THE CHARACTERISATION OF TWO MID-HOLOCENE SUBMERGED FORESTS

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PULLOUTS

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Abstract

This thesis seeks to characterise two areas of mid-Holocene submerged forests at Hightown, Merseyside and the east Lincolnshire coast. This is achieved by the application of forest stand dynamic and palaeoecological models to data provided by plant macrofossil identification and metrical analysis of the standing tree remains. Such characterisation has not previously been undertaken.

It demonstrates that the application of the above techniques enables the developmental and ecological history of the submerged forests to be reconstructed at a level of detail previously unachieved. The data obtained from the analysis of the spatial distribution of the tree remains of the two regions shows that they experienced different disturbance regimes resulting in the two regions having a dissimilar population structures. The palaeoecological data provided by the plant macrofossil remains contained within the deposits demonstrates that the two submerged forests were of the same type of woodland which is associated with areas having high watertables. The identification of the tree species also highlights disimilarites between the regions, with east Lincolnshire being more species rich than Merseyside. This has been interpreted as being linked to the disturbance patterns experienced by each submerged forest. However, the submerged forests show no indication of management and there are few archaeological artefacts associated with the deposits. This is explainedin terms of the overall character of the woodlands, which were very difficult to penetrate and dangerous to exploit.

It is hoped that the characterisation of Submerged Forests using the techniques outlined above, will help archaeologists and palaeoecologists to reach a better understanding of how past human populations utilised their local environment.

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Chapter One

INTRODUCTION

Since the termination of the last (Weichselian) ice-age approximately ten thousand years ago, there has been an improvement in climate especially with regard to temperature and rainfall. This climatic amelioration has taken place at different rates throughout the Holocene and has guided the changes in the vegetation cover of the British Isles. It has long been ascertained via palynology that the majority of the British Isles was covered by some kind of woodland during the Holocene. The development of this forest cover is thought to have reached its zenith at around 5000 BP and was considered by the earliest ecologists to consist of a blanket of mixed oak forest. With the development and refinement of palynological and plant macrofossil techniques, however, it has been shown that different tree species were dominant in different areas. These depended on soil, topographical, and climatic conditions and led to a forest cover consisting of a mosaic of woodland types.

The woodland cover present at 5000 BP is considered to be the original 'wildwood'. At about this time, the palynological records show that there is a noticeable decline in the content of certain tree species, especially elm (*Ulmus* sp.). This has been related to the clearance of the forest cover by Neolithic cultures. Although more recent work (Peglar, 1993) has provided evidence that disease may have played just as important part in the decline of elm at this time. Since the initial alteration of the forest cover by these early farmers, forests have been continually altered and managed up to the present day. This has changed the character of the forest so much that it is impossible to be sure what was the nature of the original 'wildwood', although in some cases, where woodlands have been continually managed for centuries using the same practices, it has been possible to make limited deductions as to their character. However it is impossible to be certain to what extent the tree species composition of such ancient woodlands has been altered from that of the original 'wildwood'. The presence of submerged forests around the coasts of Britain offer the opportunity to deduce the character of some types of 'wildwood' via the application of dynamic ecological models and plant macrofossil analyses presented in this thesis.

Submerged forests around the coasts of Britain have been historically documented for many centuries. They have been dated using methods including dendrochronology and radiocarbon dating, and have been shown to have been formed throughout the Holocene period, with a major concentration of submerged forest deposits at between 5000-4000 BP. It is possible therefore that these deposits may represent the remains of the original 'wildwood'.

Clement Reid, in his 1913 publication entitled *'Submerged Forests'* was one of the first palaeoecologists to attempt to characterise deposits from around the coasts of England and Wales and to deduce the processes involved in their formation. The use of plant macrofossil analyses which Reid employed, was eclipsed by the advent of pollen analytical techniques in the early decades of this century. This method has since dominated the examination of submerged forest deposits, and it has provided much evidence for the species composition of submerged forests but little towards their characterisation.
For example, pollen analysis cannot determine how close to each other the trees were growing, or the size of each individual tree. This lack of local detail can only be determined by studying the tree remains themselves, which, linked with plant macrofossil analysis, can provide a better understanding of the nature of the submerged forests.

Following previous research by the author, using ecological models to interpret both charred and waterlogged archaeological plant macrofossil assemblages (Clapham & Scaife, 1988; Hubbard & Clapham, 1992; Jones & Clapham, 1993, Clapham, 1995a & b and Clapham, 1996) this thesis will seek to demonstrate that it is possible to characterise submerged forests using plant macrofossil analysis, the examination of the distribution pattern of stumps and trunks within the deposits, and the application of forest stand dynamic models. This characterisation should reveal the dynamic processes involved in woodlands in interactions between the biotic and abiotic environments. It will seek to show how these coastal woodlands may have appeared to the local human population. However, since the formation processes involved in the preservation of submerged forests means that they are waterlogged, the woodlands represented will necessarily be wet woodlands and are therefore probably not representative of the majority of the forest cover of the British Isles at that time. Even so, these deposits do present an opportunity to study the development of and changes to unmanaged and probably pristine woodlands in certain areas of the country.

In this thesis, the early records and research as well as the origins and distribution of submerged forest deposits are discussed in Chapter Two. Chapter Three contains a short discussion of the forest cover of the British Isles since the end of the Weicheselian glaciation until approximately 5000 BP, when the development of the forest cover reached its 'climax' before the character of the forests was altered by the clearance of woodland by the Neolithic peoples, for agricultural purposes. Chapter Four presents the methods used to survey the submerged forest deposits analysed in this thesis and discusses the problems associated with the interpretation of the plant macrofossil data. Chapter Five presents and discusses the results of the plant macrofossil and wood species identifications from deposits located at Wolla Bank and Anderby Creek on the Lincolnshire Coast. The geology, past records, archaeology and previous palaeoecological research associated with these submerged forest deposits are also discussed. Chapter Six follows the same format and discusses the results of the submerged forest deposits at Hightown, along with the geology, archaeology and previous palaeoecological research associated with the submerged forest deposits situated in Liverpool Bay. Chapter Seven discusses possible models and their relevance to the data. The application of the models and the results produced are presented in Chapter Eight. Chapter Nine discusses the conclusions reached by the analyses of the submerged forest deposits.

In summary, this thesis will seek to demonstrate that through the analyses of the plant macrofossil remains and the data provided by the distribution and dimensions of the tree remains within the deposits it is possible to characterise submerged forests in terms of development and structure.

Finally, certain terminology used in this thesis should be clarified. All radiocarbon dates quoted in this thesis are uncalibrated unless stated within the text. All plant species names follow that of Stace (1997). The term Holocene for the time period since the end of the last ice-age has been adopted throughout this thesis unless the original sources quoted use the term Flandrian.

Chapter Two

SUBMERGED FORESTS: NATURE, DISTRIBUTION, ORIGINS, HISTORICAL RECORDS and RESEARCH

2.1. Introduction

Evidence that the British Isles after the end of the Pleistocene ice-age was covered by forest has for a long time been confirmed by palynological studies as described briefly in Chapter Three (Erdtmann, 1929, Godwin, 1940a). Its initial spread and then subsequent demise and contraction has been followed using the same technique (Huntley and Birks, 1983). Pollen analysis is adequate for following developments and changes through time and space on a regional scale, but on the local level the more defined picture is usually obscured by long distant transport of extra-local and regional pollen.

To obtain a more detailed local picture of these changes and the relationship between the different species of trees and the ground flora, i.e. its palaeoecology, it is necessary to study and analyse the trees and the plant macrofossils preserved within the forest floor. Macroscopic evidence of the existence of a wooded /forested landscape can be found around the coast of Britain in the guise of submerged forests or Noah's woods (Reid, 1913, Godwin, 1943; Heyworth, 1978; Bell, 1997).

2.2. The Nature and definition of Submerged forests

What can be considered to be a submerged forest needs to be established. Reid, (1913), stated: 'It may be said that there are "submerged forests" of various geological dates, and this is perfectly true. The "dirt-bed" of the Isle of Purbeck, with its upright cycad-stems, was at one time a true submerged forest, for it is overlain by various marine strata, and during the succeeding Cretaceous Period it was probably submerged thousands of feet. Every coal seam with its underlying soil or 'underclay' penetrated by stigmarian roots was also once a submerged forest. Usage, however, limits the term to the more recent strata of this nature, and to these we will for the present confine our attention.'

Travis, (1926), described some post-glacial deposits as ' "submerged forests" and peat beds, which are to be found at intervals along the margin of the coast of the British Isles, generally situated at the mouths of drowned river-valleys.'

Godwin, (1943), stated: 'At places all around the long coastline of Britain, and along part of the western shore of the continent there are found from time to time, peat deposits clearly once formed in freshwater, but now either within reach of the tides or submerged permanently. Sometimes these beds are particularly striking in that they support the stubs of woodland trees, and to these submerged forests the term "Noah's woods" has been applied'.

Heyworth, (1978), recognised: 'Around the coasts of the British Isles are many sites where "submerged forests" are exposed on the beach. These forest beds consist of stumps, still in the position of growth, and fallen trunks; often with associated peats. The trees may be very large and are usually extremely well preserved.' Heyworth, (1986), also wrote that 'Assemblages of tree remains in their growth position and so situated that they are regularly covered by the tide. These forests are usually found as peat beds, containing the stumps and trunks of trees, which outcrop on the foreshore. They are, in many cases, visible only when the beach levels are low, being covered for much of the year, by sand or shingle. The above definition can be widened to include the buried inland extensions of such forests, and also those beds which, whilst clearly originating in the same way as submerged forests, are now as a result of uplift, above the reach of the highest tides.'

Allen, (1992c) observed that 'Peats and lignites containing fossilised trees of a "modern" character are widely preserved in the sedimentary deposits of central and north-west Europe which date within the last 65 million years. The youngest of these accumulations occur in the British Isles at about the middle of the post-glacial sequence of fenland, estuarine and coastal sediments. They are widely recorded on topographic maps as "submerged" or "fossil" forests, and are especially well exposed intertidally as extensive ledges on the shores of the inner Bristol Channel and Severn Estuary in south-west Britain.'

As can be seen from the above statements, they all have in common the fact that the submerged forests were once on dry land, are found throughout Geological time and have been engulfed by the sea as the level rose. The definition that shall be used in this study is that of Heyworth, (1986).

At any one site of a submerged forest, there are usually a large number of trees, mainly of oak with pine and to a lesser extent, alder, yew and birch. However, this is a generalisation and it is hoped that it will be demonstrated that submerged forests can be more varied than this, being composed of a mosaic of different types which relate to the differing ecological conditions that can exist within deposits as can be seen in modern day woodlands and forests.

2.3. Distribution of Submerged Forests

Submerged forests are found between the lowest tides and the Mean High Water Mark (MHWM), which can vary between locations for example in the Bristol Channel this can vary from -6.0m to -2.5m O.D. depending on the tidal range (Heyworth, 1978). According to Bell (1997), there are approximately one hundred and fourteen documented intertidal and cliff exposure peat sites in England, with at least nine pre-Holocene in date. In Wales there are a further twenty-seven records. Many of these sites contain submerged forest deposits. The greatest concentration of intertidal peats are found in the Severn Estuary further concentrations are found in Cornwall, Merseyside, the Solent, East Sussex and Holderness, (Bell, 1997) and are shown in figure 2.1.

The present location of submerged forests is in general a result of eustatic rise and isostatic uplift. The amount of isostatic uplift being governed by the ice load in the previous glaciation. In parts of Britain where the ice-load was negligible or non-existent, there has been a more relative rise in sea-level compared to isostatic change, whilst in northern Britain, where the ice load was greater, it can be found that isostatic uplift has been balanced by the eustatic change in sea-level. This means that in northern Britain, submerged forests can be found in approximately the same height O.D. as they were formed (Heyworth, 1978).

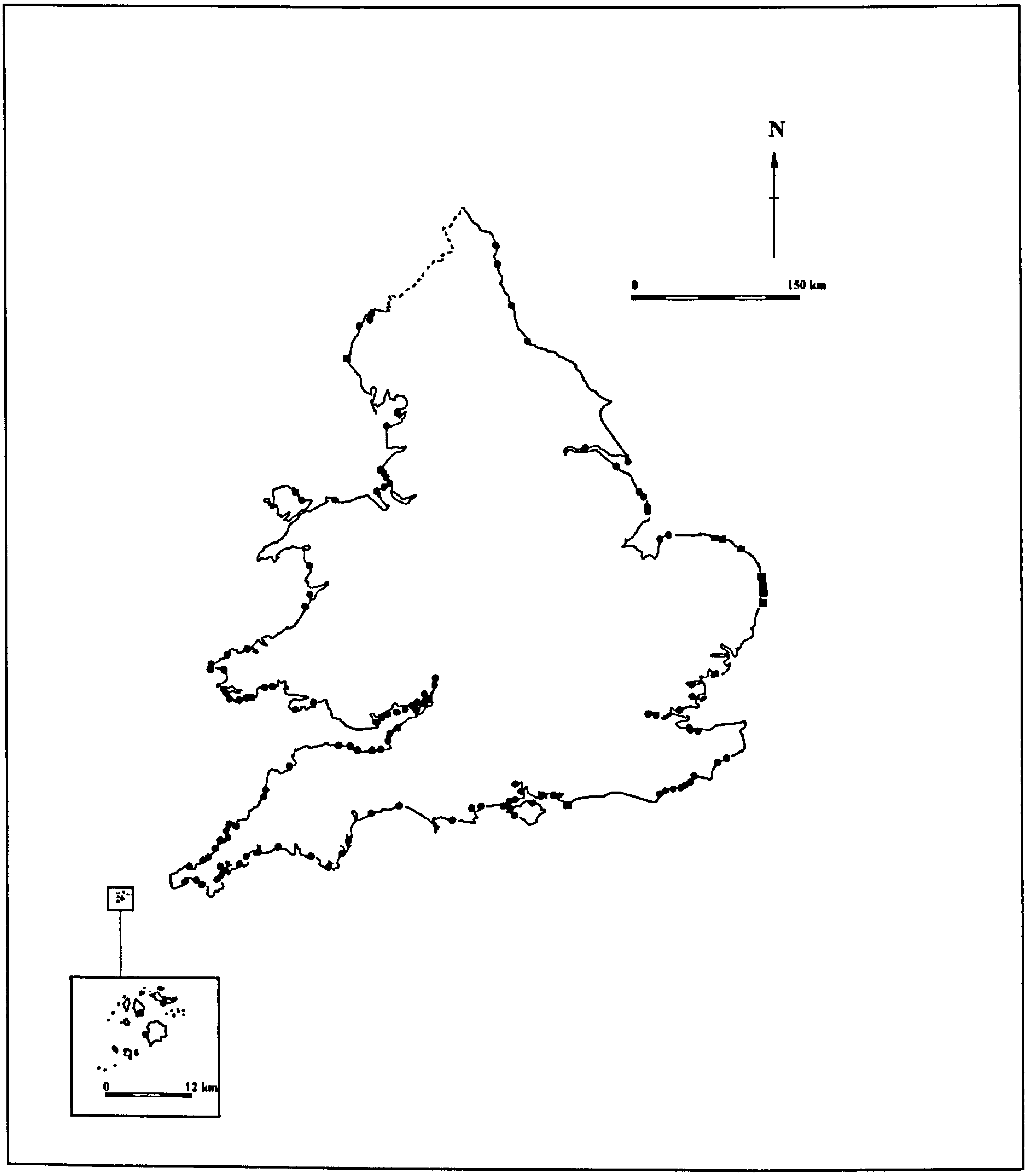


Figure 2.1. Map showing the distribution of intertidal peat sites (including submerged forests) around the coasts of England and Wales. Filled circles are Holocene peats, filled squares are pre-Holocene peats. (After Bell, 1997)

However, there are complications due to the tectonic movements of the earth's crust. As a result, the coastal areas in the north west have risen during the post-glacial period, while the coastlines in the south and east have sunk. Between these two areas, the coastline of south-west England and Wales has shown little or no vertical movement as is also the case in the vicinity of the Humber. The changes of vertical movement means that most submerged forests are easily accessible.

The distribution of submerged forests have been recorded both from sightings on the coast as well as those from deeper dock excavations, and it can be generally stated that submerged forests can be found around most of the coastline of England, Wales and Ireland, including the Channel Islands, the French coast of the English Channel as well as that bordering the Atlantic,(Welsch, 1917; Wright, 1937; Movius, 1942; Bell, 1997). Submerged forests have also been found along the North European coasts as far north as Scandinavia.

Although submerged forests are found all around the coasts of Great Britain, they are absent from three main types of coastline, (Heyworth 1986). These are: a) where changes in estuarine channels have removed all the beds; b) on a receding coastline where a coastal alluvial belt is now, or in the past, absent; and c) where accretion has caused the coastline to advance across the earlier intertidal area, so that any submerged forest beds which might have been present are now well inland.

2.4. The dating of Submerged Forests

Until the advent of radiocarbon dating and dendrochronology, the dating of submerged forest deposits was based on the archaeological artefacts associated with the exposures. This evidence ranged from Palaeolithic up to the mediaeval period, although at one time there was thought to be one great period of submergence and was known as the 'Submerged Forest Period'. This was roughly dated to the Neolithic period and in "The Antiquity of Man", Arthur Keith (1915) devoted a whole chapter to the people of the submerged forest. With the advent of radiocarbon dating and dendrochronology it became evident that submerged forests have formed throughout the Holocene. Reid (1913) stated that the submergence /burial of forests has been going on throughout geological time.

Godwin, (1943) found that the content of archaeological material is disappointingly small, and what there was, for a long time was referred to as the 'Neolithic period' in the very wide original sense of that term, which covered the Mesolithic, the Neolithic, *sensu stricto* and perhaps also sometimes the Bronze Age, or even the Iron Age, and became known as the 'Neolithic Submerged Forest Period'.

As palynological techniques were applied to the submerged forest deposits it was possible to relate the results to the development of the flora of the British Isles since the last Ice Age. This provided a relative chronology in which the submerged forests corresponded to the Atlantic and Sub-Boreal phases of development (Godwin pollen zones VIIa and VIIb). A more detailed study of the data from palynological studies from the submerged forests showed that they did not develop at the same time but gradually through time. Heyworth (1978) using dendrochronology and ^{14}C acquired a range of dates from more than 8000 years but less than 10000 years, the most common age of the submerged forests being between about 4000 and 5500 BP. According to Heyworth (1978), this date range is related to a period of moderate sea-level rise which allowed the growth of extensive coastal forests which progressively became inundated. Before this period of moderate sea-level rise, a more rapid phase of sea-level change existed which only permitted the growth of narrow bands of coastal forests. Figure 2.2 illustrates the variation of dates for submerged forests around the coasts of Britain.

At Meelick Rocks, Co. Limerick, trunks and root systems of an alder-oak woodland on the upper shore produced a radiocarbon date of 4160 ± 20 BP (2883-2623 cal. BC, GrN-21930) corresponding to the late Neolithic, on the lower shore the deposit was determined to be Mesolithic with a radiocarbon date of 6240 ± 25 BP (5312-5077 cal. BC, GrN-21929). At Poulnasharry Bay, Co. Clare, radiocarbon dates of 4960 ± 35 BP (3930-3692 cal. BC, GrN-20145) was obtained from a submerged Scots pine forest. It is hoped that the submerged forests of the Shannon Estuary will help to produce an ecological reconstruction of the ancient woodlands and the calibration of the sea-level rise in the Shannon Estuary and linked to the Prehistoric and Medieval archaeological finds and structures to provide a picture of the exploitation of the estuary through time (O'Sullivan, 1997).

The scarcity of submerged forests that date after 3,000 years BP, can be explained in part by the low rate of sea-level rise since this time and by the coastal exploitation of human populations. This low rate of sea-level rise means that few coastal woodlands would become drowned and even if the trees had been killed, they would not have been buried rapidly enough to prevent decomposition or uprooting by tidal action. Some submerged forests do date from after 3,000 BP such as the 450 year old one in Cardigan Bay (Heyworth, 1978).

Figure 2.2. Map showing the variation in radiocarbon age of some submerged forests around the coast of the British Isles. Named submerged forests are A: Solway Firth; B: Humber; C: Morecambe Bay; D: Cardigan Bay; E: Borth/Ynyslas; F: Bristol Channel; G: Stolford (Bridgwater Bay).(After Heyworth, 1978)

2.5. Early Records

Submerged forests have been noticed and recorded throughout the historical period, one of the earliest being that of Giraldus Cambrensis. In his Itinerary through Wales and the description of Wales, (1188) he refers to a storm in the winter of 1171-72 that at Niwegal Sands (Newgale in St. Bride's Bay) 'laid bare....... the surface of the earth, which had been covered for many ages, and discovered the trunks of trees cut off, standing in the very sea itself, the strokes of the hatchrt appearing as if made only yesterday......By a revolution, the road for ships became impassable and looked, not like a shore, but like a grove cut down.........being by degrees consumed and swallowed up by the violence and encroachment of the sea'. This description of Giraldus was repeated (including the hatchet marks) by later writers. For example, George Owen at the beginning of the 17th Century and Richard Fenton in the 19th Century. According to North (1964) there is evidence that early man wandered in some of these forests before they were submerged, but they were there as hunters and not in the search of trees to cut down. Thomas Pennant (1810) described similar occurrences of trees on the foreshore near Abergele in Denbighshire saying that 'The wood is collected by the poorer people and carried home and used as fuel'. It has been remarked (Owen, 1595) that there has been a long deficiency of wood for fuel in many parts of Pembrokeshire and it is possible that the hatchet marks reported by Giraldus were not made in antiquity but in historic times (North, 1964).

In 1695, more reports appeared. Camden in his Magna Britannia said of the Mersey Flats 'As for the trees when the roots of them were loosen'd by reason of the too great moisture of the earth 'twas impossible but that they should fall, and so sink and be drowned in such a soil'. Edward Lhuyd (1695), recorded 'As for the roots or stumps I have observed them myself betwixt Borth and Aberdovey..... they appeared more like cole-black peat than timber', (Condry, 1981). Around 1663, Samuel Pepys noticed hazel trees in excavations, on one of his official visits to the dockyards of London (Reid, 1913). Later writers are also full of remarks on the ancient yew trees and oaks found well below sea-level.

As Reid (1913), states, most of these early accounts are of little scientific value, the exception being a correspondence with the July 1796 issue of the Gentleman's Magazine where a reader G. Holt, reported on a 'submerged forest at Crosby, extending upward of a mile towards Formby. What might have been its original extent, either in that or in any other direction, seems at present impossible to ascertain; but vestiges of it are visible dipping westwardly into the sea, which doubtless covers a great part of the land on which a considerable portion of it grew. There are numberless trunks of trees standing upright, some feet above the surface, in the very place in which they must have grown, with their prodigious roots extending into the ground in all directions in their natural positions' (cited by Travis, 1926). This account can be considered the earliest which tried to interpret and understand the depositional history of the submerged forests.

In 1902, at St Ouen's Bay on Jersey, Sinel noted a record exposure of the old forest bed. 'the fine white sand which usually lies throughout this bay from 5-10 feet thick, had disappeared, and in its place there stretched, as far as the eye could reach - north, south and seaward, an expanse of firm brownish-black peaty soil, which was studded with innumerable tree stumps, most of these just level with the soil, but many hundreds of them projecting above it for 2 or 3 feet. Between these stumps were prostrate trunks and large branches with acorns, seeds of telia [*Tilia* sp.] and hazelnuts in abundance.' (Sinel, 1914).

2.6. Origin of the Submerged Forests

As the submerged forest deposits became exposed on the shores, vernacular tradition had it that these deposits were the result of the biblical flood and came to be known as Noah's Woods. During the late nineteenth and early twentieth centuries, landslips, compression of the underlying strata or the removal of a protective barrier such as a shingle beach or line of sand dunes were all considered as possible causes of submerged forests by geologists. According to Reid (1913), these causes were used in order to avoid the conclusion that a recent change in sea-level was the more likely cause. Reid (1913) in agreeing with Lyell (1830) dismissed these accidental causes as not being adequate in explaining the true origins of the submerged forests. Landslips, he argued would cause some disturbance to the underlying deposits, but close examination of the deposits show that the roots of the trees descend unbroken into the lower strata therefore showing no signs of disturbance, this added to the fact that most submerged forests occupy large areas on relatively level surfaces precluded, in his argument, landslip as the origin of the submerged forests.

The compression of the underlying strata and the consequent sinking of the land surface above is more difficult to disprove. Reid (1913) again reasoned that, where the roots of the submerged forest penetrate hard rock or firm undisturbed strata of ancient date, there is no possibility of compression playing a part in their origin. But, some submerged forests can be found to be above alternating layers of soft silts and vegetable matter. This vegetable matter will decay somewhat leading to a packing of the intervening silts which could cause the land surface above to sink slowly, as it is known to have happened in the Fenlands and The Netherlands.

The third method of origin, that of the destruction of a protective barrier, Reid (1913) again states that the presence of a barrier would allow the development of marsh or meadow behind the barrier which could support trees. Although the level of this protected land surface cannot be below mean tide level otherwise it would be inundated with either fresh or sea water. As submerged forests stretch well below meantide level and usually to the lowest spring tides and beyond, this rules out any breach of an ancient barrier as the origins of the submerged forests. In dismissing the geologists theories of origin of the submerged forests, Reid, proposed that the only method which could produce these deposits would be an increase in sea level (Reid, 1913; pp 3, 4, 5, 9, 28, 52, 114, 117 & 118). Although after considering the submerged forest deposits around the coasts of Britain he concluded that he was unsure if sea-level change or land subsidence was responsible for the formation of the submerged forests, (Reid, 1913; p106).

Although Clement Reid may have been generally correct in assuming that rising sea-levels were responsible for the creation of the submerged forests, evidence suggests that in many instances, growing trees were protected by a coastal barrier which has subsequently been pushed up and back by wave action, across the forest bed, which now appears on the foreshore (Heyworth, 1986). In other cases, shingle barriers are seen to have been overtaken by the rising sea, and largely left behind by it, so that the submerged forest is found behind the 'fossil' shingle ridge on the beach, at a lower level than the present storm beach (Kidson & Heyworth, 1973).

The development of new analytical techniques, especially, those of dendrochronology and radiocarbon dating have proved that this is the case (Heyworth, 1986). Where, often the trees are embedded in peat of carr or fen origin, which shows a constant relation to a rising water table. Sometimes the trees are rooted in peat but more often in a soil, or in estuarine silts and clays. The relationship of the rooting horizon to the water table is the same in each case. The almost perfect state of preservation of most submerged forest trees which is the immediately apparent indication of a rising water table. But, the original forest was killed not by a single catastrophic overwhelming or submergence event on a large scale but by a gradually rising water-table or the ingress of salt water (Campbell & Baxter, 1979). Therefore it is possible that trees of different ages can be found at different heights above sea-level as the water table rises due to the rise in sea-level, thus it is possible to observe a forest decreasing in antiquity further up the shore above mean low spring water level.

Observations made by Reid (1913) on sections through submerged forest deposits made during dock excavations revealed a general character of these deposits. The deposits associated with a typical submerged forest can be seen table 2.1.

Strata	Relative Position	Description
A	Sea-Level or just above	Uppermost deposits are estuarine silts with the remains of cockles, Scrobicularia with salt marsh vegetation. Also included are historic artefacts such as sunken boats *etc.*
B	Below Mean Tide Level.	Black peaty soil full of vegetable matter, with sallows, alder and hazel rooted in their growth positions. There may be seams of shell or Chara marl such as would form in shallow pools or channels in a freshwater marsh. These are the **Submerged Forests.**
C	Below Level of Low Water.	Bed of estuarine silt of a depth over a metre extending well below the level of low water.
D	Well Below Level of Low Water.	A second land surface, perhaps with trees differing from stratum **B**. This may be replaced by a thick layer of marsh peat.
E		More estuarine silt.
F		Another Submerged Forest
G		More estuarine silt
H	Up to 15 metres below the Level of High Water.	Stools of oak still rooted in the undisturbed rock below.

Table 2.1. Table showing the stratigraphy of the deposits associated with a typical submerged forest (After Reid, 1913)

The mechanism for this alteration of sediment types is associated with Holocene sea-level fluctuations. As already intimated, when sea-level changes occur, it can be expected that the fresh-water watertable will also alter in accordance. These changes in watertable levels can be expected to influence (along with other maritime effects such as sea-spray) the vegetation growing in the vicinity of these changes. These tendencies whether positive or negative will also influence the sedimentation regime, whereby negative tendencies promote the development of saltmarsh from mudflat and as sea-level continues to drop this is followed by freshwater reedswamp, which in turn is succeeded by swamp carr and then fen carr, this succession is reversed as sea-level begins to rise. The stratigraphy will alter from one which is mud to one dominated by peat deposits of one type or another followed by a return to mud as positive tendencies are experienced. But care must be taken as to whether the changes in vegetation and sedimentation are due to actual sea-level tendencies or to some changes in local coastal processes, as have been modelled by Allen and Rae, (1987) (Long and Roberts, 1997). Figure 2.3 demonstrates the general changes in vegetation and stratigraphy that can be expected to arise as alterations of sea-level occur.

According to Heyworth (1986), there are two main types of submerged forest. Those in which the trees were growing on pre-Holocene deposits which become drowned by the rising sea. This leads to a continuous basal submerged forest bed resting on an undulating surface, the age of the bed decreasing with an increase in altitude. The second type consists of trees which grew out across an expanse of a more or less horizontal Holocene alluvial surface, on an accreting coastline. A very slight rise in sea-level was enough to drown the trees over a wide area and produce extensive horizontal submerged forest beds such as those that can be found at Borth in Cardigan Bay.

Heyworth (1978, 1986) argued that in most cases coastal forests were overtaken by water shortly after death and then preserved. The trees are usually embedded in carr or fen peat which shows a constant relationship to a rising water-table. The trees are usually rooted in the underlying silts and clays. Heyworth carried out some investigations on modern coastal woodlands and recorded that oaks can survive the occasional Highest Astronomical Tide (HAT), and in many cases exist between Mean High Water Spring Tide (MHWST) and HAT.

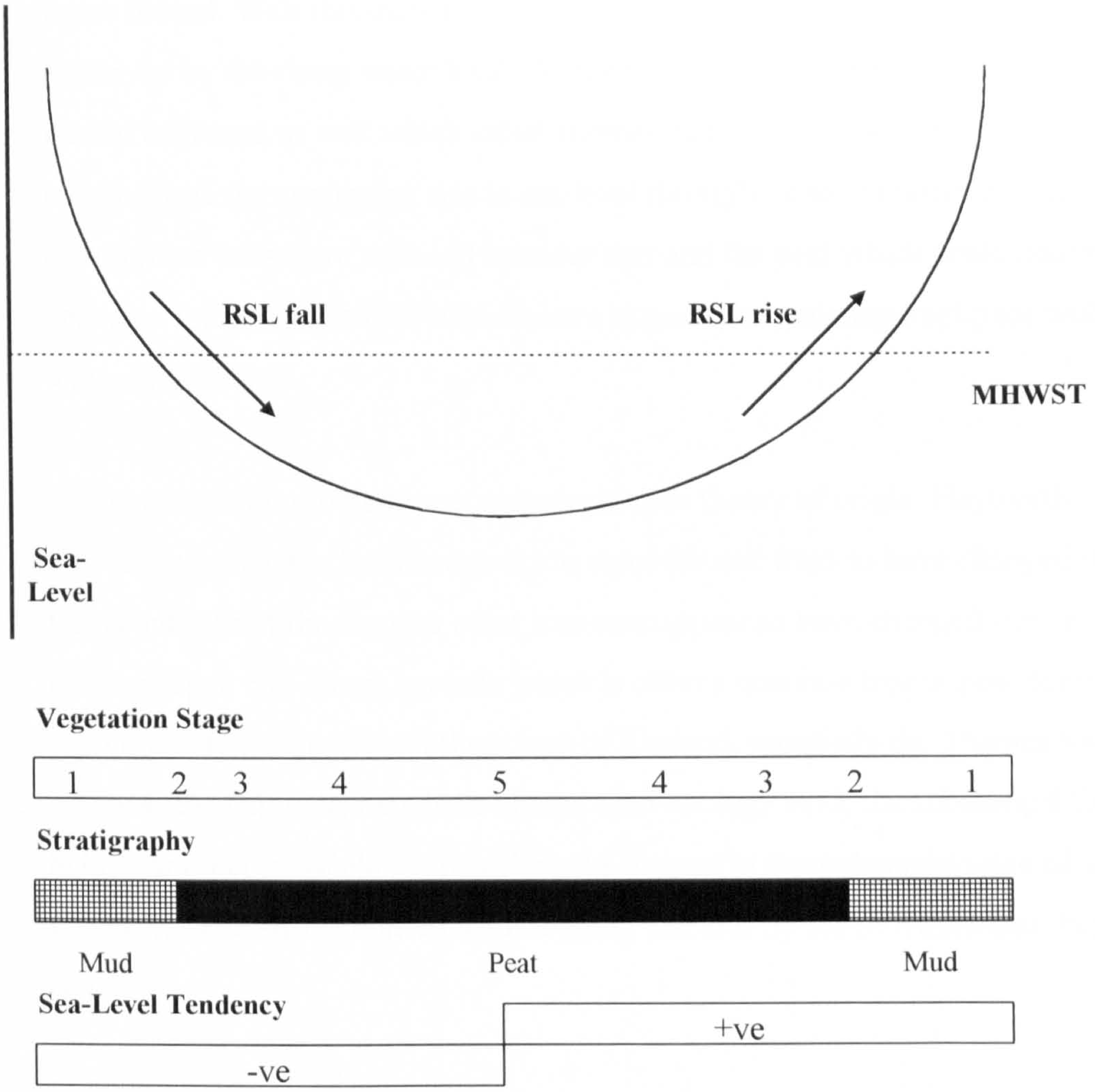


Figure 2.3. A simplified graph to show the relationship between relative sea-level (RSL), vegetation succession, stratigraphy and sea-level tendencies. (After Long and Roberts, 1997). (1) mudflats; (2) saltmarsh; (3) freshwater reedswamp; (4) swamp carr; (5) fen carr.

Therefore it follows that the roots of oak trees are below the level reached by several high tides each year and the trunks of oaks can survive submergence in sea-water up to 1 metre in depth many times during its life time. In order for oaks to survive this inundation, Heyworth suggests that oak roots possess root hairs which have the ability to actively control the entry of ions into the root system, although, in reality the water surrounding the roots is not sea water but at best brackish. He suggests that what actually kills the trees is not submergence in sea-water but the anaerobic conditions provided by a constantly high water table produced as a response to a rise in sea-level. Therefore as to the origin of the submerged forest deposits Heyworth argues that as the sea rose, a coastal barrier ponded up water behind. With this increase in the water-table the oaks were killed and in turn preserved by the rising water level. As the barrier moved landward the area ponded up moved landward as well which killed another belt of trees, thereby producing a deposit which charts the continuing rise in sea-level throughout the Holocene period. As sea-level rose further oaks were replaced by alder carr and fen peat which could perhaps have persisted for 100's if not 1000's of years as peat accumulation kept pace with the rising water levels.

There are several problems associated with this theory of origin. Heyworth declares that the time period since the last ice-age is too short for oak trees to have changed their ecology, this is indeed not the case, as other tree taxa appear to have changed their ecology during this time span e.g. *Taxus baccata* which is often a common tree in peat deposits and submerged forests in the southern part of England, especially the Thames Valley, therefore it is possible that oaks may have altered their ecology since the submerged forests were living. Another possibility is that the oaks present in these deposits were of a genotype which was less susceptible to waterlogging whether by sea or freshwater but has since died out.

Secondly, if the sea level rises and induces a corresponding rise in water table, this would not be a local effect but would surely kill not just the trees immediately behind the coastal barrier but those further back would also die. Therefore no successive deaths of belts of trees would occur as the barrier migrated landward. Heyworth (1978), when studying the tree rings of the oaks at Stolford states that the outer rings of the oaks were very narrow, this suggests that the trees were under some sort of stress and as the sequences of narrow rings were large it can be suggested that the trees were able to survive long periods of waterlogging before being killed. It may also be possible that oaks would be able to survive in fen carr situations with its inherent build up of fen peat. In fact woodlands which are mainly dominated by alder have been recorded as having oaks present in the drier parts (Rodwell, 1991a) therefore it could be possible that what appears at first to be a succession to alder carr in the submerged forests after the death of the oaks, may well not be the case and that some of the oaks may well be part of the development of the alder carr with new roots developing above the rising water-table, only dying when the water-table becomes too high and the trees die from physiological drought due to anoxic conditions.

It has been observed by European researchers that *Quercus robur* has a tendency to grow in more moist conditions whilst *Quercus petraea* prefers to grow in drier situations (Jones, 1959). Hence *Quercus robur* can be found growing in moist hollows, by streams and rivers and on wet soils in general. In Europe, *Quercus robur* forms riverine forests associated with *Ulmus* spp, *Carpinus betulus, Acer campestre* and *Fraxinus excelsior* they are often flooded every winter and *Quercus robur* can withstand prolonged flooding, (Babos, 1953; Puster, 1924 in Jones, 1959) which appears to contradict the observations made by Heyworth (1986). According to Jones, (1959), *Quercus robur* is one of most tolerant of tree species to inundation by sea-water both in East Anglia and the Netherlands (Richardson, 1955), but if completely submerged the trees are rapidly killed off (Pfeil, 1847; Puster, 1924). This suggests that oak trees are able to survive in waterlogged conditions whether freshwater or sea-water for longer periods than Heyworth has suggested, in fact if Heyworth is correct and that the trees are soon killed off after an increase in water-table, there must have been a large rise in sea-level in order for the trees to become completely submerged. In fact, Richardson (1955) discovered that one year old oak seedlings could survive at least eight weeks flooding, although the existing roots ceased to elongate after twenty-four hours' submergence, new roots were produced, suggesting that if flooding was short term the forests would be able to regenerate easily enough to ensure the continual presence of coastal woodland.

It may therefore be stated that there may be more than one mode of origin for the submerged forests and their origin is dependent on the local conditions. Although it is plain that a rise in the water table (related to a corresponding rise in sea level) is one of the main factors in their formation.

2.7. Early Research

Reid (1913) realised the potential for submerged forests at the beginning of this century. In these deposits, he suggested that geologists would be able to study ancient changes in sea-level, whilst archaeologists would be able to find remains of ancient human cultures with associated artefacts such as weapons and tools along with domestic objects such as basketry and pottery. Zoologists and botanists, he continued could study each successive layer which would yield evidence of gradual changes and fluctuations in our fauna and flora during periods of little or no human influence.

Early work, although usually of an excellent scientific standard tended to be carried out unsystematically or from the point of the geologist alone. To address this imbalance, Clement Reid (1913) suggested that the deposits should be examined bed by bed with nothing being overlooked, whether it belonged to geology, archaeology or natural history. He thought it was more important to get a full overview of what was happening in the past, such as, how did past human cultures exploit the environment, the distribution and nature of past faunas and floras as well as on the methods of migration of animals, plants and humans across from Europe after the end of the last Glacial period. This approach to studying the submerged forest deposits in such detail was in the main initiated by Clement Reid himself, although inspiration was sought from other key workers such as, Fleming, (1822); Godwin-Austen, (1865); Pengelly, (1865); Day, (1866); Lucy, (1877); Keeping, (1878); Praeger, (1895); Prevost *et. al* , (1901); Rogers, (1908) and Wright, (1912).

2.8. Later Twentieth Century Research

After this initial interest in submerged forests, research began to tail off, as the questions that could be asked of the deposits using the current techniques diminished. It was not until the advent of pollen analysis that the research interest in submerged forests was rekindled. Most of the palynological work on the British submerged forests was carried out by Godwin and his co-workers. Most of this work was concentrated on the exposed forest beds in Wales mainly at Borth, but other studies were carried out on sections exposed during dock excavations as at Southampton, and from boreholes at Swansea, Portsmouth as well as on the East Anglian Coast. (Godwin & Newton, 1938; Godwin & Godwin, 1940; Godwin, 1945b, 1968, 1978). This work mainly entailed the analysis of the tree pollen spectra from the relevant sites in order to build up a picture of the past forest history of the British Isles, The plant macrofossil evidence was rarely studied as this was thought to have been covered sufficiently by earlier workers as mentioned above, Godwin (1940b) himself regarded the plant identifications as not being very useful as 'for all were of species still within our own flora: the deposit was not old enough to include plants now extinct here, and except in rare interglacial beds we cannot expect to find such in our coastal peats'.

Although he did mention that the 'identification of fruits and seeds may of course still be most profitably pursued, not only to establish climatic & edaphic conditions during the formation of the bed, but also to trace by correlations with all the dating indices which may be available, the actual occurrences of our native plants in the different stages of our prehistory'. But, very little of this work involved any ecological analyses of the macroremains.

Other work has been carried out on the submerged forests of Britain using the remains of the tree stumps themselves. This work has taken several directions: Bibby (1940), was one of the first workers to realise the potential of using the submerged forests in determining past storm events. Using the exposed submerged forest deposits at Rhyl and Abergele in north Wales, Bibby recorded the general direction of fall of the prostrate tree trunks. This helped to determine the prevailing wind pattern in the past and aided palaeoclimatologists and palaeoecologists to study past climate changes. This work has been carried out more recently by Allen (1992a, b & c), working mainly on the exposed forest beds in the Severn Estuary and Bristol Channel. By comparing the effect of strong winds on modern trees and forests with the evidence found in the submerged forests he has been able to deduce the direction of strong palaeowinds, which in turn may help to understand the future effects of global warming.

As it is now generally accepted that submerged forests were killed by an increase in sea-level, submerged forests have been used to help determine the pattern of past Holocene sea-level changes. This has been approached by using dendrochronology (Heyworth, 1978 & 1986) and radiocarbon dating (Campbell & Baxter, 1979; Godwin & Willis, 1961 & 1964; Heyworth, 1978; Tooley, 1974). Heyworth argued that the use of dendrochronology on submerged forests would be more sensitive in detecting discrete events of changing sea-level rather than radiocarbon dating, due to the differences in the frequency of sampling between the two methods. Heyworth (1978) from analysing tree ring-width patterns in a particular locality at different elevations was able to determine the rate at which the sea-level rose. From studying tree ring patterns from distant areas, (in this case, Bridgwater, Cardigan and Morecambe Bays) and now at slightly different elevations, the trees have been found to have died, as a result of marine transgressions , at almost exactly the same time.

The uncertainties of the isostatic movement of land that can confuse the true history of sea-level rise can be removed by using dendrochronology (Heyworth, 1978). Studies have shown that the trees at Stolford, Borth and Alt Mouth were all radiocarbon dated to approximately 4,500 BP and had died as a result of a marine transgression within a period of less than 50 years (Heyworth, 1978). Heyworth recorded the present altitudes of each site (Stolford, +2.0m; Borth, +0.1m; Alt Mouth, +3.3m O.D.) and allowing for the differences in tidal range, the equivalent heights of each submerged forest deposit relative to zero datum at Stolford are:- Borth, -0.1m; Alt Mouth, +2.5m. He implied from this that since the trees died, there has been an isostatic uplift relative to Stolford of 0m at Borth and 2.5m at Alt Mouth. The present MHWM at Stolford is +4.5m O.D., whilst at 4,500 BP it was +2.0m (the altitude of the submerged forest) and therefore there has been an eustatic sea-level rise of +2.5m, which disputes Mitchell's (1970) hypothesis that the sea-level at 4,500 BP was almost 4m above that of today.

According to Heyworth it may be possible in the future to link all known submerged forest dendrochronologies in this way and to provide a measure of absolute and relative sea-level rise of far greater precision and reliability than hitherto possible.

In conjunction with radiocarbon dating, the use of dendrochronology has led to a better understanding of not just how the submerged forests formed but for how long they existed. The trees at Stolford produced a chronology of 4052-3779 BC whilst at Woolaston, the submerged forest deposits produced two chronologies of 4096-3809 BC and 2843-2692 BC reflecting two phases of tree growth. At Wotton Quarr on the Isle of Wight a total chronology of 3463-2694 BC was obtained but consisted of a least seven separate inundation events (Hillam, 1994). Radiocarbon dating of the submerged forest deposits on the Essex coast has shown that they date from 4190-3660 BP, the later Neolithic, (Wilkinson & Murphy, 1995). Tree ring studies at Stolford submerged forest in Bridgwater Bay (Heyworth, 1978) have shown that the submerged forest lasted for over 500 years. Tree rings of two adjacent trees have shown that one died 160 years later than the other providing evidence for a long period of sea-level stability allowing for the trees to grow quite successfully and for re-generation to occur. The presence in some trees of long sequences of narrow rings which were absent in others also suggests that there were long periods of little change.

Submerged forests have also been used to aid the solving the problem of past fluctuating atmospheric ^{14}C concentrations which dog the accuracy of radiocarbon dating. Campbell and Baxter (1979) measured the ^{14}C concentration within ten ring width samples from a variety of well dendrochronologically studied submerged forests, (Borth, Ynyslas and Stolford). They managed to show that the atmospheric concentration of ^{14}C changed smoothly through time although there were occasional more rapid fluctuations superimposed on the gradual trends.

2.9. Most Recent Research

The archaeology of coastal areas has in recent years become a main focus of English Heritage and the Royal Commission for Historic Buildings and Monuments England and has resulted in a joint publication, "England's Coastal Heritage" (Fulford, Champion and Long, 1997). A complete chapter is devoted to submerged forests and provides a brief resume of past and current research (Bell in Fulford, *et.al.* 1997).

The most recent work has been carried out on the Essex Coast with the Hullbridge Survey (Murphy & Wilkinson, 1982; Wilkinson & Murphy ,1983 a & b; 1984; 1986a & b; 1987; 1988;1995) and on the Welsh coast of the Severn estuary, these surveys have been concerned with the surveying of the intertidal deposits and recording and sampling both archaeological features as well as natural ones such as submerged forests. In both cases the submerged forests have been surveyed, sampled and analysed to produce an environmental background for the associated archaeological features. On the Essex coast, substantial submerged forest deposits were recorded in the estuaries of the Crouch (where 600 metres of fallen trunks and *in situ* stumps were recorded), Blackwater and Thames. The *in situ* stumps have been found to be rooted in various substrates either in the old land surface (Blackwater estuary), freshwater fen (Crouch estuary) or in estuarine clays (Thames estuary) submerged forests have been radiocarbon dated to be between 4190-3660 BP, the later Neolithic. The species of trees identified from the submerged forests on the Essex coast include oak at Blackwater, oak, alder and elm on the Crouch and at Purfleet on the Thames, ash, alder, yew, holly and elm have been found within and on the surface of the peat beds, whilst the drifted trunks on the surface of the underlying estuarine clays consisted of elm, alder, hazel and ash. A full regime of environmental sampling and analyses (pollen, diatoms, plant macrofossils as well as molluscs and other faunal remains) has been carried out in conjunction with a comprehensive radiocarbon dating programme and limited archaeological excavation and recording has resulted in the production of a model of the changing environment of the Essex coast from the Mesolithic to the present day and its exploitation by past cultures.

On the Severn estuary a similar survey has been ongoing since 1989 at Goldcliff, 5 km east of the River Usk at Newport (Bell, 1993). The original work by Smith and Morgan (1989) produced a fully radiocarbon dated pollen sequence from the area which provided a "baseline for a research programme on the archaeological and environmental history of the Severn estuary under the aegis of the Severn Levels Research Committee". The discovery of the archaeological features at Goldcliff since then has underlined the importance of carrying out large scale surveying and small scale excavations of both natural and archaeological features in the intertidal zone, (Bell, 1993). In 1993, three kilometres of shore had been surveyed, a total of 1.6% of the Severn Estuary shore with fourteen areas having been planned and excavated. Samples for dating, wood analysis and environmental studies were also taken and are currently being processed and analysed.

Apart from the archaeological features (trackways and various other structures), an exposure of submerged forest was recorded, planned and sampled. This submerged woodland on the peat shelf is as yet undated but samples for dendrochronological analysis have been taken (Johnson, 1993), but it is estimated to be Mesolithic to Neolithic in age. Alder and birch predominate over the whole area with smaller amounts of willow recorded in the southern part with oak and Pomoideae trunks and stumps present in the northern part (Johnson, 1993). Other species such as alder buckthorn, ash, elm and field maple have been identified from the trackways and structures in the form of stakes, pegs and brushwood. So far, the analysis of plant macrofossils from the submerged forest deposits have not been published.

Another comprehensive survey and analysis has been undertaken on the Isle of Wight at Wooton Quarr, not only have the stumps and trunks been recorded *in situ*, but a whole suite of palaeoenvironmental investigations have been undertaken including pollen, diatom and insect analysis. Again there is archaeology associated with the remains which are under threat of erosion from the wash of passing ferries.

In Eire, as part of the Discovery Programme, the North Munster Project carried out surveys of the Shannon Estuary between 1992 and 1995. These surveys produced a range of Prehistoric and Medieval finds, wooden structures and environmental deposits (O'Sullivan, 1997). Amongst the environmental deposits submerged forests were recorded. Nine separate exposures of Neolithic submerged forests of Scots pine and oak were located in the estuary.

Therefore, more recently, submerged forests have been recorded and analysed, but the main aim of these recent surveys is to record and analyse the archaeological remains present on the foreshore and to use the presence of submerged forests to provide the environmental backdrop, without any further detailed analyses being carried out apart from those summarised above.

2.10. Summary

It has been established that submerged forests can be seen around many parts of the coast of the British Isles and have been recorded from a very early date (Giraldus Cambrensis, 1188). They have been found to vary in date, but the majority are found between 4000 and 5000 BP. Models of their origins have ranged from the subsidence of the land due to the weight of the deposits to landslips, but it is now accepted that the rise in sea-level since the last glaciation has been responsible for their preservation. The early work on these deposits was mainly carried out by geologists with later work being dominated by palaeoecologists and archaeologists. The early work concentrated on the recording of the tree remains within the deposits. This was followed by the pioneering work of Clement Reid at the end of the Nineteenth and beginning of the Twentieth Century who concentrated on the identification of the plant macrofossils within the deposits which culminated in the production of a volume entitled "Submerged Forests" (Reid, 1913). With the advent of pollen analysis, the majority of the modern work has concentrated on using the method to help determine the Holocene forest history of the British Isles. The development of more accurate dating techniques such as radiometric dating and dendrochronology, the submerged forests became a useful tool for determining the pattern of sea-level change throughout the Holocene.

In more recent times, surveys of the coastal areas of Britain and Eire have been initiated and have produced a wealth of environmental and archaeological evidence for past coastal processes and environments and their exploitation by past human communities. These more recent surveys have characterised the submerged forest deposits to a certain extent but have not attempted a more dynamic approach to their characterisation. The following chapters will show an approach towards this more dynamic characterisation of two submerged forest deposits.

Before these chapters are presented, it is necessary to give an brief outline of Holocene woodland history in order to put the results and applications of this thesis into perspective.

Chapter Three

EARLY- MID HOLOCENE WOODLAND HISTORY

3.1. Introduction

In order to put the findings of this work into perspective, it is necessary to give a brief outline of the development of forest cover since the end of the Weichselian Glacial period, approximately 10,000 years ago, up until the end of the end of the Atlantic Period (5500-5000 BP). By this time, the majority of the native trees had entered the British Isles and the introduction of further species was hindered by sea-level rise. This led to competition between the tree species present which produced the character of the 'wildwood' cover of the British Isles. The end of the Atlantic Period is marked by the decline of elm pollen in pollen profiles, which is generally attributed to the increase of agricultural practices and forest clearances (both temporally and spatially) associated with Neolithic cultures. More recent work by Peglar (1993) analysing pollen contained within annually laminated sediments at Diss Mere, Norfolk has provided evidence for the role of disease in the decline in elm pollen within that area. At Diss Mere, the *Ulmus* pollen values decline by 73% over six years. Peglar suggests that this rapid decline is more attributable to a pathogen. Therefore the mid-Holocene 'elm decline' was caused by a combination of disease and human activity. This conclusion is supported by researchers working in other parts of the UK, (Girling & Greig, 1985; Girling, 1988; Scaife, 1988).

Most of the evidence for forest development has arisen from palynological data gathered from suitable deposits such as peat bogs, valley basin mires, lake sediments and fen peats. Due to the unequal distribution of these deposits, certain areas of Britain such as the midlands and the south-east of England are under-represented. Therefore only general patterns can be ascertained.

Most early workers considered the climatic climax vegetation of the British Isles to be mixed oak forest with areas locally dominated by other species where favourable conditions were found. The only areas considered not covered were coastlines, lakes, large rivers and mountain tops (Godwin, 1940a; Erdtman, 1928; Moss *et. al.*, 1910; Moss, 1911 ; Tansley, 1939).

As research progressed and more sites analysed and more rigorous techniques developed it became obvious that this was not the complete story and that variations did exist due to changes in local climate, topography, soil types, aspect and other non-biological factors.

The study of forest history of the British Isles has been in many cases supported by macrofossil evidence such as fruits and flowers or even buried trees preserved within the deposits. Charcoal deposits from Palaeolithic and Mesolithic sites have been useful in reconstructing the vegetational history of the British Isles.

3.2. Climate

At the end of the Weichselian glacial period there was a swift improvement in climate with a rise in temperature reaching a maximum at the 'Hypsithermal' interval between 7000 BP and 5000 BP where the mean summer temperatures were 2-3 °C warmer than present (Godwin, 1975 a & b). Temperatures then began to fall although not uniformly with changes in oceanicity also occurring, and by 5000 BP, sea-level had reached its approximate present level.

3.3. Pre-Atlantic forest history

The palynological evidence has allowed the identification of nine pollen zones which characterise changes in vegetation of the British Isles, from the late glacial until the present day. Although this zonation is now considered to be too crude to be applied to every pollen diagram (due to the recognition of local variations and non-synchronous changes in vegetation), it can be used here as a useful guide to the development of the forest cover of the British Isles (Godwin, 1975 a & b; Peterken, 1993; Rackham, 1980).

3.3.1. Zone IV - The Pre-Boreal, 10500-9500 BP

During this zone at the end of the Weichselian glacial period the climate warmed up rapidly leading to a continuous forest over almost the whole of Britain, except at altitude where there remained open vegetation. Birch (*Betula* sp.) was the commonest tree with pine widespread and especially abundant in the southern part of Britain. Hazel (*Corylus avellana*) was very abundant in the north-west. There are records of aspen (*Populus tremula*) and alder and a few records of lime (*Tilia* sp.).

3.3.2. Zone V - Early - Mid Boreal, 9500-9000 BP

Hazel continues to increase and extended southwards in England and Ireland. Pine (*Pinus sylvestris*) increases northwards with birch decreasing in abundance but still remaining generally common. The Highland Zone was predominately a mix of hazel and birch and the Lowland Zone, one of pine and birch. Rare records of oak (*Quercus* sp.) and elm (*Ulmus* sp.) appear but are widespread, lime is still rare.

3.3.3. Zone VI. Mid-Late Boreal. 9000-7500 BP

This is known as the age of hazel which became very abundant throughout the British Isles. Pine is common in Scotland, Ireland, Wales and England. The abundance of oak increases in England, Wales and Ireland but is still rare in Scotland. Elm increased everywhere but especially in Ireland. Lime is common in the southern half of England. Alder (*Alnus glutinosa*) has a modest increase in abundance but still not commonly found in pollen profiles. Birch is declining and becoming uncommon in most of England and Ireland. Ash (*Fraxinus excelsior*) is first recorded in this zone where it is rare but widespread. Holly (*Ilex aquifolium*) is widespread and especially abundant in Ireland, Wales and western England. In southern England beech (*Fagus sylvatica*) is recorded for the first time along with hornbeam (*Carpinus betulus*).

3.3.4. Zone VIIa. The Atlantic Forests. 7500-5000 BP

High temperatures which began towards the end of the Boreal, continued into the Atlantic period. These increased temperatures led to a rise in sea-level which in turn cut off Ireland from Britain and then Great Britain from mainland Europe. More recent research suggest that earlier dates for separation are the case. Wingfield (1995), suggests that the final landbridge between Britain and the Isle of Man was transgressed after 9,000 BP. Devoy (1985), proposed a pre-Holocene separation between Britain and Ireland at approximately 12,000 BP. The separation of Britain from mainland Europe by rising sea-levels in the Strait of Dover is currently estimated to have occurred around 8300 BP (Bennett, 1995; Jelgersma, 1979). This isolation meant that few, if any plant species could migrate into these islands, although this is debatable (Bennett, 1995). This coupled with the long period of stable climate allowed the plants especially the tree taxa to produce a series of climax plant communities by prolonged competition and succession (Bennett, 1989; Godwin, 1975 a & b; Rackham, 1980).

This period of stable climate also allowed those tree species present in the British Isles to expand and in most cases reach the limit of their ranges due to climatic improvement. Alder rapidly increased throughout Britain and in many deposits it becomes the commonest type, this was partly a thermal response and due to the general waterlogging of the plains and valleys where the tree occupied wet glades.

Lime, a thermophilous species becomes very common in England except in the extreme north, and in Wales. Lime never reached Ireland and there are doubtful records in Scotland. Oak increased modestly in abundance with pine declining considerably except in the Scottish highlands and parts of Ireland. There are moderate decreases in hazel and birch probably due to increase in the closed canopy. The abundance of elm was almost unaltered from that attained in the Boreal period. Holly and ash also increased in abundance during the Atlantic period.

The only trees not to have completed their migratory movements were the latecomers beech and hornbeam. The distributions of the tree species were in the main determined by natural environmental controls. Pronounced regional differences were noticed by the early workers

(Erdtman, 1929; Godwin, 1940a; Pennington, 1974) between England and Wales and central and northern Scotland. In the former, the deciduous woodland is dominated by oak, lime and elm with abundant hazel and alder with ash in smaller amounts extending over the whole of England and Wales at higher altitudes than conditions allow today. North-western woodlands still had a lot of birch while its presence further south was restricted by the closed canopy of the woodland. In the central and northern highlands of Scotland the climax vegetation was pine-birch forest with oak, elm, hazel and alder locally common in the west of Scotland responding to the local soil and climate conditions. South of the Clyde-Forth line there are higher frequencies of oak, hazel and alder leading to a more southern type of woodland. This regional difference may be in part explained by a marine transgression north of the Clyde-Forth line which was responsible for the carse clay deposits.

3.3.5. The end of the Atlantic Period 5500-5000 BP

The woodlands that were established at the end of the Atlantic represent the last wild wood before Neolithic cultures had an increasing effect on the nature of the woodland. The end of the Atlantic is marked by the elm decline.

As more sites were studied and the interpretative tools developed, it became evident that the Atlantic forests were not a blanket mixed oak woodland. Regional and local variations were noted by several authors (Huntley & Birks, 1983; Birks *et. al.* , 1975; Rackham, 1980 & 1986; Greig, 1982; Bennett, 1989).

3.4. Woodland Variation in the Atlantic Period, approximately 5500 years ago

Birks *et. al.* (1975), carried out principal components ordination on 145 pollen diagrams taken from all over the British Isles. The pollen frequencies in the profiles had been recalculated using coefficients which compensate for the differential production of pollen by different tree taxa. (Andersen, 1970). Lowland England and the extreme north-east of Scotland and the islands were poorly represented due to pollen preserving deposits being rare or absent in these areas.

These analyses recognised six variations in the Atlantic wildwood. These are as follows:-

1. Pinewoods. These were present in the central Scottish highlands and on certain mountains in Ireland. Pine retreated from the rest of England, although it was present locally in the Lake District and in the Fens.

2. Birchwoods. These were found in the Scottish highlands and other Irish mountains and locally in southern Scotland, the Lake District, Wales and southwest England.

3. Woods of hazel and elm which predominate over the most of Ireland and locally in Wales and southwest England.

4. Woods of oak and hazel which predominate in western Ireland and most of the highland region of Great Britain, a variant in northern England included ash.

5. Lime woods. Where lime is the commonest tree, these woodlands predominate throughout lowland England and found as far north in Lancashire. The second commonest tree varied irregularly between oak, hazel or ash.

6. Woods of alder occurred throughout Britain but rare in the Scottish highlands, western Ireland and southwest England. It mainly fringed lakes and peat basins.

Rackham,(1986), simplified and amalgamated this evidence with more recent data and proposed five woodland provinces (Figure 3.1)

1. The Pine Province of the eastern Scottish highlands, with outliers on mountains in England and Ireland.

2. The Birch Province of the western Scottish highlands.

3. The Oak-Hazel Province of southern Scotland, highland England, most of Wales, and parts of Ireland.

4. The Hazel-Elm Province of most of Ireland and probably of southwest Wales.

5. The Lime Province of lowland England.

A more detailed map showing the variation of woodland at 5000 BP was attempted by Bennett (1989) (figure 3.2). He pointed out that there had been little interest in producing a palaeovegetation map of the British Isles due to the low density of sites across the British Isles that would show up detailed variations due to complexities of topography, local climate and edaphic conditions.

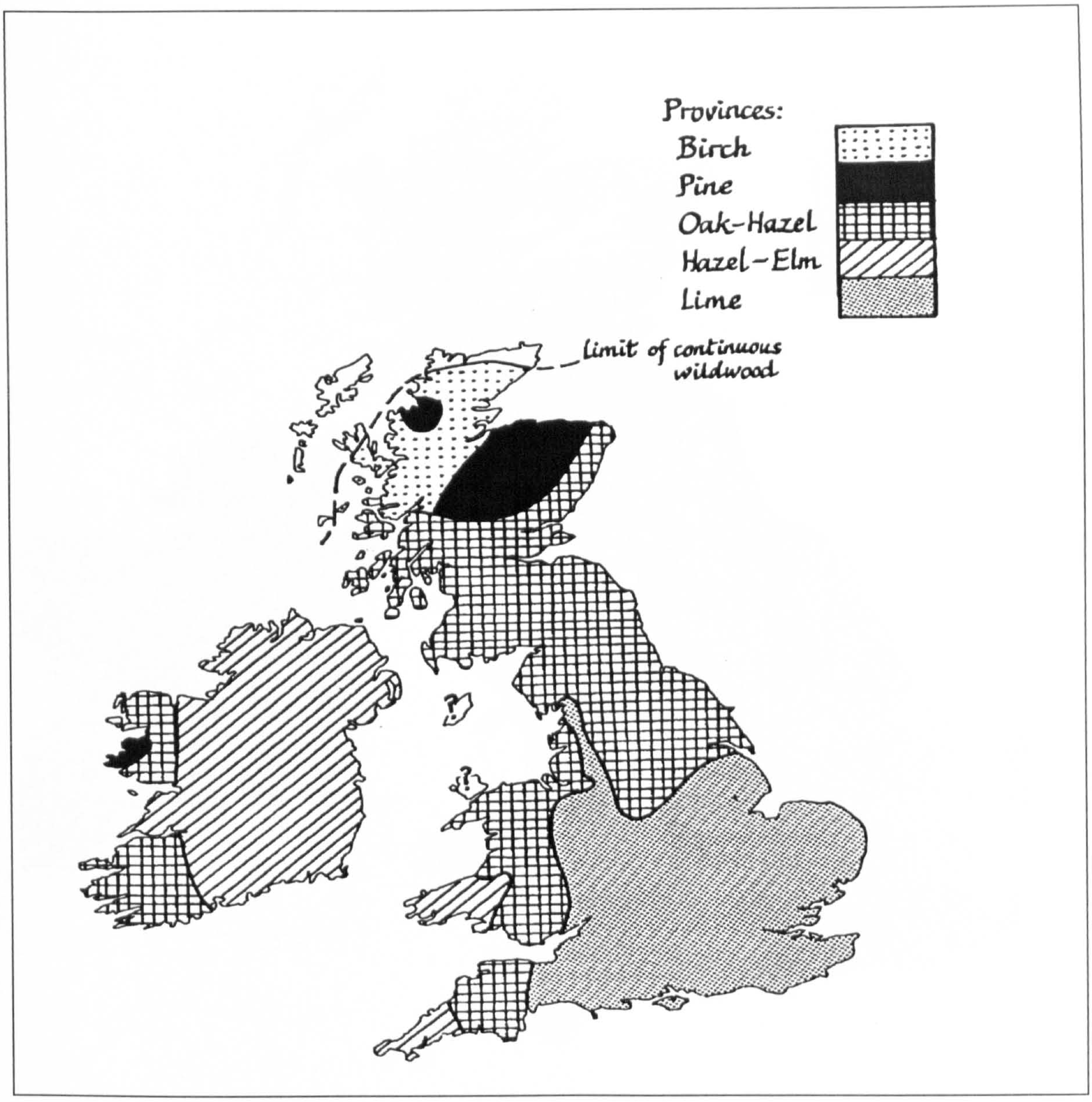


Figure 3.1. General Map of the Five Woodland Provinces proposed by Rackham, using data from Birks *et. al.* (1975). (From Rackham, 1986).

Using summaries of pollen data combined with the soil maps of the British Isles and the modern ecologies of the taxa present which helped to determine which taxa were most likely to be dominant on which soil types in each region of the British Isles. Allowances were made for major soil changes since 5000 BP (e.g. the spread of blanket peat), the effects of altitude and spatial variation in climate across the British Isles. The provisional map (Figure 3.2) consisted of the following units:-

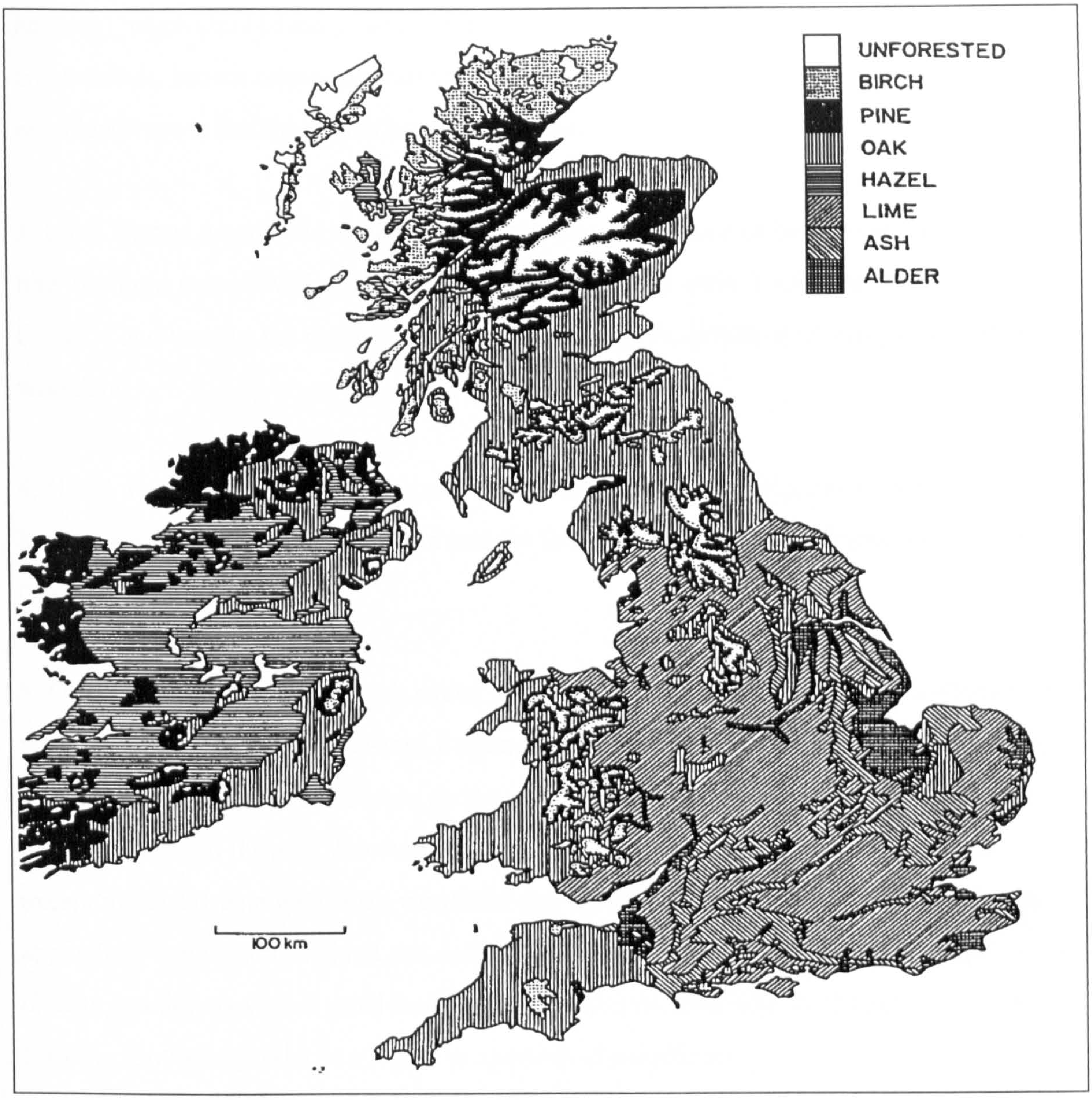


Figure 3.2. A provisional map of the forest cover of the British Isles around 5000 BP. (After Bennett, 1989)

1. Alder. This woodland type occurred on alluvial earthy peat soils which occurred frequently across the British Isles mainly at lake margins and river valleys. Only occasionally are the alluvial soils extensive enough to be mapped. Bennett suggested that alder woods may also occur on flushed hillsides in north-western Scotland.

2. Ash. Woodlands on calcareous soils and shallow soils on chalk. According to Bennett, the only trees that are abundant on calcareous soils are ash, lime, hazel, yew (*Taxus*

baccata), wych elm (*Ulmus glabra*) and maple (*Acer campestre*). Ash is the main dominant on rendzinas, brown calcareous earths and calcareous palaeosols. Distribution of this woodland type is limited to south and east Britain.

3. Lime. Forms woodlands on fertile non-calcareous soils such as brown earths, podzols and fine -textured non-alluvial, gley soils in England, north to north Yorkshire and south Cumbria and west to the uplands of Wales. Further north, similar soils carry oak dominated woodland.

4. Hazel. Forms woodlands on calcareous soils and poorly drained gleys as well as the basaltic soils of north-eastern Ireland and the Inner Hebrides in areas beyond the 5000 BP range of ash.

5. Oak. Of the two species of oak native to Britain, *Quercus petraea* forms woodlands on acidic infertile soils in south eastern England. Oak dominated woodland forms on nutrient poor sands and podzols and brown earths as well as fine textured, non-alluvial gley soils, north and west of the area dominated by lime and on all non-calcareous soils in Ireland except in the extreme west. Oak woodland also formed an altitudinal band below pine but above lime in northern England and eastern Wales. In these areas the combination of wetter climate, leading to a more rapid leaching of soils and the generally harder siliceous rocks than the southeast produces a higher proportion of suitable soils.

6. Pine. Forms woodland in western and northern Ireland and an altitudinal band above oak (or hazel) in the uplands of England, Wales and the rest of Ireland and the central and eastern Scottish highlands. Pine had not reached its widest distribution at 5000 BP as it is absent from the Hebrides and extreme north of Scotland despite the presence of suitable soils and climate. Pine was never abundant in southwest England and south Wales.

7. Birch. Birch grows on virtually all soils and at 5000 BP it is present over most of the British Isles. Its low shade tolerance means that birch is able to form woodland where the climate is too extreme for other tree taxa. It is also found in areas of the extreme limit of woodland growth in the north and west and at high altitude.

Bennett (1989), states that his map displays a spatial arrangement of vegetational units much closer to reality. The patterns revealed are as follows:- The woods of Ireland differ to those of Britain due to soil differences and absence at 5000 BP of ash. The oakwoods of western Wales and the south west Scotland have counterparts in eastern Ireland on acid soils. In central Ireland, hazel predominates on the calcareous soils, pine has a curious distribution it occurs in most mountainous areas as an altitudinal band. It was present in extreme western Ireland but not in the extreme west or south western Scotland. In the east and central Scottish mountains it forms extensive tracts at middle altitude (200-300m) with declining altitude limits northwards, pine reaches sea-level. In central England and Wales it was possible to find an altitudinal zonation at 5000 BP from lime at the lowest elevation followed by oak then pine, birch and then open ground at the top.

The approaches of Birks *et. al.* and Rackham produce a rough idea of the forest types of the British Isles whilst Bennett tries to produce a more accurate map by combining pollen evidence with soil type distribution. With this approach, problems arise in the use of the modern ecology of the trees and soil distribution as it is possible that since five thousand years ago, the ecology of the tree species may have altered and the modern distribution of soil types may not have matched that of the past and may not have even been present. All the researchers mention that in reality there was probably more local variation than be expressed on small scale maps, with most of the woodland being composed of mosaics of tree species rather than blanket cover. This would be due to the local variations in soils and climate, although there is no real evidence for this in the pollen record.

Studies of the submerged forests around the coast of Britain may help to fill this gap in the knowledge of the nature of past woodland types and may help to elucidate the nature of the local variation simply due to the fact that the stumps and trunks are preserved *in situ*. This would also permit for the possibility of showing the character and variation that can occur in woodlands then, as can be certainly seen in woodlands today. (Rackham, 1992). The following chapters show how this can be approached, beginning with how the submerged forest deposits were recorded and sampled in the field and the laboratory techniques used to extract the relevant data.

