 Core descriptions summarised from field notebooks

6.2 Results

6.2.1 Lithostratigraphy

A series of five boreholes were studied at Bawdrip (Fig. 6.2) with National Grid references for each borehole shown in Table 6.1. The sediments recovered are described in Table 6.2 taken from field notes and is shown graphically at Fig. 6.5.

As with other sites investigated, the lithostratigraphy at Bawdrip exhibits elements of the classic clay-peat-clay sequence common to much of the Somerset Levels (Kidson and Heyworth 1976), the Somerset Levels Formation by Campbell *et al* (1999) and Haslett *et al* (2001b). Bawdrip differs though in that, similar to the other sites examined in this study, only one marine transgression is recorded in the lithostratigraphic sequence. Because of this only the lower and middle units of the Somerset Levels Formation are present. These have been identified as the North Yeo Member and Nyland Hill Peat Member by Haslett and Davies (2002).

A basal red clay, presumably mantling the bedrock basement, is recorded here up to 38 cm thick (in borehole BAW4), but as the hole was abandoned still within the red clay, it is likely to be an underestimate of the true thickness. The surface altitude of this red clay varies between 2.5 m OD and –1.33 m OD, and is overlain by a blue grey clay that attains a maximum thickness (at BAW2) of 29cm. The surface altitude of this blue grey clay varies between 2.79 m OD at BAW2 and –1.14 m OD at BAW5.

In common with the other sites recorded in this study a peat succeeds the blue grey clay, and at Bawdrip the lower intervals of the peat appear to be woody fen peat, including roots and charcoal at BAW3. This peat then becomes detrital upsequence comprising considerable numbers of fresh water molluscs, that are reported in section 6.2.2. BAW 5 also contains *Phragmites* and wood throughout this detrital peat interval. The surface altitude of the peat varies between 3.92 m OD and 3.34 m OD. At the top of the detrital peat at BAW4 and BAW5 a thin pale snail rich marl deposit is recorded. Overlying the peat at Bawdrip is an organic brown peaty clay. It is found at its maximum thickness at BAW3, where it is 27 cm thick, and its surface altitude varies between 4.17 m OD and 3.58 m OD.

A bluish buff clay overlies the peaty clay. At BAW1 and 2 it is seen to contain freshwater molluscs and peat inclusions and at BAW3 orange mottling is recorded. This evidence suggests that this deposit is freshwater in origin rather than marine. The surface of this clay varies between 4.47 and 3.72 m OD. A brown clay topsoil from the Downholland 1 Association finishes the present lithological sequence at Bawdrip, with the surface altitude of the study site varying between 5.27 and 4.03 m OD.

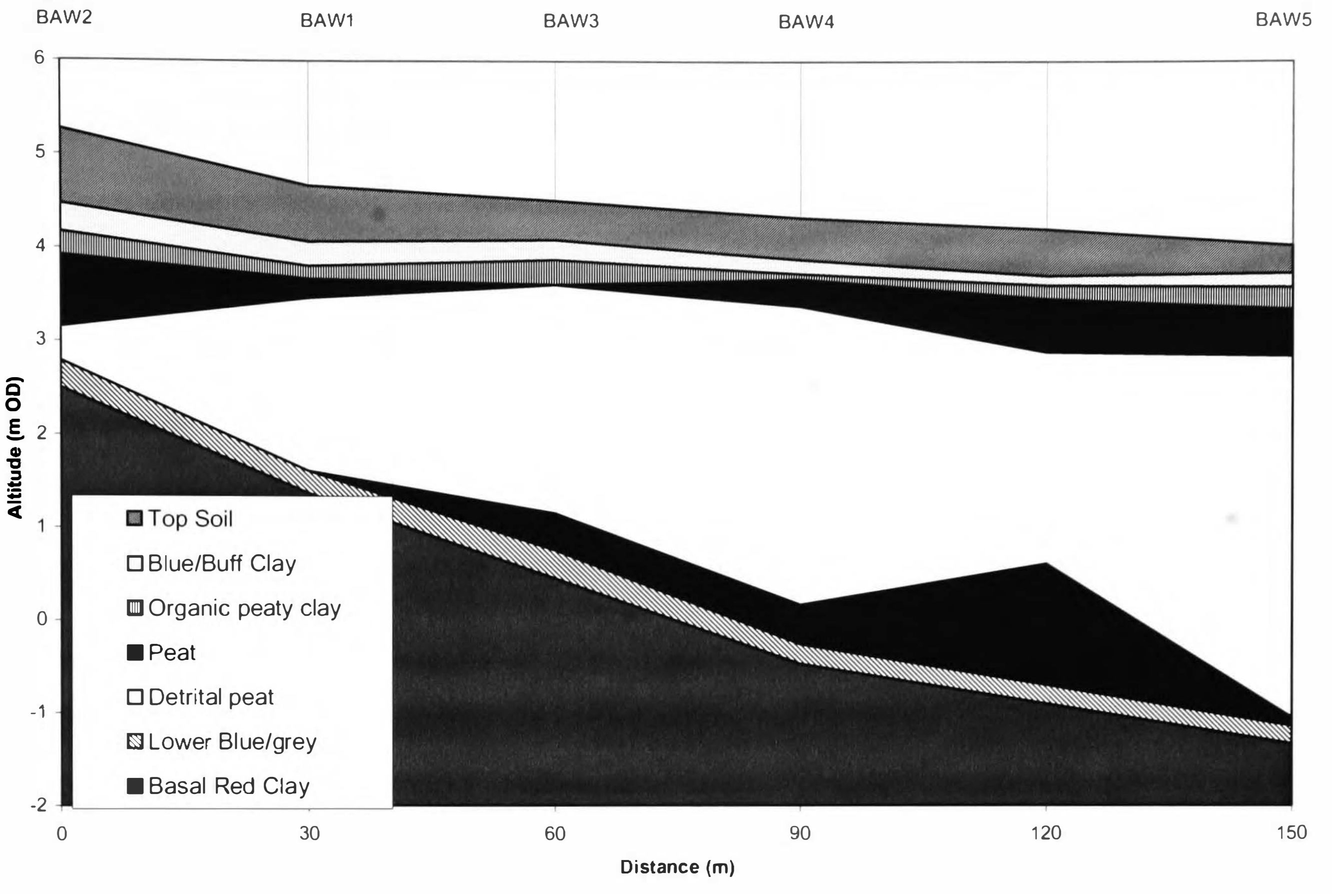


Fig. 6.5 Lithostratigraphy along the Bawdrip transect (see Figure 6.4 and Table 6.1)

6.2.2 Biostratigraphy

The sediments recovered from Bawdrip were analysed for biological indicators that can be used to infer the environment in which they were deposited (Berglund 1986, Haslett 2002).

6.2.2.1 Foraminiferal analysis

As at Dundon Hayes, foraminifera were also very sparse at Bawdrip with only one foraminifera specimen being recovered from the lower blue-grey clay. The specimen of foraminifera in question belongs to a species (*Ammonia becarii*) found in modern salt marsh environments, usually on the low and mid marsh areas (Haslett *et al* 1998b). Also found within the lower blue clay at Bawdrip were examples of a `Slum' species of fresh water mollusc (*Anisus leucostoma*) and other unidentifiable fragments.

Depth	**Lithostratigraphy**	***A becarii***	**Other findings**
515 – 517	Brown organic clay - transition to blue clay	1	Fresh water Mollusc fragments
517 – 519	Blue grey clay	0	1 *A. leucostoma* – Slum species freshwater mollusc
523 – 525	Blue grey clay	0	Fresh water mollusc fragments
527 – 529	Blue grey clay	0	
531 – 533	Blue grey clay	0	
535 – 537	Blue grey clay	0	

Table 6.3 Biostratigraphic results at BAW5

6.2.2.2 Freshwater molluscs

A sequence of freshwater molluscs was recovered from the peat deposit at Bawdrip and the core at BAW5 was analysed to establish species diversity and abundance variation (Figs. 6.6 and 6.7). The sequence is relatively extensive at Bawdrip, spanning an interval of 3.5 m. It was clear from field identification of some mollusc specimens that the molluscan sequence recovered from BAW5 represents an environment that is characterised by freshwater conditions. Some specimens of terrestrial species were also found at Bawdrip and are included in the raw count diagram (Fig. 6.7). Cluster analysis was carried out on the results to determine zones within the data which are shown on the diagrams as dendrograms. The full statistical analysis is included at Appendix III for reference.

The results at Bawdrip reveal a diverse molluscan assemblage with varying numbers of individuals in the samples examined. Some samples contained more than 300 individuals while a barren interval is evident with two samples containing no specimens at all (145 – 150 and 165 – 170 cm). On the whole preservation of specimens was good although fragmentation of some had occurred indicating occasional poor preservation.

The lower part the molluscan sequence (zone 1) includes *Lymnaea peregra* a species known as an early coloniser of newly established freshwater habitats (Macan 1960). Another species present in this part of the sequence is *Gyraulus laevis*, a species which is known to tolerate slightly brackish conditions and, therefore, may have been present on the fringes of a previous intertidal

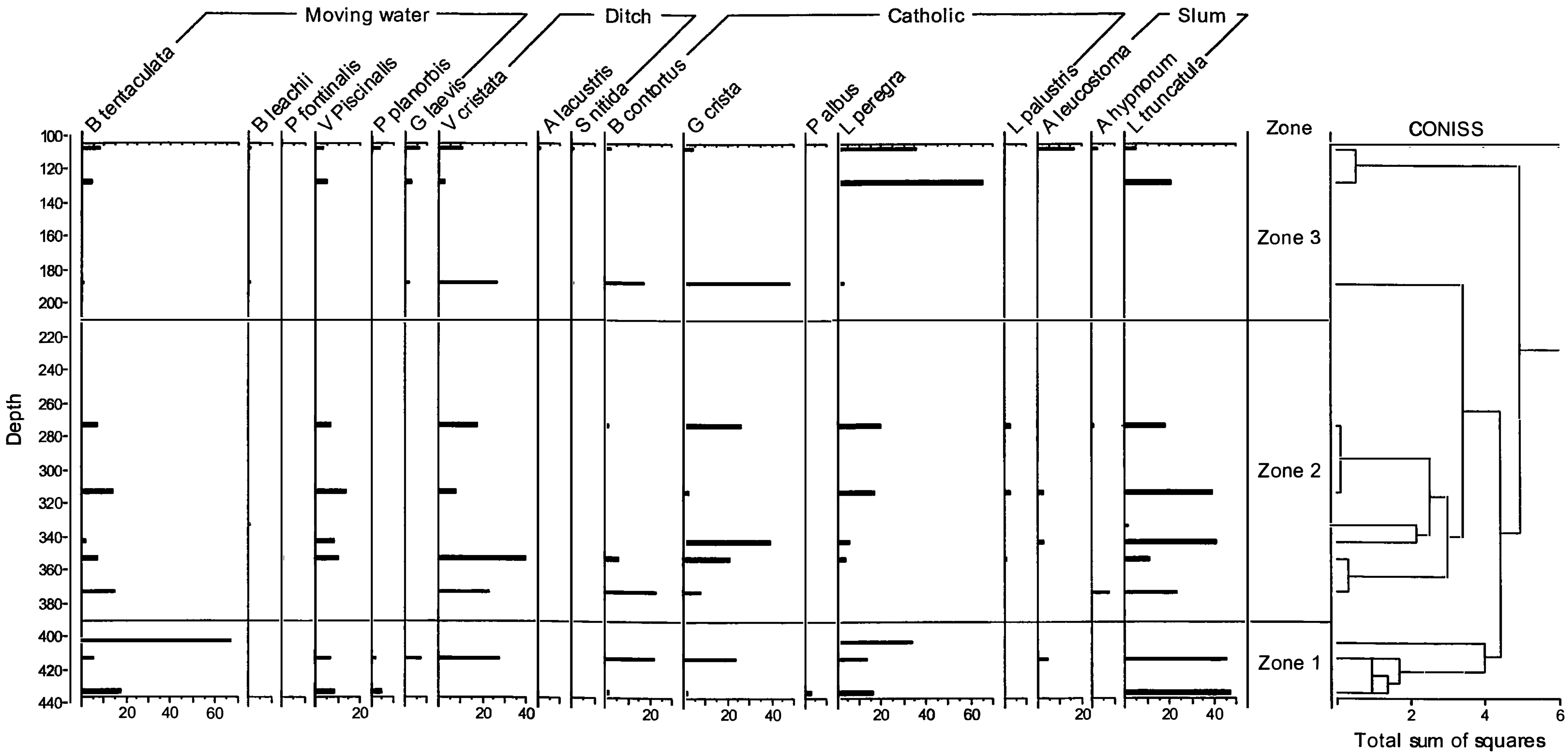


Fig. 6.6 Molluscan results from BAW5 shown as percentage counts against depth (cm)

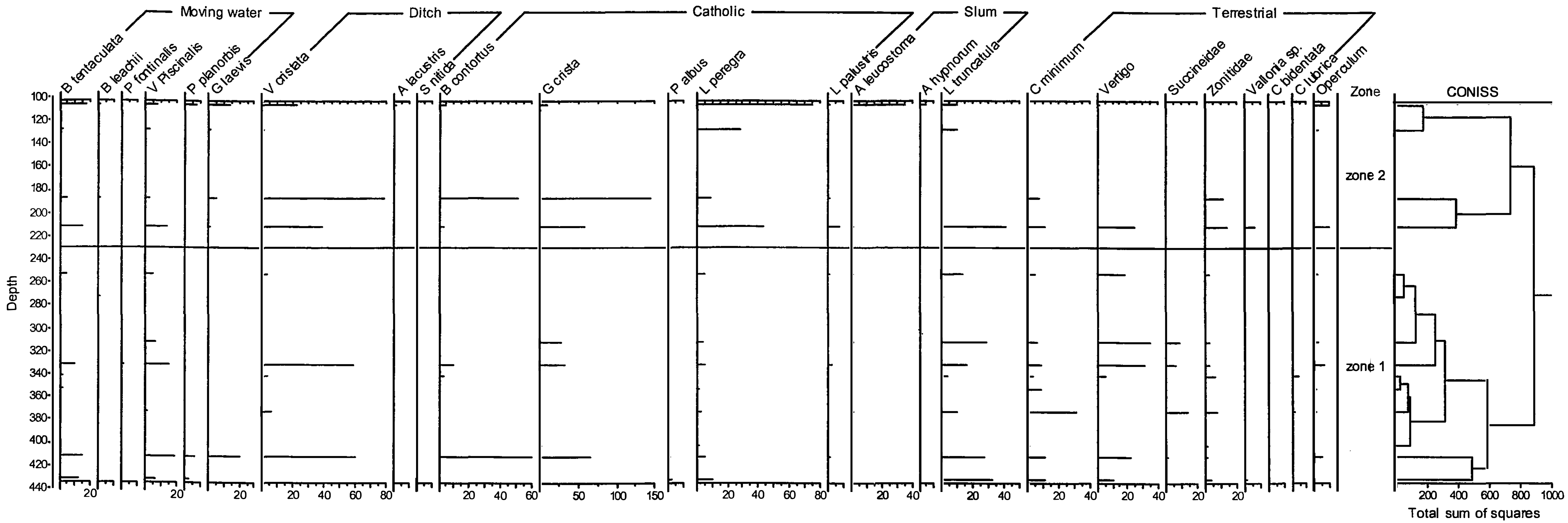


Fig. 6.7 Molluscan results from BAW5 shown as raw counts against depth (cm)

environment. *Lymnaea truncatula* is also present in high numbers in the zone 1. This species is amphibious, and was probably present during the transition as the local conditions began to become wetter. Numbers of *Bithynia tentaculata* and *Valvata piscinalis* rise towards the top of zone 1, indicating the environment becoming more like a lake as these are both species that prefer substantial water bodies that are well oxygenated. Numbers of *Valvata cristata*, *Bathyomphalus contortus* and *Gyraulus crista* also rise upwards through zone 1, inferring that the habitat at Bawdrip was also richly vegetated.

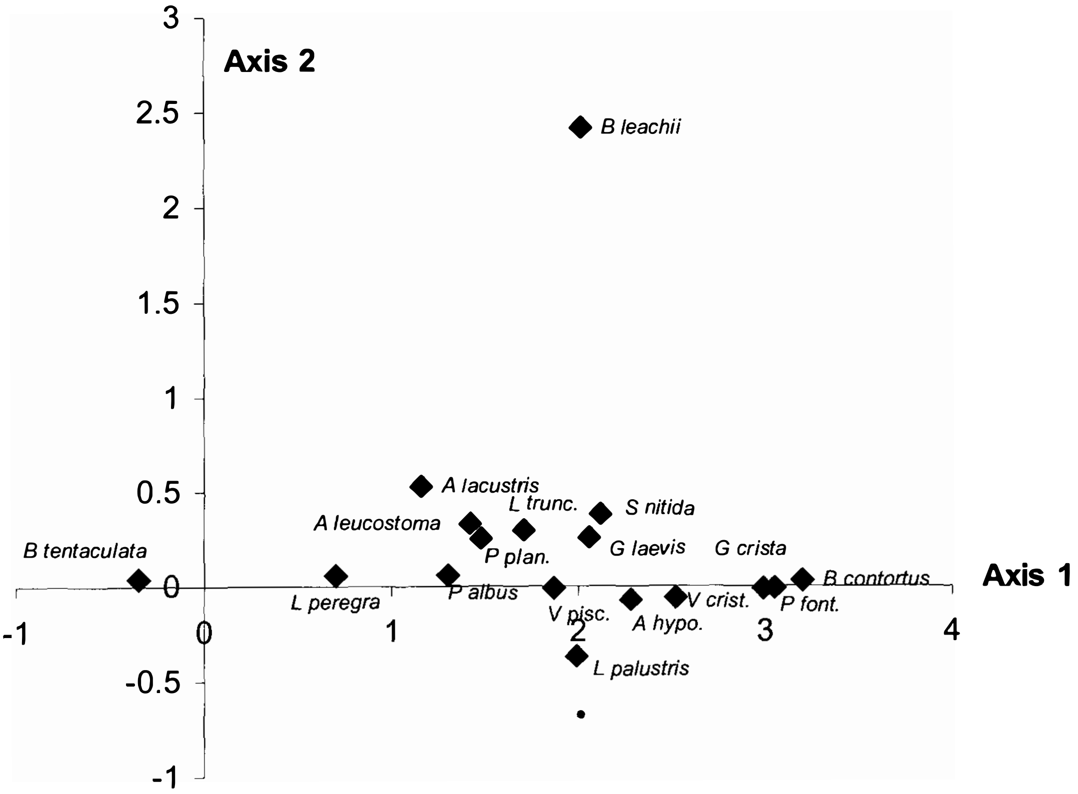


Fig. 6.8 Axis 1 and Axis 2 results from the DCA of the percentage molluscan data at Bawdrip

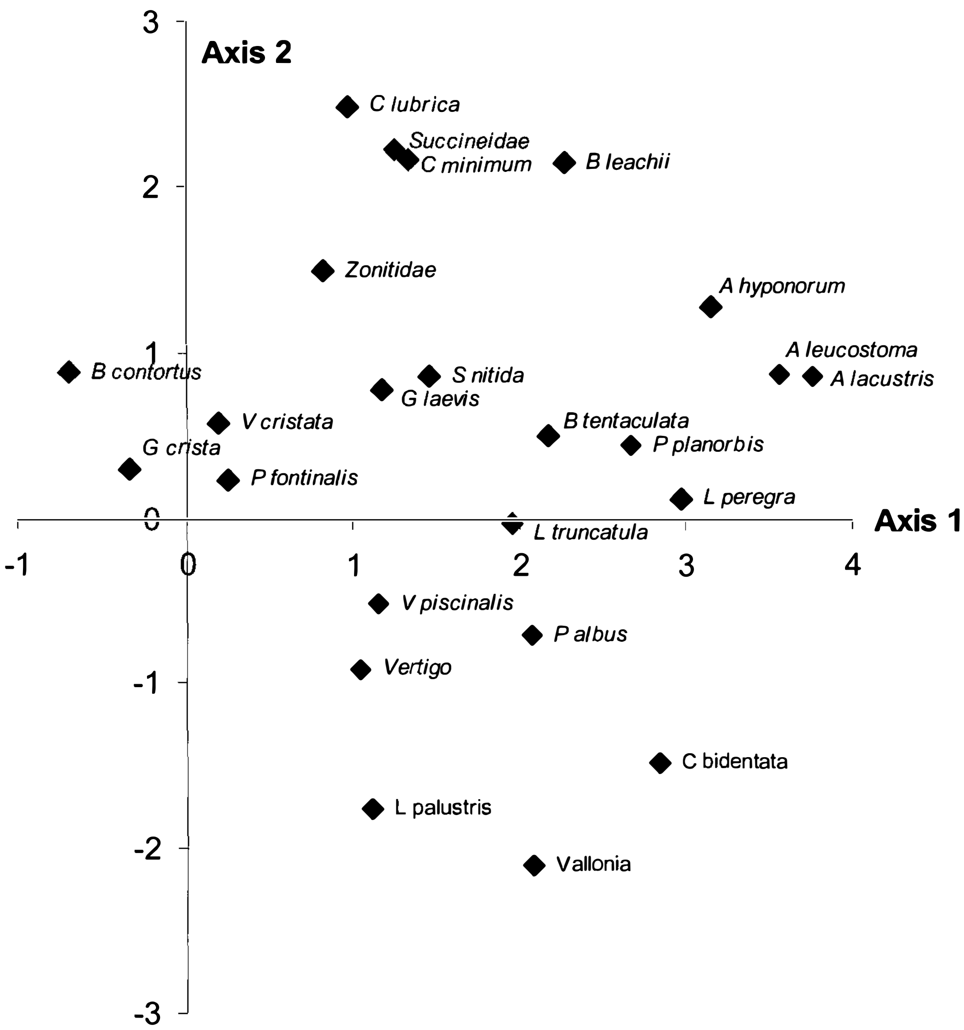


Fig. 6.9 Axis 1 and Axis 2 results from the DCA of the raw molluscan data at BAW5

DCA analysis was carried out on the molluscan data from Bawdrip (Dale and Dale 2002) and the results shown in Figures 6.8 and 6.9.

The molluscan information from borehole BAW5 shows that the large open water body that had established during zone 1 subsequently became shallower, richly vegetated and more ditch like. The water would have been still and may have been prone to periodic drying. Species like *Vertigo* sp. are present which are known to inhabit wetlands and are known to occur in association with *Phragmites* (Kerney 1999) which are recorded in the lithostratigraphy between 219 - 349 and 142 – 210 cm. The presence of other species also infers a swampy wetland habitat. For example, *Zonitoides* sp. and *Succineidae* sp., which are both present in this sequence, are known to inhabit wetlands and *Phragmites* particularly (Kerney 1999). `Moving water' species can be seen to fall throughout this period with the overall assemblage being dominated by the `Catholic' and `Slum' species.

As previously mentioned two samples analysed where barren of molluscan remains at 145 – 150 and 165 – 170 cm. It is not possible in this study to identify why these samples were barren of molluscs, but plant macrofossils within these two samples have been analysed as a further indicator of habitat and the results are shown in Table 6.4.

Sample (BAW5) (cm)	Results
145 –150	Contained fragments of *Carex* species (Sedge), which are fairly frequent. *Cladium mariscus* (Great Fen sedge) is also found within this sample, which is characteristic of shallow standing water and can form part of a sedge swamp community on usually neutral or alkaline soils. Other marsh species such as *Cirsium* sp. and moss were present along with *Urtica dioca* (common nettle).
165 – 175	Similar community to the 145-150 sample, but no sedge present. Fragments of *Cladium mariscus* present also examples of *Mentha aquatica* (Water-mint), *Ranunculus lingua* (Great Spearwort) and *Chara oospore* (Stonewort). *Mentha* and *Ranunculus lingua* are both marsh/fen species. The presence of *Chara*, a macroscopic green algae again suggests calcareous conditions

Table 6.4 Plant macrofossil evidence from BAW5

The absence of molluscs from the above two samples remains a mystery as it would seem the same habitat type existed through the samples that are barren of individuals. It is known, however, that plant and animal communities react at differing rates to environmental stresses with plants being slower to react as they are less able to migrate quickly from a stressed situation.

Above the barren samples, *Lymnaea peregra* is again present, probably as an initial coloniser. The `Catholic' and `Slum' groups dominate the uppermost samples in the molluscan sequence studied, terminating at 105 cm.

6.2.3 Radiocarbon Dates

Three samples retrieved from the boreholes at Bawdrip were selected and submitted for radiocarbon analysis. The results are given in Table 6.5. In order to date the marine regression at Bawdrip the initial sample chosen for dating was from the contact between the lower blue-grey clay and the peat. A sample from the base of the peat immediately above this contact at BAW5, at a depth of 490 – 500 cm, was selected and submitted. The contact has an altitude of –0.87 m OD and was dated to 6920 to 6450 cal. yrs BP (4960 to 4500 cal. yrs BC).

The sample analysed at the peat-upper clay boundary was BAW5 45-55 cm. The contact is from an altitude of 3.58 m OD and yielded a 2σ date of 1720 to 1420 cal. yrs BP (230 to 530 cal. yrs AD).

A further sample was analysed, BAW 360 – 365 cms, in order to date the start of a molluscan sequence recovered in the cores. This sample was taken from an altitude of 0.43 m OD, and yielded a 2σ age range of 6100 to 6070 cal. yrs BP and 6020 to 5720 cal. yrs BP (4150 to 4120 cal. yrs BC and 4070 to 3770 cal. yrs BC).

Lab Code	Sample	Context	Altitude M OD	Conventional ^{14}C Age BP	2 Sigma cal. calendar yrs BP	2 Sigma cal. results BC/AD	Calibrated Intercept Age calendar Yrs BP
Beta – 164543	BAW5 490-500 cm	Clay-peat boundary	-0.87	5880+/- 100 BP	6920 to 6450	4960 to 4500 BC	6680
Beta – 164542	BAW5 45-55 cm	Top of peat	3.58	1680 +/- 60 BP	1720 to 1420	230 AD to 530 AD	1560
Beta – 169232	BAW5 360-365 cm	Base of mollusc sequence	0.43	5150 +/- 80 BP	6100 to 6070 and 6020 to 5720	4150 to 4120 BC and 4070 to 3770 BC	5920

Table 6.5 Radiocarbon dates from Bawdrip

6.2.4 Particle size analysis

Crude particle size analysis was carried out on the lower clay samples retrieved from Bawdrip as a way of further understanding the depositional environment. Grain size is linked to energy and in salt marshes grain size reduces from the salt marsh shore (Allen 1994, 1996). The results from Bawdrip are shown in Fig. 6.10 and are outlined in full at Appendix VII.

Results show that the lower blue-grey clay at Bawdrip is characterised by the fine particles throughout the sequence. No significant change or patterns can be seen in the data, but it may be inferred that the depositional environment would have been one of relatively low energy.

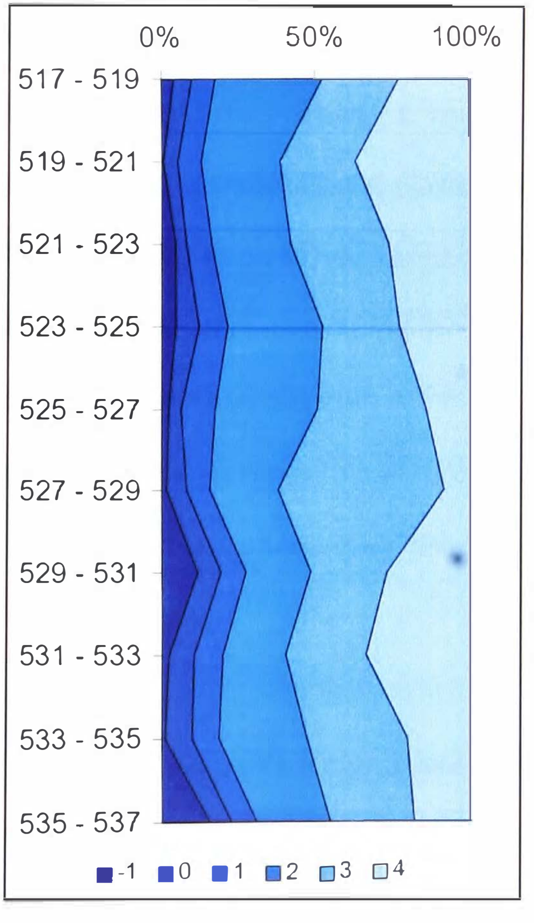


Fig. 6.10 Particle size analysis from the lower clays at Bawdrip

6.3 The mid to late Holocene environmental history of Bawdrip

The evidence examined at Bawdrip supports that seen at both Dundon Hayes (see Chapter 4) and Briarwood Farm (see Chapter 5). The lithostratigraphy is consistent in showing that around 7000 years ago a red palaeosol mantled the bedrock in the area around Bawdrip. This palaeosol has been measured at Bawdrip to a maximum thickness of 38 cm, without reaching the bedrock. The surface altitude of this deposit is lower at Bawdrip than at the other sites studied varying between 2.5 m OD and –1.33 m OD.

The marine transgression seen elsewhere in this study is also seen at Bawdrip and the sequence is consistent in that some time before 6000 cal. years BP the environment around Bawdrip experienced a marine transgression and became intertidal. The blue-grey clay deposited at Bawdrip has been measured up to a maximum of 29 cm, but also contains evidence that freshwater conditions may have been present in the areas surrounding the palaeo-salt marsh, as a `Slum` component of freshwater mollusc species are found to occur, perhaps close to HAT. Foraminifera recorded in modern salt marshes are present confirming, as shown at the other sites, that the blue-grey clay has been influenced by a marine processes during its deposition.

The lithological sequence suggests a significant change in depositional environment indicated by a transition from blue-grey clay deposition under a marine influence to non-marine peat. This change may be explained by a change from an intertidal depositional environment to one dominated by fresh water.