Chapter Four

METHODOLOGY

4.1. Field Methodology

As stated in the introduction, submerged forests provide an excellent opportunity to study past forest ecosystems. It may be argued that these forests may be marginal and not truly representative of the real primeval forest cover due to the coastal context, nevertheless, it must be stressed that they do represent a variant of the primeval forest biotype and are therefore suitable for the overall objective of understanding the past ecology of these habitats.

Submerged forests can be found all around the coasts of Britain (see chapter 2, section 2.3 and figure 2.1). Two areas have been chosen to be analysed in this thesis, these are Hightown near Formby on the Sefton coast and Anderby Creek and Wolla Bank on the Lincolnshire coast. The reason why these two areas were chosen was to deduce the similarities and differences between submerged forest deposits on the east and west coasts and to see if similar processes occurred at both locations.

Sampling procedures for each submerged forest has been on four levels. The first level concerns the actual recording and planning of *in situ* stumps and other significant features of the submerged forest, such as large fallen trunks and branches. This involves the determination of the O.D. of the forest; measurements of stump diameter; length & diameter of fallen trunks and branches including their orientation. This enables the reconstruction of the final character of the submerged forest as it was killed. It has not been possible to determine whether the trunks had fallen or been blown over pre- or post death of the forest. Large tracts of the forest beds have been difficult to survey due to the reliance on exposure of the forests by tides which limits the time for planning *in situ*. Beaches tend to aggrade in summer therefore cover up most of the submerged forest exposure, whilst in winter, with the increased frequency of storms larger tracts of submerged forest will be visible. Although there will be an increase in the amount of erosion leading to the possibility of sample bias. This has led to smaller areas being surveyed in greater detail.

The second level of investigation involves the sampling of the stumps and trunks/branches considered not to be too decomposed in order to permit the identification of the tree species and for radiocarbon dating to establish the age of the deposits.

The third level of investigation involves the sampling of complete vertical sections through the forest floor and the underlying sediments. Metal 50 x 10 x 10 cm monolith tins were driven into cleaned vertical sections in order to maintain the inherent stratigraphy to permit the fourth level of sampling in the laboratory for plant macrofossil investigation. As well as sampling the vertical stratigraphy of the sites, it was also decided to study samples of the forest floor, in order to detect any spatial variation across the sites. These samples were collected in monolith tins placed horizontally across the exposures, this has only been possible at Hightown.

4.2. Laboratory Techniques

4.2.1. Tree species identification

The wood samples have been thin sectioned with a razor blade and examined microscopically so as to obtain species identifications. Thin sections need to be taken from the transverse, radial and tangential sections in order to achieve a correct identification. These thin sections obtained are temporarily mounted in water and examined under a high power microscope (x40 -x1000). A large enough section is required so that any ring-porous characters can be determined. Comparisons are made with a modern reference collection and anatomic atlases e.g. Schweingruber, (1982).

4.2.2. Plant macrofossil analysis

The analysis of the monoliths for plant macrofossils follows standard procedures (Kenward, *et. al.*, 1980, Behre, 1986). The description of the section *in situ*, is the primary requirement recording the main stratigraphical divisions. After description the sections were processed for macrofossil analysis. The stratigraphical samples were sub-divided into upper and lower portions of each stratigraphical division and analysed separately. This permitted the flexibility of combining the upper and lower samples if no significant difference could be found.

Samples for macrofossil analysis were washed with water through a series of granulometric sieves ranging in aperture diameter from 4mm to 0.3mm. The separate fractions of each sample were sorted in water using a low-powered stereomicroscope (x10-x50). Identifiable plant remains (seeds and other flowering or vegetative parts) were scored as being complete or as fragments. Notes on the condition of preservation and other components, such as insect remains of the sample were also recorded in order to aid the final interpretation. The results for each fraction were then amalgamated and tabulated in the final score sheet. Critical identifications of the plant macrofossil material were compared with modern reference collections, held in the George Pitt-Rivers Laboratory, Department of Archaeology, University of Cambridge, to ensure correct identifications.

4.2.3 Problems of sampling and analysing submerged forest deposits

Apart from the usual problems associated with palaeoecological investigations (section 4.3), submerged forest deposits have their own peculiar difficulties. As has already been mentioned, submerged forests are situated in the intertidal zone and are therefore covered by the tide twice a day, some are only exposed at the very low spring tides (such as those on the Lincolnshire coast) therefore limiting the time that can be spent recording and sampling the deposits. Times of exposure can be deduced from studying the relevant Tide Tables, but weather conditions on the day will determine whether the deposits are exposed (an on shore wind can produce conditions whereby the deposits will not be exposed). Once exposed, the deposits are uncovered for a short period of time, which leads to the development of a 'dash and grab' strategy as has been experienced by other workers on coastal deposits (Bell, 1993, Wilkinson & Murphy, 1995).

As coasts are a major area of erosion, this produces its own difficulties and it may not be possible to visit the same site twice as it may have been eroded away. The time-scale of this event can be very short, with the deposit being present one day and gone the next.

Most submerged forest beds are eroded to seaward creating a low-lying cliff. This provides an opportunity, once cleaned up, to record the stratigraphy and take samples using standard monolith tins. In some cases the depth of exposure is shallow and requires improvisation. In some cases in this study, it has proved impractical to use full length monolith tins (50 x 10 x 10cm) and bread tins have been found to be more than adequate. In most cases it is not possible to dig test pits as these fill up with water rapidly.

Sampling of *in situ* tree stumps and trunks can also create problems. Some woods are harder than others and therefore take more time to sample, whilst others may contain wood-boring molluscs or even be partially mineralised which again makes sampling and the production of thin sections for species identification difficult.

Once the samples have been processed and analysed, problems can arise with the interpretation of the plant macrofossil assemblages. Surface samples may well contain an allochthonous element produced either from in-wash from sources inland (such as from a river or stream draining through the deposits), or plant macrofossils from contemporary deposits that have been eroded from elsewhere. Some seeds and other plant debris may become incorporated from the modern vegetation that is growing either on the beach or immediately behind the exposure such as sand dunes or sea-banks. This component should be easy enough to identify and eliminate from the interpretation.

A more serious problem could be the mixing of remains between the different levels by the burrowing fauna on the beach. The overlying modern deposits sometimes present on these exposure contains an active fauna which can not only cause contamination by the incorporation of modern seeds and other plant parts but also cause plant macrofossils to be removed from the upper deposits (Wilkinson and Murphy, 1995, p13). This may not be as great a problem in those deposits found further down the shore at the low-water mark which are only exposed on a few occasions each year.

If these difficulties are kept in mind, then the samples taken and analysed from submerged forests can be used in helping to characterise and determine the palaeoecology of these deposits.

4.3. Taphonomy and the effect on the Plant Macrofossil Assemblage

For an accurate interpretation of a plant macrofossil assemblage it is essential that the taphonomy of the components of the assemblage are understood. It is necessary to discover the potential sources of plant macrofossils, whether they are local or have been transported from a distance before final deposition at the sample site. Modern experimental work on peat formation sites (Greatrex, 1983) and clastic (i.e. riverine and lacustrine) sediments (Collinson, 1983) have shown that depending on the type of sediment being studied the make up of the plant macrofossil assemblage can vary. Plant macrofossil taphonomy in lacustrine and riverine environments has been the subject of a recent doctoral thesis by Field (1992). This thesis showed that the composition of plant macrofossils in lacustrine assemblages is a complex result of position within the lake basin, prevailing wind direction and surrounding bankside vegetation.

Greatrex, (1983) has shown from analysing surface samples for plant remains from a variety of peat forming sites such as swamp, fen-carr and fen and comparing the results with the recorded abundance and cover of vegetation in the local area, it can be generally seen that the makeup of the assemblage is from a radius of one metre around the sample site. Preservation between the different types of site can vary, mainly due to the height of the water table in the area. Therefore the remains are better preserved in fen and swamp than in carr conditions. Greatrex, (1983) also stresses that the quantitative relationship between plants as macrofossils and their abundance in plant communities is complex and is affected by the variation in seed production between species and within a given species under different conditions. Problems also arise due to differential preservation. Collinson,(1983) has noted that palaeoecological samples tend to be dominated by seeds and fruits or by leaf remains. This variation is due to the fact that where deposition of sediment is slow in low energy sites, aerobic conditions exist for a longer period and therefore, the less resistant material such as leaves and the thin walled seeds and fruit can be attacked and degraded by microfauna and flora and thence disappear from the macrofossil record. Where sedimentation occurs at a higher rate burying the remains rapidly, the aerobic conditions last for less time and therefore allow leaves and other delicate tissues to survive. In sites, where transport from other plant communities can be expected such as in lake sediments and lake deltas, those plant propagules that are adapted for long distance dispersal by water are more likely to be represented, whilst other less aquatic communities will be under-represented, (Birks, H.H., 1980). Likewise, Greatrex found that seeds and fruits that are adapted for wind dispersal can be found to be deposited at sites, where the nearest possible parent is some distance away. Although as in the case of birch, the presence of high numbers of seeds if associated with catkin scales and fragments, may indicate that the parent was growing over the sample site. This is also true for water dispersed seeds when flooding episodes can be expected. In light of this, it is important to determine the type of sediment and thus environment in which the plant assemblage has been deposited. In most cases in this study it can be assumed that the environment has been one where the deposition of propagules from a long distance can be ruled out and therefore most of the components in the samples have arrived from sources approximately of a one metre radius from the sample site. Therefore it is most appropriate in this study to consider that the plant macrofossils are deposited not far from the parent plant and can be used as valuable palaeoecological indicators on a local scale, to help determine the local nature of the submerged forests. The processes involved in the taphonomy of a plant macrofossil assemblage are outlined in figure 4.1.

Post-depositional factors that can influence the interpretation of an assemblage begin with the sampling of a deposit in the field. The amount of material collected from a clearly defined stratified deposit will bias the interpretation of the deposit. Too small a sample will lead to an incomplete record of the plant remains contained within the deposit, therefore it is advisable to take as large a sample as possible. The amount taken is determined by the discretion and experience of the collector. Proper storage of samples after collection is also important, as re-exposure to an aerobic environment will lead to the resumption of decomposition. It is usually advisable to store samples in the condition in which they were found, i.e. if waterlogged, samples should under no circumstance be allowed to dry out, as this leads to the breaking up and loss of identifiable plant macrofossils. Samples taken from fossiliferous deposits if not being processed immediately should be stored at low temperature, in order to stave off any post-sampling decay.

Contamination of samples with modern intrusive material can occur if a deposit is not completely sealed. Burrowing animals such as worms and ants as well as larger mammals such as rabbits and in this instance, the intertidal fauna, can incorporate more modern material into the deposit. Mixing between stratified layers can also occur in lake sediments due to bioturbation and physical forces, although reworking of more ancient deposits should be detectable by the observant analyst, as is the case for more modern contaminants. In submerged forest deposits, the presence of burrowing animals, such as crabs and other intertidal fauna can cause the intermixing of plant macrofossils between stratigraphical layers, although the presence of burrows within the section is easily detected and therefore counteracted.

Processing the sampled deposit can also lead to loss of important macrofossil material. Prolonged soaking in Sodium hydroxide or Hydrogen peroxide can lead to irreversible damage or loss of material. Too vigorous a washing with water can also lead to fragmentation of more delicate fossils such as leaves and flowers. Too weak a washing with water can lead to the incomplete breakdown of the sediment and therefore concealing macrofossils within the lumps. The processing of too much material can lead to the clogging of sieves leading to overflow and loss of valuable material. The use of mesh sizes is usually a compromise (Clapham *et.al.*, 1992), between trying to retain as much of the plant material as possible whilst trying to lose most of the sedimentary matrix. Too fine a mesh size will cause continual clogging and produce a large amount of material to sort, whilst too coarse a mesh size will mean that the loss of smaller plant macrofossils will produce a bias of remains recovered leading to an impoverished fossil assemblage and therefore an incomplete interpretation will follow.

After processing, sorting techniques can also lead to the loss of material. Too much of the plant material placed in a petri dish can lead to seeds, fruits and other identifiable plant macrofossils being hidden and therefore not picked out. It is important, especially with waterlogged material, to place a small amount of material in the dish, just enough to cover the bottom. It is also advisable to sort through each fraction at least twice, in order to pick out the maximum number of plant macrofossils. Storage of material after sorting is also a problem and can lead to loss of material through fungal attack. There have been many methods of storage recommended, including the use of fungicides, a 1:1:1 mixture of alcohol, glycerine and formaldehyde or a mixture of alcohol and water (at least 50% alcohol). In this study, a dilution of alcohol was used and then storage in a refrigerator.

It can be seen that the sampling and post-sampling processing of samples can be added to the taphonomic processes acting on any given fossil assemblage and careful handling of the material will produce the maximum amount of information available to the analyst. The ability of the analyst to recognise different plant parts, not just the seeds and fruits will lead to a more complete interpretation of the assemblages studied.

The analysis of plant macrofossils is a time consuming activity and therefore within a given amount of time, only a limited amount of material can be analysed. This is mainly due to the variety of the remains that can be preserved and the taxonomic level to which they can be identified.

4.4. Problems associated with Ecological Interpretations of Data from Submerged Forests

In the chapters 5, 6, and 8 it will be shown that plant macrofossil remains from submerged forests deposits can be utilised to understand the local character and variation that may occur both within a submerged forest exposure and as a comparison between different localities. In order to interpret the results produced by these analyses it is necessary to interpret via the use of ecological data obtained from the modern distribution of the plant species involved. It has long been accepted that the concept of uniformitarianism is essential to interpreting the remains from ancient deposits. Whether they are geologically modern or ancient. But it must be remembered that although the present may well be the key to the past, it does not necessary mean that past environments are in anyway represented by modern ecosystems. It is largely assumed that the processes that govern present day ecosystems (both biological and non-biological) were in the main responsible for the character of past plant communities. As mentioned in section 4.3, one of the pitfalls to this approach is the process of taphonomy, whereby the original complete assemblage or components of it are subjected to different degrees of attack and weathering.

This obviously leads to an incomplete record being preserved within the deposit. Further post-depositional processes may further deplete the assemblage, therefore leaving us with a very incomplete record. Experimental work on modern taphonomic processes (Collinson, 1983; Greatrex, 1983; Field, 1992) have deduced that it is possible to interpret assemblage via their plant macro-fossil record if taphonomic processes are taken into account.

Another problem in using modern ecological data to interpret ancient assemblages is the fact there is a possibility that the past ecology of a species is no longer reflected in its present one. This is more difficult to assess and in the more recent deposits, such as those formed during the Holocene, it must be assumed that in the majority of cases the time elapsed has not been sufficient for a particular plant species to have totally altered its ecology. Although it must be remembered that anthropogenic activities may have reduced or destroyed a species' preferred habitat.

4.5. Presentation of Results

The results of each analysis are displayed in several forms. The results of the macrofossil analyses are displayed in the form of tables. Complete tables along with scores for each taxa recorded can be found in Appendix 1, whilst summary tables and charts are provided within the text to allow as full a discussion as required. In order to compare the plant macrofossil assemblages throughout the profile, it has been necessary to produce corrected scores for each plant macrofossil sample. The smallest sample size of a profile is taken as the common denominator and the scores for the other samples in the profile are amended accordingly. The reason for choosing the smallest sample from a profile and not the largest, is the fact that it then can be guaranteed that at least one example of each taxon is present in the sample.

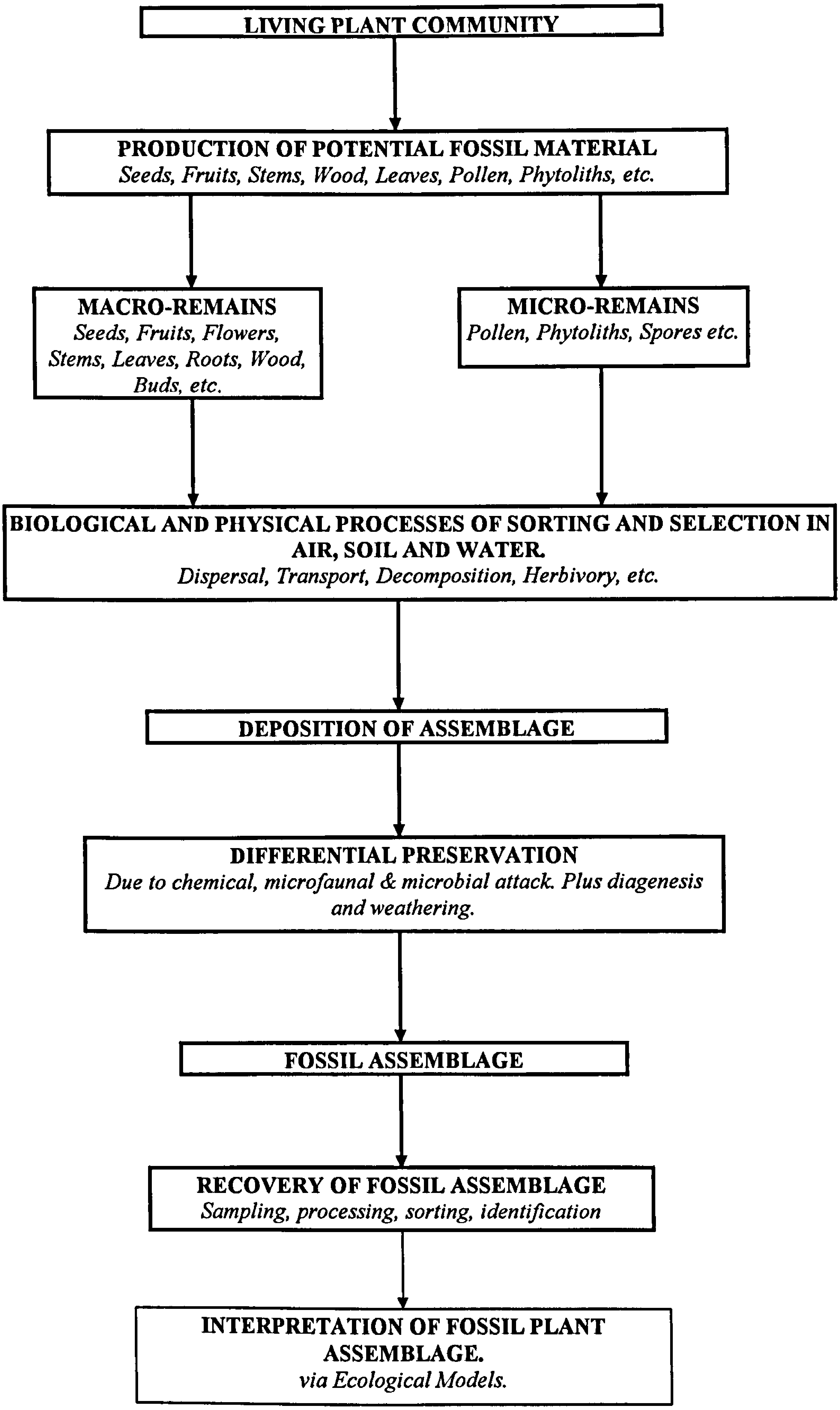


Figure 4.1. Diagram showing the main components of taphonomy of a plant macrofossil assemblage leading to its interpretation. (After West, 1977)

The resulting plant macrofossil diagram produced is therefore a concentration diagram which makes direct comparison between samples possible. The results will be laid out according to site (Chapter five for Wolla Bank and Anderby Creek, Chapter six for Hightown) and then discussed at first separately and then comparatively. The results of the wood identifications and the size of stumps will be displayed by means of tables and barcharts in order to show the distribution of tree species from each site as well as the range of stump sizes that were found at each site.

The plans of the stump and trunk distributions from each of the sites which allowed this method of recording are presented. The models used to interpret the plant macrofossil evidence and the distribution of the plant remains are described in Chapter seven and the application of these models to the macrofossil record is recorded and discussed in Chapter eight.

4.6. Conclusions

There are many problems with the sampling and studying of submerged forest deposits, ranging from; the short time that the deposits are exposed, leading to a "dash and grab" sampling strategy; the unpredictability of the re-exposure of the deposits leading to the need to sample quickly and efficiently; the unpredictability of the preservation of the tree remains which may limit species identification and the recording of them *in situ*; to the problems of obtaining samples of the deposits associated with the tree remains.

Other problems arise with the laboratory analysis of the tree remains and the samples from plant macrofossils, from the sectioning of the tree remains to the preservation of the plant macrofossils which may hinder the identification of taxa.

In order to produce an accurate interpretation of the plant macrofossils, taphonomic processes must be taken into consideration, which are discussed in sections 4.3 and 4.4 and outlined in figure 4.1. Taphonomic processes arise at every stage of deposition, sampling and recovery of the plant macrofossil assemblage. If these are taken into account then the submerged forest deposits can be used to help characterise the type of woodland represented by the submerged forest deposits.

Using the techniques described in this chapter, the results of the plant macrofossil analyses from Wolla Bank and Anderby Creek, Lincolnshire are discussed in chapter five and in chapter six, the results of the plant macrofossil analyses from Hightown, Merseyside are described and discussed. In order to put the analyses presented in this thesis into perspective, the post-glacial geology, history and archaeology of each region is also discussed.

Chapter Five

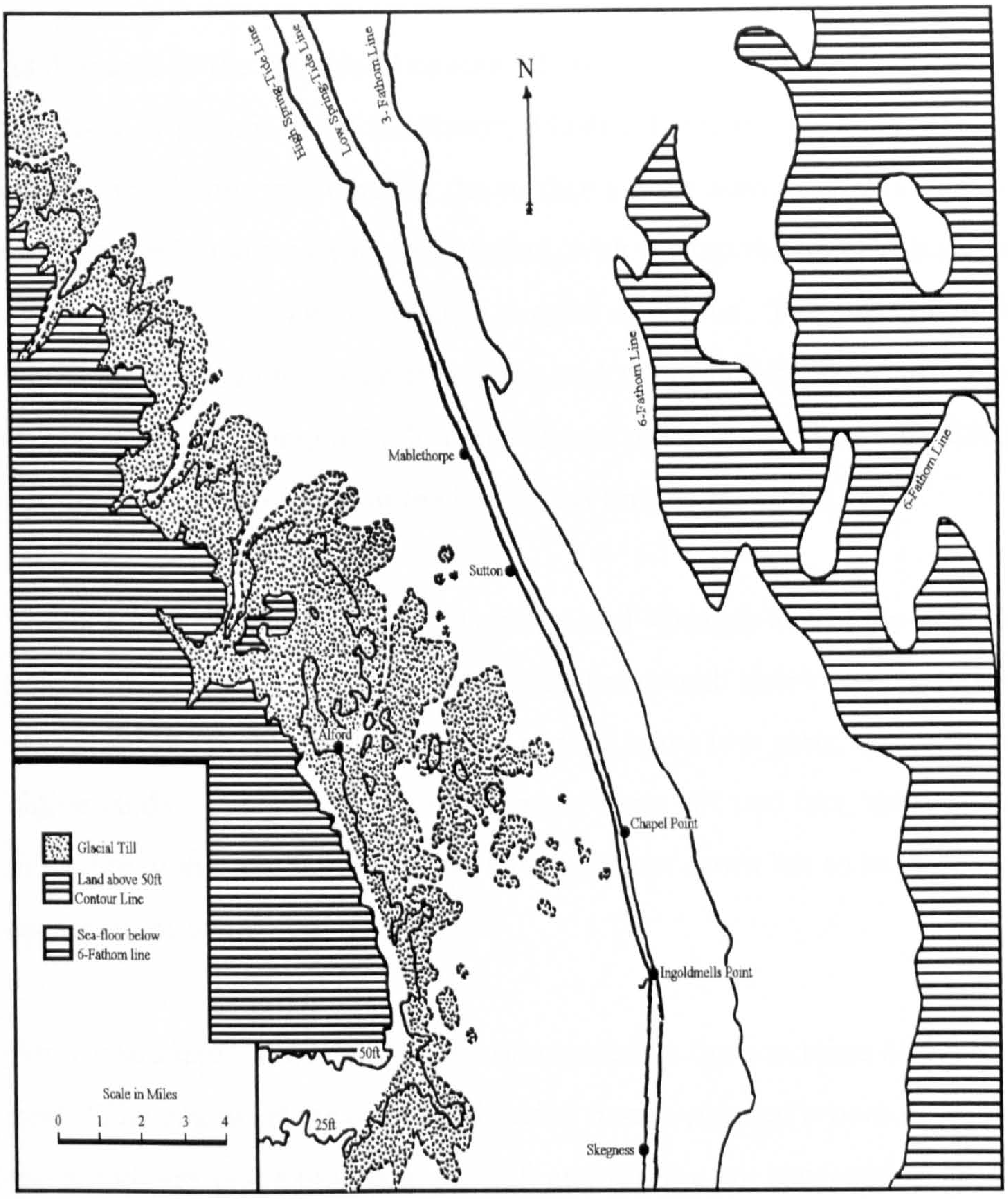
THE EAST LINCOLNSHIRE SUBMERGED FORESTS

5.1. General Description of the Lincolnshire Coastal Area

Between the Lincolnshire Wolds and coast there is a narrow belt of low-lying land known as the Lincolnshire Marsh (Swinnerton, 1931). Map 5.1. This low-lying belt consists of two types of scenery, the first is a well wooded hummocky surface of glacial till which forms a continuous strip at the foot of the Wolds. The seaward edge of this strip is irregularly indented with outlying patches forming mounds in the Marshland proper. The other type of scenery is flat and treeless and consists of stiff clays which are estuarine in origin. The process of building up of marshland is still continuing on the coast south of Skegness and north of Mablethorpe, whilst between these two points the coast is being eroded. It is between these two points of erosion that most of the observations of submerged forests have been reported.

5.2. Records of the Submerged/Buried forests of Lincolnshire

The presence of submerged/buried forests have been known for a long time in Lincolnshire. In 1662 Dugdale recorded the presence of several kinds of trees, mostly oak and fir (this refers to *Pinus sylvestris* and not *Abies* spp.) which had been discovered when channels were excavated in order to drain the marshlands. Some of the trees were no longer attached to their roots and Dugdale had been informed that many tree remains could be found in other places in Lincolnshire. He also observed that in the Isle of Axholme 'trees of oaks and fir found in such great numbers at the making of ditches and sewers for draining that fen which ..... was apparently a woody country at the first'. (Dugdale, 1662).



Map 5.1. Map of the geology of the East Lincolnshire Coast (After Swinnerton, 1931)

De la Pryme in 1701, described in greater detail the buried forest of the Isle of Axholme and mentions finding ' infinite millions of the roots and bodies of trees, great and little.......firs, oaks, birch, beech, yew, wirethorn, willow, ash.......the roots of all, or most of which stand in the soil in their natural positions'. He also recorded that the large trees lie with their tops commonly north-east, though the smaller trees lie almost everyway cross those, some above, some under, a third part of all which are firs, some of which have been found 30 yards in length and above'. Apart from observing the presence of trees he noted that at the bottom of the "soil" hazel nuts and acorns were frequently found along with large quantities of fir cones (*Pinus sylvestris*).

As drainage of the marshland continued, more observations were forthcoming. A survey of the River Witham in 1769 (Robinson, 1984) at Bodiam Sands near Bardney at approximately one metre below the surface a great number of oak, yew and alder roots and trunks were found on a thin bed of sand, with the tap roots of the trees penetrating the lower 'strong blue clay full of large coggles or stones'. The boles of some trees were five feet in diameter. In the same area in the mid 19th Century an oak trunk over 90 feet long and calculated to contain 1,440 cubic feet of timber was found embedded in the peat. Large oak trees were also found in the bed of the Forty-foot Drain.

Thompson in 1856 in Friskney, Wainfleet and Wrangle and in the East Fen in the south of the county recorded 'great numbers of fir trees, with their roots, have been discovered lying in the moory soil one foot below the surface in the low parts, and from two to six feet in the higher lands...... These trees are not large, some girt two feet, many are only poles. They lie in all directions, and appear not to have been cut down but to have been torn up by the operation of water'.

Forty years later, Wheeler (1896) commented on the condition of the trees embedded in the peat. 'The colour of the oak wood varied from a rich red brown to jet black and that when the wood was first exposed it was soft and spongy but hardened as it dried. After some time it became very hard and black as ebony....' At Billingby the principal trees found were oak, birch, alder and fir with elm and hazel being identified at Digby Fen.

In the Fen, Skertchley (1877) in his Geological Memoirs of the area recorded that 80% of the trees found were oak, elms were rare and birches not common. The birch wood was much decayed but the characteristic silvery, papery bark was still intact. Yews were mainly found on a sandy subsoil and the firs possessed a thick bark which when exposed to air crumbled. In places where large areas of trees were exposed Skertchley noted that the trees were close together and the straight trunks suggested a formerly dense forest.

The records of the inland buried forests were made possible due to the need to drain the marshland and fen areas in order to "improve" and reclaim the land for agriculture whilst the exposures along the Lincolnshire coast were and are a result of the natural action of the sea as it attacks the coastline. Mitchell's 1765 coastal sailing chart mentions the presence of

"Clay Huts" located between Sutton and Anderby. A visit to these Clay Huts by Sir Joseph Banks and Carrea de Serra between 19-21 September 1796 discovered that they were outcrops of a submarine or submerged forest. The outcrops were described as large extents of islets of moor and were visible only at the lowest ebbs of the year and were chiefly composed of roots, trunks, branches and leaves of trees and shrubs. They identified fir, oak and a great quantity of birch. Some of the trees were still attached to their roots, 'while the trunks of the greater part lay scattered on the ground, in every possible direction' (de Serra, 1799). Banks and de Serra also noted that in the majority of cases the trunks of the trees were flattened, the cause of which they surmised was due to the pressure from the overlying deposits. The trees were rooted in a soft greasy clay; 'but for many inches above the surface of the soil is composed of rotten leaves' (de Serra, 1799) and leaves of holly and willow and the rhizomes of *Phragmites australis* were identified from the deposit.

Further visits by Banks and de Serra to well borings in Sutton and Mablethorpe where they observed peat occurring at depth led de Serra to conclude that the moory exposures on the shore at Sutton were in fact part of an extensive subterraneous stratum which had been stripped of its uppermost layers by the sea and these exposures were contemporary with the inland records.

Jukes-Browne at the July Spring tides in 1881 examined the forest bed at Mablethorpe where he found it outcropping at the bottom at of a gentle slope on the shore which was composed partly of clay and partly of sand lying on the clay 'under which the turf or forest bed appears to pass', (Jukes-Browne, 1887). He also visited brickyards and examined records of well borings in the area and found in all cases a thin turf bed containing the roots of oak trees. Using Skertchley's evidence from the Fenland he deduced like Banks and de Serra, that the submerged forest of the shoreline was an outcrop of an extensive subterranean stratum. Both Skertchley and Jukes-Browne were clear that the undulating clay surface on which the trees had grown was the Upper Boulder Clay of glacial origin and that the forest and peat bed was the first of a series of post-glacial strata.

At the Low Spring tides of September 1921 the submerged forest was exposed for eleven miles along the coast. N.S. Stevenson (1923) examined and photographed the deposits at

Sutton, he also visited the exposures at Trusthorpe in September 1923. He recorded that the tree stumps were 'much worn and tended to be more or less conical due to the constant friction of sand in moving water'. He also observed that many of the stumps had a lean towards the north-east, as did de la Pryme in 1701 on the Isle of Axholme. Stevenson noted that the inner wood of the stumps was still whitish in parts and quite sound allowing the annual rings to be clearly seen in some stumps. More than fifty rings were counted in one worn stump and the size of nearby trunk in the peat suggested to Stevenson that the tree could be well over 100 years old. Where the stumps were still protected by the peat, the bark was several inches thick. Fifteen specimens of wood were cut for examination and were all found to be Scot's pine.

Whilst many records of the submerged and buried forests of Lincolnshire have been noted and have shown that the coastal outcrops belong to a more extensive stratum which stretches inland, few, if any of the observers have attempted to put the submerged forest deposits into context and try and understand their relationship to the underlying and overlying deposits and to the geological and vegetational history of this part of Britain.

The first and definitive attempt to achieve this by carrying out a thorough examination of the deposits of the Lincolnshire coast was by Swinnerton (1931) and is the basis for the following section.

5.3. Description of the deposits

5.3.1. Glacial Deposits

These are generally resistant to wave erosion and therefore hummocks of glacial till remain after the post-glacial deposits have been eroded away forming slight projections on the coastline. This is the mode of origin of the promontories of Chapel Point, Addlethorpe Point and Ingoldmells Point, the latter being the highest. Overlying the glacial deposits are the post-glacial deposits and these according to Swinnerton (1931) can be divided into three groups. A general section of the deposits on the Lincolnshire coast are shown in figure 5.1.

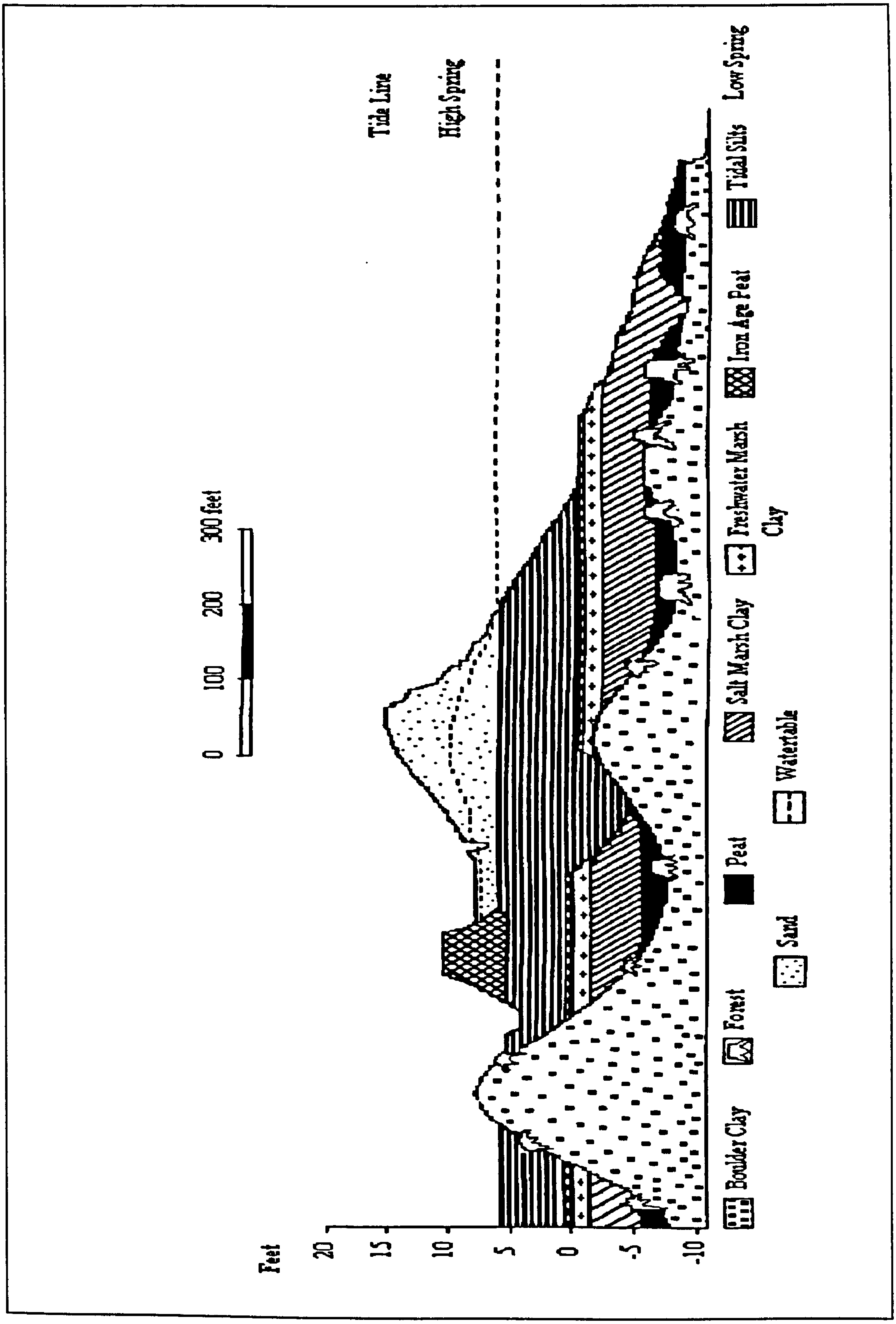


Figure 5.1 Geological Section of the Lincolnshire Coast (From Swinnerton, 1936)

5.3.2. Lower Post-glacial Deposits

At low spring tides there are exposed extensive stretches of late glacial till which are overlain by a layer of peat varying in thickness up to approximately 0.76m and outcrops at about -2.4m O.D. (Godwin, 1940b,1943, 1945a), although recent surveys (Brooks, 1990) have shown that the depth of peat is not so great due to erosion. The level of peat rises and falls with the undulating surface of the glacial till. Projecting upwards into and often through the peat there are numerous stumps of trees which have roots ramifying through the underlying glacial till. Some stumps are prone in various directions both in and on the peat. Broken branches abound as do the trunks of trees. Species that have been identified by colleagues of Swinnerton include *Alnus, Betula, Quercus* and *Prunus*. *Taxus* was identified north of Chapel Point. According to Swinnerton (1931) except for the absence of *Corylus* and *Pinus* the species found here at the coast are the same as those found in the bottom peats of the Fenland deposits.

For approximately a metre below the peat the glacial till is disturbed by root action and the character is altered with the chalk pebbles which are normally common in the glacial till being greatly reduced in size or have disappeared completely due to the solvent action of the humic acids seeping down from the rotting vegetation. (Swinnerton, 1931). The clay matrix changes colour downwards from dirty-white or grey immediately underneath the peat to light-blue or blue blotched with brown until between 1-1.2m below the surface the normal colour of the glacial till returns.

In places beneath the peat and resting upon the clay surface there are accumulations of gravel and angular fragments of flint. These deposits are the debris of denudation which preceded the establishment of the trees and the formation of peat. Neolithic implements have been found associated with these accumulations (Warren, 1907; Swinnerton, 1931; Robinson, 1984).

5.3.3. Middle Post-glacial deposits

These consist of stiff clays whose base rests directly on the surface of the peat but in places it can be found lying on the surface of the bluish podzolised glacial till where the erosion of the peat took place before the deposition of the clays. As the peats lay on the hummocky glacial till, the base of the clays of the middle group of post-glacial deposits can vary in height from the level of the low spring tides to almost mid-tide level.

The upper boundary of the series is defined by a thin layer of peat 7-15cm thick this upper peat maintains a constant level slightly above mid-tide. The whole series can vary in thickness. Approximately 100 metres north of Ingoldmells Point there is 7-8cm of clay between the glacial till below and the upper peat above. Elsewhere it is usually 1.8 metre thick although where it rests on the eroded surface it may be up to 2.4 metres thick. The colour varies from blue-grey at the bottom, the middle section is purple which can be laminated and the top 45-60 cm returns to the blue/grey. Rhizomes and rootstocks of various plants are common in both the upper and lower blue-grey clay and have been identified as *Triglochin maritimum*, *Phragmites australis*, *Juncus maritimus*, *Limonium* sp. and *Armeria* sp. The centre of the purple clays contained very little in the way of plant remains except for the presence of vertical black streaks which Swinnerton (1931) thought represented the remains of roots of *Salicornia* sp..

Above the barren purple clays, the upper blue-grey clays between 30-45 cm below the base of the upper peat show a definite succession where the lower levels contain only *Juncus* rootstocks followed by layers containing great numbers of *Triglochin maritimum* rhizomes succeeded by *Limonium* sp. and *Armeria* sp. rootstocks with the *Triglochin maritimum* and *Juncus* remains either diminishing or disappearing altogether. Above this level *Phragmites australis* predominates with the other species being absent.

The differences in the plant remains contained within the deposits allowed Swinnerton to divide these middle deposits into a lower portion known as Triglochin clays and the upper as the Arundo clays. Rhizomes of *Phragmites* appear in the upper levels of the Triglochin clays but this is due to penetration by the rhizomes at a later date. At the upper surface of the Arundo clays the *Phragmites* rhizomes continue into the overlying upper peat at -0.3m O.D., which in many places is entirely composed of rhizomes and leaves of this species giving the peat a flaky texture which distinguishes it from the Lower Peat and Forest beds. In the vicinity of Ingoldmells at about 0m O.D. the upper layers of the upper peat consists, of leaves and contains fragments of small woody branches of *Salix* and *Taxus*. This peat also fills the occasional channels which have cut through the underlying deposits into the glacial till, reaching a depth of -2.75m O.D. No estuarine shells are found in the middle series of deposits although foraminifera belonging to the genus *Trochammina* are common and possess thin flexible tests which are indicative of forms that are found in estuarine and brackish pools (Swinnerton, 1931).

5.2.4. The Upper Post-glacial deposits

The upper boundary of these deposits corresponds with the general ground surface of the Marsh country found between 0m and +2.1m O.D. The lower boundary is mainly defined by the surface of the upper peat although in some places it sinks into erosion channels.

The main mass of clay has a purple tint the same as that of the middle portion of the Triglochin clays but is less consolidated. The lowest layers contain large numbers of shells of *Cardium edule*, *Scrobicularia plana* and *Hydrobia ulvae* and often adopt the position associated with living examples suggesting that they are *in situ*. Plant remains are not abundant and are derived either from eroded masses of lower peat or from stalky fragments of sea-purslane (*Halimone portulacoides*) indicative of the vicinity of salt marshes. The ecology of the molluscs found within the sediment suggest that they were formed in quiet sheltered conditions either in estuaries or in brackish water with an influx of freshwater.

The stratigraphy of Swinnerton, 1931 no longer conforms with the current lithostatigraphical nomenclature and Brooks (1990) has proposed a new stratigraphical nomenclature and is set out in table 5.1.

Swinnerton, 1931	**Godwin, 1940b**	**Brooks, 1990**
Scrobicularia Clay	Scrobicularia clay	Ingoldmells beds
Upper Peat Arundo Clay Triglochin Clay	Upper Peat Phragmites clay Triglochin clay	Anderby beds
Peats and Forest Bed	Lower Peat	Huttoft beds
Boulder Clay	Marsh Till	Upper Marsh Till

Table 5.1. Nomenclature of the stratigraphy on the Lincolnshire Coast and their relationship to each other

5.4. The Palaeoecology of the deposits

Following Swinnerton's extensive 1931 survey of the post-glacial deposits on the foreshore between Skegness and Mablethorpe, Brooks carried out a similar survey between 1989 and 1990, (Brooks, 1990). This recent survey was in order to assess the amount of erosion that had occurred since the Swinnerton survey and to ascertain the palaeoecological history of the deposits. The amount of erosion that has occurred will be discussed in section 5.5.

Three main sites were sampled by Brooks, (1990) for palaeoecological data which was provided by pollen analysis. Two sampling areas were at Vickers Point; Vickers Point 1 (TF573694); Vickers Point 2 (TF574694) and one at Chapel Point (TF562738). The complete series of deposits were analysed, although the Ingoldmells beds produced no interpretable palaeoecological data. The resultant pollen diagrams were divided into Assemblage Biozones and are outlined below.

At Vickers Point 2 a section through the Lower Peat (0-6cm), Huttoft beds (6-10cm below the surface of the peat) and the Upper Marsh Till (10-16cm below the peat surface) was sampled. The first biozone VPA at 6-9cm below the surface of the peat occurs in the Huttoft beds and consists of high Filicales and high *Pinus*, *Quercus* and *Tilia* counts whilst *Polypodium* and *Pteridium* spores were common. Just above the base of the biozone *Alnus* and *Corylus* are present along with *Ulmus*. Pollen from open ground herbs and marsh plants are rare. Recycled pollen grains and fungal spores are common at the biozone but decline towards the top of the biozone.

This biozone has been interpreted by Hunt *et. al.* (in Brooks, 1990) as representing the remains of a soil profile developed on the surface of the Upper Marsh Till which is also the source of the recycled pre-Quaternary palynomorphs. According to Havinga (1964) the presence of fungal spores, Cryptogram spores and *Pinus* pollen are indicative of damp soil profiles. Accordingly the biozone represents a local environment of mixed oak woodland (*Quercus-Ulmus-Tilia-Alnus-Pinus-Corylus*) along with some signs of an open landscape shown by the presence of Poaceae, Liguliflorae and *Plantago lanceolata* pollen.
Assemblage Biozone VPB is found in the basal part of the Lower Peat, 4-6cm below the top of the peat and consists of high Cyperaceae and Filicales with some *Quercus* and *Pinus*

with a little *Tilia, Alnus, Ulmus, Corylus, Ilex, Hedera, Phragmites, Polypodium* and *Sphagnum*. No aquatic plant pollen is present within the biozone but there are some recycled palynomorphs. Due to the high sedge and high tree pollen deposition must have occurred in a boggy place amongst trees. This biozone appears to be a continuation of the previous biozone; the local vegetation is of a mixed oak forest (*Quercus-Ulmus-Tilia-Alnus-Pinus-Corylus-Ilex*) with an understorey of ferns and sedges. (Hunt *et. al.* in Brooks, 1990).

The third assemblage biozone at Vickers Point 2, VPC is from 0-3cm below the top of the peat and consists of high incidences of tree pollen with much *Quercus, Tilia, Alnus, Ulmus, Ilex, Acer* and *Corylus*. *Pinus* and *Fagus* are rare representing a regional component. Other pollen types include grass, cereal and herb pollen suggesting nearby cleared agricultural land possibly including pasture and arable. The low incidences of marsh plant pollen indicates local wet places and this biozone appears to be a continuation of biozone VPB.

At Vickers Point 1 (TF573694) samples were taken from the Upper Peat and the Anderby Beds. The Upper Peat extends from the surface to 4cm below the top of the peat and the Anderby beds are from 4-12cm below the top of the peat. Assemblage biozone VPD covers the uppermost part of the Anderby beds and the Upper Peat. There appears to be high counts of *Typha, Phragmites*, Cyperaceae and Filicales and fairly high *Sphagnum* spores. Some pollen of *Betula, Pinus, Quercus, Corylus*, Chenopodiaceae, Poaceae, *Pteridium* and aquatics with Ericaceae and *Artemesia* are also present. *Ulmus, Tilia, Plantago lanceolata* and other herbs and cereal pollen are sometimes present and *Fagus* appears half-way up the biozone.

The high marsh species and aquatic counts and along with the presence of aquatic algae is consistent with the presence of shallow water with emergent reedmace, reed and sedge flora. Nearby deeper water contains *Myriophyllum* and the water body was probably tidally influenced and the presence of Foraminifera in the upper part of the peat suggests saline conditions. The regional pollen picture suggests a largely forested landscape possibly with occasional clearings for pastoral and arable agriculture.

At Chapel Point (TF562738) samples were taken from the Upper Peat and Anderby beds. The top of the Anderby beds 6-9cm below the top of the peat forms the biozone CPA which consists of high *Phragmites* with moderately high *Quercus* and Chenopodiaceae. There is also present some pollen of *Corylus*, Poaceae, Cyperaceae, *Typha*, Filicales and *Pteridium* and pollen of *Pinus*, *Ulmus*, *Tilia*, *Alnus*, *Fraxinus* and *Fagus* are often present. Coastal species include Chenopodiaceae, *Hippophae*, *Limonium* and *Aster*. Cereal pollen and arable weed pollen can be found at the top and base of the biozone. The peak of the pastoral weeds occurs at about 10-11cm below the surface of the peat. The pollen of aquatics, Foraminifera and marine dinoflagellate cysts are also present within the biozone. The presence of high counts of *Phragmites*, Chenopodiaceae and other coastal plants are characteristic of tidal flats in front of the reed belt. *Phragmites* is tolerant of low salinities. The freshwater microfossils and aquatic pollen may be from a nearby freshwater body such as a river. Away from the coastal flats there is a largely wooded landscape of a diverse mixed forest with areas of cleared agricultural land.

Assemblage Biozone CPB at 4-5cm below the top of the peat marks the base of the deposit and consists of extremely high *Phragmites* with some *Quercus*, Cyperaceae, *Typha* and Filicales. A little *Pinus*, *Ulmus*, *Alnus*, *Corylus*, Poaceae and *Plantago lanceolata* can also be found. Cereal pollen is also present at the base of the biozone. This biozone continues the seral development initiated in biozone CPA. The high *Phragmites* and shallow-water microfossil assemblage suggests the spread of reed swamp across the salt-marsh. Further afield there still continues to be a forested landscape of mixed woodland with some agricultural activity, although this activity is shown to diminish through the biozone, rare signs of pasture persist through the profile.

The top of the Upper Peat is characterised by the biozone CPC which consists of very high *Typha* and high *Phragmites* with moderately high *Quercus*. There is also some Poaceae and Filicales spores present. There is a little *Betula*, *Pinus*, *Fraxinus*, *Corylus* and coastal herb pollen. No aquatic plant pollen is present within the biozone. Again this biozone represents the continuation of seral development initiated in biozone CPA. The reed marsh of CPB is invaded by the less salt tolerant reedmace. Inland, an oak dominated mixed woodland exists with areas of grassland.

Most of the Anderby Beds were not sampled (Hunt *et. al.* in Brooks, 1990), although Swinnerton, (1931), Godwin, (1940b) and Swinnerton & Kent, (1981) suggested that they were upper tidal flat deposits which were a response to sea-level rise behind a coastal barrier. Hunt *et. al.* sampled and analysed the top of the Anderby beds at Chapel Point and Vickers Point. The biozones VPD and CPA-CPC are thought to belong to Godwin Zone VIII (Godwin, 1975a) and are Iron Age/Roman in date. At Vickers Point the freshwater marsh has a mixed bulrush-sedge-reed flora, whilst at Chapel Point there was a saltmarsh with chenopods which then develops into reedswamp and then bulrush bed. Hunt *et. al.* (in Brooks, 1990) found that the initiation of the Upper peat cannot be correlated between the two sites. According to Hunt the higher incidence of *Quercus* and the lower incidence of *Betula* pollen at Chapel point may suggest that the base of the Upper peat is older at Chapel Point than it is at Vickers Point. The landscape was forested during the deposition of the upper part of the Anderby beds and Upper peat. There was some agricultural activity with oscillations between arable and pastoral activity recorded at Chapel Point.

Hunt *et.al.* (in Brooks, 1990) suggest that if the base of the Upper peat is diachronous at the two sites this implies that the peat was formed as a response to local changes in sedimentation as has been suggested for the Bristol Channel by Kidson & Heyworth, (1973 & 1978) and Heyworth and Kidson, (1982) following Sheppard (1963). If the initiation of the peat is synchronous it implies that is was formed as a response to the oscillations in global sea-level as suggested for the Fenland by Shennan, (1982) following Fairbridge (1961).

After the deposition of the Upper Peat there followed a marine incursion laying down the Ingoldmells beds and due to the fine particle size and this is more likely to be a response to widespread sea-level rise as suggested by Godwin (1940b, 1945a) and Shennan (1982) rather than a breaching of a coastal barrier as forwarded by Swinnerton (1931).

In conclusion, the palaeoecology of the deposits shows that through time there is a development from a damp wooded landscape which with a rise in sea-level changed to a local landscape dominated by a salt-marsh community. As the deposit accumulates above the influence of the sea, there is a further development towards a more freshwater environment dominated by reedmace and reed. This seral succession follows that outlined by Godwin (1975a) for the seral development in the Fenlands. At a more regional scale, there appears to be a constant presence of a mixed oak woodland with some clearing dedicated to agriculture and pasture, although in the Upper Peat there appears to be a change from an arable component to one dominated by pastoral conditions.

Hunt *et.al.* (in Brooks, 1990), admit that the results do not represent a complete history. In the early part of the Holocene, the area was wooded and at some distance from the sea. Pollen Biozone VPA represents a soil which started to form in the Late Palaeolithic and continued into the Late Mesolithic, while biozone VPB is indicative of local wet conditions whether this is due to a rise in sea-level or to locally impeded drainage. With the presence of cereal pollen and *Acer* pollen, there is evidence for nearby prehistoric (Neolithic) clearance and agricultural activity, a drier environment is also indicated.

5.5. Problems of erosion of the Coastal deposits on the Lincolnshire Coast

In 1796 Serra and Banks recorded that the 'islets of moor' extended for twelve miles along the coast and was seen to be a mile wide at Sutton and similar 'moors could be found from Grimsby to Skegness. At the Spring tides of September 1921 the submerged forest was exposed for eleven miles along the coast and Stevenson noticed that the clay with peat capping was 'broken up into small banks and ridges by fairly deep fissures, usually running at right angles to the sand-dunes. These were the 'islets' described by Serra in 1799 when the channels between the islets were four to twelve feet deep. The channels are still conspicuous today, although not as marked. This feature of the outcrop is due to the lines of drainage from the wave backwash. In 1923, the observed width of the outcrop was no more than 150 yards. even allowing for the shifting pattern of the sand covering the foreshore and the fact that the tides might not have fallen as low in 1923 as on the 1796 visit this is evidence for considerable erosion of the outcrop in a century and a quarter (Robinson, 1984).

The problem of erosion as shown above has been evident ever since the deposits were first recorded. Swinnerton in 1931 was well aware of the problem of continual erosion and noted the washing up of stumps of pine trees, antlers of deer and bones of humans and other mammals and it is evident that the strip of coast from Skegness to Mablethorpe is no longer one of deposition but erosion. In 1989-1990 Brooks et al carried out a survey of the Lincolnshire coast from Friskney in the south to just north of Mablethorpe. The object of this survey was to assess and record the exposure of the archaeologically important post-glacial strata as the total exposure had not been recorded prior to 1990. From 49 separate exposures of the submerged forest, a total length of 6.61km with an average width of 46.12m was recorded in this initial survey. The length, width and general shape of each exposure varied along the coast and is probably due to the varying strength of wave action along the coast.

A further assessment was carried out along the coast by Brooks between 7/3/90 and 12/3/90 after the storms of January and February 1990 and concentrated on the areas that the previous assessment recorded as having exposures of the relevant deposits within the parishes of Ingoldmells, Chapel St. Leonards, Anderby, Huttoft and Mablethorpe and Sutton. The number and size of the exposures were fewer and less extensive but because of the shifting pattern of the sand beach, the range of deposits was extended and did not necessarily conform to the pattern of the previously recorded deposits. At Ingoldmells the Lower Peat exposures were restricted to a series of small exposures in the low beach region, there was a restriction in the previous recorded pattern and no new deposits were exposed. Chapel St. Leonards produced no Lower Peat and again at Anderby there was a much reduced pattern with patches of the Lower Peat, at the north end of the parish it was associated with a large exposure of the underlying Upper Marsh Till which corresponded to a previously recorded patch of Lower Peat showing the degree of erosion along this sector of the coast. At Huttoft there was a limited exposure of Lower Peat but the pattern extended the distribution pattern of post-glacial deposits within the parish. In Maplethorpe and Sutton there were a few patches of Upper Marsh Till; this also extended the pattern of exposure for this sector of the coast.

It can be concluded that from the previous records of the outcrops of the post-glacial deposits in general and especially the submerged forest beds and from the recent survey carried out by Brooks (1990) that the exposure of the deposits along the coast appear to be very temporary due to the sand of the beach moving frequently, which exposes different portions of the deposits at different times. The constant scouring has much reduced the submerged forest outcrop and the stumps and trunks within it. Even the last fifty years has seen considerable changes (Robinson, 1984), and this present rate of erosion shows that the submerged forest is declining rapidly with time, resulting in the loss of an important source of evidence for determining the character of past woodland communities.

5.6. Archaeological discoveries on the Lincolnshire coast

There has been a limited amount of systematic archaeological work carried out on the coast of Lincolnshire with only a limited amount of pre-Iron Age use of the coastline has been documented.(Brooks, 1990).

The earliest archaeological evidence from the deposits has arisen from below the forest beds themselves. Warren (1907), found a scraper *in situ* in the old forest soil underneath the roots of one of the large trees at Ingoldmells Point. Other flint flakes and cores were discovered *in situ* in this area, including numerous fragments of burnt flint and were thought by Warren to be either Late Neolithic or Early Bronze Age in date. A possible Palaeolithic flint was found *in situ* in one of the patches of drift gravel, overlying the glacial till and beneath the forest bed, the age being inferred by being beneath what Warren considered to be the Neolithic soil of the forest bed (Warren, 1907; Swinnerton, 1931)

According to Brooks (1990), there are extensive saltworking areas recorded along the present coast and inland parishes. Most of the sites are concentrated in the parishes of Ingoldmells, Addlethorpe, Orby, Hogsthorpe, Winthorpe, Skegness and Chapel St. Leonards (Baker 1960). Swinnerton (1931) recorded twelve sites between Sandbank Villa, Trunch Lane (TF567710) and a site 2.4 kilometres south of Ingoldmells Point a distance of approximately four kilometres. In general the sites discussed by Swinnerton consisted of many fragments of shattered pottery and masses of pulverised pottery debris with occasional accumulations of black vegetable ash, and one or more ruined hearths, (Swinnerton, 1932). The stratigraphical position of these sites is uncertain and it is not known if they are single or multiple phase sites. Swinnerton (1931) thought that they were contemporary with the surrounding upper peat and Bronze Age in date, but Ambrose and White (1986) recorded a briquetage site in Ingoldmells parish as being below the Upper Peat and resting on the grey clay below. Two briquetage sites have been recorded as being separated by a layer of clay "several inches thick", (Baker, 1960) with the upper site containing pottery of a "Belgic" origin. A briquetage site inland at Hogsthorpe produced a radiocarbon date of 2490 ± 80 BP (HAR 3092) (Kirkham, 1981).

The only non-briquetage site of possible Iron Age date was discovered by Warren in 1932 near Ingoldmells Point, at the level of the briquetage sites and below that of the Roman occupation, and consisted of oval timber structures 3m x 4m in size and constructed of round poles and split timbers with mortised and doweled joints, (Warren, 1932). These structures have only been exposed once and were not associated with any datable cultural material, although Warren thought that they were associated with the nearby briquetage site.

The Roman occupation and use of the coastline was concentrated between the first and third centuries AD mainly with a continuation of the salt industry. A small Roman station below Ingoldmells Point has been recorded, stratified above a saltern of probable Late Iron Age (Swinnerton, 1931; Baker, 1960) along with a ditch on the south side of Ingoldmells Point, filled with Romano-British pottery and bone fragments of *Bos longifrons*, sheep etc. (Warren, 1932). These are the only Roman non-saltern sites recorded for this coastline.

Subsidence at the end of the first millennium AD resulted in the erosion of a coastal barrier and led to the inundation of both Late Iron Age and Romano-British sites (May, 1976), this possible cause of erosion of the coastal barrier is now outdated and the accepted method for inundation is by sea-level rise. Nevertheless, there is no evidence of salt working between the late Roman Period and the 11th Century AD (Owen, 1984). The presence of a salt industry along this coast is well documented in the Domesday Book in 1087 at Croft, Grainthorpe, Ludney, Wragholme, Marshchapel, Fulstrom, Northcoats, Saltfleet & Skidbrooke and Tetney (Rudkin & Owen, 1960) but these have not been exposed along the modern coastline as they are concentrated on the landward side of the seabank. The salt industry lasted into the seventeenth Century AD until it became uneconomic.

The survey carried out by Brooks (1990) produced a limited number of new finds. A limited quantity of flint artefacts was recovered from two locations. At Ingoldmells Point nine finds were found at the interface of the Lower Peat and the Upper Marsh Till, all were translucent and between dark yellow brown and olive black in colour and are peat stained. None of the flints were diagnostic but a possible late Neolithic date can be given due to their stratigraphic position. At Vickers Point (south) three flints were recovered from the Anderby Beds, no diagnostic flints were present and no possible date can be given, although the source was most likely to be the Upper Marsh Till.

Most of the artefacts recovered in this survey were of briquetage which was recovered from the upper peat and associated layers. Three sites with briquetage were recorded in the survey area, Seathorne, Vickers Point and Trunch Lane. Three categories of find were recovered from these sites and included evaporating troughs, hand bricks or supports for the evaporating trough and kiln fragments.

Brooks (1990) after the survey was able to conclude that the survey area could be divided into four zones. Zone one consists of the coastline south and west of Gibraltar Point (TF560572) to the southern most extent of the survey area at Friskney, within the mouth of the Wash. This is an area of active mud accretion and therefore no archaeologically important strata can be expected to be revealed. The same extends to Zone two which covers the coastline between Gibraltar Point north to a point south of Seathorne (TF563652), this is an area of active sand accretion.

Zone three extends from Seathorne to the south end of Mablethorpe (TF515843). Here there are exposures of archaeological importance. Both the Lower and Upper Peat are exposed within the zone and major archaeological deposits are associated with these outcrops. The Lower Peat contains a low density of archaeological material, mainly flint artefacts which appear to be late Neolithic-Early Bronze Age. There are no known Mesolithic or reliable Palaeolithic material recorded along this stretch of coast. There is a marked concentration of archaeological material in the Ingoldmells Parish especially of Iron Age and Roman date. Zone four extends from north of Mablethorpe to Humberston (TA340053). This again is a zone of sand accretion backed by salt marshes and no archaeologically important deposits are exposed.

5.7. Dating

5.7.1. Non-Radiocarbon Dating

Skertchley, (1877), estimated the age of the Fen Forest to be 7,000 years old which he calculated by reference to the so-called Roman Bank and the rate of silting. Stevenson, (1923), inferred from the tree succession in the Danish bogs where Scot's pine was found to be superseded by oak and then beech, deduced that the coastal submerged forest was older than that of the Fens due to the preponderance of oak found on the coast. Using the Drayson theory, which stated that a 'glacial age' occurred roughly every 30,000 years and after each one the ice caps melt, with a subsequent rise in sea-level. Stevenson supposed that one rise of sea-level destroyed the Fen forest and that a previous one had submerged the coast forest at least 37,000 years ago. This age estimate has been proved to be very inaccurate, as earlier work by Warren, (1907), had produced flints from the gravel underneath the forest beds of a Neolithic date and therefore the forest must be Neolithic or younger. Dating provided by the palynological work carried out by Hunt (in Brooks, 1990) showed that the base of the peat corresponds to Godwin's pollen zone VIIa, (Godwin, 1975a) which begins around 7,000 BP and finishes at 5000 BP and the upper part of the Lower peat corresponds to Godwin's pollen zone VIIb which begins at 5,000 BP and gives a broad Neolithic date for the peat as ascertained by Godwin (1940b).

5.7.2. Radiocarbon dating

A radiocarbon date for the Lower Peat at Chapel Point of 3940 BP was obtained by Robinson, (1984). Another ^{14}C date of 4090 ± 120 BP (2140 ± 120 bc) (OxA-132) was obtained from an oak stump found in the submerged forest on the beach at Cleethorpes (Leahy, 1986). Further ^{14}C dates have been obtained for the work presented here and four uncalibrated dates were produced from three oak stumps, two from the exposure at Anderby Creek and one from Wolla Bank, and alder twigs from a monolith taken from the exposure at Wolla Bank. The dates are given in table 5.2.

It can be seen from table 5.2 that the dates appear to cover the broad timespan of the mid-early fourth millennium. Although the date from the oak at Wolla Bank is slightly earlier than either the oak from Anderby Creek and the alder obtained from the monolith at Wolla Bank it can be stated that the two exposures are broadly contemporary, whilst the oak from Wolla Bank, although older than the other stumps and twigs could still be contemporary by the fact that oak is long growing and may represent an earlier phase of the woodland. From table 5.2 it can be seen that there was woodland in this area for at least nearly 400 years, from 4865 ± 65 BP to 4480 ± 55 BP if not longer and that there was continual growth throughout the whole period. The dates show that the woodland is Neolithic in date.

Reference No.	**Sample**	**Date (uncalibrated) BP**
OxA-5963	Anderby Creek, stump 32, wood (*Quercus*)	4480 ± 55
OxA-5964	Anderby Creek, stump 34, wood (*Quercus*)	4625 ± 55
OxA-5965	Wolla Bank, stump 8, wood, (*Quercus*)	4865 ± 65
OxA-5966	Wolla Bank, monolith, wood, (*Alnus*)	4500 ± 55

Table 5.2. Radiocarbon dates obtained from wood samples from Anderby Creek and Wolla Bank

5.7.3. Differences in Radiocarbon dates from the Lincolnshire Coast

As can be seen from the radiocarbon dates obtained from the deposits analysed in this study and those obtained from earlier work there appears to be some discrepancy between the dates. The earliest was obtained from an oak stump at Wolla Bank dated at 4850 ± 65 BP and the latest was from the Lower peat at Chapel Point at 3940 BP. This could relate to a disparency of approximately 1000 years.

Reasons for this difference could be manifold and are outlined here. One of the reasons for the discrepancy could well be due to the type of material used for dating the deposit. At Wolla Bank the dated material was an oak stump rooted in the underlying glacial till whilst it is not known what material was dated at Chapel Point. If it was a sample of the peat itself, this could lead to an averaging of the dates whereby the older material is mixed with younger material thereby giving a general date for the peat. It could be argued that the oak stump being rooted in the underlying stratum predates the formation of the peat. But as alder wood from within the monolith taken at Wolla Bank are dated at 4500 ± 55 BP this shows that the two dates from this exposure are broadly contemporary. The monolith was extracted from a section close to an alder stump which was also rooted in the underlying glacial till and therefore shows that the alder wood from the monolith was most likely was derived from this stump.

Another problem arises with the early date, in the fact that most of the stumps were badly worn, with very few of the stumps or trunks having bark present. Therefore it makes it very difficult to determine where the wood used for dating came from. If the wood was taken from close to the centre of the stump then an earlier date would be produced than if it was taken from the outer part of the stump, and as oaks can grow to a considerable age, this sampling problem could be part of the cause of such discrepancies.

The position of the exposure of the Lower Peat on the beach may also lead to a difference in date. The stump sampled from Wolla Bank was very close to the low spring tide mark in March 1994 and therefore may represent an earlier part of the submerged forest if the date from the Lower Peat at Chapel Point was derived from an exposure further up the beach. As Heyworth (1978) has shown at Bridgewater Bay those stumps dated either by radiocarbon or dendrochronology were shown to be older lower down the beach than those higher up. The mechanism for this he suggested was due to the migration of the original forest up the beach as sea-level continued to rise. Even so, the discrepancy does fall within the life period of a modern woodland, suggesting that the dates do belong to a single forest phase.

Without the information on the type of material and the position of the exposure at Chapel Point it is very difficult to assess which of the above explanations can be used to determine the differences in dates and it may be the case that all of the above reasons may play some part.

5.8. Present Studies of the Submerged Forest (Lower Peat) deposits

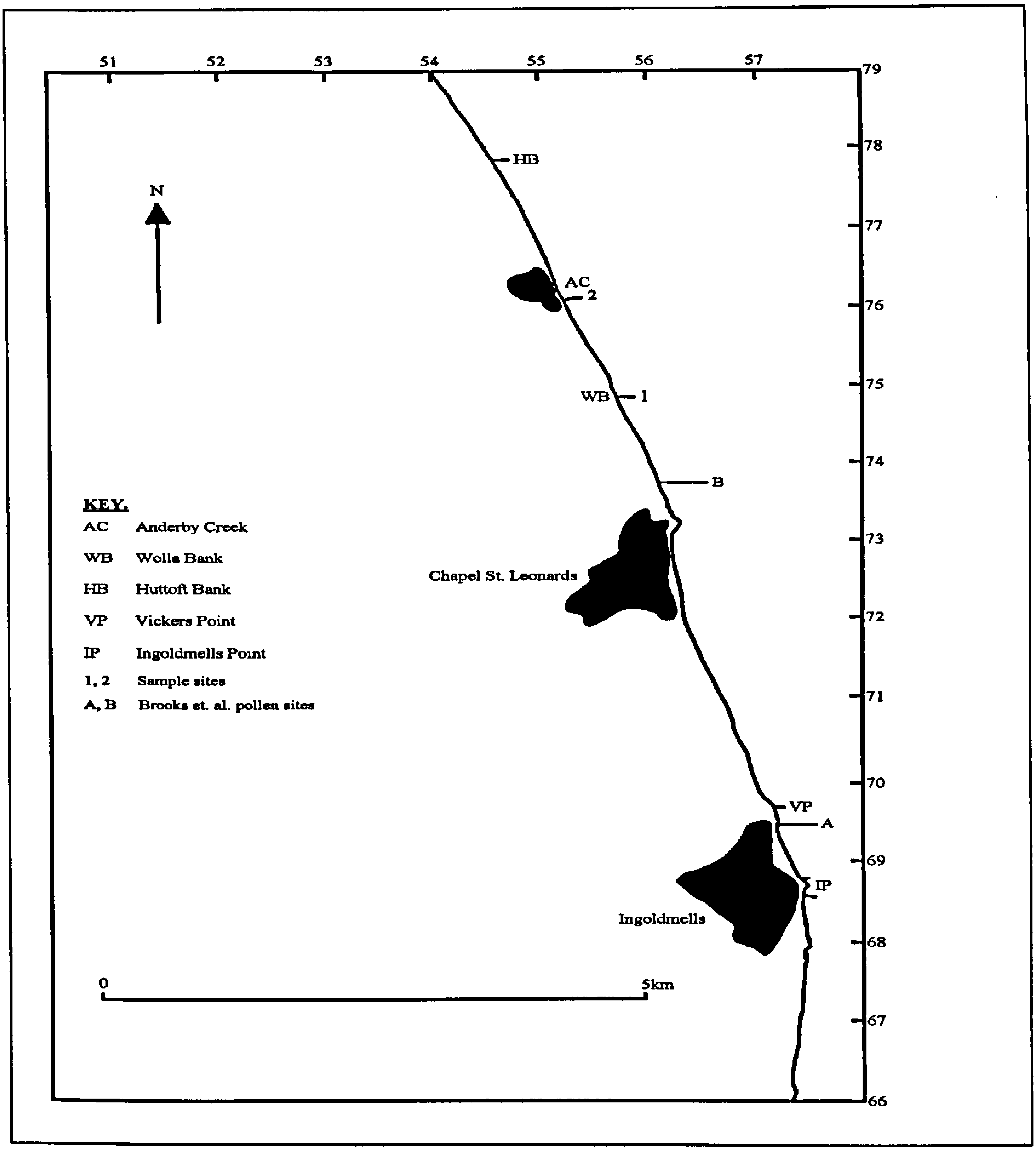
5.8.1. Wood Identifications from Wolla Bank and Anderby Creek

Two areas of the lower peat beds were surveyed, the southern most at Wolla Bank (TF557749) and the northern most at Anderby Creek (TF552758)(Map 5.2). Both areas were surveyed and planned with regards to the relative positions of the major tree remains. Each stump or large trunk was labelled and samples were taken for further species identification. A record of diameter/width, length and angle of fall were taken where appropriate. The results are recorded in tables 5.3 & 5.4 and figures 5.2 & 5.3.

The wood samples from both of the areas of exposed Lower Peat were of variable conditions of preservation, many were well preserved allowing a satisfactory identification, although only one was too decomposed to allow accurate identification. Some of the woods were partly mineralised and very hard to section, although, once sectioned identification was not hampered. The hardness of the wood could be due to wood boring animals or the inclusion of sand and clay particles from the eroding deposits. Some of the samples identified showed signs of compression. This is most likely to have occurred post-deposition as the later deposits were laid down.

5.8.2. Results of Wood Identification

The results of the species identifications are shown in tables 5.3 & 5.4 and shown graphically in figures 5.2 & 5.3. Figures 5.2 & 5.3 demonstrate that, although the species are fundamentally the same, the proportion of each is different at each site. At the Wolla Bank site, from a total of twenty-one identifications, nine were of alder, five of ash, three of oak, three of willow/poplar and one of birch. Whilst at Anderby Creek, from a total of twenty-seven samples the dominant species identified is oak (18 finds), with smaller numbers of alder (4), ash(2) and willow/poplar (2) with one specimen remaining unidentified. This proves to be an interesting result as it was expected to find a more or less uniform range from both sites, but the more southerly site (Wolla Bank) is dominated by alder and ash, whilst the northern site of Anderby Creek is dominated by oak.



Map 5.2. Map showing the location of the Wolla Bank and Anderby Creek submerged forest exposures on the east Lincolnshire coast.

There are several possible explanations for this difference, firstly, it may well be the result of sample bias, where only specimens deemed suitable (because of size) for identification were sampled leading to an artificial spread of species, although, this bias factor should be similar at each site. Another factor could be due to the preservation differences between the two sites, where slight differences in wave action could result in differential erosion, therefore certain tree species could well have been washed out of the peat and redeposited elsewhere. But the more likely scenario is that the results represent a local environmental difference such as variance in the height of the local watertable or the differences in the development and maturity of the woodland such as may be caused by storm or fire damage, chronological differences must also be considered. Differences due to artificial management may be ruled out as no evidence (such as axe marks on the stumps) was noticed.

It is possible that the differences between the two areas reflect local environmental conditions. This can only be confirmed by further analysis of the plant macrofossil remains contained within the profile. Radiocarbon dating has shown the two deposits to be broadly contemporary. One fact that must be noted is that the expanse of the peat platform exposed was greater at Anderby Creek than at Wolla Bank and therefore may be a factor in influencing the species recovered.