Radiocarbon dating at BAW 5 indicates this change took place between 6920 and 6450 cal. years BP. The altitude of this sample was from –0.87 m OD making it altitudinally the lowest sample dated throughout this study, which lends further support to the argument that peat in the Somerset Levels formed first at the lowest altitudes and grew up over the exhumed clay surface (Haslett *et al* 2001b). The peat at Bawdrip is initially a woody fen peat with roots, but later becomes a detrital peat forming environment, probably a standing body of freshwater, in which freshwater molluscan communities existed. The molluscan sequence examined at borehole BAW5 indicates a succession of freshwater habitats throughout detrital peat deposition, with `Moving water', `Ditch', `Catholic' and `Slum' groups being represented along with some terrestrial species. Radiocarbon analysis dates the start of the detrital peat sequence at BAW5 to between 6100 and 5720 cal. years BP. It is from an altitude of 0.43 m OD making it the oldest and altitudinally lowest mollusc sequence dated throughout this study. The 3.5m long molluscan sequence suggests a protracted period when conditions were wet at Bawdrip. The `Moving water' group of molluscs do not come to dominate the sequence as has been shown at the other sites. At Bawdrip, it seems that conditions were slightly drier, more ditch like, and may have been prone to occasional drying. The molluscan evidence also suggests a well vegetated environment and limited plant macrofossil analysis suggests species such as *Carex* were present. Archaeological investigations have suggested that wooden trackways were in operation in the location at this time supporting the existence of a wetland or boggy environment, rather than a lake (Norman and Clements 1979; Coles and Orme 1985b). The molluscan sequence continues until a depth of 1.05 m OD when the lithology shows a marl like deposit which contains mollusc-rich bands before returning to a brown peaty clay. The surface of this peaty deposit was dated to between 1720 and 1420 cal. years BP. This is at a time that archaeology indicates that Romano-British settlers were present at Bawdrip, and the termination of peat formation may be physical evidence of the draining of the Somerset Levels by the Romans, a topic that will be discussed in Chapter 7.

A blue-buff clay overlies the peat deposit which is described in the lithostratigraphy (Table 6.2) as containing freshwater molluscs and peaty inclusions. This infers a possible fresh water flood and Williams (1970) indicates that the River Parrett flowed near here in an earlier course before being altered in 1677. The red clay topsoil is assigned to the Downholland soil association (Findlay *et al* 1984), and caps the modern soil profile. The site at Bawdrip adds considerably to the Holocene palaeoenvironmental history of the Sedgemoor valley and will be discussed further in Chapter 7.

Chapter 7 Discussion

The results presented for each of the sites investigated, in Chapters 3 - 6, provide information on the detailed lithostratigraphic character of each of the sites, and evidence for the palaeoenvironmental development of the landscape at each location. Before putting these data into a regional and, ultimately, a wider context, it is necessary to establish an area-wide lithostratigraphic correlation and palaeoenvironmental development sequence.

7.1 The Lithostratigraphic correlation

The lithostratigraphy reported in Chapters 4, 5 and 6 (sections 4.2.1, 5.2.1 and 6.2.1) indicate that a relatively consistent mid to late Holocene sequence exists in the Sedgemoor Valley. In general terms, the sequence comprises a basal red clay palaeosol, a blue-grey silty-clay , followed by an extended unit dominated upwards by peat and muds. Fig. 7.1 shows a generalised model for the development of the lithostratigraphy in the Sedgemoor valley. The sites investigated in Sedgemoor display varying local influences (to be discussed later), but generally it is possible to recognise the sequence similar to that observed throughout the Somerset Levels. One important difference in Sedgemoor is the absence of a second major phase of marine transgression, that clearly has affected extensive areas of the North Somerset and Gwent Levels between 4000 and 3000 years ago.

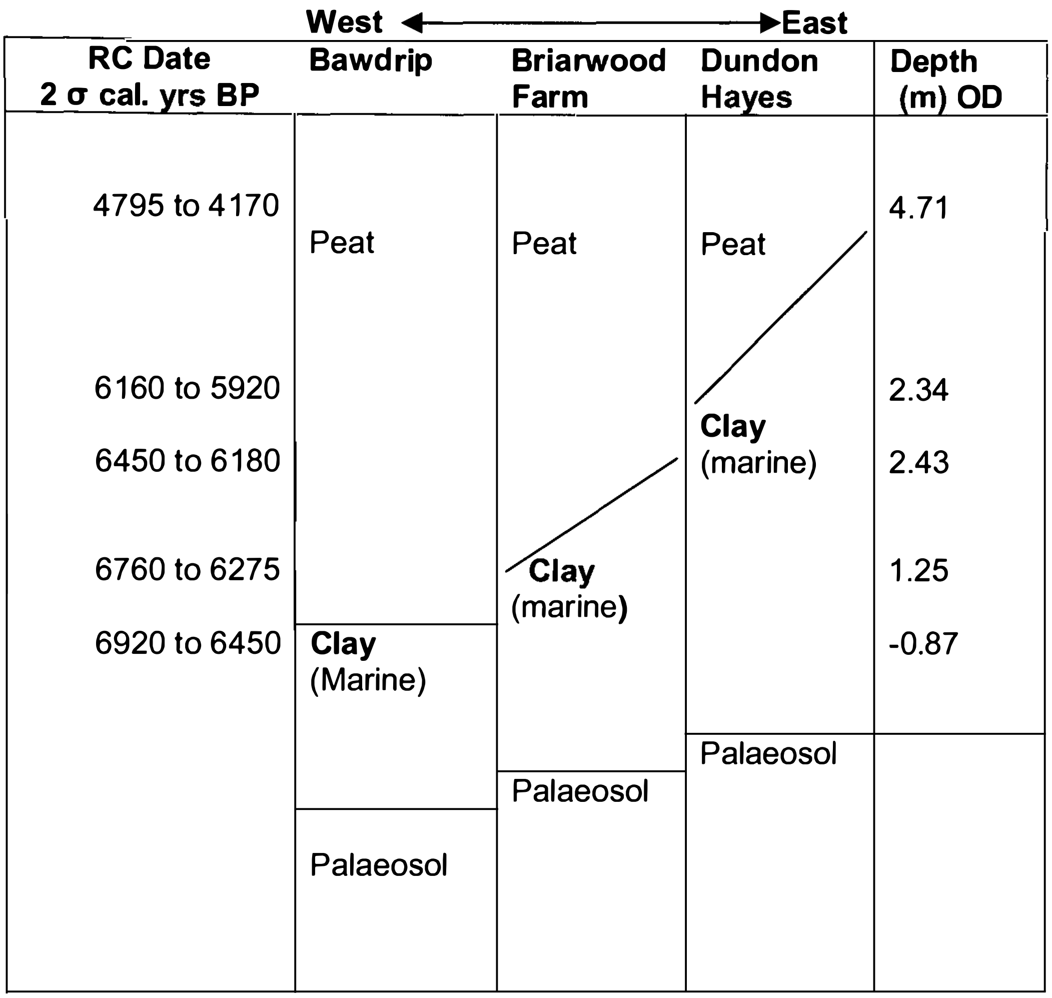


Fig. 7.1 A model of the marine clay to peat transition in the Sedgemoor valley

7.1.1 The lower clays of the Sedgemoor Valley

A lower red clay was identified at each of the three sites within the Sedgemoor Valley. The surface altitude of this clay varied between a maximum of 6.2 m OD at Dundon Hayes (DH2) and a minimum of –1.33 m OD at Bawdrip (BAW5). This clay contained clasts of angular gravel and wood at both Dundon Hayes and Briarwood Farm. At Briarwood Farm a sandy blue layer was also recorded in the red clay.

Site	Maximum recorded surface altitude m OD and borehole reference	Minimum recorded surface altitude m OD and borehole reference	Additional points to note and borehole reference
Dundon Hayes	6.20 DH2	1.66 DH1	Contained limestone, wood and sandy layer (DH2) Contained wood (DH6)
Briarwood Farm	3.21 BF8	0.0 BF5	Sandy blue layer in clay (BF6) Contained gravel (BF7) Contained charcoal (BF9)
Bawdrip	2.50 BAW2	-1.33 BAW5	Stopped coring in basal clay before being able to establish its extent

Table 7.1 The basal red clay at the Sedgemoor sites

Other authors have reported this red soil in their studies with Kidson and Heyworth (1976) proposing that it was a wooded surface with a birch forest being present in the Levels. Submerged forest beds on the foreshore of Bridgwater Bay were described by Heyworth (1978) who argued that they indicated that postglacial sea level rise inundated a wooded land surface. This soil has also been described as a Head deposit (Green and Welch, 1965; Findlay *et al* 1984; Kellaway and Welch 1993) and there is evidence from the sites reported here at Sedgemoor to support this in that the red clay contains some angular gravel clasts.

Overlying the red clay is a blue silty-clay that was deposited during a marine transgression in the mid Holocene. Biostratigraphic analysis of samples examined from the sites investigated in this study has yielded foraminifera, confirming that this clay is marine in origin.

Site	Maximum recorded surface altitude m OD and borehole reference	Minimum recorded surface altitude m OD and borehole reference	Additional points to note and borehole reference
Dundon Hayes	5.51 DH4	2.34 DH1	Wood present in DH1, DH3 and DH6 Limestone fragments at DH2
Briarwood Farm	4.22 BF4	0 BF5	Wood at BF4 Fragments of charcoal and *phragmites*
Bawdrip	2.79 BAW2	-1.14 BAW5	Fragments of freshwater snails

Table 7.2 The lower blue clay at the Sedgemoor Valley

Table 7.2 shows the maximum and minimum altitudes of the surface of the lower blue clay at the three sites in Sedgemoor. An important point to note is that the maximum altitude recorded at 5.51 m OD at Dundon Hayes is the highest altitude that this clay has been reported throughout the Somerset Levels. Kidson and Heyworth (1976) referred to this clay as being "at about OD" which they argue was colonised by forests of oak and pine. Wood fragments were found at the top of the samples supporting this theory.

7.1.2 The clay to peat contact in Sedgemoor

The earliest dates obtained throughout the lithological sequence are at the contact between the lower blue clay and the overlying peat. Table 7.3 lists all the radiocarbon evidence for this contact at Sedgemoor that is presented in this study. This contact represents the marine regression of the mid Holocene for this valley and it is clear from the evidence shown here that the formation of the freshwater peat in Sedgemoor began at the lowest altitudes and grew up over the exposed clay surface. The results from Bawdrip show that between 6920 and 6450 cal. yrs BP the peat began to form at an altitude of –0.87m OD. The highest altitude for this contact at Sedgemoor is 4.71 m OD at Dundon Hayes, which was dated to between 4795 to 4170 cal.yrs BP. The growth of the peat then took around 2000 years to spread the 15 km from Bawdrip up the valley to reach the higher slopes of Dundon Hayes.

The lowest altitude contact between the blue grey clay and the peat at Bawdrip is also important as it can be recognised as a Sea Level Index Point (SLIP). SLIPs are points at which age, altitude, tendency of sea level, and indicative meaning and range (Haslett 2000) are known. Table 7.3 shows the age and the altitude of this sample and in addition the tendency of sea level at this point is known from litho/biostratigraphic analysis. The tendency of sea level is the direction of sea level at the SLIP whether it be negative for a regression or positive for a transgression. At this contact in Sedgemoor there is a negative tendency as it has been established by lithostratigraphic investigations that a freshwater peat environment overlies the marine clay. The age, altitude and tendency can be established for the Bawdrip site but the indicative meaning is unclear. The indicative meaning and range refer to the position within the palaeo-tidal range of the point identified. Biological evidence is the most reliable in inferring indicative range and, as this evidence was poor at Bawdrip, we can use other sites in the Somerset Levels where the biological evidence is better represented to infer the position in the tidal frame of this SLIP. Haslett *et al* (1998a, b) have shown in the Axe valley that this contact has an indicative meaning and range of MHWST.

Lab Code	**Sample**	**Context**	**Altitude m OD**	**Conventional ^{14}C age BP**	**2 Sigma calibrated Calendar yrs BP**	**2 Sigma cal. results yrs BC/AD**	**Calibrated intercept age Calendar yrs BP**
Beta – 164543	BAW5 490-500cm	Clay-peat boundary	-0.87	5880+/- 100 BP	6920 to 6450	4960 to 4500 BC	6680
Beta – 131491	BF6 390-397	Clay-peat boundary	1.25	5700+/- 130 BP	6760 to 6275	4810 to 4325 BC	6475
Beta – 131492	BF7 310-324	Clay-peat boundary	2.43	5520+/- 80 BP	6450 to 6180	4500 to 4230 BC	6300
Beta – 131493	DH1 445-454	Clay-Peat boundary	2.34	5200+/- 40	6160 to 6145 6110 to 6050 6035 to 5920	4210 to 4195 4160 to 4100 4085 to 3970 BC	5985
Beta – 131494	DH3 298-308	Clay-Peat boundary	4.71	3970+/- 80	4795 to 4770 4620 to 4215 4210 to 4170	2845 to 2820 2670 to 2265 2260 to 2220 BC	4425

Table 7.3 Radiocarbon dates for the blue clay and peat contact at Sedgemoor

7.1.3 Peat Facies

The peat deposits at Sedgemoor contain evidence of local environmental change that can be inferred from the variations in the molluscan communities present throughout the deposit and changes in the form of peat.

The peat varies in nature from site to site in Sedgemoor. At all of the sites in this study there is evidence of *Phragmites* being present in the deposit immediately above the marine clay. The remainder of the sequences contain peats that are either detrital or *turfa* in nature. Detrital peat is formed in very wet conditions from the accumulation of particulate organic matter that does not degrade and was found at all of the Sedgemoor sites where it contained populations of fresh water molluscs. The other type of peat commonly found was *turfa* peat, which is more terrestrial in nature and contains roots in growth position. The peats were also frequently very woody in nature. The lithostatigraphy shows some evidence of an interchanging of these peat types in Sedgemoor, suggesting an environment that fluctuates from a terrestrial surface before being overwhelmed by flood-water. This implies a very high water table in the valley throughout the period of detrital peat deposition.

From the molluscs recovered within the detrital peat layers the local environmental conditions may be inferred, which prevailed at the sites in Sedgemoor during the period that the deposits were laid down. The molluscan evidence from the sites at Dundon Hayes and Briarwood Farm show that large open water bodies were present. The indications are that the water bodies would have been large enough for us to consider them lake-like with currents and oxygenated water. There is also evidence to suggest that the lake(s) would have been well vegetated with a muddy substrate. At Dundon Hayes the molluscan sequence studied covered a depth of 0.55 m while at Briarwood Farm the sequence was present for 1.85 m. This suggests that the very wet conditions at Briarwood Farm may have continued for a longer period than that at Dundon Hayes. However, dating evidence from this study cannot confirm this, as dates are not available for the base and top of the peat containing the molluscan sequences at both of these sites. The two sites have radiocarbon dates available for the lower blue clay and peat contact which are, taking the lowest available date at each site, at Dundon Hayes 6160 to 5920 cal. yrs BP and 6760 to 6275 cal. yrs BP at Briarwood Farm. At Dundon Hayes the molluscan sequence began 0.92 m into the peat deposit, which compares to 0.24 m at Briarwood Farm. The start of the molluscan sequence at Dundon Hayes is dated to between 3820 and 3490 cal. yrs BP in borehole DH5. The date for the end of the sequence is not known but a date of 1050 to 780 cal. yrs BP is available for the top of the peat at this borehole.

At Briarwood farm, the date of the clay-peat contact in the borehole containing the molluscs studied (BF7) is 6450 to 6180 cal. yrs BP. It has been established that the molluscs were present 0.24 m above the base of the deposit and so it may be inferred that the molluscan presence began only a relatively short time after the peat had started to form. The date at the end of the mollusc sequence in the same borehole is 4520 to 4170 cal. yrs BP. It could be inferred from this evidence that the water body at Briarwood Farm was in existence for approximately 2000 years.

At Bawdrip the molluscan sequence is longer than at the other two sites and displays a wider range of habitats. The evidence suggests that the environment at Bawdrip remained drier than at Briarwood Farm and Dundon Hayes and was instead a boggy, swampy environment rather than a lake. The sequence covers a depth of 3.5m indicating that, not withstanding the possibility of rapid deposition, this environment existed for a considerable period of time.

Both Dundon Hayes and Bawdrip possess an upper clay within the lithostratigraphy. Evidence suggests that these clays are freshwater in origin. At Bawdrip the upper clay is up to 0.3m thick and contains evidence of freshwater molluscs and, significantly, the site is known to have been situated close to an old course of the River Parrett. The site at Dundon Hayes has been subject to considerable in-wash from the nearby hill. The colluvial deposit contains several bands of clay showing intermittent slope-wash over a period of time. The evidence suggests that Dundon Hayes and Bawdrip were probably subject to periods of fluvial flooding and slope wash, which may explain the upper clay bands. No upper clay was evident in the lithostratigraphy at Briarwood Farm.

Lab Code	Sample	Context	Altitude MOD	Conventional ^{14}C age BP	2 Sigma calibrated Calendar yrs BP	2 Sigma cal. results yrs BC/AD	Calibrated intercept age Calendar yrs BP
Beta – 164542	BAW5 45-55cm	Top of peat	3.58	1680 +/- 60 BP	1720 to 1420	230 AD to 530 AD	1560
Beta – 169234	BF9 52-67	Top of peat	4.84	2340+/- 50 BP	2460 to 2320	400 BC	2350
Beta – 148754	DH5 120-125	Top of peat	6.31	1010+/- 60	1050 to 780	900 to 1170 AD	930
Beta – 148755	DH7 131-141	Top of peat	6.04	880+/- 70	940 to 670	1010 to 1280 AD	780
Beta – 169232	BAW5 360-365cm	Base of mollusc sequence	0.43	5150 +/- 80 BP	6100 to 6070 and 6020 to 5720	4150 to 4120 BC and 4070 to 3770 BC	5920
Beta – 169233	BF7 115-135	In molluscan sequence	4.32	3930+/- 60 BP	4520 to 4220 4210 to 4170	2580 to 2270 2260 to 2220 BC	4410
Beta – 153513	DH5 267-271	Base of mollusc sequence	4.79	3400+/- 50	3820 to 3780 3730 to 3490	1870 to 1840 1780 to 1540 BC	3640

Table 7.4 Radiocarbon results from the peat deposit at Sedgemoor

7.1.4 Human influence evident in the lithostratigraphy

Archaeological evidence shows that since the Mesolithic humans have lived in and around Sedgemoor. At Greylake, near to Briarwood Farm, a Mesolithic flint-chipping site was found during excavations in 1930 (SHER 10570) and a Mesolithic blade of dark grey chert was found with three flints at Middlezoy (SHER 11763). These communities would have been forced to live on the fringes of Sedgemoor when the area became intertidal but may have still utilised the area for fishing. Later, when the landscape became dominated by freshwater and peat began to form, evidence for trackways is clear with the Strangways Causeway (Grey 1926) at Greinton and Sutton Hams trackway (Norman and Clements 1979; Coles and Orme 1985b). Humans continued adapting to the conditions and again using the area to move around, hunt, and possibly worship. It has been suggested that a further wooden structure adjacent to Grey's (1926) site may have been a ritual site where human bones, pottery sherds and other artefacts were discovered in what would have been shallow fresh water (Brunning 1998). Dendrochronology on one of the oak piles from this structure indicates that it was from a tree felled after 2892 cal. yrs BP, and an oak plank also dated was 2913 cal. yrs BP (Brunning 1998).

Throughout the Iron Age the Somerset Levels was part of the territory of the Durotriges tribe and pottery and coins relating to them has been found on the Polden Hills and near the rivers Parrett and Yeo (Cunliffe1982). Iron Age sites overlook Sedgemoor including Dundon and Bradley Hill, with the former being the site of a major hillfort (Cunliffe 1982).

A rising relative sea-level trend had continued alongside the deposition of freshwater sediments in Sedgemoor, causing a second marine inundation to occur in some areas of the Somerset Levels (Kidson and Heyworth 1976, Haslett *et al* 1998a, 2001a). Most human occupation of Sedgemoor at this time would have been restricted to the higher ground of the Poldens. In the Roman Period, the Somerset Levels began to be strongly influenced by human activity. Evidence for Roman reclamation of the Severn Levels has come from the Welsh side of the Severn estuary where Allen & Fulford (1986) found drainage ditches on the Wentlooge level containing Roman pottery, bones, teeth and stones which provided the first specific evidence of planned reclamation. Later, on the English side, Allen *et al* (1996) located evidence of Roman drainage ditches while excavating the Brean Down sea defences. Also, Rippon (1996) reported on drainage ditches at Puxton, Banwell and Kenn in the Northern Somerset Levels. The presence of the Roman settlement of Crandon Bridge near Bawdrip confirms that these reclamation works seen elsewhere in the Levels were also occurring within the Sedgemoor Valley. Haslett *et al* (2001a) showed that this Roman reclamation of the coastal areas took place against a still rising sea level trend in their study at Nyland Hill. They argue that during the deposition of the Nyland Hill Clay Member a progressive lowering of the intertidal surface can be seen along with increased hydraulic duty and palaeochannel enlargement (Haslett *et al* 2001a).

As explained in Chapter 1, Williams (1970) showed that the systematic reclamation of the Levels began again in around the 11th Century. The area became under the control of religious houses which leased land to the Saxon settlements that grew around the high ground. They utilised the moors for summer grazing as pasture rights became an important part of the manorial economy. The grazing rites became difficult for the religious houses to control and illegal pasturing was common. In the 13^{th} Century feuds in the religious houses made them weak and financially unstable and vigorous efforts were then made to stem the tide of leasehold and to recover and drain their lands (Williams 1970). It is this vigorous draining that created the landscape that exists today. The radiocarbon dates for the top of the peat at the sites in Sedgemoor (Table 7.4) indicate a late Roman date for reclamation at Bawdrip, between 1720 and 1420 cal. yrs BP (230 to 530 AD), and Medieval dates for this contact at Dundon Hayes which are between 1050 to 780 cal. yrs BP and 940 to 670 cal. yrs BP (between 900 to 1170 AD and 1010 to 1280 AD). The dates and lithology reported here are the first physical evidence to support the known written evidence of the drainage of the Somerset Levels. The anomalous old date of 2460 to 2320 cal. yrs BP for the upper peat at Briarwood Farm in addition to the lack of an upper clay at this site could be the result of erosion of the peat or desiccation and decomposition if drainage works were severe.

7.1.5 The modern estuary

The modern day and core information analysed revealed that the marsh at Stert was retreating landward and accreting substantially in response to relative sea level rise. The results from the chemostratigraphic analysis of the core samples indicate that the 1 m of marsh examined had all accreted since 1958.

The information gathered from the study at Stert cannot establish the estuarine dynamics during the 1900 year gap between 2000 yrs ago and the samples examined but all indications are that during this intervening period sea level has continued to rise as has been suggested by other authors (Haslett *et al* 1998a, Allen 1991).

7.2 The temporal and spatial model of mid to late Holocene environmental change in the Sedgemoor Valley

In examining the lithostratigraphy, biostratigraphy, dating evidence and the archaeological information gathered here a model of the environmental change in Sedgemoor has been devised (Fig. 7.2 and Tab. 7.5). The mid to late Holocene palaeoenvironmental development of Sedgemoor began with a wooded valley around 8000 years BP which was transgressed by the rising sea levels of the mid Holocene. This transgression occurred around 7000 years BP when the valley became a coastal wetland, an environment that persisted for more than 1000 years (Haslett *et al* 1998a, 2001a,b). As a result of this a marine clay was deposited throughout the valley. Dating evidence reported here shows that peat began to form at the lower altitudes in Sedgemoor and that this peat grew up over the clay surface to cover the whole valley by around 6000 years BP. Since the peat started forming in Sedgemoor it has been a freshwater environment and much of the peat in Sedgemoor is detrital in nature. This detrital peat contained diverse populations of fresh water molluscs inferring that large persistent fringing water bodies were present. It is during this detrital phase that recorded archaeological artefacts of Sedgemoor, such as trackways, may have been necessary during this wetter phase. This wet phase also corresponds with other areas that were experiencing a second marine transgression at this time, which did not occur in Sedgemoor but may have caused the ponding of fresh water by impeding river discharge into the estuary.

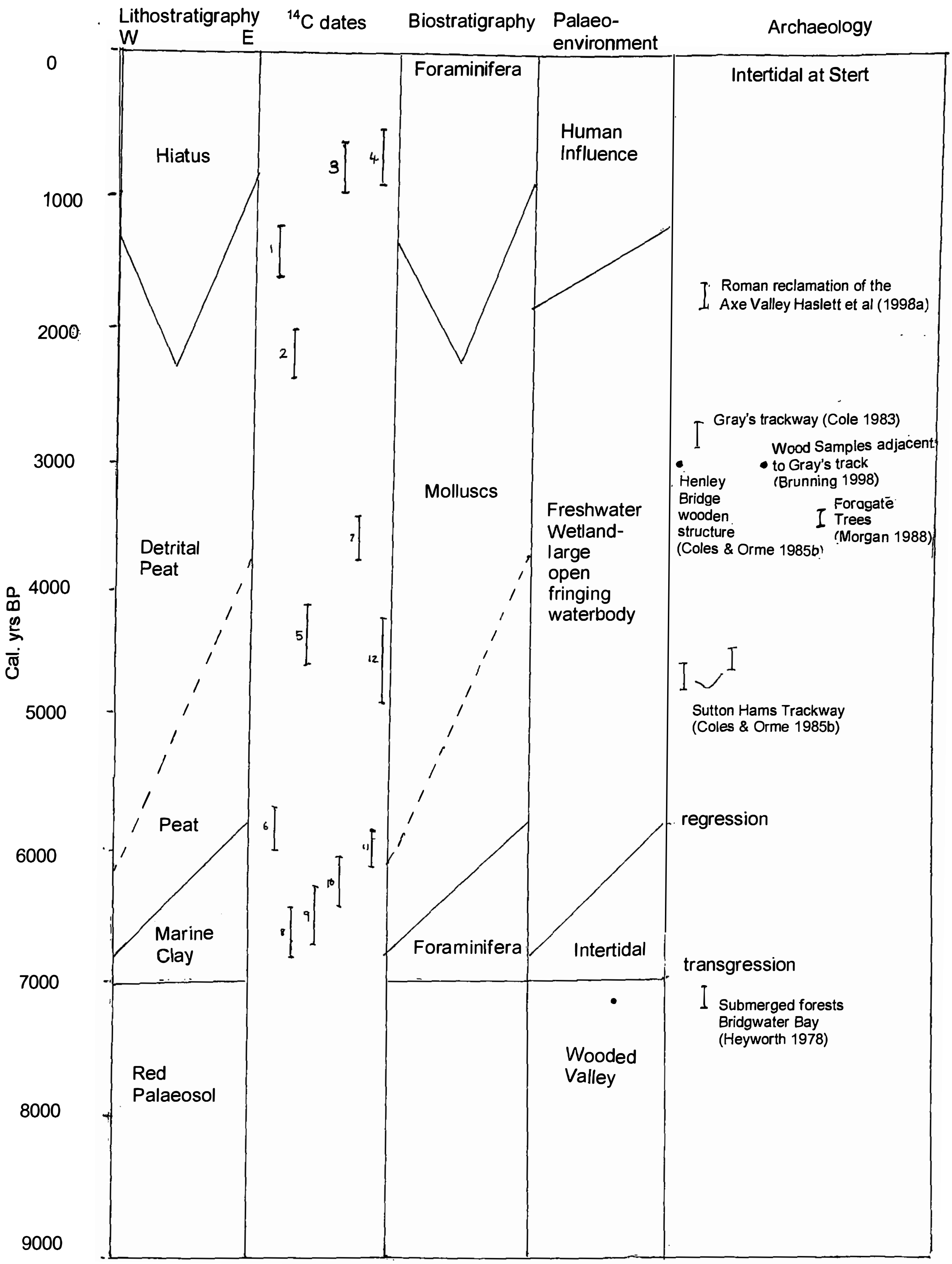


Fig 7.2 A temporal and spatial model of mid to late Holocene environmental change in The Sedgemoor Valley

Ref from Fig 7.2	Sample ref from this study	2 Sigma calibrated Calendar yrs BP
1	BAW5 45-55	1720 – 1420
2	BF9 52 – 67	2460 – 2320
3	DH7 131-141	940 – 670
4	DH5 120 –125	1050 – 780
5	BF7 115 - 135	4520 – 4170
6	BAW5 360 – 365	6100 – 5720
7	DH5 267-271	3820 – 3490
8	BAW5 490 – 500	6920 – 6450
9	BF6 390 – 397	6760 – 6275
10	BF7 310 - 324	6480 – 6450
11	DH1 445 - 454	6160 – 5920
12	DH3 298 - 308	4795 – 4170

Table 7.5 Table of radiocarbon references to accompany Fig. 7.2

7.2.1 Regional palaeoenvironmental change

The evidence reported here for the Sedgemoor Valley is consistent with that previously shown for the rest of the Somerset Levels. A common red palaeosol is seen throughout the Levels on either side of the Severn Estuary. Also consistently found is the lower blue clay that represents the marine transgression of the mid Holocene. This clay was termed the North Yeo Member by Haslett and Davies (2002) and is part of the Somerset Levels Formation (Campbell *et al* 1999). The altitude reached by this clay is unusual in the area as within Sedgemoor it reaches an altitude of 5.51 m OD whereas the previously highest recorded altitude was in the Axe valley at 4.64 m OD (Haslett *et al* 1998a).

The radiocarbon date for the mid Holocene regression has been shown here to be earlier at the lowest altitudes with the formation of peat growing up over the exhumed clay surface. The dates for the contact at Sedgemoor vary between 6920 and 6450 cal. yrs BP at Bawdrip and between 4795 and 4170 cal. yrs BP at Dundon Hayes. At Sutton Hams, Coles and Orme (1985) report the contact as being 5020 +/- 80 ^{14}C yrs BP. Haslett *et al* (2001a) reported the marine regression at Nyland Hill, within the Axe Valley, as occurring at 6855-6490 cal. yrs BP and proposed that the peat had been formed at the lower altitudes first. The evidence presented in this study suggests this process also occurred in the Sedgemoor Valley. These regression dates in Sedgemoor and the Axe valley also correspond to dates from the Brue Valley, where Coles and Dobson (1989) dated the clay peat contact to between 5650 and 5020 cal. yrs BP.

The peat deposit found at Sedgemoor is also common to the region. It has been formally defined as the Nyland Hill Peat Member (Haslett and Davies 2002) and is the mid section of the Somerset Levels Formation (Campbell *et al* 1999). Common to the other valleys the peat formation at Sedgemoor began with the development of a *Phragmites* swamp-like environment. Importantly, following this *Phragmities*, the peat types at Sedgemoor differ to those found in the other valley of the Levels. In the Brue and Axe valleys raised bog deposits are common whereas raised bogs in Sedgemoor appear to have been localised and infrequent (Alderton 1983). Evidence suggests that the peat development within the Sedgemoor valley took place against a high water table, which frequently overtook the development of terrestrial peats with fresh water flooding. Extended sequences of detrital peats can be seen in Sedgemoor containing freshwater molluscs. The evidence presented here indicates that the eastern and middle parts of Sedgemoor became dominated by fringing freshwater lakes while the area to the west remained a swamp or bog-like environment.

The third unit in the Somerset Levels Formation (Campbell *et al* 1999) has been defined as the Nyland Hill Clay Member (Haslett and Davies 2002). This clay unit was deposited by a second marine inundation of the Somerset Levels and is recorded all along the coastal plains and in the Axe Valley. It is equivalent to the Upper Wentlooge Formation of the Gwent Levels (Allen 1987). This deposit was not found during the investigations reported here in Sedgemoor. The absence of evidence for this second marine transgression is also the case for the Brue Valley, to the north of the Polden Hills. Alderton (1983) located brackish incursions in the upper deposits within the West Moor area inferring minor marine influence in parts of Sedgemoor in the late Holocene. It seems that these were minor and may be the result of the tidal nature of the River Parrett which would have been prone to flooding.

Returning to the Kidson and Heyworth (1976) model that was outlined in chapter 1, the model for Sedgemoor fits the general history described by them. but with some notable exceptions. Kidson and Heyworth (1976) date the maximum of the marine transgression to around 6000 years BP. The results reported here show that this transgression in the Sedgemoor valley has been dated at the eastern edge of Sedgemoor to between 4795 and 4170 cal. yrs BP . They also describe the surface of the clay deposited by this transgression as being at about OD while here it is shown to have attained an altitude of 5.51 m OD. In addition Kidson and Heyworth (1976) proposed that sea level had reached that of today by around 3000 years BP while the evidence here suggests that sea level has continued rising through the late Holocene enhanced by isostatic subsidence.

The results presented here for the Sedgemoor valley support the existing research for the Region and add considerably to the known palaeoenvironmental history of the Area.

7.2.2 Mid to late Holocene environmental change, the wider context

The Sedgemoor Valley and the Somerset Levels can be seen to fit into the wider context of the mid to late Holocene that has been proposed by other authors (Table 7.6). Chapter 1 included examples of studies from South of the isostatic divide in the United Kingdom (Green and Tucker 1973, Long and Innes 1993, Healy 1995, Walker *et al* 1998, Gaunt and Tooley 1974) and the work reported here in Sedgemoor can be seen to contribute to research within this wider context. A common Holocene history is seen in all of the studies from south of the isostatic divide in Britain. The marine transgression of around 7000 yrs BP in Sedgemoor corresponds to the date seen in Essex of 7500 yrs BP (Greensmith and Tucker 1973) and in the Humber wetlands of 6970 ±100 ^{14}C yrs BP and 6890 ± 100 ^{14}C yrs BP (Gaunt and Tooley 1974). The mid Holocene regression again corresponds to the other studies outlined with all the relevant dates being outlined in Table 7.6. As has been discussed previously the second marine transgression is not recorded in the sites studied in Sedgemoor and it is also known to be absent from the Brue Valley (Coles and Coles 1999). The Roman reclamation of Sedgemoor is consistent with that seen in the Axe valley.

In addition to putting these main mid to late Holocene occurrences into a wider context it should be appreciated that that local factors such as surface run-off and the level of water table have played a large role in the palaeoenvironmental development of Sedgemoor.

	Essex	Romsey Marsh	Cornwall	Humber Wetlands	Caldicot Levels	Somerset Levels	Sedgemoor
Human influence						Axe Valley roman reclamation = 1776 ± 46 cal. yrs BP (Haslett *et al* 2001)	Roman reclamation = 1720 to 1420 cal. yrs BP
Late Holocene marine transgression	1400 ^{14}C yrs BP (Greensmith and Tucker 1973)	2341 – 2185 cal. yrs BP (Long and Innes 1993)	Between 1210 ± 40 and 1610 ± 40 ^{14}C BP(Healey 1995)	Between 3120 and 2700 ^{14}C yrs BP (Wright and Churchill 1965)	Between 2347 – 2745 and 2859 – 3213 cal. yrs BP (Walker *et al* 1998)	Axe valley = 3640 – 3330 cal. yrs BP (Haslett *et al* 2001a)	
Holocene marine regression		4050 to 2200 cal. yrs BP (Long and Innes 1993)	Between 5420 and 4380 ^{14}C yrs BP (Healey 1995)	6170 ^{14}C yrs BP (Gaunt and Tooley 1974)	5740 ± 70 yrs ^{14}C BP (Walker *et al* 1998)	Axe Valley = 6855 – 6490 cal.yrs BP (Haslett *et al* 2001a) Brue Valley = 5650 – 5020 yrs ^{14}C yrs BP (Coles and Orme 1985b)	From between 6920 and 6450 cal.yrs BP to Between 4795 and 4170 cal.yrs BP
Mid Holocene marine transgression	Episodes starting 7500 ^{14}C yrs BP (Greensmith and Tucker 1973)			6970± 100 BP and 6890 ± 100 ^{14}C yrs BP (Gaunt and Tooley 1974)			Around 7000 yrs BP

Table 7.6 Comparison of events with British sites south of isostatic divide outlined in Chapter 1

It has been shown that during the mid Holocene Sedgemoor experienced a marine regression which was followed by a very wet fresh water environment. Other factors than sea level must have contributed to this palaeoenvironmental change, for example climatic changes. Temperatures reached a maximum between 4500 and 6000 years BP which is known as the Holocene Climatic Optimum (Bryant 1997). Godwin (1975) has proposed that during this time summer temperatures were approximately 2°C warmer than today. It is generally believed that in Britain a more continental climate existed prior to 7000 years ago with hot short summers, slightly colder winters and rainfall a little less than the present day (Mannion1991). After 7000 years BP a more oceanic climate developed in Britain with higher winter temperatures, longer spring and autumn seasons and increased rainfall which Mannion (1991) suggests is as a result of Britain being severed from the continent by sea level rise. Mannion (1991) goes on to suggest that there is little evidence for climatic deterioration in Britain until 2800 years BP when a cooling trend with increased rainfall began.

Although it has not been possible to fully examine climate as a factor in the development of Sedgemoor it would undoubtedly have enhanced peat development and would have been an important factor in the development of the valley. The wetter climate particularly would have fed the `lake-like` waterbodies that were fringing the valley.

Chapter 8 Conclusions

The research reported in this study has resulted in a number of findings concerning the mid to late Holocene environmental change of the Sedgemoor valley in the Somerset Levels. The research undertaken has been a multidisciplinary approach involving lithostratigraphic surveys, biostratigraphic analysis and other methodologies to enable a reconstruction of the history of the Sedgemoor valley. For the first time a full sequence of palaeoenvironmental data for the Somerset Levels has been analysed and a temporal and spatial model created with twelve new radiocarbon dates being reported. Four sites were reported on in detail, three from within the present day Sedgemoor Valley and one at the mouth of the River Parrett in the Bristol Channel.

1 In the mid Holocene a marine transgression caused the Sedgemoor valley to become intertidal. The marine incursion into the valley resulted in the deposition of a blue clay unit. This study shows that the marine incursion reached higher altitudes than had previously been found in the Somerset Levels (a maximum altitude of 5.51 m OD for this clay was identified at Dundon Hayes).

2 The mid Holocene regression common to all of the Somerset Levels is confirmed by this study in the Sedgemoor valley and five new radiocarbon dates for this occurrence are reported. This study supports others (Haslett *et al* 1998a, 2001b) that suggest that the freshwater peats found all over the Somerset Levels began to form at the lowest altitudes and grew over the exhumed clay surface to cover the higher altitudes. The radiocarbon dates show that the peat was forming

in the area of Bawdrip between 6920 and 6450 cal. yrs BP and at the highest altitude at Dundon Hayes between 4795 and 4170 cal. yrs BP.

3 Lithostratigraphical and biostratigraphical investigations then show that a freshwater environment persisted in Sedgemoor. Unlike much of the Somerset Levels though only small areas of raised bogs formed in the Sedgemoor valley with investigations showing that a fen carr type environment formed with fringing water bodies dominating the landscape for much of the mid to late Holocene. Biostratigraphy indicates that these waterbodies were large enough to have currents and be considered lake-like. At the eastern edge of the valley these lakes persisted into the Dark Ages with a radiocarbon date of 1050 to 780 cal. yrs BP being reported here. At Briarwood Farm the molluscan sequence is long suggesting that the `lake like` environment persisted for a considerable period of time. At Bawdrip the evidence suggests a more `boggy` environment existed with the biostratigraphy representing a community of species that tolerate a wide range of habitats more than those that favour open water.

4 The second marine transgression known to have affected the Somerset Levels at around 4000 yrs BP has been shown in this study to be absent from the Sedgemoor valley. Upper clays of a marine origin have been absent from the lithostratigraphy in this valley. Evidence reported here suggests that fresh water levels were high in the Segdemoor valley coinciding with the marine inundation elsewhere in the levels possibly as the freshwater was impounded. It is not possible to conclusively say why this would have occurred in Sedgemoor but a

possibility could be that the peat growth and high water table had raised the altitude of the land surface above that inundated at that time.

5 This study has reported on the influence that humans have had on the Sedgemoor valley through the mid to late Holocene. Physical evidence for a series of drainage works that began in Roman times have been reported. This drainage became extensive in the 12th and 13th centuries and evidence is seen in the lithostratigraphy.

6 A study on a modern day saltmarsh highlights that sea level has continued rising in the Bristol Channel Estuary and is doing so against a background of isostatic subsidence that is enhancing the effect.

7 The lithological, biostratigraphical and chronological evidence collected as part of this study has been summarised into a model for the mid to Late Holocene environmental development of the Sedgemoor Valley.

8 In order to further improve our understanding of the palaeoenvironmental development of Sedgemoor further work is recommended focussing on establishing the full extent of the mid Holocene `lake-like' environments highlighted here. In addition, the proposed model for Sedgemoor may be enhanced by exploring more sites of study in the valley to gather more information about the local factors influencing its palaeoenvironmental development.

Bibliography

Alderton, A. M. 1983: The Sedgemoor Survey 1982: environmental results. *Somerset Levels Papers* 9, 9-15

Allen, J.R.L. 1987: Late Flandrian shoreline oscillations in the Severn Estuary: the Rumney Formation at its typesite (Cardiff area). *Philosophical Transactions of the Royal Society* B315, 157-174

Allen, J. R. L. 1990: Salt-marsh growth and stratification: a numerical model with special reference to the Severn Estuary, southwest Britain. *Marine Geology* 95, 77-96.

Allen, J.R.L. 1991: Salt-marsh accretion and sea-level movement in the inner Severn Estuary: the archaeological and historic contribution. *Journal of Geological Society* vol. 148 485 – 494

Allen, J.R.L. 1994: A continuity-based sedimentological model for temperate-zone tidal salt marshes. *Journal of the Geological Society, London* 151, 41-49

Allen, J. R. L. 1995: Salt-marsh growth and fluctuating sea level: implications of a simulation model for Flandrian coastal stratigraphy and peat-based sea-level curves. *Sedimentary Geology* 100, 21-45.

Allen, J.R.L. 1996: Shoreline movement and vertical textural patterns in salt marsh deposits: implications of a simple model for flow and sedimentation over tidal marshes. *Proceedings of the Geologists' Association* 107, 41-49.

Allen, J. R. L. 1999: Geological impacts on coastal wetland landscapes: some general affects of sediment autocompaction in the Holocene of northwest Europe. *The Holocene* 9, 1-12.

Allen, J. R. L. 2000a: Morphodynamics of Holocene salt marshes: a review sketch from the Atlantic and southern North Sea coasts of Europe. *Quaternary Science Reviews* 19, 1155-1231, plus Erratum.

Allen, J. R. L. 2000b: Holocene coastal lowlands in NW Europe: autocompaction and the uncertain ground. In Pye, K. and Allen, J. R. L., editors, *Coastal and Estuarine Environments: sedimentology, geomorphology, and geoarchaeology*, Geological Society, London, Special Publication 175, 239-252.

Allen, J. R. L. 2002: Interglacial high-tide coasts in the Bristol Channel and Severn estuary, southwest Britain: a comparison for the Ipswichian and the Holocene. *Journal of Quaternary Science* 17, 1, 69 - 76

Allen, J.R.L and Fulford, M. G. 1986: The Wentlooge Level: a Romano-British saltmarsh reclamation in southeast Wales. *Britannia* 17, 91-117

Allen, J.R.L and Rae, J. 1986: Time sequence of metal pollution, Severn Estuary, southwestern UK. *Marine Pollution Bulletin* 17, 427-431

Allen, J. R. L. and Haslett, S. K. 2002: Buried salt-marsh edges and tide-level cycles in the mid-Holocene of the Caldicot Level (Gwent), South Wales, UK. *The Holocene* 12, 303-324.

Allen, J. R. L. and Rae, J. E. 1987: Late Flandrian shoreline oscillations in the Severn Estuary: a geomorphological and stratigraphical reconnaissance. *Philosophical Transactions of the Royal Society* B315, 185-230.

Baeteman, C. 1985: Development and evolution of sedimentary environments during the Holocene in the western coastal plain of Belgium. *Eiszeitalter und Gerenwart* 35, 23-32

Baeteman, C and Declercq P-Y 2002: A synthesis of early and middle Holocene coastal change in the western Belgian lowlands. *Belgeo* No.2, 77-108

Berglund, B.E 1983: Palaeoclimatic changes in Scandinavia and on Greenland – a tentative correlation based on lake and bog stratigraphical studies. *Quaternary Studies in Poland* 4, 27 – 44

Berglund, B.E. 1986 (Ed): *Handbook of Holocene paleaeoecology and palaeo-hydrology*. Wiley, Chichester.

Birks, H.J.B. 1986a: Numerical zonation, comparison and correlation of Quaternary pollen-stratigraphical data. In: Berglund, B.E. (ed.) *Handbook of Holocene Palaeoecology and Palaeohydrology.* Wiley, Chichester pp. 743 - 774

Boulton, G.S. 1967: The development of a complex supraglacial moraine at the margin of Søbreen, Ny Friesland. *Journal of Glaciology* 7, 213 - 229

Boulton, G.S. 1968: Flow tills and related deposits on some Vestspitsbergen glaciers. *Journal of Glaciology*, 7 391 – 412

Boulton, G.S. 1972a: Modern Arctic glaciers as depositional models for former ice sheets. *Journal of the Geological Society*, London 128, 361 – 393

Boulton, G.S. 1974: Processes and patterns of glacial erosion, In D.R.Coates (ed), *Glacial Geomophology,* State university, New York, Binghampton. 41-87

Boycott, A.E. 1936: The habitats of Freshwater Mollusca in Britain. *Journal of Animal Ecology* 5, 116 -186

Brunning, R. 1998: Two Bronze Age wooden structures in the Somerset Moors. *Archaeology in the Severn Estuary* 9 (for 1997), 5-8.

Bryant, E. 1997: *Climate process and change*. Cambridge University Press, Cambridge

Bulleid, A. 1946: Oak piles in King's Sedgemoor. *Proceedings of the Somerset Archaeological and Natural History Society* 91, 43.

Burton, J.D. and Liss, P.S. 1976: *Estuarine Chemistry*. Academic Press, London.

Butler, S 1987: Coastal Change since 6000 BP and the Presence of Man at Kenn Moor, Avon. *Proceedings of the Somerset Archaeological and Natural History Society* 131, 1-11

Campbell, S., Hunt, C.O., Scource, J.D., Keen, D.H. and Croot, D.G. 1999: Southwest England. In: Bowen D.Q.(Ed) *A revised correlation of Quaternary deposits in the British Isles*. The Geological Society of London, London 23, 66-78

Charman, D. and Elmes, A 1998: A computer based formative assessment strategy for a basic statistics module in geography. *Journal of Geography in higher education* 19, 22.

Clark, J. G. D. 1933: Mesolthic sites on the Burtle Beds near Bridgwater, Somerset. *Man* 65, 63-65.

Clifton, R.J and Hamilton, E.I. 1979: Lead – 210 chronology in relation to levels of elements in dated sediment core profiles. *Estuarine Coastal Marine Science* 8, 259-269

Cole, R. P. 1983: A brushwood structure on King's Sedgemoor. *Somerset Levels Papers* 9, 16-18.

Coles, J. 1989: Prehistoric Settlements in the Somerset Levels. *Somerset Levels Papers 15*, 14 – 33

Coles, J. M. and Campbell, K. R. 1982: Archaeology in the Somerset Levels 1981. *Somerset Levels Papers* 8, 4-9.

Coles, B. and Coles, J. 1999: Passages of time. *Archaeology in the Severn Estuary* 9 (for 1998), 3-16.

Coles, B. J. and Dobson, M. J. 1989: Calibration of radiocarbon dates from the Somerset Levels. *Somerset Levels Papers* 15, 64-69.

Coles, J. M., Flemming, A. M. and Orme, B. J. 1980: The Baker site: a Neolithic platform. *Somerset Levels Papers* 6, 6-23.

Coles, J. M. and Orme, B. J. 1983: The Sedgemoor Survey 1982. *Somerset Levels Papers* 9, 6-8.

Coles, J. M. and Orme, B. J. 1985a: Archaeology in the Somerset Levels 1984. *Somerset Levels Papers* 11, 5-6.

Coles, J.M. and Orme, B. J. 1985b: Radiocarbon dates: fifth list. *Somerset Levels Papers* 11, 85.

Cunliffe, B. 1982: Iron Age settlements and pottery 650 BC-60 AD. In Aston, M. and Burrow, I., editors, *The Archaeology of Somerset*, Somerset County Council, Taunton, 53-61, 136-143.

Dale, A.L. and Dale, B. 2002: Application of ecologically based statistical treatments to micropalaeontology. In S.K.Haslett (Ed) *Quaternary Environmental Micropalaeontology*, Arnold, London. 259 – 287

Dawson, A.G.1980: The Low Rock Platform in Western Scotland. *Proceedings of the Geologists' Association* 91, 339-344

Dawson, A.G. 1984: Quaternary sea-level changes in western Scotland. *Quaternary Science reviews* 3, 345 – 368

Dawson, A.G. 1992: *Ice Age Earth, Late Quaternary geology and climate*. Routledge, London and New York

Dawson, A.G., Smith, D.E. 1998: Holocene relative sea-level changes on the margin of a glacio-isostatically uplifted area: an example from northern Caithness, Scotland. *The Holocene* 7, 59 77

Denton, G.H. and Hughes, T.J. 1981: *The Last Great Ice Sheets,* Wiley, New York

De Rijk, S. 1995: Salinity control on the distribution of salt marsh foraminifera (Great Marshes, Massachusetts). *Jurnal of Foraminiferal Research* 25, 56-166

De Rijk, S. 1997: Salt marsh foraminifera from the Great Marshes, Massachusetts: environmental controls. *Palaeogeography, Palaeoclimatology, Palaeoecology* 130, 81-112

Dominik, J., Forstner, D., Mangini, A. and Reineck, H-E. 1978: ^{210}Pb and ^{137}Cs Chronology of heavy metal pollution in a sediment core from the German Bight (North Sea). *Senckenbergiana Maritima* 10, 213-227.

Findlay, D.C., Colborne G.J.N., Cope, D.W., Harrod T.R., Hogan, D.V. and Staines, S.J. 1984: *Soils and their use in South West England. Soil Survey of England and Wales Bulletin No. 14*. Harpenden

Forstner, U. and Wittmann, G.T.W. 1979: M*etal pollution in the aquatic environment*. Berlin: Springer – Verlag

French, P.W. 1993: Areal distribution of selected pollutants in contemporary intertidal sediments of the Severn Estuary and Bristol Channel (UK). *Marine Pollution Bulletin* 26, 692 –697

French, P.W. 1996: Implications of a saltmarsh chronology for the Severn Estuary based on independent lines of dating evidence. *Marine Geology* 135, 115-125

Friedman, G.M. and Sanders J.E. 1978: *Principles of sedimentology*. John Wiley & Sons, New York,

Gaunt, G.D. and Tooley, M.J. 1974: Evidence for Flandrian sea level changes in the Humber Estuary and adjacent areas. *Bulletin of Geological Survey of Great Britain 48,* 25 – 41

Gehrels, W.R. 1994: Determining relative sea-level change from salt-marsh foraminifera and plant zones on the coast of Maine, USA. *Journal of Coastal* Research 10, 990 - 1009

Gehrels, W.R., Belknap, D.F. and Kelley, J.T. 1996: Integrated high-precision analysis of Holocene relative sea-level changes: lessons from the coast of Maine. *Geological Society of America Bulletin* 108, 1073 - 1088

Gehrels, W.R., Belknap, D.F., Black, S., and Newnham R.M. 2002: Rapid sea-level rise in the Gulf of Maine, USA since AD 1800. *The Holocene* 12, 383-389

Gibbard, P.L. and Lewin, J. 2003: The history of the major rivers of southern Britain during the Tertiary. *Journal of Geological Society, London* 160, 829-845

Gilbertson, D.D and Hawkins, A.B. 1983: A Prehistoric Wooden Stake and the Alluvial Stratigraphy at Kenn Moor, Avon. *Somerset Archaeology and Natural History Society* 127, 1-6.

Godwin, H. 1941: Studies in the ecology of Wicken Fen. 3. The establishment of fen carr (scrub). *Journal of Ecology* 24, 82-116

Godwin, H. 1943: Coastal Peat Beds of the British Isles and North Sea. *Journal of Ecology* 31, 199-247

Godwin, H. 1948: Studies of the Post-Glacial History of British Vegetation; X. Correlation between Climate, Forest Composition, prehistoric agriculture and peat stratigraphy in Sub-Boreal and Sub Atlantic Peats of the Somerset Levels. *Philosophical Transactions of the Royal Society, London* 233 B, 275 – 286

Godwin, H. 1955: Studies of the Post-Glacial History of British Vegetation XIII. The Meare Pool Region of the Somerset Levels. *Philosophical Transactions of the Royal Society,* London 239 B, 161-190

Godwin, H. 1975: *The History of the British Flora*. Cambridge University Press, Cambridge

Godwin, H. 1981: *The Archives of the Peat*. Cambridge University Press, Cambridge.

Gray, H. St. G. 1926: Archaeological remains at Middlezoy. *Proceedings of the Somerset Archaeological and Natural History Society* 72, 85-88.

Green, G.W. and Welch, F.B.A. 1965: *Geology of the Country around Wells and Cheddar*. HMSO, London.

Greensmith, J.T. and Tucker E.V. 1973: Holocene Transgressions and Regressions on the Essex Coast and Outer Thames Estuary. *Geologie En Mijnbouw* 193-202

Haslett, S. K. 1997: An Ipswichian foraminiferal assemblage from the Gwent Levels (Severn Estuary, UK). *Journal of Micropalaeontology* 16, 136.

Haslett, S.K. 2000: *Coastal Systems*. Routledge, London and New York.

Haslett, S. K. and Davies, P. 2002: Holocene lithostratigraphy and coastal change in the Somerset Levels: evidence from Nyland Hill, Axe Valley, Somerset. *Bath Spa University College Occasional Papers in Geography* 2 37 - 43

Haslett, S. K., Davies, P., Curr, R. H. F., Davies, C. F. C., Kennington, K., King, C. P. and Margetts, A. J. 1998a: Evaluating late-Holocene relative sea-level change in the Somerset Levels, southwest Britain. *The Holocene* 8, 197-207.

Haslett, S.K., Davies, P. and Strawbridge, F. 1998b: Reconstructing Holocene sea levels in the Severn Estuary and Somerset Levels: the foraminifera connection. *Archaeology in the Severn Estuary* 8, 29 - 40

Haslett, S. K., Howard, K. L., Margetts, A. J. and Davies, P. 2001a: Holocene stratigraphy and evolution of the northern coastal plain of the Somerset Levels, UK. *Proceedings of the Cotteswold Naturalists' Field Club* 42, 78-88.

Haslett, S. K., Davies, P., Davies, C. F. C., Margetts, A. J., Scotney, K. H., Thorpe, D. J. and Williams, H. O. 2001b: The changing estuarine environment in relation to Holocene sea-level and the archaeological implications. *Archaeology in the Severn Estuary* 11 (for 2000), 35-53.

Haslett, S.K., Strawbridge, F., Martin, N.A. and Davies, C.F.C. 2001c: Vertical salt marsh accretion and its relationship to sea level in the Severn Estuary, UK.: An investigation using foraminifera as tidal indicators. *Estuarine, Coastal and Shelf Science* 52, 143 – 153

Haslett, S. 2002: *Quaternary environmental micropalaeontology* (Ed). Arnold, London

Hawkins, A. B. 1971a: The late Weichselian and Flandrian transgression of south west Britain. *Quaternaria* 14, 115-130.

Hawkins, A. B. 1971b: Sea level changes around south west Britain. *Colston Papers* 23, 67-87.

Healy, M.G 1995: The Lithostratigraphy and biostratigraphy of a Holocene coastal sediment sequence in Marazion Marsh, west Cornwall, U.K. with reference to relative sea level movement. *Marine Geology* 124, 237 – 252

Heyworth, A. 1978: Submerged forests around the British Isles. In Fletcher, J. M., editor, *Dendrochronology in Europe*, B. A. R. S51, 279-288.

Heyworth, A. and Kidson, C. 1982: Sea level changes in southwest England and Wales. *Proceedings of the Geologists' Association* 93, 91-111.

Keen, D.H., Jones, R.L. and Robinson, J.E. 1984: A Late Devensian and early Flandrian fauna and flora from Kildale, north-east Yorkshire. *Proceedings of the Yorkshire Geological Society* 44(4), 385-397

Kellaway, G.A. and Welch F.B.A. 1993: *Geology of the Bristol district*. HMSO, London

Kennard, A.S. and Woodward, B.B. 1917: Report on the non marine mollusca from Avelines Hole, Burrington Combe. *Proceeding of the University of Bristol Speleological Society* 2, 32 – 33

Kerney, M.P. 1977a: British non-marine Mollusca: a brief review. In: *British Quarternary Studies: Recent Advances*. F.W. Shotton (ed) Clarendon Press, Oxford.

Kerney, M.P. 1999: *Atlas of the Land and Freshwater Molluscs of Britain and Ireland*. Harley Books, Colchester

King, C.P. and Haslett, S. 1998: Modern saltmarsh foraminifera distribution in Stert Flats, Bridgwater Bay, UK: preliminary results. *Archaeology in the Severn Estuary* 9, 92-93

Kidson, C. and Heyworth, A. 1973: The Flandrian sea-level rise in the Bristol Channel. *Proceedings of the Ussher Society* 2, 565-584.

Kidson, C. and Heyworth, A. 1976: The Quaternary deposits of the Somerset Levels. *Quarterly Journal of Engineering Geology* 9, 217-235.

Kidson, C. and Heyworth, A. 1978: Holocene eustatic sea level change. *Nature* 273, 748-750.

Kidson, C., Gilbertson, D.D., Haynes, J.R., Heyworth, A., Hughes, C.E. & Whatley, R.C. 1978: Interglacial marine deposits of the Somerset Levels, south west England. Boreas 7, 215 - 228

Knighton, A.D., Mills, K., and Woodroffe, C.D. 1991: Tidal creek extension and saltwater intrusion in northern Australia. *Geology* 19, 831-834

Lambeck K. 1993: Glacial rebound of the British Isles – I preliminary model results. *Geophysical Journal International* 115, 941-959

Lambeck K. 1995: Glacial rebound of the British Isles – II A high resolution, high precision model. *Geophysical Journal International* 115, 960 - 990

Leech,R. H. 1977: Romano-British Rural Settlement. *Unpublished PhD thesis,* University of Bristol

Leech, R. and Leach, P. 1982: Roman town and countryside 43-450 AD. In Aston, M. and Burrow, I., editors, *The Archaeology of Somerset*, Somerset County Council, Taunton, 63-81, 136-143.

Long, A.J. and Innes J.B. 1993: Holocene sea level changes and coastal sedimentation in Romney Marsh, Southeast England, UK. *Proceedings of the Geologists Association* 104, 223-237

Long, A.J., Dix J.K., Kirby, R., Lloyd Jones, D., Roberts, D.H.,Croudace, I.W., Cundy, A.B., Roberts, A. Shennan, I. 2001: *The Holocene and Recent Evolution of Bridgwater Bay and the Somerset Levels*. An unpublished report for the Environment Agency

Lloyd, J.M., Shennan, I., Kirby, J.R., Rutherford M.M. 1999: Holocene relative sea level changes in the inner Solway Firth. *Quaternary International* 60, 83-105

Lowe, J.J. and Walker, M.J.C. 1997: *Reconstructing Quarternary Environments* (2nd Edition). Longman, Harlow.

Lozek, V. 1986: Molluscan analysis in: *Handbook of Holocene Palaeoecology and Palaeohydrology*. In: Berglund, B.E. (ed) Wiley, Chichester

McEwen, L.J. and Withers C.W.J. 1989: Historical records and geomorphological events: the 1771 "eruption" of Solway Moss. *Scottish Geographical Magazine*. 105, 149-157

Macan, T.T. 1960: A key to the British Fresh and Brackish-water Gastropods with notes on their ecology. *Freshwater Biological Association Scientific Publication* 13

Mannion, A. M. 1991: *Global Environmental Change*. Longman Scientific & Technical, Harlow

Mannion, A.M.1999: *Natural Environmental Change*. Routledge, London

Minnit, S. & Coles J. 1996: *The Lake Villages of Somerset*. Glastonbury Antiquarian Society, Somerset Levels Project and Somerset County Council Museums Service.

Morner N.-A. 1979: The deglaciation of southern Sweden: a multi-parameter consideration, *Boreas* 8, 189 -198

Morner N.-A. 1980: The north west Europe sea level laboratory and Regional Holocene eustasy. *Palaeogeography, Palaeoclimatology and Palaeoecology* 19, 63-85

Morner N.-A. 2000: Sea Level Changes in Western Europe. Integrated Coastal Zone Management. *IPC Publications* 31 - 36

Murray, J.W. 1979: *British nearshore foraminiferids*. London:Linnean Society, 68

Murray, J.W. 1991: *Ecology and palaeoecology of benthic foraminifera*. Harlow: Longman

Musgrove, D. 1997: The Medieval explotation and reclamation of the inland peat moors in the Somerset Levels. *Archaeology in the Severn Estuary* 8, 89-97.

Norman, C. 1975: Four mesolithic assemblages from west Somerset. *Proceedings of the Somerset Archaeological and Natural History Society* 119, 26-37.

Norman, C. 1980: Timber structures in the peat, Chedzoy. *Proceedings of the Somerset Archaeological and Natural History Society* 124, 159-163.

Norman, C. and Clements, C. F. 1979: Prehistoric timber structures on King's Sedgemoor: some recent discoveries. *Proceedings of the Somerset Archaeological and Natural History Society* 123, 5-18.