Sample no.	Length (m)	Diameter (m)	Species
Trunk 1	5.2	0.3	Alnus
Trunk 2	3.2	0.1	Alnus
Trunk 3	1.7	0.25	Salicaceae
Trunk 4	1.0	0.14	Alnus
Trunk 5	1.5	0.09	Salicaceae
Trunk 6	1.1	0.1	Alnus
Stump 1		0.2	Alnus
Stump 2		0.45	Quercus
Stump 1		1.5	Fraxinus
Stump 2		0.45	Fraxinus
Stump 3		0.24	Alnus
Stump 4		0.34	Fraxinus
Stump 5		0.35	Salicaceae
Stump 6		0.25	Fraxinus
Stump 7		0.55	Fraxinus
Stump 8		1.0	Quercus
Stump 9		0.4	Betula
Stump 10		0.4	Alnus
Stump 11		0.25	Alnus
Stump 12		0.33	Alnus
Big Trunk		0.75	Quercus

Table 5.3. Data of the tree stumps and trunks recorded at Wolla Bank, Lincolnshire on 28/3/94 & 29/3/94.

From studying table 5.5, showing the comparison between species identified by Swinnerton (1931) and the author, it can be seen that there is a great deal of similarity between the two groups, with two major differences. In the first case, Swinnerton, records the presence of *Prunus* wood, which can be considered unusual. The occurrence of waterlogged wood of *Prunus* according to Schweingruber, (1982), is rare and therefore, some doubt can be allotted to this identification, *Prunus* wood is usually characterised by spiral thickenings in the xylem vessels, but as Swinnerton, (1931) gives no description of his identifications it is difficult to determine whether his identification is accurate, but if it considered with the other species present it is ecologically not out of place.

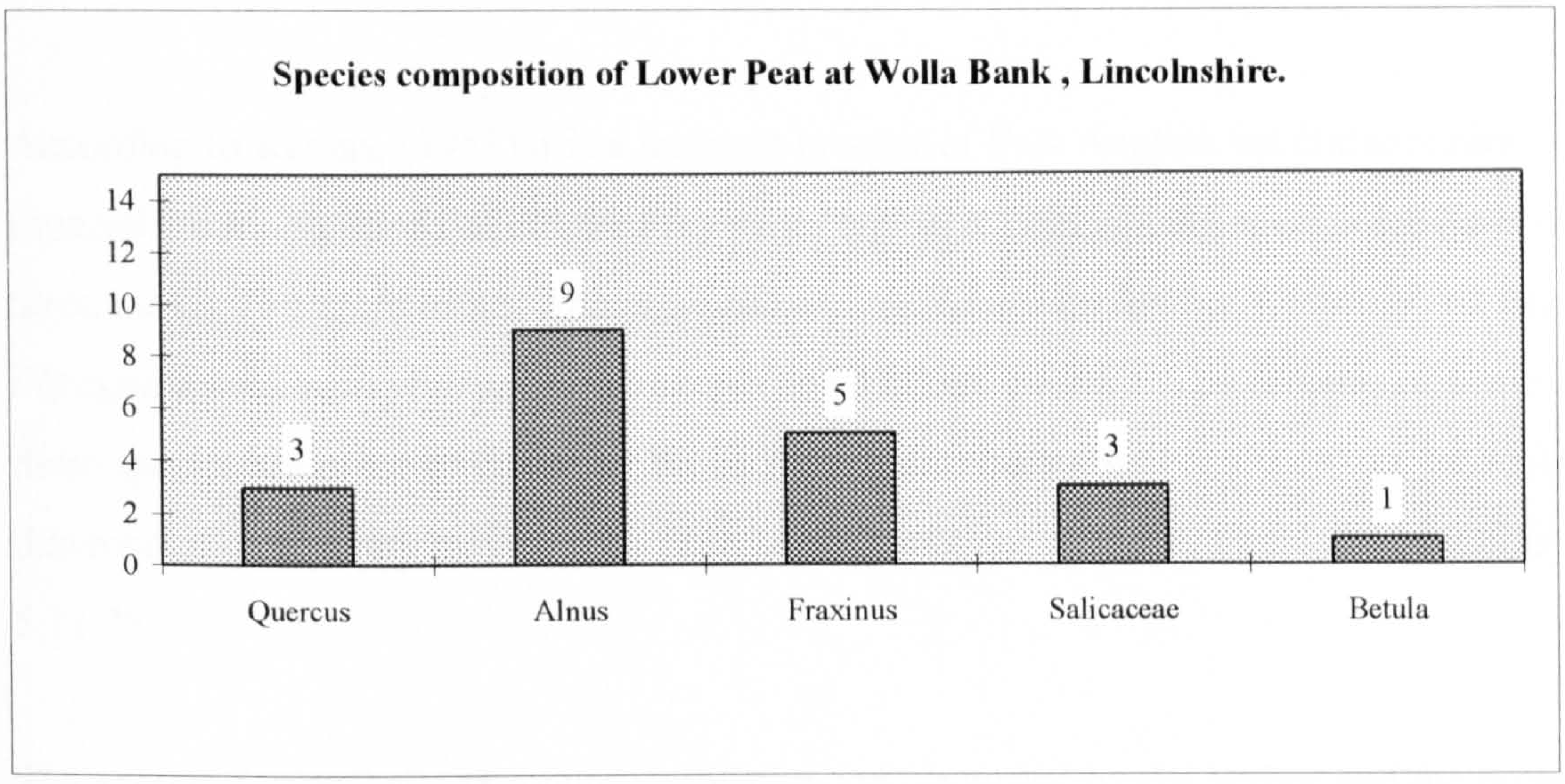


Figure 5.2. Tree species composition of Lower Peat at Wolla Bank, Lincolnshire

It is interesting to see that a number of the trunks and stumps identified were of ash, *Fraxinus excelsior*. The modern day habitat of ash is accepted as being that of well drained soils usually with a base rich (calcareous) substrate, although according to Wardle, (1961) it can be found growing on waterlogged sites where it can be common or even dominant.

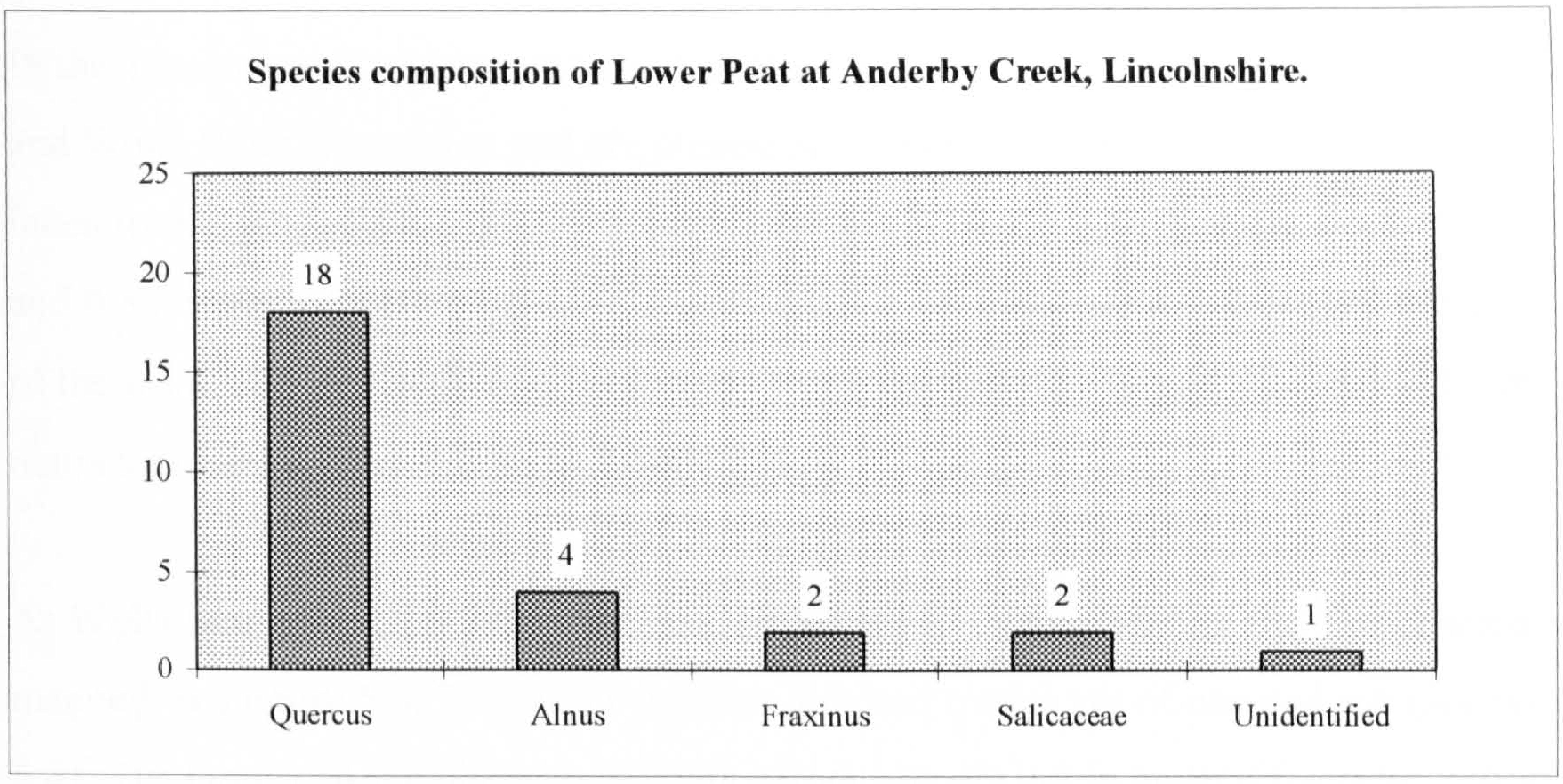


Figure 5.3. Tree species composition of Lower Peat at Anderby Creek, Lincolnshire

According to Kassas, (1951) it is a frequent invader of East Anglian fen communities, especially during periods of efficient drainage, typical accompanying species are *Salix atrocinerea*, *Frangula alnus*, *Rhamnus cathartica*, *Viburnum opulus*, *Cladium mariscus*, *Phragmites australis*, *Filipendula ulmaria* and *Molinia caerula*. The remains of some of these species are present within the Wolla Bank plant macrofossil analyses suggesting that this type of community may be present at Wolla Bank and Anderby Creek (see section 5.11.2).

The presence of Salicaceae (willow/poplar) wood recorded by the author and the presence of *Taxus* (yew) only recorded by Swinnerton (1931) are easier to explain as local differences, as Godwin (1940b, 1943) recorded that *Taxus* and *Salix* leaves were recorded in the Upper Peat.

5.8.3. Dimensions of the stumps and trunks recorded at Wolla Bank and Anderby Creek

Brooks, 1990, recorded that the Lower Peat exposures at Anderby Creek consisted of small patches south of the outflow of Anderby Creek, and at Wolla Bank, the fallen timbers within the Lower Peat reached lengths up to 5 metres and diameters of up to 0.6m.

In this present work, measurements of trunks and stumps exposed at both Anderby Creek and Wolla Bank were taken and are presented in tables 5.3 and 5.4. At Wolla Bank, the fallen trunks ranged from one metre to 5.2 metres in length with diameters between 0.09m and 0.3m at the widest point, there seems to be no correspondence with diameter and length of the trunk exposed, although the longest trunk did have the largest diameter. Stump diameters ranged from 0.20m to 1.5m.

At Wolla Bank, a total of 604.4 m^2 was surveyed and twenty stumps and trunks were mapped, see figure 5.4. The larger sized stumps and trunks are of oak and ash (see table 5.4). The largest stump diameter of 1.5m belongs to ash but in general the other ash stumps are bigger than the other species of trees identified at Wolla Bank, with only one stump below 0.3m in diameter. The oak stumps have diameters of 1.0m, 0.75m and 0.45m. The alder stumps vary in diameter from between 0.10m and 0.4m. The one birch stump is recorded with a diameter of 0.4m and the three willow/poplar stumps measure 0.09, 0.25 and 0.35m in diameter. The distribution of diameter sizes can be seen in figure 5.5. The trunks range from 1.0m to 5.2m in length, four of the trunks were of alder and measured 1.0, 1.1. 3.2 and 5.2m and two were willow/poplar and were recorded as being 1.5 and 1.7m in length. One trunk which had drifted away from the deposits and came to rest against a groyne measured 6.4 metres in length and 0.75m in diameter. It can be suggested that at Wolla Bank, the main canopy consisted of ash and oak with an understorey of alder, willow/poplar and birch.

At Anderby Creek, a total of 2121.9 m^2 were surveyed and a total of fifty-one stumps and trunks were recorded in two islands of the Lower Peat, see figure 5.6 a & b (figure 5.6a is situated forty metres north-west of figure 5.6b). The same species are recorded with the exception of *Betula*, but unlike Wolla Bank not all the stumps and trunks were sampled for identification. This was due to the poor preservation of some of the tree remains. The largest diameter trunks and stumps belonged to oak (see table 5.4) with the smallest being 0.14m and the largest 1.1m in diameter. The other large diameter trunks and stumps belonged to ash (0.6m) and alder (0.52m). The distribution of diameter measurements can be seen in figure 5.7. The trunks ranged from 1.23m to 8.83m in length, with the majority of the stumps sampled being of oak (10) and one of ash. The oak trunks ranged from 1.23-5.6m and the ash was measured at 3.95m. As mentioned above oak was the dominant tree species recorded at Anderby Creek. As at Wolla Bank, the canopy can be seen to be composed mainly of oak with a smaller amount of ash, with an understorey of alder and willow/poplar.

Sample no.	Length (m)	Diameter (m)	Species
Trunk 1	4.98	0.34	Quercus
Stump 2		0.5	Quercus
Trunk 3	5.6	0.8	Quercus
Trunk 4	4.05	0.5	n/s
Stump 5		0.35	Quercus
Trunk 6	3.8	0.25	n/s
Stump 7		0.4	Alnus
Trunk 8	2.25	0.15	Quercus
Stump 9		0.55	n/s
Trunk 10	2.95	0.14	Quercus
Stump 11		1.1	Quercus
Trunk 12	2.89	0.2	Quercus
Stump 13		0.25	Fraxinus
Trunk 14	3.52	0.21	Quercus
Trunk 15	1.65	0.18	n/s
Stump 16		0.2	Salicaceae
Stump 17		0.2	n/s
Stump 18		0.4	Alnus
Trunk 19	2.14	0.19	n/s
Stump 20		0.26	n/s
Stump 21		0.22	n/s
Stump 22		0.2	Quercus
Stump 23		0.2	n/s
Stump 24		0.15	n/s
Stump 25		0.15	n/s
Stump 26		0.2	n/s
Stump 27		0.25	n/s
Stump 28		0.15	n/s
Trunk 29	1.23	0.8	Quercus
Stump 30		0.52	Alnus
Trunk 31	2.87	0.3	Quercus
Stump 32		0.4	Quercus
Stump 33		0.4	n/s
Stump 34		0.4	Quercus
Stump 35		0.38	n/s
Stump 36		0.19	n/s
Trunk 37	1.36	0.12	Quercus
Stump 38		0.27	unidentified
Trunk 39	5.2	0.21	Quercus
Stump 40		0.17	Quercus
Stump 41		0.3	Salicaceae
Stump 42		0.15	Alnus
Stump 43		0.38	n/s
Stump 44		0.28	n/s
Trunk 45	3.95	0.6	Fraxinus
Stump 46		0.6	Quercus
Trunk 47	5.28	0.54	n/s
Trunk 48	2.5	0.6	n/s
Trunk 49	8.83	0.38	n/s
Stump 50		0.45	n/s
Stump 51		0.2	n/s

Table 5.4. Data of the tree trunks and stumps recorded at Anderby Creek, Lincolnshire, on 28/4/94 & 29/4/94. (n/s = not sampled)

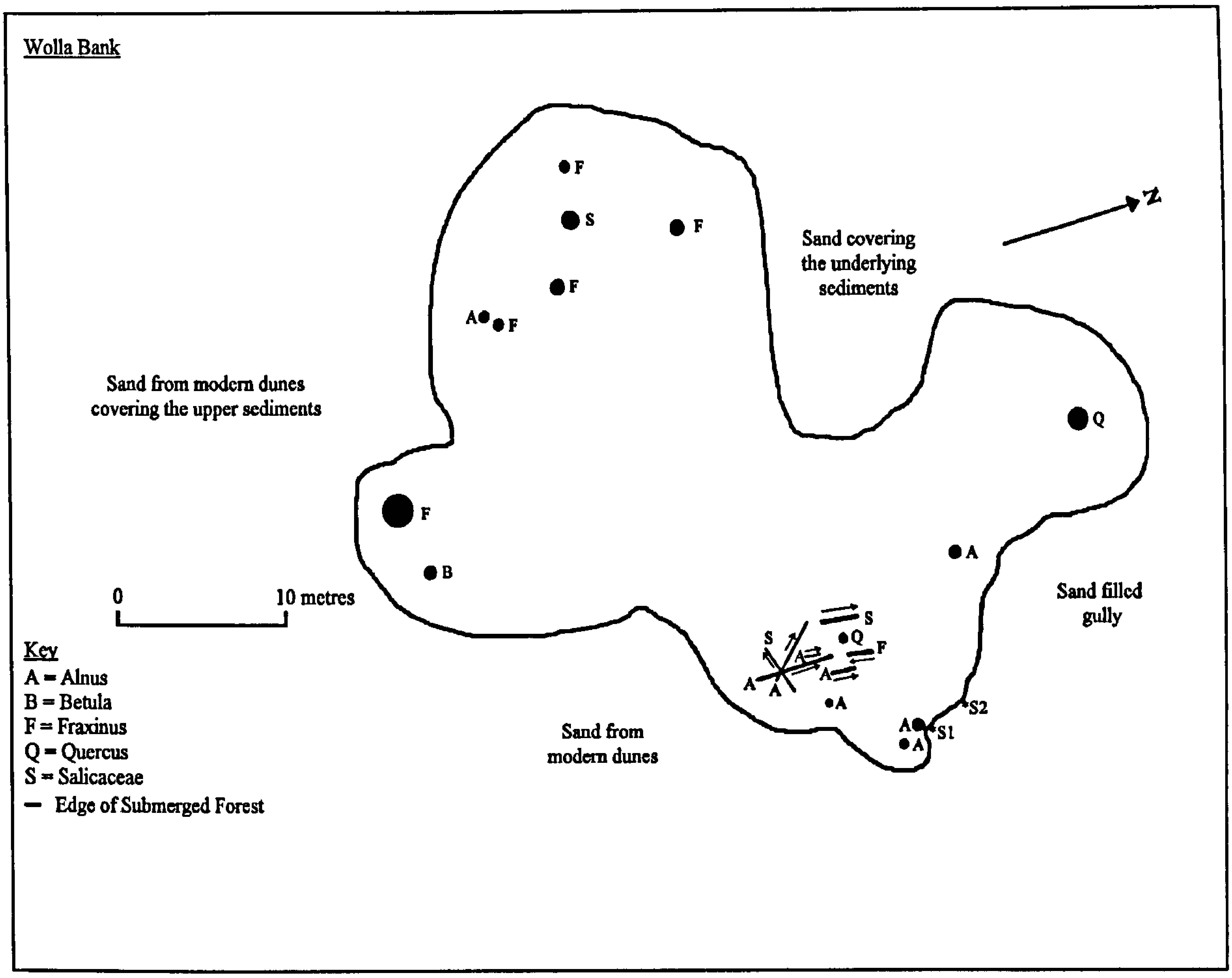


Figure 5.4. Plan showing the distribution of stumps and trunks at Wolla Bank. (The boundaries of the submerged forest are schematic)

Species (Common name)	Swinnerton, (1931)	Clapham, (1998)
Alnus (Alder)	*	*
Betula (Birch)	*	*
Fraxinus (Ash)		*
Prunus (Cherry etc.)	*	
Quercus (Oak)	*	*
Salicaceae (Willow/Poplar)		*
Taxus (Yew)	*	

Table 5.5. Comparison of tree species identified by Swinnerton (1931) & Clapham (1998) from the Lower Peat on the Lincolnshire Coast.

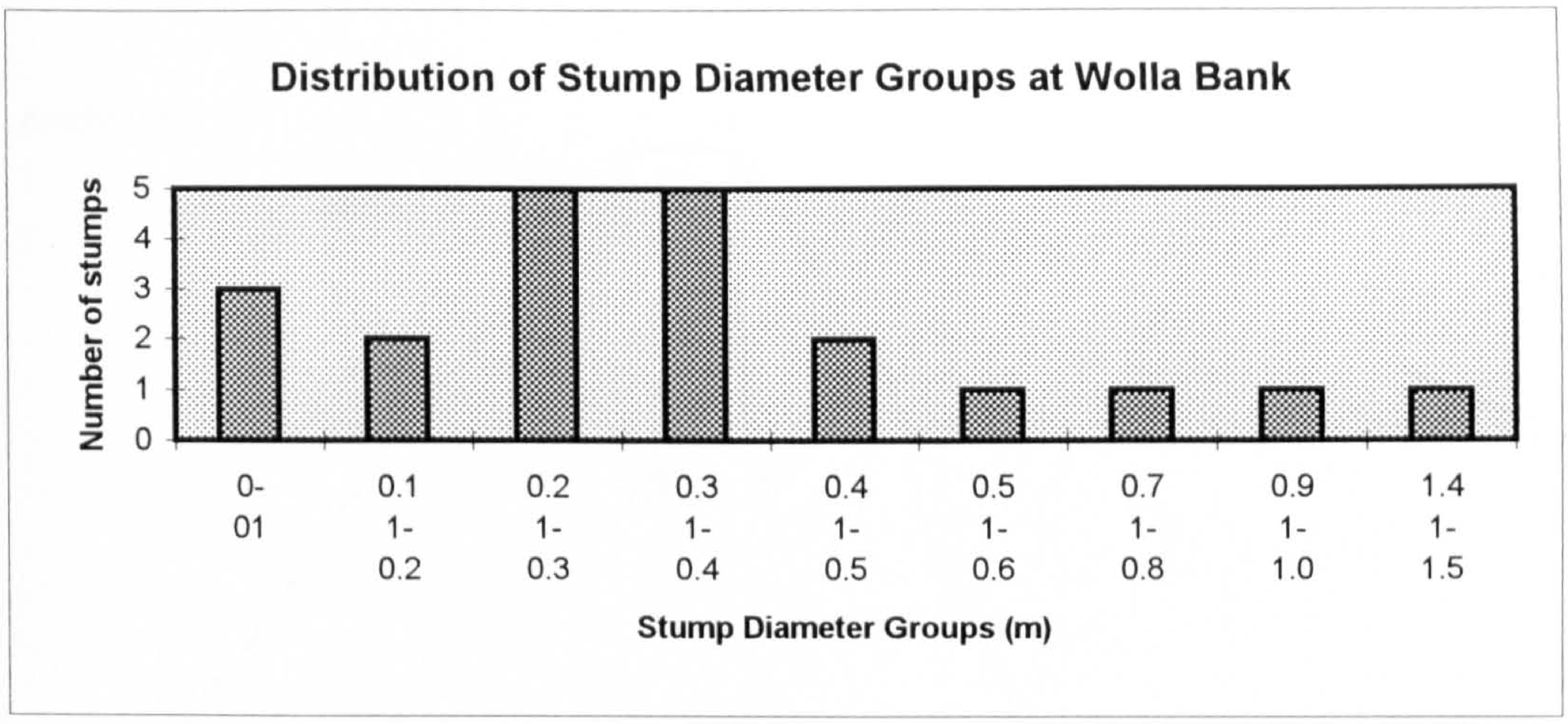


Figure 5.5. Distribution of Stump Diameter Groups at Wolla Bank

5.8.4. Angle of fall of the stumps and trunks at Wolla Bank and Anderby Creek

As well as the dimensions of the trunks and stumps being recorded, the angle of fall for the trunks at both locations was also noted and are presented in figures 5.8 and 5.9. A total of twenty-three were measured, seven at Wolla Bank and sixteen at Anderby Creek. The general direction of fall was confined to between 340° and 100° North. From studying figures 5.8 and 5.9 it can be seen that the orientation of fall recorded for those trunks at Wolla Bank fit neatly into the gap left by the orientation of the trunks at Anderby Creek, giving an overall range of fall from NNW to ESE. This neat fit cannot really be explained, but it may be due to the smaller number of trunks recorded at Wolla Bank, limiting the spread of angle of fall. Another possibility may be due to the position on the coast, whereby Anderby Creek is further North presenting the trees at a slightly different angle to the prevailing winds than perhaps those at Wolla Bank. In general, the direction of fall corresponds with the directions noted by earlier observers (de la Pryme, 1701; Stevenson, 1923), although Thompson, noted at Friskney, Wainfleet and Wrangle the trunks laid in all directions (Thompson, 1856).

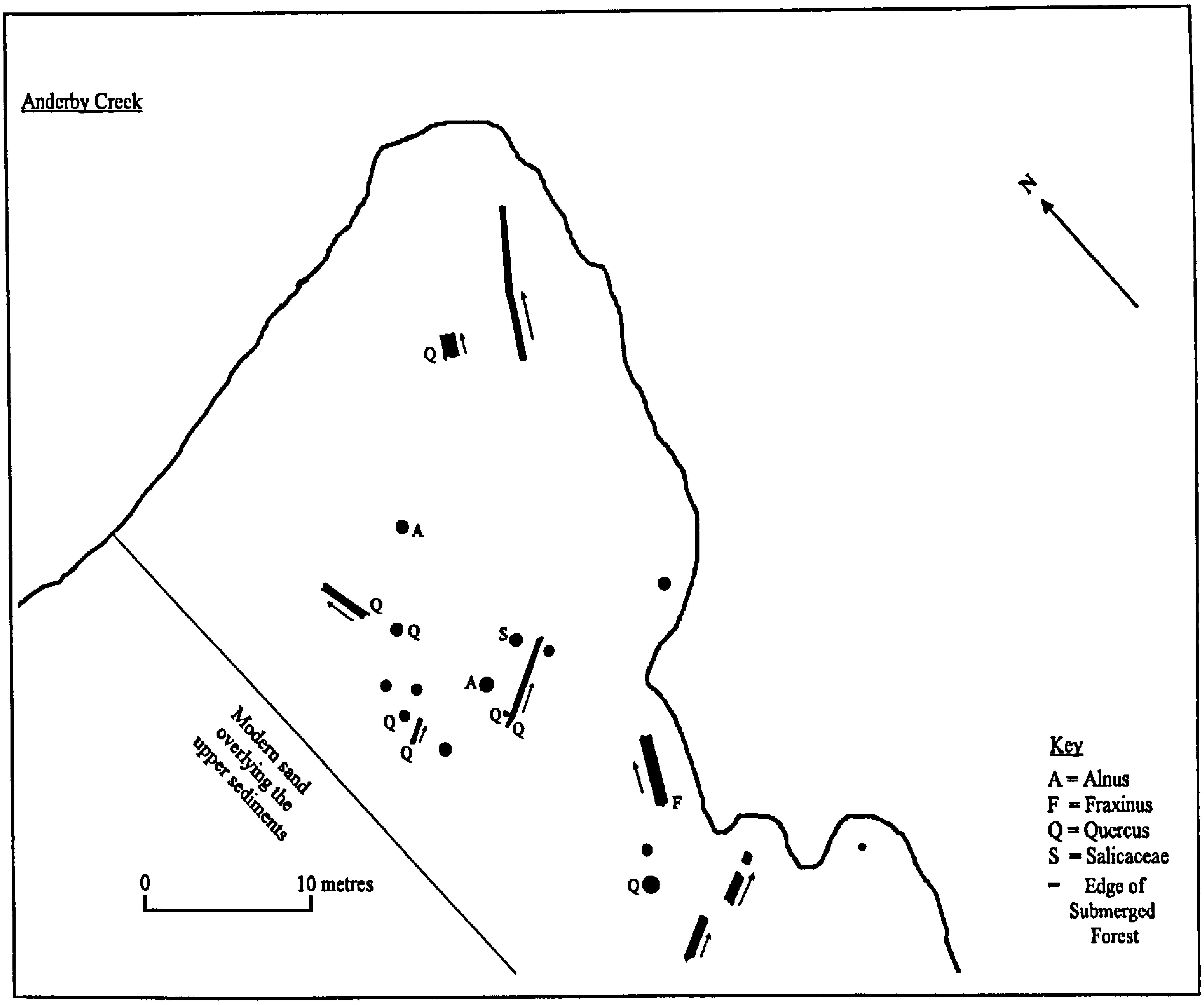


Figure 5.6a. Plan of the stumps and trunks at Anderby Creek, east Lincolnshire. (The boundaries of the submerged forest are schematic)

It cannot be stated with total confidence that the records of angle of fall reflect either the prevalent wind directions at the time of the submerged forests, or even the average direction of storm winds on the forests, as some of the trunks may have been realigned after the death of the trees by the action of the sea, and may even have been at one stage redeposited.

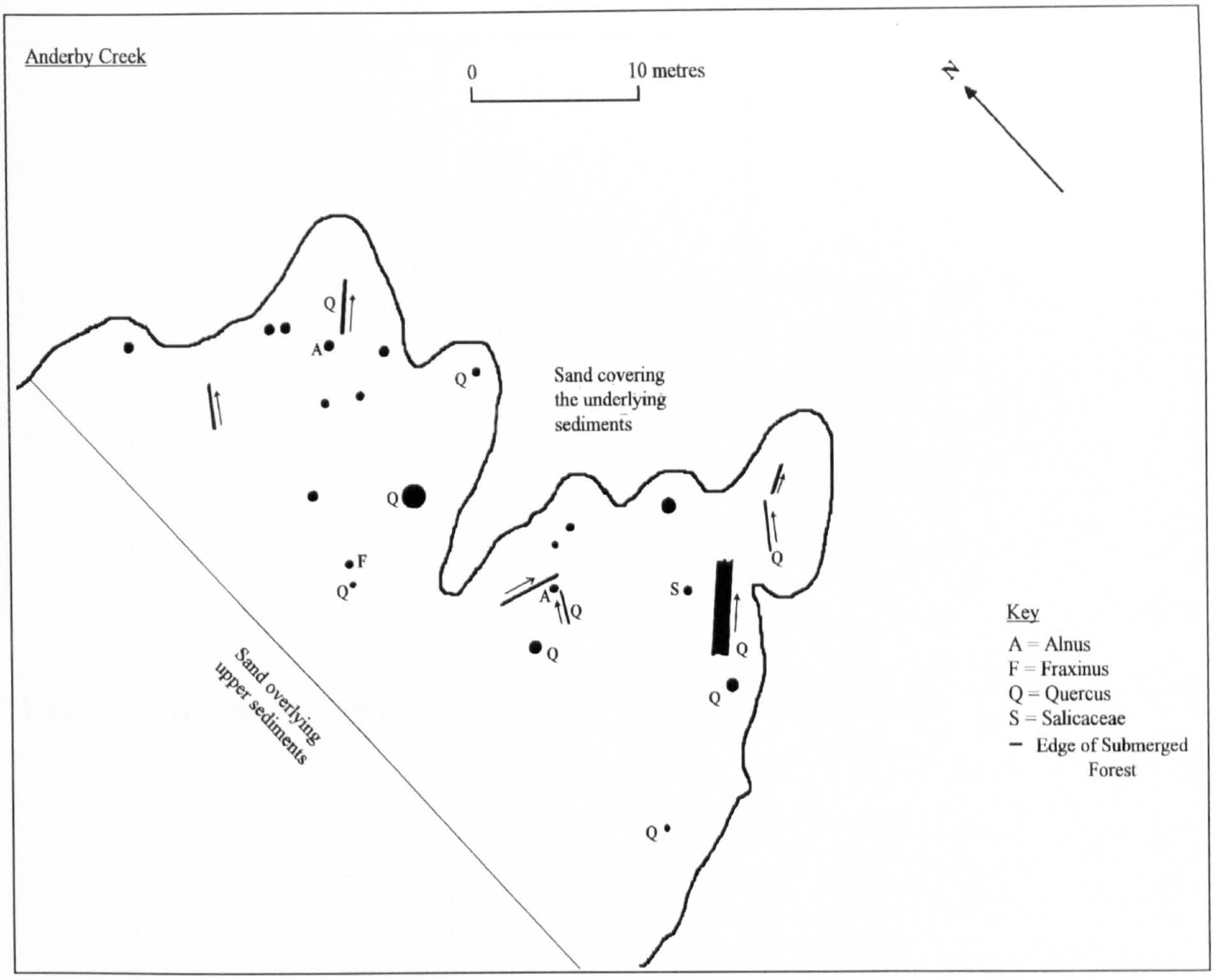


Figure 5.6b. Plan of the stumps at Anderby Creek, east Lincolnshire. (The boundaries of the submerged forest are schematic)

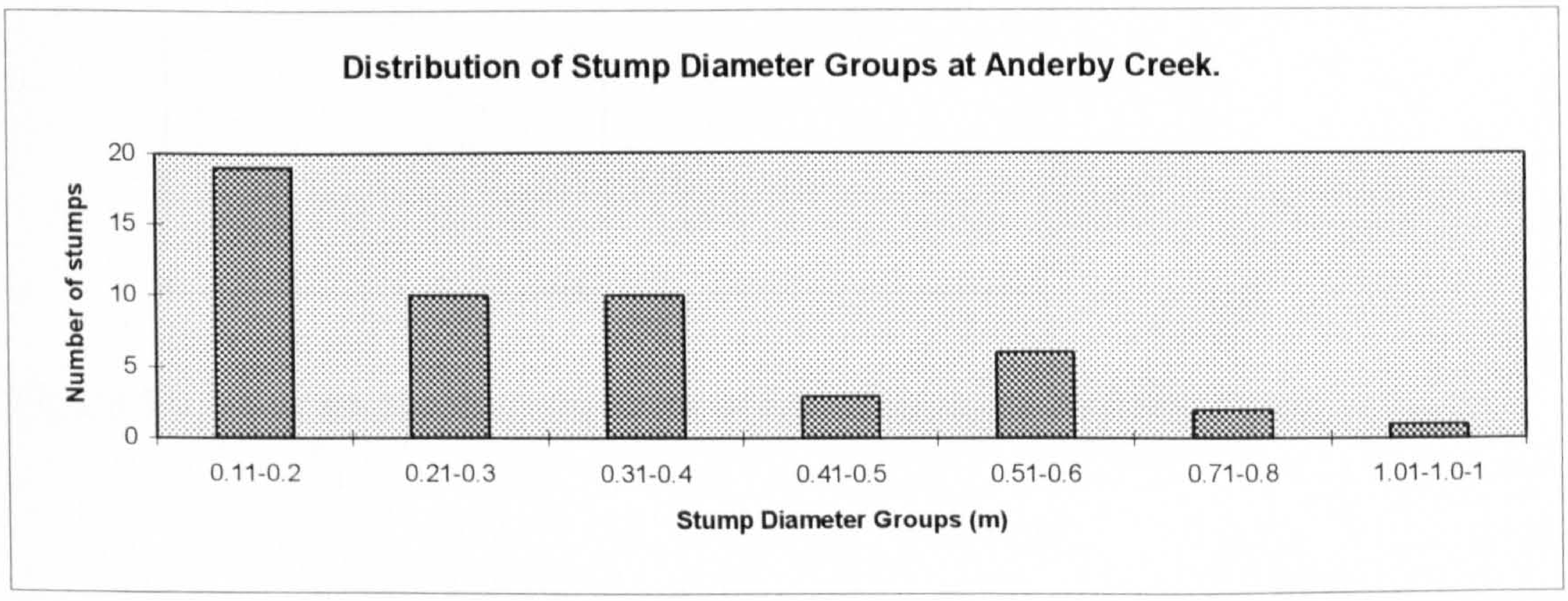


Figure 5.7 Distribution of Stump Diameter Groups at Anderby Creek

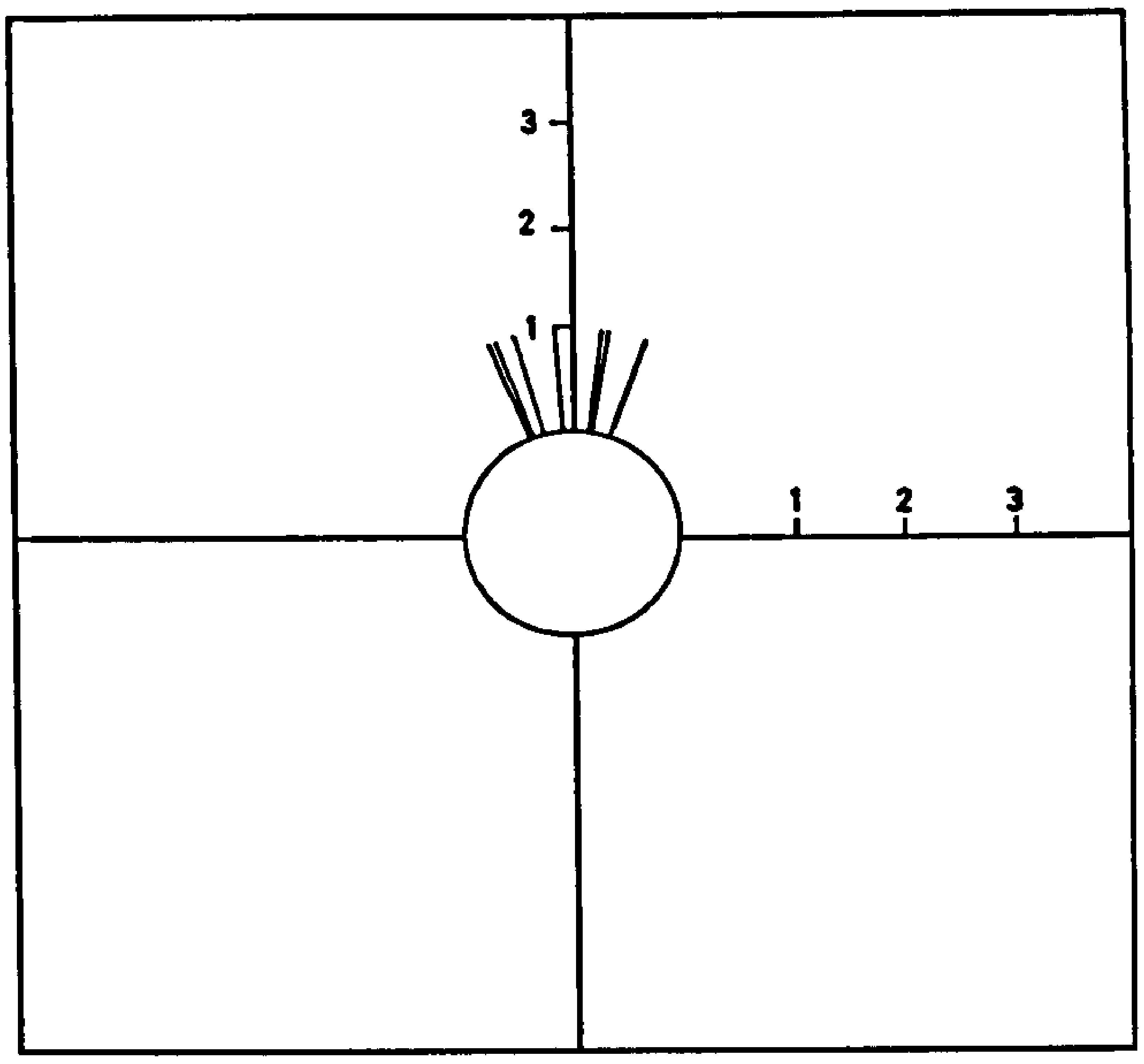


Figure 5.8. Diagram showing the angle of fall of trunks at Wolla Bank

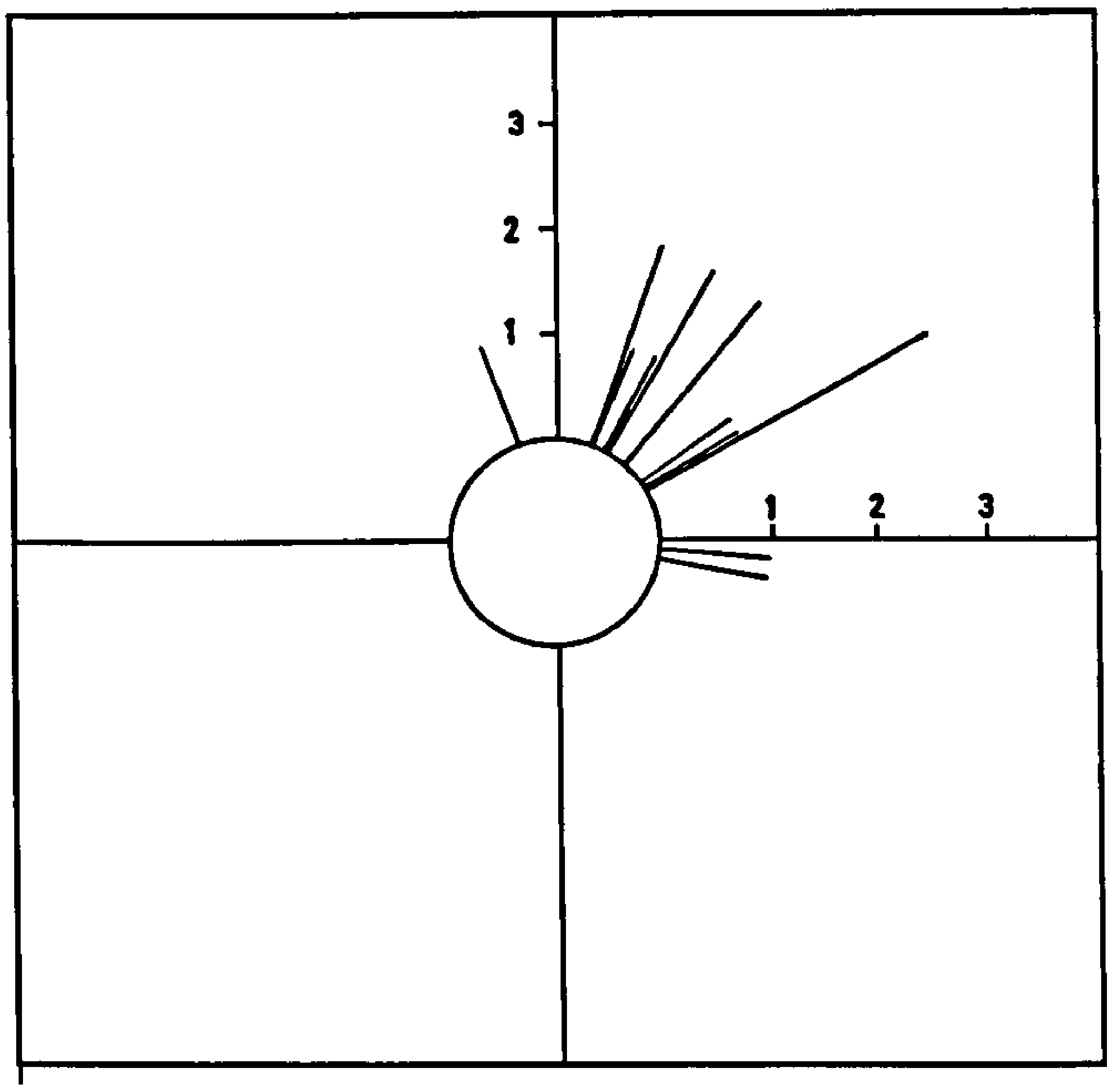


Figure 5.9. Diagram showing the angle of fall of trunks at Anderby Creek

5.9. Plant Macrofossil Studies

5.9.1. Plant Macrofossil Monolith descriptions

Two sections at Wolla Bank were sampled, section one was taken from the base of stump twelve (identified as alder),the second section was taken from 1 metre seaward and 1 metre north of stump 12.

5.9.1.1. Section One

This comprised two overlapping monoliths which were combined to produce the section diagram, figure 5.10. A total length of 30cm was sampled, this was limited due to the level of the water and the depth of sand in the bottom of erosion channel where the section was exposed. A description is provided below.

0-10cm below surface.	Black fibrous peat with numerous wood fragments. Three macrofossil samples were taken. Sample 1: 0-4.5cm. Sample 2: 4.5-7.0cm. Sample 3: 7-10.0cm. Sample 1 provided alder wood for ^{14}C dating.
10-14.5cm below surface.	Peat/clay matrix. Light brown/grey in colour containing root fragments. One sample for macrofossil analysis was taken. Sample 4: 10-14.5 cm. This part of the profile appeared to represent a soil horizon and soil micromorphologial analysis was undertaken. (See section 5.10.4 below).
14.5-30cm below surface.	Grey/blue clay with some roots both woody and herbaceous. Black specks and streaks also present most likely to be the remains of roots. A root fragment was present at 20cm. Three samples were obtained. Sample 5: 14.5-19cm. Sample 6: 19-25.0cm and Sample 7: 25-30cm.

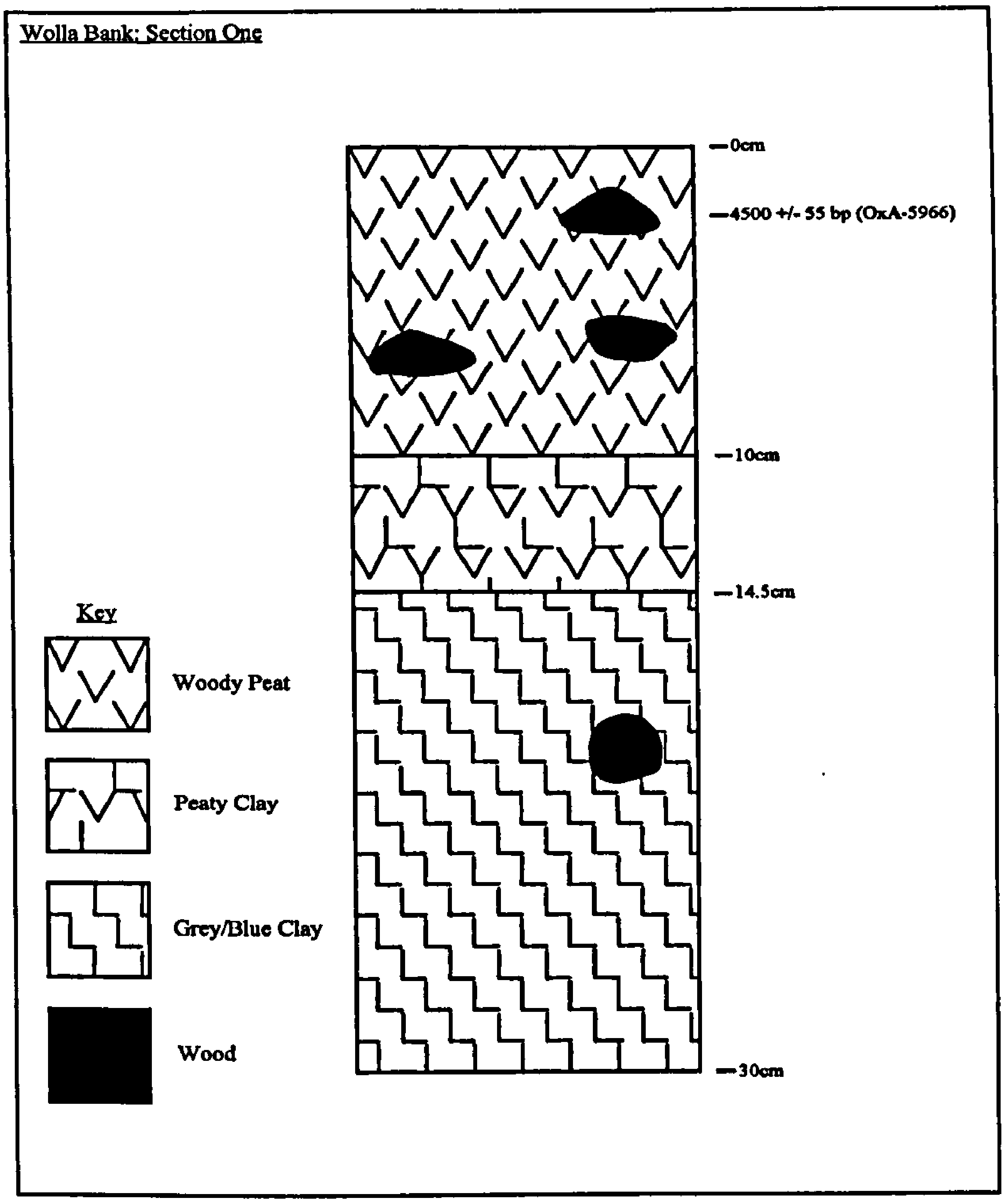


Figure 5.10. Section diagram for Wolla Bank, Section One

5.9.1.2. Section Two

Section two (Figure 5.11) at Wolla Bank was taken from an exposed profile caused by wave backwash, and was located one metre seaward and one metre north of section one. A total of 22cm was sampled. In general appearance there was a sloping of the layer from left to right in the monolith. This sloping could either have been caused by the slumping due to wave action or an effect of the undulating nature of the underlying glacial till as described by Swinnerton, (1931).Description of section as seen in the monolith is given below. Measurements from the left hand side are given throughout.

0-7.0cm below surface	Woody/laminated peat, dark brown in colour and contained fragments of wood and roots. Two samples were taken. Sample 1: 0-3.5cm. Sample 2: 3.5-7.0cm.
7cm-8.0cm below surface	Band of Brown/grey clay with fine texture. Some roots present. One taken. Sample 3: 7-8.0cm.
8-10.0cm below surface	Brown woody laminated peat. One sample taken. Sample 4: 8-10.0cm.
10-17.0cm below surface	Brown/grey clay with organic intrusions mainly *Phragmites australis* rhizomes. Two samples taken. Sample 5: 10-14.0cm. Sample 6: 14-17cm.
17-18.0cm below surface	Black horizon. Sample 7. 17-18.0cm.
18-22.0cm below surface	Brown/grey clay with organic intrusions mainly *Phragmites australis* rhizomes. One sample taken. Sample8: 18-22.0cm.

5.9.3. Anderby Creek Section

A section from the Anderby Creek deposits was taken two years later, in April 1996, as outlined above locating the exact areas where previous work had been carried out can be extremely difficult. The tide did not uncover the exposures of 1994 either to the south or north of the outfall pipe/drain at TF 553762, although an exposure of what was thought to be the lower peat was located further north towards Huttoft Bank, TF 549769, a few stumps were exposed and the roots were seen to penetrate the underlying clays, the initial appearance of the deposits at this site showed that it was different to that exposed at Anderby Creek in March and April 1994. There appears to be very little peat in the profile and the blue/grey clay is apparent at the surface. A wood sample was taken for identification but appeared to be very decayed oak. A complete profile was taken from a cleaned back low lying cliff with a monolith. The description of which is presented here and shown in figure 5.12.

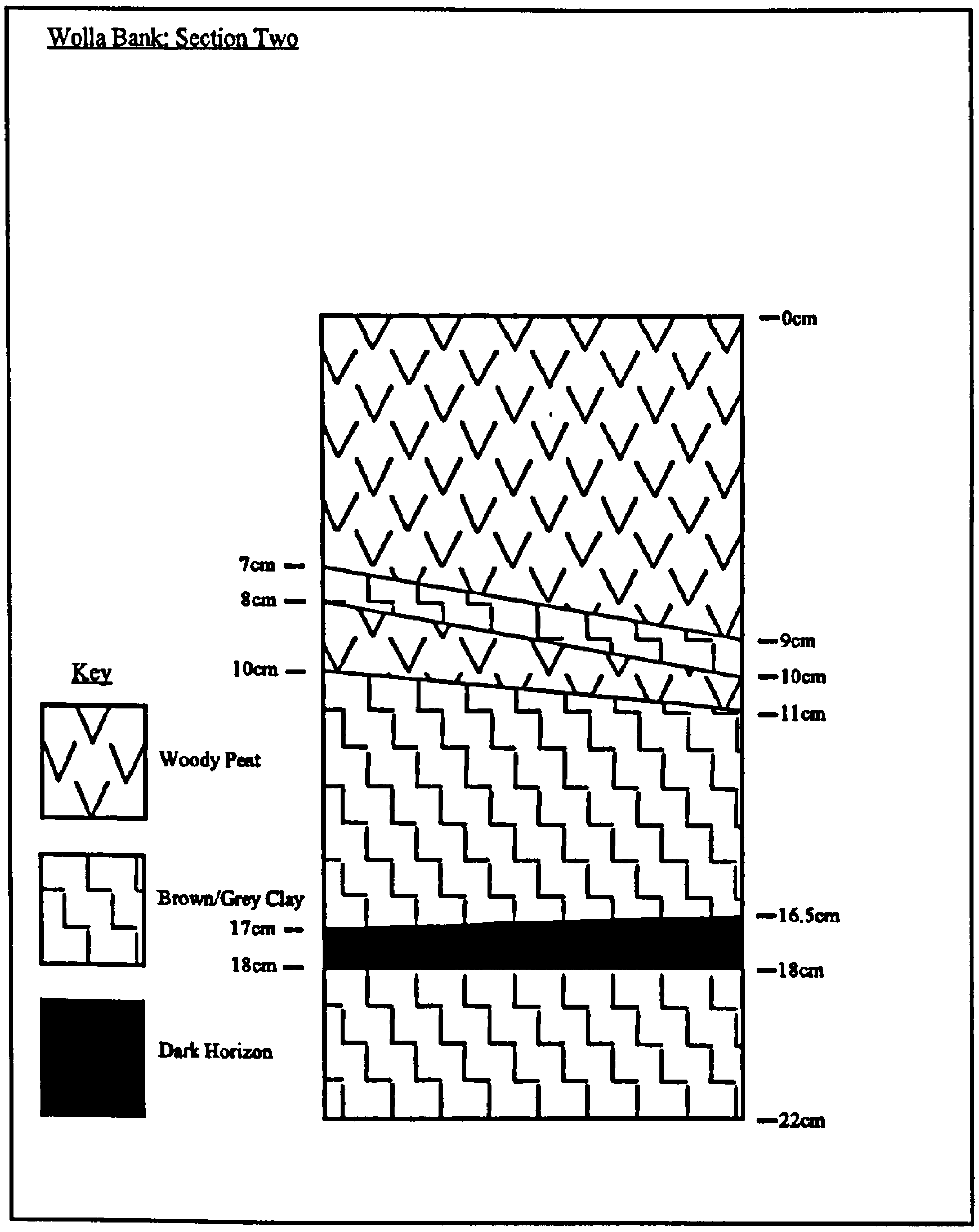


Figure 5.11. Section diagram for Wolla Bank, Section Two

A sediment profile of 49cm was obtained, giving the following stratigraphy:-

0-7cm below surface	Grey Brown clayey peat. This was divided into two samples, the top half 0-4cm (sample 8) and 4-7cm (sample 7).

7-13.5cm below surface	Brown clayey peat. This was divided into two samples, sample 6; 7-10.5cm and sample 5; 10.5-13.5cm.
13.5-17cm below surface	A transition zone with a mix of the upper brown clayey peat and the underlying blue/grey clay. This zone represented one sample (sample 4).
17-41.5cm below surface	A blue/grey clay with large stone inclusions. A root was present on the left hand side of the section at 17-21cm. This stratum was divided into two samples; sample 3: 1-30.5cm (includes the root fragment); sample 2: 30.5-41.5cm. Apart from the root at 17-21cm no other roots appear to have penetrated the blue/grey clay.
41.5-49cm below surface	A coarse, large grained brown clay. This stratum was sample 1.

5.9.4. Soil Micromorphology

Within the monolith taken from Wolla Bank, section one. at 10-14.5cm below the peat a possible soil horizon was identified. This was sampled and prepared by J. Boast and analysed by C. Ellis and Dr. C.A.I. French at the geoarchaeology Laboratory, Department of Archaeology, University of Cambridge. The results are presented below.

The section comprises of two units, a upper semi-degraded peat, c. 3cm and a lower, well sorted clayey silt. There are vughs and fissures in the clayey silt; many with associated organic fragments. The voids/vughs range between 40 microns to approximately 150 microns in size, with moderate sphericity and are subrounded to subangular. The porosity of the lower unit is approximately 10%. The voids/vughs have a planar pattern and a random distribution. The structure of the clayey silt is basically massive.

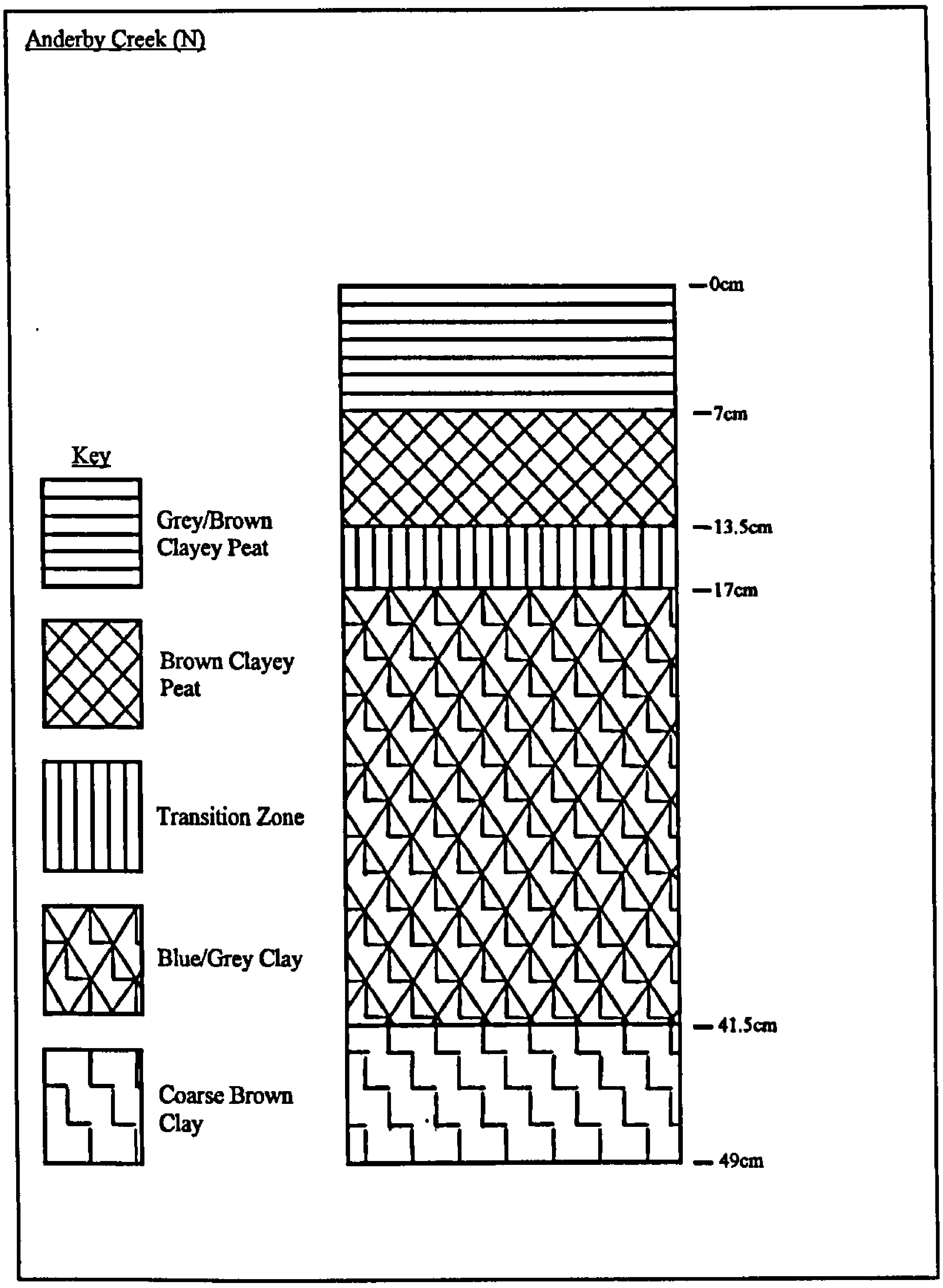


Figure 5.12. Section diagram for Anderby Creek, North

The coarse components consist of c. 20% very fine sand and silt-sized quartz grains; these are slightly coarser at the base of the section. The quartz grains are monocrystalline, rounded to subrounded and have a smooth sphericity. Plagioclase feldspar grains, with multiple twinning make up less 1% of the coarse component. The fine-grained component is dominated by rounded to subrounded quartz grains, with smooth sphericity.

The matrix is dominated by silt and clay-sized quartz grains and clay minerals; the latter are well oriented. Around some of the silt-sized quartz grains is a thin zone of oriented clay. The matrix is predominately brown in colour, with some yellowish brown. Amorphous organic matter occurs throughout this matrix. The matrix above the peat horizon contains more amorphous organic matter than below.

Isolated plant residues occur within the silt horizon. The peaty horizon at the top of the section is roughly horizontal in orientation. There is a sharp, undulating lower boundary between the peat unit and the clayey silt. Clusters of black, iostropic, spherical faunal pellets occur within the organic matter in the peat under and to a lesser extent in the clayey silt; in the latter the faunal excrement generally occurs as loosely packed clusters in voids. The faunal excrement material is c. 20-60 microns in diameter.

The clayey silt represents a weathered surface and can be described as a poorly developed 'green' soil. However, post-depositional processes such as wetting and drying and leaching have removed most soil characteristics. The clayey silt has seen faunal activity, as identified by faunal excrement. There is no horizonation within the clay silt; although the latter could be regarded as a B horizon and the upper peat as an A horizon. It is not possible to determine the origin of the clay component; however it is most likely to have been derived from the till, rather than from in-situ mechanical weathering of mineral grains. This sediment can be compared to those described by McPhail (1994) for the Essex coast.

5.9.5. The Macrofossil Analyses from Wolla Bank

5.9.5.1 Section One

Two sections from Wolla Bank were analysed for plant macrofossil remains. Section one was taken from next to an alder stump. Seven contiguous samples were taken from the section avoiding the crossing of obvious boundaries within the profile. The corrected results are shown in table 5.6 and figure 5.13a. The reasons for using corrected results are put forward in the methodology.

The plant macrofossil content both in numbers and the number of taxa was low but well preserved. Within the profile the larger number of plant macrofossils were found within the peat samples. The underlying grey/blue clay contained very few taxa and plant macrofossil remains (see figure 5.13a).

The grey/blue clay samples (from 14.5-30cm) were dominated by charcoal fragments and sclerotia of the soil fungus *Cenococcum geophilum*. The largest number occurring in the sample 14.5-19.0cm immediately below the woody peat. This sample also contained a nutlet of *Carex remota* and bark fragments were common. From the profile diagram (figure 5.10) it can be seen that tree roots penetrated the grey/blue clay at 20cm.

The peat/clay matrix sample at 10-14.5cm contained more plant remains which were represented by a number of habitat types. The majority of the remains were of woodland habitat types, although the number of taxa was small. Woodland was represented by the presence of *Rubus fruticosus* pyrenes whilst a wet woodland component was represented by the presence of nuts of *Ajuga reptans* and *Carex remota*, bark fragments were frequent, but not as common as in the underlying sample at 14.5-19.0cm. The other remains present in this sample were sclerotia of *Cenococcum geophilum* and charcoal fragments. Insect remains were common and the presence of worm cocoons was also recorded.

The lower sample of the peat at 7.0-10cm contained a greater number of habitat types and a larger number of remains. A woodland habitat was represented by two elements, a drier one by whole and fragments of *Rubus fruticosus* pyrenes and a wetter type by alder wood fragments and nutlets of the sedge *Carex remota*. The presence of woodland was also indicated by bud scales.

A wetland component was represented by common finds of fragments of *Phragmites australis* rhizomes. No sclerotia of *Cenococcum geophilum* were recovered and the number of charcoal fragments also declines. Insect remains are abundant as were worm cocoons.

The middle sample of the woody peat horizon at 4.5-7.0cm has less plant remains and habitat types recorded. The presence of woodland was indicated with an alder twig and a single nutlet of *Carex remota*, bud scales were also present. A wetland component was represented by a fragment of a Cyperaceae stem and twelve fragments of *Phragmites* *australis* rhizomes. Insect remains are less common and the number of worm cocoons is also reduced, no charcoal fragments were recorded.

Wolla Bank Section 1.							
Sample	0-4.5cm	4.5-7cm	7-10cm	10-14.5cm	14.5-19cm	19-25cm	25-30cm
Original volume (cm^3)	300	150	300	400	150	400	300
Woodland							
Prunus spinosa	1.5 + 11.5f						
Rubus fruticosus	10 + 15.5f		2.5 + 6f	0.38 + 0.76f			
Wet Woodland							
Alnus wood	1		1				
Alnus twig		1					
Ajuga reptans				1.15			
Carex remota	2	1	52.5	20	1		
Woodland Miscellaneous							
Twigs 2-3mm diameter	43						
Twigs >3mm diameter	****						
Bark fragment				**	***		
Buds							
Bud Scales	15.5	1	4				
Wetland/Aquatics							
Oenanthe aquatica	0.5						
Carex sp. trigonous	0.5						
Cyperaceae stem		1f					
Phragmites australis rhizomes		12f	***				
Miscellaneous							
Fungal sclerotia				36.53	39		13
Charcoal fragments			0.5	25	23	5.76	7.5
tuber						0.38	
Pyritized wood							0.5
Insect remains	***	**	***	***			
Worm cocoons	0.5	1	9	6.9			
?	1						
Total of Whole Seeds	15.5	2	56	21.53	1	0.38	0
Total of Seed fragments	27	13	6.5	25.76	23	5.76	7.5
No. of Taxa/Type of Remains	12	7	8	8	4	2	3
Key							
f = fragments							
***** = very abundant							
**** = abundant							
*** = common							
** = frequent							
* = rare							

Table 5.6. Plant Macroremains recovered from Wolla Bank, Section One. (Corrected to 150 cm^3)

The upper sample from the peat horizon (0-4.5cm), possessed the greatest number of taxa. The woodland habitat was represented by both a drier and wetter element. The drier element was indicated by the presence of stones of *Prunus spinosa* and *Rubus fruticosus* pyrenes, whilst the wetter element was represented by alder twigs and nutlets of *Carex remota*. The main indicator of the woodland habitat was indicated by the dominance of the sample by twigs ranging in size from 2mm to over 3mm in diameter. Bud scales were also present in greater numbers. A wetland habitat was represented by finds of *Oenanthe aquatica* and sedges (*Carex* spp.). Insect remains were common but worm cocoons are present in reduced numbers.

In summary, it can be said that the top four samples from 0-14.5cm represent damp woodland with some areas being slightly wetter than others. The indicators for wet woodland such as *Carex remota* disappear towards the top of the profile, although the possible decrease in the height of the watertable can be regarded as being slight. The lower sample, where the peat is mixed with a clay component suggests a mixing with the underlying grey/blue clay, possible by the activity of earthworms and may indicate the formation of a soil and soil micromorphology (see section 5.9.4) has shown that this may well be the case. The presence of large numbers of twigs ranging in size from 2 to over 3mm diameter suggests that the top sample could represent the forest floor and a radiocarbon date obtained from some alder twigs in this sample gave an uncalibrated date of 4500 ± 55 BP (OxA 5966).

The presence of numbers of nutlets of possible remote sedge (*Carex remota*) suggests that a wet woodland was present very early on, this sedge prefers shady situations on peaty or silaceous soils with a high water level for part of the year and according to Jermy *et. al.* (1982) it is commonly found in alder or wet birch carr. The numbers of this species decline towards the top of the profile perhaps suggesting that a drying out of the fen woodland is occurring through time, although the situation is complicated by the presence of *Oenanthe aquatica* which prefers a habitat with still or slightly flowing water present, although it can be found in situations where water dries up in summer (Tutin, 1980). *Carex remota* is also able to tolerate these conditions and therefore it suggests that the water table may be higher in winter than in summer.

The identification of pellets of faunal excrement by soil micromorphology in the lower peat boundary and the upper clay horizon could explain the mixing of the two horizons, although under high power microscopy, the thin section showed that there was a sharply undulating boundary between the peat and clay. The presence of worm cocoons and sclerotia of *Cenococcum geophilum* suggests the presence of an immature soil.

There are no plant species present which may suggest the proximity of a coastal environment which can be taken to indicate that when this woodland was alive it was further from the sea than its present position would suggest.

5.9.5.2. Section Two

A second twenty-two centimetre profile was sampled one metre seaward and one metre north of section one. Eight contiguous samples were taken and are described above and in figure 5.11. Care was taken that no natural boundaries were crossed within the profile. The corrected results can be seen in table 5.7a & b and the resulting diagram in figure 5.13b.

The total number of plant remains and individual taxa recorded from this profile were far greater than that recorded from the previous section. The number of taxa recovered, ranged from six in the bottom most sample to thirty-eight in the uppermost sample. The number of habitat types varied from two at the bottom of the profile to six at the top, these included woodland, wet woodland, woodland miscellanea, wetland/aquatic, open/disturbed/grassland and miscellaneous. In general the plant remains were sparse in the lower samples, increasing in numbers towards the top of the profile.

The bottom-most sample (from 18-22cm) consisted of a brown/grey clay with organic inclusions. The commonest find was of sclerotia of *Cenococcum geophilum* along with charcoal fragments less than 1mm in diameter (table 5.7). A single find of *Eupatorium cannabinum* can be taken to represent the presence of a wet woodland or marsh environment, other finds include flint fragments (not possible to determine if products of knapping), pyritised Poaceae culm nodes and rare insect remains. The next sample up the profile was that of the dark horizon occurring within the brown/grey clay (see figure 5.11) at 16.5-18.0cm. This was dominated by charcoal fragments less than 1mm in diameter and sclerotia of *Cenococcum geophilum.* A Rosaceous thorn was recovered along with unidentified wood fragments, a Cyperaceae stem and a flint flake. Like the sample below, pyritised wood fragments and roots and stems were a common occurrence. There were no other plant remains present in the sample.

A sample from the middle of the brown/grey clay immediately above the dark horizon (14-17cm) was found to contain a greater amount of plant remains and representatives of two habitat types were recovered. A woodland element was indicated by *Betula* spp. fruits and a *Rubus fruticosus* pyrene, indeterminate wood fragments were common. A possible wetland component was represented by the presence of an indeterminate sedge (*Carex* sp.) nutlet, but the dominant finds were of fungal sclerotia and small charcoal fragments. Monocotyledonous stems and roots were abundant, but the remains of insects were rare.

The sample above this at 10-14cm represents the top of the brown/grey clay horizon. The total number of remains was higher than the previous sample and was dominated by large numbers of fungal sclerotia and small charcoal fragments. Habitats represented include a woodland component which was comprised of a wet element in the form of fragments of alder male catkin, *Ajuga reptans* and *Carex remota.* A drier woodland element was represented by birch fruits and whole and fragments of *Rubus fruticosus* pyrenes, woody twigs were also common. A more open wetland environment was indicated by the presence of rush seeds (*Juncus* spp.) and sedges (*Carex* spp.). A *Viola* sp. seed was also recovered which can be found in a variety of environments from woodland to open habitats. Insect remains were rarely recovered.

The bottom of the woody peat was sampled at 8-10cm, again the number of plant remains recovered was greater than the previous sample. A total of five habitat types were recorded. A woodland component was comprised of two elements, with *Betula* sp. fruits and large numbers of *Rubus fruticosus* pyrenes, including *Rubus* sp. prickles representing the drier element with *Solanum dulcamara,* alder fruits, male catkin scales and nutlets of *Carex remota* representing the wetter element.