Olsson, I.U. 1986: Radiometric dating, In :Berglund B.E. (ed) *Handbook of Holocene Palaeoecology and Palaeohydrology*. Wiley, Chichester

Peltier W.R. 1998: Postglacial variations in the level of the sea: Implications for climate dynamics and solid-earth geophysics. *Review of Geophysics* 36, 603-689

Pethick, J.S. 1992: Saltmarsh geomorphology. In: J.R.L. Allen and K. Pye (eds), *Saltmarshes: Morphodynamics, Conservation and Engineering Significance*. Cambridge University Press, Cambridge 41-62

Psuty, N.P and Moreira M.E.S.A. 2000: Holocene Sedimentation and Sea Level Rise in the Sado Estuary, Portugal. *Journal of Coastal Research* 15,1, 125-138

Pugh D.T. 1987: The global sea-level observing system. *Hydrographic Journal* 45, 5 - 8

Ranwell, D.S. 1964: *Spartina* salt marshes in Southern England. Rate and seasonal pattern of sediment Accretion. *Journal of Ecology* 52, 79-94

Reed, D.J. 1990: The impact of sea level rise on coastal saltmarshes. Progress in Physical Geography 14, 465 - 481

Reed, D.J. 1995: The response of coastal marshes to sea level rise: survival or submergence? *Earth Surface processes and Landforms* 20, 39-48

Rippon, S. 1997: Roman and Medieval settlement on the North Somerset Levels: the second season of survey and excavation at Banwell and Puxton. *Archaeology in the Severn Estuary* 8, 41-54

Rippon, S. 1998: Medieval Settlement on the North Somerset Levels: the fourth season of survey and excavation at Puxton. *Archaeology in the Severn Estuary* 10, 65-73

Severn Barrage Project 1989: General Report. HMSO, London

Scott, D.B. and Medioli, F.S. 1978: Vertical zonations of marsh foraminifera as accurate indicators of former sea-levels. *Nature* 272, 528- 531

Scott, D.B. and Medioli, F.S. 1986: Foraminifera as sea-lvel indicators. In: O. van de Plassche (ed.) *Sea-level Research: A Manual for the Collection and Evaluation of Data*. Geo-Books, Norwich, 435-456

Shennan, I. 1983: Flandrian and Late Devensian sea level changes and crustal movements in England and Wales. In Smith D.E. and Dawson A.G. *Shorelines and Isostacy* 255 – 283. Academic Press, Institute of British Geographers Special Publication 16

Shennan, I. 1989a: Late Quaternary sea-level changes: measurement, correlation and future applications – the international significance of IGCP Project 200. *Journal of Quaternary Science* 4, 3-5

Shennan, I. 1989b: Holocene crustal movements and sea level changes in Great Britain. *Journal of Quaternary Science* 4, 77-89

Shennan, I. and Gehrels R. (Eds) 1996: IGCP 367 Themmatic Section: `Late Quaternary coastal records of rapid change: Applications to present and future conditions`. *Journal of Coastal Research,* 12 1-89

Shennan, I. and Horton, B. 2002: Holocene land and sea level changes in Great Britain. *Journal of Quaternary Science* 17(5-6), 511 – 526

Shennan, I. Innes, J.B., Long, A.J. 1996: Late Devensian and Holocene relative sea-level change in Northwestern Scotland: New data to test existing models. *Quaternary International* 26, 97 – 123

Shennan, I., Innes, J.B., Long, A.J. and Zong, Y., 1994: Late Devensian and Holocene relative sea level changes at Loch nan Eala, near Arisaig, northwest Scotland. *Journal of Quaternary Science* 9, 261 – 283

Shennan, I., Long, A.J., Metcalfe, S. and Balson, P. 1998: Late Quaternary records of rapid change: application to present and future conditions. *The Holocene* 8, 125 – 247

Shotton, F.W. 1967: The problems and contributions of methods of absolute dating within the Pleistocene period. *Journal of the Geological Society* London 122, 357 -383

Shotton, F.W. 1977a: (ed) *British Quaternary Studies – Recent Advances*. Oxford University Press, Oxford.

Shotton, F.W. 1977b: The Devensian Stage: its development , limits and substages. *Philosophical Transactions of the Royal Society*, London. B280 107 – 118

Simmons, I.G. and Tooley, M.J. (eds) 1981: *Environment in British Pre-history*. Duckworth Press, London

Sissons, J.B. 1966: Relative sea-level changes between 10000 and 8000 BP in part of the Carse of Stirling. *Transactions of the Institute of British Geographers* 39, 19 – 29

Sissons, J.B. 1967a: *The Evolution of Scotland's Scenery*. Oliver and Boyd, Edinburgh

Sissons, J.B. 1967b: Glacial stages and radiocarbon dates in Scotland. *Scottish Journal of Geology* 3, 375 – 381

Sissons, J.B. 1972: The last glaciers in part of the southeast Grampians, *Scottish Geographical magazine* 88, 168 – 181

Sissons, J.B. 1974c: The Quaternary in Scotland: a review, *Scottish Journal of Geology* 10, 311-37

Sissons, J.B. 1976: *The Geomorphology of the British Isles: Scotland*, Methuen, London and New York

Sissons, J.B. 1979b: Palaeoclimatic inferences from former glaciers in Scotland and the Lake District. *Nature* 278, 518 - 521

Sissons, J.B. 1981: The last Scottish ice-sheets: facts and speculative discussion, *Boreas* 10, 1-17

Sissons, J.B. 1983: Shorelines and isostasy in Scotland. In Smith D.E. and Dawson A.G. *Shorelines and Isostacy.* 255 – 283. Academic Press, Institute of British Geographers Special Publication 16

Sissons J.B. and Dawson A.G. 1981: Former sea levels and ice limits in Wester Ross, northwest Scotland. *Proceedings of the Geologists Association*, 92 115-124

Smith, A.G. and Morgan, L.A. 1989: A succession to ombrotrophic bog in the Gwent Levels, and its demise: a Welsh parallel to the peats of the Somerset Levels. *New Phytologist* 112, 145-167

Smith, D.E., Wells, J.M., Mighall, T.M., Dawson, S., Haggart, B.A., Cullingford, R.A. and Tipping R.M. 2003: Holocene relative sea level change in the lower Nith valley and estuary. *Scottish Journal of Geology* 39, 97-120

Somerset County Council Website- www.Somerset.gov.uk/HER – Somerset County Council website accessed 1st February 2004

Stenner, R.D. 1978: The concetration of copper, lead and zinc in sediments in Wookey Hole cave, Somerset. *Proceedings of the University of Bristol Spelaeological Society* 15, 49-52

Stuiver, M., Reimer, P.J., Braziunas, T.F. 1998: High Precision radiocarbon age calibration for terrestrial and marine samples. Radiocarbon 40, 1127-1151

Sparks, B.W. 1961: The ecological interpretation of Quaternary non-marine mollusca. *Proceedings of the Linnean Society*. London 172, 71-80

Tooley, M.J. 1982: Introduction. In: Greensmith, J.T. and Tooley, M.J. (eds) I.G.C.P. Project 61 Sea-level movements during the last deglacial hemicycle (about 15000 years). *Proceedings of the Geologists' Association,* 93, 3-6

Van de Noort, R., and Davies, P. 1993: *Wetland Heritage, An archaeological assessment of the Humber Wetlands*. English Heritage Humber Wetlands Project.

Wainwright, G. J. 1960: Three microlithic industries from south-west England and their affinities. *Proceedings of the Prehistoric Society* 26, 193-201.

Walcott, R.J. 1970: Isostatic response to loading of the crust in Canada, *Canadian Journal of Earth Science* 7, 716 - 726

Walker, M.J.C., Bell, M., Caseldine, A.E., Cameron, N.G., Hunter, K.L., James, J.H., Johnson, S. and Smith, D.N. 1998: Palaeoecological investigations of middle and late Flandrian buried peats on the Caldicot Levels, Severn Estuary, Wales. *Proceedings of the Geologists Association* 109, 51-78.

Walton, W.R.1952: Techniques for recognition of living foraminifera. *Contributions from the Cushman Foundationfor foraminiferal research* 3, 56-60

West, R.G. 1977a: *Pleistocene Geology and Biology,* (2nd Edition). Longman, London and New York

Whittaker A. and Green G. W. 1983: Geology of the country around Weston-Super-Mare. *Memoir for 1:50,000 geological sheet 279, New series with parts of sheets 263 and 295.* HMSO, London

Williams, M. 1970: *The Draining of the Somerset Levels*. Cambridge University Press, Cambridge

Woodward, H. B. 1906: Geology. In Page, W., editor, *The Victoria History of the County of Somerset*, Volume 1, James Street, Haymarket, 1-33.

Appendix

Appendix I

Statistical analysis of molluscan data at Dundon Hayes

Dundon Hayes raw molluscan count detrended correspondence analysis

Axis 1

Residual 0.013043 at iteration 0
Residual 0.002992 at iteration 1
Residual 0.000202 at iteration 2
Residual 0.000003 at iteration 3

Eigenvalue 0.06212

Length of gradient 1.020
Length of segments 0.10 0.10 0.11 0.11 0.11 0.11 0.11 0.10 0.09 0.08
Length of gradient 1.008
Length of gradient 0.983
Length of segments 0.09 0.09 0.10 0.11 0.11 0.10 0.10 0.10 0.09 0.09
Length of gradient 0.973

Axis 2

Residual 0.007908 at iteration 0
Residual 0.000416 at iteration 1
Residual 0.000004 at iteration 2

Eigenvalue 0.02602

Length of gradient 1.152
Length of segments 0.12 0.12 0.12 0.12 0.11 0.11 0.11 0.11 0.11 0.11
Length of gradient 1.159
Length of gradient 1.168
Length of segments 0.12 0.12 0.12 0.12 0.11 0.11 0.11 0.12 0.12 0.12
Length of gradient 1.176

Axis 3

Residual 0.003647 at iteration 0
Residual 0.000620 at iteration 1
Residual 0.000024 at iteration 2

Eigenvalue 0.01148

Length of gradient 1.276
Length of segments 0.10 0.10 0.11 0.12 0.13 0.13 0.14 0.14 0.15 0.16
Length of gradient 1.339
Length of gradient 1.328
Length of segments 0.12 0.13 0.13 0.14 0.14 0.14 0.14 0.14 0.13 0.12
Length of gradient 1.318

Axis 4

Residual 0.002647 at iteration 0
Residual 0.000026 at iteration 1

Eigenvalue 0.00708

Length of gradient 0.438
Length of segments 0.05 0.05 0.05 0.05 0.05 0.04 0.03 0.03 0.03 0.04
Length of gradient 0.518
Length of gradient 0.547
Length of segments 0.06 0.06 0.06 0.06 0.06 0.05 0.04 0.04 0.05 0.07

Length of gradient 0.483

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
B tentaculata	1.29	-0.33	-0.77	0.77
B leachii	1.32	2.48	6.17	0.37
P fontinalis	0.60	0.28	0.47	0.30
V Piscinalis	-0.72	1.77	2.10	0.60
P planorbis	1.76	-1.07	0.67	0.43
G laevis	1.24	1.83	-0.19	0.18
V cristata	-0.11	0.21	0.29	-0.20
L glabra	-3.74	4.19	-1.22	0.95
A lacustris	0.01	-2.00	2.10	-0.74
S nitida	1.13	-1.71	1.33	-0.50
B contortus	1.80	0.49	1.45	0.34
G crista	0.72	0.48	0.53	0.36
P albus	-3.52	-0.50	0.48	-0.24
L peregra	-0.29	0.12	1.36	-0.09
L palustris	6.46	0.28	0.47	0.30
A leucostoma	-0.09	-0.59	-0.17	-0.69
A hypnorum	-1.52	-1.45	-2.10	0.85
L truncatula	0.05	1.37	-1.13	9.24
C minimum	3.62	-0.03	2.20	-0.86
Vertigo	0.60	0.28	0.47	0.30
Succineidae	0.60	0.28	0.47	0.30
Zonitidae	0.00	0.34	3.15	-6.82
Vallonia sp.	0.60	0.28	0.47	0.30
C bidentata	0.60	0.28	0.47	0.30
C lubrica	0.60	0.28	0.47	0.30
Operculum	1.03	0.86	0.80	-0.99

Axis 1 ranked. Eigenvalue = 0.06212

Name	Score
L glabra	-3.74
P albus	-3.52
A hypnorum	-1.52
V Piscinalis	-0.72
L peregra	-0.29
V cristata	-0.11
A leucostoma	-0.09
Zonitidae	0.00
A lacustris	0.01
L truncatula	0.05
P fontinalis	0.60
Succineidae	0.60
Vallonia sp.	0.60
Vertigo	0.60
C lubrica	0.60
C bidentata	0.60
G crista	0.72
Operculum	1.03
S nitida	1.13
G laevis	1.24
B tentaculata	1.29
B leachii	1.32
P planorbis	1.76
B contortus	1.80

C minimum	3.62
L palustris	6.46

Axis 2 ranked. Eigenvalue = 0.02602

Name	Score
A lacustris	-2.00
S nitida	-1.71
A hypnorum	-1.45
P planorbis	-1.07
A leucostoma	-0.59
P albus	-0.50
B tentaculata	-0.33
C minimum	-0.03
L peregra	0.12
V cristata	0.21
L palustris	0.28
P fontinalis	0.28
C lubrica	0.28
Vallonia sp.	0.28
Vertigo	0.28
Succineidae	0.28
C bidentata	0.28
Zonitidae	0.34
G crista	0.48
B contortus	0.49
Operculum	0.86
L truncatula	1.37
V Piscinalis	1.77
G laevis	1.83
B leachii	2.48
L glabra	4.19

Axis 3 ranked. Eigenvalue = 0.01148

Name	Score
A hypnorum	-2.10
L glabra	-1.22
L truncatula	-1.13
B tentaculata	-0.77
G laevis	-0.19
A leucostoma	-0.17
V cristata	0.29
P fontinalis	0.47
Succineidae	0.47
Vallonia sp.	0.47
Vertigo	0.47
C lubrica	0.47
C bidentata	0.47
L palustris	0.47
P albus	0.48
G crista	0.53
P planorbis	0.67
Operculum	0.80
S nitida	1.33
L peregra	1.36
B contortus	1.45
A lacustris	2.10
V Piscinalis	2.10
C minimum	2.20

Zonitidae	3.15
B leachii	6.17

Axis 4 ranked. Eigenvalue = 0.00708

Name	Score
Zonitidae	-6.82
Operculum	-0.99
C minimum	-0.86
A lacustris	-0.74
A leucostoma	-0.69
S nitida	-0.50
P albus	-0.24
V cristata	-0.20
L peregra	-0.09
G laevis	0.18
L palustris	0.30
C bidentata	0.30
P fontinalis	0.30
Vallonia sp.	0.30
Vertigo	0.30
Succineidae	0.30
C lubrica	0.30
B contortus	0.34
G crista	0.36
B leachii	0.37
P planorbis	0.43
V Piscinalis	0.60
B tentaculata	0.77
A hypnorum	0.85
L glabra	0.95
L truncatula	9.24

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
221	0.73	0.36	0.85	0.17
223	0.97	0.26	0.56	0.16
225	0.52	0.16	0.66	0.35
227	0.42	0.20	0.80	0.13
229	0.39	0.00	0.66	0.14
233	0.50	0.06	0.69	0.00
237	0.33	0.13	0.59	0.09
241	0.43	0.31	0.58	0.27
245	0.31	0.53	0.80	0.07
249	0.32	0.48	0.53	0.06
254	0.58	1.18	0.41	0.13
258	0.00	0.54	0.44	0.18
262	0.39	0.21	0.00	0.24
266	0.00	1.13	1.32	0.48

Axis 1 ranked. Eigenvalue = 0.06212

Name	Score
266	0.00
258	0.00
245	0.31
249	0.32

237	0.33
262	0.39
229	0.39
227	0.42
241	0.43
233	0.50
225	0.52
254	0.58
221	0.73
223	0.97

Axis 2 ranked. Eigenvalue = 0.02602

Name	Score
229	0.00
233	0.06
237	0.13
225	0.16
227	0.20
262	0.21
223	0.26
241	0.31
221	0.36
249	0.48
245	0.53
258	0.54
266	1.13
254	1.18

Axis 3 ranked. Eigenvalue = 0.01148

Name	Score
262	0.00
254	0.41
258	0.44
249	0.53
223	0.56
241	0.58
237	0.59
229	0.66
225	0.66
233	0.69
227	0.80
245	0.80
221	0.85
266	1.32

Axis 4 ranked. Eigenvalue = 0.00708

Name	Score
233	0.00
249	0.06
245	0.07
237	0.09
254	0.13
227	0.13
229	0.14
223	0.16
221	0.17

258	0.18
262	0.24
241	0.27
225	0.35
266	0.48

Dundon Hayes raw molluscan count cluster analysis

File: DHRAWMOL.TIL
Number of samples = 14
Number of variables = 26
Square root transformation
Dissimilarity coefficient is Euclidian distance

Constrained Incremental Sum of Squares Cluster Analysis

Stage	Clusters merged	Increase in dispersion	Total dispersion	Within-cluster dispersion	Mean within-cluster dispersion
1	3 4	5.711487	5.711487	5.711487	2.855744
2	5 6	6.711362	12.42285	6.711362	3.355681
3	5 7	5.894057	18.31691	12.60542	4.201807
4	10 11	9.024432	27.34134	9.024432	4.512216
5	10 12	6.481105	33.82244	15.50554	5.168512
6	10 13	10.37696	44.1994	25.8825	6.470624
7	3 5	11.90772	56.10712	30.22463	6.044925
8	3 8	10.87709	66.98421	41.10172	6.850286
9	10 14	27.22162	94.20583	53.10411	10.62082
10	3 9	33.12764	127.3335	74.22936	10.60419
11	2 3	44.70903	172.0425	118.9384	14.8673
12	1 2	202.1346	374.1771	321.073	35.67478
13	1 10	472.1639	846.341	846.341	60.45293

Sample numbers

1	221
2	223
3	225
4	227
5	229
6	233
7	237
8	241
9	245
10	249
11	254
12	258
13	262
14	266

Dundon Hayes percentage molluscan detrended correspondence analysis results

Axis 1

Residual	0.021614	at	iteration	0
Residual	0.013977	at	iteration	1
Residual	0.000583	at	iteration	2
Residual	0.000012	at	iteration	3

Eigenvalue 0.13068

Length of gradient	1.206									
Length of segments	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.11	0.10	0.10
Length of gradient	1.252									
Length of gradient	1.273									
Length of segments	0.12	0.12	0.12	0.13	0.13	0.14	0.14	0.13	0.12	0.12
Length of gradient	1.269									

Axis 2

Residual	0.024288	at	iteration	0
Residual	0.000222	at	iteration	1
Residual	0.000002	at	iteration	2

Eigenvalue 0.05448

Length of gradient	1.058									
Length of segments	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11
Length of gradient	1.059									
Length of gradient	1.063									
Length of segments	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.11	0.11	0.11
Length of gradient	1.064									

Axis 3

Residual	0.006762	at	iteration	0
Residual	0.000107	at	iteration	1
Residual	0.000002	at	iteration	2

Eigenvalue 0.01493

Length of gradient	0.682									
Length of segments	0.07	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.06	0.06
Length of gradient	0.680									
Length of gradient	0.691									
Length of segments	0.07	0.07	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.07
Length of gradient	0.695									

Axis 4

Residual	0.003881	at	iteration	0
Residual	0.000040	at	iteration	1

Eigenvalue 0.00904

Length of gradient	1.478									
Length of segments	0.16	0.16	0.17	0.16	0.15	0.14	0.14	0.14	0.13	0.13
Length of gradient	1.475									
Length of gradient	1.460									
Length of segments	0.14	0.15	0.16	0.16	0.15	0.14	0.14	0.14	0.14	0.14

Length of gradient 1.456

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
B tentaculata	0.39	-0.29	0.65	2.08
B leachii	-1.03	0.18	0.84	-0.54
P fontinalis	0.45	0.33	0.33	1.07
V Piscinalis	1.34	1.54	0.65	-0.81
P planorbis	-1.43	1.69	1.43	-0.09
G laevis	2.06	0.83	1.00	0.68
V cristata	0.81	-0.09	-0.31	1.10
L glabra	4.00	0.03	0.52	0.70
A lacustris	-1.59	2.74	0.06	-0.07
S nitida	-2.03	-0.88	-0.51	1.81
B contortus	0.28	2.98	1.78	-1.31
G crista	0.27	0.44	0.57	0.81
P albus	1.89	-1.24	-2.12	4.83
L peregra	-0.03	-0.61	-0.84	1.70
L palustris	-1.28	4.55	8.02	-2.24
A leucostoma	-0.29	-1.11	-1.18	2.19
A hypnorum	1.29	-0.93	-0.99	3.33
L truncatula	-1.87	-1.43	4.56	-2.93

Axis 1 ranked. Eigenvalue = 0.13068

Name	Score
S nitida	-2.03
L truncatula	-1.87
A lacustris	-1.59
P planorbis	-1.43
L palustris	-1.28
B leachii	-1.03
A leucostoma	-0.29
L peregra	-0.03
G crista	0.27
B contortus	0.28
B tentaculata	0.39
P fontinalis	0.45
V cristata	0.81
A hypnorum	1.29
V Piscinalis	1.34
P albus	1.89
G laevis	2.06
L glabra	4.00

Axis 2 ranked. Eigenvalue = 0.05448

Name	Score
L truncatula	-1.43
P albus	-1.24
A leucostoma	-1.11
A hypnorum	-0.93
S nitida	-0.88
L peregra	-0.61
B tentaculata	-0.29
V cristata	-0.09
L glabra	0.03
B leachii	0.18
P fontinalis	0.33

G crista	0.44
G laevis	0.83
V Piscinalis	1.54
P planorbis	1.69
A lacustris	2.74
B contortus	2.98
L palustris	4.55

Axis 3 ranked. Eigenvalue = 0.01493

Name	Score
P albus	-2.12
A leucostoma	-1.18
A hypnorum	-0.99
L peregra	-0.84
S nitida	-0.51
V cristata	-0.31
A lacustris	0.06
P fontinalis	0.33
L glabra	0.52
G crista	0.57
B tentaculata	0.65
V Piscinalis	0.65
B leachii	0.84
G laevis	1.00
P planorbis	1.43
B contortus	1.78
L truncatula	4.56
L palustris	8.02

Axis 4 ranked. Eigenvalue = 0.00904

Name	Score
L truncatula	-2.93
L palustris	-2.24
B contortus	-1.31
V Piscinalis	-0.81
B leachii	-0.54
P planorbis	-0.09
A lacustris	-0.07
G laevis	0.68
L glabra	0.70
G crista	0.81
P fontinalis	1.07
V cristata	1.10
L peregra	1.70
S nitida	1.81
B tentaculata	2.08
A leucostoma	2.19
A hypnorum	3.33
P albus	4.83

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
221	0.21	1.06	0.69	0.31
223	0.13	0.62	0.67	0.75
225	0.03	0.27	0.33	0.89
227	0.11	0.26	0.14	0.96
229	0.00	0.20	0.08	1.08
233	0.02	0.24	0.10	1.08

237	0.20	0.11	0.00	1.20
241	0.23	0.22	0.25	0.93
245	0.47	0.17	0.06	1.05
249	0.57	0.08	0.03	1.18
254	1.27	0.60	0.58	0.68
258	0.75	0.09	0.01	1.22
262	0.63	0.00	0.09	1.46
266	0.80	0.99	0.61	0.00

Axis 1 ranked. Eigenvalue = 0.13068

Name	Score
229	0.00
233	0.02
225	0.03
227	0.11
223	0.13
237	0.20
221	0.21
241	0.23
245	0.47
249	0.57
262	0.63
258	0.75
266	0.80
254	1.27

Axis 2 ranked. Eigenvalue = 0.05448

Name	Score
262	0.00
249	0.08
258	0.09
237	0.11
245	0.17
229	0.20
241	0.22
233	0.24
227	0.26
225	0.27
254	0.60
223	0.62
266	0.99
221	1.06

Axis 3 ranked. Eigenvalue = 0.01493

Name	Score
237	0.00
258	0.01
249	0.03
245	0.06
229	0.08
262	0.09
233	0.10
227	0.14
241	0.25
225	0.33
254	0.58

266	0.61
223	0.67
221	0.69

Axis 4 ranked. Eigenvalue = 0.00904

Name	Score
266	0.00
221	0.31
254	0.68
223	0.75
225	0.89
241	0.93
227	0.96
245	1.05
233	1.08
229	1.08
249	1.18
237	1.20
258	1.22
262	1.46

Dundon Hayes percentage molluscan cluster analysis results

File: DHMOL%SC.TIL
Number of samples = 14
Number of variables = 18
Data converted to proportions
Square root transformation
Dissimilarity coefficient is Edwards and Cavalli-Sforza's chord distance

Constrained Incremental Sum of Squares Cluster Analysis

Stage	Clusters merged	Increase in dispersion	Total dispersion	Within-cluster dispersion	Mean within-cluster dispersion
1	5 6	0.006956061	0.006956061	0.006956061	0.003478031
2	3 4	0.01292106	0.01987712	0.01292106	0.006460528
3	5 7	0.01456466	0.03444178	0.02152072	0.007173575
4	9 10	0.03090284	0.06534462	0.03090284	0.01545142
5	3 5	0.03197956	0.09732417	0.06642134	0.01328427
6	3 8	0.02907476	0.1263989	0.0954961	0.01591602
7	2 3	0.104391	0.2307899	0.1998871	0.02855529
8	12 13	0.1300979	0.3608878	0.1300979	0.06504895
9	2 9	0.1653994	0.5262872	0.3961893	0.04402103
10	11 12	0.2191995	0.7454867	0.3492974	0.1164325
11	1 2	0.2536529	0.9991396	0.6498421	0.06498421
12	1 11	0.3593974	1.358537	1.358537	0.1045028
13	1 14	0.7132235	2.07176	2.07176	0.1479829

Sample numbers

1	221
2	223
3	225
4	227
5	229
6	233
7	237
8	241
9	245
10	249
11	254
12	258
13	262
14	266

Appendix II

Statistical analysis of molluscan data at Briarwood Farm

Briarwood Farm (BF7) molluscan raw count detrended correspondence analysis

Axis 1

Residual 0.111317 at iteration 0
Residual 0.000020 at iteration 1

Eigenvalue 0.26409

Length of gradient 2.003
Length of segments 0.27 0.26 0.23 0.19 0.16 0.15 0.15 0.15 0.15 0.15
0.15
Length of gradient 2.054
Length of gradient 2.111
Length of segments 0.25 0.24 0.22 0.20 0.17 0.16 0.16 0.16 0.17 0.19
0.19
Length of gradient 2.119

Axis 2

Residual 0.009639 at iteration 0
Residual 0.000203 at iteration 1
Residual 0.000015 at iteration 2

Eigenvalue 0.02627

Length of gradient 1.028
Length of segments 0.11 0.11 0.10 0.10 0.10 0.10 0.10 0.10 0.10 0.10
Length of gradient 1.030
Length of gradient 1.032
Length of segments 0.11 0.11 0.10 0.10 0.10 0.10 0.10 0.10 0.10 0.10
Length of gradient 1.032

Axis 3

Residual 0.003969 at iteration 0
Residual 0.000401 at iteration 1
Residual 0.000052 at iteration 2

Eigenvalue 0.01150

Length of gradient 0.922
Length of segments 0.11 0.11 0.10 0.10 0.09 0.08 0.08 0.08 0.08 0.09
Length of gradient 0.954
Length of gradient 0.973
Length of segments 0.11 0.11 0.10 0.10 0.10 0.09 0.09 0.09 0.09 0.09
Length of gradient 0.963

Axis 4

Residual 0.002752 at iteration 0
Residual 0.000597 at iteration 1
Residual 0.000040 at iteration 2

Eigenvalue 0.00732

Length of gradient 0.659
Length of segments 0.07 0.07 0.06 0.07 0.07 0.07 0.07 0.07 0.06 0.06
Length of gradient 0.660
Length of gradient 0.667

Length of segments	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Length of gradient	0.667									

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
B tentaculata	-0.01	0.16	-0.08	0.73
B leachii	1.40	-0.98	2.21	0.03
P fontinalis	0.14	9.32	10.45	1.63
V Piscinalis	-0.38	1.45	1.85	-1.20
P planorbis	3.16	0.25	2.02	-0.58
G laevis	2.26	1.00	1.66	1.90
V cristata	-0.12	1.93	-0.03	0.97
L glabra	-0.88	-1.73	-8.99	0.08
A lacustris	2.08	0.69	2.39	0.60
S nitida	-0.45	0.42	0.84	2.54
B contortus	2.39	1.19	0.91	1.13
G crista	1.19	1.82	-1.25	-0.28
P albus	-0.99	1.27	-0.21	-0.63
L peregra	1.92	1.23	0.67	-0.52
L palustris	0.81	0.80	0.62	0.27
A leucostom	0.81	0.80	0.62	0.27
A hypnorum	0.81	0.80	0.62	0.27
L truncatula	0.81	0.80	0.62	0.27
C minimum	3.23	-3.37	1.58	-1.92
Vertigo sp.	0.81	0.80	0.62	0.27
Succineidae	0.81	0.80	0.62	0.27
Zonitidae	0.81	0.80	0.62	0.27
Vallonia sp.	0.81	0.80	0.62	0.27
C bidentata	0.81	0.80	0.62	0.27
C lubrica	0.81	0.80	0.62	0.27
Operculum	0.21	-0.37	0.40	-0.10

Axis 1 ranked. Eigenvalue = 0.26409

Name	Score
P albus	-0.99
L glabra	-0.88
S nitida	-0.45
V Piscinalis	-0.38
V cristata	-0.12
B tentaculata	-0.01
P fontinalis	0.14
Operculum	0.21
L palustris	0.81
C bidentata	0.81
Zonitidae	0.81
Succineidae	0.81
Vertigo sp.	0.81
C lubrica	0.81
A hypnorum	0.81
A leucostoma	0.81
L truncatula	0.81
Vallonia sp.	0.81
G crista	1.19
B leachii	1.40
L peregra	1.92
A lacustris	2.08
G laevis	2.26

B contortus	2.39
P planorbis	3.16
C minimum	3.23

Axis 2 ranked. Eigenvalue = 0.02627

Name	Score
C minimum	-3.37
L glabra	-1.73
B leachii	-0.98
Operculum	-0.37
B tentaculata	0.16
P planorbis	0.25
S nitida	0.42
A lacustris	0.69
Vallonia sp.	0.80
C lubrica	0.80
Zonitidae	0.80
Vertigo sp.	0.80
C bidentata	0.80
L palustris	0.80
L truncatula	0.80
A hypnorum	0.80
A leucostoma	0.80
Succineidae	0.80
G laevis	1.00
B contortus	1.19
L peregra	1.23
P albus	1.27
V Piscinalis	1.45
G crista	1.82
V cristata	1.93
P fontinalis	9.32