Sample	0-3.5cm	3.5-7cm	7-8cm	8-10cm	10-14cm
Original Volume (cm^3)	350	300	100	130	300
Woodland					
Betula sp. fruits	247.4	11	4	0.76	0.6
Betula pendula female cone scales	2.857				
Betula sp. female cone scales	8.857	0.6			
Ilex aquifolium	0.28	1			
Prunus spinosa	0.57+5.7f	1			
Rubus fruticosus agg	21.4 + 83.7f	23.33 + 47.42f	24 + 158f	33 + 204.6f	0.3 + 0.66f
Rubus fruticosus prickles	81.7	29.66	3	4.6	
Rosaceae thorns		0.66			
Vaccinium myrtillus	0.57				
Solanum dulcamarra	7.7 + 2.57f	3.3 + 2.6f	1f	0.76 + 0.76f	
Wet Woodland					
Alnus glutinosa fruits	31.7	25 + 12.3f	1	1.53	
Alnus glutinosa female cones	4.28	5	1		
Alnus glutinosa female cone stalks		1.32			
Alnus glutinosa male catkins	37.7f	1f			0.3f
Alnus glutinosa male catkin scales		31.6	1	0.76	
Alnus glutinosa anthers	16.85	17.6			
Frangula alnus	1.42f				
Ajuga reptans					0.3
Eupatorium cannabinum	3.71f		1		
Eupatorium cannabinum pappus frags.	0.85				
Carex remota		37.3	108	59.2	6
Dryopteris/Thelypteris sporangia	*****	*****	*	*	
Osmunda type spore		0.3			
Wetland/Aquatics					
Ranunculus sceleratus		1.3			
Oenanthe aquatica	26 + 22.57f	6.33 + 6f			
Callitriche sp.	104	26	1		
Lycopus europaeus	9.14 + 3.1f	3 + 8.6f			
Typha angustifolia/latifolia	0.28				
Phragmites australis rhizome	23.4f	9f	23f	23.8f	
Juncus spp.	188.85	333+	226	475.38	0.3
Carex sp. (lentic)	2 + 0.57f	18.6 + 7.33f	20 + 70f	33.84 + 47.69f	3.33 + 0.6f
Carex sp. trigonus		0.3f			
Open/Disturbed/Grassland					
Ranunculus a/r/b		0.3			
Viola sp.					0.3
Cirsium sp.	0.28	0.6			
Small Poaceae	1.428				
Poaceae indet.	0.57	0.3			
Poaceae culm node	0.28				
Miscellaneous					
Fungal sclerotia	2.285	4.6	15	76.92	333+
Charcoal frags.< 1mm	1.714f	1	3	44.6	333+
Cyperaceae stem					
?	0.57				
Worm cocoons	3.14	3.3 + 2.6f	23	16.92	
Total Whole Seeds	740.712	559.18	390	609.9	11.3
Total Seed frags.	203.854	114.47	255	321.45	334.56
Total number of Taxa	38	38	19	16	13

Table 5.7a. Plant Macroremains recovered from Wolla Bank, Section Two. (Corrected to 100 cm^3)

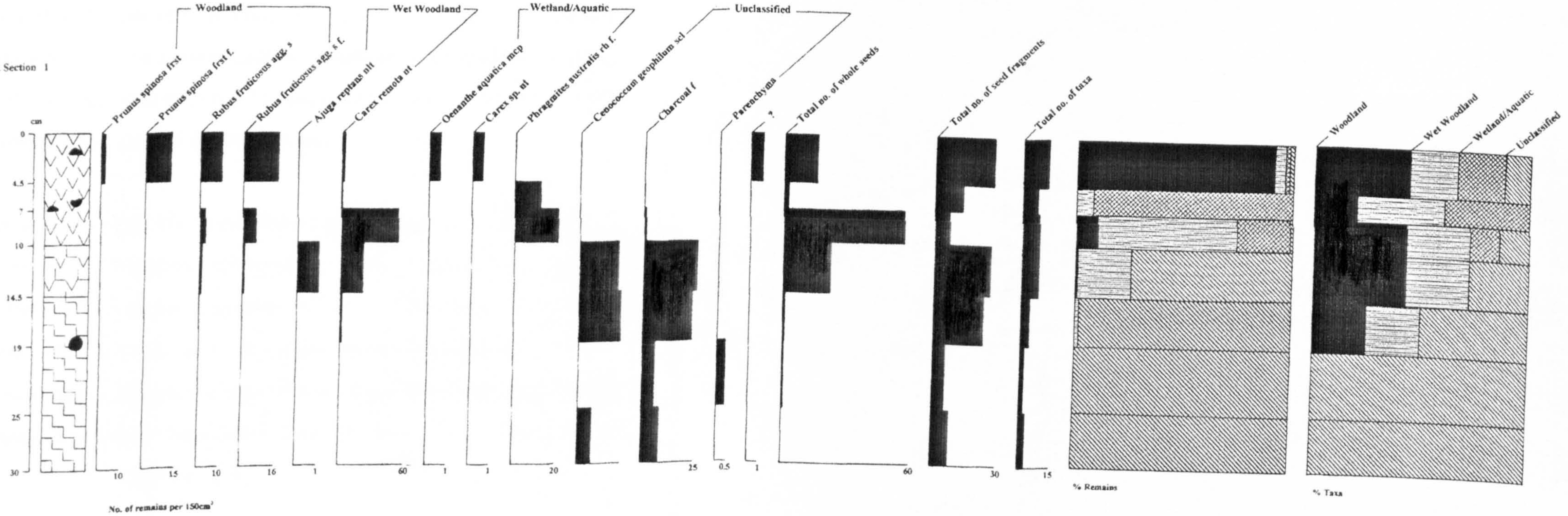
Sample	14-17cm	17-18cm	18-22cm		Key
Original Volume (cm^3)	120	100	200		f = fragments
Woodland					*** = common
Betula sp. fruits	3.3				** = frequent
Betula pendula female cone scales					* = rare
Betula sp. female cone scales					
Ilex aquifolium					
Prunus spinosa					
Rubus fruticosus agg	0.83				
Rubus fruticosus prickles					
Rosaceae thorns		1			
Vaccinium myrtillus					
Solanum dulcamarra					
Wet Woodland					
Alnus glutinosa fruits					
Alnus glutinosa female cones					
Alnus glutinosa female cone stalks					
Alnus glutinosa male catkins					
Alnus glutinosa male catkin scales					
Alnus glutinosa anthers					
Frangula alnus					
Ajuga reptans					
Eupatorium cannabinum			0.5f		
Eupatorium cannabinum pappus frags.					
Carex remota					
Dryopteris/Thelypteris sporangia					
Osmunda type spore					
Wetland/Aquatics					
Ranunculus sceleratus					
Oenanthe aquatica					
Callitriche sp.					
Lycopus europaeus					
Typha angustifolia/latifolia					
Phragmites australis rhizome					
Juncus spp.					
Carex sp. (lentic)	0.83				
Carex sp. trigonus					
Open/Disturbed/Grassland					
Ranunculus a/r/b					
Viola sp.					
Cirsium sp.					
Small Poaceae					
Poaceae indet.					
Poaceae culm node					
Miscellaneous					
Fungal sclerotia	209.1	43	33.5		
Charcoal frags.< 1mm	286.6	45	10.5		
Cyperaceae stem		1f			
?					
Worm cocoons					
Total Whole Seeds	4.96	1	0		
Total Seed frags.	286.6	49	11		
Total number of Taxa	8	9	6		

Table 5.7b. Plant Macroremains recovered from Wolla Bank, Section Two. (Corrected to 100cm^3)

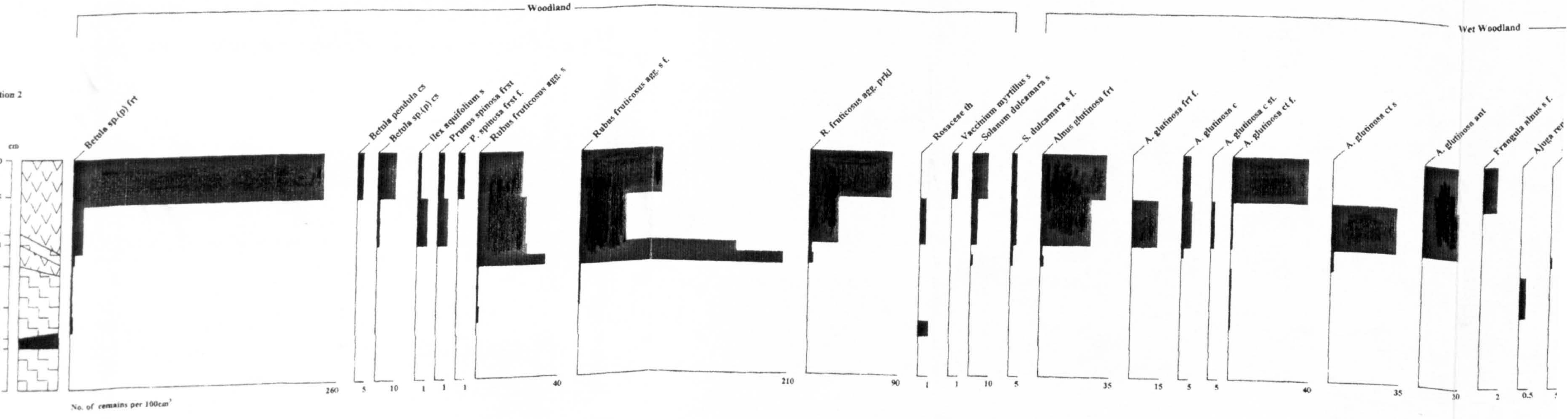
Figure 5.13a. The plant macrofossil diagram for Wolla Bank, Section One

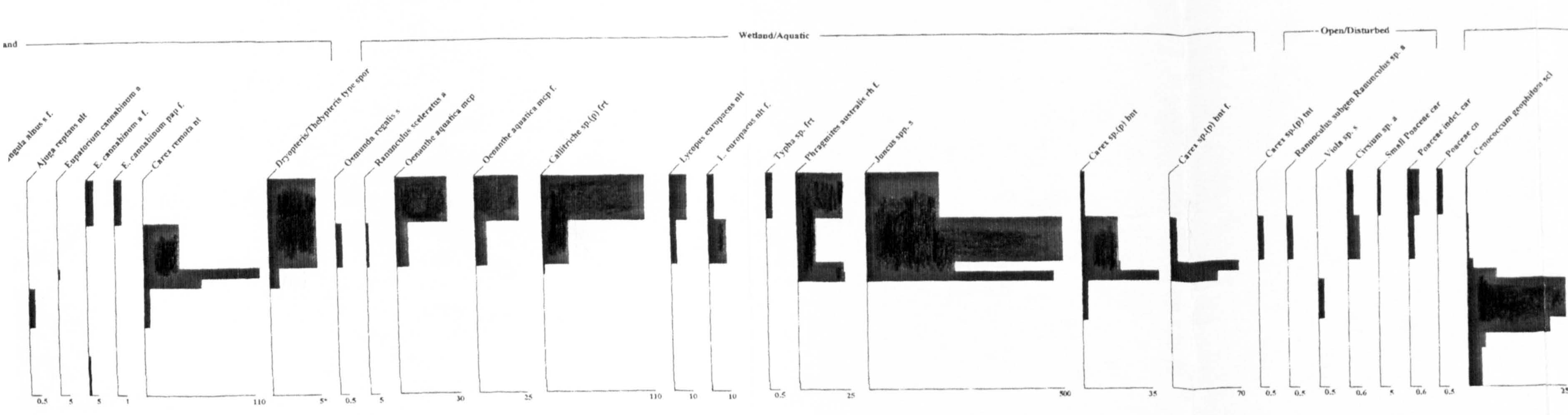
Figure 5.13b. Plant macrofossil diagram for Wolla Bank, Section Two

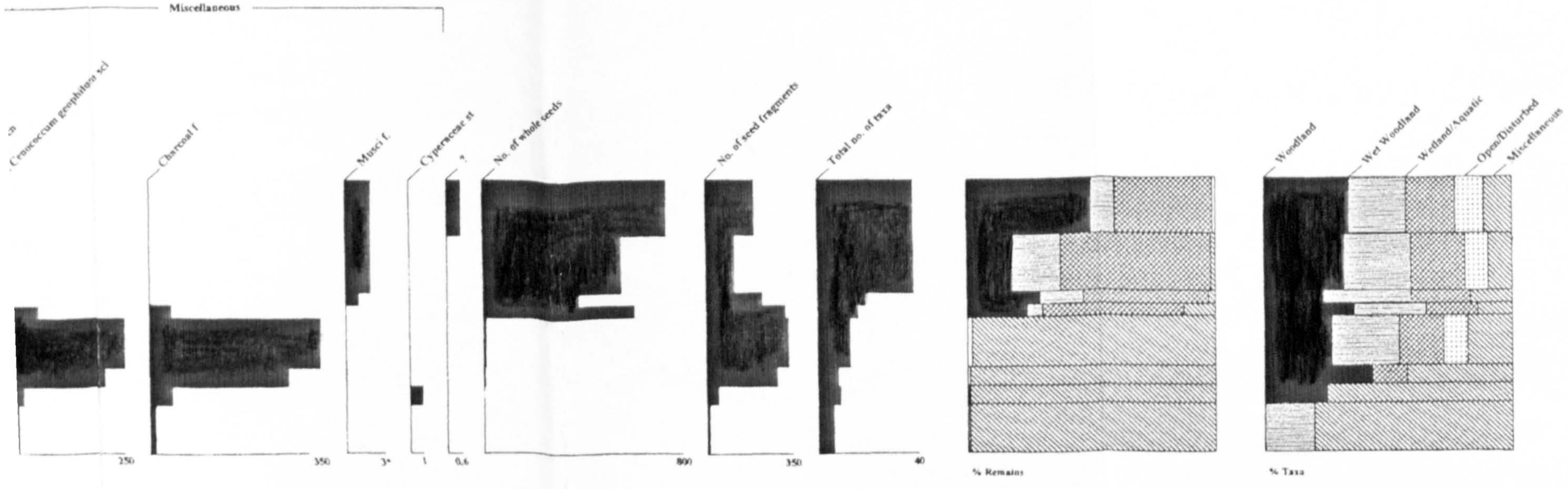
Wolla Bank Section 1



Wolla Bank Section 2




and
Wetland/Aquatic
Open/Disturbed
ngula alnus s f.
Ajuga reptans nlt
Eupatorium cannabinum a
E. cannabinum a f.
E. cannabinum pap f.
Carex remota nt
Dryopteris/Thelypteris type spor
Osmunda regalis s
Ranunculus sceleratus a
Oenanthe aquatica mcp
Oenanthe aquatica mcp f.
Callitriche sp.(p) frt
Lycopus europaeus nlt
L. europaeus nlt f.
Typha sp. frt
Phragmites australis rh f.
Juncus spp. s
Carex sp.(p) bnt
Carex sp.(p) bnt f.
Carex sp.(p) tnt
Ranunculus subgen Ranunculus sp. a
Viola sp. s
Cirsium sp. a
Small Poaceae car
Poaceae indet. car
Poaceae cn
Cenococcum geophilum scl
0.5
5
5
1
110
5*
0.5
5
30
25
110
10
10
0.5
25
500
35
70
0.5
0.5
0.5
0.6
5
0.6
0.5
25


Miscellaneous
cn
Cenococcum geophilum scl
Charcoal f
Musci f.
Cyperaceae st
?
No. of whole seeds
No. of seed fragments
Total no. of taxa
Woodland
Wet Woodland
Wetland/Aquatic
Open/Disturbed
Miscellaneous
250
350
3*
1
0,6
800
350
40
% Remains
% Taxa

Dryopteris/Thelypteris sporangia are also indicative of a wetter woodland habitat but were rarely found. woody twigs were common. The wetland component of the assemblage was dominated by large numbers of seeds of rush, other indicators of this type of habitat present included sedges and fragments of *Phragmites australis* rhizomes. The number of fungal sclerotia and small charcoal fragments decreased whilst insect remains were still rare. The presence of worm cocoons was recorded for the first time.

At 7-8cm a thin wedge of brown/grey clay was sampled and again there a woodland component composed of the two elements was recorded. The drier element was comprised of finds of *Betula* sp. fruits and whole and fragments of *Rubus fruticosus* pyrenes, *Rubus* sp. prickles were also found. The wetter element was represented by the presence of a fragment of *Solanum dulcamara*, alder fruits, alder female cones, alder male catkin scales, an achene of *Eupatorium cannabinum* along with a large number of *Carex remota* nutlets and sporangia of the *Dryopteris/Thelypteris* type.

A wetland/aquatic component was represented by finds of *Callitriche* sp. (water starwort), fragments of *Phragmites australis* rhizomes and large numbers of *Juncus* spp. seeds. Sedges (*Carex* sp.) were also well represented. In this sample there was a significant decrease in the number of *Cenococcum geophilum* sclerotia and small charcoal fragments. Moss stems and leaves were present in small numbers but insect remains were abundant, the number of worm cocoons also increased.

Above this thin wedge of brown/grey clay the woody laminated peat continued from 7-0cm. This was split into two samples. The lower sample from 3.5-7cm was rich in plant remains and the largest number of taxa were recorded from this sample.

Habitat types represented included woodland, wet woodland, wetland/aquatic and open/disturbed/grassland. The woodland component as in previous samples consisted of a drier and wetter element. The drier element was represented by *Betula* sp. fruits and female cone scales, *Ilex aquifolium*, *Prunus spinosa*, *Rubus fruticosus* pyrenes and *Rubus* sp. prickles. The wetter component was indicated by *Solanum dulcamara*, and remains of alder which included fruits, female cones, male catkins (with anthers containing pollen) and male catkin scales. Other wet woodland taxa were *Carex remota* and sporangia of the *Dryopteris/Thelypteris* type as well as a single *Osmunda regalis* spore.

Miscellaneous woodland components such as wood fragments, buds and bud scales were common to abundant.

The wetland component consisted of finds of *Ranunculus sceleratus, Oenanthe aquatica, Callitriche* sp., *Lycopus europaeus,* fragments of *Phragmites australis* rhizomes, a large number of *Juncus* sp. seeds as well as sedge (*Carex* sp.) nutlets. A more open component was identified by the remains of *Ranunculus acris/repens/bulbosus, Cirsium* sp. and indeterminate Poaceae caryopses. The number of fungal sclerotia and charcoal fragments continued to decline along with the number of worm cocoons. Moss stems were more common whilst insect remains and Cladoceran eggs were abundant.

The top sample 0-3.5cm was the richest sample in the profile, in terms of the total remains. Representatives of woodland, wetland and a more open environment were present. The woodland component consisted of a drier and wetter element. The drier woodland was dominated by a large number of *Betula* sp. remains, mainly of fruits. Female cone scales were also recovered, some of which were identified to be *Betula pendula. Ilex aquifolium, Prunus spinosa, Rubus fruticosus* pyrenes and *Rubus* sp. prickles were also considered as indicators of the drier woodland environment. The wetter element was dominated by the presence of alder remains which included fruits, female cones and male catkin fragments which contained anthers full of pollen. Other wetland taxa included *Frangula alnus, Eupatorium cannabinum* and *Solanum dulcamara.* Abundant finds of the sporangia of *Dryopteris/Thelypteris* type which can also indicate the presence of wet woodland. A possible indicator of a more heathy element, although it can be present in a woodland environment was represented by finds of *Vaccinium myrtillus.* Miscellaneous woodland indicators such as wood fragments and buds and budscales were commonly found.

A wetland habitat was dominated by the presence of *Callitriche* sp. and *Juncus* sp., *Oenanthe aquatica* was also found in considerable abundance as were fragments of *Phragmites australis* rhizomes, other wetland species include *Lycopus europaeus, Typha angustifolia/latifolia* and *Carex* sp. nutlets. A more open habitat was represented by the presence of *Cirsium* sp. and indeterminate Poaceae caryopses and culm nodes. Fungal sclerotia and charcoal fragments were rarely recovered, but moss stems and leaves were frequent. The number of Cladoceran eggs had also declined along with the numbers of worm cocoons.

In this section it can be seen that there was a greater diversity of taxa recovered from the samples, than those from section one. Although there was still a paucity of plant remains recovered from the clay samples below the woody peat. The higher up the profile, the number of the plant remains increased as did those representing the woodland habitat. From 14-17cm the indicators of woodland are present, but do not reach high numbers until the top 7.0cm where the section is dominated by woodland indicators. The indications of soil formation processes can be detected from 8-10cm by the presence of worm cocoons, although just below this at 10-14cm the number of *Cenococcum geophilum* sclerotia peaks, these can also be used to indicate the presence of soil formation processes. After 7-8cm the number of worm cocoons begins to decline perhaps suggesting, along with an increase in taxa indicating wetter conditions that there is an increase in the level of the water-table. It may be possible to suggest that at this point the development of fen conditions followed by the development of the fen woodland is represented here.

There appears to be a flooding episode occurring at between 7-8cm with a lens of the brown/grey clay, but the plant macrofossil content of the sample does not suggest that this had any effect in the development of the fen woodland. These wetter conditions could be linked to a rise in the water-table which may be due to an increase in sea-level.

5.9.5.3. Comparison between Sections One and Two

Although sections one and two were only separated by one metre, the difference in the number of plant remains found within each profile is very noticeable (see figures 5.13a & b). Section one was taken next to an alder stump, this suggests that the alder tree had a 'sheltering effect' preventing an ingress of plant material into the deposit, whilst one metre away, section two was far enough away from the alder stump for this effect to be reduced and therefore more plant remains could be deposited.

Even so, the differences in the plant macrofossil content do not disguise that each section tells a similar story, with the emergent clay substratum being occupied at first by a fen peat. The trees are found to be rooted in the underlying clays and an immature soil is found at the boundary of the woody peat and clay, as demonstrated by soil micromorphology (section 5.9.4). A fen peat develops at first but this is soon dominated by alder carr especially towards the top of the sections. The radiocarbon date from section one indicates that this woody peat is roughly contemporary with the surrounding stumps. The presence of *Carex remota* in the lower samples suggests a fluctuating water-table, which was most likely to have been higher in winter than in summer. The reduction in the numbers of *Carex remota* nutlets through the profile and the introduction of species which can tolerate constant high water-table conditions suggests that fen carr woodland dominates with some areas are wetter than others, this may be due to the undulating underlying clays which will cause some areas to be closer to the level of the water-table than others. The plant macrofossil assemblage present at the top of each section is typical of alder carr woodland and will be discussed in greater detail in chapter 8.

The source of most of the plant macrofossil assemblages present in both profiles appears to be of local origin, although the presence of an allocthanous element cannot be ruled out. In both sections, at the interface between the clay and peat horizons there is a concentration of charcoal (see figures 5.13a & b). This occurs on the surface of the clay before the development of the peat horizon. It is not possible to determine whether this is a natural phenomenon or anthropogenically induced, but the lack of archaeological artefacts associated with this level suggests the former scenario.

5.9.6. Plant Macrofossil Analysis from Anderby Creek

At the north end of Anderby Creek a profile was sampled from a low cliff and the description and profile diagram can be seen in figure 5.12. A total of 49cm was sampled and the corrected results and the resultant diagram can be seen in table 5.8 and figure 5.14.

A total of eight contiguous samples were taken but only four were analysed due to the lack of time and the samples did not appear to represent the submerged forest deposits. The samples analysed were from the transition zone at 13.5-17cm, the brown peaty clay at 7-

13.5cm (two samples; an upper and lower) and the upper half of the grey/brown clayey peat.

The plant remains were well preserved and were common in all the samples analysed. the poorest sample being from the transition zone at 13.5-17cm and the top-most sample of the grey/brown clay at 0-4cm. The richest samples were from the brown clayey peat. The habitat types represented by the plant remains include salt-marsh, woodland and wetland/aquatic environments.

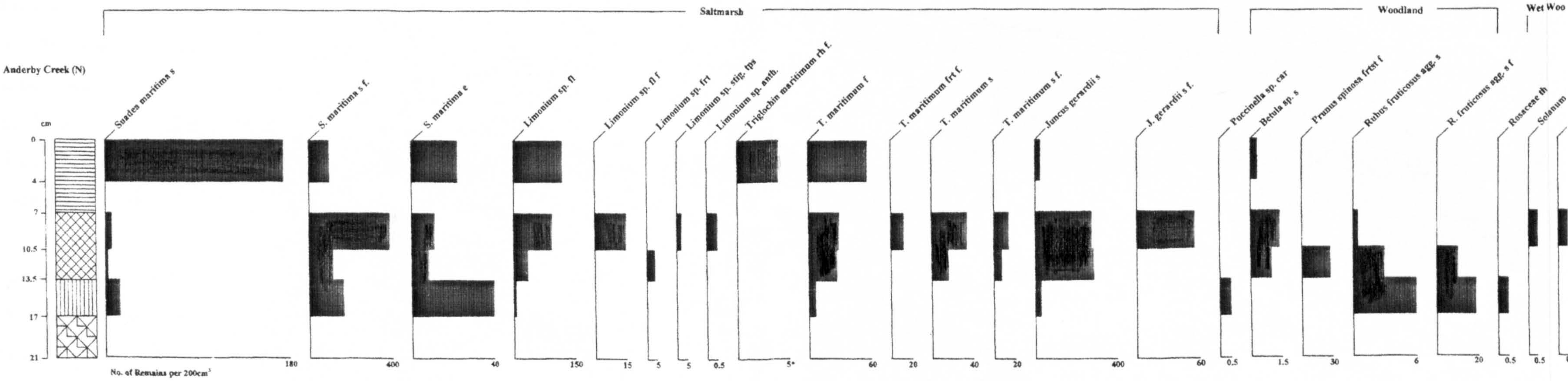
The transition zone at 13.5-17.0cm was the poorest in terms of plant macrofossil content. Representatives of salt-marsh in the form of seeds and embryos of *Suaeda maritima*, *Limonium* sp. flowers and calices, *Triglochin maritimum* fruits and *Juncus gerardi* seeds were identified. A woodland component consisting of whole and fragments of *Rubus fruticosus* pyrenes and budscales were found, with a wetter element being represented by an achene of *Eupatorium cannabinum*, although both of these species can be found in other environments, *Rubus fruticosus* in this case, may well be representative of an open scrubby habitat associated with the finds of *Potentilla* sp. and *Galium* sp. whilst *Eupatorium cannabinum* can be found in marshy conditions along with the presence of *Juncus* spp. seeds. The dominant finds were those of sclerotia of *Cenococcum geophilum* and charcoal fragments. Insect remains and foraminifera were a rare occurrence.

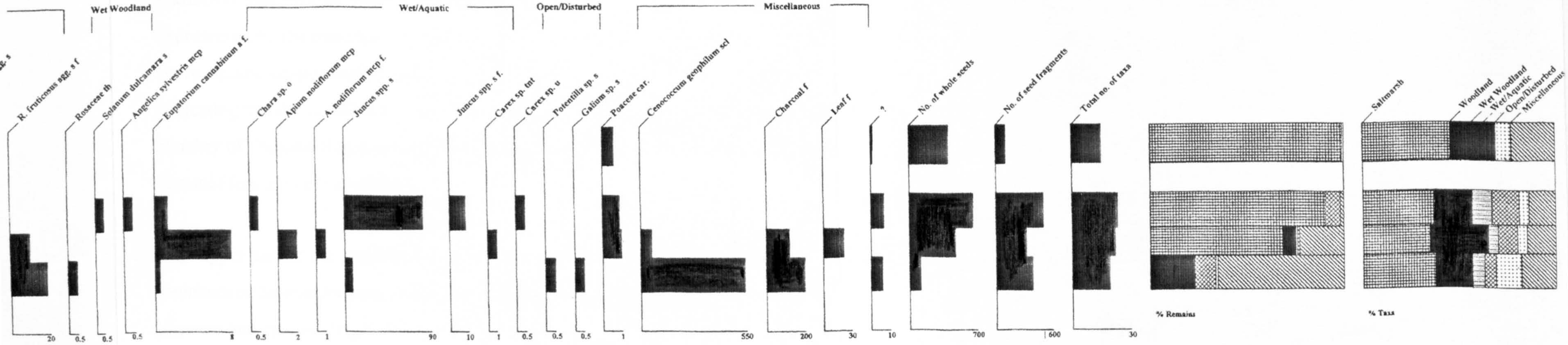
The lower half of the brown peaty clay at 10.5-13.5cm also contained representatives of a salt-marsh habitat, although the number of *Suaeda maritima* seeds and embryos was lower than that of the previous sample. *Limonium* sp. flowers, calices and fruits were found in greater quantities as were *Triglochin maritimum* fruits and seeds and *Juncus gerardi* seeds. The woodland component was represented by a *Betula* sp. fruit and fragments of *Prunus spinosa* stones as well as buds and budscales. The presence of *Rubus fruticosus* may represent a more scrubby element to the woodland, as the finds of *Eupatorium cannabinum* may indicate the wetter element, although as mentioned above this may also be indicative of a more marshy environment. A wetland/aquatic habitat was indicated by the presence of *Apium nodiflorum* mericarps and sedge nutlets (*Carex* spp.). The number of fungal sclerotia has vastly decreased and the number of charcoal fragments are slightly less. Insect remains

Sample	0-4cm	10.5-7cm	10.5-13.5cm	13.5-17.0cm
Original volume (cm^3)	600	425	200	400
Salt Marsh				
Suaeda maritima seeds	17.3 + 103.6f	6.58 + 393.4f	1 + 120f	13.5 + 170f
S. maritima embryos	21.6	10.82	8	39.5
Limonium sp. flowers+calices	120	95 + 14.1f	34	6
Limonium sp. fruits			4	
Limonium sp. stigma tips		1.88		
Limonium sp. anthers		0.47		
Triglochin maritima rhizomes	abundant			
Triglochin maritima fruits	56	28.7 + 11.29f	16	6
Triglochin maritima seeds		34.82 + 13.64f	16 + 7f	
Juncus gerardii	26.3	379.29 + 57.41f	384	25
cf. *Puccinella* sp.				0.5
Woodland				
Betula sp. seeds	0.3	1.41	1	
Prunus spinosa			27f	
Rubus fruticosus		0.47	3 + 10f	6 + 18.5f
Rosaceae thorn				0.5
Solanum dulcamarra		0.47		
Bud scales	1		3	98
Buds			2	
Bark			2f	
Wet Woodland				
Angelica sylvestris		0.47		
Eupatorium cannabinum		1.41f	8f	0.5f
Wetland/Aquatic				
Characeae oogonium		0.47		
Apium nodiflorum			2 + 1f	
Juncus sp.		81.4 + 8.47f		7.5
Carex sp. Trigonous			1	
Carex sp. utricle		0.47f		
Open/Disturbed/Grassland				
Potentilla sp.				0.5
Galium sp.				0.5
Poaceae	0.6	0.94	1	
Miscellaneous				
Fungal sclerotia	2		42 + 17f	541
Charcoal	2f	3.764f	121f	200f
Culm node		0.47		
Leaf fragments			22f	
Unknown	1.3	7.058		6.5
Total Whole Seeds	399.1	650.7	471	112
Total Seed Fragments	105.6	503.9	316	389
No. of Taxa/Types of Remain	15	23	22	19

Table 5.8. Plant Macroremains recovered from Anderby Creek, North. (Corrected to 200 cm^3)

Figure 5.14. The Plant macrofossil diagram for Anderby Creek, North


Saltmarsh
Woodland
Wet Woo
Anderby Creek (N)
cm
0
4
7
10.5
13.5
17
21
Suadea maritima s
S. maritima s f.
S. maritima e
Limonium sp. fl
Limonium sp. fl f
Limonium sp. frt
Limonium sp. stig. tps
Limonium sp. anth.
Triglochin maritimum rh f.
T. maritimum f
T. maritimum frt f.
T. maritimum s
T. maritimum s f.
Juncus gerardii s
J. gerardii s f.
Puccinella sp. car
Betula sp. s
Prunus spinosa frtst f
Rubus fruticosus agg. s
R. fruticosus agg. s f
Rosaceae th
Solanum
No. of Remains per 200cm³
180
400
40
150
15
5
5
0.5
5*
60
20
40
20
400
60
0.5
1.5
30
6
20
0.5
0.5


Wet Woodland
Wet/Aquatic
Open/Disturbed
Miscellaneous
R. fruticosus agg. s f
Rosaceae th
Solanum dulcamara s
Angelica sylvestris mcp
Eupatorium cannabinum a f.
Chara sp. o
Apium nodiflorum mcp
A. nodiflorum mcp f.
Juncus spp. s
Juncus spp. s f.
Carex sp. tnt
Carex sp. u
Potentilla sp. s
Galium sp. s
Poaceae car.
Cenococcum geophilum scl
Charcoal f
Leaf f
?
No. of whole seeds
No. of seed fragments
Total no. of taxa
Saltmarsh
Woodland
Wet Woodland
Wet/Aquatic
Open/Disturbed
Miscellaneous
20
0.5
0.5
0.5
8
0.5
2
1
90
10
1
0.5
0.5
0.5
1
550
200
30
10
700
600
30
% Remains
% Taxa

are more frequent and foraminifera finds are common. Dicotyledonous leaf fragments are also present.

The upper half of the brown peaty clay at 7-10.5cm is also rich in the total number of plant remains as well as the number of individual taxa. The sample is dominated by representatives of salt-marsh habitat with the presence of *Suaeda maritima* seeds and embryos. *Limonium* sp. is represented by flowers, calices, stigma tips and anthers. The presence of *Triglochin maritimum* is recorded by the remains of fruits and seeds. *Juncus gerardi* is also present in large quantities. A woodland element is recorded by the presence of *Betula* sp. fruits, and wood fragments are frequently encountered. The finds of *Rubus fruticosus* may indicate a more scrubby element. A wetter woodland component is represented by the presence of *Angelica sylvestris* and *Eupatorium cannabinum* achenes. A more aquatic environment is identified by Characeae oogonia, seeds of *Juncus* spp indicating marshy conditions. There are no fungal sclerotia present in the sample and the number of charcoal fragments has drastically reduced. Insect remains are frequent and foraminifera are very abundant.

The upper part of the grey/brown clay at 0-4cm is dominated by salt-marsh taxa. Large numbers of *Suaeda maritima* seeds and embryos are recorded along with *Limonium* sp. flowers and calices. *Triglochin maritimum* rhizomes are abundant in this sample as are the fruits, but the number of *Juncus gerardi* seeds is greatly reduced. The woodland element is represented by a *Betula* sp. seed and a budscale, although wood fragments were common. A few fungal sclerotia are present as are charcoal fragments. Insect remains are abundant and foraminifera remains are very abundant.

The analysis of the plant macrofossils from this profile suggests that it has been taken from a saltmarsh environment, which is dominated by *Suaeda maritima, Limonium* sp. and *Juncus gerardi*, although at the top of the profile, *Suaeda maritima, Limonium* sp. and *Triglochin maritimum* dominate with *Juncus gerardi* present in lower numbers.

The presence of the woodland component in the lower three samples could be explained by the remnants of the submerged forest deposits, which in this part could have been eroded away before the initiation of the saltmarsh environment by rising sea-level. The inclination towards a more brackish/marine environment can be confirmed by the increase in the abundance of foraminifera remains throughout the profile.

Again at the interface of the underlying clays and the overlying saltmarsh deposits there are fragments of charcoal present and as at Wolla Bank the origin of this is difficult to identify. Throughout this profile it is not possible to deduce a change in saltmarsh zonation, therefore it can be suggested that after the initial increase in sea-level, this remained relatively constant for the duration of the salt-marsh phase. The profile analysed here corresponds to the Anderby Beds identified by Brooks (1990) and these developed due to either a rise in sea-level or a change in local coastal processes.

5.9.7. Comparison between the pollen diagrams of Brooks et. al. (1990) and the plant macrofossil analyses

5.9.7.1. The Lower Peat Bed Deposits

Only one area of Lower Peat was sampled for palynological studies by Brooks *et.al.* (1990), this was at Vickers Point (VP2) (TF 574694), the two sections at Wolla Bank were located 4.1 km north of this area. The depth of the Lower Peat at Vickers Point and Wolla Bank is the same, being seven centimetres. There appears to be no loss in the depth of peat by wave action since the sampling of the deposits for pollen and macrofossils.

In general, there appears to be some agreement between the pollen diagram (Figure 5.15) and that of the macrofossil analyses (figures 5.13a & b) for the tree and shrub taxa, although there is some variation. As mentioned in the chapter on methodology, plant macrofossils will be more representative of the local environment than the pollen evidence which will be derived from a variety of sources and will provide more information about the more regional picture. The ability to identify most macrofossils to species is also another advantage over pollen.

The Lower Peat at Vickers Point, revealed pollen of trees and shrubs such as, *Betula*, *Pinus*, *Quercus*, *Ulmus*, *Tilia*, *Alnus*, *Ilex*, *Acer*, *Corylus*, *Salix* and Ericaceae. The identification of the tree stumps at both Wolla Bank and Anderby Creek can confirm the presence of *Betula*, *Quercus*, *Alnus* and *Salix*, whilst the plant macrofossil evidence from Wolla Bank can also confirm the presence of *Betula* and *Alnus* as well as *Ilex aquifolium*. The *Betula* species is most likely to be *Betula pendula*. The pollen record shows the absence of *Fraxinus*, although it is present as stumps both at Wolla Bank and Anderby Creek. The dominance of oak in the pollen record can be confirmed by the majority of stumps and trunks identified at both sites were of *Quercus*. *Prunus spinosa* and *Rubus fruticosus* were present in the macrofossil record at Wolla Bank, although the presence of these two taxa were not reflected in the pollen record. The occurrence of Ericaceae pollen in the upper part of the Lower Peat can be perhaps associated with the finds of *Vaccinium myrtillus* in the upper part of the Lower Peat in section two at Wolla Bank.

The presence of *Ulmus*, *Tilia*, *Pinus*, *Acer* and *Corylu*s cannot be confirmed by the macrofossil record. This may be due to either the pollen belonging to the regional component of the assemblage or that differential preservation of tree stumps and other remains mean that it is not present in the macrofossil record. Another possibility for this discrepancy maybe that these tree species were not growing in the area sampled for the macrofossil analyses.

There seems to be very little correspondence between the pollen record for herbaceous taxa and those recorded in the macrofossil assemblages. Although similar habitat types are represented. This may be due to the fact that the pollen assemblage may be derived from several sources whilst the macrofossil record is usually a reflection of the more local conditions. Taxa such as *Oenanthe aquatica* and *Lycopus europaeus* are not represented at all in the pollen diagram. It appears that in some cases the pollen of herbs such as Chenopodiaceae, *Limonium* and *Aster* are representative of a salt-marsh environment and may well be intrusive from the overlying Anderby Beds. Another possibility is that they have been imported into the assemblage from a contemporary salt-marsh further sea-ward,. The former possibility seems to be more likely as the macrofossil assemblages from Wolla Bank show no marine influence, whilst the plant macrofossil assemblage from Anderby Creek is from the Anderby Beds and is dominated by salt-marsh species.

The more arable component in the pollen record has no counterpart in the macrofossil assemblage at Wolla Bank and again this could be part of the regional component of the pollen assemblage. The marsh/aquatic taxa present in the pollen record are reflected in the macrofossil record and are most likely to be local in origin, as are the records of spores of Cryptograms especially those of *Thelypteris*.

Overall, the pollen diagram from Vickers Point and the pollen assemblage biozones identified by Hunt *et. al.* in Brooks (1990) appears to support the macrofossil evidence of an alder carr being present throughout the woody peat horizon, although this is more open at the initiation of the peat, with a fen environment being present. The trees may have been present before the onset of peat initiation, as is perhaps suggested by the radiocarbon dates. But this does not mean that they could not have survived the initiation and continued development of fen peat and become part of the fen carr environment. This is supported by the continued presence of tree pollen throughout the Lower Peat sequence.

5.9.7.2. The Anderby Beds

The main location for the palynological analysis of the Anderby Beds was at Chapel Point (TF562738) (Brooks, 1990) which is 1.9 km south of the macrofossil section at Anderby Creek. The resultant pollen diagram is presented in figure 5.16.

From studying the pollen diagram in figure 5.16 and the macrofossil assemblage presented in figure 5.14, it can be seen that there is very little resemblance between the two sets of data. The macrofossil evidence as described above represents a salt-marsh environment with a possible scrub habitat with a few birch trees and a ground flora dominated by *Rubus fruticosus*, although this component may have been reworked from the underlying Lower Peat bed.

There is very little indication of the presence of salt-marsh within the Chapel Point pollen assemblage, although the large concentrations of Chenopodiaceae pollen throughout the Anderby Beds sequence could be that of *Suaeda maritima* which is very common in the macrofossil profile. The large number of remains of *Limonium* sp. in the macrofossil assemblage at Anderby Creek are not reflected in the pollen diagram from Chapel Point.

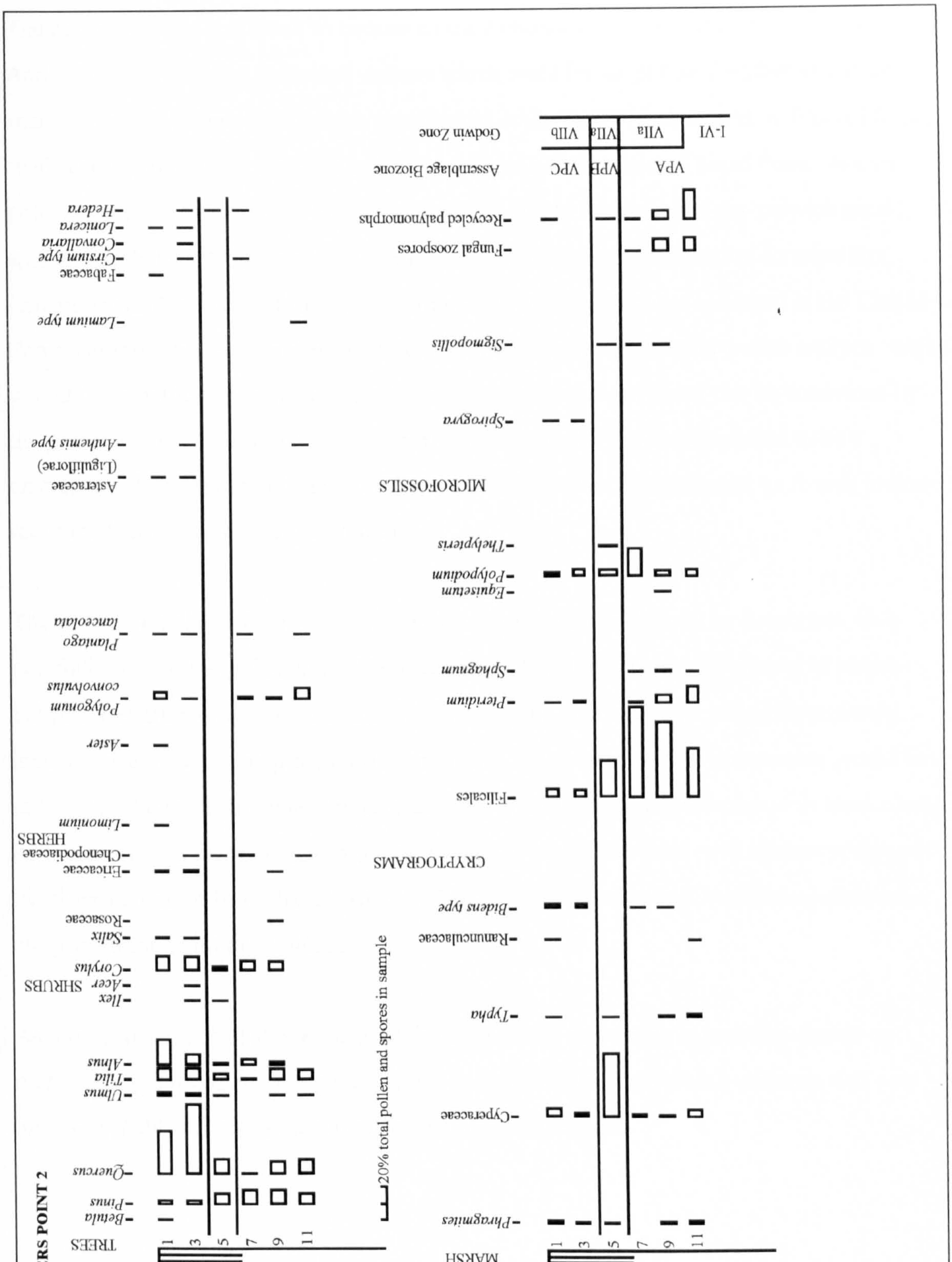


Figure 5.15. Pollen diagram for the Lower Peat Beds at Vickers Point (VP2), east Lincolnshire coast. (After Brooks *et. al.* (1990)

The reason for this is difficult to deduce as the *Limonium* flowers recovered from the Anderby Creek samples contained anthers which were full of pollen. Another salt-marsh species, *Triglochin maritimum* was represented in the macrofossil record by finds of fruits, seeds and rhizomes, but the pollen of this taxon was absent from Chapel Point. *Juncus* pollen cannot be expected to be recorded as it is rarely found within any palynological studies (Godwin, 1975a, p374). The presence of increasing abundance of foraminifera remains towards the top of the profile from Anderby Creek are not reflected in the Chapel Point diagram, this may be explained by the processing of samples for pollen analysis, which would destroy them. The presence of *Betula* sp. in the pollen record can be confirmed by the presence of *Betula* fruits in the Anderby Creek profile, but there appears to be a discrepancy between the pollen record and that of the plant macrofossils, as *Betula* pollen is recorded below that of the macrofossils.

The reasons for the differences between the two data sets is difficult to determine. One possibility is that the pollen assemblage at Chapel Point may be more regional in nature. Saltmarshes are more open landscapes permitting the deposition of pollen from distant habitats which may swamp the local component. This more regional component would be reduced in the macrofossil assemblage as seeds and other propagules cannot in most cases be transported as far as pollen. Another possibility is that the local environment at Chapel Point was different from that at Anderby Creek, with the saltmarsh being some distance away from the point of sampling.

As has been suggested above the establishment of the salt-marsh is probably due to an increase in sea-level, and the pollen evidence supports the macrofossil evidence that sea-level was stable for some time after the initial transgression.

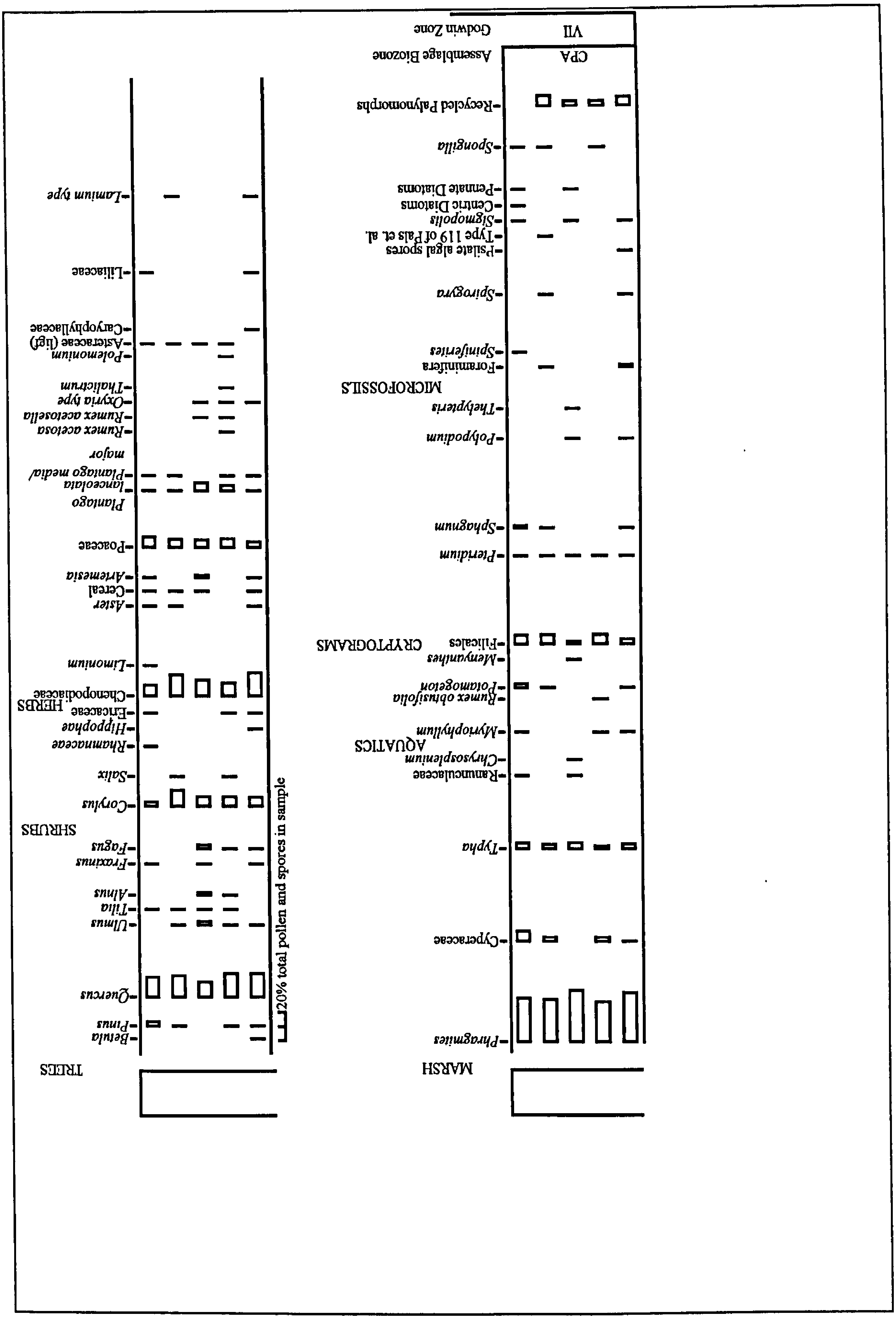


Figure 5.16. Pollen diagram for the Anderby Beds at Chapel Point (CP), east Lincolnshire. (After Brooks *et. al.*, 1990)

5.10. Summary

The history, post-glacial geology and previous studies of the east Lincolnshire submerged forests are discussed in sections 5.1- 5.6. The results from the planning, wood and plant macrofossil identifications from Wolla Bank and Anderby Creek are discussed separately and then compared, in order to deduce similarities and differences between the two exposures, in section 5.7 - 5.10. In general, the submerged forests consist of the same tree species but differ in the proportions of each species present at each exposure. Unfortunately only Wolla Bank provided plant macrofossil data from the submerged forest deposits whilst at Anderby Creek, the plant macrofossil content of the deposits reflected a salt-marsh environment which succeeded the submerged forest phase.

Section 5.9.7 compares the pollen diagrams produced by earlier work with the macrofossil data produced by this study. The pollen diagram (although located 4.1 km south of Wolla Bank) for the submerged forest deposits supports the evidence provided by the plant macrofossil analyses, indicating the presence of carr woodland. The pollen diagram and the plant macrofossil data from Anderby Creek do not reflect similar types of environment. This may be due to the pollen spectrum from the Anderby Beds represents a more regional picture of the vegetation in the, whilst the plant macrofossil evidence reflects a more local environment. Another contributing factor to the difference to the pollen and plant macrofossil record of the Anderby Beds is that the pollen site is located 1.9 km south of the plant macrofossil site.

The following chapter presents the geological, palaeoecological history of Merseyside and the results of the planning and macrofossil analysis of the submerged forest present at Hightown.

Chapter Six

THE SUBMERGED FORESTS OF MERSEYSIDE

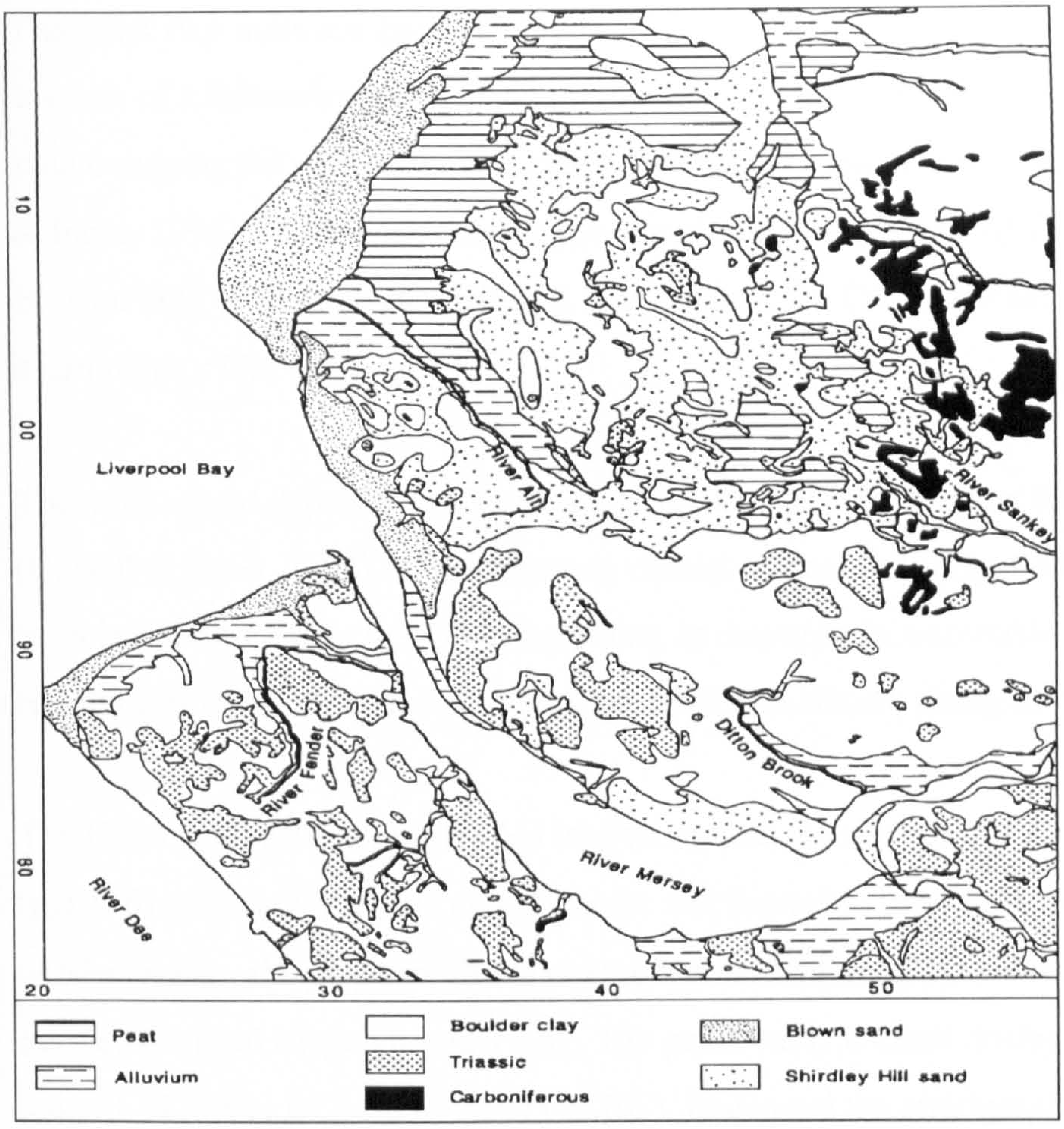
6.1. Introduction

The coastal deposits of South Lancashire and Cheshire can be considered as part of Merseyside as described by Cowell and Innes (1994). Merseyside is on the low lying Lancashire Plain bounded by the Pennines in the east and Wales in the south-west. The north-west limit is formed by the Irish Sea, although the current coastline does not indicate its true boundary as it continues beneath the sea, as can be seen in map 6.1, (Cowell & Innes, 1994).

6.2. The Geology of Merseyside

The landscape of Merseyside can be divided into four geological units each producing a distinctive topography as illustrated in figure 6.1. The earliest deposits are Triassic and Carboniferous rocks which produce the main relief of the area with low sandstone hills and ridges rising to 60-70m O.D. and are distributed across the central and north-eastern part of the area. The Carboniferous sandstone rising to *c*100m O.D. forming the Billinge ridge, extends north-westwards into Lancashire and marks the eastern edge of the Lancashire Plain (Cowell & Innes, 1994).

The second geological unit is associated with the Devensian ice-age which not only helped to shape the sandstone ridges but produced the major river channels of the area. This second characteristic landscape is of undulating plains and low-lying hills formed by the deposition of a thick sheet of glacial till by the retreating glaciers. This clay varies in texture and composition depending on source and mode of transportation. These two topological units dominate the southern two-thirds of Merseyside, (Cowell & Innes, 1994).



Map 6.1. Map showing the general geology of the Merseyside area. (From Cowell & Innes, 1994)

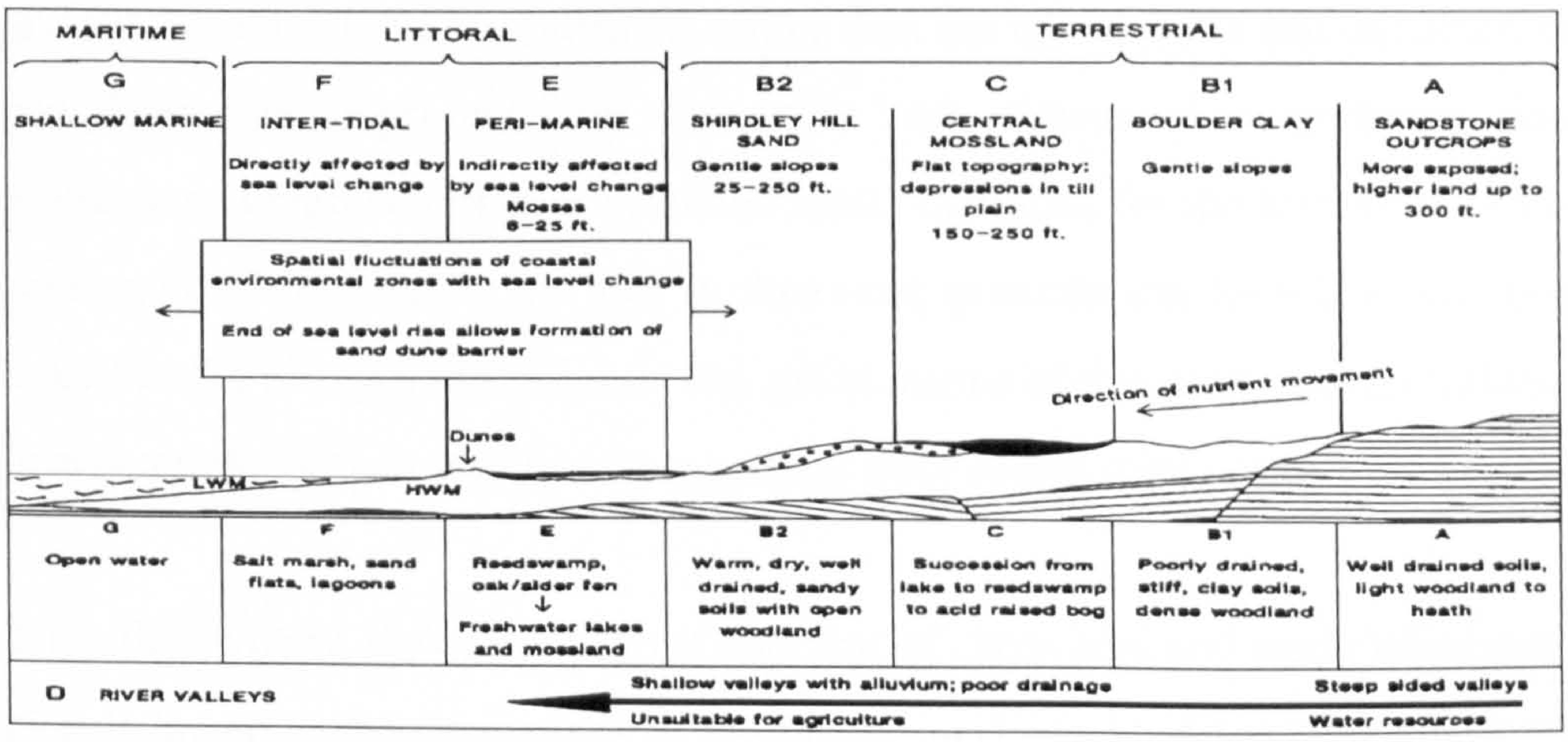


Figure 6.1. Geological section across the Merseyside area. (From Cowell & Innes, 1994)

The other two units are generally found in the northern third of the area. The earliest consists of a featureless plain made up of a thin but widespread layer of windborne sand overlying the glacial boulder clay which was deposited *c*9000-8200 BC (Cowell & Innes, 1994). In the west there is the occasional low ridge rising from *c*6m O.D. to 10-15m O.D. and in the east where it butts against the Carboniferous sandstone ridges it can reach *c*75m O.D.

The most recent deposits are Holocene in age and relate to the last 8000 years (Cowell & Innes, 1994). These deposits consist of peats, clays and silts and form in hollows and in the low-lying plains, in response to watertable changes resulting from factors associated with sea-level and climate changes.

The Holocene peats can be divided into two types, (Cowell & Innes, 1994). The first type is found away from the modern coast and formed in local hollows. In the south of Merseyside, the peats are found overlaying the boulder clay whilst in the north they overlay the sand capped boulder clay. The peats were initiated during Flandrian II (*c*6190-5720 Cal BC - 3990-3640 Cal BC). In general the stratigraphy of these peats is one of base rich, species rich fen and carr peats which over time became less dependent on groundwater and more reliant on atmospheric precipitation forming acid, species poor raised bog peats.

The second type of Holocene peat is found in the remaining coastal areas of Sefton and the Wirral. These were formed earlier than the inland peats and remained as fen peat dependent on groundwater throughout their existence. Low gradients, poor drainage and high watertables provided ideal conditions for the formation of these species rich fen peats. As the peat surface rose, groundwater level also rose probably linked to the changes in sea-level. The maintenance of this groundwater influence prevented the initiation of the more species poor raised mire peats.

The other type of Holocene deposit was that of clays, silts and sands which are more closely linked to the oscillations of sea-level experienced in Merseyside between the seventh millennium BC and the fifth millennium Cal BC (Tooley, 1978, 1985, Kenna, 1986). Each successive fluctuation of sea-level led to the burial of former landscapes by clay, silt and blown sands. These deposits contain evidence of the changing environments of the present coastal areas and show that a diversity of landscapes was present including sand dunes, intertidal sand and mudflats, saltmarsh, marine and freshwater lagoons and swamps, meres and fens, (Cowell & Innes, 1994).

In summary, the geology of the Merseyside area consists of Triassic and Carboniferous sandstone hills and ridges found in the central and north-eastern parts of the area which were shaped by the Devensian ice sheets. Independent of the solid geology, a thick layer of glacial boulder clay was deposited by the retreating Devensian glaciers forming an undulating landscape of plains and ridges. These two landscape types dominate the southern two thirds of Merseyside. The northern third is dominated by an extensive windborne sand deposit of varying thickness overlying the boulder clay and deposited between *c*9000 and 8200 Cal BC. On top of the glacial boulder clay in the south and the sand capped boulder clay in the north a series of Flandrian peats, clays, silts and sands were deposited. It is these more recent deposits which are of interest in this study, especially the coastal fen peat deposits.

6.3. Early Records of submerged/subterranean forests in Merseyside

Exposures of subterranean and submerged forests have been recorded in Lancashire and Cheshire since the 16th Century and have been recorded regularly up to the present day and are mainly concerned with the exposures on the Wirral, at Leasowe, Dove Point, Hoylake, Liverpool Bay and sections exposed in the excavations for new docks at Liverpool and other engineering works. The inclusion of both subterranean and submerged forest records is justified as Hume (1865) reported that the submerged forests are just seaward exposures of the subterranean forests and therefore records of both are worthy of consideration. (Leland, 1535-43(1768); Camden, 1610; James, 1636; Leigh, 1700; Greenough, 1819; Kaye, 1827; Stevenson, 1828; Yates, 1843; Baines, 1835-45; Mortimer, 1843; Hume, 1845, 1863; Picton, 1849; Smith, 1849; Cunningham, 1854; Morton, 1863, 1897; Smith, H.E., 1865, 1866; Boult, 1865; Potter, 1868, 1875, 1876,1894; De Rance, 1870; Reade, 1872 a & b, 1878 a & b, 1883; Greenwood, 1910; Walker, 1913; Jones, 1919; Maidwell, 1920; Mem. Geol. Survey, 1923; Erdtman, 1926; Travis C.B., 1906, 1913, 1926, 1929; Birks, 1964; Kenna, 1978, 1979, 1986; Tooley, 1977, 1978, 1979, 1985; Cowell & Innes, 1994).

As Travis (1926) mentioned, most observers and recorders of the submerged forest deposits only noted the species of the tree remains present within the exposed deposits, with only hand specimens and the presence of bark being used to identify the tree species. The only reference to other macrofossil remains are usually in the guise of the presence of aquatic plants, marsh plants and leaves with no attempt to identify any of the remains to species or to carry out further investigations. The early records are of great importance as the deposits which they describe have been long since eroded away and they provide evidence that suggests that the extent of the submerged forest deposits was far greater than is now visible.

One of the earliest references to the submerged forest in south Lancashire was to the exposure between Waterloo and Hightown. This appeared in the July 1796 issue of the Gentleman's Magazine, a letter with an engraving of the exposure, from a Mr. George Holt of Walton who described 'A submerged forest at Crosby, extending upwards of a mile towards Formby. What might have been its original extent, either in that or in any other direction, seems at present impossible to ascertain; but vestiges of it are visible dipping westwardly into the sea, which doubtless covers a great part of land on which a considerable portion of it grew. There are numberless trunks of trees standing upright some feet above the surface, in the very place in which they must have grown, with their prodigious roots extending into the ground in all directions in their natural positions.' (in Travis, 1926).

The submerged forest and peat beds on the South Lancashire and Cheshire coast were considered to be of novelty interest until fifty years after Holt's description before the submerged forest deposits attracted the attention of local geologists. The twenty years after this initial interest was marked by an enthusiastic and sometimes heated debate on their origin.

6.4. History of the controversy surrounding the origins of the submerged forests of Merseyside

In the late nineteenth century, the origins of the submerged forests were often debated as discussed in chapter two, section 2.6, the submerged forests of Lancashire and Cheshire provided much fuel for this debate.

The controversy surrounding the origins of the submerged forest beds of South Lancashire and Cheshire coasts began in 1865 with the publication of a paper by Joseph Boult in the Journal of the Liverpool Polytechnic. Boult proposed that the idea of a submarine forest on the coast at Leasowe and Formby was a delusion and that the records of thousands of trees visible on the sea margin could be accounted for in a more rational way. Boult put forward the theory that the deposits had a distant origin. He proposed that approximately three hundred years prior to the publication of his paper a small brook on the borders of Salford Hundred flooded and large portions of Chat Moss, to the extent of 18-20 square miles were carried down into the Mersey and the roots, trunks, branches, nuts and turf bog now found on the shores were the result of this inundation. To account for the various strata containing tree remains being interspersed with blue clay or silt bands, Boult suggested that there were several eruptions of water and turf bog from Chat Moss. The variation of depth between each layer of bog and tree remains can be accounted for by the variation in the time intervals between each successive flood.

The Reverend Hume, (1865) replied to Boult dismissing his theory of distant origin and accused him of playing a practical joke on the members of the Polytechnic Society, and regarded the idea of the deluge as a cause of the submerged forests as being “that last resort of ignorance....”. Hume argued that if the coastal exposures occur in a bed continuous with that under dry land, did not grow *in situ*, there is no reason to assume that those on dry land grew *in situ*. And if they were of distant origin, where did they come from and how were they placed there? After studying the available documentary evidence and with limited fieldwork, Hume concluded that the submerged forests formed as a result of *in situ* woods being engulfed by rising sea-levels and the submergence of the land mass, he also maintained that the seaward exposure of the forests were extensions of the landward subterranean forests.

Boult, after reading Hume's 1865 reply does abandon many of his conclusions although he still disputes that the several remains of forests are formed *in situ* and whether the coast has been subject to accretion and diminution over the last 2000 years. Boult uses other documentary sources to defend his theory of distant origin, although most of the work quoted is anecdotal with no substantial field evidence to substantiate his conclusions.

Potter in 1876 added to the controversy in a paper published in the Transactions of the Historical Society of Lancashire and Cheshire. Potter originally supported the idea that the forests were developed *in situ*, but doubt about this method of origin arose after discovering a small unresinous fir, in an undecayed state, underlying the bole of a large oak, both of which were closely and firmly imbedded in their surrounding matrix. Potter argued that since the number of trunks outnumbered those of stumps and that horizontal tree trunks are found throughout the thickness of the deposit is proof that they were being deposited during the whole period of the formation of the beds and suggested a drifted nature.

In 1878, T. Mellard Reade noted that other researchers had recorded that none of the roots and stumps of the trees of the submarine forest penetrated the blue clay or silt below the peat and had used this to suggest the drifted nature of the deposits. To prove that this was not the case, Reade with a team of labourers excavated two tree stools from different parts of the of the exposure at the Alt Mouth and found that the main roots embedded in the peat when traced carefully were found to penetrate the blue clay beneath. Mellard Reade concluded that the trees of the submerged forest grew and fell in the same place and the continual erosion of these deposits provided daily evidence that the tree roots penetrate the underlying deposits, (Reade, 1878a & b).

The arguments for the *in situ* formation of the peat and forest bed deposits appear to be stronger than those suggesting a drifted origin. And subsequently the former theory has proved to be more durable, with changes in both sea and land levels leading to the deposition of the different strata. Modern palaeobotanical techniques, especially palynology have helped to dismiss the theory of distant origin and work at Chat Moss (Birks, 1964) has shown that there is no evidence for mass eruptions of peat from the area.

6.5. The Generalised Stratigraphy of the Merseyside Submerged Forest Deposits

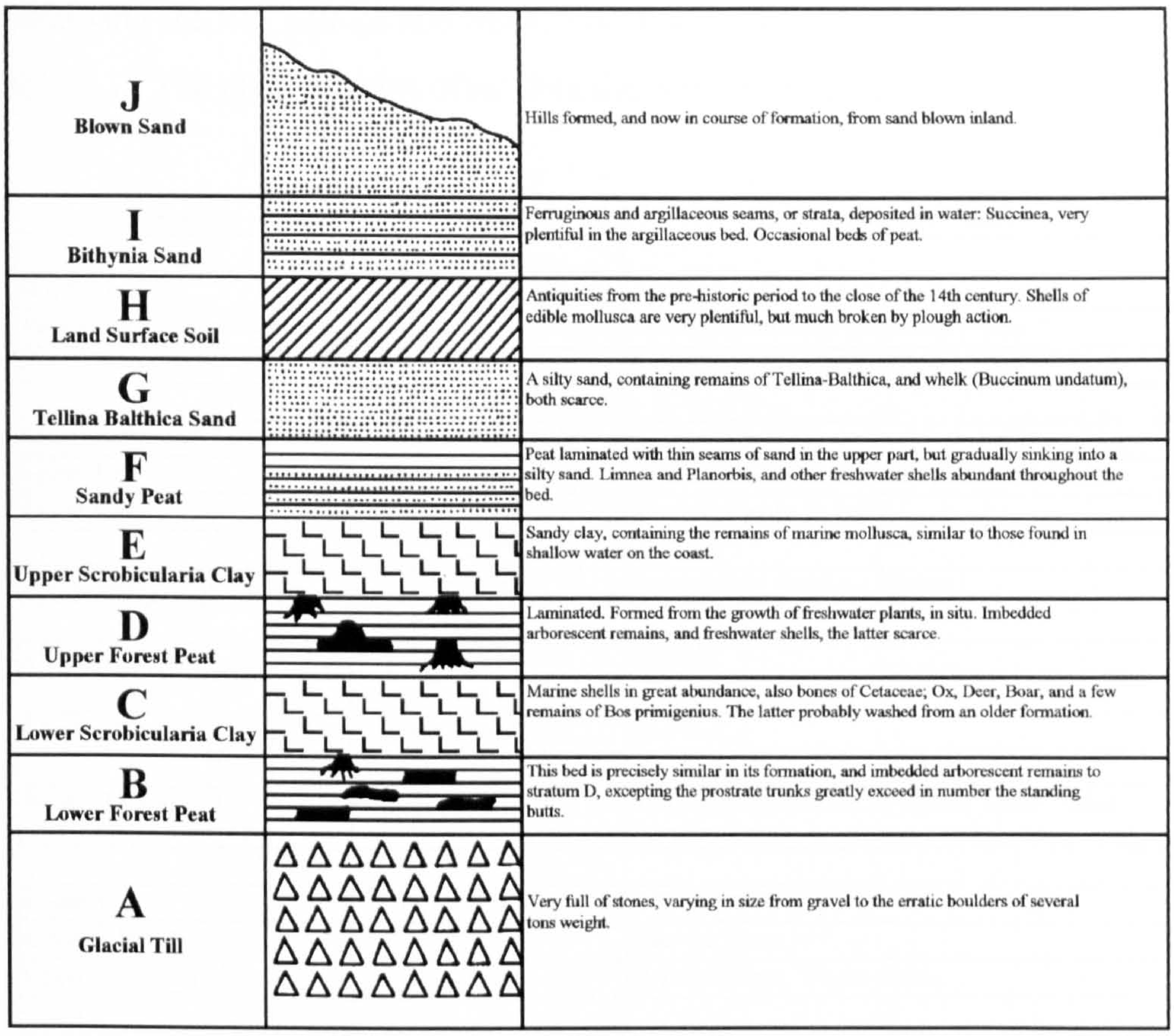
Travis (1926), describing the submerged forest deposits at Hightown demonstrated that the stratigraphy at Hall Road was characteristic of the majority of the submerged forest deposits present on the coasts of South Lancashire and Cheshire that had been recorded by previous workers referenced in section 6.2 which have been taken from a variety of sources such as bore holes and sections from excavations of new docks in the Liverpool area.

The sequence of deposits at Hightown consisted of peat which varied in depth from 20cm to 1.2m, averaging between 45-53cm. This is overlain by a dark coloured peaty sand 45cm-1.5m thick which forms the base of the sand dunes. The peat bed rests on a bed of grey sand and laminated blue clay which on the foreshore is visible for a thickness of between 30cm-1.2m. The upper surface of the Peat and Forest Bed was determined to be 3.15-3.6m above O.D. In 1906, Travis, recorded several borings made through the sand dunes at Hightown which revealed beds of much greater thickness as they had been unaffected by erosion, a generalised profile from these borings is giving below.

Sand	6.0 metres	Blown Sand
Black Peaty Sand	1.95 metres	"Soil Bed" (Morton)
Dry Firm Peat with Trees	0.25-1.2 metres	Upper Peat and Forest Bed (Morton)
Blue Clay and Black Sand	6.6 metres	Grey Clay and Sandy Silt (Morton): Formby and Leasowe Marine Beds (Reade)
Brown Stiff Clay	3.3 metres	Boulder Clay
Red and Blue Shale	2.4 metres	Keuper Marl

A generalised section can be seen in figure 6.2. The only variations that appear to occur between the description presented above and those sections and boreholes described by earlier authors are the relative depths of each of the strata. The variation in bed thickness of the submerged forest deposits from point to point was considered a result of the erosion to which they had been subjected to before the deposition of the overlying beds, as well as the undulating surface of the floor of the boulder clay (Travis, 1926).

Another variation was found on the Wirral at Leasowe, where Morton (1897) described a second, Lower Forest Bed occurring at 2.4m below the ordinary spring tide which was 30cm thick. The thickness of this Lower Forest Bed according to Travis (1929) can vary from less than 2.5cm to between 10-15cm which is probably due to the undulating underlying late-glacial boulder clay. The Lower Forest bed usually rests on the boulder clay but in some areas they can be separated by a layer of grey sand up to 15cm thick or in other areas by a lead-coloured clay between five and ten centimetres in depth.



J **Blown Sand**	Hills formed, and now in course of formation, from sand blown inland.
I **Bithynia Sand**	Ferruginous and argillaceous seams, or strata, deposited in water: Succinea, very plentiful in the argillaceous bed. Occasional beds of peat.
H **Land Surface Soil**	Antiquities from the pre-historic period to the close of the 14th century. Shells of edible mollusca are very plentiful, but much broken by plough action.
G **Tellina Balthica Sand**	A silty sand, containing remains of Tellina-Balthica, and whelk (Buccinum undatum), both scarce.
F **Sandy Peat**	Peat laminated with thin seams of sand in the upper part, but gradually sinking into a silty sand. Limnea and Planorbis, and other freshwater shells abundant throughout the bed.
E **Upper Scrobicularia Clay**	Sandy clay, containing the remains of marine mollusca, similar to those found in shallow water on the coast.
D **Upper Forest Peat**	Laminated. Formed from the growth of freshwater plants, in situ. Imbedded arborescent remains, and freshwater shells, the latter scarce.
C **Lower Scrobicularia Clay**	Marine shells in great abundance, also bones of Cetaceae; Ox, Deer, Boar, and a few remains of Bos primigenius. The latter probably washed from an older formation.
B **Lower Forest Peat**	This bed is precisely similar in its formation, and imbedded arborescent remains to stratum D, excepting the prostrate trunks greatly exceed in number the standing butts.
A **Glacial Till**	Very full of stones, varying in size from gravel to the erratic boulders of several tons weight.

Figure 6.2. A generalised profile of the submerged forest deposits on Merseyside (after Potter, 1876)

The Upper and Lower Forest Beds are usually separated by a blue clay layer 75cm thick, but towards Leasowe Castle the clay layer gradually thins resulting in the two Forest Beds amalgamating. The roots of the trees in the lower bed penetrate the underlying boulder clay suggesting an *in situ* origin, (Travis, 1929). On the south Lancashire coast only one Forest Bed has been described, the Upper Peat and Forest Bed, although in localised circumstances such as that recorded by Travis (1913 & 1926), at the construction of the Gladstone Dock at Seaforth two beds can occur.

6.6. Earlier Palaeoecological Investigations of the Submerged Forest exposures on Merseyside

Prior to Travis' (1926) investigation of the Peat and Forest Bed at Hall Road, Hightown, no attempt had been made to characterise the deposits other than by identifying the tree stumps and trunks contained within the peat, as can be seen in table 6.1. The plant remains other than the trees, were given scant attention and were often dismissed as being of aquatic in origin and bore no relation to the tree stumps and trunks, only growing after the death of the trees. According to Travis (1926 & 1929), earlier workers had mistakenly identified the rhizomes of *Phragmites australis* for those of *Iris pseudoacorus,* which Travis, (1926, 1929) had failed to find in the deposits at Hightown and Leasowe. Travis used both plant macrofossil analysis (with the help of his brother, W.G. Travis and E.M. Reid) and the then new discipline of palynology, to characterise the deposits and a summary of his finds can be seen in table 6.2a-c.

Location	**Author**	**Stump/Trunk Remains**
Hightown	Travis, 1926	
Dark Peaty Sand 2m thick		*Betula, Quercus, Corylus, Alnus, Pinus*
Peat & Forest Bed		*Betula, Quercus, Corylus, Pinus, Alnus*
Leasowe, Bennett's Lane, Meols	Travis, C.B., 1929	
Upper Peat		*Quercus, Betula, Pinus, Corylus*
Lower Peat		*Quercus, Betula, Corylus*
Martin Mere	Leigh, 1700	*Pinus, Betula, Fraxinus, Quercus*
Cheshire Coast	Kaye, 1827	*Quercus*
Cheshire Coast	Stevenson, 1828	*Quercus*
Bidston Marsh	Smith, 1849	*Alnus, Quercus, Ulmus, ?Juglans, Taxus, Betula, Corylus*
Leasowe	Potter, 1876	
Lower Forest Bed		*Quercus, Pinus*
Upper Forest Bed		*Quercus, Pinus, ?Fagus, Taxus*
?	Reade, 1883	*Quercus, Pinus, Corylus*
?	De Rance, 1877	*Quercus, Salix, Corylus, Spurge?*
Leasowe	Potter, 1872	*Quercus, Pinus, Corylus, Betula, Larix, Ulmus*
Leasowe- Hoylake	Hume, 1863	*Quercus, Pinus*
Dove Point	Roberts, in Morton, 1897	*Alnus, Betula, Ulmus, Pinus, Quercus*
Wallasey & Liverpool district	Mem. Geol. Survey, 1923	*Quercus, Pinus, Betula* etc.

Table 6.1. Table showing tree identifications from previously reported submerged forest deposits

Horizon	Dark Peaty Sand	Peat & Forest Bed	Dark Sand	Blue Clay	**Key**
Species					a = achene
Trees					ac = acorn
Pinus sylvestris		w, bk, p			bk = bark
Quercus robur	w, p	w, bk, ac, p			car = caryopses
Betula pendula	bk, sd, p	w, bk, p			ckn = catkin
Alnus glutinosa		cn, frt	frt		cn = cone
Corylus avellana		w, nt			frt = fruit
Tilia sp.		p			lvs = leaves
Shrubs					nlt = nutlet
Myrica gale		lvs, sd, ckn			nt = nut
Salix cinerea		lvs			nu= nucule
Salix aurita		lvs			p = pollen
Salix repens		lvs			pin = pinnules
Ilex aquifolium		lvs			sd = seed
Aquatic					sp = spore
Chara sp.	nu				st = stone
Nymphaea alba	sd, p				ste = stems
Nuphar lutea	sd				rhi = rhizome
Ceratophyllum submersum			sd		w = wood
Ranunculus subgen. *Batrachium*	a		a		
Myriophyllum spicatum	sd				
Oenanthe aquatica			sd		
Oenanthe sp.			sd		
Hippuris vulgaris		sd			
Potamogeton gramineus	frt				
Wet Margin/ Marsh					
Dryopteris cristatus		sp			
Thalictrum flavum			sd		
Stellaria palustris		sd, p			
Viola palustris		sd			
Hydrocotyle vulgaris	sd				
Sium latifolium		p			
Scutellaria sp.		p			
Mentha aquatica	nlt				

Table 6.2a. Table of Travis' plant macrofossil identifications from Hightown, (Travis, 1926)

Travis (1926) examined the upper layers of the forest bed which contained small fragments of carbonised wood, grass stems, small twigs, and seeds of bog bean (*Menyanthes trifoliata*). In other places, the upper peat was laminated and spongy when sodden with sea-water and composed of decayed fibres, stems, leaves of grasses and sedges with layers of sallows, (*Salix* spp.) bog myrtle (*Myrica gale*) and bogbean as well as remains of the royal fern (*Osmunda regalis*). Travis (1926) stated that "lower down the profile, the peat is dark brown in colour and becomes more compact and often woody in nature, with a well humified matrix. It contains a great abundance of twigs, branches, pieces of bark, mostly silver birch, (*Betula* sp.) together with numerous stools and prostrate trunks. At the base of the peat 20-30cm above the sand and clay interface very little in the way of plant remains were preserved."

Horizon	Dark Peaty Sand	Peat & Forest Bed	Dark Sand	Blue Clay
Species				
Alisma plantago-aquatica	p			
Juncus articulatus		sd		
Juncus sp.	sd			
Carex paniculata		nt		
Carex divisa		nt		
Carex extensa			nt	nt
Carex flava				nt
Carex viridula ssp. *viridula*	nt			
Carex diversa			nt	
Carex spp.	nt	nt		
Bog				
Sphagnum sp.	sp			
Menyanthes trifoliata		lvs, sd, p		
Indeterminate				
Chenopodium album	sd			
Atriplex patula	sd	sd, p		
Potentilla anserina	sd			
Rumex acetosa		p		
Poaceae		ste, lvs		
Woodland				
Polypodium vulgare		sp		
Rubus fruticosus			sd	
Rubus sp.	sd			
Potentilla sterilis				sd
Alder Carr				
Osmunda regalis		sp, ste, pin		
Thelypteris palustris		sp		
Athyrium felix-femina		sp		
Heaths				
Huperzia selago		sp		
Lycopodiella inundata		sp		
Brackish				
Ruppia maritima			sd	sd
Ruppia cirrhosa			sd	sd

Table 6.2b. Table of Travis' plant macrofossil identifications from Hightown, (Travis, 1926)

The upright stools of the larger trees varied in size from 30cm to 91cm and in one case 1.8m in diameter (Travis, 1926). The prostrate trunks as measured by Travis (1926) were between 1.8-3.6m in length. It was common to find stools of trees, 60cm in diameter and strongly rooted at the actual junction of the peat and underlying sediments. In many cases the roots could be seen to penetrate the clay and sand

Horizon	Upper Peat	Peaty Sand	Compact Peat	Blue Clay	Lower Peat
Species					
Trees					
Pinus sylvestris			p, w		p
Ulmus sp.			p		
Quercus robur			ac, w, p		w, p
Betula pendula			sd, w, p	sd	bk, w, p
Alnus glutinosa			cn, frt, w, p		
Corylus avellana			nt, w, p		nt, w, p
Tilia sp.			p		
Shrubs					
Prunus spinosa					st
Aquatic					
Chara sp.			nu		
Ranunculus subgen. *Batrachium*			a		
Apium nodiflorum			sd		
Hippuris vulgaris			sd		
Potamogeton sp.		frt	frt		
Phragmites australis			lvs, rhi		rhi
Sparganium natans			frt		
Wet Margin/ Marsh					
Ranunculus flammula			a		
Viola palustris			sd		
Hydrocotyle vulgaris			sd		
Lycopus europaeus			nlt		nlt
Mentha aquatica		nlt			
Cirsium palustre			sd		
Eupatorium cannabinum					ac
Alisma plantago-aquatica			sd		
Eleocharis uniglumis			nt		
Schoenoplectus lacustris		nt		nt	nt
Isolepis setacea			nt		
Cladium mariscus			nt		
Carex spp.			nt	nt	nt
Indeterminate					
Chenopodium album		sd			
Atriplex prostrata		sd	sd		sd
Stellaria media			sd		
Potentilla anserina			sd		
Lamiaceae indet.			nlt		
Poaceae			car		car
Woodland					
Urtica dioica		sd		sd	
Viola sp.				sd	
Rubus fruticosus			sd		
Solanum dulcamara				sd	
Alder Carr					
Osmunda regalis			sp		
Athyrium felix-femina			sp		
Brackish					
Zannichellia palustris		sd	sd		

Table 6.2c. Table of Travis' plant macrofossil identifications from Leasowe, (Travis, 1929)

proving that the trees grew *in situ*. The trunks were observed to present at all depths in the peat and prostrate trunks can be found to overlie and cross each other at all angles but mainly between the north-east and north-west.

Travis found the timber in various stages of decay, but often internally sound. The twigs and branches show the effects of compression. The larger trees were of oak and birch, the latter being particularly abundant, being readily identified by the characteristic silvery bark. These observations of Travis are still pertinent today, except that the large expanses of the submerged forest recorded by Travis have been eroded away and the tree stumps are in a more decomposed state. The trees and shrubs identified by Travis can be seen in table 6.3.

Species	**Type of remain**.
Pinus sylvestris	bark, wood
Pinus sp.	pollen
Myrica gale	cones, seeds, leaves
Quercus sp.	bark, wood, acorns, pollen
Betula sp.	bark, wood, pollen
Alnus glutinosa	cones, seeds
Corylus avellana	wood, nuts, pollen
Tilia europaea	pollen
Salix cinerea	leaves
Salix aurita	leaves
Salix repens	leaves
Salix sp.	pollen, wood
Ilex aquifolium	leaves

Table 6.3. Table showing tree and shrub species with type of fossil remain identified at Hightown by Travis, (1926)

In 1929, Travis examined similar deposits at Leasowe, Cheshire and found similar species present within the Forest Bed at Hightown and the Upper Forest Bed at Leasowe, although the total number of species recovered at Leasowe was slightly less than that at Hightown, (table 6.2), Travis concluded that the reason for this discrepancy was due to the limited expanse of deposits available at the Cheshire location. With regards to the trees present within the beds, the same species were identified although pine was more abundant at Leasowe than at Hightown. As mentioned above in section 6.5 a second, Lower Forest Bed was found at this location. A comparison of the plant assemblages of the two Forest Beds found that they were similar and Travis found no species which indicated that the lower bed was formed in different climatic conditions to those present at the initiation of the Upper Forest Beds and therefore concluded that unlike most geologists at the time, there was not a considerable time gap between the formation of these two deposits.

Travis also carried out rudimentary pollen analyses at Leasowe and Hightown, (Travis 1926,1929). The technique of palynology was in its infancy at this time (von Post, 1916) and the more refined techniques of both identification and interpretation were not available. Some of the identifications of Travis, especially of those of the herbs at Hightown (Travis, 1926) can be considered as "very optimistic" by today's standards.

At Leasowe and Hightown, oak and birch pollen predominated, although there is a large difference between the two sites. At Leasowe, oak and birch reached similar maxima of 69% and 58% respectively whilst at Hightown, birch reached a peak of 80% and oak, 16%. This is reflected in the greater number of birch tree remains found at Hightown than those of oak. At Leasowe the frequencies of hazel, alder and pine are insignificant compared to the peaks of oak and birch. Erdtman (1928) in an earlier study of the deposits at Leasowe found the same pollen taxa as Travis, with the addition of *Tilia* and *Ulmus* which he recorded with maxima of 3-6%. At Hightown, pine pollen was less abundant than that of hazel, averaging less than 2%, whilst Travis identified a single grain of *Tilia* in the basal levels of the Peat and Forest beds.

Pollen and spores of other taxa identified by Travis at Hightown include; *Stellaria palustris*, *Menyanthes trifoliata*, *Scutellaria* sp., *Myriophyllum spicatum*, *Sium latifoilum*, *Atriplex patula*, *Rumex acetosa*, *Salix* sp., *Gentiana pneumonanthe*, *Polypodium vulgare*, *Athyrium felix-femina*, *Osmunda regalis*, *Dryopteris* sp., *Thelypteris palustris*, *Lycopodiella inundata* and *Huperzia selago*.

Travis (1926, 1929), interpreted the plant assemblages from both the Forest Beds at Leasowe and Hightown as representing an area which was initially woodland which developed subsequently with wetter conditions, brought about by one or a combination of the following (Travis was unsure of which mechanism at the time); impeded inland drainage by the coastal sand dunes, by the depression of the land surface or by rising sea-level, into 'fen-carr' or 'swamp-carr'.

More recent pollen analysis by Tooley, (1977, 1985), of the deposits at Alt Mouth (SD29500290) shows a dominance of tree taxa, along with a smaller proportion of herb taxa. The proportion of hazel (*Corylus*) appears to be constant throughout the profile within a smaller shrub component. Very few aquatic taxa were represented in the analysis. This assemblage has been interpreted as being representative of a succession towards an Alder-Willow carr (*Alnus-Salix*) with alder buckthorn (*Frangula alnus*), purple loosestrife (*Lythrum salicaria*) and woody climbers such as bittersweet (*Solanum dulcamarra*) which formed within a tidal flat and lagoonal zone, the peat at the Alt Mouth (at + 3.1m O.D.) produced a radiocarbon date of 4545 ± 90 BP (Hv 2679) (Tooley, 1976,1977).

6.7. The Holocene Palaeoecological evidence generated by the North West Wetlands Survey of Merseyside

6.7.1. Introduction

The North West Wetlands Survey (NWWS) was carried out in the Merseyside Region between 1990 and 1992 (Cowell and Innes 1994). The aim of this survey was to increase the knowledge of the environmental history and archaeology of the region. Of the different areas studied within Merseyside, two are of importance to this thesis, they are the North Wirral peninsula and the Sefton Mosslands. These two areas are more coastal than the other areas studied as they can be linked to the foreshore peat deposits on the Wirral and at Hightown. A summary of that work is presented here. The archaeological evidence is outlined in section 6.8 and the environmental history of the two areas area given in this section.

6.7.2. The North Wirral Mosses

On the Wirral, there are approximately 1880 hectares of peat and associated silts, clays and sands, which were laid down during successive changes in sea-level. These coastal sediments contain evidence for environmental change resulting from fluctuations in sea-level and groundwater during the last *c*9000 years of the Flandrian. The spatially and temporally changing environments played an important role in the nature and development of early human activity in the area , (Cowell and Innes 1994). The built up nature of the North Wirral hindered the identification of suitable sites for the investigation of the environmental history of the area, although, three mosses in the North Wirral peninsula are of palaeoecological interest, these are; Bidston Moss (SJ285915), Newton Carr, Hoylake (SJ225885) and Park Road, Meols (SJ239901). The palaeoecological history in all cases is based on palynological studies (Cowell and Innes 1994).

6.7.2.1. Bidston Moss (SJ285915)

The altitude of the surface at Bidston Moss is +2.31m OD and the altitude at the top of the basal clay is recorded as +0.31m OD and the bottom of the overlying peat and therefore the onset of biogenic accumulation has been dated to 6400-6080 Cal BC (7360 ± 60 BP; SRR-2926). The site was colonised by reedswamp communities dominated by the presence of *Phragmites australis* rhizomes in the lower peat and basal clay and represented by some of the Poaceae pollen recorded at this level. Other reedswamp species present include *Typha angustifolia* and *Nymphaea alba* which are indicative of open water. This was succeeded by fen woodland communities dominated by *Alnus* along with sedge fen taxa also being prominent. Pollen of *Filipendula*, *Caltha* and spores of *Thelypteris* also indicated as being present at this stage. There is an early high record of *Salix* and *Betula* showing an early stage in the development of drier fen carr communities before water depth and quality had progressed far enough to permit the formation of eutrophic alder swamp. A mosaic of open water, fen and alder swamp persisted for much of the ecological history of Bidston Moss.

The termination of the alder swamp is recorded by an increase in *Quercus* levels leading to oak dominated drier fenwood with the presence of *Calluna* suggesting a change from minerotrophic to ombrotrophic conditions and is further confirmed by the presence of *Sphagnum* moss spores indicating the beginning of mire development. Until this phase, there had been little change in the alder swamp where the pollen record for tree taxa had been of consistently high values of between 80-60% with the introduction of more acid species such as *Calluna* and *Empetrum* the tree pollen levels were reduced to 40% and the range of shrub taxa were also reduced. The accumulation of organic matter had initially been slow leading to a compact and humified peat. The persistence of alder swamp was probably due to the site being subjected to seasonal flooding for much of its history which provided a regular influx of nutrients which allowed the continuation of the minerotrophic ecosystem. Pollen types present included Rosaceae, Ranunculaceae, *Potentilla*-type, *Polygonum*, *Succisa* and Apiaceae many of which are indicative of marsh-fenwood habitats. The pollen of *Anemone*, *Malva* and *Sanguisorba* are representative of a drier environment although still damp. Ferns were abundant and included *Osmunda* and *Polypodium* indicating the presence of rich, shady damp habitats. The shrub component was represented by *Rhamnus*, *Euonymus* and *Viburnum* which can be found in alder swamp conditions.

Towards the top of the profile (from approximately 0.68m below the surface) the pollen evidence suggests a much drier, more acid environment due to terrestialisation via vegetation succession and reduced groundwater influence. This marked reduction in water depth is indicated by the presence of *Sphagnum*, *Calluna* and *Empetrum* associated with a rise in Cyperaceae levels. Macrofossil remains, in the form of rhizomes and stems of *Eriophorum* spp. also indicate more acid conditions. This change from a minerotrophic to an ombrotrophic system led to the development of a raised mire. At the top of the profile at +2m OD an organic clay is present indicating an estuarine situation dated to *c*3690-3360 Cal BC (4740 ± 70 BP; SRR-2924).

Several phases of open dryland habitat are indicated throughout the profile by the presence of weed pollen suggesting breaks in the forest cover as reflected by the fluctuations in the tree and shrub pollen curves. A total of sixteen phases of woodland disturbance and regeneration were noted by Cowell and Innes, (1994). At 1.06-0.94m in the profile and dated to 4900-4530 Cal BC (5840 ± 70 BP; SRR-2925) there is a major episode of forest disturbance with a sharp increase in the non-tree pollen, the shrubs *Calluna*, *Salix* and Coryloid also increase in value and may reflect more open conditions. Cyperaceae and Poaceae pollen accounts for much of the rise in non-arboreal pollen, there are records of indicators of forest clearance such as *Plantago lanceolata*, *Rumex*, *Artemisia*, *Senecio*-type, Apiaceae, *Matricaria*-type, and Chenopodiaceae. Cereal-type pollen was also recorded in association with the disturbance evidence. After this phase the periods of woodland disturbance are represented by large falls in the tree pollen values. Between each phase there is a partial regeneration of the woodland cover. Towards the top, radiocarbon dated to 3690-3360 Cal BC (4740 ± 70 BP; SRR-2924) there appears to be a general replacement of the woodland taxa with those more associated with grassland environments. Some areas may well have been given over to cereal cultivation as cereal-type pollen as well *Plantago major/media*, *Artemisia*, *Matricaria*-type, Brassicaceae, Chenopodiaceae, *Centaurea cyanus* and Caryophyllaceae which may represent arable weeds are present.

6.7.2.2. Newton Carr, Hoylake (SJ225885)

The stratigraphy at Newton Carr is more complicated. The lowest peat is a thin compacted layer containing wood fragments which rests on sand over boulder clay at an altitude of -5.5m OD to -5.1m OD. This is overlain by a blue/grey silt followed by a layer of thin peat at -2.45 to -2.25m OD. This mid-altitude peat is also overlain by clayey silts or silty sands, resting on this is the upper peat at +2 - +3m OD. This upper peat is analogous to the Upper Peat/Forest Bed (Kenna 1986; Cowell and Innes 1994) and is in turn overlain by an alluvial clay.

The basal peat is the oldest deposit at Newton Carr and has been assigned to Flandrian Chronozone I, due to the presence of high *Pinus* and low *Alnus* values. The boundary between this level and the following may be relatively dated to a little before 6000 Cal BC. High values of *Alnus* and *Ulmus* pollen from approximately -5.2m OD to +1.5m OD allows this section of the profile to be allocated to Flandrain Chronozone II, between c6180-5720 Cal BC and 3990-3640 Cal BC (7107 ± 120 - 5010 ± 80 BP; Q-915/Q-912), the levels above this record reduced values of *Ulmus* (between +1.5 - +3.2m OD suggesting that these belong to Flandrian Chronozone III, post-elm decline and therefore later than c3990-3640 Cal BC.

The basal peat was initiated by rising watertables due to rising sea-levels. At this time the area surrounding Newton Carr was heavily wooded with a mixed *Pinus, Betula, Corylus* forest, high grass pollen counts probably relate to the presence of local reedswamp (Cowell and Innes 1994).

The Flandrian Chronozone II at Newton Carr was dominated by repeated marine inundations leading from freshwater to estuarine conditions via saltmarsh environments. During the middle of Flandrian II a relative fall of sea-level occurred allowing the expansion of terrestrial and freshwater conditions leading to the development of fen carr and reedswamp. The pollen of *Alnus* is very common with *Quercus* and *Betula* also present in the carr communities. The regional picture suggests a dryland mixed deciduous forest with *Ulmus*, *Quercus* and *Corylus* abundant. *Pinus* is still present in the record and may have been growing in the area in suitable habitats.

Towards the end of Flandrian Chronozone II before 3990-3640 Cal BC there was a greater extension of drier conditions with no marine influence. The pre-*Ulmus* decline vegetation at Newton Carr was dominated by woodland with *Quercus* being more abundant than *Alnus*. *Pinus* and *Betula* had reduced values but wetland taxa were still common. Soon after the *Ulmus* decline the dense *Quercus/Alnus* woodland was maintained, although increasing wetness was indicated by aquatic and coastal types becoming more common. This can be related to a rising of sea-level which in turn influenced the rising of the local watertable. Following this local flooding, drier conditions pervaded and the *Quercus/Alnus* woodland remained dominant. *Betula* carr communities appeared to have dominated the immediate environs of Newton Carr with drier more acidic conditions prevailing until another rise in sea-level produced flooding leading to the replacement of *Betula* carr by that of *Alnus*.

From the pollen record at Newton Carr, no indication of human impact on the vegetation during the earlier Flandrian II was observed. A single grain of cereal-type pollen occurs at 2.20m below the surface, at a point not long after the elm decline and therefore maybe be present in a Neolithic context. This cereal-type grain is associated with indicators of forest clearance which includes a peak of *Plantago lanceolata.* The forest clearances after the *Ulmus* decline appear to be limited in extent and duration (Cowell and Innes 1994). There may be a possibility of Neolithic cultivation on the coast in the early Flandrian III Chronozone during the period of lowered sea-level, although indicators of disturbed and open ground can be expected to occur naturally on the coast (Cowell and Innes 1994).

6.7.2.3. Park Road, Meols (SJ239901)

A complex sequence of intercalated organic and clastic sediments are present at Park Road, Meols (Cowell and Innes 1994), but in general, the lower blue/grey clay is overlain by a thick 0.65m peat bed, which rests below a grey clay which grades into an oxidised surface. Within the upper part of the peat a thin grey clay layer occurred which seemed to represent the extreme landward limit of a clay wedge which thickened and formed a significant stratigraphic layer closer to the modern coast (Cowell and Innes 1994). The surface of the deposit is recorded at an altitude of +3.52m OD.

The boundary between the underlying clay and the base of the peat at a relative altitude of +2.27m OD and dated to 4234-3980 Cal BC (5250 ± 50 BP; SRR-2694) and falling into the late Flandrian II suggests that this layer is of marine or estuarine origin. The change from clay to peat is suggestive of a relative fall in sea-level with the flora of marine and brackish water diatoms being replaced by one dominated by *Phragmites* reedswamp and can be held as a classic example of a gradual ecological response to a change from saltwater to freshwater conditions (Cowell and Innes 1994), although the coastal communities still existed. The pollen taxa at this level indicates an extremely rich aquatic and semi-aquatic herb flora with the presence of such taxa as *Lythrum*, *Teucrium*, *Caltha*, *Ranunculus*, *Nymphaea*, *Hydrocotyle* and *Potamogeton* showing the presence of extremely wet fen/reedswamp environments with a high nutrient status. The aquatic species such as *Nymphaea* and *Potamogeton* increase towards the zone suggesting an increase in areas of deeper water. The tree taxa comprise fifty percent of the total land taxa with *Quercus*, *Ulmus*, *Coryloid*, *Betula* and *Alnus* being represented. The percentage of *Alnus* is relatively low in comparison to *Quercus* and *Salix* is not heavily represented indicating the lack of carr woodland around the site at this stage. The high values of *Quercus* belong to the regional component of the pollen rain and represents *Quercus* woodland on drier ground with *Ulmus* also present with a *Corylus* understorey. There is a rapid accumulation of peat during this period as freshwater sedimentation keeps pace with increasing sea-levels. There is no evidence for hydroseral succession towards a more terrestrial environment as the fen communities are sustained by rising sea-levels.

Around 3510-3140 Cal BC (4620 ± 50 BP; SRR-2693) there occurred a short lived marine inundation with the deposition of a thin clay layer which contained marine and brackish water diatoms and the pollen diagram shows a peak in saltmarsh types e.g. Chenopodiaceae and *Armeria*, although fen and reedswamp pollen was still prominent at this time. After this short phase, peat deposition was re-initiated.

From 3510-3140 Cal BC until the end of peat formation at 3100-2704 Cal BC (4315 ± 70 BP; GU-1312) (Kenna 1986) there is a progressive reduction in evidence for marine conditions which are replaced by indicators of a succession towards terrestrial freshwater environments. There is also a replacement of the regional *Quercus* component by one of a more local nature. This is indicated by the marked increase of *Alnus* and *Salix* pollen reflecting a more densely wooded local carr vegetation. An increase in wetland shrubs such as *Rhamnus* is also a product of the presence in the local area of carr and fenwood vegetation. The end of the peat formation around 3100-2704 Cal BC is marked by the presence of a grey clay indicating the return to more marine conditions.

There is little evidence for human impact in the area with few herb taxa indicative of forest openings occurring. The extremely wet nature of this site and its location at the seaward margin of a large area of homogeneous swamp and fen woodland may have restricted human access. The early Flandrian III marine episode clearly occurred throughout the north Wirral at altitudes up to approximately +2.75m OD, the expression and distribution of which depends upon the local topographic factors and may have had major implications for Neolithic settlement and activity in this area (Cowell and Innes 1994).

6.7.3. The Sefton Coastal Mosses

6.7.3.1. Introduction

These Mosslands stretch from the river Alt to Liverpool Bay in a narrow belt of coastal peat overlain by blown sand. Most of the peats are interspersed with a series of earlier coastal deposits reflecting environments such as mudflats, saltmarshes and dune systems all of which were controlled by changes in sea-level, and it is within this coastal belt that the submerged forest at Hightown is located.

The coastal group of peatlands is represented by Flea Moss Wood and Sniggery Wood. This main coastal belt of peat is *c*1 km wide and *c*2.5 km from north to south. Hightown marks the approximate north-east edge and the presence of a blue/grey clay which is marine in origin and represents the inundation of the area by estuarine or saltmarsh deposits (Huddart 1992). The southern boundary of the coastal peat deposits is marked by a gentle rise in the landscape onto the boulder clay starting at the northern outskirts of Great Crosby. These deposits cover a total area of *c*280 hectares. The depth of the peat deposits vary in depth from *c*3m at Flea Moss Wood to *c*1-0.3m around the eastern and northern margins, the average depth in the coastal region is *c*0.7m (Cowell and Innes 1994). A section through the coastal peats is presented in figure 6.3. The NWWS only managed to trace the peat intermittently across the area, as it was in the main part covered by *c*0.4-0.8m of blown sand from former dunes. The peats do extend into the intertidal area as noted by Travis (1926), Tooley (1977, 1978), Lewis (1982) and this work, near Hightown (SD29500295). Cowell and Innes (1994), suggest that the peat could continue under the dunes for another *c*0.5km to the west of the area surveyed by the NWWS.

6.7.3.2. Flea Moss Wood (SD311027)

A three metre core was recovered, analysed and reported by Cowell and Innes (1994). The altitude of the site was +4.09m OD. Peat formation began at Flea Moss Wood (FMW) at the very end of the Flandrian Chronozone I as a response to surface waterlogging caused by rising watertables which in turn was a response to rising sea-levels. This has been radiocarbon dated to occur at 6215-5960 Cal BC (7230 ± 70 BP) which is about 1500 radiocarbon years before peat initiation at Sniggery Wood at 4780-4510 Cal BC (5770 ± 50 BP). This is due to the lower altitude of the sub-peat land surface at FMW which is almost two metres lower (+ 1.09m OD) than at Sniggery Wood (+ 3.00m OD). At the initiation of peat formation the local woodland was dominated by *Pinus*, *Quercus* and Coryloid. This mixed *Quercus*/*Pinus* woodland was soon replaced by *Alnus* carr as the conditions became wetter, although at this time few wetland or aquatic pollen taxa were present suggesting that suitable aquatic habitats were not immediately available and again shows the gradual ecological changes between two types of vegetation. Aquatic habitats became more available as the site moved through early marsh and reedswamp phases to *Alnus* carr or swamp carr. Apart from the many aquatic habitats, the pollen assemblage also consisted of a rich wetland and shrub flora.

The *Alnus* dominated wetland conditions were widespread and the values of dry land pollen taxa were low. Much of the *Quercus* pollen was derived from oaks present in the drier areas of the fenwood communities or perhaps represent a more regional component of the pollen assemblage. The reduction of *Pinus* is linked to the spread of bog conditions although the higher sandy soils may still have had pine growing on them. The fall of pine is part of the long term edaphic changes which started at the end of Flandrain I and its continued replacement by alder during the wetter Flandrian II.

During the mid-Flandrian Chronozone II there was a replacement of the fen carr conditions with a more acidic bog component, this has been radiocarbon dated to 4939-4720 Cal BC (5920 ± 50 BP; SRR-2696). This replacement is marked by a decline in the value of aquatic pollen taxa such as *Nymphaea* and the presence of fibres of *Eriophorum* spp. occur in the stratigraphy, replacing the detrital peats in the lower profile (Cowell and Innes 1994). Towards the end of Flandrian II, the values of *Ulmus* declined and unfortunately, pollen preservation at 0.4m in the profile was very poor, although this horizon was dated to 3622-3340 Cal BC (4670 ± 50 BP;) it seems almost certain that that the *Ulmus* decline occurred at about 4000-3650 Cal BC regionally and therefore it can be postulated that the *Ulmus* decline is represented by these falling values at the depth of 0.3-0.5m in the profile (Cowell and Innes 1994).

The average sedimentation rate between the upper two radiocarbon dates is about 10mm every thirteen radiocarbon years (Cowell and Innes 1994). Above this level there is a replacement of the *Alnus* dominated communities by *Betula,* which reflects drier and perhaps a more acidic nature of the bog surface which could have contributed to the poor pollen preservation at the 0.4m level.

The presence of many dryland weed pollen types confirms these changes to a more open, drier environment. The upper counted pollen levels consisted of a well humified humus similar to a woodland floor and the pollen assemblage reflects the natural colonisation of the drier ground surface. A wide range of shrubs were present but the upper levels were dominated by *Acer* which according to Cowell and Innes (1994) reflects the natural succession through Flandrian III, although contamination of the humus in the upper layers by modern woodland floor deposits containing *Acer pseudoplantanus*, *Fagus sylvatica* and *Fraxinus excelsior* which may well have been planted cannot be ruled out.

Throughout the pollen profile at FMW, Cowell and Innes (1994) detected indications of human impact at a number of pollen levels. At 2.45-2.15m ruderal species are recorded but not in high frequencies. These include *Plantago lanceolata, Rumex, Artemisia,* Chenopodiaceae, *Melampyrum* and spores of *Pteridium.* This may indicate the creation of small clearances within the local woodland in drier parts of the area, although the dominance of tree taxa is little reduced therefore suggesting that any disturbance is limited in extent and duration.

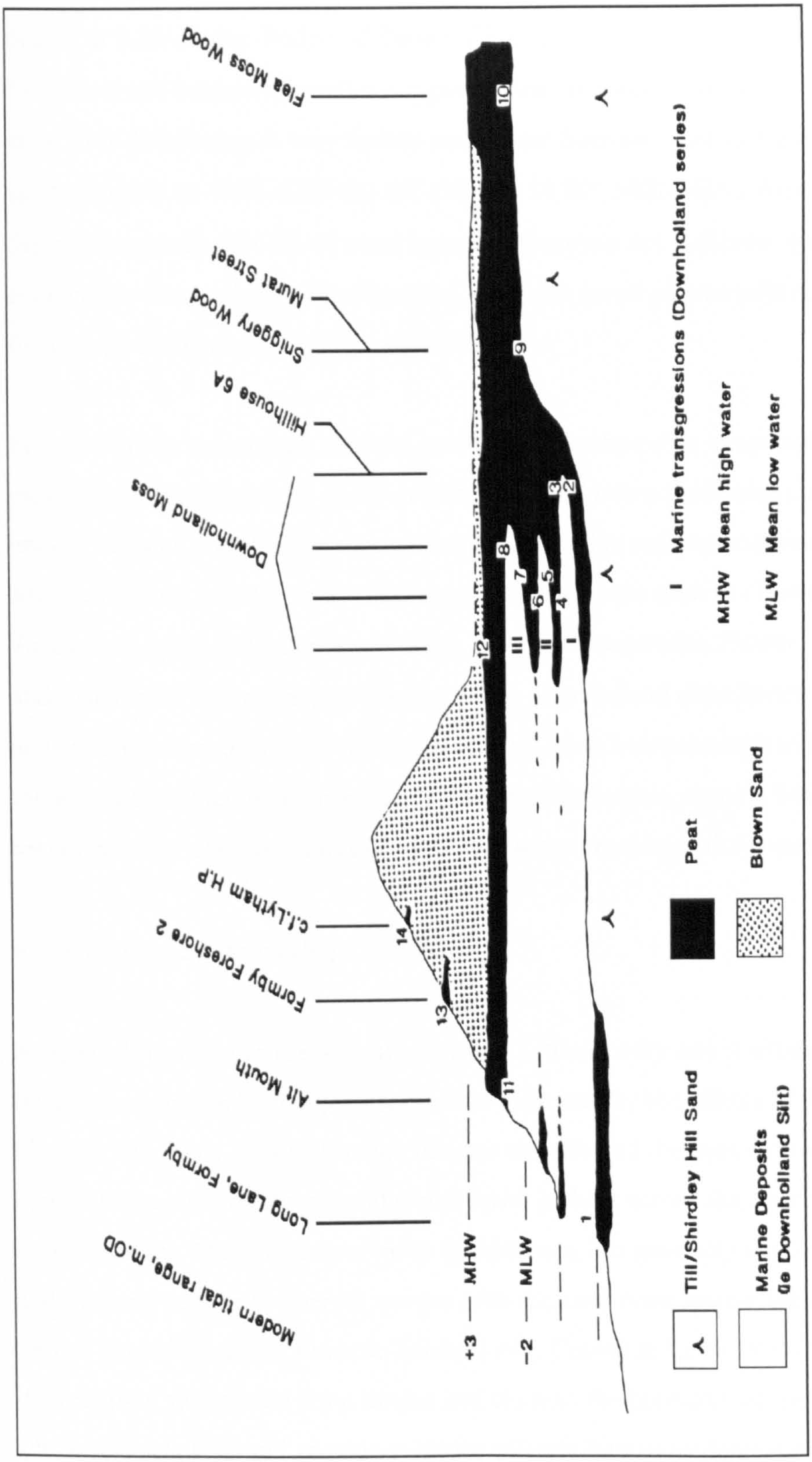


Figure 6.3. Section through the Sefton coastal peat, (from Cowell & Innes, 1994)

A second phase of disturbance which can be more surely attributed to human activity occurs at 1.35-1.15m. Pollen of *Rumex*, *Plantago lanceolata*, Chenopodiaceae, *Pteridium* and cereal-type pollen suggesting the creation of small clearings in the local area. This disturbance is very limited and of low frequency and is dated to approximately to 4939-4720 Cal BC (5920 ± 50 BP; SRR-2696). From 1.15-0.35m there are sporadic records of weed types but there are not sufficient quantities to form evidence to renewed woodland opening. The high levels of tree pollen suggests that the canopy in the main, remains undisturbed.

From 0.35m to the surface, there is considerable evidence for woodland disturbance, especially in the upper part of the profile. The total tree pollen values are temporarily heavily reduced and the presence of cereal-type pollen suggests cultivation near to the site. Associated with this is a wide range of dryland taxa such as *Centaurea nigra*, *Taraxacum*-type, *Polygonum aviculare*, *Plantago lanceolata*, *Rumex*, Brassicaceae and *Artemisia*. This represents a major phase of woodland disturbance for agricultural activity and is dated to 3622-3340 Cal BC at 0.28-0.36m permits it to be attributed to the activities of Neolithic farmers. At the end of this phase, there is limited regeneration of trees and shrubs but the landscape remains mainly open.

6.7.3.3. Sniggery Wood (SD307015)

Sniggery Wood lies to the seaward fringe of Little Crosby and is situated in arable fields, the stratigraphy has been somewhat truncated by the effects of drainage (Cowell and Innes 1994), although this has not affected the peat sediments as they are covered by a layer of blown sand which forms a sheet across the western part of the Sefton district. The sand cover varies in thickness, but generally attenuates landwards and thickens seawards where it merges with the sand dune system which fringes the Sefton coast (Pye 1990; Innes & Tooley 1993; Cowell & Innes 1994). The site due to its proximity to the sand dune fringes and close to the boundary of the Downholland silt (marine clay) should provide evidence of early human settlement and its relationship with coastal change. Reade (1908) during an excavation for the construction of an outfall sewer showed that the peats at Sniggery Wood are part of the same general sequence which outcrops on the beach at Altmouth near Hightown

(Reade 1872b; de Rance 1877), where pollen analysis has been undertaken previously (Travis 1926; Tooley 1977) and is the subject of analysis in this thesis. The depth of the profile was 1.74m.

Two radiocarbon determinations were carried out to mark the beginning and end of peat formation, which was from c4780-4510 Cal BC to c3370-3040 Cal BC which suggests that the *Ulmus* decline of the Flandrian II/III transition should be present with the pollen record and is recorded at 56cm and is dated to 3900 Cal BC by analogy to other dated Merseyside profiles (Innes & Tomlinson 1991; Cowell & Innes 1994). The record of *Ulmus* pollen at this site has the lowest frequency than at any other Merseyside site. Levels are probably lower here during the Flandrian II due to edaphic factors caused by the Shirdley Hill Sand soils.

Indications of woodland disturbance which may have been caused by human activity occur at intervals throughout the profile. There appears to be nine phases of forest clearance represented within the pollen profile. At 1.74-1.60m, there are few indicators of human activity, the open habitat taxa are probably present due to the proximity of coastal environments or to the naturally unstable sandy soils prior to stabilisation by rising water levels and peat formation. On the drier areas inland, *Quercus* dominated forest fringed with fringing *Alnus* fenwood was present. *Ulmus* appears to be a minor constituent of the forest with few understorey shrubs being present apart from Coryloid.

Above this level at 1.60-1.48m, there appears to be some limited clearance of the oak woodland with the *Quercus* and *Alnus* values being reduced. Ruderal herbs such as *Plantago lanceolata*, *Rumex*, *Taraxacum*-type and a high peak of *Senecio*-type are present. *Salix* and Coryloid values rise sharply at this level and *Calluna* appears for the first time. Tree taxa such as *Fraxinus* and *Prunus* suggest a more open woodland. A small peak of *Pteridium* spores helps to suggest a period of small openings in the woodland canopy.

From 1.48-1.12m, a phase of forest regeneration was detected by Cowell and Innes (1994), the previously recorded open taxa are absent, but the canopy may not have been completely closed as there is a slight indication of continued open conditions recorded by the occasional pollen of weeds and heliophyte shrub taxa, but these are not sufficient to suggest breaks in the forest cover.

Above this, up to 1.0m, a second phase of forest disturbance is noted with *Quercus* values declining and *Plantago lanceolata* returning. The increases in other taxa of disturbed ground along with increased *Pteridium* values there appears to be renewed creation of small clearings in the forest. From 1.0-0.72m, open *Quercus* and *Alnus* woodland dominates with little evidence for significant interference with the vegetation cover.

Above 0.72m to below 0.64m, several open habitat taxa are recorded. *Quercus* values fall sharply whilst Coryloid, *Salix* and *Calluna* increase. *Plantago lanceolata*, Chenopodiaceae, Caryophyllaceae and *Senecio*-type pollen all occur, along with another increase in *Pteridium* values, this appears to indicate a significant recession of woodland took place. From 0.64-0.56m, there is no evidence of pollen of clearance indicators and the tree values recover, the clearings from the previous forest disturbance phase have returned to mixed woodland and remains undisturbed.

At 0.56-0.32m, evidence for extensive clearance is present which begins with the *Ulmus* decline (3900 Cal BC). Tree pollen frequencies are sharply reduced being replaced by ruderals with high values, the percentage of *Pteridium* increases and there is a continuous *Plantago lanceolata* curve, suggesting the creation of open grassy land. *Rumex* exhibits a major peak with *Senecio*-type and *Artemisia* being present in quantity. Chenopodiaceae and Brassicaceae are also present. The high and sustained levels of *Melampyrum* suggests that there is some fire disturbance of the woodland.

From 0.32-0.10m a regeneration of woodland with a high proportion of dryland tree pollen taxa, although there is a continual presence of dryland herb pollen with significant frequencies of *Fraxinus*, *Fagus*, *Acer* and Coryloid suggesting a more open woodland which is probably due to the effects of long term ecological change rather than renewed clearance.

At this point there is a possibility of confusion between the effects of human activity with those of vegetation instability induced by the movement of blown sand across the area around 3200 Cal BC. The higher herb and bracken values along with the high *Calluna*, *Pinus* and Coryloid values are more likely to be attributable to natural blown sand fringe environments rather than human activity.

In conclusion, it can be seen that the palaeoecological evidence suggests that the dominant factor controlling the vegetation changes within the area are changing groundwater levels which are governed by changes in sea-levels. The main vegetation recorded by the mosslands in both the north Wirral and Sefton coastal area is that of *Alnus* carr and reedswamp communities, with *Quercus* dominated woodland on the drier areas. The palaeoecological evidence appears to be at odds with the archaeological evidence (see section 6.8) concerning human activity. The pollen evidence suggests that the human impact on the vegetation is limited both in extent and duration, whilst the archaeological evidence suggests that some of these habitats could have been exploited by past human cultures. The possible reason for this discrepancy may be the fact that the majority of the sites sampled for palaeoecological evidence are situated in areas where access to human populations may have been restricted by the swampy and boggy conditions. Human activity may well have been restricted to the more drier areas and therefore not be represented within the local pollen component of the pollen assemblages and was limited to small-scale clearances in the dense alder carr and oak woodlands surrounding the sites.

6.8. The Archaeological Record of the Wirral and Sefton Mosses

Prior to the North West Wetlands Survey (Cowell and Innes, 1994),of the area of Merseyside, the archaeological evidence was very sparse for both the Wirral and Sefton areas of Merseyside. In general the majority of finds were accidental and in many cases were found when building work or erosion had exposed them. In the Wirral, some of the more important archaeological finds of the nineteenth century were recovered by antiquarians such as Hume, Potter and Ecroyd Smith (1863, 1876

& 1865 respectively). The artefacts spanned many archaeological phases, with material being collected from settlements of prehistoric hunters and early farmers from places such as New Brighton and Hoylake. Medieval metalwork and pottery were often recovered from the sand dunes which border the coast. Most of the material from both prehistoric and historic phases was divorced from the associated deposits leaving the collections without any provenance. Very little systematic fieldwalking was carried out in the area until that of Cowell (1991) which concentrated on the western fringes of the large central mossland complex, where a number of flint sites had been identified. This work has been complemented by the field surveys carried out under the auspices of the North West Wetlands Survey (Cowell and Innes, 1994).

6.8.1. Location and nature of the archaeological evidence

Apart from the area of flint sites identified by Cowell in the early 1990's (Cowell, 1991), the main locations for sites, which are mainly represented by small scatters of flint and other lithic material were identified in the following topological locations:

a) River valleys flowing through the sand areas to the west of the central mosses and across the boulder clay plain in the south, particularly near their confluences with the Mersey.

b) On the sandstone ridges of the North Wirral.

Artefacts from all archaeological periods from prehistory to recent have been identified from the Merseyside area. In this brief summary of the archaeological evidence the periods up to and slightly younger than the date of the upper submerged forest beds recorded on the Wirral and Sefton Coasts are dealt with here. Although the intertidal deposits in the Wirral and Sefton area were not surveyed by the NWWS, the peat areas in the coastal area behind the coast were surveyed and a brief summary of that work is presented here. In many cases it has been difficult to place the flint and other lithic materials in a precise chronological framework, due to the lack of excavated, well stratified archaeological sites in this area. A Gazetteer containing and describing all finds from sites recorded prior to the North West Wetlands Survey as well as those sites and artefact discovered via this survey can be found in Cowell and Innes (1994, Appendix 1; 219-236).

6.8.1.1. The Early Mesolithic *c*8000-6800 Cal BC

Flintwork scatters occur throughout the Wirral but are scarce but flintwork from the 8th /early 7th Millennium Cal BC has been recovered from land surfaces now submerged due to sea erosion. At New Brighton a chronologically mixed flint assemblage was recorded.

Prior to the NWWS there was very little archaeological interest in the Sefton coastal belt, with very few chance or casual finds being made. The evidence for the early Mesolithic in the Sefton area is very limited and tentative. A single struck flint piece on the north edge of Woodham Knoll, Little Crosby is thought to be Palaeolithic. The early Mesolithic material in this area is very difficult to distinguish from later material. At Lunt in the Alt Valley, chert artefacts associated with a blade assemblage was identified and thought to be early Mesolithic in date. A flint scatter over an area of approximately 120m x 80m on the north edge of the sand ridge at Flea Moss Wood, Little Crosby was thought to be late Mesolithic in date. The scatter was found close to the river channel suggesting the possibility of exploitation of the riparian landscape, apart from this there is little evidence for early Mesolithic exploitation of the area.

6.8.1.2. Later Mesolithic/earliest Neolithic *c*6800-4000 Cal BC

The archaeological evidence for the late 7th Millennium is sparse due to the built up nature of the Wirral. Sefton has the richest evidence in Merseyside for the later Mesolithic and earliest Neolithic, although most of the flintwork is attributed to the Mesolithic. The lack of excavated sites of this date in Merseyside has meant that it has not been possible to identify the introduction of Neolithic culture into the area as there is no chronological control for the dating of the flint assemblages. During the 6th Millennium Cal BC the flint material in Sefton is restricted to small clusters of material which is concentrated in two main areas. The first is around the northern edge of Woodham Knoll ridge, Little Crosby. The majority of the material is concentrated on the brow of the ridge and on its eastern slopes, whilst material dated to this period is more scattered on the western slopes overlooking the coastal plain. The second area of artefact concentration is in the Alt Valley where struck flint concentrations can be found on the floodplain and on the lower part of the western terrace slopes. Between these two areas there is very little in the way of archaeological material as it is assumed that most sites are buried beneath the peat deposits.

Most of the sites in these areas consists of five to thirty-five pieces of struck flint, whilst single find sites occur along the 4m OD contour of the Alt Valley. The raw material in the late Mesolithic consisted of light grey or blue/grey patinated flint and is thought to have originated from the coastal margins which was acquired during the 6th and 5th Millennium Cal BC. One site on the Little Crosby ridge consisted of four cores which is thought to represent several reoccupations of the area rather than a more intensely settled locus (Cowell and Innes, 1994). On the Alt floodplain, a similar size flint assemblage to that found at Little Crosby consisted of cores, flakes and blades as well as primary knapping debris and flint pebbles many of which are less than 30mm in diameter. According to Cowell and Innes (1994), this implies that the assemblage may form the basis of toolkits and therefore the site may represent an 'industrial' area, whereby the material was collected, roughly prepared and the waste was left behind.

Other types of Mesolithic sites are more restricted in area and are more complex flint assemblages. Nine sites were located on small sand islands in the peat on the floodplain. The assemblages are small and possess a blade element suggesting small specialist camps or similar in function to the larger site at Lunt. Single find spots are common on the Alt Valley ridge, although it is thought that most of the sites are mostly likely to be covered by alluvial clays and peats (Cowell and Innes, 1994).

6.8.1.3. Earlier Neolithic *c*4000-3200 Cal BC

Again, archaeological evidence for the earlier Neolithic in the Wirral is sparse, with a few spot finds of hand axes being made. There is very little settlement evidence apart from the scattered artefact finds. In the north west of the peninsula the archaeological evidence is slight and consists entirely of previously recorded chance finds of leaf arrowheads.

In Sefton, the early Neolithic material is difficult to identify. It is presumed that leaf arrowheads and stone axes characteristic to this period were introduced into this area as no local pottery dating to this period has been recovered. The Neolithic sites are identified by flint scatters but they are difficult to date due to the small size of the assemblages and the lack of locally excavated sites with which the surface material can be compared. Two stone axes dated to the early Neolithic were recorded from the intertidal zone to the south-west of Hightown. Other artefacts from this period consisting of about fifty pieces are of varied raw materials including patinated beach pebbles and boulder clay flint. On Little Crosby ridge an axe roughout has been recorded from the brow of the ridge. Other common finds consist of split pebbles, primary blades and flakes. The material is difficult to date but is regarded as belonging to this period as the technology is different from that of the Mesolithic and is not part of the late Neolithic/early Bronze Age material in the area.

6.8.1.4. Late Neolithic/early Bronze Age *c*3500-1650 Cal BC

The evidence for late Neolithic settlement in the Wirral is also scant with finds of a Neolithic pot on the beach at Meols and a single discoid core at Newton Carr Basin. On Hilbre Island finds of oblique arrowheads have been recorded. In the early Bronze Age the archaeological evidence is more substantial with barbed and tanged arrowheads being recovered from the peat beds at Dove Point as well as on the west Kirby ridge, Hilbre Island and New Brighton. A series of unurned cremations were also discovered south west of Newton Carr on the sandstone ridge whilst a stone hammer was recovered from the east Birket channel west of Bidston Moss. North-west of Bidston Moss a bone midden containing the remains of red deer and oxen was recorded and dated to c2861-2310 Cal BC (3980± 70 BP; Birm-1013).

Certain classes of flintwork recovered from the Sefton area is attributed to this period although it is still difficult to use a finer chronological resolution due to the lack of excavated sites. At Woodham Knoll, five small to medium cores of flintwork including implements and large flakes possibly indicative of on-site happening were found and dated to the late Neolithic/early Bronze Age, although it has been difficult to assign the assemblage to the late Neolithic or early Bronze Age, but they due date before the third Millennium Cal BC. Finds of this period is more restricted in the Sefton area, none have been found in the Alt Valley and only single finds from Orrell Hill. At the south-east end of the channel at Woodham Knoll, burnt flint find spots and sites have been found, these have been difficult to date as no late Neolithic/early Bronze Age flintwork is associated with these sites.

The lack of sites around Orrell Hill implies that the Little Crosby ridge is in a more favourable situation for human activity at this time. The small, reasonably tight concentrations of material suggests repeated visits to sites rather than one contemporary settlement as there is no evidence of flint knapping.

6.8.1.5. Later Prehistoric Period *c*1650 Cal BC-AD 43

Little evidence for this period is forthcoming from the Wirral, and it mainly consists of later Bronze Age metalwork such as the find of a socketed axe on Hilbre Island and a mid-Bronze Age dirk was found on the beach. On the sandstone outcrop at Wallasey, Cowell (1991) recorded a thin scatter of Bronze Age metalwork. The nineteenth century collections made in the area consist of a rich assemblage of artefacts which unfortunately in most cases are unprovenanced. Included in this assemblage are several first century BC coins along with some more recent Medieval ones. The presence of an Iron Age settlement at Dove Point is uncertain as very little dated Iron Age material has been recovered from this area.

In Sefton, there is a recurring type of site assigned to this period although dating is tentative as excavated parallels are lacking. The sites consist of small flint assemblages of two-five pieces which lack formal knapping characteristics. The artefacts are generally of small irregular natural pebbles and pebble fragments and in some cases struck waste chunks which have been retouched to produce a serviceable edge to form scrapers or cutting tools. A whole range of pebble types have been used to produce these artefacts. Again, Woodham Knoll, Little Crosby is the main location of these sites, fewer examples can be found Orrell Hill, very few sites were located on the slopes of the Alt terrace or the floodplain overlying the upper peat.

Thin scatters of burnt flint nodules were occasionally found in the general area of the floodplain. These have been difficult to date and have often been assigned to the Bronze Age or a later Prehistoric date. The human activity in this area during this later prehistoric period is wide ranging and less structured (Cowell and Innes, 1994). It has been difficult to decide if the artefacts associated with this period are chronologically distinct from earlier material, although the deterioration of flint knapping techniques in this later prehistoric period has been associated with a more marginal landuse in the area, (Cowell and Innes, 1994).

6.8.1.6. Conclusions

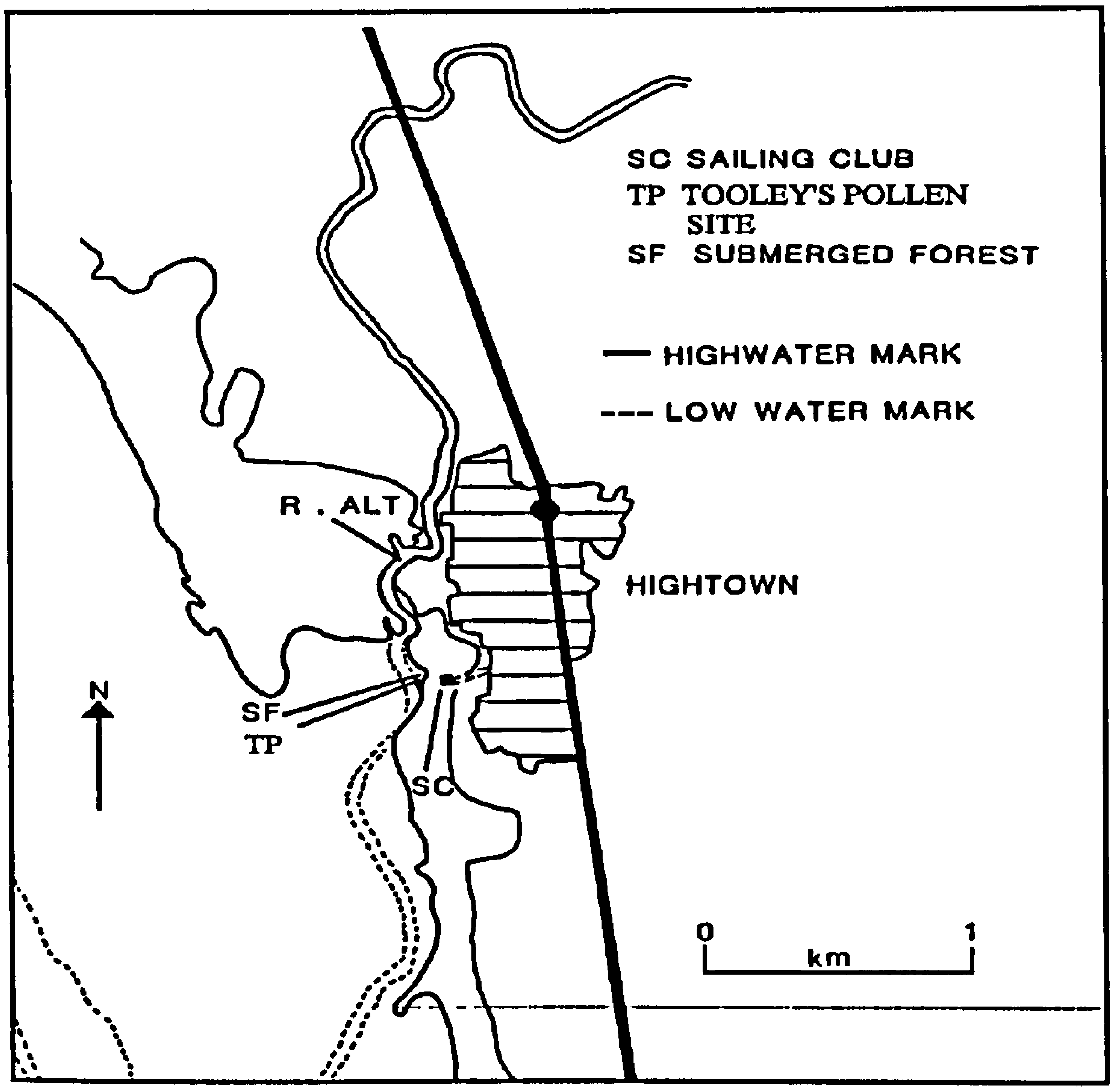
In conclusion it can be seen that in both areas the archaeological evidence for human activity from early Mesolithic to the later Prehistoric period is restricted and is limited in many cases to small flint scatters. Dating of these sites has been complicated by the lack of excavated sites of the relevant periods in the area. The sparcity of evidence for human activity in this area may in fact be related to the environmental conditions present in the area which are outlined in the previous section 6.7.

6.9. New Palaeoecological investigations of the Submerged Forest exposure at Hightown, South Lancashire

6.9.1 Introduction

The largest exposure of the submerged forest at Hightown, is situated between the Sailing Club and the course of the River Alt (Grid reference SD29500295) (map 6.2) and covers an area of approximately, 70 metres by 150 metres. The most densely populated expanse of the exposure covered an area of approximately 60m x 45m and was mapped for this study in August 1994. The Alt river is constantly changing its course (Travis, 1920) and has cut into the submerged forest deposits which occur along its landward (east) bank. This erosion and undercutting has lead to large chunks of the deposits being dislodged providing a cliff of about 1.5m. This cliff reveals a complete section of the submerged forest and underlying deposits. The most noticeable feature of this section is that the stumps present in the forest beds appear to be rooted in the underlying blue clay as noted by Travis and others, (Travis, 1926). The peat bed lies at an altitude of +3.4m O.D., (Tooley, 1977).

The samples taken for plant macrofossil analysis consisted of two types. A vertical monolith (50x10x10cm) was taken through the main stratigraphical units of the exposure, this was taken to help establish the development of the submerged forest through time. During the mapping of the distribution of the tree stumps and trunks, a variation in the surface of the forest bed was noted, near to the sand dunes (landward) the surface appeared to consist of small twigs and other fibrous plant material most likely monocotyledonous stems and root whilst further seaward (closer to the course of the River Alt) the surface appeared to be comprised of networks of *Osmunda regalis* rhizomes (see plates 6.1 & 6.2). In order to assess the variation across the exposure, a horizontal monolith of similar dimensions to the vertical section was taken from each of the different areas. In order to identify any variation between the upper and lower levels of each of these monoliths, they were divided into top and bottom samples and the plant macrofossil assemblage of each sample was compared. In the case of one a third, middle sample was taken. In both cases when sub-sampled the monoliths comprised of laminations which formed natural boundaries. Although in the case of the sample from the area of *Osmunda* rhizomes the rhizomes appeared to penetrate from the top to the bottom of the sample. Sampling of the vertical section followed the stratigraphical units, in order to detect any subtle changes through these units they were subsampled.



Map 6.2. Map showing the location of the submerged forest at Hightown

6.9.2. The trees of the submerged forest

A total of two hundred and ninety-eight stumps and trunks were recorded as described in chapter four and can be seen as a plan in figure 6.4. In all cases the stumps were reduced to the level of the peat surrounding them, a wide variety of diameters were present ranging from 0.05-1.87m and trunk lengths were in the range from 0.33-6.5m.(See Appendix I, table I.3 a-e). As with Travis, the stump and trunk remains varied in their appearance. Due to the poor condition of some of the trunks, it determine that they were trunks by the presence of attached roots. It was also evident that many of the trunks had at one stage been of larger proportions but due to erosion had been reduced in size. The remains of most of the trees were badly preserved preventing in many cases the sampling of wood for species determination. It was noticeable that a lot of the stumps and trunks could be identified as birch by the presence of many fragments of the characteristic bark within the deposit, therefore it can be assumed that the majority of the tree remains were of this species. As Travis (1926) had recorded, a high proportion of the tree remains were compressed which is most likely due to the pressure of the overlying sand which now forms the dunes behind the submerged forest, although the harder woods, such as oak appear not to be deformed.

Of the tree remains which were preserved well enough to allow identification from cell patterns, seven stumps were of willow/poplar (Salicaceae) and one of oak (*Quercus* sp.). The general appearance of each wood sample can be seen in table 6.4, with the identification of the stumps it can be suggested that, the larger diameter stumps are not of birch but are most likely to be of either willow or oak. From wood identifications alone it is not possible to determine which species of willow is represented, although the macrofossils identified by Travis (table 6.3) suggests that they could be either *Salix aurita* or *S. cinerea*, but other species should not be ruled out as these two species are nowadays recorded as shrubs rather than trees, although *Salix cinerea* can be found as a small tree.

In July 1999, a further visit to the exposure was made. A further ten samples, four *Betula* sp., three *Quercus* sp., two *Alnus* sp. and one *Corylus* sp. were identified. These are also described in table 6.4. It must be noted that on this visit it was apparent that some erosion had occurred since August 1994. The deposit had been reduced in size by approximately 30 percent. This made the task of increasing the number of species of trees identified from the site more difficult. It was also observed that the majority of the remaining area was covered by a 1-2 centimetre thick layer of silty clay, obscuring many of the stumps previously recorded.

Clearly, the reconstruction of the submerged forest exposed at Hightown relies on the assumption that all of the exposed stumps are contemporary. Whether or not this is the case can only be determined by extensive cross-matching of the tree-rings of the stumps. This has not been possible at Hightown due to the fact that most of the stumps are too decomposed to permit this analysis. However the general position of the stumps in the field suggest that they are contemporary.

Figure 6.4 show the overall distribution of the stump diameter groups of the 298 stumps and trunks recorded in the survey area at Hightown, near the Alt Mouth. There is no apparent pattern in the distribution of the groupings. Small clumps of four or five trees can be seen, which may represent the replacement of a fallen larger tree, some of the larger diameter trunks appear to be associated with smaller diameter stumps which may represent competition between individuals, whereby only one of the clump of saplings is capable of filling the gap in the canopy and therefore restricting the growth of the others. Unfortunately, due to the preservation conditions at Hightown, the determination of whether the larger stumps are of the same date and species as the smaller ones was not possible.

The measurement of the diameter of tree trunks is a standard method for estimating the age of modern trees, this is usually measured at breast height, (Peterken, 1993). Since none of the trees in the submerged forest survive to breast height, the diameter of the stumps has been taken to represent the relative ages of the trees. Data from the measurement of modern trees has shown that there is a correlation between diameter at ground level with diameter at breast height (Wilkinson, *pers. com.*) and therefore can be used to age the trees. The actual age of each stump cannot be determined via this method as growth rate (and therefore increase in diameter) is controlled by many factors such as climate, soil, and nutrient conditions, as well as the level of the watertable. These factors can vary greatly over the lifetime of the tree and therefore directly influence the amount of annual growth. This method can only provide a relative age structure of the submerged forest which is considered sufficient for this study.

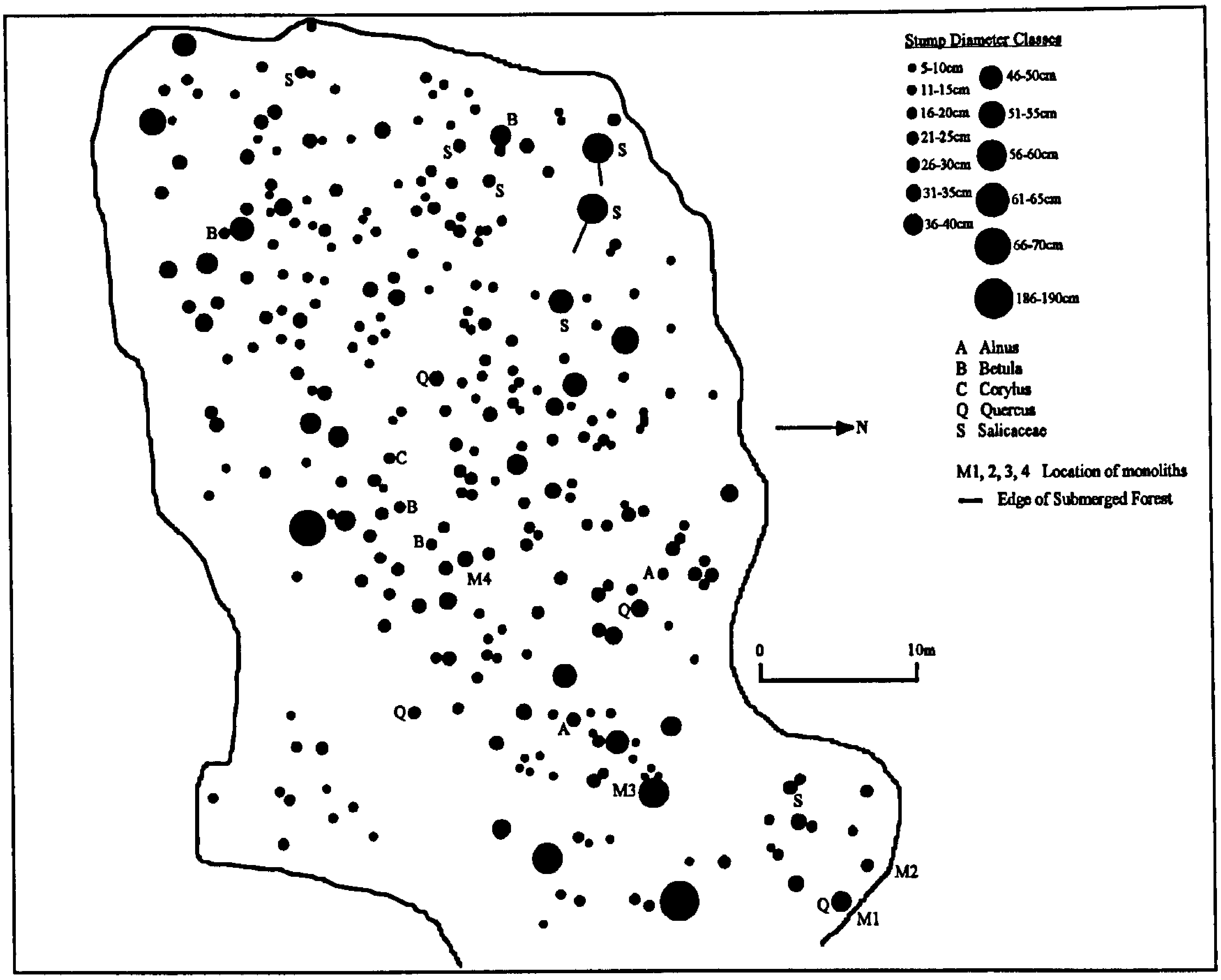


Figure 6.4. Overall plan of the distribution of stump diameter classes of the submerged forest at Hightown. The northern and southern edges are defined by 1m cliffs produced by erosion. The western edge is marked by the channel of the River Alt and the eastern edge by modern sand dunes.

In figure 6.5, it can be seen that the 5-10cm, 11-15cm and 16-20cm diameter groups appear to dominate the distribution, with numbers decreasing with the increase in stump diameter, which when the diameters are translated into relative ages, the submerged forest at Hightown appears to be dominated by young trees, with some middle aged ones and few mature trees which are widely distributed.