Axis 3 ranked. Eigenvalue = 0.01150

Name	Score
L glabra	-8.99
G crista	-1.25
P albus	-0.21
B tentaculata	-0.08
V cristata	-0.03
Operculum	0.40
L palustris	0.62
C lubrica	0.62
C bidentata	0.62
Zonitidae	0.62
Succineidae	0.62
Vertigo sp.	0.62
L truncatula	0.62
A hypnorum	0.62
A leucostoma	0.62
Vallonia sp.	0.62
L peregra	0.67
S nitida	0.84
B contortus	0.91
C minimum	1.58
G laevis	1.66
V Piscinalis	1.85

P planorbis	2.02
B leachii	2.21
A lacustris	2.39
P fontinalis	10.45

Axis 4 ranked. Eigenvalue = 0.00732

Name	Score
C minimum	-1.92
V Piscinalis	-1.20
P albus	-0.63
P planorbis	-0.58
L peregra	-0.52
G crista	-0.28
Operculum	-0.10
B leachii	0.03
L glabra	0.08
L palustris	0.27
C lubrica	0.27
C bidentata	0.27
Vallonia sp.	0.27
Zonitidae	0.27
Succineidae	0.27
Vertigo sp.	0.27
L truncatula	0.27
A hypnorum	0.27
A leucostoma	0.27
A lacustris	0.60
B tentaculata	0.73
V cristata	0.97
B contortus	1.13
P fontinalis	1.63
G laevis	1.90
S nitida	2.54

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
120	2.12	0.75	0.96	0.41
130	1.37	0.79	0.50	0.39
145	1.15	1.03	0.37	0.39
155	0.76	0.95	0.63	0.31
165	0.44	0.75	0.46	0.00
175	0.15	0.99	0.60	0.19
185	0.21	0.52	0.36	0.13
195	0.12	0.70	0.21	0.25
205	0.07	0.91	0.20	0.31
215	0.04	0.65	0.40	0.35
225	0.08	0.56	0.37	0.18
245	0.18	0.72	0.18	0.40
255	0.19	0.94	0.21	0.15
265	0.00	0.65	0.26	0.22
275	0.15	0.81	0.00	0.03
285	0.40	0.56	0.22	0.67
295	0.04	0.00	0.67	0.12

Axis 1 ranked. Eigenvalue = 0.26409

Name	Score
265	0.00
295	0.04
215	0.04
205	0.07
225	0.08
195	0.12
275	0.15
175	0.15
245	0.18
255	0.19
185	0.21
285	0.40
165	0.44
155	0.76
145	1.15
130	1.37
120	2.12

Axis 2 ranked. Eigenvalue = 0.02627

Name	Score
295	0.00
185	0.52
225	0.56
285	0.56
215	0.65
265	0.65
195	0.70
245	0.72
165	0.75
120	0.75
130	0.79
275	0.81
205	0.91
255	0.94
155	0.95
175	0.99
145	1.03

Axis 3 ranked. Eigenvalue = 0.01150

Name	Score
275	0.00
245	0.18
205	0.20
255	0.21
195	0.21
285	0.22
265	0.26
185	0.36
225	0.37
145	0.37

215	0.40
165	0.46
130	0.50
175	0.60
155	0.63
295	0.67
120	0.96

Axis 4 ranked. Eigenvalue = 0.00732

Name	Score
165	0.00
275	0.03
295	0.12
185	0.13
255	0.15
225	0.18
175	0.19
265	0.22
195	0.25
205	0.31
155	0.31
215	0.35
145	0.39
130	0.39
245	0.40
120	0.41
285	0.67

Briarwood Farm (BF7) molluscan raw data cluster analysis

File: BF7RAWMO.TIL
Number of samples = 17
Number of variables = 26
Square root transformation
Dissimilarity coefficient is Euclidian distance
Constrained Incremental Sum of Squares Cluster Analysis

Stage	Clusters merged		Increase in dispersion	Total dispersion	Within-cluster dispersion	Mean within-cluster dispersion
1	13	14	3.366071	3.366071	3.366071	1.683036
2	13	15	5.973189	9.33926	9.33926	3.113087
3	6	7	6.984864	16.32412	6.984864	3.492432
4	8	9	7.466175	23.7903	7.466175	3.733088
5	8	10	7.128686	30.91899	14.59486	4.864954
6	2	3	8.269837	39.18882	8.269837	4.134919
7	4	5	11.08453	50.27336	11.08453	5.542267
8	13	16	11.19868	61.47204	20.53794	5.134486
9	1	2	12.61748	74.08952	20.88732	6.96244
10	11	12	13.08959	87.17911	13.08959	6.544796
11	11	13	11.03099	98.2101	44.65852	7.443087
12	1	4	16.92058	115.1307	48.89244	9.778487
13	6	8	22.02681	137.1575	43.60653	8.721307
14	11	17	23.44864	160.6061	68.10717	9.729595
15	6	11	193.0462	353.6523	304.7599	25.39666
16	1	6	102.2846	455.9369	455.9369	26.81982

Sample numbers

1	120
2	130
3	145
4	155
5	165
6	175
7	185
8	195
9	205
10	215
11	225
12	245
13	255
14	265
15	275
16	285
17	295

Briarwood Farm (BF7) molluscan percentage detrended correspondence analysis

Axis 1

Residual 0.162361 at iteration 0
Residual 0.000314 at iteration 1
Residual 0.000000 at iteration 2

Eigenvalue 0.37949

Length of gradient 2.216
Length of segments 0.26 0.24 0.22 0.20 0.17 0.15 0.15 0.15 0.15 0.16 0.18 0.19
Length of gradient 2.266
Length of gradient 2.278
Length of segments 0.23 0.23 0.22 0.20 0.18 0.16 0.16 0.16 0.16 0.17 0.19 0.21
Length of gradient 2.278

Axis 2

Residual 0.031093 at iteration 0
Residual 0.000319 at iteration 1
Residual 0.000001 at iteration 2

Eigenvalue 0.09725

Length of gradient 2.064
Length of segments 0.20 0.20 0.19 0.18 0.18 0.18 0.18 0.18 0.18 0.19 0.22
Length of gradient 2.055
Length of gradient 2.012
Length of segments 0.20 0.20 0.18 0.18 0.17 0.17 0.17 0.17 0.18 0.19 0.21
Length of gradient 1.993

Axis 3

Residual 0.007732 at iteration 0
Residual 0.005392 at iteration 1
Residual 0.000339 at iteration 2
Residual 0.000026 at iteration 3

Eigenvalue 0.02772

Length of gradient 0.784
Length of segments 0.10 0.09 0.08 0.08 0.08 0.08 0.08 0.07 0.06 0.06
Length of gradient 0.742
Length of gradient 0.740
Length of segments 0.08 0.08 0.07 0.07 0.07 0.07 0.07 0.07 0.08 0.08
Length of gradient 0.738

Axis 4

Residual 0.007544 at iteration 0
Residual 0.000063 at iteration 1

Eigenvalue 0.01989

Length of gradient 1.873

Length of segments	0.18	0.18	0.17	0.17	0.16	0.16	0.16	0.19	0.24	0.26
Length of gradient	1.705									
Length of gradient	1.563									
Length of segments	0.17	0.17	0.16	0.15	0.14	0.14	0.14	0.15	0.17	0.17
Length of gradient	1.517									

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
B tentaculata	0.13	1.14	-0.44	0.54
B leachii	1.32	3.15	-0.02	5.10
P fontinalis	-0.39	2.28	8.54	5.65
V piscinalis	-0.06	2.37	1.93	0.91
P planorbis	3.32	1.30	0.75	0.62
G laevis	2.33	1.28	0.77	0.73
V cristata	0.16	-0.48	0.68	-0.08
L glabra	-1.03	1.77	-8.23	-1.89
A lacustris	2.46	1.36	0.92	1.52
S nitida	0.06	1.62	-0.99	2.13
B contortus	2.57	1.30	0.57	0.64
G crista	1.22	2.06	0.37	-0.82
P albus	-1.17	2.64	-0.03	-0.54
L peregra	1.77	0.15	1.14	0.11
L palustris	1.11	1.16	0.60	0.42
A leucostom	1.11	1.16	0.60	0.42
A hypnorum	1.11	1.16	0.60	0.42
L truncatula	1.11	1.16	0.60	0.42
C minimum	2.35	4.23	-2.83	9.57
Vertigo sp.	1.11	1.16	0.60	0.42
Succineidae	1.11	1.16	0.60	0.42
Zonitidae	1.11	1.16	0.60	0.42
Vallonia sp.	1.11	1.16	0.60	0.42
C bidentata	1.11	1.16	0.60	0.42
C lubrica	1.11	1.16	0.60	0.42

Axis 1 ranked. Eigenvalue = 0.37949

Name	Score
P albus	-1.17
L glabra	-1.03
P fontinalis	-0.39
V piscinalis	-0.06
S nitida	0.06
B tentaculata	0.13
V cristata	0.16
L palustris	1.11
C bidentata	1.11
Succineidae	1.11
Zonitidae	1.11
Vertigo sp.	1.11
Vallonia sp.	1.11
C lubrica	1.11
A hypnorum	1.11
A leucostoma	1.11
L truncatula	1.11
G crista	1.22
B leachii	1.32
L peregra	1.77
G laevis	2.33
C minimum	2.35

A lacustris	2.46
B contortus	2.57
P planorbis	3.32

Axis 2 ranked. Eigenvalue = 0.09725

Name	Score
V cristata	-0.48
L peregra	0.15
B tentaculata	1.14
Succineidae	1.16
C bidentata	1.16
L palustris	1.16
A hypnorum	1.16
Vallonia sp.	1.16
L truncatula	1.16
Vertigo sp.	1.16
A leucostoma	1.16
Zonitidae	1.16
C lubrica	1.16
G laevis	1.28
P planorbis	1.30
B contortus	1.30
A lacustris	1.36
S nitida	1.62
L glabra	1.77
G crista	2.06
P fontinalis	2.28
V piscinalis	2.37
P albus	2.64
B leachii	3.15
C minimum	4.23

Axis 3 ranked. Eigenvalue = 0.02772

Name	Score
L glabra	-8.23
C minimum	-2.83
S nitida	-0.99
B tentaculata	-0.44
P albus	-0.03
B leachii	-0.02
G crista	0.37
B contortus	0.57
L palustris	0.60
C bidentata	0.60
Zonitidae	0.60
Vertigo sp.	0.60
Vallonia sp.	0.60
L truncatula	0.60
A hypnorum	0.60
A leucostoma	0.60
C lubrica	0.60
Succineidae	0.60
V cristata	0.68
P planorbis	0.75
G laevis	0.77
A lacustris	0.92
L peregra	1.14
V piscinalis	1.93

P fontinalis	8.54

Axis 4 ranked. Eigenvalue = 0.01989

Name	Score
L glabra	-1.89
G crista	-0.82
P albus	-0.54
V cristata	-0.08
L peregra	0.11
L palustris	0.42
C lubrica	0.42
Vertigo sp.	0.42
Zonitidae	0.42
Succineidae	0.42
C bidentata	0.42
Vallonia sp.	0.42
L truncatula	0.42
A hypnorum	0.42
A leucostoma	0.42
B tentaculata	0.54
P planorbis	0.62
B contortus	0.64
G laevis	0.73
V piscinalis	0.91
A lacustris	1.52
S nitida	2.13
B leachii	5.10
P fontinalis	5.65
C minimum	9.57

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
120	2.28	1.22	0.63	0.56
130	1.64	1.24	0.44	0.48
145	1.41	0.92	0.64	0.18
155	1.16	1.21	0.74	0.43
165	0.68	1.54	0.68	0.37
175	0.33	1.27	0.70	0.54
185	0.35	1.53	0.29	0.60
195	0.27	1.23	0.25	0.41
205	0.23	1.15	0.35	0.27
215	0.19	1.22	0.30	0.55
225	0.20	1.23	0.36	0.40
245	0.35	0.00	0.46	0.10
255	0.36	1.35	0.50	0.21
265	0.08	1.23	0.29	0.32
275	0.22	1.46	0.30	0.00
285	0.67	1.22	0.00	0.53
295	0.00	1.99	0.47	1.52

Axis 1 ranked. Eigenvalue = 0.37949

Name	Score
295	0.00
265	0.08
215	0.19

225	0.20
275	0.22
205	0.23
195	0.27
175	0.33
185	0.35
245	0.35
255	0.36
285	0.67
165	0.68
155	1.16
145	1.41
130	1.64
120	2.28

Axis 2 ranked. Eigenvalue = 0.09725

Name	Score
245	0.00
145	0.92
205	1.15
155	1.21
215	1.22
285	1.22
120	1.22
265	1.23
225	1.23
195	1.23
130	1.24
175	1.27
255	1.35
275	1.46
185	1.53
165	1.54
295	1.99

Axis 3 ranked. Eigenvalue = 0.02772

Name	Score
285	0.00
195	0.25
185	0.29
265	0.29
275	0.30
215	0.30
205	0.35
225	0.36
130	0.44
245	0.46
295	0.47
255	0.50
120	0.63
145	0.64
165	0.68
175	0.70
155	0.74

Axis 4 ranked. Eigenvalue = 0.01989

Name	Score
275	0.00
245	0.10
145	0.18
255	0.21
205	0.27
265	0.32
165	0.37
225	0.40
195	0.41
155	0.43
130	0.48
285	0.53
175	0.54
215	0.55
120	0.56
185	0.60
295	1.52

Briarwood Farm (BF7) molluscan percentage data cluster analysis

File: BF7MOL%S.TIL
Number of samples = 17
Number of variables = 25
Data converted to proportions
Square root transformation
Dissimilarity coefficient is Edwards and Cavalli-Sforza's chord distance

Constrained Incremental Sum of Squares Cluster Analysis

Stage	Clusters merged	Increase in dispersion	Total dispersion	Within-cluster dispersion	Mean within-cluster dispersion
1	8 9	0.02600812	0.02600812	0.02600812	0.01300406
2	8 10	0.03725899	0.06326711	0.06326711	0.02108904
3	7 8	0.04636317	0.1096303	0.1096303	0.02740757
4	6 7	0.05116476	0.160795	0.160795	0.03215901
5	13 14	0.05521021	0.2160053	0.05521021	0.02760511
6	6 11	0.07210498	0.2881102	0.2329	0.03881667
7	13 15	0.08230854	0.3704188	0.1375188	0.04583959
8	2 3	0.1241982	0.494617	0.1241982	0.06209909
9	1 2	0.1844863	0.6791033	0.3086845	0.1028948
10	5 6	0.215059	0.8941623	0.4479591	0.06399415
11	13 16	0.2637338	1.157896	0.4012525	0.1003131
12	1 4	0.4215723	1.579468	0.7302568	0.1825642
13	12 13	0.4964521	2.07592	0.8977046	0.1795409
14	5 12	0.1659055	2.241826	1.511569	0.1259641
15	5 17	0.9492434	3.191069	2.460813	0.1892933
16	1 5	1.482655	4.673724	4.673724	0.2749249

Sample numbers

1	120
2	130
3	145
4	155
5	165
6	175
7	185
8	195
9	205
10	215
11	225
12	245
13	255
14	265
15	275
16	285
17	295

Appendix III

Statistical analysis of molluscan data at Bawdrip

Bawdrip molluscan raw data detrended correspondance analysis results

Axis 1

Residual 0.147135 at iteration 0
Residual 0.014009 at iteration 1
Residual 0.002160 at iteration 2
Residual 0.000091 at iteration 3

Eigenvalue 0.36654

Length of gradient 2.467
Length of segments 0.20 0.20 0.19 0.18 0.18 0.18 0.19 0.21 0.23 0.23
0.18 0.15 0.14
Length of gradient 2.501
Length of gradient 2.520
Length of segments 0.20 0.19 0.19 0.18 0.18 0.18 0.18 0.20 0.23 0.23
0.21 0.18 0.17
Length of gradient 2.522

Axis 2

Residual 0.053286 at iteration 0
Residual 0.000969 at iteration 1
Residual 0.000010 at iteration 2

Eigenvalue 0.12528

Length of gradient 1.479
Length of segments 0.21 0.20 0.18 0.16 0.14 0.13 0.12 0.11 0.11 0.11
Length of gradient 1.509
Length of gradient 1.600
Length of segments 0.19 0.19 0.19 0.19 0.17 0.15 0.14 0.13 0.13 0.13
Length of gradient 1.630

Axis 3

Residual 0.016681 at iteration 0
Residual 0.000023 at iteration 1

Eigenvalue 0.03512

Length of gradient 1.094
Length of segments 0.14 0.14 0.13 0.12 0.12 0.11 0.10 0.08 0.07 0.07
Length of gradient 1.165
Length of gradient 1.195
Length of segments 0.13 0.13 0.13 0.12 0.12 0.12 0.11 0.11 0.11 0.11
Length of gradient 1.193

Axis 4

Residual 0.002782 at iteration 0
Residual 0.000452 at iteration 1
Residual 0.000008 at iteration 2

Eigenvalue 0.01004

Length of gradient 1.331
Length of segments 0.11 0.11 0.10 0.10 0.12 0.13 0.15 0.16 0.17 0.17
Length of gradient 1.441

Length of gradient 1.518
Length of segments 0.15 0.13 0.12 0.13 0.16 0.18 0.18 0.17 0.16 0.15
Length of gradient 1.521

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
B tentaculata	2.17	0.51	-0.54	0.52
B leachii	2.26	2.15	-0.49	-0.51
P fontinalis	0.25	0.23	1.20	0.17
V Piscinalis	1.15	-0.52	0.86	1.39
P planorbis	2.67	0.45	0.87	2.36
G laevis	1.18	0.78	0.39	1.51
V cristata	0.19	0.58	-0.10	0.86
L glabra	1.00	0.86	0.76	1.05
A lacustris	3.76	0.86	0.76	1.05
S nitida	1.46	0.86	0.76	1.05
B contortus	-0.69	0.88	0.36	1.45
G crista	-0.34	0.30	0.78	0.92
P albus	2.07	-0.71	1.26	4.98
L peregra	2.97	0.12	-0.41	0.94
L palustris	1.12	-1.76	-3.19	0.52
A leucostoma	3.56	0.88	1.11	1.18
A hypnorum	3.15	1.28	-1.40	1.32
L truncatula	1.95	-0.03	1.28	2.11
C minimum	1.33	2.16	0.96	-0.24
Vertigo	1.04	-0.91	1.61	1.40
Succineidae	1.25	2.23	2.88	2.73
Zonitidae	0.82	1.50	-0.63	2.00
Vallonia sp.	2.08	-2.11	-4.17	1.89
C bidentata	2.84	-1.49	1.51	6.48
C lubrica	0.96	2.49	-1.29	3.56
Operculum	2.47	0.61	-0.42	0.21

Axis 1 ranked. Eigenvalue = 0.36654

Name	Score
B contortus	-0.69
G crista	-0.34
V cristata	0.19
P fontinalis	0.25
Zonitidae	0.82
C lubrica	0.96
L glabra	1.00
Vertigo	1.04
L palustris	1.12
V Piscinalis	1.15
G laevis	1.18
Succineidae	1.25
C minimum	1.33
S nitida	1.46
L truncatula	1.95
P albus	2.07
Vallonia sp.	2.08
B tentaculata	2.17
B leachii	2.26
Operculum	2.47
P planorbis	2.67
C bidentata	2.84

L peregra	2.97
A hypnorum	3.15
A leucostoma	3.56
A lacustris	3.76

Axis 2 ranked. Eigenvalue = 0.12528

Name	Score
Vallonia sp.	-2.11
L palustris	-1.76
C bidentata	-1.49
Vertigo	-0.91
P albus	-0.71
V Piscinalis	-0.52
L truncatula	-0.03
L peregra	0.12
P fontinalis	0.23
G crista	0.30
P planorbis	0.45
B tentaculata	0.51
V cristata	0.58
Operculum	0.61
G laevis	0.78
S nitida	0.86
A lacustris	0.86
L glabra	0.86
A leucostoma	0.88
B contortus	0.88
A hypnorum	1.28
Zonitidae	1.50
B leachii	2.15
C minimum	2.16
Succineidae	2.23
C lubrica	2.49

Axis 3 ranked. Eigenvalue = 0.03512

Name	Score
Vallonia sp.	-4.17
L palustris	-3.19
A hypnorum	-1.40
C lubrica	-1.29
Zonitidae	-0.63
B tentaculata	-0.54
B leachii	-0.49
Operculum	-0.42
L peregra	-0.41
V cristata	-0.10
B contortus	0.36
G laevis	0.39
S nitida	0.76
A lacustris	0.76
L glabra	0.76
G crista	0.78
V Piscinalis	0.86
P planorbis	0.87
C minimum	0.96
A leucostoma	1.11
P fontinalis	1.20
P albus	1.26

L truncatula	1.28
C bidentata	1.51
Vertigo	1.61
Succineidae	2.88

Axis 4 ranked. Eigenvalue = 0.01004

Name	Score
B leachii	-0.51
C minimum	-0.24
P fontinalis	0.17
Operculum	0.21
L palustris	0.52
B tentaculata	0.52
V cristata	0.86
G crista	0.92
L peregra	0.94
S nitida	1.05
A lacustris	1.05
L glabra	1.05
A leucostoma	1.18
A hypnorum	1.32
V Piscinalis	1.39
Vertigo	1.40
B contortus	1.45
G laevis	1.51
Vallonia sp.	1.89
Zonitidae	2.00
L truncatula	2.11
P planorbis	2.36
Succineidae	2.73
C lubrica	3.56
P albus	4.98
C bidentata	6.48

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
107.5	2.23	0.41	0.12	1.07
127.5	2.52	0.13	0.00	1.15
187.5	0.00	0.54	0.38	1.01
212.5	1.20	0.19	0.24	1.13
252.5	1.56	0.00	0.75	1.24
272.5	1.85	1.43	0.58	0.45
312.5	1.11	0.09	1.19	1.43
332.5	0.75	0.28	0.56	1.09
342.5	0.96	0.88	0.23	1.52
352.5	1.68	1.63	0.51	0.00
372.5	1.37	1.55	0.97	1.07
402.5	1.10	0.81	0.15	0.84
412.5	0.51	0.42	0.51	1.20
432.5	1.80	0.21	0.62	1.45

Axis 1 ranked. Eigenvalue = 0.36654

Name	Score
187.5	0.00
412.5	0.51

332.5	0.75
342.5	0.96
402.5	1.10
312.5	1.11
212.5	1.20
372.5	1.37
252.5	1.56
352.5	1.68
432.5	1.80
272.5	1.85
107.5	2.23
127.5	2.52

Axis 2 ranked. Eigenvalue = 0.12528

Name	Score
252.5	0.00
312.5	0.09
127.5	0.13
212.5	0.19
432.5	0.21
332.5	0.28
107.5	0.41
412.5	0.42
187.5	0.54
402.5	0.81
342.5	0.88
272.5	1.43
372.5	1.55
352.5	1.63

Axis 3 ranked. Eigenvalue = 0.03512

Name	Score
127.5	0.00
107.5	0.12
402.5	0.15
342.5	0.23
212.5	0.24
187.5	0.38
412.5	0.51
352.5	0.51
332.5	0.56
272.5	0.58
432.5	0.62
252.5	0.75
372.5	0.97
312.5	1.19

Axis 4 ranked. Eigenvalue = 0.01004

Name	Score
352.5	0.00
272.5	0.45
402.5	0.84
187.5	1.01
107.5	1.07
372.5	1.07
332.5	1.09

212.5	1.13
127.5	1.15
412.5	1.20
252.5	1.24
312.5	1.43
432.5	1.45
342.5	1.52

Bawdrip molluscan raw data cluster analysis

File: BAWMOLRA.TIL
Number of samples = 14
Number of variables = 26
Square root transformation
Dissimilarity coefficient is Euclidian distance

Constrained Incremental Sum of Squares Cluster Analysis

Stage	Clusters merged	Increase in dispersion	Total dispersion	Within-cluster dispersion	Mean within-cluster dispersion
1	9 10	15	15	15	7.5
2	5 6	27.02227	42.02227	27.02227	13.51114
3	9 11	27.08414	69.10642	42.08415	14.02805
4	9 12	13.11557	82.22199	55.19972	13.79993
5	5 7	39.00692	121.2289	66.02919	22.00973
6	1 2	55.7106	176.9395	55.7106	27.8553
7	5 8	72.9019	249.8414	138.9311	34.73277
8	5 9	61.6361	311.4775	255.7669	31.97086
9	3 4	79.34601	390.8235	79.34601	39.673
10	13 14	97.54082	488.3643	97.54082	48.77041
11	5 13	102.4903	590.8546	455.798	45.5798
12	1 3	146.5767	737.4313	281.6333	70.40833
13	1 5	151.5501	888.9814	888.9814	63.49867

Sample numbers

1	107.5
2	127.5
3	187.5
4	212.5
5	252.5
6	272.5
7	312.5
8	332.5
9	342.5
10	352.5
11	372.5
12	402.5
13	412.5
14	432.5

Bawdrip molluscan percentage data detrended correspondence analysis results

Axis 1

Residual 0.106205 at iteration 0
Residual 0.017896 at iteration 1
Residual 0.000443 at iteration 2
Residual 0.000011 at iteration 3

Eigenvalue 0.44037

Length of gradient 2.692
Length of segments 0.34 0.25 0.19 0.17 0.16 0.16 0.16 0.17 0.17 0.17
0.17 0.18 0.19 0.20
Length of gradient 2.731
Length of gradient 2.753
Length of segments 0.33 0.27 0.19 0.17 0.16 0.16 0.17 0.18 0.18 0.18
0.18 0.19 0.19 0.20
Length of gradient 2.751

Axis 2

Residual 0.058106 at iteration 0
Residual 0.030966 at iteration 1
Residual 0.000333 at iteration 2
Residual 0.000004 at iteration 3

Eigenvalue 0.27485

Length of gradient 1.051
Length of segments 0.16 0.16 0.16 0.16 0.15 0.09 0.05 0.05 0.05 0.05
Length of gradient 1.066
Length of gradient 1.174
Length of segments 0.18 0.18 0.18 0.18 0.17 0.10 0.05 0.05 0.05 0.05
Length of gradient 1.358

Axis 3

Residual 0.048930 at iteration 0
Residual 0.002328 at iteration 1
Residual 0.000055 at iteration 2

Eigenvalue 0.12603

Length of gradient 1.365
Length of segments 0.17 0.16 0.16 0.15 0.14 0.13 0.12 0.12 0.11 0.11
Length of gradient 1.409
Length of gradient 1.414
Length of segments 0.16 0.15 0.15 0.14 0.13 0.13 0.13 0.13 0.14 0.14
Length of gradient 1.403

Axis 4

Residual 0.006687 at iteration 0
Residual 0.000171 at iteration 1
Residual 0.000001 at iteration 2

Eigenvalue 0.02719

Length of gradient 1.403

Length of segments	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.14	0.13	0.12
Length of gradient	1.424									
Length of gradient	1.428									
Length of segments	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.14	0.14
Length of gradient	1.428									

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
B tentaculata	-0.35	0.04	1.09	1.16
B leachii	2.02	2.42	1.86	0.00
P fontinalis	3.05	-0.01	1.20	-0.35
V Piscinalis	1.85	-0.01	-0.60	-0.01
P planorbis	1.48	0.25	1.53	0.31
G laevis	2.06	0.26	2.27	-0.65
V cristata	2.52	-0.06	1.61	1.06
L glabra	1.81	0.15	1.03	0.48
A lacustris	1.16	0.53	3.68	-2.61
S nitida	2.12	0.38	2.60	-1.34
B contortus	3.20	0.03	2.14	2.13
G crista	2.99	-0.01	-0.02	-0.64
P albus	1.30	0.06	-2.29	2.37
L peregra	0.70	0.06	1.22	-0.21
L palustris	1.99	-0.37	-0.56	-1.12
A leucostoma	1.42	0.33	2.27	-1.35
A hypnorum	2.28	-0.07	3.51	3.66
L truncatula	1.71	0.30	-0.23	1.22

Axis 1 ranked. Eigenvalue = 0.44037

Name	Score
B tentaculata	-0.35
L peregra	0.70
A lacustris	1.16
P albus	1.30
A leucostoma	1.42
P planorbis	1.48
L truncatula	1.71
L glabra	1.81
V Piscinalis	1.85
L palustris	1.99
B leachii	2.02
G laevis	2.06
S nitida	2.12
A hypnorum	2.28
V cristata	2.52
G crista	2.99
P fontinalis	3.05
B contortus	3.20

Axis 2 ranked. Eigenvalue = 0.27485

Name	Score
L palustris	-0.37
A hypnorum	-0.07
V cristata	-0.06
V Piscinalis	-0.01
P fontinalis	-0.01
G crista	-0.01
B contortus	0.03

B tentaculata	0.04
P albus	0.06
L peregra	0.06
L glabra	0.15
P planorbis	0.25
G laevis	0.26
L truncatula	0.30
A leucostoma	0.33
S nitida	0.38
A lacustris	0.53
B leachii	2.42

Axis 3 ranked. Eigenvalue = 0.12603

Name	Score
P albus	-2.29
V Piscinalis	-0.60
L palustris	-0.56
L truncatula	-0.23
G crista	-0.02
L glabra	1.03
B tentaculata	1.09
P fontinalis	1.20
L peregra	1.22
P planorbis	1.53
V cristata	1.61
B leachii	1.86
B contortus	2.14
A leucostoma	2.27
G laevis	2.27
S nitida	2.60
A hypnorum	3.51
A lacustris	3.68

Axis 4 ranked. Eigenvalue = 0.02719

Name	Score
A lacustris	-2.61
A leucostoma	-1.35
S nitida	-1.34
L palustris	-1.12
G laevis	-0.65
G crista	-0.64
P fontinalis	-0.35
L peregra	-0.21
V Piscinalis	-0.01
B leachii	0.00
P planorbis	0.31
L glabra	0.48
V cristata	1.06
B tentaculata	1.16
L truncatula	1.22
B contortus	2.13
P albus	2.37
A hypnorum	3.66