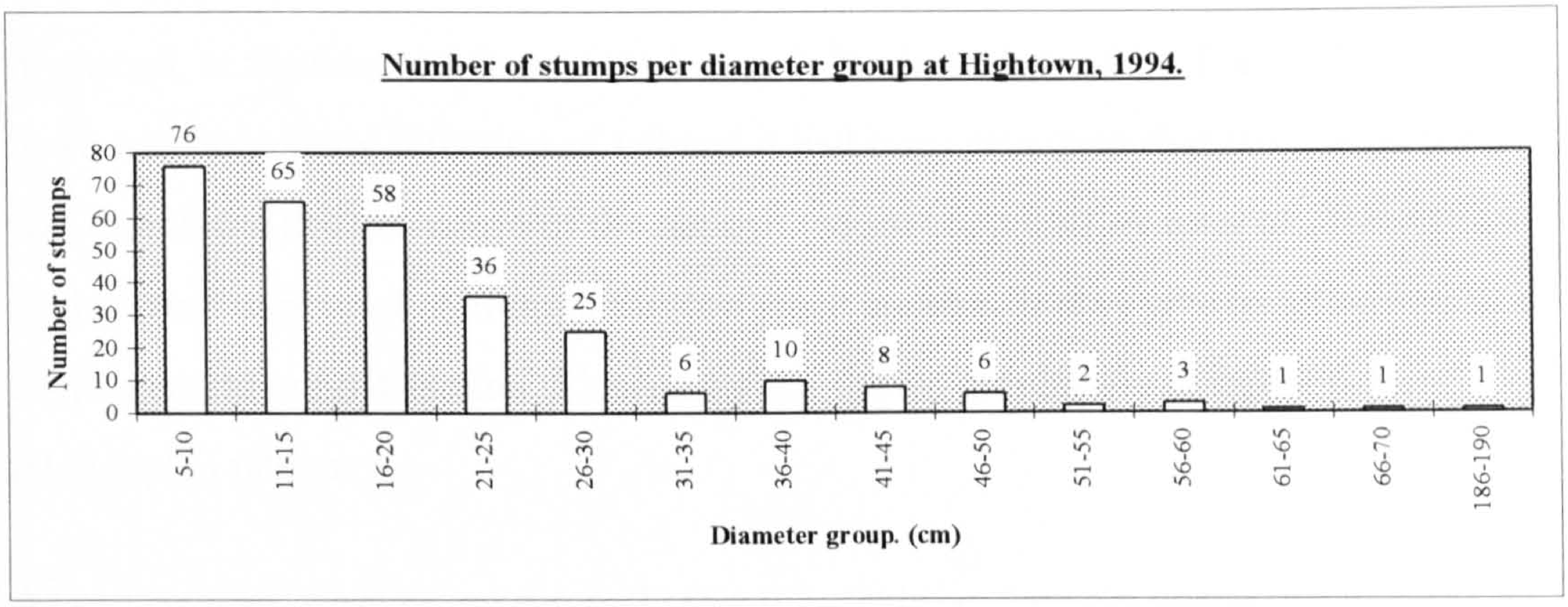


Figure 6.5. Chart showing the distribution of the number of stumps per diameter group at Hightown

Stump Number	Identification	Diameter (cm)	General description
64	Salicaceae	46	Red/brown heartwood, very hard to section
72a	Salicaceae	56	Red/brown heartwood, very hard to section
72b	Salicaceae	56	Red/brown heartwood but very compressed but has general appearance of Salicaceae
119	*Quercus* sp.	43	Very black & very hard
122	Salicaceae	28	Red/brown heartwood, very hard to section
235	Salicaceae	25	Very compressed & has lost most of features but has general appearance of Salicaceae
238	Salicaceae	24	Very compressed & has lost most of features but has general appearance of Salicaceae
270	Salicaceae	23	Red/brown heartwood, very hard to section
3*	*Quercus* sp.	40	Very black & very hard
13*	*Alnus* sp.	20	Not compressed, red/brown heartwood
74*	*Alnus* sp.	38	Slightly compressed, red/brown heartwood
127*	*Quercus* sp.	28	Very black & very hard
143*	*Betula* sp.	16	Bark sample
159*	*Betula* sp.	20	Very compressed
165*	*Corylus* sp.	18	Well preserved
188*	*Quercus* sp.	30	Very black & very hard
237*	*Betula* sp.	45	Very compressed
265*	*Betula* sp.	19	Very compressed

Table 6.4. General description of wood samples taken for microscopic identification (* those identified in July 1999, by Dr. J. Hather)

6.9.3. Windthrow of the trunks

As part of the mapping of the stumps and trunks of the exposure of the submerged forest at Hightown, the angle of fall of the trunks was measured and recorded. This measurement may be able to give an indication of the general wind direction especially of storms, at the time the forest was living. It has been argued by Travis (1926) that there was no general direction of fall and it had been proposed that the reason for this was due to the drifted nature of the deposit (see section 6.4). A total of fifteen trunk angles were measured. Although this is a small number, it may give us some indication of the general wind direction. The results are shown graphically in figure 6.6 and tabulated in table 6.5.

As can be seen, from figure 6.6 and table 6.5, that the majority of the trunks lie at an angle between east-north-east and south with a few lying outside this range towards the north-east and south-south-west. The fallen trunks were not restricted to any diameter group as can be seen from table 6.5, although none of the lowest stump diameter groups were recorded as fallen trunks. This suggests that the prevailing wind direction, at least winds strong enough to blow over the trees was from the north-west. It is impossible to determine whether the trees were blown over when they were alive or when the encroaching sea-level had began to have an effect on the woodland and weaken the trees, or if they had been blown over post-death.

From the plant macroremains recovered from the peat surrounding the trunks there was no indication of any maritime influence, and as the trees present in this exposure are often associated with areas of high watertables it can be suggested that the angle of fall of the trunks represented previous prevailing wind directions conditions while the woodland was extant.

The overall picture from the mapping of the tree stumps and trunks exposed at Hightown is of a forest which consists mainly of small diameter birch trees, identified by the presence of the characteristic bark, with few large diameter trees, although the majority of the larger stumps identified were in fact of willow, with only one being of oak.

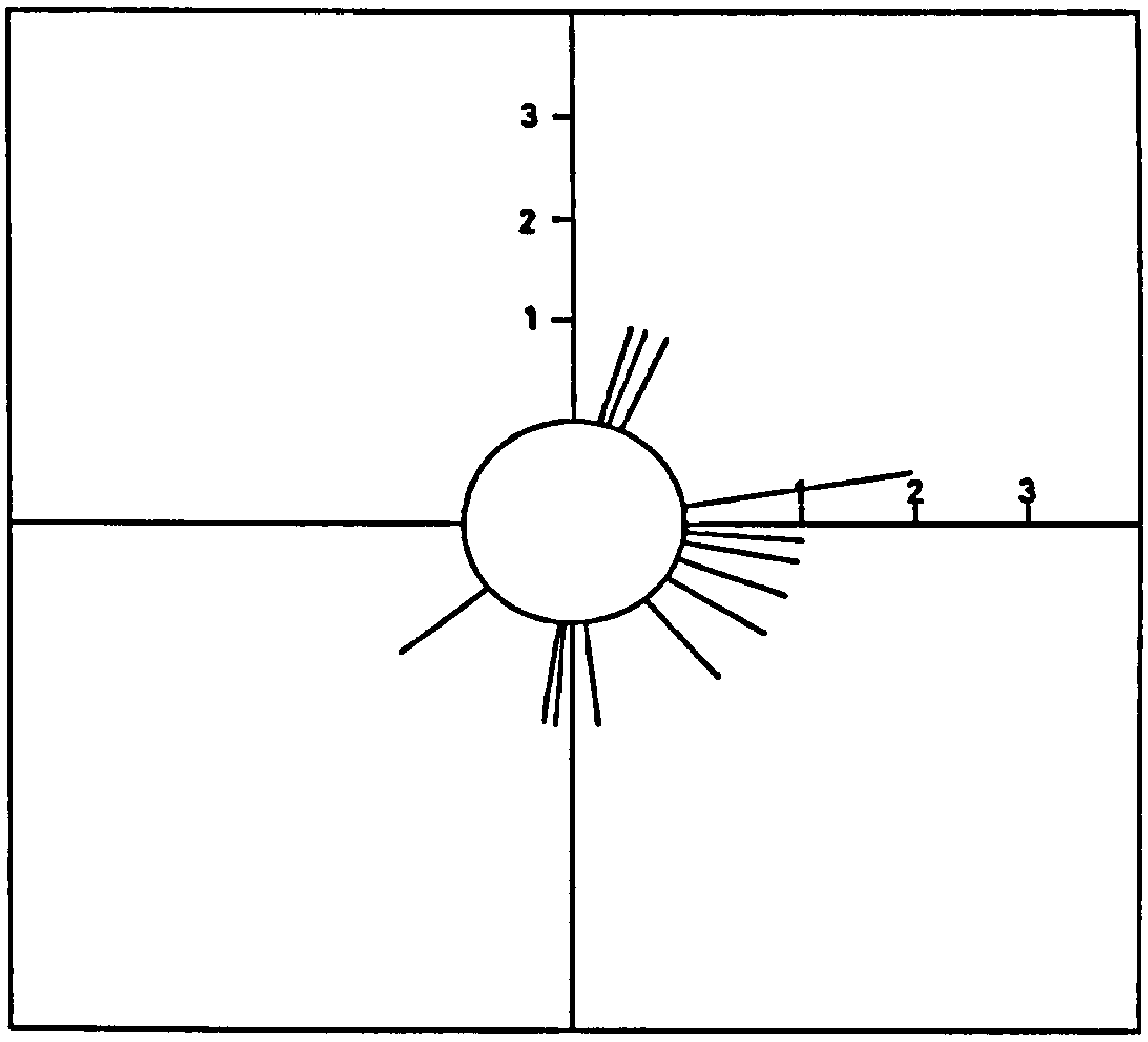


Figure 6.6. Diagram showing the orientation of the windthrown trunks at Hightown

Stump	Diameter	Trunk length	Angle °N	Species
3	40	196	90	*Quercus* sp.
14	30	96	230	
15	17	63	15	
17	28	270	180	
25	20	96	100	
27	36	136	80	
32	31	97	80	
72a	56	245	94	Salicaceae
72b	56	328	122	Salicaceae
77	32	65	19	
86	48	340	187	
115	20	243	173	
119	43	650		*Quercus* sp.
122	28	170	149	Salicaceae
163	24	33	120	
235	25	100	185	Salicaceae
254	50	144		
270	23	127	24	Salicaceae

Table 6.5. Table showing the diameter, length and angle of fall of trunks recorded at Hightown

The angle of fall shows that the majority of the trunks lie between east-south-east and south, which does not agree with the findings of Travis (1926) who recorded that most of the stumps although not showing a main direction of fall, all lay between north-east and north-west.

6.9.4. Plant Macrofossil Studies

As previously mentioned a total of three monoliths were analysed for plant macrofossil content in order to determine further characteristics of the submerged forest. A vertical monolith covering a depth of 27cm and two horizontal monoliths taken from two areas of the exposure, in order to determine spatial differences across the deposit. Monolith three was taken from the deposit landward and consisted mainly of woody remains (see plate 6.1), whilst monolith four was taken from the area of the exposure containing traces of *Osmunda regalis* rhizomes (plate 6.2).

6.9.4.1. The Vertical Profile - Monolith Two

Six samples were taken from a 27cm vertical section of the submerged forest and underlying clay deposits the profile can be seen in figure 6.7. Three major zones were identified and sampling was governed by this zonation with each zone being divided into a top and bottom subsample.

The bottom sample (18-27cm) was not analysed due to time constraints, the other samples were all analysed and 400cm^3 was processed from each except the topmost sample (5-0cm) of which only 300cm^3 was available.

Plate 6.1. Photograph showing the twiggy area to landward at Hightown

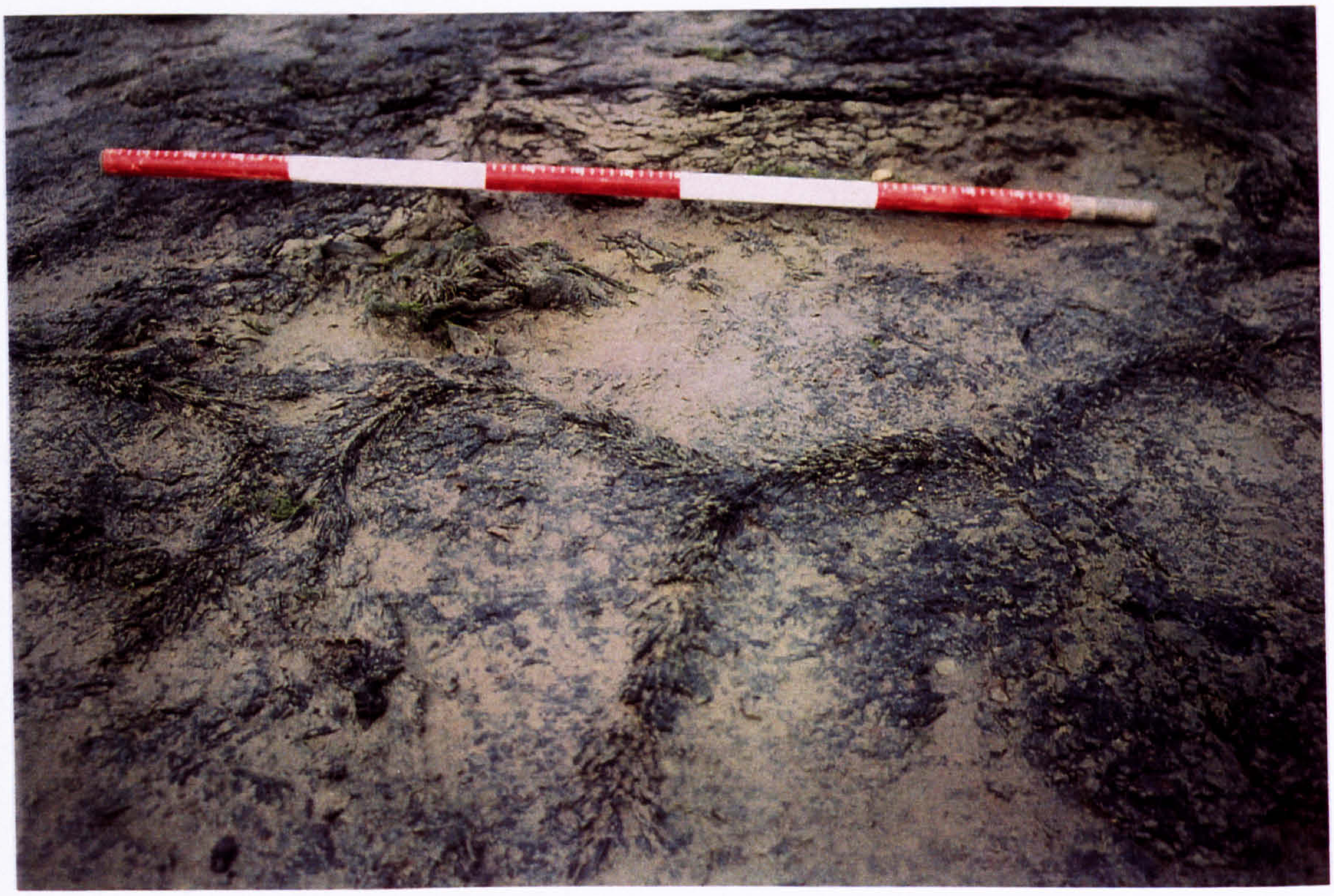


Plate 6.2. Photograph showing the area of *Osmunda regalis* rhizomes to seaward at Hightown

The three horizons are described as follows;

0-10cm below surface	Fibrous compact peat with a fine texture, dark brown in colour, uniform throughout with wood and bark which is mainly of birch present. Monocotyledonous roots and stems were present in great quantities. Sample 6: 0-5cm; Sample 5: 5-10cm.
10-18cm below surface	A looser fibrous peat with large fragments of wood and twigs present. *Phragmites australis* rhizomes present, dark brown in colour. Sample 4; 10-14cm; Sample 3: 14-18cm.
18-27cm below surface	A brown/black/grey spotted clay containing fragments of wood, twigs and *Phragmites australis* rhizomes, very silty in nature. Sample 2: 18-22.5cm Sample 1: 22.5.27cm.

The results of the analyses can be seen in table 6.6 and figure 6.8. In general the plant macrofossil remains were few in number both in terms of taxa and finds and were poorly preserved.

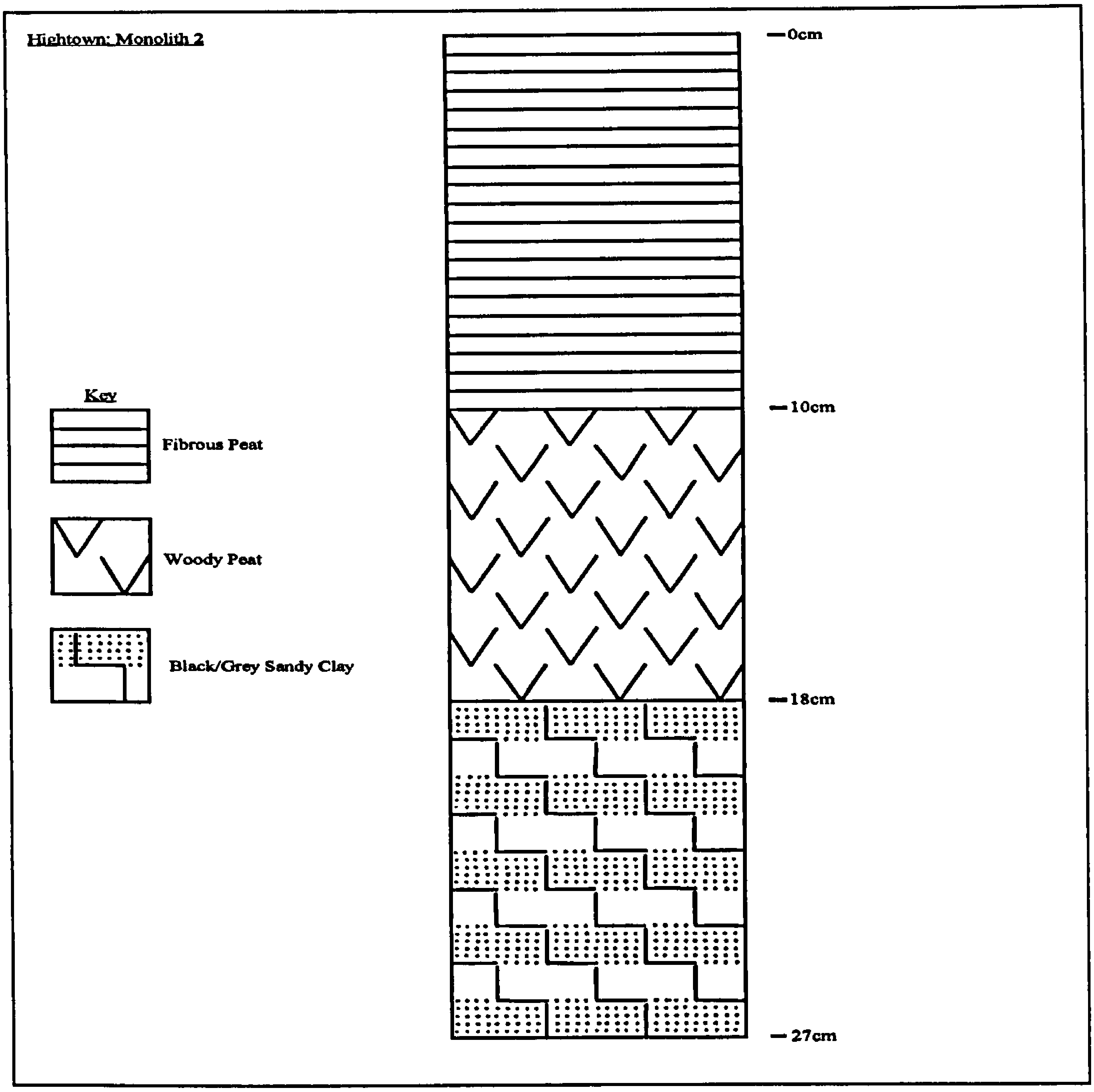


Figure 6.7. Schematic profile of the vertical section at Hightown

In the sample at 18-22.5cm, the lowest sample in the profile to be analysed, taken from the upper part of the brown/black/grey spotted clay, the dominant plant taxa were *Juncus* spp. of which two of the seeds were charred followed by *Carex* spp. with *Phragmites australis* rhizomes being common. These species are representative of a waterside/margin environment where the watertable is relatively higher. A scrub/woodland was represented by single finds of *Rubus fruticosus* and *Solanum dulcamara*. A single find of *Apium nodiflorum* is indicative of aquatic conditions. A more open/disturbed habitat is perhaps represented by *Chenopodium* sp. along with the caryopses of Poaceae. Apart from the common finds of twigs and wood fragments the other more abundant remains are those of charcoal fragments less than 0.3mm in length and worm cocoons.

Sample	6	5	4	3	2	1
Depth	0-5cm	5-10cm	10-14cm	14-18cm	18-22.5cm	22.5-27cm
Original Volume (cm3)	300	400	400	400	400	400
Species						
Shrubs						
Frangula alnus				1f		
Waterside/margin						
Hydrocotyle vulgaris			1			
Mentha sp.				7		
Juncus sp. seeds			1	3	181+2charred	
Isolepis setacea						125
Carex sp. lentic	12	24	22+4f	41+5f	24+1charred	10+1f
Carex sp. trig		1	2	1		
Phragmites australis rhizomes	common		rare	rare	common	common
Scrub/woodland						
Rubus fruticosus	2	4+1f	1	2+21f	1	
Solanum dulcamarra			1		1f	
Aquatic						
Apium nodiflorum					1	
Alisma sp.			1			
Potamogeton coloratus			2+1f			
Open/disturbed						
Chenopodium sp.					6	1
Atriplex patula						1
Stellaria media						1
Coastal grassland						
? Linum bienne				2		
Poaceae	2			5	6(small)	8(small)
Miscellaneous						
Charcoal	5f		1f	9f	57f	100f
Buds, bud scales, leaf fragments			1bscale+1leaf f	4buds+1leaf f		
Leaf abscission plates	2		1	7		
?			1	3		2
Monocot stems/roots	common	abundant	rare			
Twigs & wood fragments	common	common	common	common	v. common	v. common
Cladoceran eggs			14	7		
Worm cocoons	8	16	22	36	35	90
Fungal sclerotia	1000's	100's	345	2	1	
Insect remains	common	common	common	common		
Modern marine molluscs	3					

Table 6.6. Table showing the plant macrofossil data from the vertical section, Monolith Two at Hightown

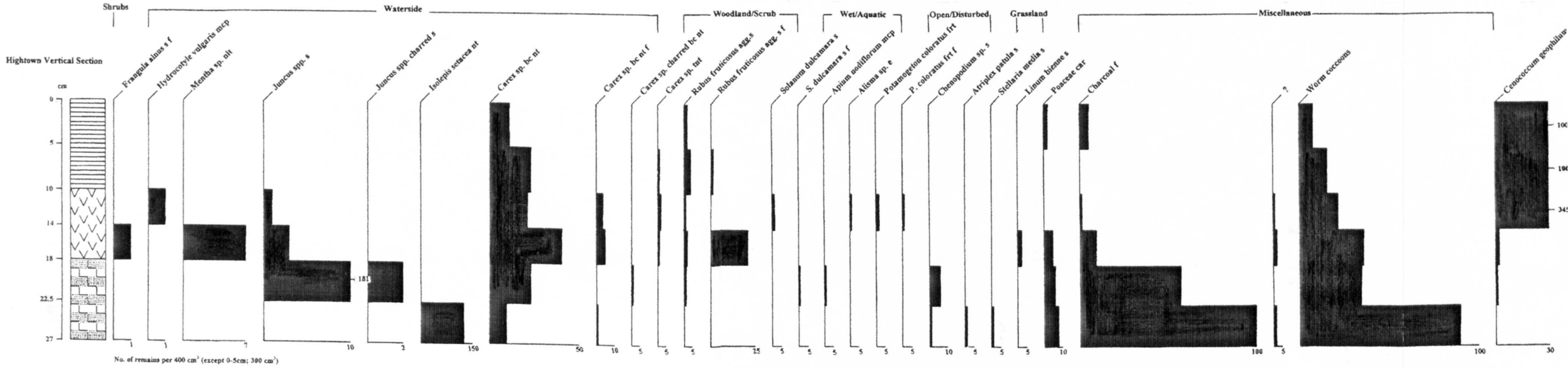
In the sample at 14-18cm, taken from the lower part of the dark brown loose fibrous peat, the number of *Juncus* spp. seeds is drastically reduced, although the *Carex* spp. nutlets increase with a decline in the abundance of the *Phragmites australis* rhizomes. A new taxon is introduced at this stage, *Mentha* sp., which like the previous taxa is representative of a waterside environment. Scrub/woodland is represented by an increase in *Rubus fruticosus* remains and a wet woodland component is indicated by a find of *Frangula alnus.* A more aquatic environment is not represented in this sample.

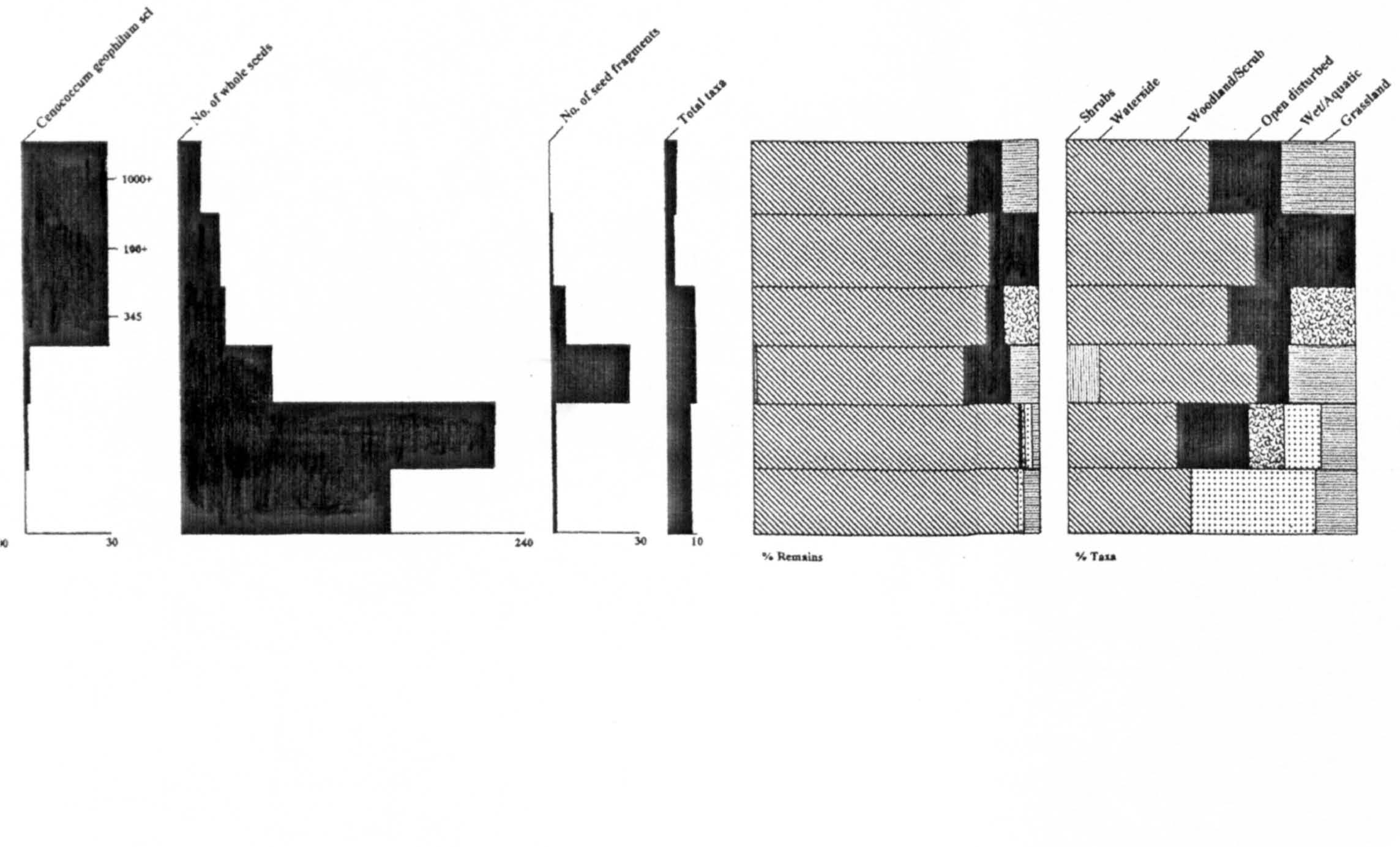
Possible indicators of a coastal grassland are the finds of *Linum bienne* and the caryopses of Poaceae. Only nine fragments of charcoal were recovered, although buds, leaf fragments and leaf abscission pads were found. Cladoceran eggs were found in small numbers and worm cocoons were present in the same magnitude as the previous sample.

The sample at 10-14cm from the upper part of the dark brown loose fibrous peat, contained representatives of a waterside environment such as *Hydrocotyle vulgaris, Juncus* spp. (reduced to a single find) and *Carex* spp. with rare finds of *Phragmites australis* rhizomes. Single finds of *Rubus fruticosus* and *Solanum dulcamarra* are indicative of a woody/scrubby environment, although both species can tolerate high watertables. An aquatic environment is represented by *Alisma* sp. and *Potamogeton coloratus.* Only one fragment of charcoal was recovered as is the case for leaf fragments, bud scales and leaf abscission pads. Monocotyledonous stems and roots were rarely recovered and Cladoceran eggs were found in a larger number which is associated with a subsequent decrease in worm cocoons. The commonest find was that of *Cenococcum geophilum* sclerotia.

In the lower sample of the compact dark brown fibrous peat at 5-10cm, the number of taxa recorded was severely reduced with the waterside/margin environment only being represented by *Carex* spp. and Scrub/woodland by *Rubus fruticosus.* Monocotyledonous stems and roots were abundant with twigs and fragments of wood (mainly birch) common. worm cocoons dropped in numbers with a massive increase in the numbers of sclerotia of *Cenococcum geophilum* being recorded in hundreds.

Figure 6.8. The plant macrofossil diagram for the vertical section, Monolith Two at Hightown


Hightown Vertical Section
Shrubs
Waterside
Woodland/Scrub
Wet/Aquatic
Open/Disturbed
Grassland
Miscellaneous
Frangula alnus s f
Hydrocotyle vulgaris mcp
Mentha sp. nlt
Juncus spp. s
Juncus spp. charred s
Isolepis setacea nt
Carex sp. bc nt
Carex sp. bc nt f
Carex sp. charred bc nt
Carex sp. tnt
Rubus fruticosus agg.s
Rubus fruticosus agg. s f
Solanum dulcamara s
S. dulcamara s f
Apium nodiflorum mcp
Alisma sp. e
Potamogeton coloratus frt
P. coloratus frt f
Chenopodium sp. s
Atriplex patula s
Stellaria media s
Linum bienne s
Poaceae car
Charcoal f
?
Worm coccoons
Cenococcum geophilum
cm
0
5
10
14
18
22.5
27
181
1
1
7
10
2
150
50
10
5
5
5
25
5
5
5
5
5
5
10
5
5
5
10
100
5
100
30
100
10
34
No. of remains per 400 cm³ (except 0-5cm; 300 cm³)


Cenococcum geophilum scl
1000+
100+
345
30
No. of whole seeds
240
No. of seed fragments
30
Total taxa
10
Shrubs
Waterside
Woodland/Scrub
Open disturbed
Wet/Aquatic
Grassland
% Remains
% Taxa

The sample at 0-5cm, the upper part of the compact dark brown fibrous peat, was also poor in the number of remains and taxa recovered, with *Phragmites rhizomes* and *Carex* spp. nutlets being representative of the waterside habitat with *Rubus fruticosus* representing the scrub/woodland component. No representatives of other habitats were present but other finds include caryopses of Poaceae, five fragments of charcoal and leaf abscission plates. Monocotyledonous root and stem remains were common but not as abundant as the previous sample. Wood fragments and twigs (over 4mm in length) were also common. The number of worm cocoons was reduced to half the number of the previous sample but the sclerotia of *Cenococcum geophilum* were present in thousands. Insect remains were common finds from sample three to sample six.

Although, the plant macrofossil remains recovered from the profile do not suggest the likelihood of a submerged forest, the presence of large quantities of wood and twigs within the samples tend toward the assumption that one was present in the vicinity. The height of the watertable appears to remain high throughout the profile, although the presence of large quantities of worm cocoons suggest that this could be seasonal. Most of the plant species present are tolerant of high watertables even though the dominant species change up through the profile. *Juncus* spp. becomes less important, whilst *Carex* spp. is constantly present along with *Rubus fruticosus* and *Phragmites australis.*

The species represented in the samples suggests that the area was dominated by *Phragmites australis* and *Carex* spp. throughout the profile with Poaceae also being important. The lack of seeds and fruits of tree species suggests that this part of the submerged forest exposure represents a more open environment. The single find of *Frangula alnus* may represent a lone shrub within the vicinity.

6.9.4.2. The Horizontal Monoliths

Two horizontal monoliths measuring 50x10x10cm were taken and were sampled and then processed using standard sieving techniques. Monolith three was subdivided into two subsamples, top and bottom as it divided along a natural break at five centimetres depth. Monolith four was also divided into two equal halves and then further subdivided into three samples corresponding to natural breaks in the deposit. The top and bottom samples were three centimetres in depth and the middle one four centimetres.

6.9.4.2.1. Monolith Three

Two hundred cubic centimetres of each sample was processed. The two samples appear to be well laminated and very peaty with twigs and other wood fragments present. The top sample contained large pieces of birch bark and other wood fragments over four centimetres in length. There is evidence of compression in the two samples with most of the twiggy material having a flattened appearance. The top sample contained a small amount of sand but this is probably derived from the dunes backing the exposure. The results of the macrofossil analysis are shown in table 6.7 and figure 6.9.

In general the two samples seem to represent a wet woodland with birch and alder being the dominant trees with a shrub layer of *Cornus sanguinea* and *Frangula alnus* with a lower layer of *Rubus fruticosus*. A high watertable element is represented by the presence of *Ranunculus flammula*, *Filipendula ulmaria*, *Angelica sylvestris*, *Lycopus europaeus* and sedges (*Carex* spp.). An aquatic environment is represented by finds of water-plantain (*Alisma* sp.) and pondweeds (*Potamogeton* spp.).

Other finds such as twigs, budscales, leaf fragments, and wood fragments all suggest the presence of a woodland environment. The finds of worm cocoons and fungal sclerotia indicate that at some stage the watertable lowers enabling earthworms to thrive as they do not like waterlogged soils. This linked with the presence of fungal sclerotia suggests that some sort of soil is present.

In comparing the bottom and top samples, the two samples may be considered similar and therefore representing similar types of environment, there are some striking differences. The top sample is richer in the number of remains as well as the total number of taxa, see table 6.7 and figure 6.9. This may be a product of time, as the bottom most sample can be assumed to be older and therefore exposed for a longer period to the agents of decomposition, as suggested by the higher number of fungal sclerotia in the bottom sample.

The top sample contained a greater number of high watertable species (seven compared to three) than the bottom sample, although the bottom one has more aquatic taxa. The presence of a higher number of both aquatic and wet marginal plants as well as higher numbers of Cladoceran eggs suggests that the local environment in the top sample maybe slightly wetter than that of the bottom one or it may represent the alteration of wet and dry phases often experienced in alder carr. Whether this change is due to a seasonal effect or due to a rise in sea-level cannot be determined too readily, but from the plant macrofossil remains there appears to be no evidence of a more maritime environment. Although an increase in sea-level can lead to a backing up of freshwater and therefore leading to a rise in the local watertable.

It appears that the two samples represent a wet woodland dominated by birch in the drier parts and alder in the wetter areas with a shrub layer of *Cornus sanguinea* and *Frangula alnus* and a herb layer of *Ranunculus flammula*, *Filipendula ulmaria*, *Angelica sylvestris*, *Lycopus europaeus* and Carices and in the drier parts *Rubus fruticosus*. In parts where the watertable reached the surface small pools would be present with *Alisma* sp. and *Potamogeton* spp. present. These pools could be temporary and appear and disappear with the seasons. The finds of mosses are more numerous in the upper sample and along with an increase in the number of waterside plants suggests that the woodland is becoming wetter with time.

Sample	bottom	top
Original Volume (cm^3)	200	200
Species	Bottom	Top
Trees		
Betula sp. seeds	18	62
Betula sp. female cone bracts	2	10
Alnus glutinosa fruits	2	24
Shrubs		
Cornus sanguinea		3
Frangula alnus	3	11
Frangula alnus fragments		23
Scrub/woodland		
Rubus fruticosus	2	3
Rubus fruticosus fragments	7	5
Rubus sp. prickles	3	10
Wet/pool/streamside		
Ranunculus flammula		2
Filipendula ulmaria		4
Angelica sylvestris		1
Lycopus europaeus	5	3
Carex sp. lentic	271	387
Carex sp. lentic large		52
Carex sp. trig	19	10
Carex sp. utricles		6
Aquatic		
Alisma sp.	1	
Potamogeton sp.	3	10
Miscellaneous		
Musci	rare	common
Poaceae	37+1f	27
Calyx unident	1	
Buds, bud scales. leaf fragments	common	v. common
Twigs & wood fragments	v. common	v. common
Cladoceran eggs	4	38
Worm cocoons	6	8
Fungal sclerotia	167	33
Insect remains	common	common

Table 6.7. Plant macrofossil data from the horizontal monolith, Monolith 3 at Hightown

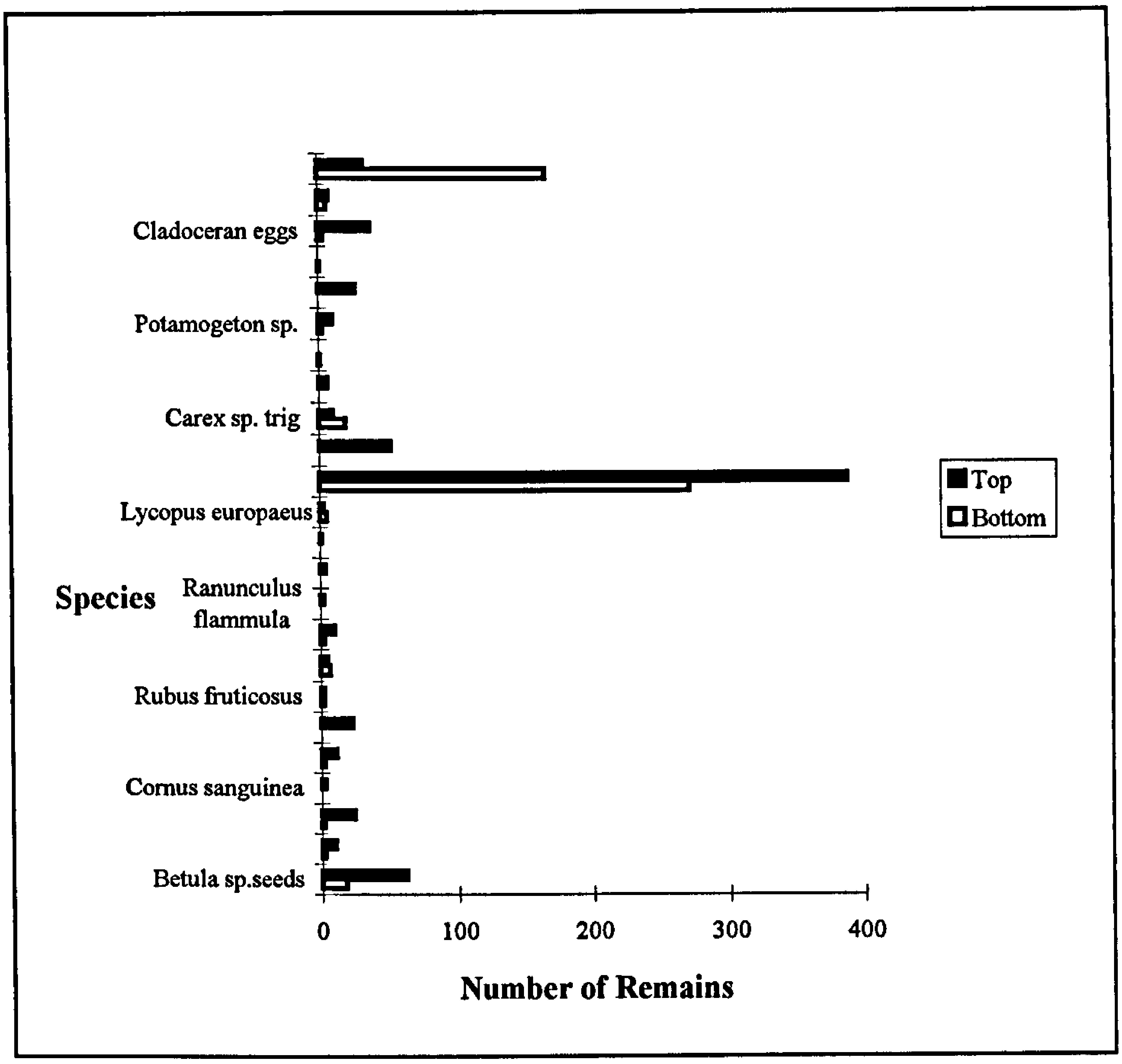


Figure 6.9. Macrofossil diagram from Monolith 3, Hightown

6.9.4.2.2. Monolith Four

This monolith was divided into three subsamples, top, middle and bottom. An additional smaller sample from the top was processed down to a mesh size of 180 µm in order to recover any *Osmunda regalis* sporangia or other microscopic elements that may be present.

In general, this sample was dominated by the presence of large pieces of *Osmunda regalis* rhizome, which can be identified by its characteristic feathery appearance which in past studies has been misidentified as pine branches, (Travis, 1926). The sporophyte of *Osmunda* has a short upright or creeping stem that is invested with persistent remains of old sclerenchymatous leaf bases. The stem has numerous adventitious rots which were evident in the samples, two of which arise at each leaf base. The stems usually bifurcate into equally sized branches and occasionally one of the branches bifurcates again, this can be seen clearly in plate 6.2. The rest of the sample was very fibrous and consisted of fine laminations. The *Osmunda* rhizomes were present throughout the depth of the sample apart from the bottom most sample. A small amount of mineral material was present within the samples, especially the top one and is probably derived from the present day dunes.

The results of the analyses of the four samples are shown in table 6.8 and figure 6.10. The table shows both corrected. The reasons for the corrected figures are given in the methodology chapter.

The samples overall represent a wet environment with little in the way of trees or shrubs being indicated. The only tree remains are seen in the bottom sample with *Betula* sp. fruits and female catkin scales being recorded. The shrub *Frangula alnus* is also recorded in this sample. The aquatics are represented by *Menyanthes trifoliata* (bogbean) and *Potamogeton polygonifolius*. This species is recorded in high numbers in the lower sample but diminishes towards the top. Waterside plants are also common throughout the samples with two types of lenticular sedge being recorded, but due to the poor condition of the nutlets it was not possible to identify them to species. The main dominant waterside plant was that of *Phragmites australis*. It can be argued that the rhizomes may not be contemporary with the rest of the samples, as they can often penetrate to a great depth and may belong to a later phase. The flattened nature and the lack of disturbance through the samples suggests that this is not the case here and can be considered contemporaneous. The leaves, buds and branches of *Sphagnum* sp. moss are also present in the bottom sample suggesting a boggy component. Other remains present within sample one include, Poaceae caryopses, unidentifiable monocotyledonous roots and stems, and buds, budscales and wood fragments. Non-plant remains include a large number of worm cocoons and insect remains. The lower sample, therefore contains representatives of wooded, aquatic, waterside and bog environments.

The middle sample contains no remains of trees or shrubs apart from the presence of twigs and other wood fragments. An aquatic environment is represented by finds of *Menyanthes trifoliata* and *Potamogeton polygonifolius* whilst a waterside habitat is present in the form of *Lychnis flos-cuculi*, and *Carex* spp. as well as *Phragmites australis* rhizomes. Some *Sphagnum* sp. leaves are present but not in the same quantities as in the previous sample. *Osmunda regalis* rhizomes are the commonest find in this sample. Other plant remains present include indeterminate Poaceae caryopses, monocotyledonous stems and roots, a few buds and bud scales. Among the non-plant remains recorded are Cladoceran eggs which are not common, a large number of worm cocoons are also present suggesting a fluctuating water-table. Insect remains are also present. This sample therefore contains representatives of aquatic, marginal, bog and damp woodland environments The top sample also contains no representatives of trees or shrubs, apart from one possible *Crataegus/Prunus* thorn. The sample is dominated by a large number of seeds and fragments of seeds of *Menyanthes trifoliata*, the other aquatic representative being a single fruit of *Potamogeton polygonifolius*. The waterside component has been diminished in this sample being represented only by *Hydrocotyle vulgaris*, *Carex* spp. and *Phragmites australis* rhizomes. *Osmunda regalis* rhizomes are common and a fragment of a pinna was identified.

Miscellaneous plant macroremains include monocotyledonous stems and roots, buds and budscales as well as twig and wood fragments which were very common and suggesting the presence of a wooded environment. The number of worm cocoons was small compared to the previous two samples. A fourth sample was processed as mentioned above in order to recover other microscopic remains of *Osmunda* such as sporangia and spores. Sporangia were recovered although they were not of *Osmunda*, but of a *Dryopteris* type. Three spores of *Osmunda* were recovered. Several of the sporangia still contained spores and these were examined under a high-powered microscope (x100-x1000). The spores were very degraded with very few surface tubercles being present leaving a generalised "bean" shape. One species of fern that has tubercles which apparently erode readily is *Thelypteris palustris*, but the condition of the spores was such that it was not possible to confirm this identification. This uppermost sample mainly consists of representatives of aquatic, waterside and wet woodland environments.

Hightown Monolith 4 (Horizontal)			
Sample	Bottom	Middle	Top
Original Volume (cm^3)	850	525	300
Species			
Trees			
Betula sp. seeds	4		
Betula sp .female cone scales.	1		
Shrubs			
Crataegus/Prunus sp. thorns			1
Frangula alnus	7		
Frangula alnus fragments	17		
Aquatic			
Menyanthes trifoliata		2	37
Menyanthes trifoliata half seeds			48
Menyanthes trifoliata fragments		7	45
Potamogeton polygonifolius	73	6	1
Potamogeton polygonifolius frags	22	1	
Waterside/margin			
Lychnis flos-cuculi		1	1
Hydrocotyle vulgaris			2
Iris pseudoacorus	1		
Carex sp. lentic (1)	94	19	9
Carex sp. lentic (2)	83	2	
Carex sp. trig	1	1	
Carex sp. utricules	3		
Phragmites australis rhizomes	common	v.common	v.v.common
Peat bog			
Sphagnum sp. leaves	54	1	2
Sphagnum sp. branches	2		
Sphagnum sp. buds	2		
Bog/fen/damp woodland			
Osmunda regalis pinnule			1
Osmunda regalis rhizomes fragments		v.common	common
Osmunda regalis spores			3
Dryopteris type sporangia			129
Dryopteris type annulus frags			185
Miscellaneous			
Poaceae	1	2	
Monocot stems/roots	v.common	common	v.common
Buds	3		1
Budscales	7		1
Worm cocoons	131	222	39
Fungal sclerotia	1	2	1
Insect remains	v.common	v.common	common
Total No. of Taxa	21	17	16

Table 6.8. Plant macrofossil data from horizontal Monolith 4 at Hightown

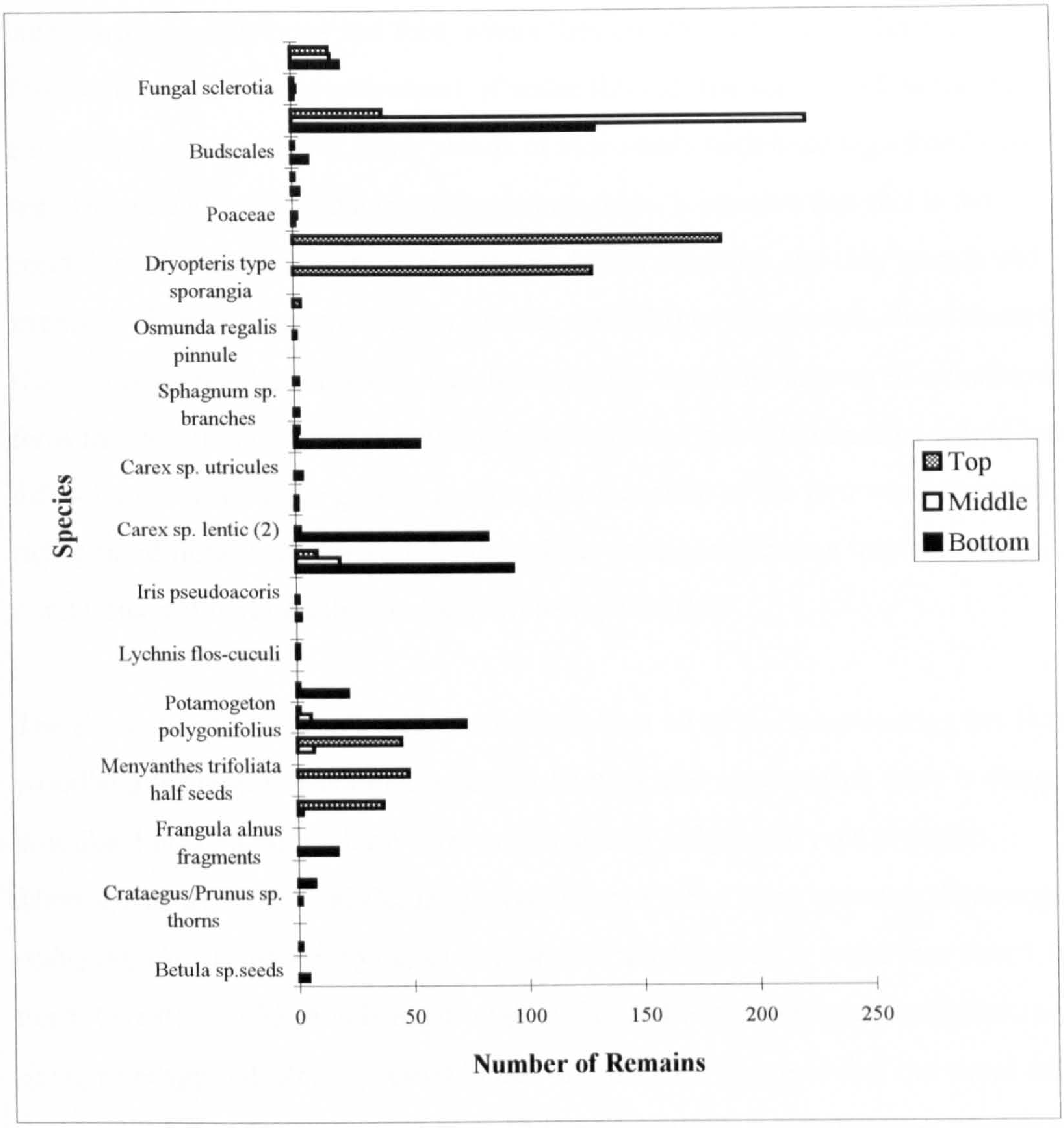


Figure 6.10. Macrofossil diagram from Monolith 4, Hightown

It appears that the three samples may represent a change in environment through time. With the fact that the only tree and shrub remains in the form of seeds and fruits was in the bottom sample. There may be an explanation for this in the fact that *Osmunda regalis* is a tall fern usually reaching 60-120cm high but in exceptional cases it has been recorded as tall as 3-4m and 1 metre broad. *Osmunda regalis* can be found growing in a wide range of wet acidic places, but its occurrence has been greatly reduced since the late nineteenth century by over-collecting and increased drainage in the twentieth century, it can still be found around fens and boggy woodland especially in areas of mild western oceanic climates with high and frequent rainfall, it is also tolerant of salt laden air and can be seen growing on many cliffs in SW England at the present time. Other habitats include, wet heaths, ditches, damp woodland, river banks, lake margins, valley bogs and fens, where they are developed over deep alluvial soil. *Osmunda* requires some movement of water through the soil as well as mineral enrichment. In woodlands dense stands of individuals with head high fronds growing with rhizome just above the prevailing water table. It appears that this is the conditions that were present at Hightown. As the rhizomes age they branch and eventually build up massive, heavy, woody, raised rhizome clumps, these clumps give rise to a large number of fronds which can totally dominate an area of woodland. With ferns this size it is possible to envisage that remains from other species would have difficulty in reaching the ground and the dense growth of the fern would prevent a rich ground flora from developing, only those species which can tolerate low light conditions or flower earlier are likely to be represented.

The presence of a twiggy/woody peat throughout all of the samples suggests that woodland is present. The other habitat indicators also suggest that there is damp woodland present with a herb layer dominated by sedges and reed in which *Menyanthes trifoliata* and *Potamogeton polygonifolius* were growing. *Potamogeton polygonifolius* is usually found in wet terrestrial habitats or in water less than 1.5m deep, (Preston, 1995) and is most often associated with *Menyanthes trifoliata* and *Sphagnum* spp. which are present in this sample. This suggests that the water table within the woodland was rather high, and at some times throughout the year there could have been pockets of standing water which were temporary.

6.9.4.2.3. Comparison between Monoliths Three and Four

In comparing the two monoliths from separate parts of the exposure, care has to be taken in considering whether the two samples are contemporary or are diachronous. As one sample is taken seaward from the other, diachronicity cannot be ruled out, although the general similarity between the two monoliths may reduced this possibility. The major difference between the two samples is the presence of the *Osmunda* rhizomes which dominated monolith four. The apparent lack of tree remains (apart from the twig and wood fragments in the latter samples) may well be explained by the presence of the *Osmunda* rhizomes. As stated above this pteridophyte is capable where the right conditions prevail of producing a vast expanse of fronds up to head height. This species is also slow growing and long lived and therefore may have been persistent for the whole length of time that the woodland was extant. This dense shadow cast upon the woodland floor would have prevented many plant from growing as well as preventing any tree seeds or fruits from reaching the woodland floor. Species that may be able to survive under such conditions are those which can exploit the annual timescale of the appearance and disappearance of the fronds of *Osmunda*. The frond begin to appear and expand in mid-April but are not fully expanded until late May, but then they are persistent until mid-October when they begin to die and by mid-December all are dead. It can be noticed from table 6.8, that the majority of the other plant remains occur in the bottom-most sample where the *Osmunda* rhizomes appear not to be present, this suggests that *Osmunda* had not become established then and only became established further up the profile. As stated above, the rhizomes grow just above the prevailing watertable and therefore little disturbance can be expected below this. The only species that appears to occur in any great numbers is that of *Menyanthes trifoliata* and *Phragmites australis*.

It may well be that the two monoliths are contemporaneous as many of the species found in each are similar and exploit similar habitats. The differences between the two samples may be due to the presence of the *Osmunda regalis* rhizomes in one area and not the other, which produces a dense shade and therefore preventing plant macrofossils which indicate the presence of more damp woodland elements. The presence of *Dryopteris* type sporangia, as well as spores of *Osmunda* and possibly *Thelypteris* suggests that the area around monolith four was dark and damp, whilst the remains from monolith three suggest that the area around the sample was a little more open with *Betula* sp. and *Alnus glutinosa* present with a shrub layer of *Cornus sanguinea* and *Frangula alnus* and a dense herb layer of fen species such as sedges, *Filipendula ulmaria*, *Lycopus europaeus* and *Angelica sylvestris*, with pools containing *Potamogeton* species.

6.9.4.2.4. Comparison between Monoliths Two, Three & Four

If it can be assumed that the samples from the forest bed deposits from each monolith are contemporary although diachronicity cannot be ruled out, especially to seaward. From studying tables 6.6-6.8 and figures 6.8-6.10 as well as plates 6.1 and 6.2 it can be seen that these samples represent spatial variation between the areas sampled, with one area being dominated by *Osmunda regalis* (monolith four) and monolith three representing a more varied environment within the woodland. In general all sampled areas experience a high watertable. A highly organic soil is indicated by the high numbers of worm cocoons associated large numbers of *Cenococcum geophilum* sclerotia.

From the profile samples (monolith two) it can be seen that in the clays beneath the forest deposits there is a change from a more open environment dominated by *Juncus* spp., *Carex* spp. and *Phragmites australis* to one of a more wooded landscape in the peat samples. The evidence is circumstantial, the indicators being the presence of twigs and wood fragments including buds, budscales, leaf fragments and leaf abscission pads. The variation in the preservation conditions between the vertical profile and the horizontal samples may be due to the fact that the profile is from an area at the edge of the exposure being more exposed to the agents of erosion and decay and therefore losing most of the macrofossil plant content of the deposit.

In conclusion to this section it may be suggested that if the samples are synchronous then each represents spatial variation within a fen woodland which is dominated by *Betula* sp. but with *Alnus glutinosa*, Salicaceae and *Quercus* present in smaller quantities. *Cornus sanguinea* and *Frangula alnus* are present as an understorey in some parts with small pools present where the watertable reaches the surface due to the undulating nature of the underlying clays. In these pools, *Potamogeton* spp. may be present along with *Alisma* sp. growing on the margins with *Menyanthes trifoliata*.

The herb layer is dominated by plant species that tolerate high watertable conditions whilst in other parts large tracts are dominated by dense growths of *Osmunda regalis*. Other areas especially those to the edge of the exposure may have been more open or may represent small clearings within the woodland where the herb layer is dominated by a mixture of *Phragmites australis*, *Carex* spp. and Poaceae. These clearings may have been formed by fallen trees or by dying ones, and have a less diverse flora associated with them. This give the impression of a woodland of a fen carr type which is diverse in habitat types with some areas being more open and interspersed with areas of dense growth and small pools.

6.10 Comparison between Travis' 1926 study, Tooley's 1970 pollen diagram and the present analyses

6.10.1 Comparison with Travis' 1926 study

From comparing table 6.2 of Travis' results with the results of the present study presented in tables 6.6-6.8, it can be seen that there is a difference between the two data sets and are presented in table 6.9.

Travis recovered and identified more plant species, 32 taxa from the forest bed compared with 23 from the present study as well as in the type of remain, whether it be seeds, pollen, spores or other vegetative material. The main reasons for the differences between the species identified are manifold. As mentioned above, both in this present study and in Travis 1920 and 1926 the submerged forest exposure has been subjected to a great deal of erosion from both the sea and the changing course of the River Alt, therefore the majority of the submerged forest layers analysed by Travis could well have disappeared by the time of the present study. In some areas the depth of deposit has eroded from 15cm in 1926 to 10cm at the present day, and because of this continual erosion different areas of exposure are going to be available for sampling as Travis (1929) pointed out when comparing the results from Leasowe with those of Hall Road, Hightown, the differences may well be due to the limited amount of exposure of the deposit available at the time of sampling. If spatial variation is a key part of the characterisation of this woodland then different exposures will inevitably lead to different species being recovered.

Species not in present study	Species not in Travis	Species in common
Pinus sylvestris	*Frangula alnus*	*Betula* sp.
Corylus avellana	*Angelica sylvestris*	*Quercus* sp.
Tilia sp. (pollen)	*Lycopus europaeus*	*Alnus glutinosa*
Myrica gale	*Iris pseudoacorus*	Poaceae
Salix cinerea	*Phragmites australis*	*Osmunda regalis*
Salix aurita	*Potamogeton polygonifolius*	*Juncus* spp.
Salix repens		*Carex* spp.
Ilex aquifolium		*Menyanthes trifoliata*
Myriophyllum spicatum (pollen)		
Hippuris vulgaris		
Stellaria palustris		
Viola palustris		
Sium latifolium (pollen)		
Scutellaria sp. (pollen)		
Atriplex patula		
Rumex acetosa (pollen)		
Polypodium vulgare (spore)		
Athyrium felix-femina (spore)		
Huperzia selago (spore)		
Lycopodiella inundata (spore)		

Table 6.9. Table showing dissimilarities and similarities between Travis and present study

On a more practical level, it is not known what volume of sample Travis processed in order to produce his macroremain list. If large volumes were processed it can be expected that a larger number of species will be recovered. Due to time constraints it was not possible for the present study to determine the optimal sample size for these deposits and therefore the present samples may not have been large enough to encompass all the plant species present within the area of exposure sampled. Also the Travis analyses from both Hightown and Leasowe include the results of the palynological analyses which were not carried out in the present work.

6.10.2 Comparison with Tooley's 1970 pollen diagram

Excavations at the end of the Blundellsands Sailing Club jetty in 1968 revealed 28 centimetres of compact hard peat with compressed woody remains of *Alnus*, *Quercus*, and *Betula*. On the surface rhizomes of *Osmunda regalis* were found. Underneath this compact peat was 7 centimetres of *Phragmites* peat which overlay 110 centimetres of inorganic sediments (Tooley, 1970).

Pollen analysis was carried out on samples taken every 2 centimetres throughout the 35 centimetres of peat, the results are shown in figures 6.11a & b. The pollen assemblages were dominated by arboreal pollen with a maximum of 60% at 27 centimetres (Figure 6.11a). As with Travis' earlier analyses, Tooley's pollen spectra show very little variation throughout the profile (Tooley, 1970).

At the base of the peat, the salt marsh communities are replaced by reedswamp communities dominated by *Phragmites australis* associated with *Typha angustifolia* and *T. latifolia* (Tooley, 1970). With the removal of the marine influence, the reedswamp is replaced by fen woodland dominated by *Alnus* and *Quercus* with some *Betula.* An understorey of *Myrica* and *Salix* with woody climbers such as *Solanum dulcamara* is also evident (Tooley, 1970).

According to Tooley (1970), the conditions within the woodland probably varied considerably with areas of standing water colonised by *Potamogeton* spp. and *Hydrocotyle vulgaris.* This is in agreement with the macrofossil evidence presented in this chapter.

When the pollen evidence is compared to that provided by the plant macrofossils (Figures 6.8, 6.9, 6.10, 6.11a & b and Tables 6.6, 6.7, 6.8 & 6.10) it can be seen that there is a great deal of similarity. This should not be surprising as the pollen site is approximately 100 metres south of the plant macrofossil site. Table 6.10 shows the taxa which are common to both the pollen and macrofossil record and those that are not.

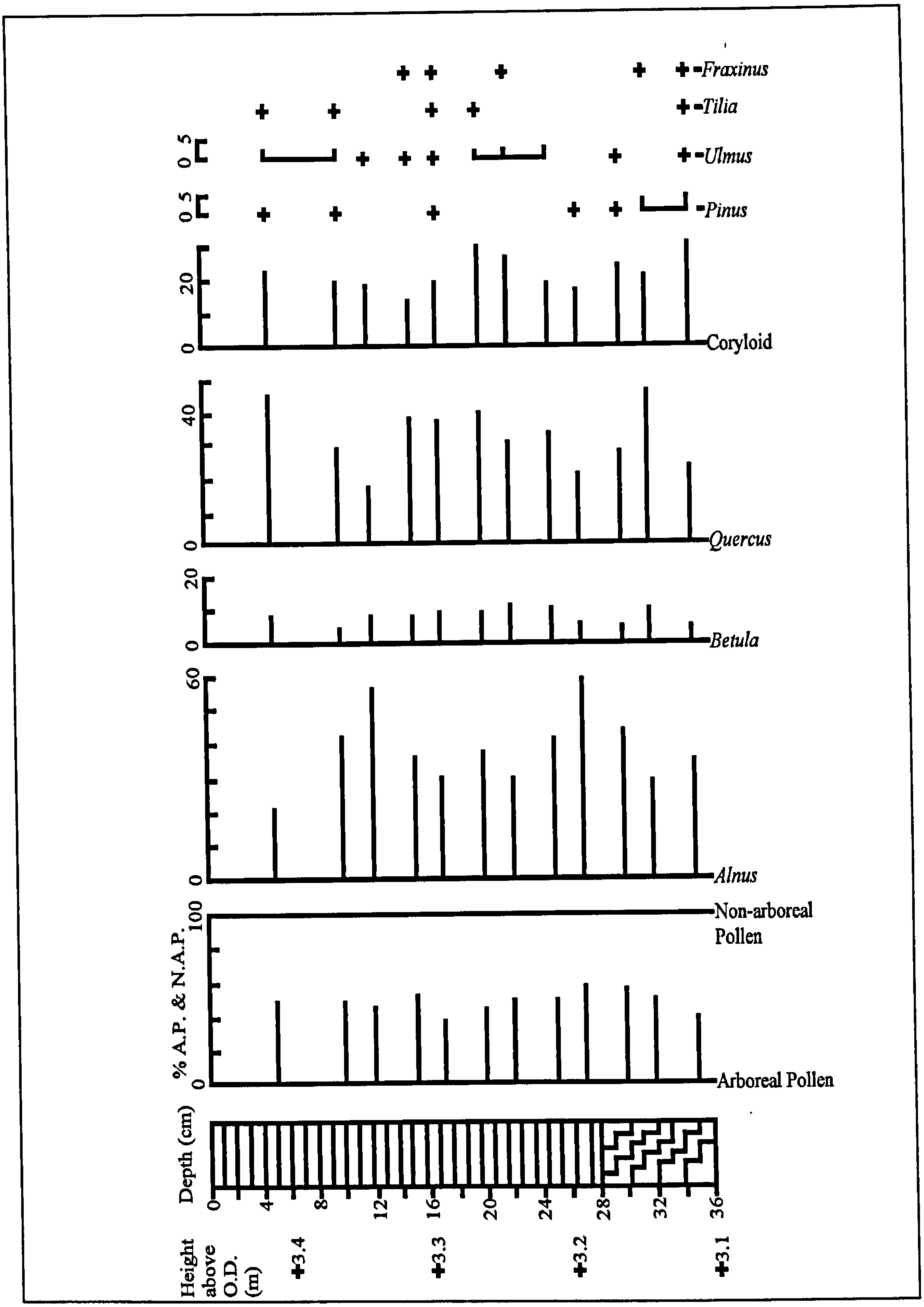


Figure 6.11a Pollen diagram from the Alt Mouth. (From Tooley, 1970) (Pollen sums are expressed as percentage of the tree pollen sum)

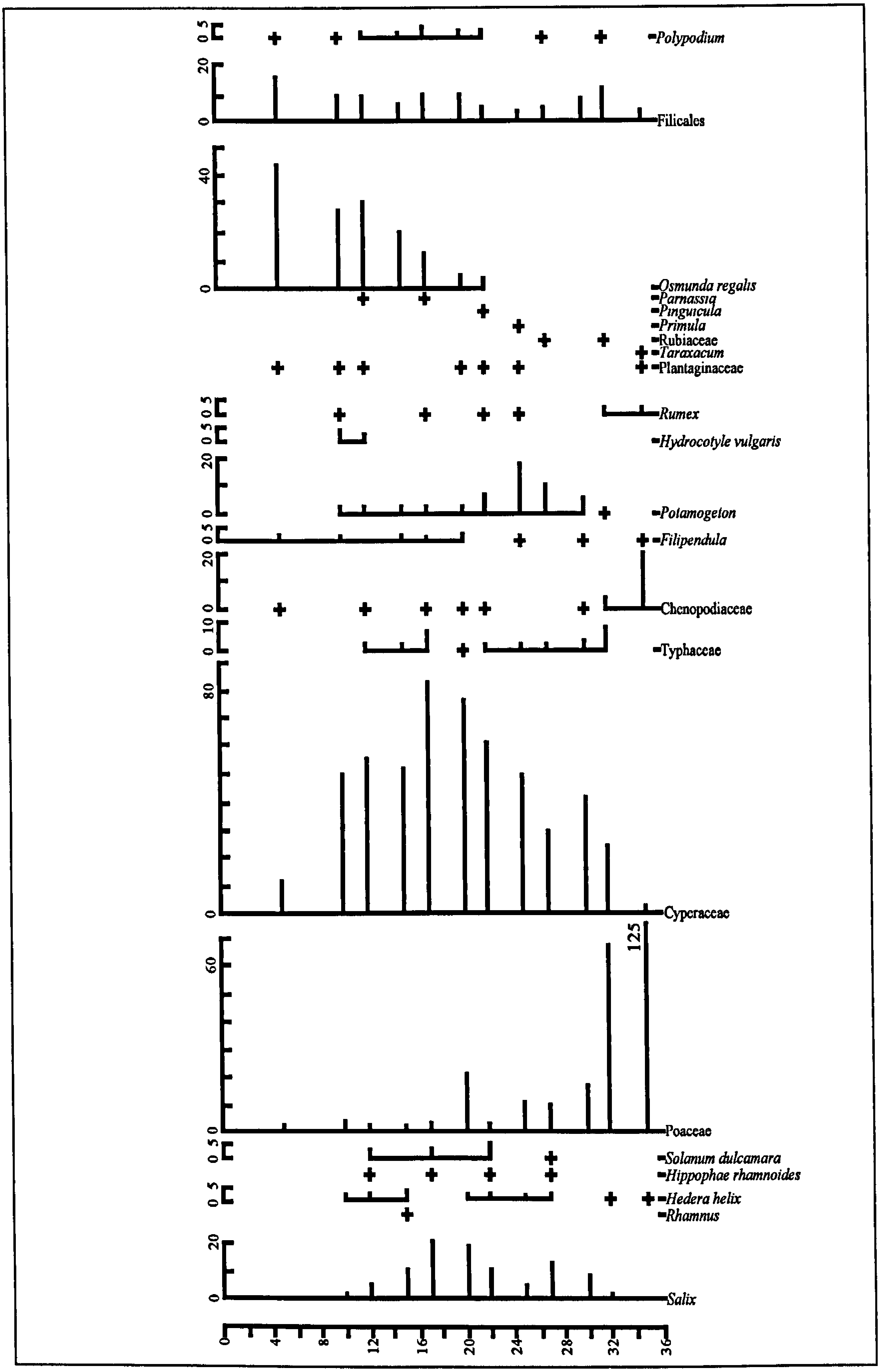


Figure 6.11b Pollen diagram from the Alt Mouth. (From Tooley, 1970) (Pollen sums expressed as percentage of tree pollen sum)

Taxa in plant macrofossil record	Taxa in the pollen record	Taxa in common in both records
Sphagnum sp.	*Pinus*	*Osmunda regalis*
Ranunculus flammula	*Ulmus*	*Quercus*
Stellaria media	*Myrica*	*Betula*
Lychnis flos-cuculi	*Rumex*	*Alnus*
Rubus fruticosus	*Tilia*	*Corylus* (Coryloid)
Crataegus/Prunus sp.	*Primula*	Chenopodiaceae (*Chenopodium* sp. & *Atriplex* sp.)
Cornus sanguinea	*Parnassia*	*Salix*
Frangula alnus	*Hippophäe rhamnoides*	*Filipendula ulmaria*
Apium nodiflorum	*Rhamnus*	*Hydrocotyle vulgaris*
Angelica sylvestris	*Hedera helix*	*Solanum dulcamara*
Menyanthes trifoliata	Plantaginaceae	*Potamogeton* spp.
Lycopus europaeus	*Fraxinus*	Cyperaceae (*Carex* spp. & *Isolepis setacea*)
Mentha sp.	*Pinguicula*	Poaceae
Alisma sp.	Rubiaceae	
Juncus sp.	*Taraxacum*	
Iris pseudoacorus	Typhaceae	

Table 6.10 Table showing the relationship between the taxa recorded in the plant macrofossil record and those of the pollen record

A total of sixteen taxa are recorded as macrofossils and are not present within the pollen record. A further sixteen taxa are found in the pollen record but not in the macrofossil assemblages. Thirteen taxa are found to be common between both sets of data.

The apparent differences can be accounted for by the dominant components of each type of evidence. Pollen, apart from having a local component also has a regional one, and those taxa which are not found in the macrofossil record are in general, only recorded in small quantities. These taxa include *Pinus*, *Ulmus* and *Tilia* (Figure 6.11a & b). This suggests that these taxa are representative of the regional component of the pollen assemblages.

Those taxa recorded in the macrofossil assemblages and not in the pollen record most likely represent a more local component. Plant macrofossils rarely travel further than one metre from the source plants in these types of environment (Greatrex, 1983). Another possibility for the differences between the two datasets may be due to differential preservation, whereby some taxa are more resilient to decay than others.

There is a good agreement between Tooley's pollen data and that provided by the macrofossil record presented in this chapter.

6.11. Interpretation and conclusions of the plant macroremains from the submerged forest at Hightown

Although there are dissimilarities between the work of Travis and the present study it can be noted that the plant macroremains recovered from each of the studies are from similar habitat types. These being species which require or can tolerate a high water-table, whilst, as Travis (1926) suggests and this work corroborates that this high watertable was not high enough to inhibit tree growth as indicated not only by the presence of seeds of trees and shrubs but by the ubiquitous presence of woody twigs, wood and bark fragments throughout the thickness of the Forest Bed. Both the current work and that of Travis cannot find any evidence for the succession of tree species which is commonly recorded within pollen records from peat bogs and lakes. There appears to have been a continuous growth of trees since the initiation of the woodland on the underlying blue/grey estuarine clay. This is also supported by the pollen analyses of Tooley (1970 and Figure 6.11a & b).

Travis, (1926), suggested from the macrofossil remains recovered from the base of the forest beds that marshy conditions may have prevailed before the full onset of the woodland, with abundant finds of *Salix* sp., *Alnus glutinosa*, *Menyanthes trifoliata* and *Myrica gale* as well as aquatic plants (see table 6.2), this is supported by the plant macroremains recovered in this study. These species would have survived and formed part of the woodland that developed into a fen-carr situation with the development of a highly organic matrix. The presence of worm cocoons recovered from the present analyses suggest that soil formation processes were active producing a highly organic soil typical of fen-carr woodland. The pollen analysis of Tooley (1970, 1977, 1985, Figure 6.11a & b) at the Alt Mouth also supports the development of a fen-carr woodland.

Therefore a picture of a woodland with a swampy floor which in places has small pools in which aquatics and *Sphagnum* species can be found growing. The presence of both *Potamogeton coloratus* and *Potamogeton polygonifolius* in the samples suggests that conditions may have changed from one of base-richness to a more oligotrophic nature, although *P. polygonifolius* can be found growing in areas where relatively base-rich water flows over less base-rich peats. In both cases *P. coloratus* and *P. polygonifolius* are usually found in shallow water as is *Potamogeton gramineus* identified by Travis which is usually found in mesotrophic waters. In other areas, the woodland floor was dominated by massive clumps of the fern *Osmunda regalis*, which would have shaded out most of surface preventing other plant species from flourishing. In other parts between the shallow pools which also contained *Hippuris vulgaris*, *Alisma* sp. and *Apium nodiflorum* and the dense stands of *Osmunda regalis*, the floor was dominated by species tolerant of a high watertable such as *Lycopus europaeus*, *Carex* spp., *Ranunculus flammula*, *Filipendula ulmaria*, *Hydrocotyle vulgaris*, *Iris pseudoacorus*, *Solanum dulcamara*, *Phragmites australis* and *Thelypteris palustris*. The shrub layer was dominated by *Salix* species, such as *S. cinerea*, *S. aurita* and *S. repens*. Other species such as *Frangula alnus*, *Corylus avellana*, *Ilex aquifolium*, *Myrica gale* and *Cornus sanguinea*. The tree layer consisted of *Alnus glutinosa*, *Quercus* sp. and small diameter *Betula* sp. which was the dominant tree, although Travis suggested that *Pinus sylvestris* was also present. The orientation of the fallen trunks are generally in the direction between north-east and south-west as demonstrated in figure 6.6. The species present within the samples analysed both by Travis and in this study are typical of fen-carr woodlands and agree with the pollen evidence provided by the North West Wetlands Survey work in Merseyside and Tooley (1970).

This and the previous chapter have presented the results of the mapping and macrofossil analysis of the submerged forests on the east Lincolnshire and Merseyside coasts. Chapter seven considers models which may be of some guidance to the interpretation of these deposits in terms of woodland history and floristic composition.

Chapter Seven

MODELS FOR THE CHARACTERISATION OF SUBMERGED FORESTS

7.1. Introduction

In the past, authors have suggested that the presence of submerged forests around the coasts of England and Wales offer the opportunity to record the actual character of past wooded landscapes, (Skertchley, 1887; Rackham, 1992; Bell, 1997). These attempts to characterise the submerged forests have not been on a quantitative basis but on a qualitative one, in many cases, the tree trunks present in the submerged forest exposures have been described as being tall with few lower branches, which has led to the suggestion that in the past the trees were more closely spaced than those in modern woodlands or indeed in the remnants of ancient woodland. This approach has been reappraised and more quantitative methods have been employed on recently studied submerged forest exposures such as at Goldcliffe in the Severn estuary (Bell 1997)

It is proposed that both the data recorded from the measurements of the stumps and trunks present in the exposures, in conjunction with the detailed plant macrofossil analyses will provide a more accurate picture of these tracts of past woodlands, producing a more quantitative and therefore more comparable approach to the characterisation of submerged forest exposures. This will provide a more ecological and dynamic view of the submerged forests which if successful can be used to help characterise other submerged forest exposures to be studied in the future.

Several methods are outlined below, which are considered to be of use in the characterisation of submerged forests. In some cases both the macrofossil data and that obtained from the measurement of the stumps and trunks is used in tandem, in other cases the two datasets are employed independently.

The approaches can be divided into two main groups, one being a metrical approach and the other a more species orientated one. The first group of methods displays the development of the forest and is taken from modern forestry approaches to woodlands in the USA. This methodology introduces a dynamic element which has not (as far as the author is aware) been used to describe and characterise submerged forest deposits. In using this method, several assumptions have to be made, including that the majority of the stumps and trunks present are contemporary; in most cases this is difficult to demonstrate unless dendrochronological techniques are used to determine contemporeneity. Where both the tree data and the macrofossil data are used in conjunction, it is necessary to assume that the macrofossils are contemporary with the trees. This can be demonstrated to be true, as macrofossils, in the form of bark remains and/or seeds/fruits of the component tree species are found within the deposits. Associated with this methodology are quantitative measures of density of trees and basal area of trees within a stand. These provide an idea of how dense a stand is and how much timber would have been available for exploitation.

A second group of methods rely on the ecology and the phytosociological associations of plant species found in different types of woodland and other communities present within the macrofossil record. In this study the use of the National Vegetation Classification (Rodwell 1991-1995), will be used to help characterise the macrofossil and tree remain content of the deposits.

The different methods are outlined below and in the following chapter each approach to characterisation is tested and evaluated with data obtained from two submerged forest deposits.

7.2. Forest Stand Development Processes

7.2.1. Introduction

Two approaches have been recently used to study and manage forests. One concentrates on the processes of change following major (stand-replacing) and minor disturbances and the second method concentrates on the stand structures which provide various social and economic values.(Oliver & Larson, 1996).

Successive changes in species dominance after a major disturbance have been recognised by ecologists for a long time and has led to two major interpretations of these changes. The earliest considered that one or a few species invaded an area and became predominant, as these species altered their environment this allowed other species to invade and dominate, these in turn altered the environment further permitting other species to enter and dominate the stand. This constant invasion and replacement by new species after the environment had been altered by the previous is known as relay floristics (Clements 1916; Cline & Spurr 1942; Daubenmire 1952; Oosting 1956; MacArthur & Connell 1966). This succession occurs in an all-aged manner and eventually a species or group of species invades and predominates and instead of being replaced by other species, it replaces itself, reaching a stable point to succession ("steady-state") known as the climax (Cowles 1911; Clements 1916, 1936; Braun 1950; Oosting 1956; Danseran 1957; Odum 1959; Daubenmire 1968).

The alternative hypothesis suggests that soon after a major disturbance, most plant species existing in a stand invade (Egler 1954; Stephens 1956; Raup 1957, 1964; Olsen 1958; Niering & Goodwin 1974; Oliver 1978a, 1981), rather than different species invading throughout the life of the stand, with the species present dominating at different times throughout the life of the stand, this is known as Initial floristics.

7.2.2. Floristic Sequence models

In 1954, Egler noted that any instance of succession may be a mix of relay and initial floristics, with initial floristics predominating in most cases. He observed that in old-field succession, 95% of the trees and shrubs in the forest that eventually developed were established at the time of field abandonment and the remaining five percent was due to incoming relay floristics.

Both relay and initial floristics spatial relationships are important. Initial floristics predominate in slight disturbances and are aided by the following conditions;- i) a close proximity of seed sources, this minimises any differences in dispersal capacity of the stand composition; ii) the site conditions are receptive to woody species, e.g. a good depth of humus providing a good seed bed and bird dispersed trees are aided by scattered trees; iii) the species of local trees are all equally fast in dispersal capability and have the same requirement for germination and establishment. Initial floristics are appropriate for describing post-blowdown succession in broadleaved forests, relay floristics tend to predominate in sparsely wooded districts where most of the woody species need to immigrate into the area.

Elements of both initial and relay floristics are characteristic of forest development, however the invasion pattern after a disturbance predominantly follows the initial floristics pattern. Initial floristics describes the succession displayed by a single cohort containing a mixture of species. It applies through Oliver and Larsons' stand initiation and stem exclusion phases (Oliver & Larson, 1996) and Bormann-Likens' reorganisation and aggradation phases (Bormann & Likens, 1979) but fails to describe the whole community when understorey reinitiation or transition phases are reached whereby relay floristics predominate. However, initial floristics continue to describe succession in the canopy and within each new group initiated in a gap. In old growth or steady-state phases, succession ceases in the community as a whole, though it continues within individual groups as an initial floristics process and relay floristics continues in the form of advance regeneration.

Stands which develop after major disturbances lead to 'even-aged' (single cohort) stands, since all the component trees have been assumed to regenerate after the disturbance. A group of trees regenerating after a single disturbance is known as a cohort (Oliver & Larson 1996), the age range of the cohort may be as narrow as one year or as wide as several decades depending on how long trees continue to regenerate to fill the available growing space after a disturbance, see table 7.1. Stands whose component trees arose after two or more disturbances, all but the first being minor are known as multicohort (uneven-aged or all-aged) stands.

7.2.3. Stages of Stand Development

Patterns of species dominance and changes in stand structures through time are not the result of obligatory laws which forest stands must follow (Oliver & Larson 1996, p148) but are the result of the complex interactions of the species present in the stands between individuals of the same species, different species and the local environmental conditions.

These patterns of stand development although complex can be partly anticipated and are presented below.

The patterns which develop after a disturbance can be divided into several stages and those of Oliver and Larson (1996), outlined here in table 7.1 are similar to those recognised by Issac 1940; Jones 1945; Raup 1946; Watt 1947; Bloomberg 1950; Horton 1956; Daubenmire & Daubenmire 1968; Reiners *et.al.* 1971; Day 1972; Harris & Farr 1974; Bormann & Likens 1979; Crow 1980; Hartshorn 1980; Wallmo & Schoen 1980; Peet 1981; Alaback 1982a, b, 1984; Brady & Hanley 1984; Felix *et. al.* 1983; Nakashizuka 1984a, b; Whitmore 1975, 1984 & Peet & Christensen 1987.

The speed of change between stages is variable and is linked to topography, climate, soil conditions and other environmental factors. In the case of longer lived trees, further disturbances intervene before the later stages are reached (Oliver & Larson, 1996). The species composition of each stand is largely the result of the type of disturbance which initiated it, (Ahlgren, 1960; Buckman, 1964; Pase, 1971; Tappeiner, 1971; Drury & Nisbet, 1973; Cattelino *et. al.*, 1979; Johnson, 1981a,b; Oliver, 1981; D.M. Smith, 1982, Tappeiner & McDonald, 1984; Adams & Adams, 1987). Gradients of soil, seed availability, predation, microsite suitability and climate also influence which species have the competitive advantage. This concept of a single area capable of being occupied by different, relatively stable groups of species (Botkin 1979; Sprugel 1991) is different from the early assumptions that each area returns to a single equilibrium vegetation composition soon after disturbance (Clements 1916). As a given environment permits only certain individuals to grow within an area, this process of species limitation is referred to as an environmental sieve (Harper 1977), the composition of a stand is therefore restricted to those species that are able to 'pass' the environmental sieve, other environmental sieves include, disturbance types, microclimates and soil conditions. An environmental sieve may change slightly during stand initiation as some plants slightly modify the environment, such as by creating slight shade which allows more shade tolerant species to germinate.

Stand Development Stage	Description	Initiation/ Duration of stage.	Species richness	Age of stand at conclusion of stage
Stand Initiation Stage	After a disturbance has killed all the large trees, new individuals and species continue to appear for several years, via seeds, sprouts, advance regeneration, buried seeds and roots. Other changes occur to the forest floor and the soil environments either immediately or several years after the disturbance. The first species to enter grow rapidly and occupy the available growing space and exclude later invading species. Invasion continues as long as growing space is available. The age range of plants is limited by time taken for growing space to be reoccupied. The size distribution of saplings in rapidly regenerated stands is initially narrow but increases as some individuals overtop others. With slower regeneration the size difference is greater and numbers peak at lower levels, those that become established first are generally larger. The number of individuals can be up to 100,000 per hectare.	Few years to many decades depending how rapidly the growing space is reoccupied. In open areas, recruitment takes longer as there is no advance regeneration and seed must immigrate. Time taken in larger blowdown gaps is 5-10 years	High numbers of plant and animal species.	Few years to many decades. But in most mesic forests this stage is completed in under 30 years.
Stem Exclusion Stage	After several years, new individuals do not appear and some of the existing ones die due to competition. Surviving trees grow larger and express differences in height and diameter. First one species and then another may appear to dominate the stand. At ground level the light levels are very low throughout the whole of this stage. The shaded floor becomes devoid of living plants and generally consists of dead leaves, twigs and stems. Several processes can be recognised to occur in this stage:- 1. Growth & Mortality of Individuals:- the number of individuals decreases as the size of the survivors increases following the negative exponential (-3/2) thinning rule. Initially sparse populations decline slower than the initially dense populations. (Peet & Christensen, 1980). 2. Increasing Stand Biomass and Basal Area. 3. Tightening of Age-Class Distribution:- smaller individuals which includes a large number of younger individuals tend to die first leading to a progressive narrowing of the initial spread of ages towards the upper age limit of the stand. 4. Changes in Diversity:- As species numbers decline throughout this stage so do the proportions of the surviving species. 5. Stratification between Species:- Intolerant species grow rapidly to form a canopy whilst the tolerant species grow more slowly to form an underwood. The degree of stratification and the composition of each stratum depends on the differences in age, spacing and rates of height growth.	Transition to stem exclusion stage can be decades. But starts earliest and proceeds most rapidly in dense, fast-growing thickets.	Low. Numbers of both plant and animal species declines during this stage due to increased shading and the lack of living foliage near the forest floor to serve as food, cover and habitat diversity. Some animal species specifically live in this development stage. The species that tend to be excluded are those growing on non-optimal sites; those initially established in low numbers and short-lived species.	Decades.

	Stratification lasts until the intolerants die but relationships between the strata can change within this stage with the suppressed species becoming dominant. **6.** Size Differentiation within Species:- there is some stratification within species so that some individuals dominate with other becoming suppressed due to intra-specific genetic variation and microsite variation. The outcome of these processes is a stratified, increasingly even-aged stand with decreasing diversity. Disturbances can disrupt the thinning process and allow suppressed individuals to survive and grow thus generating markedly different structures and composition in hitherto similar stands.			
Understorey Reinitiation Stage.	Forest floor herbs, shrubs and advance regeneration again appears and survives in the understorey. Species capable of living in dense shade are found. The species can be the same or different from those in the overstorey and those shrubs and herbs which grew during stand initiation. Not clear why this stage occurs, several factors may be involved i.e. more light reaches the understorey as suppressed trees die; higher CO_2 levels near the forest floor increasing the photosynthetic efficiency of the understorey plants; pedogenic processes may create more growing space near the forest floor. Some species have seeds which remain dormant for many years, but are able to germinate after subtle changes in growing space during this stage. Many shrub and herb species initiate from rhizomes and root sprouts. Plants in the forest floor stratum do not grow rapidly due to the lack of sufficient light.	Initiation is usually after approximately 30-50 years. The duration of this stage can be up to sixty years in shade intolerant or stressed stands and 150 years in shade tolerant stands.	More plant and animal species than previous stage but fewer than stand initiation. Many animal species are adapted to living in this stage.	100 years on highly stressed sites and up to 500 years if the understorey is shade tolerant.
Old Growth Stage.	Overstorey trees die in an irregular fashion and some of the understorey trees begin growing into the overstorey. If there are no disturbances, trees die from various agents i.e. winds, pathogens, droughts or insect attacks. When the trees which invaded immediately after a disturbance have all died, the stand enters True Old Growth Stage. Transition from the previous stage to old growth stage can be gradual and spatially varied producing a large variety of structures within a stand. True Old Growth Stage is rarely achieved due to the increased likelihood of major disturbances. This stage shows the greatest horizontal and vertical variation in structure with large and small trees growing in separate and intermixed patches. Eventually, no trees are left alive which are relics of the past disturbances other than minor ones caused by the deaths of individual overstorey trees. At that time, all existing stems have begun from autogenic origins.	From 60-150 years initiation & may last up to 500 years	Animal and plant species are more numerous than most other stages but less than the open structure of the stand initiation stage. Some plants and animals are dependent on rotting wood and other conditions found exclusively in old growth forests for their survival.	Between 100 - 600 years depending on level of stress and suppression and absence of any major disturbance.

	Timing of the canopy break up is dependent on 1. longevity of initial dominants. 2. Degree of mixture within a stand. If 'pioneer' tree species dominate the stand, they tend to be short-lived, e.g. *Betula* sp. , if there are longer-lived species present within the lower strata they move into the canopy. If no long-lived species present, the stand collapses. If the pioneer species are long-lived by the time of their death, a complex underwood is present. The onset of canopy break-up can occur earlier if the canopy is damaged or killed leading to more tolerant species being released. The break-up of the old growth canopy generates new gaps and patches releasing the underwood trees. As the pioneers die, stand structure and biomass declines.			

Table 7.1 Table giving the main features of the stages of forest stand development after a major disturbance (after Oliver & Larson, 1996; Peterken, 1996)

Contrary to the earlier interpretations of forest development, tree species often invade newly disturbed areas without other non-woody species preceding which modify the soil and microclimatic conditions (Niering & Egler 1955; Hack & Goodlet 1960; Ohmann & Ream 1971; Purdie & Slatyer 1976; Johnson 1981a, b). For example, tree species have been found to invade newly available growing space within a few years after the soil was uncovered by a retreating glacier (Sigafoos & Hendricks 1969; Oliver *et.al.* 1985).

7.3. Development Patterns following Minor Disturbances

Minor disturbances that injure or kill some of the trees in a stand can occur between or instead of major disturbances. The frequency of minor disturbances is determined by both allogenic and autogenic factors, and in some cases, minor disturbances may reduce the frequency of major disturbances.

A minor disturbance leads to changes in stand structure, species composition and tree shapes and can occur in any stratum of a stand. The severity of the disturbance and the vigour of the surviving trees determines how many and what trees are killed and the amount of growing space that becomes available. If the disturbance is light the residual species may take up the growing space by a change in growth rate, if it is more severe, greater growing space is created which may permit a new cohort of trees to enter and become a major component of the stand, creating a multicohort stand. If the residual trees are vigorous, the increase in growth rate may prevent a new cohort from entering the stand. The vigour of the surviving trees is dependent on age, canopy strata and crown classes, crowding and site conditions (Awaya *et. al.* 1981). The time of disturbance is also important, if it occurs at the early stem exclusion stage, most stem are vigorous and are able to grow rapidly into the spaces left in order to maintain a single cohort stand. If a disturbance occurs at stand initiation, it prolongs the time of plant invasion (Oliver & Stevens, 1977; Franklin & Hemstrom, 1981).

Disturbances can be intense, such a landslides in which they drastically alter the site, moderate such as fire, whereby the stand and/or advance regeneration is destroyed or light such as blowdown where the site is left with considerable biological legacy. The variation of disturbances during succession, if they are non-catastrophic accelerates or deflects the existing succession e.g. stand thinning by high winds accelerates stem exclusion or the onset of old growth. The scale and intensity of disturbances influences the duration and character of the subsequent succession (see table 7.2)

	Intense disturbance	Slight disturbance
Large area disturbed	All or most new growth must be by species which colonise from outside. Necessarily dominated initially by species which produce propagules regularly and copiously, and which disperse them far and rapidly. Other species spread in slowly	New growth by: (a) sprouts from mature individuals present before the disturbance; (b) advance regeneration of tolerant species present before the disturbance; (c) new individuals from dormant seed; and (d) new individuals from propagules that arrive from a distance
.	Result: a long succession	Result: a moderate amount of succession
Small area disturbed	Surrounding vegetation colonises vegetatively or by propagules. Tolerant species also colonise from a distance, but do not grow strongly	Small gap is filled by growth of surrounding vegetation and advance regeneration
	Result: some succession	Result: no succession

Table 7.2. The effect of size of area disturbed and intensity of disturbance on the course of succession. (After Peterken, 1996, modified from Connell and Slatyer, 1977)

7.4. Diversity of Successions

The Succession/Development model presented above, as with all models simplify the variety of observed vegetation changes. The factors which diversify real life successions are itemised below but often they overlap and interact producing even more diverse scenarios (Peterken, 1996).

1) *The species previously on the site.* Unless the disturbance is severe, successions are influenced by inheritance from earlier vegetation.

2) *The kind of disturbance.* The effect of wind throw is different from that of defoliation which is different from that of fire.

3) *The intensity of disturbance.* This can either just thin the stand or blow it all down, therefore either limited advance regeneration occurs or in the latter case a completely new stand is initiated, as outlined in section 7.3.

4) *The state of the vegetation on the site at the time of the disturbance.* e.g. old growth which may have been affected/weakened by earlier smaller disturbances might be more susceptible than if no previous disturbance had been experienced.

5) *Temporary conditions during stand initiation.* If the species available vary in response to a factor i.e. soil moisture, the composition of the stand may be influenced by the amount of rainfall in the years immediately before and after disturbance, or a rodent plague will remove the most palatable at stand initiation and these species become excluded from succession.

6) *Availability of seed.* This is influenced by the pattern of disturbance which affects the distribution of surviving seed sources and conditions on site (i.e. the availability of suitable perches for fruit-eating and seed distributing birds)

These factors generate variation in a) the state of the site immediately after disturbance b) the biological legacy from the previous stand c) the composition of the new regeneration d) the rate of growth and survival through stand initiation.

The factors outlined above are the major determinants to the composition and structure of a new stand as it embarks on stem exclusion, the influence may last a long time, because the initial composition and structure are important in the outcome of aggradation and composition of canopy will influence composition of the later regeneration during understorey re-initiation (Peterken, 1996).

A spatial element to the diversity of succession at any given site is introduced with factor (6), whereby succession can vary from place to place even on uniform sites. Spatial diversity can be further influenced by the variation in the frequency and timing of disturbance. Within a site, stands which are disturbed more frequently are likely to be composed of intolerant species (quick growth response etc.) than stands which escape disturbance which will allow tolerant species to predominate the stand (Peterken, 1996).

Another factor influencing the probability that consecutive post-disturbance successions will follow different pathways is that of gradual background change, which occurs over a longer time scale than those outlined above. The vegetation gradually responds to changes in the environment or the site. Types of gradual change include:-

a) *Climatic changes.* This initially alters the performance of the species at a given site and eventually the range of species and composition at a site.

b) *Geomorphological change.* For example a floodplain rising gradually in relation to sea-level.

c) *Changes in the site caused by the vegetation.* This affects both primary and secondary succession, but unsure if the vegetation changes the site or the site changes to facilitate the vegetation change.

d) *Change in impact of a non-catastrophic disturbance.* e.g. changes in the intensity or seasonality of grazing, will change the rate of succession and selectively inhibit palatable species.

e) *Arrival of new species.* e.g. arrival of sycamore in British Woodlands, changes the successional possibilities.

f) *Extinction or reduction in a species.* Impact of catastrophic disturbances e.g. dutch elm disease.

Each factor acts as a continuous variable and is to some extent independent in timing and intensity of other factors, the number of possible combinations in space and time are effectively infinite. It is expected that differences in successive successions at any given point will be seen, producing patchiness in the state of vegetation even in uniform sites and unpredictable shifts in successional trajectory during succession. Therefore, it is possible to make broad predictions about course of succession between disturbances in terms of physiogamy, structure and classes of species, but only state probabilities with large levels of uncertainty in proportions of individual species present within any stand at any given time and at some level of detail, every instance of vegetation change is likely to be unique.

But there are successions which have a high probability of repeating themselves almost exactly in structure and composition. The chances are highest if:-

1. One kind of disturbance more influential than all others.

2. Site conditions created by disturbance are more or less identical from time to time.

3. Few tree species are present; or one species dominates the system.

4. Species involved are all good colonists, wide dispersers and capable of rapid early growth; or the disturbances are small scale.

5. No significant long-term changes are taking place in the site or the climate.

These conditions are approached most closely in the fire-dependent boreal conifer forest and woodland which colonises new islands and bars in the floodplains of major rivers, where succession has been observed to be regular and predictable (Peterken, 1996).

Many of these factors will not be observable within the submerged forest deposits, but they need to be taken into account when interpreting submerged forest deposits using this model.

7.5. Overview of Forest Development Patterns

Both initial and relay floristic patterns occur at various times in forest development. The shifting dominance among species during the stand initiation, stem exclusion and understorey reinitiation stages are not the result of relay floristics. An Initial floristics pattern occurs after a disturbance with most species and individuals invading during a relatively short interval. Once established they exclude plants arriving later. Later development of shade tolerant species in understorey during understorey reinitiation follows the relay floristics pattern. This invasion can be interpreted as a directional development of a stand towards specific species compositions, since the trees invading during understorey reinitiation are generally shade tolerant and only a limited number of such species exist in each region. Patterns of forest stand development are the casual result of competitive interactions rather than by any predictable sequence or external force on forest development.

7.6. Quantitative measurement of stand development

The quantitative measurement of stand and individual tree development is usually in the terms of growth and yield of both individuals and of stands. The volume of a standing tree or stand is known as yield and any change in a tree or stand volume with time is known as growth. Growth and yield are usually expressed as volume/area (Oliver and Larson, 1996). The measurement of total tree volume and size is difficult due to the difficulty in measuring some tree components such as the fine roots and foliage. To estimate total tree volume and size, surrogate variables tend to be used as indirect estimates of tree size, such as diameter at breast height and stem volume. This imprecision and the lack of more accurate data on growth of all parts of trees limits the understanding and quantification of tree growth and yield.

The measurements of growth and yields for single species, single cohort stands are relatively easy to calculate due to the single species stands allow relatively uniform growth conditions. These stands have been the most studied and they form the basis for understanding the growth and yield patterns of more complex stands, with many species, strata and cohorts. The measurements of the growth and yield of stands rely on the assumption that the growing space occupied by each tree is directly proportional to crown size, implying that growing space is first limited when sunlight becomes limiting, although other factors can limit growing space, but similar general growth relations occur when other factors limit growing space.

The growing space occupancy in single species single cohort stands is expressed as ground area occupied by each tree, spacing between trees, or numbers of trees per unit area. The age of the tree expresses the accumulation of growth. For some species and sites, tree height can be substituted for a combination of site and age. An assumption is always made that the same volume per tree or area accumulates when trees of a given spacing reach a certain height, regardless of how many years it has taken to reach that height. Tree height cannot be used to equate yields on different sites for time-related measures such as annual ring widths, numbers of branches or annual growth.

7.6.1. The Distribution of Tree Sizes

Single cohort stands are often thought to show a normal distribution of tree sizes (Meyer, 1930; Hough, 1932; Baker, 1934; Schnur, 1934; Lee, 1971; West *et al.*, 1981a,b) and well differentiated stands can show either a bimodal or skewed distribution of tree sizes (Oliver & Larson, 1996). The bimodal or skewed distribution is most recognisable in diameter distributions, since diameter growth is very sensitive to changes in growing space, (Oliver & Larson, 1996). A skewed distribution of diameters can occur when intermediate or suppressed trees die readily as in stands of single intolerant species or in mixed stands where overtopped trees die (Oliver & Larson, 1996).

Diameter distributions may be skewed to the left (negative) when the stand is young and skewed to the right (positive) when the stand is older (Gates *et al.*, 1983; Perry, 1985). In mixed species stands where the trees which become suppressed and relegated to the lower strata are tolerant and survive (Oliver, 1978) a more bimodal distribution occurs.

7.6.2. Spatial Distribution of Stems within a Stand

As trees do not invade at the same time or at uniform time intervals they therefore do not grow at a uniform spacing. In most cases the initial distribution is as aggregated or clumped patterns (Oliver & Larson 1996). This initial clumped pattern is caused by the spatial distribution of the advance regeneration and stumps and shoots for sprouting, suitable seedbeds for germination, competition from other plants, the behaviour of disturbance initiating the stand.

After a disturbance, characteristic spatial patterns emerge as a result of inter- and intra-specific competition. If all other conditions are equal, trees compete and die sooner at narrower spacings within clumps, which leads to the development of a random distribution and as time passes, as long as there are no intermediate disturbances, a regular (evenly-spaced) spatial distribution is reached (Oliver & Larson 1996). Greig-Smith (1952) recorded a similar pattern could be observed in mixed species stands. Even as the stand approaches a more regular distribution, spatial patterns continue to reflect the initial spacings and the relative ages within the stand and the effects of the stand edges.

As the stand ages and reaches the understorey reinitiation and old growth development stages, the older trees and all other trees return to a more random and then possibly an aggregated pattern (Oliver & Larson 1996). Within multicohort stands the trees of each stratum may well be aggregated rather than well distributed throughout the stand, whilst at other times they may be closely intermingled with other cohorts or strata (Oliver & Larson 1996).

After a disturbance the initiation of a new cohort can begin in a patch where germination and other regeneration mechanisms are favourable or trees of a new cohort can begin randomly (Oliver & Larson 1996). The new cohorts will not necessarily appear beneath openings delineated by the disturbance as sunlight and root area are not immediately released beneath the canopy of the destroyed trees, therefore new stems initiate in a broad area around the disturbance. Temporal and spatial patterns of trees in a stand are determined by the behaviours of the component individuals and species and by environmental influences.

7.6.3. Density and Basal Area Measurements of Tree Stands

The properties and characteristics of old-growth forests both in the United States and Europe have been quantified in several ways some of which can be used to quantify submerged forests in order to give an idea on how much woodland was available within the immediate vicinity for local groups to exploit. These measurements include density, measured as number of trees per hectare, basal area ($m^2 h^{-1}$). Natural stands can have from under 100 to over 10,000 stems per hectare (Maple, 1970; Mitchell & Goudie 1980; Oliver & Larson 1996) and examples of these can be seen in table 7.3.

These measurements can be used to characterise the exposures of submerged forests and may help with comparisons between submerged and extant woodlands but there are several important points which need to be addressed before any direct comparisons can be made. Due to the character of submerged forests, many of the remains that are exposed are only preserved as stumps, the diameters once recorded may not relate to the original diameter of the tree as problems with erosion will also be encountered, which means that the diameter measurements and the basal area measurements will not be directly comparable to extant woodland data. Measurements such as density and basal area will be affected by diachronicity and can lead to an overestimation of both values and therefore may reduce the effectiveness of these measurements but judgement can be used in the field to estimate whether or not diachronicity is likely to play a major role in the production of data. The differential preservation of tree species within a submerged forest exposure can have a major effect on the character of the woodland, Some trees are more resistant to decay than others, i.e. birch does not seem to preserve as well as willow which is not as good as alder which is not as good as oak, and therefore skewed species compositions may result (Rackham 1992). But if measurements such as diameter and density are determined then at least some comparison between different exposures can be carried out.

If other exposures of submerged woodlands are measured in the same way as those studied here it may be possible to produce a database which can then be used to compare submerged forests around the coasts of Britain in order to record any variation between sites.

Forest/Stand Type	Density N ha^{-1}	Lowest DBH(cm)	Author
Broadleaved	363-975	none	Auten, 1941
Broadleaved	150-200 (125-252)	18-25	Auten, 1941
Coniferous (200 y.o.)	400	none	Peet, 1989
Douglas fir (old growth)	389-556	none	Franklin *et al*, 1981
Oak	268-594	16	Korpel, 1989
Oak-beech	268-594	16	Korpel, 1989
Beech	112-272	16	Korpel, 1989
Beech-silver fir	179-453	16	Korpel, 1989
Norway spruce	202-810	16	Korpel, 1989

Table 7.3. Published results of Density (number of trees per hectare) of different types of stand

Forest/Stand Type	Basal Area m^2 ha^{-1}	Author
Broadleaved virgin	24-39	Auten, 1941
Lilley Cornett woods	21	Martin, 1975
Beall Woods (Indiana) floodplain	46	Lindsay, 1962
Beech-maple (Warren Woods)	52	Cain, 1935
Hemlock/white pine-hardwoods	42-56	Cain, 1935
Beech-silver fir	37-56	Korpel, 1989
Coast redwood	343	Franklin, 1989
Douglas fir-western hemlock (500 y.o.)	91	Franklin & DeBell, 1988
Lodgepole pine (Rockies)	35-55	Peet, 1989
Subalpine & white firs	58-118	Peet, 1989
Ponderosa pine	35-46	Peet, 1989
Pine	6.4	Goodier & Bunce, 1977
Birch	3.5	Goodier & Bunce, 1977
Strathfarrer, Scotland; Native Pine	25.9	Goodier & Bunce, 1977
Ballochbuie, Scotland; Native Pine	23.3	Goodier & Bunce, 1977
Scots Pine Plantation	41.5	James, 1966
Black Wood, Rannoch, Native Pine	12.4-30.3	Peterken & Stace, 1987
High altitude Norway spruce	36-71	Korpel, 1989.

Table 7.4. Published results of Basal Area (square metres per hectare) of different types of stand

7.7. The Classification of Woodland and other Community Types

In the past, indicator species have been used to detect and interpret past habitats/environments present within the samples. This use of modern ecology to interpret past environments has been used since the beginnings of palaeoecological studies (Reid 1899). The principle of uniformitarianism is fundamental to interpretation of past ecologies although care must be taken. It is not possible to be sure whether or not modern communities were present in the past and can be demonstrated. Delcourt and Delcourt (1991) and others have shown that in the USA some forest types present in the past (recorded from pollen evidence) do not have a modern analogue. It is also not possible to be sure that species have not altered their ecological requirements through time, this can be demonstrated by the discovery of *Taxus* and *Quercus* woodland in the Thames Estuary where the yew is growing on peat. The modern ecology of yew restricts it to well-drained, base-rich soils.

Although, there is a real potential of no modern analogues being present for the submerged forests analysed in this thesis, Huntley (1990) found this to be more of a problem in the early Holocene rather than in the mid-Holocene deposits. Therefore the problem of no modern analogues may be reduced to a minimum for these submerged forest communities.

The use of single indicator species for specific habitat types is full of pit-falls. It is unwise to use a single species to indicate a specific habitat type and therefore the practice of using more than one indicator species is the normal practice. In this thesis, it can be seen from the species present in the samples that most occur in more than one habitat type. It is proposed that by using the National Vegetation Classification (NVC) of British Plant Communities (Rodwell 1991-95) a more accurate picture of the habitats represented by the samples can be produced. The use of the NVC system in this thesis is justified by the small possibility that there are no modern analogues for these deposits, suggesting that the plant communities represented in the submerged forest deposits will be covered by the NVC and will provide a more accurate interpretation than previously used.

The application of the NVC system entails listing all the community types in which each species occurs. The community types that are considered in this study are woodland, aquatic, swamps and tall-herb fens. The scores for each species occurring in the different communities is tallied and the communities which record the highest totals are considered to be represented in the samples. In this study, the communities for each section/monolith are recorded and then treated sample by sample to see if there is any significant change through time. In order to produce a more accurate picture of the community types present within a sample the minimum number of species required for a sample to qualify for analysis is three. In some cases this rules out some of the samples which can be treated this way but it is hoped that it can be demonstrated that this methodology can be used to produce a more accurate interpretation of the samples. The results of this analysis are then presented in tables for discussion in the following chapter.

Unlike the use of the National Vegetation Classification where one site would be designated to a single community, in palaeoecological samples, due to the processes involved in their formation more than one community type (or habitat type) may be present. This means that it is not possible to designate a single community type to each palaeoecological sample/section. This does not reduce the effectiveness of using the NVC system as it is only being used as a guide to the communities that may be present within the samples/sections. Therefore caution must be exercised when using this method as the potential of over-interpretation is great. An awareness that the possibility that no modern analogues for the communities represented within the submerged forest deposits also needs to be taken into account.

It must be noted that unlike the actual NVC community analysis, where abundance and frequency are used to define the communities and sub-communities this has not been used on these samples. This was thought to be inappropriate due to the problems of taphonomy encountered with palaeoecological samples. The community types are listed in Appendix II.

Although the NVC is used in this thesis, there are some specific sites which provide possible modern analogues for the plant macrofossil assemblages recovered from the submerged forest deposits.

Heyworth (1986) studied present-day coastal woodlands both on Morecambe Bay, Lancashire and in the Dyfi Estuary, Cardigan Bay. In both cases, Heyworth was more concerned with the lowest point of growth of the trees in relation to tide levels rather than the floristic composition of the woodlands. He discovered that *Quercus robur* can grow and is perfectly healthy at the upper limit of salt marsh, where the roots are below the level reached by several high tides each year. Their trunks can survive submergence to a depth of up to 1 metre by exceptionally high storm levels. This can occur many times in the life of the tree.

Heyworth (1986), noticed that the lowest full-grown trees in these coastal woodlands were oaks, although small specimens of *Alnus glutinosa* and *Salix* spp. are sometimes found a few metres seaward and a few centimetres lower.

These sites provide evidence of the physiological tolerance of oak towards periodic flooding by seawater and that these trees are often associated with alder and willow. But, they do not provide details on the structure or floral composition of the woodland.

Sites which may provide modern analogue to submerged forests are the woodland communities which grow in association with mosses and meres. One such site can be found in Staffordshire at Chartley Moss. At this site there are several types of woodland present, which may provide analogues for the submerged forest deposits.

Birch woodland is located on firm, relatively dry peat within which three sub-communities can be recognised (Page, 1991a).

a) Birch woodland with bracken, comprising an open canopy of *Betula pubescens* with occasional *Quercus robur* and *Sorbus aucuparia.* The ground flora is dominated by *Pteridium aquilinum* which produces a thick litter layer of dead leaves, totally excluding all other species. It is unlikely that this type of woodland would provide an analogue for the submerged forests.

b) Birch woodland with wavy-hair grass, comprising a very open canopy of *Betula pubescens* with a ground flora dominated by large tussocks of *Deschampsia flexuosa.* Associated species include *Erica tetralix*, *Dryopteris dilatata*, *Galium saxatile*, *Rubus fruticosus* agg. and the mosses *Pleurozium schreberi* and *Hypnum cupressiforme.* It may be possible that this sub-community may provide an analogue for the drier parts of the submerged forest.

c) Birch woodland with *Sorbus aucuparia* and small amounts of *Frangula alnus.* The ground flora of this type is more diverse than the previous two. It includes, *Deschampsia flexuosa*, *Molinia caerulea*, *Dryopteris dilitata*, *Lonicera periclymenum*, *Galium saxatile*, sparse *Pteridium aquilinum* and hummocks of *Sphagnum palustre.* This again may provide an analogue for the drier parts of the submerged forest.

Mixed marginal woodland is limited in extent at Chartley, (Page,1991a) with a narrow strip bordering the northern, western and eastern perimeters where the peat is shallow, dry and firm with a low water table throughout the year.

Betula pubescens and *Sorbus aucuparia* form a closed canopy with occasional large trees (up to 15m) of *Quercus robur* of which many are now dead or dying and *Pinus sylvestris.* The oak and pine were probably planted in the mid-nineteenth century.

Bordering the lagg ditch there are a few large trees of *Alnus glutinosa* and in places *Frangula alnus* saplings which form thickets. As a result of the deep litter layer on the woodland floor, the ground flora is often sparse. *Dryopteris dilitata* is the most abundant species in association with *Rubus fruticosus* agg., *Lonicera periclymenum*, *Deschampsia flexuosa*, *Galium saxatile*, *Chamerion angustifolium*, and *Digitalis purpurea.* A poorly developed moss layer of *Plagiothecium undulatum*, *Plagiothecium denticulatum* and *Hypnum cupressiforme* is also found. Apart from the tree and shrub species, this type of woodland does not provide a good analogue for the submerged forest deposits.

Fen woodland is also found at Chartley Moss and is very clearly defined from all the others on the mire (Page, 1991a). It covers approximately 560m near to the western margin in an area where mineral rich spring waters rise to the mire surface.

As a result of humification and degradation of the peat caused by the flow of oxygenated, geogenous waters, the surface no longer provides a firm anchorage for large trees, many of which have fallen over creating water-filled hollows, as shown in Plate 8.1.

The major canopy species are *Alnus glutinosa* with subsiduary *Betula pubescens*, *Fraxinus excelsior*, *Salix cinerea* and *Sorbus aucuparia.* There is a well developed shrub layer of *Viburnum opulus* and *Sambucus nigra.* The herb layer is very diverse with *Angelica sylvestris*, *Calamagrostis canescens*, *Cardamine flexuosa*, *Cirsium palustre*, *Hedera helix*, *Paris quadrifolia*, *Silene dioica*, *Solanum dulcamara* and *Thelypteris palustris.* Large tussocks, up to one metre in height, of *Carex paniculata* occur throughout with a patch of *Cladium mariscus* on the wetter peat at the northern end of the fen.

The Bryophyte layer is well developed and the most abundant species are *Brachythecium rutabulum*, *Eurhynchium praelongum*, *Rhizomnium punctatum*, *Plagiomnium undulatum*, *Sphagnum palustre* and *Sphagnum teres*. The small pools of open water which dry out in summer are colonised by *Lemna minor*.

A similar fen woodland occurs at Wybunbury Moss, NNR, Cheshire where it is characteristic of those parts of the mire where the peat is wet and unstable and the mire waters are eutrophic (Page, 1991b).

The principal canopy species is *Alnus glutinosa* with lesser amounts of *Sorbus aucuparia*, *Betula pubescens*, *Quercus petraea* and *Quercus robur*, many of which are dead or dying due to increased water levels. The shrub layer consists of *Salix* spp., *Frangula alnus* and *Viburnum opulus*, and the woody climbers *Lonicera periclymenum* and *Hedera helix*. The ground flora is diverse and includes many eutrophic or mesotrophic indicator plants, e.g. *Angelica sylvestris*, *Carex acutiformis*, *C. paniculata*, *Cladium mariscus*, *Menyanthes trifoliata*, *Phragmites australis*, *Ranunculus sceleratus*, *Solanum dulcamara* and *Urtica dioica* (Page, 1991b).

Due to the degradation of the peat and the collapse of some of the larger trees, there are many small open water pools which are usually colonised by *Lemna minor*.

These two fen woodlands would seem to provide possible analogues for the submerged forest deposits. The woodland communities at these two moss sites, show that woodland structures and composition can vary over short distances and therefore may be helpful in explaining the variations that have been observed in submerged forest deposits.

At Wicken Fen, Cambridgeshire, studies on the seedbank present within the soil under fen woodland have revealed a number of species, which are listed in table 7.5. As can be seen from table 7.5, many of the species can be found in submerged forest deposits and therefore may provide a modern analogue for the submerged forest deposits studied in this thesis. It may also be noted that some of the tree species found in submerged forests, such as *Betula* sp. and *Alnus glutinosa* are not present within the seed bank studies from Wicken Fen. This is because these species do not grow on the fen. Others may be missing due to differential preservation within the soil.

In general, there are many locations of wet woodland that may provide possible modern analogues for the submerged forests deposits. In order to interpret this large amount of information efficiently it was decided that by using the NVC a clearer picture of the woodland communities present in the submerged forests could be achieved.

Thalictrum flavum	*Solanum nigrum*
Urtica dioica	*Solanum dulcamara*
Chenopodium album	*Lamium purpurem*
Stellaria media	*Mentha aquatica*
Persicaria maculosa	*Plantago major*
Viola palustris	*Rhinanthus minor*
Viola persicifolia	*Galium uliginosum*
Salix alba	*Sambucus nigra*
Samolus velerandi	*Eupatorium cannabinum*
Lysimachia vulgaris	*Juncus* spp.
Rubus spp.	*Cladium mariscus*
Rosa spp.	*Carex* spp.
Crataegus monogyna	*Poa trivialis*
Lythrum salicaria	*Phalaris arundinacea*
Epilobium hirsutum	*Calamagrostis* spp.
Rhamnus cathartica	*Molinea caerulea*
Frangula alnus	*Phragmites australis*
Linum catharticum	

Table 7.5 Table showing the species found in the seed bank at Wicken Fen, Cambridgeshire (After Rowell, 1983 and Friday *et. al.*, 1997)

7.8. Summary

The model described in sections 7.2 and 7.3 is a stand developmental model developed by foresters in the USA who needed to assess the condition of first and second growth forests. The stand developmental stage reached by a stand is determined by the severity, type and frequency of disturbances and competition between species. There are many variations in the factors which influence the development of a forest stand and these are considered in section 7.4. The quantitative recognition of the stage of development reached by the forest stand are outlined in section 7.6.

The above model enables the forest stand to be characterised by the analysis of its population structure via the size and spatial distribution of the tree stems. In order to produce a more complete characterisation of a forest stand it is necessary to consider the other plant species which may be growing on the forest floor. This will be attempted by recognising the plant communities represented by the macrofossil content of the deposits using the National Vegetation Classification produced by Rodwell (1991-1995). The methods and problems in using this classification are discussed in section 7.7. In this section specific sites which may provide modern analogues to the submerged forest deposits are also described.

The submerged forest exposures studied in this thesis will be characterised by their stage of development as outlined in sections 7.2-7.6 and ecologically via the woodland classification model outlined in sections 7.7. This will provide a more dynamic and informative analysis of the submerged forest deposits than has hitherto been available. The two sites will then be compared and contrasted to see if the two different exposures produce different characterisations. The following chapter contains the analyses.

Chapter Eight

APPLICATION AND INTERPRETATION OF MODELS

8.1. Introduction

The processual model outlined in the preceding chapter has been developed from observations made on mainly abandoned field forests in the United States of America or on forests where disturbance (in its many guises) have been recorded for over a century. The model follows the development of a woodland or forest stand from its initiation towards its old growth stage (section 7:3) (Oliver and Larson 1996).

It can be argued that these developmental models can be used to help characterise submerged forests as they are susceptible to disturbance, due to their proximity to the coast, from high winds/storms and occasional flooding. The surface of the previous submerged area can be treated as an abandoned field, leading to the invasion of the woody species of the preceding fen and swamp vegetation, justifying the use of the developmental model.

The application of these developmental models requires caution, as not all the information which is readily available for modern woodland ecologists and silviculturists will be available to the palaeoecologist. Approximations of age and growth rates of trees have to be made using diameter measurements, as tree-ring data are in many cases not available due to the poor preservation of the stumps and trunks, especially at Hightown. If caution is used, these indirect measurements can be useful guidelines and help elucidate the development and past histories of submerged forests. The amalgamation of both datasets (the tree measurements and their positions and the plant macrofossils) will help to create a better understanding of the character and development of these submerged forest deposits.

The submerged forest at Hightown will be the first to be analysed followed by that situated on the east Lincolnshire coast at Wolla Bank and Anderby Creek. Then a comparison between the two areas will be made.

8.2. Distribution of Stump Diameter and Girth Measurements at Hightown

As already mentioned in section 6.9.2, two hundred and ninety-eight stumps and trunks were planned and measured. The results are displayed in figure 6.4. In the majority of cases the stumps were of birch.

In modern American and European woodlands which are single cohort, the distribution of ages is expected to follow a normal distribution (Oliver & Larson 1996, Jones 1945), if disturbances have been light or infrequent. When disturbances have been severe, the age distribution can be expected to vary from the normal distribution curve.

From studying the distribution of diameter and girth classes of stumps and trunks recorded at Hightown (Figure 8.1a & b), it can be seen that there is an uneven age distribution. The graph in figure 8.1a represents the number of stumps of each diameter class per hectare. The diameter class with the largest number of stumps is that of 11-20cm, followed by 5-10 and 21-30cm classes, the larger classes are represented by fewer numbers producing the classic 'reverse-J' curve. The same picture can be seen in figure 8.1b where the number of stumps per girth class per hectare are plotted.

This distribution of stump diameters and girths can be explained in two ways. If the stumps represent a single cohort stand, it can be suggested that a few trees invaded initially (these are the ones in the larger diameter classes) and as these trees modified the environment it enabled more trees to invade and fill the available growing space leading to a skewed distribution with many more younger stumps/stems being present than older ones.

If on the other hand, the stumps of the exposure represent a multicohort stand, where there has been more than one disturbance, it can be expected that there would be a larger number of smaller diameter/younger stems than larger/older stems. As the trees age and become larger/older they are more prone to be killed by disturbances, for example by windthrow. After each successive disturbance, more trees are allowed to become established producing a skewed distribution similar to that of above. After the final disturbance, the stems invaded rapidly with the larger stump diameter classes representing the trees which survived the previous disturbances leading to the development of a multicohort stand, as the larger

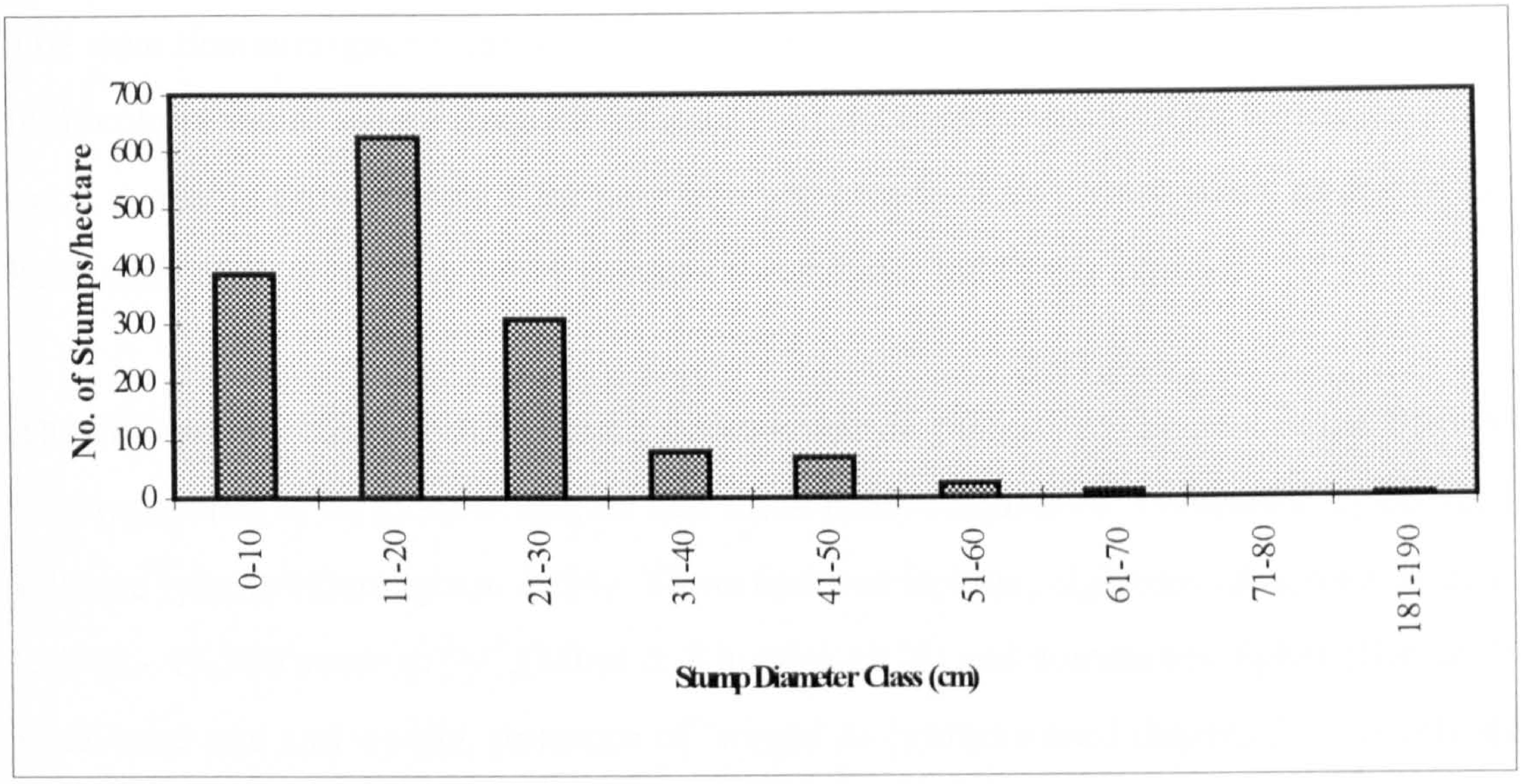


Figure 8.1a Distribution of Stump Diameter Classes per hectare at Hightown, Merseyside

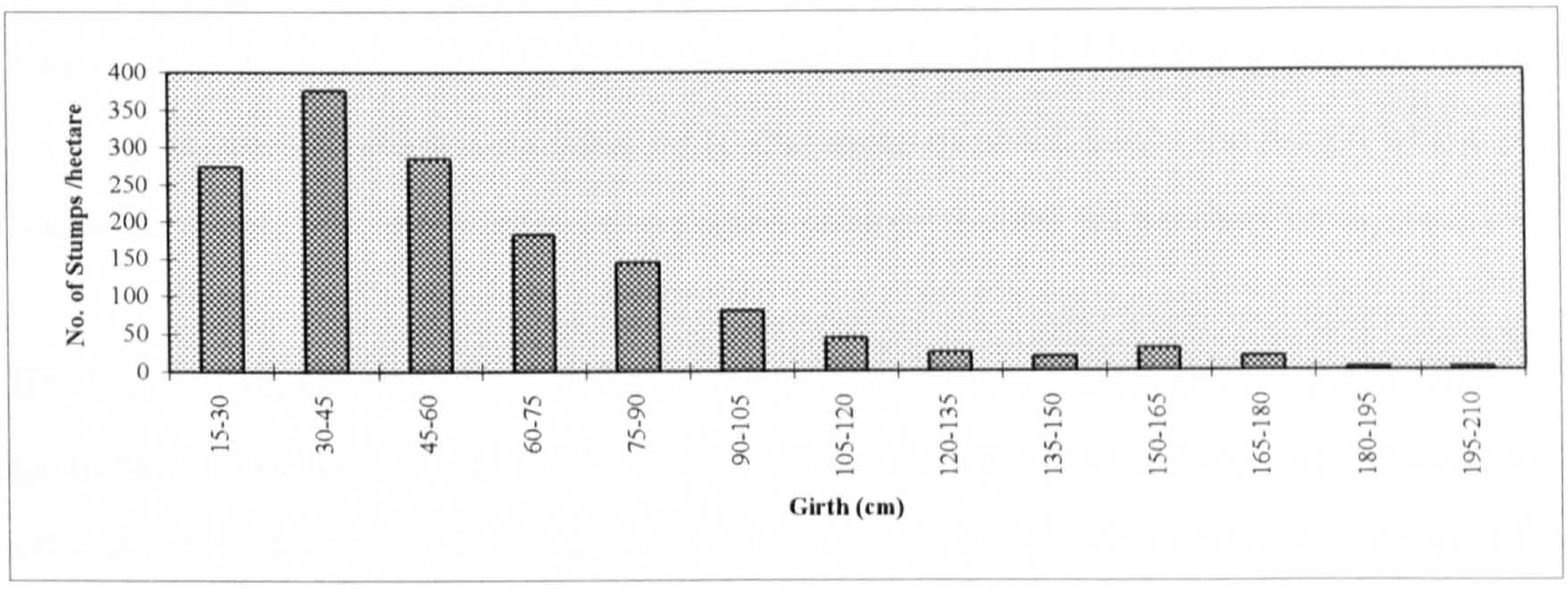


Figure 8.1b Distribution of Stump Girth Classes per hectare at Hightown, Merseyside

remaining trees did not grow quickly enough to fill the newly available growing space, therefore allowing the establishment of new stems.

As the 11-20cm diameter class or the 30-45cm girth class dominates the distribution of classes it can be suggested that the stand is about to or has entered the stem exclusion stage, whereby those stems that are either small or less vigorous become suppressed they continue to grow at a slower rate or die.

The stem diameter/girth class distribution is most likely to represent the presence of a multicohort stand, where frequent although not necessarily major disturbances produce more available growing space for new stems to invade. This is most likely as due to the behaviour of *Betula* sp. which dominates this submerged forest exposure.

The arboreal species of birch (*Betula pendula* and *B. pubescens*) present in the British Isles are considered to be pioneer species and show many features of 'r-selected' rather than 'k-selected' plants (Gimingham 1984). These features include, high reproductive capacity (3,800 - 43,300 seeds m^{-2} y^{-1},(Miles & Kinnaird 1979) and sometimes higher (Sarvas 1952), small seed size and weight, presence of 'wings' to promote seed dispersal, relatively short life-span, (usually not exceeding 100 years), wide climate and edaphic range and limited shade tolerance.

The capacity for birch to invade bare ground or vegetation such as heath or grassland is well known (Gimingham 1984). If the seed-parents are present within the vicinity the effective invasion is often found to be restricted to distances of about twice the height of the parents, the invasion of such areas appears to require a large number of seeds (Gimingham 1984).

Birch can produce seeds from 5-10 years and sometimes as early as two years after germination (Pelham *et. al.* 1984). Seeds will not germinate and seedlings will not establish on a closed stratum vegetation and the seedlings will not survive under the canopy of other tree species. Seedlings have a tendency to become established on bare ground, such as that that will be present after a disturbance, such as a windstorm, which will produce windthrown trees and the exposure of bare ground due to the lifting of the root plate of the fallen tree/s would provide an excellent site for the germination of the seeds. The densest stands of birch seedlings are usually found on bare substrates which can be either mineral or organic soils and the seedlings are characteristically aggregated (Pelham *et al.* 1984, Kinnaird 1974).

The reverse J-shape curve is usually found in multicohort stands (Oliver and Larson 1996). The fact that birch requires bare soil, if a few trees become established at first, to modify the environment, then allowing other trees in greater numbers to enter later, does not seem to follow the pattern of birch behaviour, unless there were only isolated trees in the area and invasion could only be complete after more trees become established. This situation is most unlikely as the hinterland to the coast would be wooded and provide a ready source of seeds for invasion.

Due to the pioneering behaviour of birch, with its ability to germinate quickly from seed, preventing other species from entering the stand and occupying all the available growing space before the surviving trees can respond to this availability, the development of a multicohort stand via frequent disturbances is the best interpretation of the distribution of diameter and girth sizes at Hightown.

8.2.1. Spatial Distribution of the Tree Remains at Hightown

The spatial distribution of the tree remains at Hightown can be seen in figure 8.2e. As mentioned in chapter 6 the majority of the stumps represented in this exposure are of birch with some willow and oak.

At first glance it appears that the stumps/tree remains at Hightown are randomly distributed, but if the stump diameter classes are isolated in separate plans, a pattern can be seen to emerge (Figures 8.2 a-e).

The largest diameter stumps (figure 8.2a) and therefore assumed to be the oldest tree remains within the deposit appear to be located on the periphery of the stand forming a 'U' or 'V' shaped pattern from west to east. In between and surrounding these larger stumps, the smaller diameter stumps are distributed. The large stumps also appear to be well separated from each other. These may represent the oldest remains of a previous disturbance (or even from the initial invasion), whereby others of this cohort were destroyed leaving space for the initiation of other cohorts and/or individuals.

The largest stumps are interspersed, especially in the area of the entrance of the 'V' with stumps larger than 21-25cm diameter class. These in general, are well separated from each other but there are one or two groups of two or more similar sized stumps. The stump diameter classes of 16-20cm and 21-25cm (figure 8.2b) appear to be distributed in three

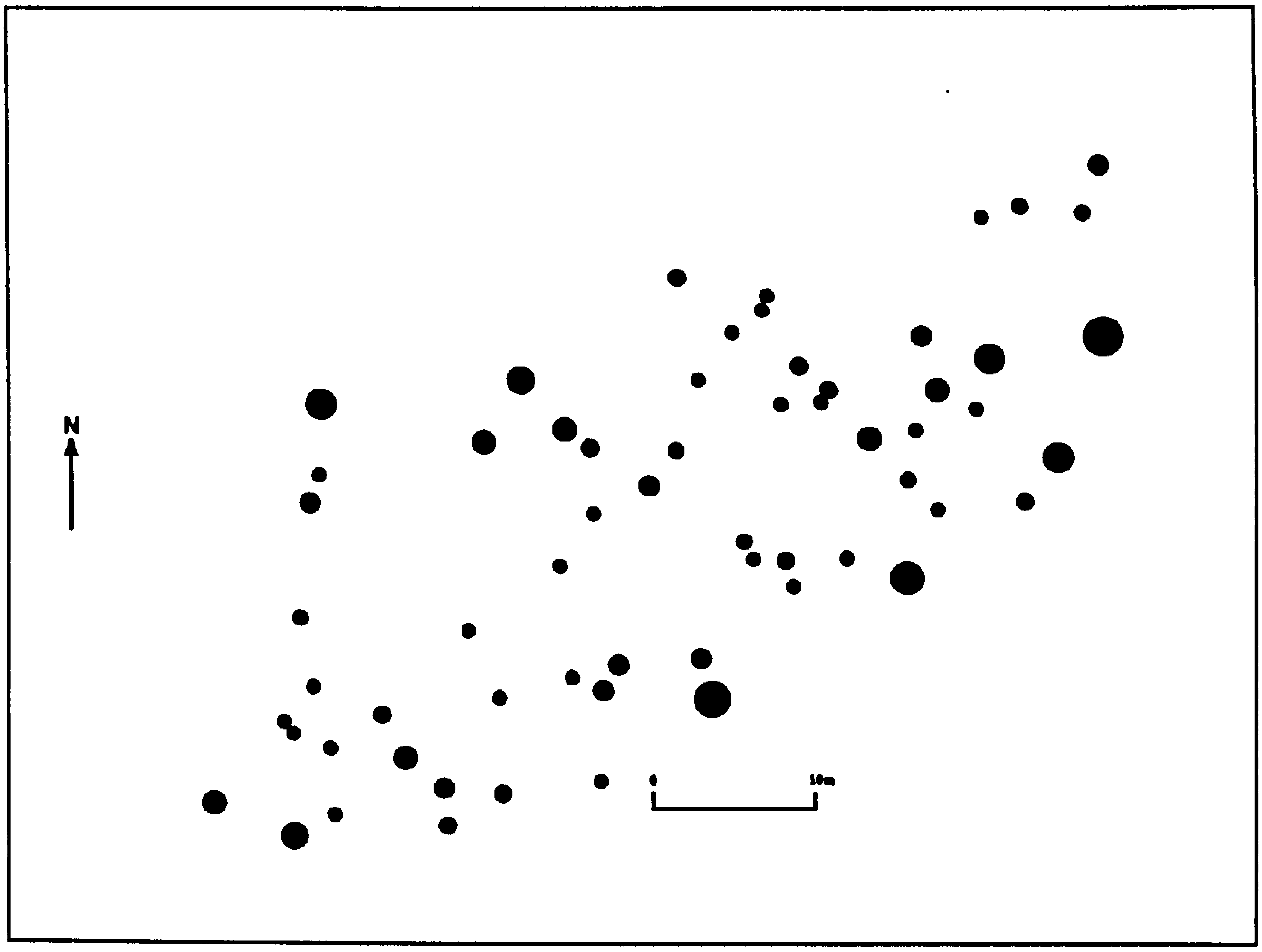


Figure 8.2a. Distribution of stump diameter classes 26-30cm to 186-190 cm at Hightown

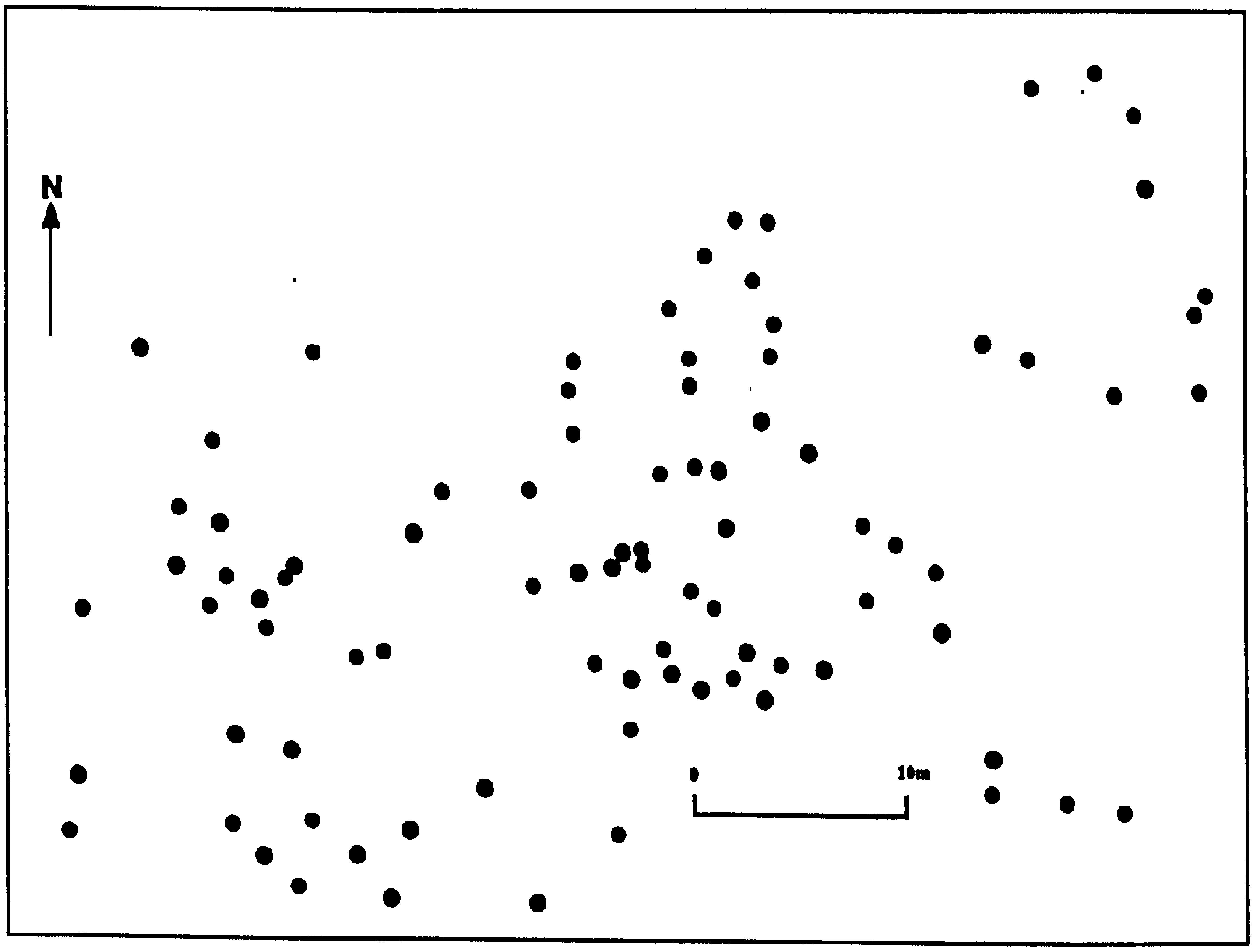


Figure 8.2b. Distribution of 16-20cm & 21-25cm stump diameter classes at Hightown

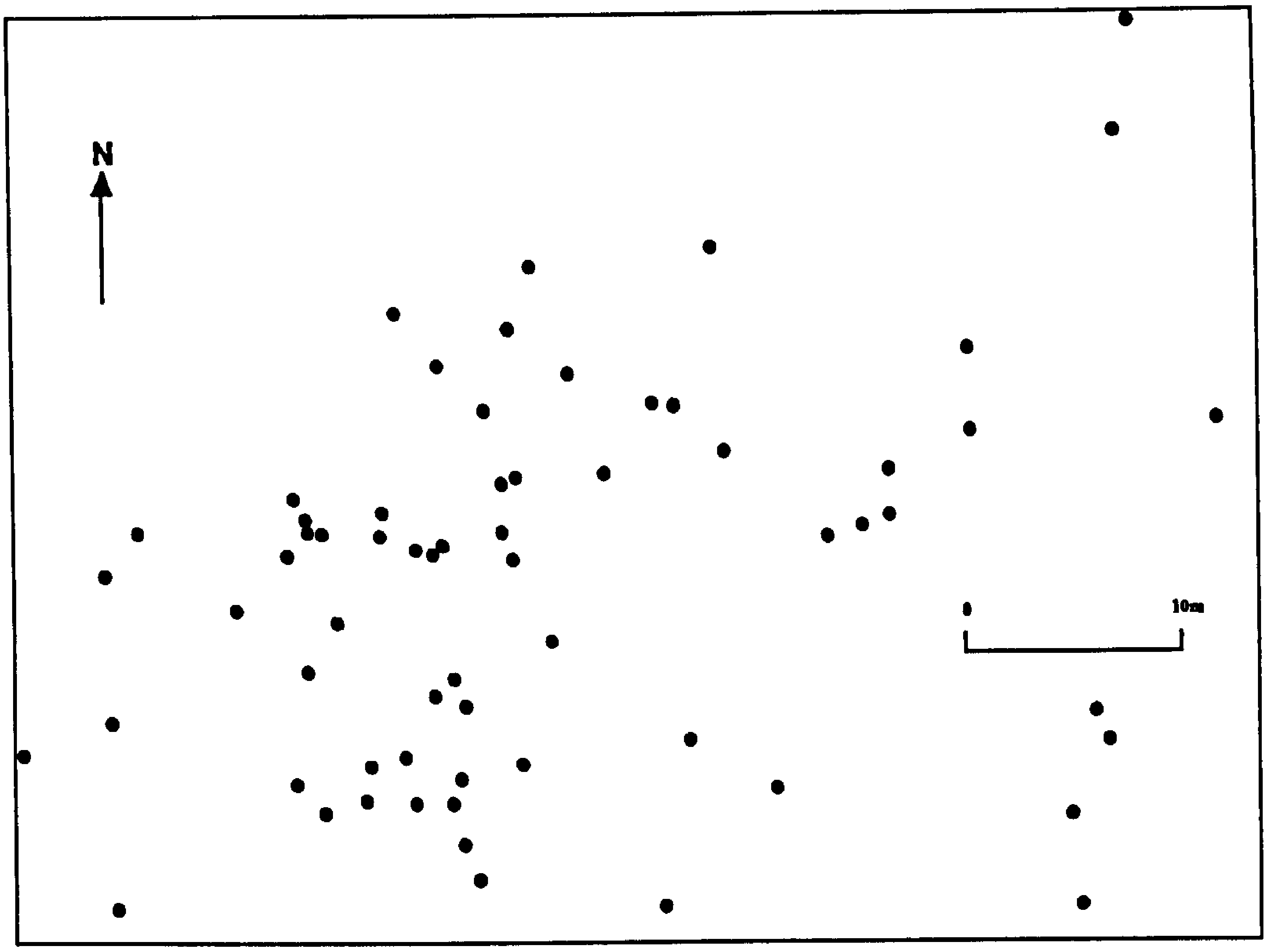


Figure 8.2c. Distribution of 11-15cm stump diameter classes at Hightown

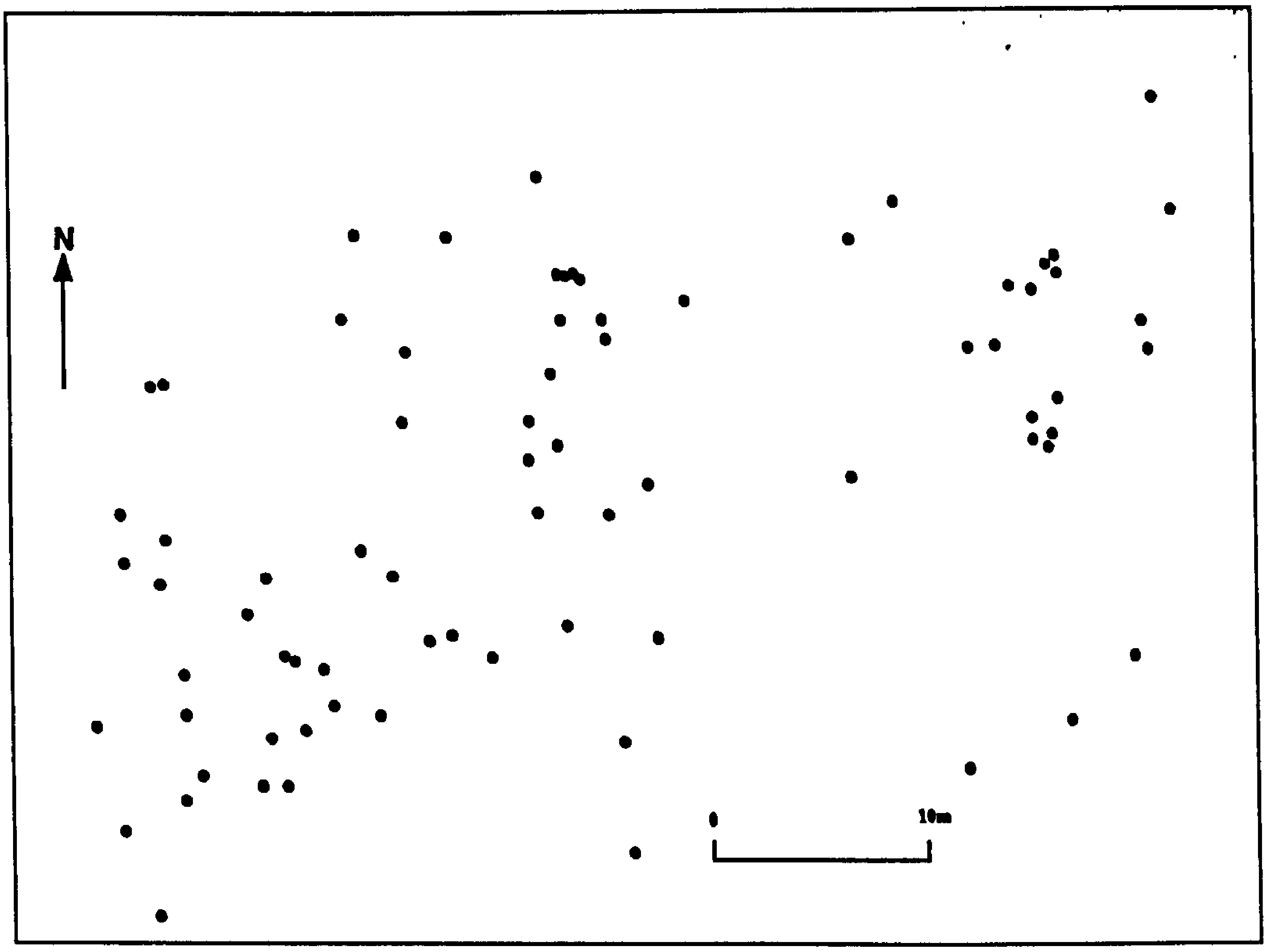


Figure 8.2d. Distribution of 5-10cm stump diameter classes at Hightown

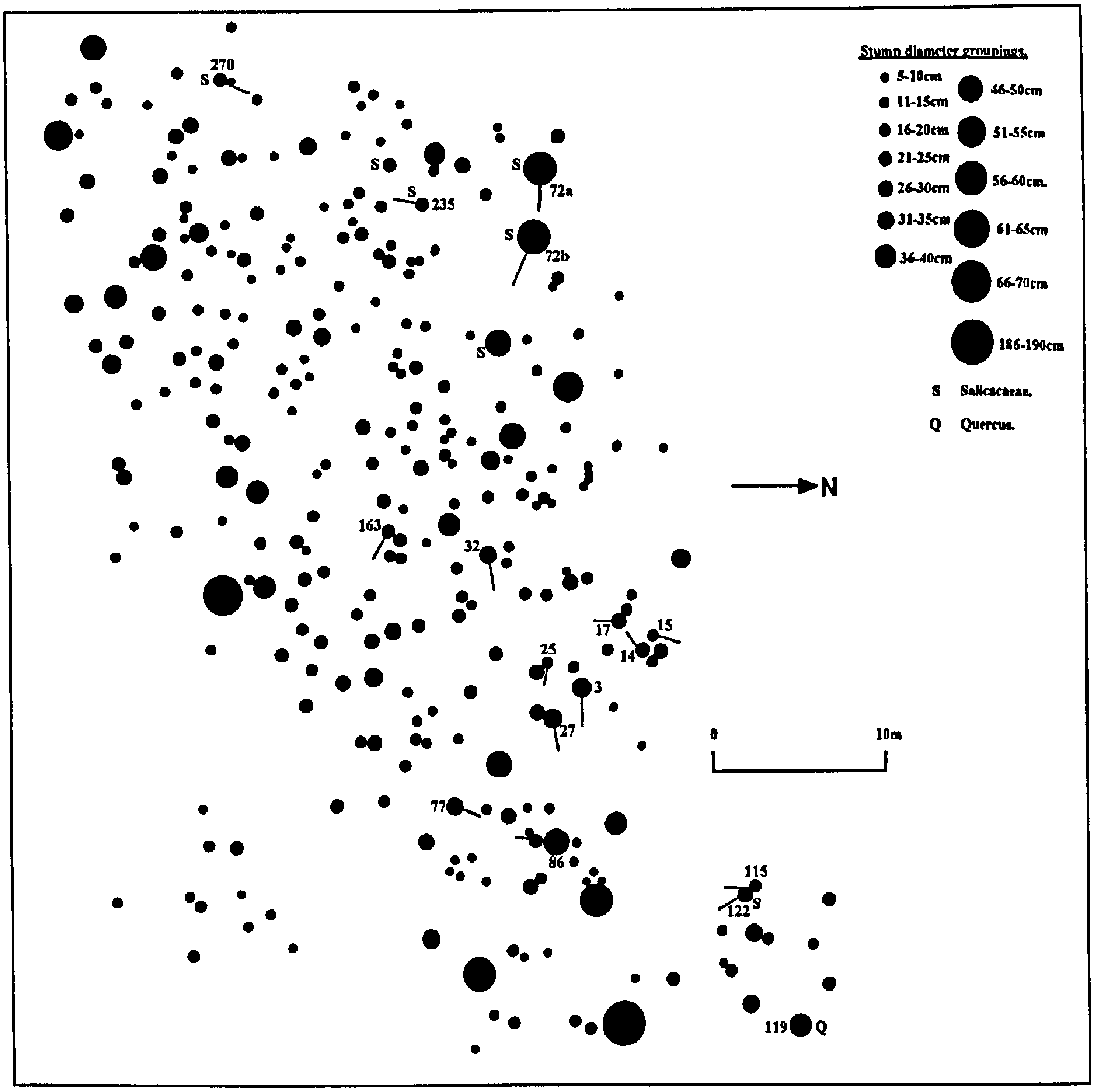


Figure 8.2e. Distribution of all stump diameter classes at Hightown (including angles of fall)

sections. The largest and densest is a central section which has stems which are well distributed apart from a group in the eastern part of the section. Towards the east (landward side of the exposure) there are fewer stumps which appear to be more widely spread than those in the central section, the western (seaward) section has more stumps than the eastern section and again appears to be regularly spaced.