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
107.5	1.34	0.13	1.40	0.00
127.5	0.99	0.11	0.86	0.18
187.5	2.75	0.00	0.89	0.32
272.5	1.89	0.05	0.55	0.28
312.5	1.38	0.12	0.36	0.60
332.5	1.87	1.36	0.82	0.61
342.5	2.13	0.13	0.00	0.21
352.5	2.24	0.01	0.79	0.59
372.5	2.07	0.06	1.25	1.43
402.5	0.00	0.05	1.14	0.70
412.5	1.69	0.14	0.62	0.81
432.5	1.11	0.03	0.77	0.10
412.5	2.41	0.04	1.01	0.67
432.5	1.21	0.17	0.26	0.85

Axis 1 ranked. Eigenvalue = 0.44037

Name	Score
402.5	0.00
127.5	0.99
432.5	1.11
432.5	1.21
107.5	1.34
312.5	1.38
412.5	1.69
332.5	1.87
272.5	1.89
372.5	2.07
342.5	2.13
352.5	2.24
412.5	2.41
187.5	2.75

Axis 2 ranked. Eigenvalue = 0.27485

Name	Score
187.5	0.00
352.5	0.01
432.5	0.03
412.5	0.04
402.5	0.05
272.5	0.05
372.5	0.06
127.5	0.11
312.5	0.12
107.5	0.13
342.5	0.13
412.5	0.14
432.5	0.17
332.5	1.36

Axis 3 ranked. Eigenvalue = 0.12603

Name	Score
342.5	0.00
432.5	0.26
312.5	0.36
272.5	0.55
412.5	0.62
432.5	0.77
352.5	0.79
332.5	0.82
127.5	0.86
187.5	0.89
412.5	1.01
402.5	1.14
372.5	1.25
107.5	1.40

Axis 4 ranked. Eigenvalue = 0.02719

Name	Score
107.5	0.00
432.5	0.10
127.5	0.18
342.5	0.21
272.5	0.28
187.5	0.32
352.5	0.59
312.5	0.60
332.5	0.61
412.5	0.67
402.5	0.70
412.5	0.81
432.5	0.85
372.5	1.43

Bawdrip molluscan percentage data cluster analysis

File: BAWMOL%S.TIL
Number of samples = 14
Number of variables = 18
Data converted to proportions
Square root transformation
Dissimilarity coefficient is Edwards and Cavalli-Sforza's chord distance

Constrained Incremental Sum of Squares Cluster Analysis

Stage	Clusters merged		Increase in dispersion	Total dispersion	Within-cluster dispersion	Mean within-cluster dispersion
1	4	5	0.1168918	0.1168918	0.1168918	0.0584459
2	8	9	0.1947816	0.3116734	0.1947816	0.09739081
3	1	2	0.2284529	0.5401263	0.2284529	0.1142265
4	13	14	0.4052971	0.9454234	0.4052971	0.2026485
5	12	13	0.4326274	1.378051	0.8379245	0.2793082
6	11	12	0.3345674	1.712618	1.172492	0.293123
7	6	7	0.4458311	2.158449	0.4458311	0.2229156
8	4	6	0.3714951	2.529944	0.9342181	0.2335545
9	4	8	0.4527144	2.982659	1.581714	0.263619
10	3	4	0.4241778	3.406837	2.005892	0.286556
11	10	11	0.6266771	4.033514	1.799169	0.3598338
12	3	10	0.3887032	4.422217	4.193764	0.3494803
13	1	3	0.5202617	4.942479	4.942479	0.3530342

Sample numbers

1	107.5
2	127.5
3	187.5
4	272.5
5	312.5
6	332.5
7	342.5
8	352.5
9	372.5
10	402.5
11	412.5
12	432.5
13	412.5
14	432.5

Appendix IV

Statistical analysis of total foraminiferal data from Stert

Total foraminiferal raw data detrended correspondance analysis

Axis 1

Residual 0.083893 at iteration 0
Residual 0.013834 at iteration 1
Residual 0.000220 at iteration 2
Residual 0.000004 at iteration 3

Eigenvalue 0.45114

Length of gradient 2.422
Length of segments 0.30 0.26 0.21 0.19 0.17 0.16 0.15 0.15 0.15 0.15
0.16 0.18 0.19
Length of gradient 2.540
Length of gradient 2.676
Length of segments 0.28 0.24 0.21 0.19 0.18 0.18 0.17 0.17 0.16 0.16
0.17 0.17 0.19 0.20
Length of gradient 2.723

Axis 2

Residual 0.044650 at iteration 0
Residual 0.032965 at iteration 1
Residual 0.002396 at iteration 2
Residual 0.000057 at iteration 3

Eigenvalue 0.21174

Length of gradient 1.966
Length of segments 0.26 0.24 0.23 0.21 0.20 0.18 0.17 0.16 0.15 0.15
Length of gradient 2.022
Length of gradient 2.009
Length of segments 0.20 0.20 0.19 0.18 0.18 0.18 0.18 0.18 0.18 0.18
0.18
Length of gradient 2.008

Axis 3

Residual 0.030866 at iteration 0
Residual 0.011799 at iteration 1
Residual 0.002564 at iteration 2
Residual 0.000377 at iteration 3
Residual 0.000090 at iteration 4

Eigenvalue 0.10113

Length of gradient 1.844
Length of segments 0.22 0.22 0.22 0.22 0.21 0.19 0.16 0.14 0.13 0.12
Length of gradient 1.973
Length of gradient 1.931
Length of segments 0.19 0.19 0.20 0.20 0.20 0.20 0.20 0.19 0.18 0.18
Length of gradient 1.905

Axis 4

Residual 0.021036 at iteration 0
Residual 0.000952 at iteration 1
Residual 0.000036 at iteration 2

Eigenvalue 0.06520

Length of gradient 1.804
Length of segments 0.15 0.16 0.18 0.21 0.21 0.21 0.19 0.18 0.17 0.15
Length of gradient 1.787
Length of gradient 1.723
Length of segments 0.15 0.16 0.17 0.19 0.19 0.19 0.18 0.17 0.17 0.16
Length of gradient 1.695

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
A. beccarii	0.00	1.48	0.34	0.53
A. batavus	-1.14	2.79	3.27	0.02
C. balkwilli	1.42	2.24	0.07	4.94
C.involvens	1.03	2.89	2.92	1.54
E. crispum	-0.30	-0.23	1.15	1.68
E. williamsoni	1.35	-0.54	1.72	1.74
J. macrescens	2.72	0.73	0.77	0.00
N. germanica	0.21	0.07	1.68	1.84
Q. seminulum	1.26	1.92	2.04	0.42
T. inflata	2.20	2.17	-0.58	2.41

Axis 1 ranked. Eigenvalue = 0.45114

Name	Score
A. batavus	-1.14
E. crispum	-0.30
A. beccarii	0.00
N. germanica	0.21
C.involvens	1.03
Q. seminulum	1.26
E. williamsoni	1.35
C. balkwilli	1.42
T. inflata	2.20
J. macrescens	2.72

Axis 2 ranked. Eigenvalue = 0.21174

Name	Score
E. williamsoni	-0.54
E. crispum	-0.23
N. germanica	0.07
J. macrescens	0.73
A. beccarii	1.48
Q. seminulum	1.92
T. inflata	2.17
C. balkwilli	2.24
A. batavus	2.79
C.involvens	2.89

Axis 3 ranked. Eigenvalue = 0.10113

Name	Score
T. inflata	-0.58
C. balkwilli	0.07
A. beccarii	0.34
J. macrescens	0.77
E. crispum	1.15
N. germanica	1.68
E. williamsoni	1.72
Q. seminulum	2.04
C.involvens	2.92
A. batavus	3.27

Axis 4 ranked. Eigenvalue = 0.06520

Name	Score
J. macrescens	0.00
A. batavus	0.02
Q. seminulum	0.42
A. beccarii	0.53
C.involvens	1.54
E crispum	1.68
E. williamsoni	1.74
N. germanica	1.84
T. inflata	2.41
C. balkwilli	4.94

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
1	0.02	1.47	0.34	0.53
2	0.51	1.41	0.41	0.52
3	1.07	1.39	0.51	0.65
4	2.29	1.57	0.21	1.25
10	2.72	0.73	0.77	0.00
11	2.72	0.73	0.77	0.00
15	2.46	1.45	0.10	1.21
27	1.12	1.24	0.76	0.90
28	0.88	0.97	1.07	0.81
29	0.80	1.06	1.18	0.79
30	1.54	0.84	1.23	0.63
31	1.15	0.03	1.46	1.38
32	0.76	0.12	1.50	1.50
33	0.10	0.77	1.01	1.19
34	0.00	1.48	0.34	0.53
35	0.03	1.30	0.50	0.70
36	0.51	0.92	0.86	0.87
37	0.08	1.16	0.61	0.80
38	0.28	0.71	1.11	1.19
39	0.21	0.96	0.80	0.95
40	0.31	0.39	1.30	1.45
41	0.15	0.50	1.27	1.44
42	0.18	0.30	1.46	1.63
43	0.05	1.13	0.67	0.86
44	0.20	0.64	1.12	1.36
45	0.45	0.69	1.04	1.10
46	0.29	1.14	0.63	0.92
47	0.50	1.06	0.85	0.97

48	0.48	1.42	0.72	0.80
49	1.14	1.37	0.54	1.46
50	1.08	1.63	0.99	1.40
51	0.77	1.52	1.16	0.93
52	0.56	1.33	0.76	1.03
53	0.67	1.15	0.62	1.11
54	0.97	1.10	0.74	0.96
55	1.08	0.65	1.06	1.09
56	2.11	1.07	0.49	1.07
57	2.32	0.97	0.58	0.50
58	2.37	0.81	0.71	0.32
59	2.68	0.72	0.79	0.03
62	0.61	0.27	1.27	1.38
63	0.34	0.67	0.99	1.15
64	0.68	1.38	1.53	1.06
65	0.89	1.89	1.91	0.93
66	0.68	0.96	1.26	1.03
67	0.49	1.61	0.98	0.89
68	0.99	2.01	1.38	1.19
69	0.18	1.04	0.89	1.03
70	0.82	0.99	0.76	0.69
71	0.97	1.29	1.02	0.51
72	0.54	1.30	0.95	0.69
73	0.58	1.27	0.95	0.66
74	1.65	0.66	1.04	0.61
75	2.01	0.69	0.89	0.38
76	2.57	0.71	0.79	0.09
77	2.69	0.70	0.80	0.05
78	2.72	0.73	0.77	0.00
79	0.11	1.31	0.45	0.63
80	0.09	1.31	0.61	0.69
81	0.49	0.77	1.02	1.04
82	0.79	1.24	1.82	1.25
83	0.09	1.29	0.59	0.73
84	1.06	1.52	1.80	0.71
85	0.07	1.23	0.60	0.76
86	0.25	1.19	0.86	0.85
87	0.98	1.65	0.36	1.15
88	0.40	0.89	0.84	1.25
89	0.31	0.76	0.97	1.29
90	0.76	1.11	1.04	0.74
91	0.83	0.89	0.72	0.69
92	0.94	0.92	1.08	1.08
93	1.55	0.21	1.22	1.06
94	2.31	0.81	0.70	0.48
95	2.42	1.55	0.00	1.38
96	1.41	1.44	1.63	1.33
97	1.18	1.06	1.64	1.37
98	0.77	1.09	1.04	1.13
99	1.91	1.63	0.52	1.39
100	1.23	1.48	1.50	1.13
101	1.01	1.70	1.65	1.03
102	1.10	1.50	1.25	0.97
103	0.68	1.46	0.99	0.71
104	0.19	1.02	0.79	0.92
105	1.62	1.84	0.02	1.70
106	0.79	0.00	1.53	1.57
107	0.54	0.86	0.84	0.94
108	2.17	0.23	1.15	0.70
109	2.64	0.97	0.55	0.40
110	2.49	1.38	0.16	1.09
111	2.22	0.60	0.95	0.37

Axis 1 ranked. Eigenvalue = 0.45114

Name	Score
34	0.00
1	0.02
35	0.03
43	0.05
85	0.07
37	0.08
83	0.09
80	0.09
33	0.10
79	0.11
41	0.15
42	0.18
69	0.18
104	0.19
44	0.20
39	0.21
86	0.25
38	0.28
46	0.29
89	0.31
40	0.31
63	0.34
88	0.40
45	0.45
48	0.48
81	0.49
67	0.49
47	0.50
36	0.51
2	0.51
107	0.54
72	0.54
52	0.56
73	0.58
62	0.61
53	0.67
64	0.68
103	0.68
66	0.68
32	0.76
90	0.76
51	0.77
98	0.77
82	0.79
106	0.79
29	0.80
70	0.82
91	0.83
28	0.88
65	0.89
92	0.94
54	0.97
71	0.97
87	0.98
68	0.99
101	1.01
84	1.06

3	1.07
55	1.08
50	1.08
102	1.10
27	1.12
49	1.14
31	1.15
97	1.18
100	1.23
96	1.41
30	1.54
93	1.55
105	1.62
74	1.65
99	1.91
75	2.01
56	2.11
108	2.17
111	2.22
4	2.29
94	2.31
57	2.32
58	2.37
95	2.42
15	2.46
110	2.49
76	2.57
109	2.64
59	2.68
77	2.69
78	2.72
11	2.72
10	2.72

Axis 2 ranked. Eigenvalue = 0.21174

Name	Score
106	0.00
31	0.03
32	0.12
93	0.21
108	0.23
62	0.27
42	0.30
40	0.39
41	0.50
111	0.60
44	0.64
55	0.65
74	0.66
63	0.67
75	0.69
45	0.69
77	0.70
76	0.71
38	0.71
59	0.72
11	0.73
10	0.73

78	0.73
89	0.76
81	0.77
33	0.77
94	0.81
58	0.81
30	0.84
107	0.86
88	0.89
91	0.89
36	0.92
92	0.92
66	0.96
39	0.96
57	0.97
109	0.97
28	0.97
70	0.99
104	1.02
69	1.04
97	1.06
29	1.06
47	1.06
56	1.07
98	1.09
54	1.10
90	1.11
43	1.13
46	1.14
53	1.15
37	1.16
86	1.19
85	1.23
82	1.24
27	1.24
73	1.27
83	1.29
71	1.29
72	1.30
35	1.30
80	1.31
79	1.31
52	1.33
49	1.37
110	1.38
64	1.38
3	1.39
2	1.41
48	1.42
96	1.44
15	1.45
103	1.46
1	1.47
34	1.48
100	1.48
102	1.50
84	1.52
51	1.52
95	1.55
4	1.57
67	1.61
50	1.63

99	1.63
87	1.65
101	1.70
105	1.84
65	1.89
68	2.01

Axis 3 ranked. Eigenvalue = 0.10113

Name	Score
95	0.00
105	0.02
15	0.10
110	0.16
4	0.21
1	0.34
34	0.34
87	0.36
2	0.41
79	0.45
56	0.49
35	0.50
3	0.51
99	0.52
49	0.54
109	0.55
57	0.58
83	0.59
85	0.60
80	0.61
37	0.61
53	0.62
46	0.63
43	0.67
94	0.70
58	0.71
48	0.72
91	0.72
54	0.74
52	0.76
70	0.76
27	0.76
78	0.77
10	0.77
11	0.77
59	0.79
104	0.79
76	0.79
77	0.80
39	0.80
107	0.84
88	0.84
47	0.85
36	0.86
86	0.86
75	0.89
69	0.89
73	0.95
72	0.95

111	0.95
89	0.97
67	0.98
50	0.99
103	0.99
63	0.99
33	1.01
81	1.02
71	1.02
90	1.04
74	1.04
45	1.04
98	1.04
55	1.06
28	1.07
92	1.08
38	1.11
44	1.12
108	1.15
51	1.16
29	1.18
93	1.22
30	1.23
102	1.25
66	1.26
62	1.27
41	1.27
40	1.30
68	1.38
42	1.46
31	1.46
100	1.50
32	1.50
64	1.53
106	1.53
96	1.63
97	1.64
101	1.65
84	1.80
82	1.82
65	1.91

Axis 4 ranked. Eigenvalue = 0.06520

Name	Score
78	0.00
11	0.00
10	0.00
59	0.03
77	0.05
76	0.09
58	0.32
111	0.37
75	0.38
109	0.40
94	0.48
57	0.50
71	0.51
2	0.52
34	0.53
1	0.53
74	0.61
30	0.63
79	0.63
3	0.65
73	0.66
70	0.69
72	0.69
80	0.69
91	0.69
35	0.70
108	0.70
103	0.71
84	0.71
83	0.73
90	0.74
85	0.76
29	0.79
37	0.80
48	0.80
28	0.81
86	0.85
43	0.86
36	0.87
67	0.89
27	0.90
104	0.92
46	0.92
51	0.93
65	0.93
107	0.94
39	0.95
54	0.96
47	0.97
102	0.97
52	1.03
101	1.03
66	1.03
69	1.03
81	1.04
64	1.06
93	1.06

56	1.07
92	1.08
55	1.09
110	1.09
45	1.10
53	1.11
98	1.13
100	1.13
63	1.15
87	1.15
33	1.19
68	1.19
38	1.19
15	1.21
82	1.25
88	1.25
4	1.25
89	1.29
96	1.33
44	1.36
97	1.37
95	1.38
31	1.38
62	1.38
99	1.39
50	1.40
41	1.44
40	1.45
49	1.46
32	1.50
106	1.57
42	1.63
105	1.70

Total foraminiferal raw data correspondence analysis

File: FORAMRAW.TIL
Number of samples = 90
Number of variables = 10
Square root transformation
Dissimilarity coefficient is Euclidian distance

Unconstrained Incremental Sum of Squares Cluster Analysis

Stage	Clusters merged	Increase in dispersion	Total dispersion	Within-cluster dispersion	Mean within-cluster dispersion
1	5 6	0	0	0	0
2	22 23	0.3781946	0.3781946	0.3781946	0.1890973
3	15 16	0.5	0.8781946	0.5	0.25
4	57 90	0.6010206	1.479215	0.6010206	0.3005103
5	5 7	0.6666667	2.145882	0.6666667	0.2222222
6	20 83	0.7785922	2.924474	0.7785922	0.3892961
7	14 21	1.085786	4.01026	1.085786	0.5428932
8	25 68	1.088947	5.099208	1.088947	0.5444737
9	10 69	1.128144	6.227352	1.128144	0.5640722
10	15 58	1.133381	7.360733	1.633381	0.5444603
11	41 42	1.275345	8.636078	1.275345	0.6376724
12	25 67	1.451992	10.08807	2.540939	0.8469797
13	18 24	1.533847	11.62192	1.533847	0.7669234
14	13 85	1.595869	13.21779	1.595869	0.7979345
15	57 87	1.661832	14.87962	2.262852	0.7542841
16	51 52	1.787519	16.66714	1.787519	0.8937594
17	40 56	1.801007	18.46814	1.801007	0.9005033
18	9 10	1.93897	20.40711	3.067114	1.022371
19	26 60	2.039386	22.4465	2.039386	1.019693
20	19 20	2.230182	24.67668	3.008774	1.002925
21	5 57	2.3537	27.03038	5.283219	0.8805365
22	18 59	2.985571	30.01595	4.519417	1.506472
23	88 89	3.170093	33.18604	3.170093	1.585046
24	39 55	3.566551	36.75259	3.566551	1.783275
25	80 81	3.694189	40.44678	3.694189	1.847095
26	76 79	3.716271	44.16306	3.716271	1.858136
27	43 45	3.751592	47.91465	3.751592	1.875796
28	17 86	3.972169	51.88682	3.972169	1.986084
29	11 53	4.109138	55.99595	4.109138	2.054569
30	9 71	4.117836	60.11379	7.18495	1.796237
31	33 34	4.202524	64.31631	4.202524	2.101262
32	62 64	4.783656	69.09997	4.783656	2.391828
33	13 41	4.896436	73.99641	7.76765	1.941912
34	14 15	4.982433	78.97884	7.7016	1.54032
35	17 19	5.06719	84.04603	12.04813	2.409627
36	62 65	5.655264	89.70129	10.43892	3.47964
37	35 77	5.732975	95.43427	5.732975	2.866488
38	39 73	6.465205	101.8995	10.03176	3.343919
39	27 28	6.833242	108.7327	6.833242	3.416621
40	48 62	7.544176	116.2769	17.9831	4.495774
41	14 82	7.641775	123.9187	15.34337	2.557229
42	27 29	8.250945	132.1696	15.08419	5.028062
43	31 80	8.727752	140.8974	12.42194	4.140647
44	30 66	9.019925	149.9173	9.019925	4.509963
45	50 51	9.204091	159.1214	10.99161	3.66387
46	39 40	9.69532	168.8167	21.52808	4.305617
47	11 70	9.987002	178.8037	14.09614	4.698713

48	61	63	10.02662	188.8303	10.02662	5.013309
49	12	72	10.44356	199.2739	10.44356	5.221779
50	37	38	10.62539	209.8993	10.62539	5.312695
51	74	88	10.98904	220.8883	14.15913	4.719711
52	17	25	11.02006	231.9084	25.60913	3.201141
53	76	78	11.09268	243.001	14.80895	4.936316
54	32	46	11.56382	254.5649	11.56382	5.781908
55	8	35	11.62211	266.187	17.35509	5.785029
56	2	3	12.6333	278.8203	12.6333	6.316649
57	8	36	13.89575	292.716	31.25084	7.812709
58	17	18	13.94048	306.6565	44.06903	4.006275
59	39	54	14.75674	321.4132	36.28483	6.047471
60	30	84	14.9074	336.3206	23.92732	7.975775
61	43	44	17.06018	353.3808	20.81177	6.937257
62	14	22	17.72746	371.1083	33.44903	4.181129
63	8	49	18.02977	389.138	49.2806	9.856121
64	31	76	18.18358	407.3216	45.41447	7.569078
65	26	33	18.32672	425.6483	24.56863	6.142157
66	9	11	20.50394	446.1523	41.78503	5.969291
67	26	48	25.40671	471.559	67.95844	8.494804
68	31	61	27.1927	498.7517	82.63379	10.32922
69	13	17	28.61324	527.3649	80.44992	5.363328
70	47	75	33.30485	560.6698	33.30485	16.65243
71	5	14	34.35904	595.0288	73.09129	5.220806
72	32	43	37.64647	632.6753	70.02206	14.00441
73	9	50	40.44782	673.1231	93.22446	9.322446
74	26	27	43.12531	716.2484	126.1679	11.46981
75	39	74	48.2154	764.4638	98.65936	10.96215
76	37	39	53.75301	818.2168	163.0378	14.82162
77	32	47	58.83955	877.0564	162.1665	23.16664
78	1	2	60.76384	937.8202	73.39714	24.46571
79	8	30	64.5932	1002.413	137.8011	17.22514
80	9	31	84.19811	1086.612	260.0564	14.44758
81	8	26	116.6214	1203.233	380.5905	20.03108
82	9	12	135.6982	1338.931	406.1981	20.30991
83	5	13	136.0026	1474.934	289.5438	9.984271
84	4	37	180.0394	1654.973	343.0771	28.58976
85	8	32	185.1104	1840.084	727.8673	27.9949
86	8	9	194.0434	2034.127	1328.109	28.87193
87	1	8	270.091	2304.218	1671.597	34.11422
88	4	5	479.6987	2783.917	1112.32	27.12975
89	1	4	765.6073	3549.524	3549.524	39.43915

Appendix V

Statistical analysis of foraminiferal data from four seasonal surveys at Stert

First modern transect at Stert. Foraminiferal raw data detrended correspondance analysis

Axis 1

Residual 0.247060 at iteration 0
Residual 0.000375 at iteration 1
Residual 0.000000 at iteration 2

Eigenvalue 0.64881

Length of gradient 1.995
Length of segments 0.32 0.30 0.28 0.23 0.17 0.15 0.14 0.14 0.13 0.13
Length of gradient 2.105
Length of gradient 2.278
Length of segments 0.25 0.24 0.22 0.21 0.20 0.19 0.18 0.17 0.17 0.16
0.15 0.15
Length of gradient 2.263

Axis 2

Residual 0.063174 at iteration 0
Residual 0.000071 at iteration 1

Eigenvalue 0.13594

Length of gradient 1.111
Length of segments 0.14 0.14 0.13 0.13 0.12 0.12 0.10 0.08 0.08 0.08
Length of gradient 1.190
Length of gradient 1.217
Length of segments 0.13 0.13 0.13 0.12 0.12 0.12 0.13 0.12 0.11 0.11
Length of gradient 1.201

Axis 3

Residual 0.011881 at iteration 0
Residual 0.000028 at iteration 1

Eigenvalue 0.02627

Length of gradient 0.973
Length of segments 0.11 0.11 0.11 0.11 0.11 0.11 0.10 0.08 0.07 0.07
Length of gradient 1.045
Length of gradient 1.054
Length of segments 0.11 0.10 0.10 0.10 0.11 0.11 0.12 0.11 0.10 0.10
Length of gradient 1.087

Axis 4

Residual 0.003220 at iteration 0
Residual 0.000006 at iteration 1

Eigenvalue 0.00686

Length of gradient 1.035
Length of segments 0.13 0.13 0.12 0.12 0.12 0.11 0.09 0.08 0.07 0.07
Length of gradient 1.109
Length of gradient 1.174
Length of segments 0.13 0.13 0.12 0.11 0.12 0.12 0.13 0.12 0.10 0.10
Length of gradient 1.176

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
J. macrescens	2.30	0.93	1.09	0.93
T. inflata	1.54	1.48	0.50	1.38
E. williamsoni	0.82	-0.90	1.02	0.00
Q. seminulum	-0.44	1.84	2.20	2.11
C. balkwilli	-0.37	2.34	1.40	2.10
C.involvens	-0.49	3.03	2.97	2.90
A. beccarii	-0.16	0.05	-0.39	-0.30
N. germanica	0.28	0.67	0.81	0.77
A. batavus	1.58	0.93	0.88	1.01
E. crispum	1.18	-1.28	3.30	1.36

Axis 1 ranked. Eigenvalue = 0.64881

Name	Score
C.involvens	-0.49
Q. seminulum	-0.44
C. balkwilli	-0.37
A. beccarii	-0.16
N. germanica	0.28
E. williamsoni	0.82
E. crispum	1.18
T. inflata	1.54
A. batavus	1.58
J. macrescens	2.30

Axis 2 ranked. Eigenvalue = 0.13594

Name	Score
E. crispum	-1.28
E. williamsoni	-0.90
A. beccarii	0.05
N. germanica	0.67
A. batavus	0.93
J. macrescens	0.93
T. inflata	1.48
Q. seminulum	1.84
C. balkwilli	2.34
C.involvens	3.03

Axis 3 ranked. Eigenvalue = 0.02627

Name	Score
A. beccarii	-0.39
T. inflata	0.50
N. germanica	0.81
A. batavus	0.88
E. williamsoni	1.02
J. macrescens	1.09
C. balkwilli	1.40
Q. seminulum	2.20
C.involvens	2.97
E. crispum	3.30

Axis 4 ranked. Eigenvalue = 0.00686

Name	Score
A. beccarii	-0.30
E. williamsoni	0.00
N. germanica	0.77
J. macrescens	0.93
A. batavus	1.01
E. crispum	1.36
T. inflata	1.38
C. balkwilli	2.10
Q. seminulum	2.11
C.involvens	2.90

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
3.374	0.17	0.00	0.33	0.09
3.377	0.07	0.15	0.00	0.00
3.559	0.12	0.21	0.30	0.20
3.629	0.00	0.48	0.29	0.35
3.837	0.54	0.65	0.54	0.68
3.924	0.31	1.20	1.01	1.18
3.984	0.01	0.99	0.93	0.96
4.117	0.09	0.50	0.37	0.41
4.17	0.31	0.26	0.22	0.22
4.221	0.57	0.47	0.46	0.44
4.226	0.64	0.15	0.68	0.38
4.282	1.61	0.81	0.82	0.88
4.352	1.90	0.91	0.87	0.88
4.386	1.95	0.80	0.93	0.81
4.427	2.26	0.92	1.09	0.92

Axis 1 ranked. Eigenvalue = 0.64881

Name	Score
3.629	0.00
3.984	0.01
3.377	0.07
4.117	0.09
3.559	0.12
3.374	0.17
3.924	0.31
4.17	0.31
3.837	0.54
4.221	0.57
4.226	0.64
4.282	1.61
4.352	1.90
4.386	1.95
4.427	2.26

Axis 2 ranked. Eigenvalue = 0.13594

Name	Score
3.374	0.00
3.377	0.15
4.226	0.15

3.559	0.21
4.17	0.26
4.221	0.47
3.629	0.48
4.117	0.50
3.837	0.65
4.386	0.80
4.282	0.81
4.352	0.91
4.427	0.92
3.984	0.99
3.924	1.20

Axis 3 ranked. Eigenvalue = 0.02627

Name	Score
3.377	0.00
4.17	0.22
3.629	0.29
3.559	0.30
3.374	0.33
4.117	0.37
4.221	0.46
3.837	0.54
4.226	0.68
4.282	0.82
4.352	0.87
3.984	0.93
4.386	0.93
3.924	1.01
4.427	1.09

Axis 4 ranked. Eigenvalue = 0.00686

Name	Score
3.377	0.00
3.374	0.09
3.559	0.20
4.17	0.22
3.629	0.35
4.226	0.38
4.117	0.41
4.221	0.44
3.837	0.68
4.386	0.81
4.352	0.88
4.282	0.88
4.427	0.92
3.984	0.96
3.924	1.18

First modern transect at Stert. Foraminiferal raw data cluster analysis

File: ST1MODRA.TIL
Number of samples = 15
Number of variables = 10
Square root transformation
Dissimilarity coefficient is Euclidian distance

Constrained Incremental Sum of Squares Cluster Analysis

Stage	Clusters merged	Increase in dispersion	Total dispersion	Within-cluster dispersion	Mean within-cluster dispersion
1	8 9	4.202524	4.202524	4.202524	2.101262
2	13 14	4.694119	8.896643	4.694119	2.347059
3	2 3	6.833242	15.72989	6.833242	3.416621
4	2 4	8.250945	23.98083	15.08419	5.028062
5	10 11	10.15791	34.13874	10.15791	5.078956
6	5 6	12.96565	47.10439	12.96565	6.482825
7	13 15	15.67883	62.78322	20.37295	6.790982
8	1 2	20.7619	83.54512	35.84609	8.961522
9	5 7	23.53592	107.081	36.50157	12.16719
10	5 8	26.48978	133.5708	67.19387	13.43877
11	12 13	29.29993	162.8707	49.67287	12.41822
12	5 10	33.23483	196.1056	110.5866	15.79809
13	1 5	48.55812	244.6637	194.9908	17.72644
14	1 12	286.2362	530.8999	530.8999	35.39333

Sample numbers

1	3.374
2	3.377
3	3.559
4	3.629
5	3.837
6	3.924
7	3.984
8	4.117
9	4.17
10	4.221
11	4.226
12	4.282
13	4.352
14	4.386
15	4.427

First modern transect at Stert. Foraminiferal percentage data detrended correspondance analysis

Axis 1

Residual 0.247060 at iteration 0
Residual 0.000375 at iteration 1
Residual 0.000000 at iteration 2

Eigenvalue 0.64881

Length of gradient 1.995
Length of segments 0.32 0.30 0.28 0.23 0.17 0.15 0.14 0.14 0.13 0.13
Length of gradient 2.105
Length of gradient 2.278
Length of segments 0.25 0.24 0.22 0.21 0.20 0.19 0.18 0.17 0.17 0.16
0.15 0.15
Length of gradient 2.263

Axis 2

Residual 0.063174 at iteration 0
Residual 0.000071 at iteration 1

Eigenvalue 0.13594

Length of gradient 1.111
Length of segments 0.14 0.14 0.13 0.13 0.12 0.12 0.10 0.08 0.08 0.08
Length of gradient 1.190
Length of gradient 1.217
Length of segments 0.13 0.13 0.13 0.12 0.12 0.12 0.13 0.12 0.11 0.11
Length of gradient 1.201

Axis 3

Residual 0.011881 at iteration 0
Residual 0.000028 at iteration 1

Eigenvalue 0.02627

Length of gradient 0.973
Length of segments 0.11 0.11 0.11 0.11 0.11 0.11 0.10 0.08 0.07 0.07
Length of gradient 1.045
Length of gradient 1.054
Length of segments 0.11 0.10 0.10 0.10 0.11 0.11 0.12 0.11 0.10 0.10
Length of gradient 1.087

Axis 4

Residual 0.003220 at iteration 0
Residual 0.000006 at iteration 1

Eigenvalue 0.00686

Length of gradient 1.035
Length of segments 0.13 0.13 0.12 0.12 0.12 0.11 0.09 0.08 0.07 0.07
Length of gradient 1.109
Length of gradient 1.174
Length of segments 0.13 0.13 0.12 0.11 0.12 0.12 0.13 0.12 0.10 0.10
Length of gradient 1.176

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
J. macrescens	2.30	0.93	1.09	0.93
T. inflata	1.54	1.48	0.50	1.38
E. williamsoni	0.82	-0.90	1.02	0.00
Q. seminulum	-0.44	1.84	2.20	2.11
C. balkwilli	-0.37	2.34	1.40	2.10
C.involvens	-0.49	3.03	2.97	2.90
A. beccarii	-0.16	0.05	-0.39	-0.30
N. germanica	0.28	0.67	0.81	0.77
A. batavus	1.58	0.93	0.88	1.01
E. crispum	1.18	-1.28	3.30	1.36

Axis 1 ranked. Eigenvalue = 0.64881

Name	Score
C.involvens	-0.49
Q. seminulum	-0.44
C. balkwilli	-0.37
A. beccarii	-0.16
N. germanica	0.28
E. williamsoni	0.82
E. crispum	1.18
T. inflata	1.54
A. batavus	1.58
J. macrescens	2.30

Axis 2 ranked. Eigenvalue = 0.13594

Name	Score
E. crispum	-1.28
E. williamsoni	-0.90
A. beccarii	0.05
N. germanica	0.67
A. batavus	0.93
J. macrescens	0.93
T. inflata	1.48
Q. seminulum	1.84
C. balkwilli	2.34
C.involvens	3.03

Axis 3 ranked. Eigenvalue = 0.02627

Name	Score
A. beccarii	-0.39
T. inflata	0.50
N. germanica	0.81
A. batavus	0.88
E. williamsoni	1.02
J. macrescens	1.09
C. balkwilli	1.40
Q. seminulum	2.20
C.involvens	2.97
E. crispum	3.30

Axis 4 ranked. Eigenvalue = 0.00686

Name	Score
A. beccarii	-0.30
E. williamsoni	0.00
N. germanica	0.77
J. macrescens	0.93
A. batavus	1.01
E. crispum	1.36
T. inflata	1.38
C. balkwilli	2.10
Q. seminulum	2.11
C.involvens	2.90

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
3.374	0.17	0.00	0.33	0.09
3.377	0.07	0.15	0.00	0.00
3.559	0.12	0.21	0.30	0.20
3.629	0.00	0.48	0.29	0.35
3.837	0.54	0.65	0.54	0.68
3.924	0.31	1.20	1.01	1.18
3.984	0.01	0.99	0.93	0.96
4.117	0.09	0.50	0.37	0.41
4.17	0.31	0.26	0.22	0.22
4.221	0.57	0.47	0.46	0.44
4.226	0.64	0.15	0.68	0.38
4.282	1.61	0.81	0.82	0.88
4.352	1.90	0.91	0.87	0.88
4.386	1.95	0.80	0.93	0.81
4.427	2.26	0.92	1.09	0.92

Axis 1 ranked. Eigenvalue = 0.64881

Name	Score
3.629	0.00
3.984	0.01
3.377	0.07
4.117	0.09
3.559	0.12
3.374	0.17
3.924	0.31
4.17	0.31
3.837	0.54
4.221	0.57
4.226	0.64
4.282	1.61
4.352	1.90
4.386	1.95
4.427	2.26

Axis 2 ranked. Eigenvalue = 0.13594

Name	Score
3.374	0.00
3.377	0.15

4.226	0.15
3.559	0.21
4.17	0.26
4.221	0.47
3.629	0.48
4.117	0.50
3.837	0.65
4.386	0.80
4.282	0.81
4.352	0.91
4.427	0.92
3.984	0.99
3.924	1.20

Axis 3 ranked. Eigenvalue = 0.02627

Name	Score
3.377	0.00
4.17	0.22
3.629	0.29
3.559	0.30
3.374	0.33
4.117	0.37
4.221	0.46
3.837	0.54
4.226	0.68
4.282	0.82
4.352	0.87
3.984	0.93
4.386	0.93
3.924	1.01
4.427	1.09

Axis 4 ranked. Eigenvalue = 0.00686

Name	Score
3.377	0.00
3.374	0.09
3.559	0.20
4.17	0.22
3.629	0.35
4.226	0.38
4.117	0.41
4.221	0.44
3.837	0.68
4.386	0.81
4.352	0.88
4.282	0.88
4.427	0.92
3.984	0.96
3.924	1.18

First modern transect at Stert. Foraminiferal percentage data cluster analysis

File: ST1MOD%F.TIL
Number of samples = 15
Number of variables = 10
Data converted to proportions
Square root transformation
Dissimilarity coefficient is Edwards and Cavalli-Sforza's chord distance

Constrained Incremental Sum of Squares Cluster Analysis

Stage	**Clusters merged**	**Increase in dispersion**	**Total dispersion**	**Within-cluster dispersion**	**Mean within-cluster dispersion**
1	13 14	0.01705241	0.01705241	0.01705241	0.008526203
2	2 3	0.0274745	0.04452691	0.0274745	0.01373725
3	6 7	0.04294154	0.08746845	0.04294154	0.02147077
4	8 9	0.04364405	0.1311125	0.04364405	0.02182203
5	10 11	0.04540649	0.176519	0.04540649	0.02270324
6	2 4	0.04591226	0.2224313	0.07338676	0.02446225
7	1 2	0.09950668	0.3219379	0.1728934	0.04322336
8	12 13	0.102861	0.424799	0.1199134	0.03997114
9	5 6	0.1455499	0.5703488	0.1884914	0.06283048
10	5 8	0.1258236	0.6961724	0.3579591	0.07159181
11	5 10	0.2145223	0.9106947	0.6178879	0.0882697
12	12 15	0.249904	1.160599	0.3698174	0.09245435
13	1 5	0.3165635	1.477162	1.107345	0.1006677
14	1 12	2.641729	4.118891	4.118891	0.2745927

Sample numbers

1	3.374
2	3.377
3	3.559
4	3.629
5	3.837
6	3.924
7	3.984
8	4.117
9	4.17
10	4.221
11	4.226
12	4.282
13	4.352
14	4.386
15	4.427

Second modern transect at Stert. Foraminiferal raw data detrended correspondance analysis

Axis 1

Residual 0.138996 at iteration 0
Residual 0.001842 at iteration 1
Residual 0.000004 at iteration 2

Eigenvalue 0.48513

Length of gradient 1.967
Length of segments 0.30 0.28 0.25 0.21 0.18 0.16 0.15 0.15 0.14 0.14
Length of gradient 2.173
Length of gradient 2.567
Length of segments 0.20 0.22 0.23 0.24 0.23 0.22 0.20 0.18 0.17 0.17
0.17 0.17 0.17
Length of gradient 2.637

Axis 2

Residual 0.043169 at iteration 0
Residual 0.000974 at iteration 1
Residual 0.000011 at iteration 2

Eigenvalue 0.10373

Length of gradient 1.312
Length of segments 0.17 0.17 0.15 0.13 0.13 0.12 0.12 0.11 0.10 0.10
Length of gradient 1.332
Length of gradient 1.294
Length of segments 0.14 0.13 0.13 0.13 0.13 0.13 0.13 0.13 0.13 0.13
Length of gradient 1.282

Axis 3

Residual 0.016943 at iteration 0
Residual 0.000008 at iteration 1

Eigenvalue 0.03810

Length of gradient 0.834
Length of segments 0.08 0.08 0.08 0.08 0.08 0.08 0.09 0.09 0.08 0.08
Length of gradient 0.830
Length of gradient 0.824
Length of segments 0.08 0.08 0.08 0.08 0.08 0.08 0.09 0.09 0.08 0.08
Length of gradient 0.822

Axis 4

Residual 0.001722 at iteration 0
Residual 0.000434 at iteration 1
Residual 0.000001 at iteration 2

Eigenvalue 0.00743

Length of gradient 1.068
Length of segments 0.10 0.10 0.10 0.10 0.11 0.11 0.11 0.11 0.11 0.11
Length of gradient 1.069
Length of gradient 1.070
Length of segments 0.10 0.10 0.10 0.11 0.11 0.11 0.11 0.11 0.11 0.11

Length of gradient 1.071

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
J. macrescens	2.67	1.21	0.78	1.03
T. inflata	-0.90	-0.98	3.18	3.69
E. williamsoni	1.55	-0.08	-1.18	-0.90
Q. seminulum	0.35	2.36	-0.07	1.45
C. balkwilli	1.57	0.99	0.55	0.74
C.involvens	-0.85	0.99	-0.28	-0.10
A. beccarii	0.61	0.88	1.12	1.14
N. germanica	0.89	-0.91	0.51	0.04
A. batavus	-0.75	1.34	0.72	1.63
E. crispum	1.57	0.99	0.55	0.74

Axis 1 ranked. Eigenvalue = 0.48513

Name	Score
T. inflata	-0.90
C.involvens	-0.85
A. batavus	-0.75
Q. seminulum	0.35
A. beccarii	0.61
N. germanica	0.89
E. williamsoni	1.55
E. crispum	1.57
C. balkwilli	1.57
J. macrescens	2.67

Axis 2 ranked. Eigenvalue = 0.10373

Name	Score
T. inflata	-0.98
N. germanica	-0.91
E. williamsoni	-0.08
A. beccarii	0.88
C. balkwilli	0.99
E. crispum	0.99
C.involvens	0.99
J. macrescens	1.21
A. batavus	1.34
Q. seminulum	2.36

Axis 3 ranked. Eigenvalue = 0.03810

Name	Score
E. williamsoni	-1.18
C.involvens	-0.28
Q. seminulum	-0.07
N. germanica	0.51
E. crispum	0.55
C. balkwilli	0.55
A. batavus	0.72
J. macrescens	0.78
A. beccarii	1.12
T. inflata	3.18

Axis 4 ranked. Eigenvalue = 0.00743

Name	Score
E. williamsoni	-0.90
C.involvens	-0.10
N. germanica	0.04
C. balkwilli	0.74
E. crispum	0.74
J. macrescens	1.03
A. beccarii	1.14
Q. seminulum	1.45
A. batavus	1.63
T. inflata	3.69

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
3.374	1.07	0.00	0.00	0.00
3.377	0.89	0.19	0.46	0.41
3.559	0.46	0.76	0.21	0.45
3.629	0.16	1.28	0.07	0.64
3.837	0.81	0.60	0.24	0.44
3.924	0.34	0.79	0.82	1.06
3.984	0.00	0.70	0.74	0.98
4.117	0.66	0.29	0.80	0.70
4.17	1.19	0.65	0.79	0.84
4.221	1.02	1.21	0.62	1.07
4.226	0.74	0.99	0.61	0.93
4.282	0.79	1.00	0.64	0.98
4.352	1.75	0.84	0.35	0.62
4.386	2.10	0.93	0.57	0.79
4.427	2.54	1.15	0.72	0.96
4.968	2.64	1.18	0.73	0.98

Axis 1 ranked. Eigenvalue = 0.48513

Name	Score
3.984	0.00
3.629	0.16
3.924	0.34
3.559	0.46
4.117	0.66
4.226	0.74
4.282	0.79
3.837	0.81
3.377	0.89
4.221	1.02
3.374	1.07
4.17	1.19
4.352	1.75
4.386	2.10
4.427	2.54
4.968	2.64

Axis 2 ranked. Eigenvalue = 0.10373

Name	Score
3.374	0.00
3.377	0.19
4.117	0.29
3.837	0.60
4.17	0.65
3.984	0.70
3.559	0.76
3.924	0.79
4.352	0.84
4.386	0.93
4.226	0.99
4.282	1.00
4.427	1.15
4.968	1.18
4.221	1.21
3.629	1.28

Axis 3 ranked. Eigenvalue = 0.03810

Name	Score
3.374	0.00
3.629	0.07
3.559	0.21
3.837	0.24
4.352	0.35
3.377	0.46
4.386	0.57
4.226	0.61
4.221	0.62
4.282	0.64
4.427	0.72
4.968	0.73
3.984	0.74
4.17	0.79
4.117	0.80
3.924	0.82

Axis 4 ranked. Eigenvalue = 0.00743

Name	Score
3.374	0.00
3.377	0.41
3.837	0.44
3.559	0.45
4.352	0.62
3.629	0.64
4.117	0.70
4.386	0.79
4.17	0.84
4.226	0.93
4.427	0.96
3.984	0.98
4.282	0.98

4.968	0.98
3.924	1.06
4.221	1.07

Second modern transect at Stert. Raw foraminiferal data cluster analysis

File: ST2MDRAF.TIL
Number of samples = 16
Number of variables = 10
Square root transformation
Dissimilarity coefficient is Euclidian distance

Constrained Incremental Sum of Squares Cluster Analysis

Stage	Clusters merged		Increase in dispersion	Total dispersion	Within-cluster dispersion	Mean within-cluster dispersion
1	1	2	1.275345	1.275345	1.275345	0.6376724
2	11	12	1.787519	3.062864	1.787519	0.8937594
3	15	16	4.653996	7.71686	4.653996	2.326998
4	13	14	5.469594	13.18645	5.469594	2.734797
5	3	4	8.438207	21.62466	8.438207	4.219104
6	10	11	9.204091	30.82875	10.99161	3.66387
7	3	5	12.37356	43.20231	20.81177	6.937257
8	13	15	17.9881	61.19041	28.11169	7.027922
9	9	10	18.59891	79.78933	29.59052	7.397631
10	3	6	22.91491	102.7042	43.72668	10.93167
11	8	9	33.15747	135.8617	62.74799	12.5496
12	3	7	53.1449	189.0066	96.87158	19.37432
13	3	8	86.99246	275.9991	246.612	24.6612
14	1	3	88.22245	364.2215	336.1098	28.00915
15	1	13	200.6147	564.8362	564.8362	35.30226

Sample numbers

1	3.374
2	3.377
3	3.559
4	3.629
5	3.837
6	3.924
7	3.984
8	4.117
9	4.17
10	4.221
11	4.226
12	4.282
13	4.352
14	4.386
15	4.427
16	4.968

Second modern transect at Stert. Foraminiferal percentage data detrended correspondance analysis

Axis 1

Residual 0.200024 at iteration 0
Residual 0.001597 at iteration 1
Residual 0.000002 at iteration 2

Eigenvalue 0.65563

Length of gradient 1.882
Length of segments 0.30 0.28 0.24 0.19 0.16 0.15 0.14 0.14 0.14 0.14
Length of gradient 2.014
Length of gradient 2.490
Length of segments 0.21 0.22 0.24 0.24 0.23 0.21 0.18 0.16 0.16 0.16
0.16 0.16 0.16
Length of gradient 2.564

Axis 2

Residual 0.045929 at iteration 0
Residual 0.001239 at iteration 1
Residual 0.000007 at iteration 2

Eigenvalue 0.12914

Length of gradient 1.456
Length of segments 0.18 0.17 0.16 0.15 0.15 0.14 0.14 0.13 0.12 0.12
Length of gradient 1.455
Length of gradient 1.430
Length of segments 0.15 0.15 0.14 0.14 0.14 0.14 0.14 0.14 0.14 0.14
Length of gradient 1.422

Axis 3

Residual 0.013032 at iteration 0
Residual 0.000470 at iteration 1
Residual 0.000007 at iteration 2

Eigenvalue 0.03090

Length of gradient 1.210
Length of segments 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.13
Length of gradient 1.206
Length of gradient 1.199
Length of segments 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.11 0.12 0.12
Length of gradient 1.196

Axis 4

Residual 0.004219 at iteration 0
Residual 0.000082 at iteration 1

Eigenvalue 0.00979

Length of gradient 0.795
Length of segments 0.09 0.09 0.09 0.08 0.08 0.07 0.07 0.07 0.07 0.07
Length of gradient 0.783
Length of gradient 0.749
Length of segments 0.08 0.08 0.08 0.07 0.07 0.07 0.07 0.08 0.07 0.07

Length of gradient 0.753

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
J. macrescens	2.56	1.12	0.80	0.49
T. inflata	-0.79	-0.14	4.45	-1.78
E. williamsoni	1.43	-0.34	0.56	1.70
Q. seminulum	0.52	2.43	-1.07	0.22
C. balkwilli	1.89	0.99	0.78	0.54
C.involvens	-0.81	1.29	-0.02	1.61
A. beccarii	0.56	1.03	1.07	-0.39
N. germanica	0.43	-0.69	1.60	0.64
A. batavus	-0.85	1.69	0.73	0.46
E. crispum	1.89	0.99	0.78	0.54

Axis 1 ranked. Eigenvalue = 0.65563

Name	Score
A. batavus	-0.85
C.involvens	-0.81
T. inflata	-0.79
N. germanica	0.43
Q. seminulum	0.52
A. beccarii	0.56
E. williamsoni	1.43
E. crispum	1.89
C. balkwilli	1.89
J. macrescens	2.56

Axis 2 ranked. Eigenvalue = 0.12914

Name	Score
N. germanica	-0.69
E. williamsoni	-0.34
T. inflata	-0.14
C. balkwilli	0.99
E. crispum	0.99
A. beccarii	1.03
J. macrescens	1.12
C.involvens	1.29
A. batavus	1.69
Q. seminulum	2.43

Axis 3 ranked. Eigenvalue = 0.03090

Name	Score
Q. seminulum	-1.07
C.involvens	-0.02
E. williamsoni	0.56
A. batavus	0.73
C. balkwilli	0.78
E. crispum	0.78
J. macrescens	0.80
A. beccarii	1.07
N. germanica	1.60
T. inflata	4.45

Axis 4 ranked. Eigenvalue = 0.00979

Name	Score
T. inflata	-1.78
A. beccarii	-0.39
Q. seminulum	0.22
A. batavus	0.46
J. macrescens	0.49
E. crispum	0.54
C. balkwilli	0.54
N. germanica	0.64
C.involvens	1.61
E. williamsoni	1.70

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
3.374	0.88	0.00	1.00	0.75
3.377	0.71	0.27	1.11	0.33
3.559	0.40	0.87	0.53	0.61
3.629	0.19	1.42	0.00	0.68
3.837	0.72	0.66	0.70	0.51
3.924	0.30	0.99	0.94	0.00
3.984	0.00	0.98	1.00	0.33
4.117	0.49	0.46	1.20	0.07
4.17	1.06	0.73	1.03	0.12
4.221	0.99	1.28	0.45	0.09
4.226	0.69	1.09	0.61	0.06
4.282	0.74	1.10	0.60	0.03
4.352	1.66	0.79	0.70	0.56
4.386	1.99	0.88	0.81	0.50
4.427	2.44	1.06	0.80	0.50
4.968	2.53	1.09	0.79	0.52
5.415	2.56	1.12	0.80	0.49

Axis 1 ranked. Eigenvalue = 0.65563

Name	Score
3.984	0.00
3.629	0.19
3.924	0.30
3.559	0.40
4.117	0.49
4.226	0.69
3.377	0.71
3.837	0.72
4.282	0.74
3.374	0.88
4.221	0.99
4.17	1.06
4.352	1.66
4.386	1.99
4.427	2.44
4.968	2.53
5.415	2.56

Axis 2 ranked. Eigenvalue = 0.12914

Name	Score
3.374	0.00
3.377	0.27
4.117	0.46
3.837	0.66
4.17	0.73
4.352	0.79
3.559	0.87
4.386	0.88
3.984	0.98
3.924	0.99
4.427	1.06
4.226	1.09
4.968	1.09
4.282	1.10
5.415	1.12
4.221	1.28
3.629	1.42

Axis 3 ranked. Eigenvalue = 0.03090

Name	Score
3.629	0.00
4.221	0.45
3.559	0.53
4.282	0.60
4.226	0.61
3.837	0.70
4.352	0.70
4.968	0.79
5.415	0.80
4.427	0.80
4.386	0.81
3.924	0.94
3.374	1.00
3.984	1.00
4.17	1.03
3.377	1.11
4.117	1.20

Axis 4 ranked. Eigenvalue = 0.00979

Name	Score
3.924	0.00
4.282	0.03
4.226	0.06
4.117	0.07
4.221	0.09
4.17	0.12
3.984	0.33
3.377	0.33
5.415	0.49
4.427	0.50
4.386	0.50
3.837	0.51

4.968	0.52
4.352	0.56
3.559	0.61
3.629	0.68
3.374	0.75

Second modern transect at Stert. Foraminiferal percentage data cluster analysis

File: ST2%MDFO.TIL
Number of samples = 17
Number of variables = 10
Data converted to proportions
Square root transformation
Dissimilarity coefficient is Edwards and Cavalli-Sforza's chord distance

Constrained Incremental Sum of Squares Cluster Analysis

Stage	Clusters merged		Increase in dispersion	Total dispersion	Within-cluster dispersion	Mean within-cluster dispersion
1	16	17	0.01324562	0.01324562	0.01324562	0.006622808
2	11	12	0.01469377	0.02793939	0.01469377	0.007346886
3	13	14	0.02802994	0.05596933	0.02802994	0.01401497
4	1	2	0.02877656	0.08474589	0.02877656	0.01438828
5	15	16	0.03516739	0.1199133	0.04841301	0.01613767
6	10	11	0.04850484	0.1684181	0.06319862	0.02106621
7	3	4	0.06129729	0.2297154	0.06129729	0.03064865
8	3	5	0.08588043	0.3155958	0.1471777	0.04905924
9	6	7	0.0937329	0.4093288	0.0937329	0.04686645
10	9	10	0.1324985	0.5418273	0.1956972	0.04892429
11	3	6	0.2244696	0.7662969	0.4653803	0.09307605
12	8	9	0.3008864	1.067183	0.4965836	0.09931671
13	13	15	0.4193064	1.48649	0.4957494	0.09914987
14	3	8	0.5127753	1.999265	1.474739	0.1474739
15	1	3	0.6424064	2.641671	2.145922	0.1788268
16	1	13	3.001925	5.643597	5.643597	0.3319763

Sample numbers

1	3.374
2	3.377
3	3.559
4	3.629
5	3.837
6	3.924
7	3.984
8	4.117
9	4.17
10	4.221
11	4.226
12	4.282
13	4.352
14	4.386
15	4.427
16	4.968
17	5.415

Third modern transect at Stert. Foraminiferal raw count detrended correspondance analysis

Axis 1

Residual 0.166612 at iteration 0
Residual 0.003813 at iteration 1
Residual 0.000025 at iteration 2

Eigenvalue 0.55433

Length of gradient 2.360
Length of segments 0.28 0.25 0.21 0.18 0.16 0.15 0.15 0.15 0.17 0.20 0.22 0.23
Length of gradient 2.418
Length of gradient 2.484
Length of segments 0.25 0.23 0.20 0.17 0.16 0.15 0.15 0.15 0.16 0.18 0.21 0.23 0.24
Length of gradient 2.604

Axis 2

Residual 0.111109 at iteration 0
Residual 0.000450 at iteration 1
Residual 0.000002 at iteration 2

Eigenvalue 0.27532

Length of gradient 1.815
Length of segments 0.14 0.14 0.14 0.16 0.18 0.20 0.21 0.22 0.21 0.21
Length of gradient 1.866
Length of gradient 1.888
Length of segments 0.16 0.16 0.18 0.20 0.21 0.21 0.20 0.19 0.19 0.18
Length of gradient 1.890

Axis 3

Residual 0.019899 at iteration 0
Residual 0.000078 at iteration 1

Eigenvalue 0.05869

Length of gradient 1.227
Length of segments 0.14 0.14 0.13 0.13 0.13 0.13 0.12 0.11 0.10 0.10
Length of gradient 1.273
Length of gradient 1.292
Length of segments 0.13 0.13 0.13 0.13 0.13 0.14 0.14 0.13 0.12 0.12
Length of gradient 1.285

Axis 4

Residual 0.006222 at iteration 0
Residual 0.000722 at iteration 1
Residual 0.000354 at iteration 2
Residual 0.000001 at iteration 3

Eigenvalue 0.02147

Length of gradient 0.673
Length of segments 0.07 0.08 0.08 0.08 0.08 0.08 0.08 0.05 0.03 0.02
Length of gradient 1.523
Length of gradient 1.576
Length of segments 0.14 0.15 0.16 0.17 0.18 0.17 0.17 0.16 0.15 0.13
Length of gradient 1.577

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
J. macrescens	2.58	1.02	0.08	1.51
T. inflata	2.62	1.05	2.18	0.45
E. williamsoni	1.15	0.26	-0.78	0.21
Q. seminulum	-0.13	-0.48	1.12	0.05
C. balkwilli	1.09	1.08	0.99	1.22
C.involvens	-1.15	-0.64	-0.03	-1.50
A. beccarii	0.14	2.04	0.62	1.70
N. germanica	0.31	1.22	1.96	0.08
A. batavus	1.09	1.08	0.99	1.22
E. crispum	-1.63	4.96	1.82	5.79

Axis 1 ranked. Eigenvalue = 0.55433

Name	Score
E. crispum	-1.63
C.involvens	-1.15
Q. seminulum	-0.13
A. beccarii	0.14
N. germanica	0.31
C. balkwilli	1.09
A. batavus	1.09
E. williamsoni	1.15
J. macrescens	2.58
T. inflata	2.62

Axis 2 ranked. Eigenvalue = 0.27532

Name	Score
C.involvens	-0.64
Q. seminulum	-0.48
E. williamsoni	0.26
J. macrescens	1.02
T. inflata	1.05
C. balkwilli	1.08
A. batavus	1.08
N. germanica	1.22
A. beccarii	2.04
E. crispum	4.96

Axis 3 ranked. Eigenvalue = 0.05869

Name	Score
E. williamsoni	-0.78
C.involvens	-0.03
J. macrescens	0.08
A. beccarii	0.62
C. balkwilli	0.99
A. batavus	0.99
Q. seminulum	1.12
E. crispum	1.82
N. germanica	1.96
T. inflata	2.18

Axis 4 ranked. Eigenvalue = 0.02147

Name	Score
C.involvens	-1.50
Q. seminulum	0.05
N. germanica	0.08
E. williamsoni	0.21
T. inflata	0.45
C. balkwilli	1.22
A. batavus	1.22
J. macrescens	1.51
A. beccarii	1.70
E. crispum	5.79

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
3.374	0.23	1.89	0.51	1.58
3.377	0.08	1.89	0.83	1.57
3.559	0.42	1.27	0.48	0.94
3.629	0.00	0.41	0.57	0.00
3.837	0.17	1.82	0.73	1.41
3.924	0.04	0.00	0.77	0.22
3.984	0.17	1.84	0.85	1.39
4.117	0.19	1.50	1.00	1.09
4.17	0.99	1.30	1.19	1.01
4.221	0.53	1.53	1.21	0.89
4.226	0.42	1.50	1.19	0.82
4.282	0.53	1.15	0.70	0.99
4.352	0.84	1.45	0.21	1.34
4.386	0.78	1.01	0.93	0.73
4.427	1.44	0.82	0.00	0.79
4.968	2.24	1.02	0.26	1.28
5.415	2.60	1.04	1.28	0.91

Axis 1 ranked. Eigenvalue = 0.55433

Name	Score
3.629	0.00
3.924	0.04
3.377	0.08
3.837	0.17
3.984	0.17

4.117	0.19
3.374	0.23
3.559	0.42
4.226	0.42
4.282	0.53
4.221	0.53
4.386	0.78
4.352	0.84
4.17	0.99
4.427	1.44
4.968	2.24
5.415	2.60

Axis 2 ranked. Eigenvalue = 0.27532

Name	Score
3.924	0.00
3.629	0.41
4.427	0.82
4.386	1.01
4.968	1.02
5.415	1.04
4.282	1.15
3.559	1.27
4.17	1.30
4.352	1.45
4.226	1.50
4.117	1.50
4.221	1.53
3.837	1.82
3.984	1.84
3.377	1.89
3.374	1.89

Axis 3 ranked. Eigenvalue = 0.05869

Name	Score
4.427	0.00
4.352	0.21
4.968	0.26
3.559	0.48
3.374	0.51
3.629	0.57
4.282	0.70
3.837	0.73
3.924	0.77
3.377	0.83
3.984	0.85
4.386	0.93
4.117	1.00
4.17	1.19
4.226	1.19
4.221	1.21
5.415	1.28

Axis 4 ranked. Eigenvalue = 0.02147

Name	Score
3.629	0.00

3.924	0.22
4.386	0.73
4.427	0.79
4.226	0.82
4.221	0.89
5.415	0.91
3.559	0.94
4.282	0.99
4.17	1.01
4.117	1.09
4.968	1.28
4.352	1.34
3.984	1.39
3.837	1.41
3.377	1.57
3.374	1.58

Third modern transect at Stert. Foraminiferal raw data cluster analysis

File: ST3RAMFO.TIL
Number of samples = 17
Number of variables = 10
Square root transformation
Dissimilarity coefficient is Euclidian distance

Constrained Incremental Sum of Squares Cluster Analysis

Stage	Clusters merged	Increase in dispersion	Total dispersion	Within-cluster dispersion	Mean within-cluster dispersion
1	10 11	1.099559	1.099559	1.099559	0.5497797
2	1 2	4.751923	5.851483	4.751923	2.375962
3	7 8	5.699336	11.55082	5.699336	2.849668
4	12 13	10.88355	22.43437	10.88355	5.441776
5	12 14	9.094605	31.52898	19.97816	6.659386
6	16 17	12.52787	44.05684	12.52787	6.263933
7	3 4	16.93327	60.99011	16.93327	8.466633
8	3 5	15.73128	76.72139	32.66455	10.88818
9	10 12	20.61153	97.33292	41.68925	8.33785
10	3 6	24.44912	121.782	57.11367	14.27842
11	3 7	30.90588	152.6879	93.71888	15.61981
12	1 3	37.79221	190.4801	136.263	17.03288
13	9 10	44.95249	235.4326	86.64173	14.44029
14	1 9	30.59042	266.023	253.4952	18.1068
15	15 16	69.10469	335.1277	81.63256	27.21085
16	1 15	135.5572	470.6849	470.6849	27.68735

Sample numbers

1	3.374
2	3.377
3	3.559
4	3.629
5	3.837
6	3.924
7	3.984
8	4.117
9	4.17
10	4.221
11	4.226
12	4.282
13	4.352
14	4.386
15	4.427
16	4.968
17	5.415

Third modern transect at Stert. Foraminiferal percentage detrended correspondance analysis

Axis 1

Residual 0.166612 at iteration 0
Residual 0.003813 at iteration 1
Residual 0.000025 at iteration 2

Eigenvalue 0.55433

Length of gradient 2.360
Length of segments 0.28 0.25 0.21 0.18 0.16 0.15 0.15 0.15 0.17 0.20 0.22 0.23
Length of gradient 2.418
Length of gradient 2.484
Length of segments 0.25 0.23 0.20 0.17 0.16 0.15 0.15 0.15 0.16 0.18 0.21 0.23 0.24
Length of gradient 2.604

Axis 2

Residual 0.111109 at iteration 0
Residual 0.000450 at iteration 1
Residual 0.000002 at iteration 2

Eigenvalue 0.27532

Length of gradient 1.815
Length of segments 0.14 0.14 0.14 0.16 0.18 0.20 0.21 0.22 0.21 0.21
Length of gradient 1.866
Length of gradient 1.888
Length of segments 0.16 0.16 0.18 0.20 0.21 0.21 0.20 0.19 0.19 0.18
Length of gradient 1.890

Axis 3

Residual 0.019899 at iteration 0
Residual 0.000078 at iteration 1

Eigenvalue 0.05869

Length of gradient 1.227
Length of segments 0.14 0.14 0.13 0.13 0.13 0.13 0.12 0.11 0.10 0.10
Length of gradient 1.273
Length of gradient 1.292
Length of segments 0.13 0.13 0.13 0.13 0.13 0.14 0.14 0.13 0.12 0.12
Length of gradient 1.285

Axis 4

Residual 0.006222 at iteration 0
Residual 0.000722 at iteration 1
Residual 0.000354 at iteration 2
Residual 0.000001 at iteration 3

Eigenvalue 0.02147

Length of gradient 0.673
Length of segments 0.07 0.08 0.08 0.08 0.08 0.08 0.08 0.05 0.03 0.02
Length of gradient 1.523

Length of gradient 1.576
Length of segments 0.14 0.15 0.16 0.17 0.18 0.17 0.17 0.16 0.15 0.13
Length of gradient 1.577

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
J. macrescens	2.58	1.02	0.08	1.51
T. inflata	2.62	1.05	2.18	0.45
E. williamsoni	1.15	0.26	-0.78	0.21
Q. seminulum	-0.13	-0.48	1.12	0.05
C. balkwilli	1.09	1.08	0.99	1.22
C.involvens	-1.15	-0.64	-0.03	-1.50
A. beccarii	0.14	2.04	0.62	1.70
N. germanica	0.31	1.22	1.96	0.08
A. batavus	1.09	1.08	0.99	1.22
E. crispum	-1.63	4.96	1.82	5.79

Axis 1 ranked. Eigenvalue = 0.55433

Name	Score
E. crispum	-1.63
C.involvens	-1.15
Q. seminulum	-0.13
A. beccarii	0.14
N. germanica	0.31
C. balkwilli	1.09
A. batavus	1.09
E. williamsoni	1.15
J. macrescens	2.58
T. inflata	2.62

Axis 2 ranked. Eigenvalue = 0.27532

Name	Score
C.involvens	-0.64
Q. seminulum	-0.48
E. williamsoni	0.26
J. macrescens	1.02
T. inflata	1.05
C. balkwilli	1.08
A. batavus	1.08
N. germanica	1.22
A. beccarii	2.04
E. crispum	4.96

Axis 3 ranked. Eigenvalue = 0.05869

Name	Score
E. williamsoni	-0.78
C.involvens	-0.03
J. macrescens	0.08
A. beccarii	0.62
C. balkwilli	0.99
A. batavus	0.99
Q. seminulum	1.12
E. crispum	1.82
N. germanica	1.96

T. inflata	2.18

Axis 4 ranked. Eigenvalue = 0.02147

Name	Score
C.involvens	-1.50
Q. seminulum	0.05
N. germanica	0.08
E. williamsoni	0.21
T. inflata	0.45
C. balkwilli	1.22
A. batavus	1.22
J. macrescens	1.51
A. beccarii	1.70
E. crispum	5.79

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
3.374	0.23	1.89	0.51	1.58
3.377	0.08	1.89	0.83	1.57
3.559	0.42	1.27	0.48	0.94
3.629	0.00	0.41	0.57	0.00
3.837	0.17	1.82	0.73	1.41
3.924	0.04	0.00	0.77	0.22
3.984	0.17	1.84	0.85	1.39
4.117	0.19	1.50	1.00	1.09
4.17	0.99	1.30	1.19	1.01
4.221	0.53	1.53	1.21	0.89
4.226	0.42	1.50	1.19	0.82
4.282	0.53	1.15	0.70	0.99
4.352	0.84	1.45	0.21	1.34
4.386	0.78	1.01	0.93	0.73
4.427	1.44	0.82	0.00	0.79
4.968	2.24	1.02	0.26	1.28
5.415	2.60	1.04	1.28	0.91

Axis 1 ranked. Eigenvalue = 0.55433

Name	Score
3.629	0.00
3.924	0.04
3.377	0.08
3.837	0.17
3.984	0.17
4.117	0.19
3.374	0.23
3.559	0.42
4.226	0.42
4.282	0.53
4.221	0.53
4.386	0.78
4.352	0.84
4.17	0.99
4.427	1.44
4.968	2.24
5.415	2.60

Axis 2 ranked. Eigenvalue =   0.27532

Name	Score
3.924	0.00
3.629	0.41
4.427	0.82
4.386	1.01
4.968	1.02
5.415	1.04
4.282	1.15
3.559	1.27
4.17	1.30
4.352	1.45
4.226	1.50
4.117	1.50
4.221	1.53
3.837	1.82
3.984	1.84
3.377	1.89
3.374	1.89

Axis 3 ranked. Eigenvalue =   0.05869

Name	Score
4.427	0.00
4.352	0.21
4.968	0.26
3.559	0.48
3.374	0.51
3.629	0.57
4.282	0.70
3.837	0.73
3.924	0.77
3.377	0.83
3.984	0.85
4.386	0.93
4.117	1.00
4.17	1.19
4.226	1.19
4.221	1.21
5.415	1.28

Axis 4 ranked. Eigenvalue =   0.02147

Name	Score
3.629	0.00
3.924	0.22
4.386	0.73
4.427	0.79
4.226	0.82
4.221	0.89
5.415	0.91
3.559	0.94
4.282	0.99
4.17	1.01
4.117	1.09
4.968	1.28
4.352	1.34
3.984	1.39

3.837	1.41
3.377	1.57
3.374	1.58

Third modern transect at Stert. Foraminiferal percentage data cluster analysis

File: ST3%MDFO.TIL
Number of samples = 17
Number of variables = 10
Data converted to proportions
Square root transformation
Dissimilarity coefficient is Edwards and Cavalli-Sforza's chord distance

Constrained Incremental Sum of Squares Cluster Analysis

Stage	Clusters merged	Increase in dispersion	Total dispersion	Within-cluster dispersion	Mean within-cluster dispersion
1	10 11	0.01612113	0.01612113	0.01612113	0.008060564
2	7 8	0.04006912	0.05619024	0.04006912	0.02003456
3	1 2	0.1436512	0.1998414	0.1436512	0.07182558
4	3 4	0.1521048	0.3519462	0.1521048	0.07605239
5	15 16	0.1678045	0.5197507	0.1678045	0.08390227
6	12 13	0.1909909	0.7107417	0.1909909	0.09549547
7	12 14	0.1776721	0.8884137	0.368663	0.1228877
8	3 5	0.1993659	1.08778	0.3514707	0.1171569
9	7 9	0.2667376	1.354517	0.3068067	0.1022689
10	7 10	0.2335488	1.588066	0.5564767	0.1112953
11	1 3	0.2977828	1.885849	0.7929046	0.1585809
12	12 15	0.4124971	2.298346	0.9489647	0.1897929
13	1 6	0.4628358	2.761182	1.25574	0.2092901
14	1 7	0.4410222	3.202204	2.253239	0.2048399
15	12 17	0.7561568	3.958361	1.705122	0.2841869
16	1 12	1.621243	5.579604	5.579604	0.328212

Sample numbers

1	3.374
2	3.377
3	3.559
4	3.629
5	3.837
6	3.924
7	3.984
8	4.117
9	4.17
10	4.221
11	4.226
12	4.282
13	4.352
14	4.386
15	4.427
16	4.968
17	5.415

Forth modern transect at Stert. Foraminiferal raw data detrended correspondance analysis

Axis 1

Residual 0.141373 at iteration 0
Residual 0.004939 at iteration 1
Residual 0.000077 at iteration 2

Eigenvalue 0.35547

Length of gradient 2.320
Length of segments 0.25 0.23 0.21 0.20 0.20 0.19 0.17 0.15 0.14 0.15 0.18 0.24
Length of gradient 2.393
Length of gradient 2.424
Length of segments 0.23 0.21 0.19 0.18 0.18 0.19 0.18 0.17 0.14 0.14 0.15 0.19 0.27
Length of gradient 2.441

Axis 2

Residual 0.020107 at iteration 0
Residual 0.000082 at iteration 1

Eigenvalue 0.09397

Length of gradient 1.918
Length of segments 0.20 0.19 0.18 0.18 0.17 0.17 0.17 0.18 0.21 0.25
Length of gradient 1.874
Length of gradient 1.863
Length of segments 0.21 0.19 0.18 0.18 0.18 0.18 0.18 0.18 0.19 0.20
Length of gradient 1.858

Axis 3

Residual 0.009500 at iteration 0
Residual 0.000065 at iteration 1

Eigenvalue 0.02575

Length of gradient 1.522
Length of segments 0.17 0.17 0.17 0.16 0.16 0.15 0.15 0.14 0.13 0.12
Length of gradient 1.538
Length of gradient 1.535
Length of segments 0.16 0.16 0.16 0.16 0.15 0.15 0.15 0.16 0.15 0.14
Length of gradient 1.534

Axis 4

Residual 0.001590 at iteration 0
Residual 0.000023 at iteration 1

Eigenvalue 0.00699

Length of gradient 1.364
Length of segments 0.17 0.16 0.15 0.15 0.14 0.13 0.12 0.11 0.11 0.12
Length of gradient 1.374
Length of gradient 1.378

Length of segments	0.14	0.15	0.15	0.15	0.15	0.14	0.13	0.13	0.12	0.12
Length of gradient	1.374									

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
J. macrescens	2.41	1.49	1.79	0.10
T. inflata	2.47	-0.02	-0.31	1.09
E. williamsoni	0.68	2.42	-0.69	1.99
Q. seminulum	1.29	-0.15	1.50	0.14
C. balkwilli	1.40	0.73	0.74	0.81
C.involvens	1.42	0.89	0.60	0.20
A. beccarii	0.01	-0.31	1.14	-0.51
N. germanica	-0.42	1.10	0.50	1.29
A. batavus	1.40	0.73	0.74	0.81
E. crispum	1.40	0.73	0.74	0.81

Axis 1 ranked. Eigenvalue = 0.35547

Name	Score
N. germanica	-0.42
A. beccarii	0.01
E. williamsoni	0.68
Q. seminulum	1.29
C. balkwilli	1.40
A. batavus	1.40
E. crispum	1.40
C.involvens	1.42
J. macrescens	2.41
T. inflata	2.47

Axis 2 ranked. Eigenvalue = 0.09397

Name	Score
A. beccarii	-0.31
Q. seminulum	-0.15
T. inflata	-0.02
E. crispum	0.73
C. balkwilli	0.73
A. batavus	0.73
C.involvens	0.89
N. germanica	1.10
J. macrescens	1.49
E. williamsoni	2.42

Axis 3 ranked. Eigenvalue = 0.02575

Name	Score
E. williamsoni	-0.69
T. inflata	-0.31
N. germanica	0.50
C.involvens	0.60
C. balkwilli	0.74
A. batavus	0.74
E. crispum	0.74
A. beccarii	1.14
Q. seminulum	1.50

J. macrescens	1.79

Axis 4 ranked. Eigenvalue = 0.00699

Name	Score
A. beccarii	-0.51
J. macrescens	0.10
Q. seminulum	0.14
C.involvens	0.20
C. balkwilli	0.81
E. crispum	0.81
A. batavus	0.81
T. inflata	1.09
N. germanica	1.29
E. williamsoni	1.99

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
3.374	1.35	1.00	0.47	0.71
3.377	1.00	1.16	0.33	0.86
3.559	0.60	0.54	0.67	0.45
3.629	1.94	0.55	0.54	0.62
3.837	1.17	0.70	0.71	0.50
3.924	1.02	0.46	0.89	0.30
3.984	1.07	0.39	0.83	0.35
4.117	0.63	0.00	1.14	0.00
4.17	0.00	0.22	0.92	0.10
4.221	1.74	0.04	0.30	0.64
4.226	0.25	1.55	0.00	1.37
4.282	0.31	0.54	0.75	0.30
4.352	1.72	1.86	0.80	0.86
4.386	2.42	1.23	1.44	0.26
4.427	2.44	0.81	0.84	0.55
4.968	1.85	1.41	1.53	0.34

Axis 1 ranked. Eigenvalue = 0.35547

Name	Score
4.17	0.00
4.226	0.25
4.282	0.31
3.559	0.60
4.117	0.63
3.377	1.00
3.924	1.02
3.984	1.07
3.837	1.17
3.374	1.35
4.352	1.72
4.221	1.74
4.968	1.85
3.629	1.94
4.386	2.42
4.427	2.44

Axis 2 ranked. Eigenvalue = 0.09397

Name	Score
4.117	0.00
4.221	0.04
4.17	0.22
3.984	0.39
3.924	0.46
3.559	0.54
4.282	0.54
3.629	0.55
3.837	0.70
4.427	0.81
3.374	1.00
3.377	1.16
4.386	1.23
4.968	1.41
4.226	1.55
4.352	1.86

Axis 3 ranked. Eigenvalue = 0.02575

Name	Score
4.226	0.00
4.221	0.30
3.377	0.33
3.374	0.47
3.629	0.54
3.559	0.67
3.837	0.71
4.282	0.75
4.352	0.80
3.984	0.83
4.427	0.84
3.924	0.89
4.17	0.92
4.117	1.14
4.386	1.44
4.968	1.53

Axis 4 ranked. Eigenvalue = 0.00699

Name	Score
4.117	0.00
4.17	0.10
4.386	0.26
4.282	0.30
3.924	0.30
4.968	0.34
3.984	0.35
3.559	0.45
3.837	0.50
4.427	0.55
3.629	0.62
4.221	0.64
3.374	0.71
4.352	0.86
3.377	0.86
4.226	1.37

Forth modern transect at Stert. Foraminiferal raw data cluster analysis

File: ST4RAWFO.TIL
Number of samples = 16
Number of variables = 10
Square root transformation
Dissimilarity coefficient is Euclidian distance

Constrained Incremental Sum of Squares Cluster Analysis

Stage	Clusters merged		Increase in dispersion	Total dispersion	Within-cluster dispersion	Mean within-cluster dispersion
1	13	14	3.022774	3.022774	3.022774	1.511387
2	6	7	3.694189	6.716964	3.694189	1.847095
3	5	6	7.155586	13.87255	10.84978	3.616592
4	13	15	8.344852	22.2174	11.36763	3.789209
5	13	16	3.890659	26.10806	15.25829	3.814571
6	8	9	8.480928	34.58899	8.480928	4.240464
7	11	12	10.35996	44.94895	10.35996	5.17998
8	4	5	12.86636	57.81531	23.71613	5.929033
9	1	2	19.42202	77.23732	19.42202	9.711008
10	1	3	25.06097	102.2983	44.48299	14.82766
11	1	4	29.25893	131.5572	97.45805	13.92258
12	8	10	36.36618	167.9234	44.84711	14.94904
13	8	11	23.25971	191.1831	78.46678	15.69336
14	1	8	68.51234	259.6955	244.4372	20.36976
15	1	13	120.3532	380.0486	380.0486	23.75304

Sample numbers

1	3.374
2	3.377
3	3.559
4	3.629
5	3.837
6	3.924
7	3.984
8	4.117
9	4.17
10	4.221
11	4.226
12	4.282
13	4.352
14	4.386
15	4.427
16	4.968

Forth modern transect at Stert. Foraminiferal percentage data detrended correspondance analysis

Axis 1

Residual 0.168964 at iteration 0
Residual 0.003079 at iteration 1
Residual 0.000014 at iteration 2

Eigenvalue 0.52103

Length of gradient 2.307
Length of segments 0.24 0.24 0.23 0.22 0.20 0.19 0.17 0.16 0.15 0.16
0.17 0.18
Length of gradient 2.355
Length of gradient 2.455
Length of segments 0.21 0.21 0.21 0.21 0.20 0.19 0.18 0.17 0.16 0.16
0.17 0.18 0.20
Length of gradient 2.493

Axis 2

Residual 0.061465 at iteration 0
Residual 0.000062 at iteration 1

Eigenvalue 0.17160

Length of gradient 1.660
Length of segments 0.19 0.18 0.17 0.16 0.16 0.16 0.16 0.16 0.16 0.16
Length of gradient 1.651
Length of gradient 1.643
Length of segments 0.18 0.18 0.16 0.16 0.16 0.15 0.16 0.16 0.17 0.17
Length of gradient 1.641

Axis 3

Residual 0.008681 at iteration 0
Residual 0.000059 at iteration 1

Eigenvalue 0.03648

Length of gradient 1.488
Length of segments 0.19 0.17 0.16 0.16 0.15 0.15 0.14 0.13 0.12 0.12
Length of gradient 1.490
Length of gradient 1.463
Length of segments 0.18 0.15 0.14 0.14 0.15 0.15 0.14 0.14 0.13 0.13
Length of gradient 1.415

Axis 4

Residual 0.002819 at iteration 0
Residual 0.000010 at iteration 1

Eigenvalue 0.01250

Length of gradient 1.684
Length of segments 0.20 0.19 0.19 0.19 0.19 0.18 0.16 0.14 0.13 0.13
Length of gradient 1.728
Length of gradient 1.727
Length of segments 0.20 0.17 0.17 0.17 0.18 0.18 0.17 0.17 0.16 0.16
Length of gradient 1.695

VARIABLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
J. macrescens	2.61	1.21	-0.04	0.14
T. inflata	1.90	1.61	2.02	2.22
E. williamsoni	0.93	-0.41	1.69	1.44
Q. seminulum	0.31	2.64	-0.56	1.00
C. balkwilli	1.49	1.16	1.06	1.11
C.involvens	0.68	2.12	0.69	0.24
A. beccarii	-0.32	1.13	1.14	1.32
N. germanica	0.42	-0.05	0.15	-0.57
A. batavus	1.49	1.16	1.06	1.11
E. crispum	1.49	1.16	1.06	1.11

Axis 1 ranked. Eigenvalue = 0.52103

Name	Score
A. beccarii	-0.32
Q. seminulum	0.31
N. germanica	0.42
C.involvens	0.68
E. williamsoni	0.93
C. balkwilli	1.49
A. batavus	1.49
E. crispum	1.49
T. inflata	1.90
J. macrescens	2.61

Axis 2 ranked. Eigenvalue = 0.17160

Name	Score
E. williamsoni	-0.41
N. germanica	-0.05
A. beccarii	1.13
E. crispum	1.16
C. balkwilli	1.16
A. batavus	1.16
J. macrescens	1.21
T. inflata	1.61
C.involvens	2.12
Q. seminulum	2.64

Axis 3 ranked. Eigenvalue = 0.03648

Name	Score
Q. seminulum	-0.56
J. macrescens	-0.04
N. germanica	0.15
C.involvens	0.69
E. crispum	1.06
C. balkwilli	1.06
A. batavus	1.06
A. beccarii	1.14
E. williamsoni	1.69
T. inflata	2.02

Axis 4 ranked. Eigenvalue = 0.01250

Name	Score
N. germanica	-0.57
J. macrescens	0.14
C.involvens	0.24
Q. seminulum	1.00
E. crispum	1.11
C. balkwilli	1.11
A. batavus	1.11
A. beccarii	1.32
E. williamsoni	1.44
T. inflata	2.22

SAMPLE SCORES

Name	Axis 1	Axis 2	Axis 3	Axis 4
3.374	1.02	1.30	0.84	0.88
3.377	0.82	0.93	0.95	0.88
3.559	0.47	0.97	0.86	0.93
3.629	1.60	1.48	1.06	1.27
3.837	0.81	1.42	0.66	0.87
3.924	0.56	1.64	0.46	0.77
3.984	0.61	1.53	0.63	1.09
4.117	0.23	1.51	0.48	1.00
4.17	0.00	0.79	0.84	0.79
4.221	1.28	1.52	1.42	1.69
4.226	0.58	0.00	1.05	0.76
4.282	0.29	0.71	0.97	0.96
4.352	1.94	0.56	0.65	0.66
4.386	2.49	1.28	0.31	0.49
4.427	2.29	1.39	0.89	1.08
4.968	2.17	0.96	0.00	0.00

Axis 1 ranked. Eigenvalue = 0.52103

Name	Score
4.17	0.00
4.117	0.23
4.282	0.29
3.559	0.47
3.924	0.56
4.226	0.58
3.984	0.61
3.837	0.81
3.377	0.82
3.374	1.02
4.221	1.28
3.629	1.60
4.352	1.94
4.968	2.17
4.427	2.29
4.386	2.49

Axis 2 ranked. Eigenvalue = 0.17160

Name	Score
4.226	0.00

4.352	0.56
4.282	0.71
4.17	0.79
3.377	0.93
4.968	0.96
3.559	0.97
4.386	1.28
3.374	1.30
4.427	1.39
3.837	1.42
3.629	1.48
4.117	1.51
4.221	1.52
3.984	1.53
3.924	1.64

Axis 3 ranked. Eigenvalue = 0.03648

Name	Score
4.968	0.00
4.386	0.31
3.924	0.46
4.117	0.48
3.984	0.63
4.352	0.65
3.837	0.66
4.17	0.84
3.374	0.84
3.559	0.86
4.427	0.89
3.377	0.95
4.282	0.97
4.226	1.05
3.629	1.06
4.221	1.42

Axis 4 ranked. Eigenvalue = 0.01250

Name	Score
4.968	0.00
4.386	0.49
4.352	0.66
4.226	0.76
3.924	0.77
4.17	0.79
3.837	0.87
3.377	0.88
3.374	0.88
3.559	0.93
4.282	0.96
4.117	1.00
4.427	1.08
3.984	1.09
3.629	1.27
4.221	1.69

Forth modern transect at Stert. Foraminiferal percentage data cluster analysis

File: ST4%MODF.TIL
Number of samples = 16
Number of variables = 10
Data converted to proportions
Square root transformation
Dissimilarity coefficient is Edwards and Cavalli-Sforza's chord distance

Constrained Incremental Sum of Squares Cluster Analysis

Stage	Clusters merged	Increase in dispersion	Total dispersion	Within-cluster dispersion	Mean within-cluster dispersion
1	5 6	0.02174029	0.02174029	0.02174029	0.01087014
2	1 2	0.02577897	0.04751925	0.02577897	0.01288948
3	5 7	0.03647266	0.08399191	0.05821295	0.01940432
4	14 15	0.04963858	0.1336305	0.04963858	0.02481929
5	1 3	0.1608108	0.2944413	0.1865897	0.06219658
6	8 9	0.1636462	0.4580875	0.1636462	0.08182309
7	11 12	0.1789626	0.6370501	0.1789626	0.0894813
8	1 4	0.2200275	0.8570776	0.4066173	0.1016543
9	1 5	0.1148478	0.9719254	0.579678	0.08281114
10	14 16	0.3308883	1.302814	0.3805269	0.1268423
11	8 10	0.3967444	1.699558	0.5603905	0.1867968
12	13 14	0.418098	2.117656	0.798625	0.1996562
13	8 11	0.4706997	2.588356	1.210053	0.2420106
14	1 8	0.8801172	3.468473	2.669848	0.2224873
15	1 13	2.44472	5.913193	5.913193	0.3695746

Sample numbers

1	3.374
2	3.377
3	3.559
4	3.629
5	3.837
6	3.924
7	3.984
8	4.117
9	4.17
10	4.221
11	4.226
12	4.282
13	4.352
14	4.386
15	4.427
16	4.968

Appendix VI

Lithostratigraphy of abandoned holes at Briarwood Farm

Abandoned holes at Briarwood Farm

BF1	5.2.98
0-50	topsoil
50-92	Detrital peat
92-110	Grey-green clay
100-3	Reddish peat with wood fragments
360-500	Blue Clay
500-900	Blue clay paleing with depth
900	Hole abandoned
BF2	
0-35	Topsoil
35-65	Grey bluey with red staining
65-85	Very dark grey clay
85	Hole Abandoned
BF3	
0-20	Topsoil
20-92	Grey clay
92	HA
BF4	
0-30	Topsoil
30-48	Grey Brown clay
48-212	Peat (very woody layer 102-116)
212-252	Blue clay with wood fragments
252	HA

Appendix VII

Particle size analysis results

Particle size analysis expressed as percentage of total sample

Dundon Hayes

Sample Depth	-1	0	1	2	3	4
454 - 456	26.08	54.35	8.7	4.35	4.35	2.17
456 - 458	13.85	53.84	23.08	6.15	1.54	1.54
458 - 460	3.51	45.62	29.82	14.03	3.51	3.51
460 - 462	8.33	33.33	29.17	12.5	12.5	4.17
462 - 464	2.5	40	32.5	17.5	5	2.5
464 - 466	8.33	44.45	25	11.11	8.33	2.78
466 - 468	21.31	49.18	19.67	4.92	3.28	1.64
468 - 470	8.96	55.22	22.39	8.96	2.98	1.49
470 - 480	17.37	34.21	17.89	13.68	10.53	6.32
480 - 490	37.39	20.87	13.48	12.17	6.96	9.13
490 - 500	39.76	16.27	11.14	9.64	9.94	13.25
500 - 511	33.66	16.71	10.32	11.79	13.27	14.25
511 - 519	3.77	6.29	7.55	15.09	18.24	49.06
519 - 522	3.1	11.62	13.18	17.83	17.83	36.44

Briarwood Farm

Sample Depth	-1	0	1	2	3	4
397 - 405	21.5	20.73	21.5	18.81	12.86	4.6
405 - 410	45.75	27.45	11.11	7.84	5.89	1.96
410 - 420	37.55	30.56	14.62	9.3	4.98	2.99
420 - 430	46.59	19.7	11.74	10.61	7.2	4.16
435 - 445	3.02	3.67	10.41	22.96	22.75	37.19
445 - 455	23.04	3.55	7.13	24.27	22.13	19.88
455 - 465	6.52	2.66	7.62	24.05	32.35	26.8
465 - 475	9.98	15.86	24.6	24.94	16.54	8.08
475 - 480	20.13	13.32	15.63	21.41	18.57	10.94
490 – 495	6.64	5.57	9.75	20.37	27	30.67

Bawdrip

sample depth	-1	0	1	2	3	4
517 - 519	3.79	5.93	7.58	34.93	24.38	23.39
519 - 521	0.85	4.54	7.23	25.53	24.26	37.59
521 - 523	4.49	3.62	7.87	25.84	31.34	26.84
523 - 525	4.42	8	9.14	30.58	24.86	23
525 - 527	2.08	4.29	10.92	32.9	35.51	14.3
527 - 529	1.54	6.76	7.02	22.43	53.35	8.9
529 - 531	11.76	7.44	8.16	20.77	24.73	27.14
531 - 533	2.44	8.25	9.18	19.96	26.34	33.83
533 - 535	1.05	8.6	8.84	28.25	32.21	21.05
535 – 537	15.75	6.93	7.83	23.85	27.19	18.45

Stert

Sample Depth	-1	0	1	2	3	4
0 – 5	42.15	9.5	10.33	14.05	13.64	10.33
5 to 10	26.11	15.62	20.51	18.88	12.12	6.76
10 to 15	12.06	19.46	22.18	21.01	14.4	10.89
15 to 20	25.12	20.09	16.66	17.58	11.87	8.68
20 to 25	32.82	14.42	14.11	15.34	13.19	10.12
25 to 30	22.13	26.26	16.81	17.99	11.21	5.6
30 to 35	18.59	28.84	20.83	17.31	10.26	4.17
35 to 40	20.29	28.75	20.29	15.94	9.9	4.83
40 to 45	19.77	29.33	20.46	16.36	9.54	4.54
45 to 50	10.13	24.8	19.2	19.47	14.67	11.73
50 to 55	34.94	14.06	10.44	11.64	12.45	16.47
55 to 60	21.42	11.61	14.29	17.86	15.18	19.64
60 to 65	12.83	8.41	15.04	23.46	23.89	16.37
65 to 70	15.03	5.88	7.19	7.84	18.96	45.1
70 to 75	26.15	13.85	14.62	15.38	14.62	15.38
75 to 80	8.26	6.09	16.52	30	24.35	14.78
80 to 85	11.41	11.41	25.51	24.15	14.77	12.75
85 to 90	32.35	2.94	11.76	17.65	20.59	14.71
90 to 95	8.56	5.41	16.22	27.02	25.68	17.11
95 to 100	14.05	8.17	17.97	30.07	20.26	9.48