The distribution of the 11-15cm stump diameter class (figure 8.2c) appears to be more random than the previous diameter classes but can be divided into sections. In the eastern section of the exposure, where this stump diameter class occurs, the stumps are either found as groups or as isolated individuals, with large spaces between them. A second concentration of this diameter class appears in the central region of the exposure, they appear to be more regularly spaced than on the eastern side, although areas without stumps appear in the eastern part of the central section. A third concentration of the 11-15cm diameter class can be found in the southwest corner of the exposure. Here the stumps are concentrated within a small area but appear to be regularly spaced. The fourth area, in the seaward (western) section of the exposure has two groups of stumps clumped together with isolated individuals in the western part of the section.

The distribution of the smallest diameter class, 5-10cm (figure 8.2d) follows a similar pattern to that of the 16-20 and 21-25cm classes, with three sections being apparent. One in the east, where there are several clusters of stumps with one or two isolated stumps at the edges of the exposure, these clumps appear to be located between and around the larger stumps. The central section the distribution seems to be opposite of the 16-20cm & 21-25cm classes, in as far as the larger diameters are mainly located in the central and southern part of the section, whilst the 5-10cm class is located in the northern and western area, here the stumps are more evenly distributed with only one clump occurring in the northern part of the section. The western section shows a more evenly spaced distribution located again in the north and west of the section.

From the distribution of the diameter size classes it can be interpreted that the distribution is related to past disturbance events. It is thought that the most likely source of disturbance whether major or minor would be windstorms. From studying the distribution of the presumed windthrown trunks in the deposit it has been ascertained that the major wind direction during storms was probably from the north-west (figure 6.6).

8.2.2. Distribution of Windblown Trees with regard to spatial relationships at Hightown

The majority of the windthrown trunks occur in the northern section of the exposure as can be seen in figure 8.2e, along with their direction of fall.

Stumps 115 and 122 have fallen in similar directions, it is difficult to know whether they toppled independently or that as 115 fell it pushed 122 over as well. Around these two trunks and that of 119 there is a small concentration of smaller diameter stumps which may be related to the fall of the three trunks. It is probable that stem initiation has taken place and competition between the stems has occurred with a few of the smaller diameter classes having survived but being suppressed by several of the larger diameter classes. The near regular distribution between the remaining stumps suggests that this represents a disturbance which occurred sometime in the past.

The direction of fall of trunk 86, has left an area exposed which has permitted the establishment of several stems of 5-10cm and upwards. The group of smaller stems may have been able to become established due to the increase in light and growing space within the area. Another factor which may have aided their establishment was probably the slower growth of the older, larger trunks in the area being unable to reoccupy the growing space left by the fallen trunk. Further growth of the smaller stems after establishment probably became suppressed as they began to compete with the larger diameter trees.

There is a small cluster of small diameter (5-10cm) stumps to the east of trunk 77. This may be due to the increased availability of growing space since the fall of the trunk. The clumped nature of the group suggests that competition between the stems was just underway when the woodland was destroyed by rising water. It appears that in that area there are a small number of smaller diameter classes between larger diameter ones, this may be due to either the trees were standing dead or old and thus having a reduced shading effect, allowing stems to initiate.

In some areas there are no stumps present, this may be due to the areas not being suitable for tree growth, such a the presence of a high watertable or a dense undergrowth, preventing the establishment of tree seedlings. In other areas, there are only small diameter classes present, this may be the result of the area just becoming available for the establishment of stems, due to an adequate fall in the watertable or the availability of bare ground (due to the decrease in dense vegetation, possibly related to the decrease in the watertable) allowing the germination and establishment of stems. The random nature of the stem distributions within those areas suggests that competition between the stems had just begun before the death of the stand.

The area to the north and west of stump 86 and 77 has the greatest concentration of fallen trunks. The trunks in that area are of similar diameter classes. A possible reason for the large number of trunks falling in that area may be due to the increased competition between stems in that area, this would weaken some of the stems and therefore they would be more susceptible to damage and to be being blown over by the next windstorm. But it is not possible with the available data to say whether this occurred at the same time or on separate occasions.

The centre of the exposure possesses the least number of windthrown trunks and the largest number of small diameter stumps. This lack of windthrown trunks may be due to the fact that the small diameter trunks would be more resistant to wind blow than the larger trunks, and those which stood above the main canopy would take the full brunt of the storm. A possible explanation for the large concentration of smaller diameter classes in the western and central part of the exposure may be due to the occurrence of an earlier disturbance, which had blown over the majority of the older (larger diameter) trees, some of which have decomposed leaving no trace, except for those standing at the edge. Hence the 'V' shape may be explained by the prevailing wind direction, which would have been westerly. The random and clumped nature of the smaller trunks suggests that competition for growing space was still occurring at the demise of the woodland.

A possible reason for the concentration of windthrown trunks in the east of the exposure could be due to a second disturbance by a windstorm, whereby the younger and therefore more supple stems to the west could resist the force of the wind, which would then hit the taller standing trees further inland and blow them over.

Although it is not possible to be absolutely sure about the cause of the spatial distribution of the diameter classes across the deposit, it does seem plausible that the distribution is in part the effect of frequent minor disturbances which has produced a multicohort stand. It appears that the frequent disturbances which are most likely to be windstorms, firstly blew down trunks in the west of the deposit, leaving some standing, the sudden availability of growing space and the possible exposure of bare ground due to the pits and mounds caused by the toppled stems, enabled seedlings to become established. The possible sources for those seedlings would be the still standing trees at the periphery and eastward (landward) side of the exposure.

As these stems were initiated and began to compete with each other, i.e. as entering the stem exclusion stage, a further windstorm hit the trees further eastward (as the protecting trees to the west had already been blown down in the last disturbance). It is possible that the second disturbance was not as severe as the previous one, leaving more trees standing and therefore preventing a large number of new stem from initiating. A few stems could have been blown down in the western area, especially those either weakened by competition or shallow rooted, but due to the close spacing and the more rapid growth of the younger stems, few new stems were allowed to become established. The random distribution of stems across the exposure may be due to the lack of availability of ideal microsites and therefore stems become concentrated in those favourable areas inducing strong competition between individuals, explaining the small diameter sizes towards the west.

The regeneration of the woodland at Hightown was recognised by Clapham *et. al.* (1997) although the actual mechanism for this regeneration was not realised at the time the paper was presented in 1995.

8.3. Distribution of Stump Diameter and Girth Measurements at Wolla Bank and Anderby Creek

The distributions of stump diameter and girth measurements of the submerged forest exposures at Wolla Bank and Anderby Creek are more complicated than those at Hightown due to the submerged forest being present in small peat platforms. The number of trunks at Wolla Bank and Anderby Creek, totalled seventy-one compared to the 298 at Hightown. The presence of the exposures in small islands (see chapter 5) also make the interpretation of spatial distribution of the tree remains more difficult.

8.3.1. Wolla Bank

Figure 8.3a shows the distribution of stump diameter classes per hectare at Wolla Bank. The distribution shows a normal curve but with a skew to the right, although not as far over to the right as shown for Hightown (figure 8.1a), suggesting that more older trees may be present. Again, the skewing to the right might be explained by a few trees entering the newly available area at first and as the site becomes modified, more trees were able to enter, this interpretation may hold true for this exposure of submerged forest. At Hightown the main species was birch. but here at Wolla Bank and Anderby Creek, the dominant species are oak, alder, ash and willow, with very few birch trees were identified.

If the girth distribution is taken into consideration (figure 8.3b) a similar picture can be seen with a normal/slightly right skewed distribution re-enforcing the interpretation that a few trees entered the stand at first, followed by more at a later date. This interpretation may well be biased by the lower number of tree remains present at this site. Another difference at Wolla Bank and Anderby Creek from Hightown is the wider spread of diameters of the stumps and trunks suggesting yet again that a few trees invaded at first.

8.3.2. Anderby Creek

The distribution of stump diameter classes per hectare at Anderby Creek is shown in figure 8.4a. The stump measurements from both of the exposures at Anderby Creek are combined to produce the figures. The distribution of the stump diameters follows a 'reverse-J' pattern meaning that there are a more smaller stumps i.e. most likely to be younger stems, than there are old (larger diameter). This distribution is often found in stands where the disturbances are regular and therefore contain many small stems and fewer, large old stems. If the distribution of girth measurements is considered (figure 8.4b) it can be seen that a bimodal or even trimodal pattern is apparent, this may be a reflection of the number of disturbances (i.e. two or three) suggesting the presence of a multicohort stand. It is necessary to be cautious about such an interpretation due to the recording of a small number of tree remains at Anderby Creek because and thus may represent an over-interpretation.

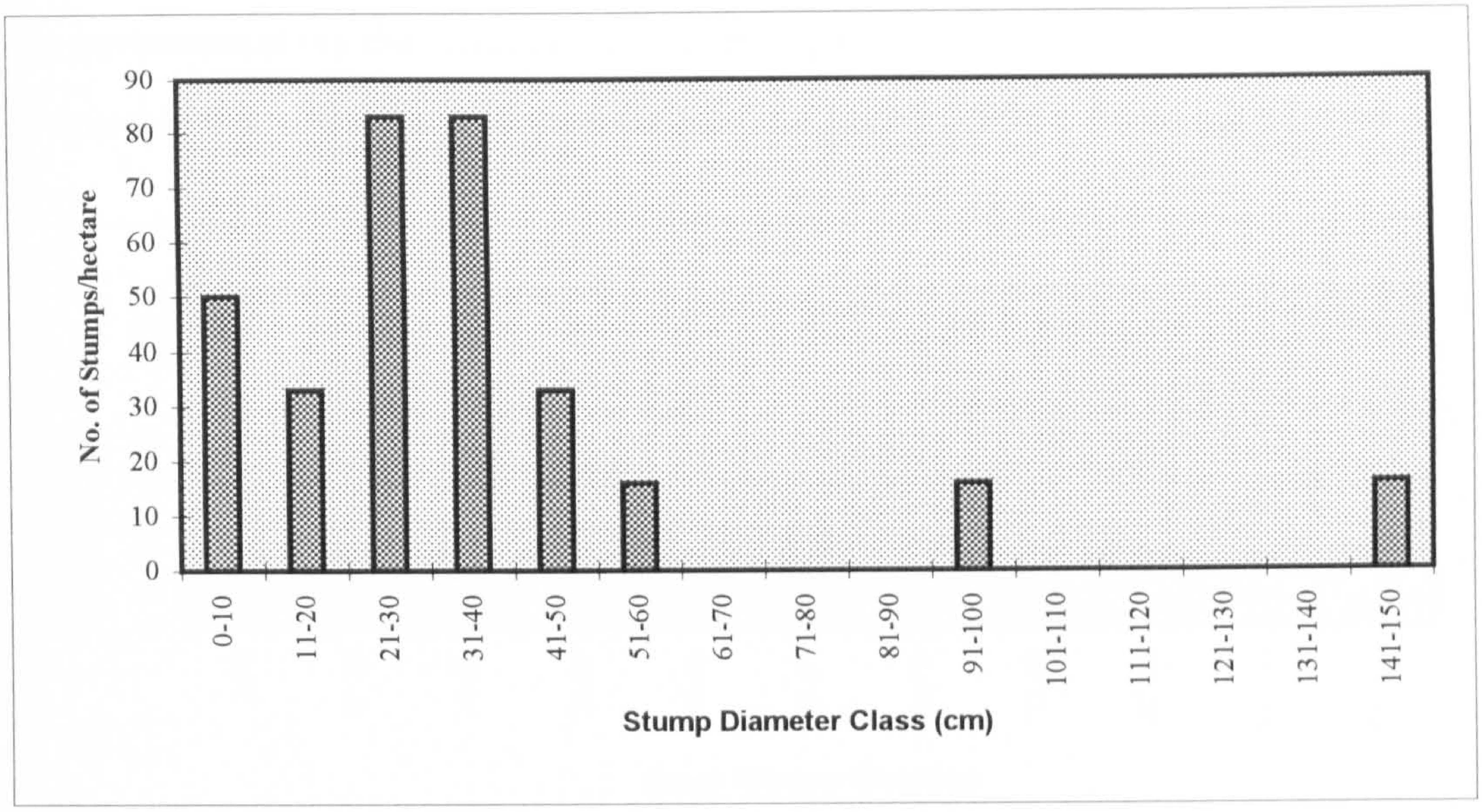


Figure 8.3a. Distribution of Stump Diameter Classes per hectare at Wolla Bank, East Lincs.

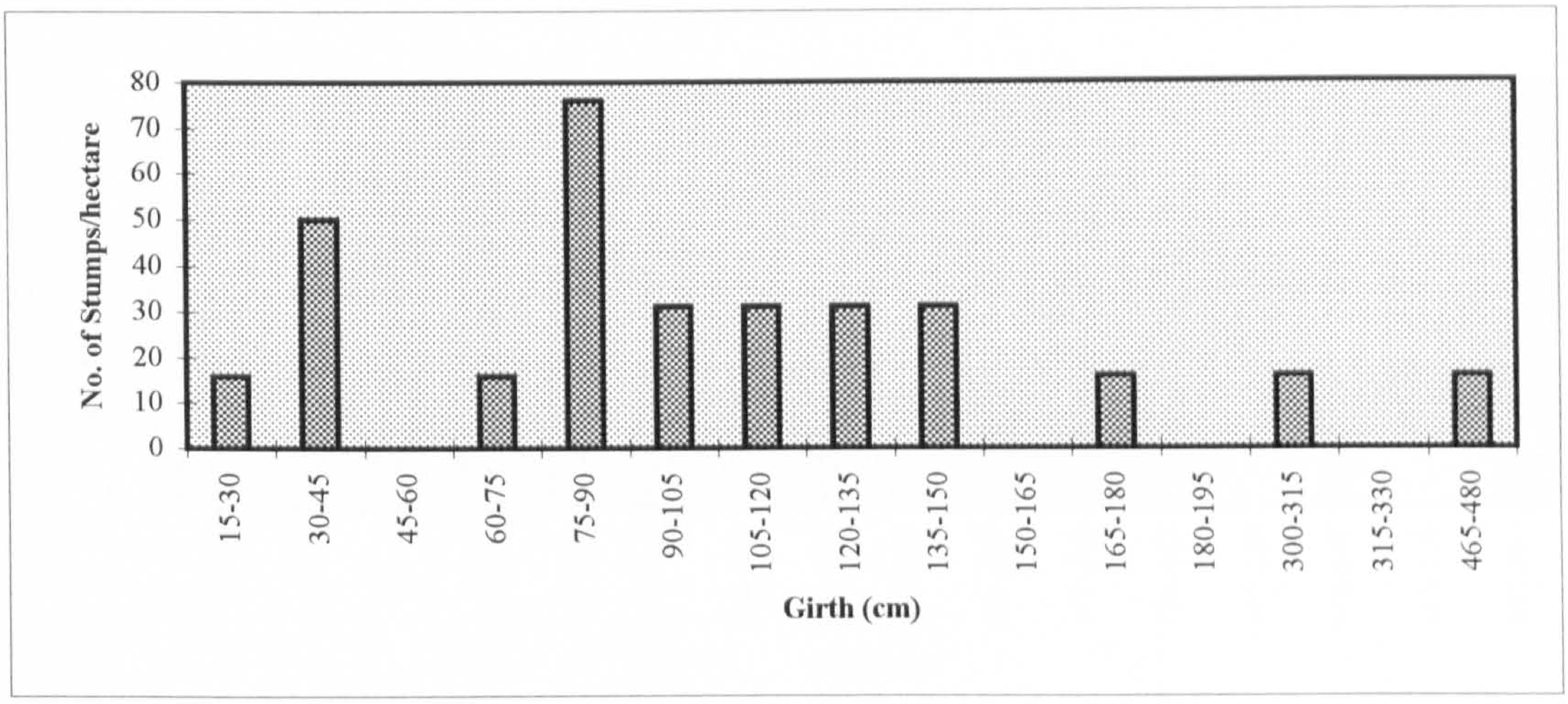


Figure 8.3b. Distribution of Stump Girth Classes per hectare at Wolla Bank, East Lincs.

Broad age ranges, which in this case are represented by diameter and girth measurements can develop in single-cohort stands if the initial invading stems grow slowly and do not exclude later stems. Broad age ranges usually occur on poor sites or where the species and regeneration mechanisms promote slow growth. Poor weather conditions such as frost damage, animal damage via browsing or where few stems initiate each year can also produce broad age ranges. The number of stems will increase once the initial stems modify the environment via the reduction of waterlogging, providing shelter and producing more favourable microsites for initiation (Oliver and Larson 1996). Although a broad age range is present at both Wolla Bank and Anderby Creek, it is not thought to be due to slow colonisation of the area, although the species such as oak and ash grow more slowly than alder and willow. The majority of the stumps are 11-20cm and 51-60cm diameter classes suggesting that they have been established for some time. What may be represented here is the old-growth stage of stand development, where the large/older trees gradually die and are replaced by younger trees, this stage is not usually reached for many (between 60-150

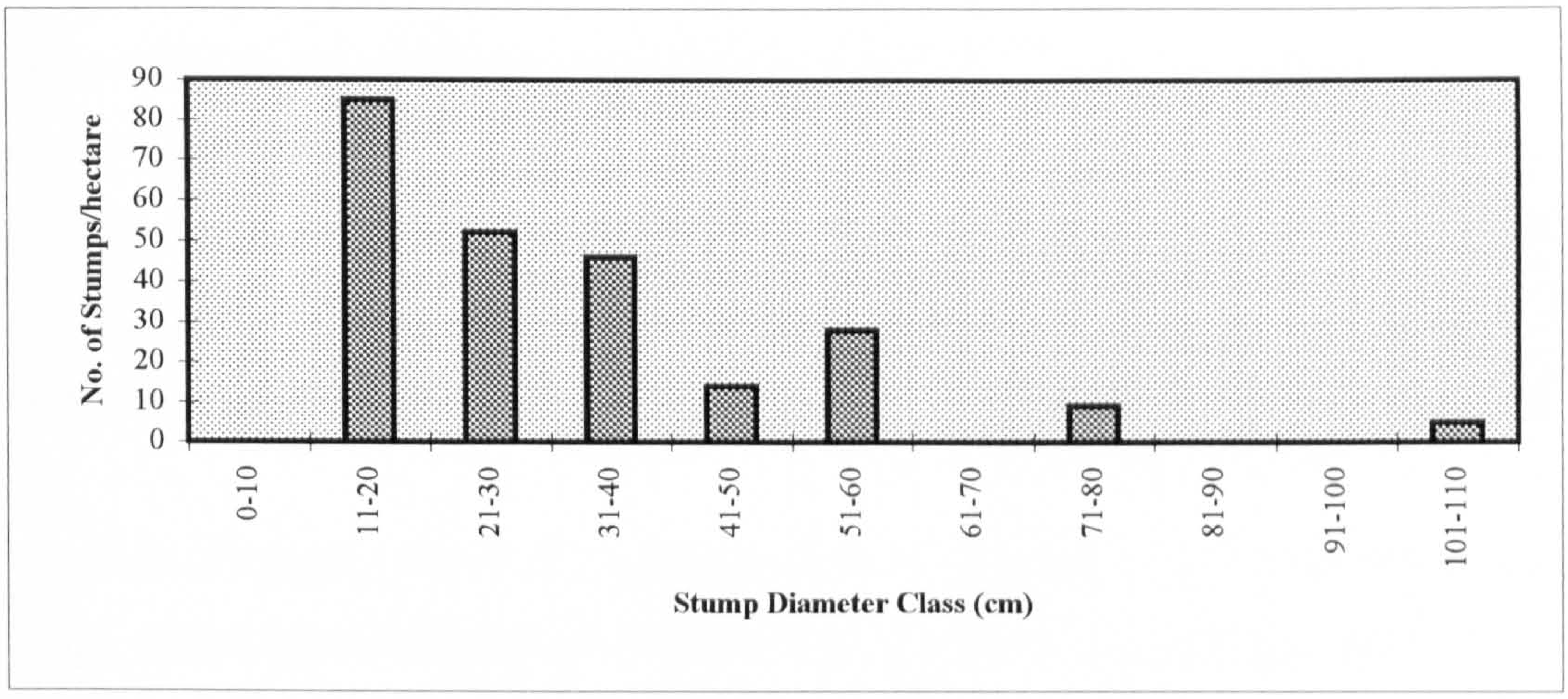


Figure 8.4a. Distribution of Stump Diameter Classes at Anderby Creek, East Lincs.

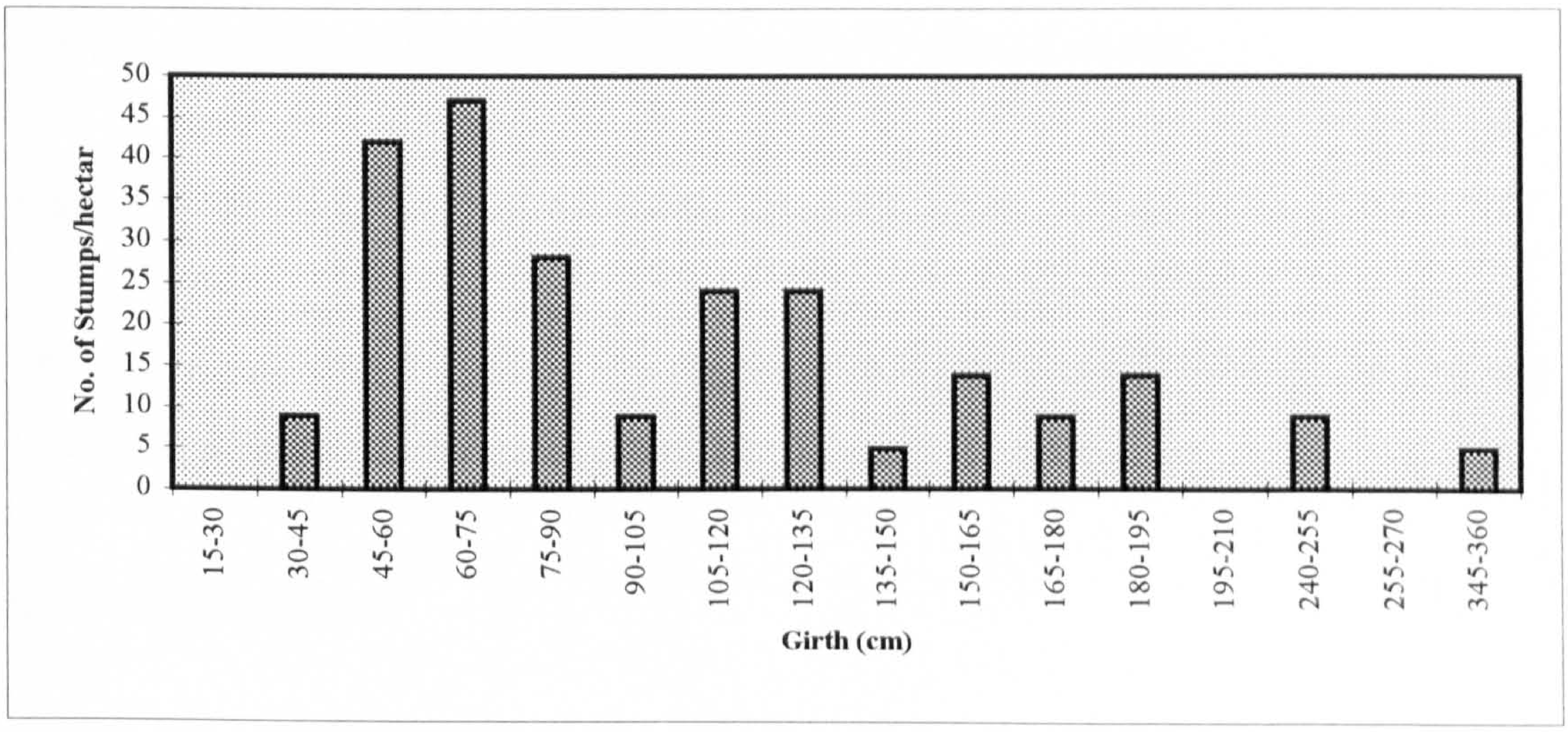


Figure 8.4b. Distribution of Stump Girth Classes at Anderby Creek, East Lincs.

years) years after stand initiation (table 7.1). This might explain the bi/trimodal girth distribution of trees at Anderby Creek, so that, when the old trees die, they are replaced by trees which have either survived as advance regeneration or have been released from suppression by the availability of more growing space. There does not appear to be any major disturbances recorded at these sites, although the possibility of minor ones occurring cannot entirely be ruled out. Although the presence of a larger number of fallen trunks at this exposure and the lack of small-sized trees suggests that some trees may have died via competition and then been blown over and rapidly replaced by trees already present.

The lack of a large number of the smaller stems suggests that the woodland has a broad age range, where the distribution of diameter classes is not so much connected with disturbances but by the death of old and suppressed trees which are being gradually replaced by younger/smaller diameter trees. These trees could be those which have been suppressed or present as advance regeneration (hence the small diameters, even though they could be the same age as the trees they are replacing). This suggests that this woodland was either at the understorey reinitiation stage or the old-growth stage.

8.3.3. Spatial Analysis at Wolla Bank and Anderby Creek

The spatial distribution of all stumps and trunk remains from Wolla Bank and Anderby Creek are presented in figures 8.5 and 8.6a & b.

8.3.3.1. Wolla Bank

As has been noted in section 8.3, the size of the exposures at Wolla Bank and Anderby Creek may make the interpretation of the spatial data more difficult than that at Hightown, even so it is thought that an interpretation can be made to help characterise the deposits.

Figure 8.5 shows the distribution of stumps and trunks at Wolla Bank. The stumps are widely spaced with one area of fallen trunks. The wide spacing of the stumps suggests that the woodland at this part of the exposure may have reached maturity. There appears to be some pairing of stumps in three places of the exposure suggesting that each pair could have initiated at the same time and competition has led to one stem suppressing the other, or one is protecting the other. Another hypothesis could be that the larger stem has died and has been replaced by the smaller one, although it is probable that the former situation is the more likely scenario.

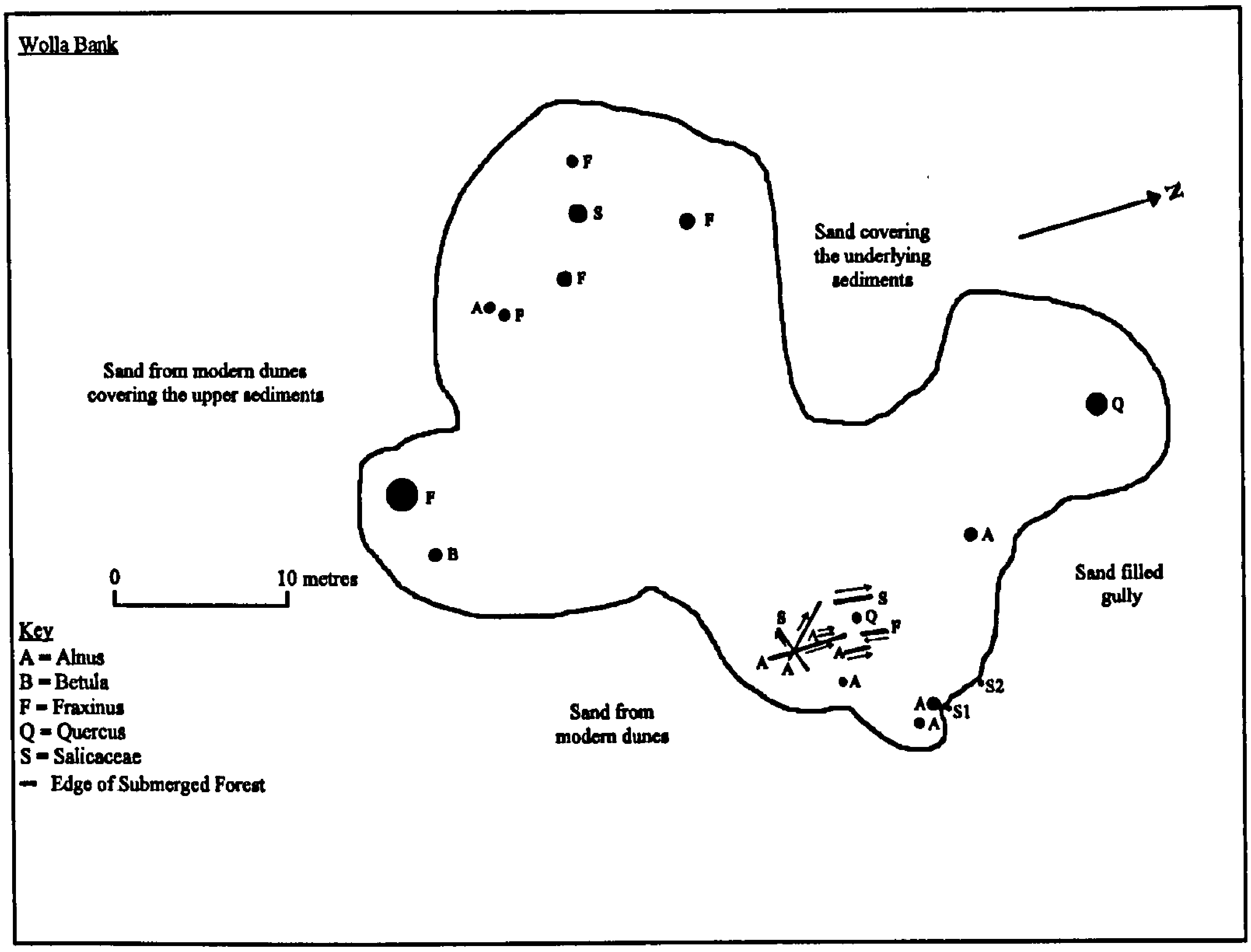


Figure 8.5. Spatial distribution of stumps and trunks at Wolla Bank

8.3.3.2. Anderby Creek

The spatial distribution of stumps and trunks at both exposures are again widely spaced (figure 8.6a & b). As at Wolla Bank there appears to be pairings of stumps and in this case the majority of pairings have one stump larger than the other, which suggests that there is either competition between the two stems where the larger one limits the growth of the other or the larger stem represents a dead/dying tree and the smaller one has become established under the shelter of the larger stem, another possible explanation is that they are the remains of multi-stemmed individuals with the smaller stump being the offshoot.

The large spacings between these pairings suggests that either advance regeneration or the old-growth stage has been reached in both of the platforms at Anderby Creek.

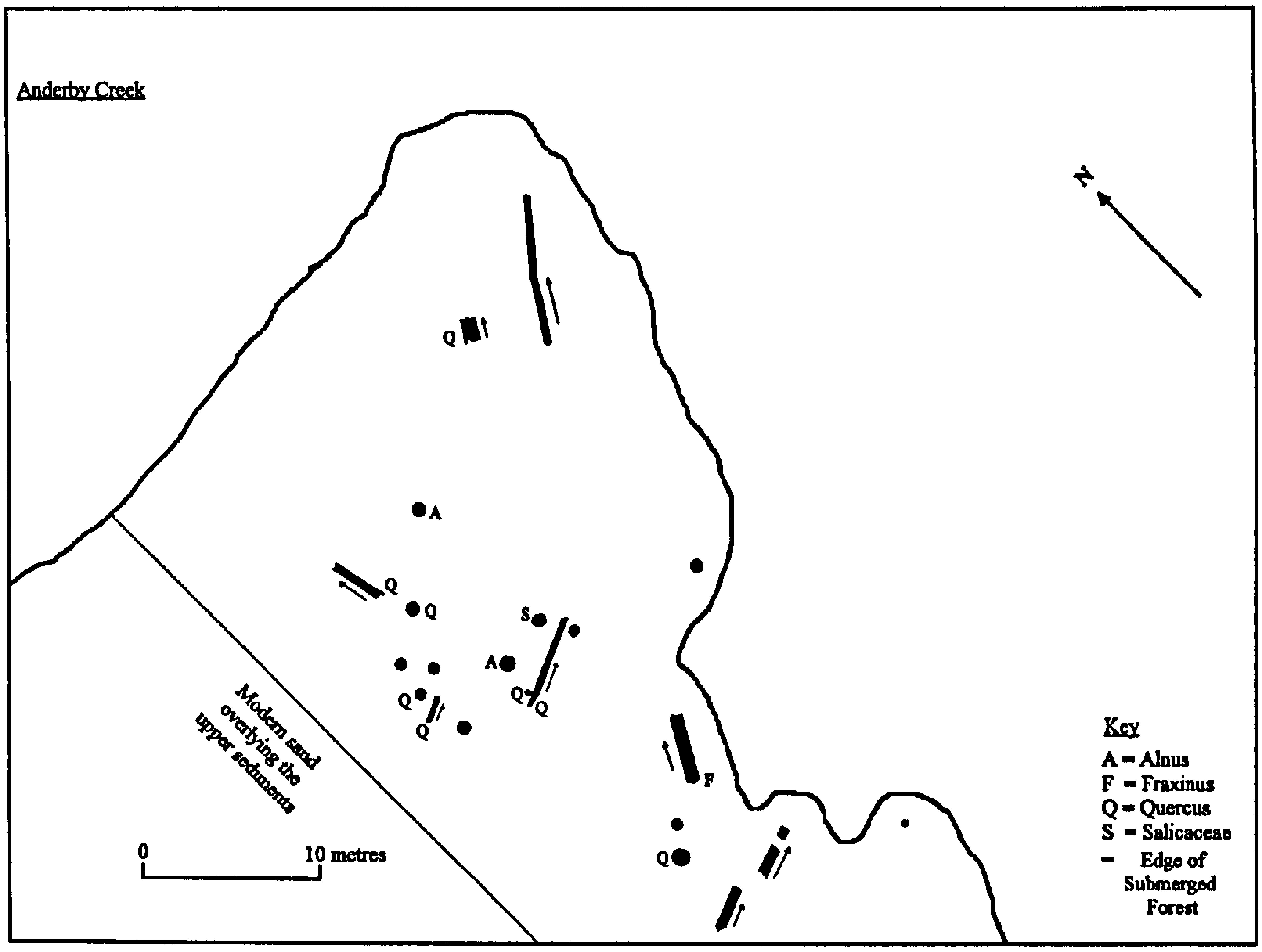


Figure 8.6a. Spatial distribution of stumps and trunks at Anderby Creek

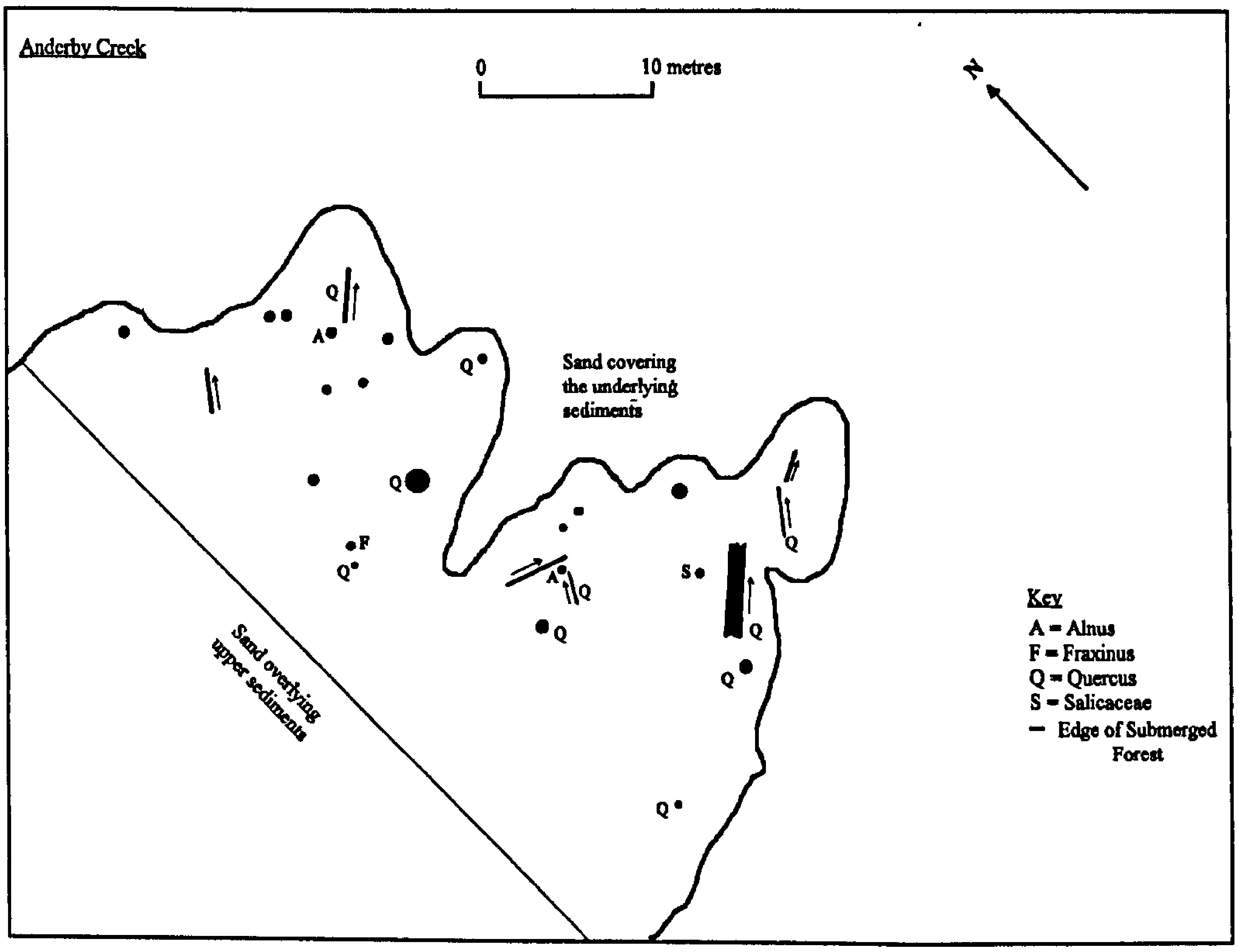


Figure 8.6b. Spatial distribution of stumps and trunks at Anderby Creek

8.3.4. Distribution of the windblown trees with regard to spatial relationships at Wolla Bank and Anderby Creek

At Wolla Bank, the number of fallen trunks measured was seven (section 5.9.4), three trunks were of 0-10 diameter class with two trunks in each of the 11-20cm and 21-30cm diameter classes.

At Wolla Bank the fallen trunks appear in one area and have fallen in all directions (figure 8.5) suggesting that they may have been suppressed stems and toppled when already dead or dying. This competition/suppression would have made them susceptible to and weakened by insect attack (Oliver & Larson 1996) and therefore would have been easily toppled by light winds bringing down those close to them which were also weakened or shallow rooted.

At Anderby Creek, sixteen fallen trunks were measured, no individuals were recorded for diameter classes 0-10cm, 41-50cm and 61-70cm. The largest number was recorded in the 11-20cm class (six). Three individuals were recorded in the 21-30cm and 51-60 cm classes, and two in each of the 31-40cm and 71-80cm classes.

The fallen trunks appear to have toppled in similar directions (see figure 8.6) and the sizes do vary. The fall of the larger trunks may be due to old age as the trees may have been weakened by disease or insect attacks and therefore easily toppled, whilst the smaller ones may have been suppressed individuals, weakened by disease and insects via competition with the surrounding trees.

8.4. Comparison of the density and basal area measurements for Hightown, Wolla Bank and Anderby Creek

The density and basal area measurements for all three submerged forest deposits can be seen in table 8.1. The highest density is recorded at Hightown with 1511 stems per hectare with Wolla Bank and Anderby Creek having densities of a similar magnitude, 325 ha^{-1} and 236 ha^{-1} respectively. The density of the woodland at Hightown is rather high and does not fit any of those densities cited in the literature (see table 7.3), whilst those Wolla Bank and Anderby Creek fit with Auten's (1941) measurements for broad-leaved woodland. A possible reason for the high density recorded at Hightown could be related to the small size of the stems recorded and linked to the developmental stage and disturbance history of the submerged forest. At Wolla Bank and Anderby Creek the densities recorded there may also reflect on the developmental and disturbance history of the deposits.

The basal area measurements for Hightown and Wolla Bank are very similar and do not seem to correspond to any of the recorded basal area data for modern woodlands (see table 7.4). The closest they correspond to is that of coniferous woodlands, mostly growing in adverse conditions. At Hightown the large number of stems may be the reason for this high figure and again is a reflection of the developmental stage and disturbance history of the submerged forest. At Wolla Bank, the high basal area measurement might be explained by the presence of a higher number of larger diameter trees which is a reflection of the later developmental stage present there. At Anderby Creek, the much lower basal area of 29.2 m^2 ha^{-1} is much more in line with records of modern broadleaved virgin woodland (Auten 1941 and see table 7.4). This is more a true reflection of the later developmental stage indicated by the diameter and girth distributions. The spatial distribution of the trees is also reflected in this basal area figure and supports the interpretation that the trees were at wider spacings again suggesting a later developmental stage.

Submerged Forest	**Density (N ha^{-1})**	**Basal Area (m^2 ha^{-1})**
Hightown, Merseyside	1511	72.45
Wolla Bank, East Lincs.	325	65.59
Anderby Creek, East Lincs.	236	29.2

Table 8.1 Table showing the density (N ha^{-1}) and Basal Area (m^2 ha^{-1}) of the Tree Remains at the Submerged Forest Exposures

8.5. Comparison of the percentage of diameter class sizes at Hightown, Wolla Bank and Anderby Creek

If the percentages of each diameter class at the three exposures of submerged forests are compared a great difference between the west coast and east coast exposures can be seen (table 8.2).

The percentage of the smallest diameter classes (0-10 and 11-20cm) are similar at Wolla Bank and Anderby Creek, (25.15 and 35.4 % respectively) whilst at Hightown 67% of the stumps are of these lower diameter classes. This supports the interpretation of the evidence so far that Wolla Bank and Anderby Creek represent woodland stands that are at a later developmental stage than that at Hightown. The higher percentage of smaller diameter classes at Hightown supports the interpretation that the woodland was subjected to more major disturbances than either stand on the east coast.

The percentage of the next four diameter classes combined (21-60cm) are 65.1% and 58.7% for Wolla Bank and Anderby Creek, while at Hightown the next five diameter classes represents 32.6% of the stumps and trunks at Hightown. This again supports the interpretation that the exposures on the east coast represent stands at a later developmental stage, most likely either advance regeneration or old-growth stages and that at Hightown due to the disturbances the stand has a multicohort character and therefore more of the earlier developmental stages are present at Hightown, mainly the stand initiation and early stem exclusion stages. Some areas, especially those where the larger/older stumps are found could also be a later developmental stage.

8.6. Conclusions

The evidence from the distribution of diameter/girth classes and spatial relationships between the diameter/girth classes and the percentage of each diameter class at Hightown, Wolla Bank and Anderby Creek has shown that two different developmental stages are present. At Hightown, the evidence suggests that a complex multi-cohort stand is present due to the large number of small diameter stumps and the more or less clumped and random spatial distribution of these stumps. It has been interpreted that a large proportion of the stand is at the stem initiation stage or entering the stem exclusion stage. In other parts especially in the areas of larger diameter trunks which have survived previous disturbances and are more regularly spaced are at a later developmental stage such as old growth.

The exposures at Wolla Bank and Anderby Creek have a broader age range of stumps and trunks present and are more widely and regularly spatially distributed. This has been interpreted as the exposures having reached the old-growth developmental stage.

	Submerged Forest		
Diameter Class (cm)	**Hightown, Merseyside**	**Wolla Bank, East Lincs.**	**Anderby Creek, East Lincs.**
0-10	25.6	15.15	-
11-20	41.4	10	35.4
21-30	20.5	25.15	21.76
31-40	5.3	25.15	19.6
41-50	4.6	10	5.8
51-60	1.6	4.8	11.7
61-70	0.6	-	-
71-80	-	-	3.8
81-90	-	-	-
91-100	-	4.8	-
101-110	-	-	2.1
141-150	-	4.8	-
181-190	0.3	-	-

Table 8.2 Table showing the percentage of each diameter class at each Submerged Forest Exposure

8.7. Ecological Interpretation of the Submerged Forests

The following sections deal with the interpretation of each submerged forest via the use of the methodology outlined in section 7.7. The methodology is reiterated here.

The taxa used to determine which National Vegetation Classification communities are present at the two submerged forests are given in Appendix II, tables, II.4a, b & c; II.5a & b and II.6a & b.

In the British Plant Communities publications, (Rodwell, 1991-1995), an index of the plant species found in each of the communities (in this case woodlands and scrub, aquatic, swamp and tall fen) have been produced. Each index lists the species alphabetically with the code numbers of the NVC communities in which they occur thereafter (Rodwell, 1991-1995). These indices have been used in this thesis to allocate the taxa recorded from the samples to the plant communities in which they are found. Once this has been accomplished, the scores for the each community type are calculated and those with the highest scores (the highest number of species) are considered to be the most likely communities represented by the plant macrofossils.

This process is carried out in two stages. The first treats the deposit as a whole, producing an overall list of the community types present. The second stage involves using the same method but on each individual sample, in order to detect any possible changes through the profiles. The results are displayed in tables 8.3-8.9. Each table shows the number of taxa recorded for each community type. The total number of indicator taxa used for each sample is given at the base of each column.

8.7.1. Wolla Bank Section One

From Wolla Bank section one, a total of seven taxa were considered as community indicators (table 8.3). The woodland indicators dominate the profile with tall-fen community indicators and aquatic ones rarely being represented. There are four woodland communities which are represented by a score of five (W2, W5, W7 & W8), with four communities being represented by a score of four (W1, W6, W10). This suggests that there are elements of a least four woodlands present as identified by the indicator taxa, these woodlands are in general, wet woodlands although the lower scores of four for W10 is a drier woodland. The tall-herb fen communities have overall lower scores, with the highest being represented by S24 & S25.

The overall interpretation for this profile is that there are representatives of both wet and drier woodlands and tall-herb fen vegetation, the most likely scenario is that the tall-herb fen communities may have formed part of the woodland field layer and may be remnants of the previous vegetation on the site. The low number of taxa present in this profile may be due to the fact that it was located next to an *Alnus glutinosa* stump. This may have had an umbrella effect and may have prevented vegetation from growing under its shade.

8.7.1.1. Changes through the profile

Of the seven samples analysed from the profile, only three had the required number of taxa present, one had five taxa, one had four and one had three, the results are presented in table 8.3. The uppermost sample had five taxa, the woodland communities were represented mainly by W1, W2, W5, W7, W8 and W10. W1, W2, W5 and W7 are wet woodland types whilst, W8 and W10 are of drier soils. Aquatic taxa were rare in this sample. The tall-herb vegetation was also rarely present with S24 and S25 being represented by two taxa each. This suggests that the sample was dominated by woodlands which had little undergrowth with the wet woodland present in the wetter areas and the drier on the higher ground, with tall-herb fen vegetation occurring as undergrowth.

The sample from 7.0-10.cm in the profile had woodland communities represented by the taxa were W1, W2 and W5. These are all wet woodland communities which suggests that the woodland was wetter than the previous sample. The tall-herb fen communities were dominated by S24 and S25 suggesting that the environment was damper than the previous sample.

The final sample at 10-14.5cm with three taxa present was dominated by W2, W5, W7 and W8 woodland communities, again suggesting a mixture of dry and wet woodland types. No aquatic communities were present. The tall-herb fen communities were poorly represented, suggesting that the woodland communities dominated this sample.

Therefore it is possible to see a change from a drier environment to a wetter one with a return to a drier one through time. This alternation of the watertable may well be due to the rise in the watertable caused by a sea-level rise, which was counter-balanced with the rise in the land surface above the watertable by the increased production of organic matter by the fen vegetation. Woodland communities are represented throughout the profile.

Community	Overall	0-4.5cm	7-10cm	10-14.5cm
W1	4	3	4	2
W2	5	3	4	3
W3	4	2	3	2
W4	2	2	2	1
W5	5	3	4	3
W6	4	2	3	1
W7	5	3	3	3
W8	5	4	3	3
W9	3	2	2	2
W10	4	3	2	2
W11	2	1	1	2
W12	2	1	1	2
W13	1	1	1	1
W14	2	2	2	2
W15	1	1	1	1
W16	1	1	1	1
W17	1	1	1	1
W21	2	2	1	1
W22	2	2	1	1
W23	1	1	1	1
W24	2	1	1	0
W25	2	2	1	1
Community	Overall	0-4.5cm	7-10cm	10-14.5cm
A4	1	1	0	0
A11	1	1	0	0
Community	Overall	0-4.5cm	7-10cm	10-14.5cm
S1	1	0	1	0
S2	1	0	2	0
S3	2	1	2	1
S4	2	1	2	1
S5	1	0	1	0
S6	2	1	2	1
S8	1	0	1	0
S13	1	0	1	0
S14	1	0	1	0
S17	2	1	2	1
S18	2	1	2	1
S20	1	0	1	0
S21	1	0	1	0
S23	2	0	1	0
S24	3	2	3	1
S25	3	2	3	1
S26	2	1	2	1
S27	1	0	1	0
S28	1	1	1	1
No. of Indicator taxa	7	5	4	3

Table 8.3. Table showing the NVC Indicator Taxa Scores for Wolla Bank, Section 1 (For the names of the woodland, aquatic, swamp and tall-fen communities see appendix II, tables II.1, II.2 & II.3)

8.7.2. Wolla Bank Section Two

A total of twenty-two taxa were used as indicators for communities represented in the profile from section two (table 8.4a & b). The woodland community represented by the highest score was that of W5 with seventeen taxa, W1, W2, W3 and W7 were represented by twelve taxa. The aquatic communities were rarely represented whilst the tall-herb fen communities were dominated by S24.

This difference between the sections at Wolla Bank is most likely to be due to the larger number of taxa present and is probably more representative of the vegetation than that of section 1 (section 2 was located one metre away from section one and was probably not affected by the umbrella effect of the alder tree). Overall, the dominant woodland type was W5 a wet woodland community with an associated vegetation of tall-herb fen species present in community S24 and is most likely to be part of the understorey of the woodland.

8.7.2.1. Changes through the profile

Of the eight samples analysed from section two, the top five samples from 0-14cm produced the required number of taxa. In the sample 0-3.5cm, sixteen taxa were used as indicators of community types, twelve taxa were found to indicate W5 communities with eleven being found in W6 and ten each for W1 and W2. These are all wet woodland communities. Aquatic communities were poorly represented and the dominant tall-fen community was S24 followed by S25.

Fifteen taxa were used as indicators in the sample 3.5-7.0cm and again the dominant woodland type was that of W5 with twelve representatives, the aquatic communities were poorly represented. S24 was the dominant tall-fen type with S6 a swamp community also being recorded for this sample.

Community	Overall	0-3.5cm	3.5-7cm	7-8cm	8-10cm	10-14cm
W1	12	10	10	7	6	4
W2	12	10	9	8	6	5
W3	12	9	9	7	5	5
W4	9	7	6	4	3	4
W5	17	12	12	8	6	6
W6	11	11	10	7	5	3
W7	12	8	9	6	4	6
W8	11	7	8	5	4	6
W9	9	6	6	3	2	4
W10	10	8	7	4	3	4
W11	6	4	3	2	2	3
W12	6	4	4	2	2	3
W13	3	3	2	2	1	1
W14	6	4	5	3	3	3
W15	5	5	3	2	2	2
W16	6	6	3	2	2	2
W17	5	4	3	2	2	2
W18	4	4	2	1	1	1
W19	3	2	2	1	1	1
W20	2	1	1	0	0	0
W21	6	5	6	2	2	2
W22	1	1	2	1	1	1
W23	1	1	1	1	1	1
W24	6	4	5	2	2	2
W25	3	3	3	1	1	1

Table 8.4a. Table showing the NVC Indicator Taxa Scores for Wolla Bank, Section 2 (For the names of the woodland communities, see Appendix II, table II.1)

From 7-8cm, eight indicators were present and the dominant woodland communities were those of W2 and W5 with W1, W3 and W6 also present, no aquatic communities were present and the tall-fen communities appear to be dominated by S24. The sample below this contained six taxa used as indicators. Here, wet woodland types, W1, W2 and W5 were the dominant communities, aquatic communities were not represented and the tall-fen communities were represented, although reduced, by S24.

Community	Overall	0-3.5cm	3.5-7cm	7-8cm	8-10cm	10-14cm
A1	1	0	1	0	0	0
A4	1	1	1	0	0	0
A11	1	1	1	0	0	0
A20	1	0	1	0	0	0
Community	**Overall**	**0-3.5cm**	**3.5-7cm**	**7-8cm**	**8-10cm**	**10-14cm**
S1	4	4	3	2	1	0
S2	1	1	1	1	2	0
S3	6	6	4	3	2	1
S4	5	4	4	2	2	1
S5	5	4	4	2	1	0
S6	6	6	7	3	2	1
S7	2	1	1	1	0	0
S8	3	3	2	1	0	0
S11	1	0	1	0	0	0
S12	4	2	3	0	0	0
S13	2	2	1	1	1	0
S14	3	3	2	1	1	0
S15	4	3	3	0	0	0
S16	1	0	1	0	0	0
S17	5	5	4	2	2	1
S18	6	5	4	3	2	1
S19	2	1	1	0	0	0
S20	3	2	2	1	1	0
S21	3	2	3	1	1	0
S22	6	1	0	0	0	0
S23	7	5	5	2	1	0
S24	10	9	7	5	3	2
S25	7	7	5	4	2	1
S26	7	6	5	3	2	1
S27	5	4	4	1	1	0
S28	4	3	3	1	1	1
No. of Indicator taxa	22	16	15	8	6	6

Table 8.4b. Table showing the NVC Indicator Taxa Scores for Wolla Bank, Section 2 (For the names of the aquatic, swamp and tall-herb communities see Appendix II, tables II.2 & II.3)

The final sample from 10-14cm also produced six indicator taxa and woodland communities W5, W7 and W8 dominated the sample. No aquatic communities were represented. The tall-herb fen types were present in reduced numbers but S24 dominated.

In conclusion, the profile was dominated by woodland types through time with a tall-herb fen understorey. Wet woodland types appear to dominate except for the sample at 10-14cm where some dryland types were more prevalent. As time passed it appears that the woodland became wetter as the tall-fen communities increased through the profile. This increase in fen types suggests a rise in the watertable probably as a result of a corresponding rise in sea-level.

8.7.3. Hightown

Three monoliths, one vertical and two horizontal were analysed from the Hightown Submerged Forest exposure and the results are presented in tables 8.5 - 8.7.

8.7.3.1. The vertical profile

Overall, there were ten taxa used as indicators for the plant communities present within the profile (table 8.5a & b). The dominant woodland types were wetland ones, W1, W2 and W5, aquatic communities were present but not to the same extent as the tall-herb fen and swamp communities which were dominated by S24.

8.7.3.2. Changes through the vertical profile

Of the six samples analysed only three samples provided enough taxa for analysis (table 8.5a & b). In the sample from 10-14cm, seven indicator taxa were present. The dominant woodland types were W1, W2, W3 and W5, aquatic communities were rarely represented and the swamp and tall-herb fen communities were represented by S4, S8, S17, S18, S24 and S25. The sample below this, 14-18cm had five taxa present to represent the communities within the samples. The woodland was dominated by W1, W2 and W5 wet woodland types. Aquatic communities again were rare, the tall-herb fen community was represented by S24. The final sample from the profile 18-22.5cm also provided five taxa for analysis, the dominant woodland types appear to be W1, W2, W3, W5 and W6, all wetland types, again the presence of aquatics were limited and the tall-fen community was represented by S26.

Community	Overall	10-14cm	14-18cm	18-22.5cm
W1	7	5	5	4
W2	7	5	5	4
W3	6	5	4	4
W4	3	3	2	2
W5	7	5	5	4
W6	5	4	4	4
W7	3	2	3	2
W8	2	2	2	2
W9	1	1	1	1
W10	3	2	2	2
W11	1	1	1	1
W12	1	1	1	1
W13	1	1	1	1
W14	2	1	1	1
W15	1	1	1	1
W16	2	1	2	1
W17	1	1	1	1
W18	0	0	0	2
W21	3	2	2	1
W22	2	1	1	1
W23	1	1	1	1
W24	2	2	1	2
W25	1	1	1	1

Table 8.5a. Table showing the NVC Indicator Taxa Scores for Hightown, Vertical Profile (For the names of the woodland communities see Appendix II, table II.1)

Therefore, there appears to be little change through the profile, with wet woodland types and tall-herb fen communities dominating the assemblage, along with swamp communities in the more waterlogged areas. The tall-herb fen communities may have been present as an understorey of the wet woodland. The lack of samples from higher up the profile may have been due to taphonomic and erosional processes.

8.7.3.3. Monolith Three

This horizontal monolith was divided into an upper and lower sample. The overall analysis of the samples produced ten taxa for analysis (table 8.6a & b). The dominant woodland types were W1 and W5, aquatic communities were rarely represented and the fen communities were dominated by S24.

In the lower sample, six taxa were present and used as indicators, the dominant woodland types were W1, W2 and W5, whilst the aquatic communities were rarely represented. The dominant tall-fen herb community was dominated by S24. The upper sample presented nine

Community	Overall	10-14cm	14-18cm	18-22.5cm
A1	2	0	1	1
A2	2	1	0	1
A4	1	1	0	0
A5	1	1	0	0
A8	2	0	1	1
A9	1	1	0	0
A18	1	0	1	0
A19	1	0	0	1
A20	1	1	0	0
Community	**Overall**	**10-14cm**	**14-18cm**	**18-22.5cm**
S1	4	3	2	2
S2	3	2	2	2
S3	4	3	3	3
S4	5	4	3	3
S5	4	2	2	2
S6	4	3	3	3
S7	2	1	1	1
S8	5	4	2	2
S9	2	1	1	0
S10	2	2	0	1
S11	2	1	1	0
S12	5	3	1	2
S13	2	3	2	2
S14	5	3	2	3
S15	4	2	1	2
S16	1	0	1	0
S17	5	4	3	3
S18	5	4	3	3
S19	3	2	1	0
S20	2	2	1	2
S21	4	2	2	1
S22	4	2	1	2
S23	5	2	2	3
S24	6	4	4	3
S25	5	4	3	3
S26	5	3	3	4
S27	5	2	2	3
S28	3	2	2	2
No. of Indicator taxa	10	7	5	5

Table 8.5b. Table showing the NVC Indicator Taxa Scores for Hightown, Vertical Profile (For the names of the aquatic, swamp and tall-herb communities see Appendix II, tables II.2 & II.3)

taxa, the woodland was dominated by W1 and W5 with rare aquatics, the dominant tall-herb fen was S24. There appears to be little change throughout the monolith which indicates a wet woodland with a tall-herb fen vegetation understorey.

Community	Overall	Lower	Upper
W1	8	5	8
W2	7	5	7
W3	7	4	7
W4	5	3	5
W5	8	5	8
W6	5	3	5
W7	6	3	6
W8	6	3	6
W9	5	3	5
W10	3	3	3
W11	3	2	3
W12	3	2	3
W13	1	1	1
W14	2	2	2
W15	2	2	2
W16	3	3	3
W17	2	2	2
W18	1	1	1
W19	1	1	1
W20	2	0	2
W21	2	1	2
W22	2	1	2
W23	1	1	1
W24	1	0	1
W25	2	1	2

Table 8.6a. Table showing the NVC Indicator Taxa Scores for Hightown, Horizontal Monolith 3 (For the names of the woodland communities see Appendix II, table II.1)

8.7.3.4. Monolith Four

Monolith four was divided into three separate sample a lower, middle and upper one. The overall communities present within the monolith are shown in table 8.7. Nine taxa were used as indicators. The dominant woodland community was of W5, few aquatics were present and the tall-fen community present was S24.

The lower sample was represented by five indicators, the woodland types were W1 and W5 and the tall-fen community was S24, with rare. The middle sample produced only four indicators, W3 was the main woodland type and the swamp communities were represented by S4, and the tall-herb fen by S27, this suggests a higher watertable, the uppermost sample also produced four taxa, with the woodland community dominated by W3, aquatics were rare and the tall-herb fen was mainly S24 and S27 and swamp types S4 and S8.

Community	Overall	Lower	Upper
A2	1	1	0
A4	1	1	0
A9	1	1	0
A20	1	1	0
A21	1	0	0
A22	1	0	1
Community	Overall	Lower	Upper
S1	1	1	1
S3	4	2	4
S4	5	2	5
S5	4	2	3
S6	4	2	4
S7	2	0	2
S8	5	2	4
S9	1	0	1
S10	3	1	2
S11	3	0	3
S12	3	2	2
S13	2	1	1
S14	5	2	4
S15	3	2	2
S17	3	3	2
S18	4	2	3
S19	2	1	1
S21	1	0	1
S22	2	1	0
S23	1	0	1
S24	8	5	8
S25	5	3	5
S26	4	3	4
S27	4	1	4
S28	3	1	3
No. of Indicator taxa	10	6	9

Table 8.6b. Table showing the NVC Indicator Taxa Scores for Hightown, Horizontal Monolith 3 (For the names of the aquatic, swamp and tall-herb communities see Appendix II, tables II.2 & II.3)

The differences between these three samples suggests that the middle sample represents a rise in the watertable which is followed by a drier phase, this can be explained by local changes in the microhabitats caused perhaps by a rise in sea-level.

Community	Overall	Lower	Middle	Upper
W1	6	3	1	1
W2	5	2	1	2
W3	4	2	3	3
W4	4	1	1	2
W5	7	3	1	2
W6	3	2	0	0
W7	2	2	1	1
W8	1	1	0	0
W9	1	1	0	0
W10	1	1	0	0
W11	1	1	0	0
W12	1	1	0	0
W14	1	1	0	0
W15	1	1	0	0
W16	2	2	0	0
W17	1	1	0	0
W18	1	1	0	0
W19	1	1	0	0
Community	**Overall**	**Lower**	**Middle**	**Upper**
A7	1	1	1	1
A11	1	1	1	1
A13	1	1	1	1
A24	1	1	1	1
Community	**Overall**	**Lower**	**Middle**	**Upper**
S1	3	1	2	3
S2	2	1	2	2
S3	1	1	1	1
S4	6	3	4	4
S5	2	2	1	1
S6	1	1	1	1
S8	5	3	3	4
S9	3	1	2	3
S10	1	0	1	1
S11	2	0	1	2
S12	3	1	2	3
S13	3	2	2	2
S14	2	2	1	1
S17	2	2	1	1
S18	2	2	0	1
S19	2	1	1	2
S20	1	1	1	1
S21	3	2	1	2
S23	2	2	1	1
S24	8	4	3	4
S25	5	2	3	3
S26	3	2	2	2
S27	6	3	4	4
No. of Indicator taxa	9	5	4	4

Table 8.7. Table showing the NVC Indicator Taxa Scores for Hightown, Horizontal Monolith 4 (For the names of the woodland, aquatic, swamp and tall-herb communities see Appendix II, tables II.1, II.2 and II.3)

8.7.4. Travis' earlier studies at Hightown and Leasowe

Previous studies at Hightown and Leasowe by Travis (1926 and 1929 respectively) have been analysed using the community indicator method. A total of 27 taxa were used. Overall the sites at Hightown and Leasowe are dominated by woodland type W5 and tall-herb fen S24 (tables 8.8a & b and 8.9a & b). The aquatic communities were dominated by A8 and A11. In general, this work supports the present studies showing the dominance of wet woodland communities and tall-herb fen communities.

At Hightown, Travis subdivided the profile into four horizons. The uppermost dark peaty sand provided thirteen indicator taxa and was dominated by W9 woodland communities with aquatic and swamp communities poorly represented. Below this twenty-eight taxa were present in the peat and Forest Bed, this horizon represents the submerged forest proper and is dominated by W4 and W5 wet woodland communities and tall-fen community S24. The aquatics were poorly represented. Only six taxa were available to help indicate habitats in the lower dark sandy horizon which separates the submerged forest from the underlying Blue Clay Horizon. The dominant woodland types is W5 and S24 is the dominant tall-fen vegetation. Aquatics were again poorly represented. In the Blue Clay Horizon only three taxa were used as indicators with no community showing dominance.

This profile shows that there is a continual drying out of the landscape, although fen vegetation and wet woodland communities dominate throughout the profile until the uppermost dark peaty sand. The small number of taxa which could be used in the lower horizons may help to explain the lack of definition within the samples.

At Leasowe, five horizons were recognised by Travis. The upper peat produced too few taxa to be used in this study. As in the other profiles the number of taxa which could be used varied greatly. The largest numbers were present in the compact peat with twenty-six taxa and the lower peat with eleven. The Blue clay which separates the two peat beds was represented by five taxa and the peaty sand between the compact peat and the upper peat provided six taxa (table 8.9a & b).

Community	Overall	Dark Peaty Sand	Peat & Forest Bed	Dark Sandy Horizon	Blue Clay
W1	16	5	7	2	0
W2	24	5	12	2	0
W3	20	3	8	2	0
W4	18	4	1	2	0
W5	26	5	13	3	0
W6	19	4	10	2	0
W7	20	4	9	2	1
W8	16	3	9	2	1
W9	15	9	9	2	1
W10	17	3	9	2	1
W11	7	2	5	1	0
W12	7	2	4	1	0
W13	5	1	2	1	0
W14	10	2	5	1	0
W15	5	2	4	1	0
W16	6	2	5	1	0
W17	7	2	7	1	0
W18	4	2	4	0	0
W19	4	0	1	0	1
W20	4	0	3	0	0
W21	13	3	5	1	1
W22	7	0	2	1	0
W23	3	0	1	1	0
W24	10	1	3	1	1
W25	6	1	2	1	0

Table 8.8a. Table showing the NVC Indicator Taxa Scores for Hightown, Travis (1926) (For the names of the woodland communities see Appendix II, table II.1)

Due to the low number of taxa in the Blue clay and peaty sand it is difficult to determine the dominant plant communities, although the Blue clay appears to be dominated by W5 woodland, with aquatics and tall-fen communities much reduced, this suggests that the land, although already wet, did not possess a high enough watertable to support either aquatics or fen vegetation.

The compact peat with twenty-six taxa, showed a horizon dominated by W5 woodland although elements of W2 and perhaps W1, W4, W6, W7 and W10 also present. Aquatics appear to be more prominent with A8 dominating. Swamp community S4 and tall-herb fen community S24 were also present producing yet again a picture of a wet woodland with a dense tall-herb fen vegetation growing beneath the canopy.

The Lower peat was dominated by W6 woodland with W2 and W5 also present, perhaps on the wetter parts of the site. Aquatic communities were poorly represented and swamp vegetation being represented by S3, S4 and S5 with tall-herb fen types S24, S25 and S26.

Community	Overall	Dk Peaty Sand	Peat & Forest Bed	Dk Sandy Horizon	Blue Clay
A1	3	1	0	0	0
A2	3	2	1	0	0
A3	1	0	0	0	0
A4	6	3	1	1	0
A5	2	2	1	0	0
A6	3	1	1	0	0
A7	4	1	1	0	0
A8	8	4	2	0	0
A9	4	2	0	0	0
A10	3	3	0	0	0
A11	8	4	2	2	1
A12	3	1	1	1	1
A13	7	4	2	0	0
A14	1	1	0	0	0
A15	3	3	1	0	0
A16	1	1	1	0	0
A18	2	2	1	0	0
A19	2	1	1	0	0
A20	1	1	0	0	0
A21	5	1	2	1	1
A22	2	0	1	0	0
A24	2	1	0	0	0
Community	Overall	Dark Peaty Sand	Peat & Forest Bed	Dark Sandy Horizon	Blue Clay
S1	13	2	4	0	0
S2	6	1	3	0	0
S3	14	1	5	1	0
S4	17	3	5	1	0
S5	8	3	0	0	0
S6	9	2	1	1	0
S7	6	1	2	0	0
S8	11	5	1	0	0
S9	6	3	2	0	0
S10	4	1	1	0	0
S11	6	2	3	0	0
S12	12	4	2	0	0
S13	8	4	2	0	0
S14	11	3	2	0	0
S15	8	2	1	0	0
S16	2	1	0	0	0
S17	8	2	1	1	0
S18	10	2	2	1	0
S19	5	4	1	0	0
S20	6	1	0	1	1
S21	11	3	2	1	1
S22	5	2	1	0	0
S23	12	3	2	1	0
S24	22	2	9	3	0
S25	17	2	7	2	0
S26	10	2	0	1	0
S27	15	2	8	0	0
S28	6	1	0	1	0
No. of Indicator taxa	27	13	28	6	3

Table 8.8b. Table showing the NVC Indicator Taxa Scores for Hightown, Travis (1926) (For the names of the aquatic, swamp and tall-herb communities see Appendix II, tables II.2 & II.3)

Community	Overall	Peaty Sand	Compact Peat	Blue Clay	Lower Peat
W1	16	1	10	2	5
W2	24	2	11	3	6
W3	20	2	9	3	4
W4	18	0	10	2	4
W5	26	2	12	4	6
W6	19	1	10	2	7
W7	20	2	10	3	6
W8	16	1	8	3	5
W9	15	1	9	3	5
W10	17	1	10	3	6
W11	7	0	5	2	3
W12	7	1	5	2	4
W13	5	1	2	1	3
W14	10	1	7	3	5
W15	5	0	4	1	3
W16	6	0	5	1	4
W17	7	0	5	1	3
W18	4	0	3	1	3
W19	4	1	0	2	1
W20	4	0	0	1	0
W21	13	1	6	3	5
W22	7	1	3	2	3
W23	3	0	1	1	0
W24	10	1	5	3	5
W25	6	1	2	2	3

Table 8.9a. Table showing the NVC Indicator Taxa Scores for Leasowe, Travis (1929) (For the names of the woodland communities see Appendix II, table II.1)

8.7.5. Comparison between the Merseyside and East Lincolnshire Submerged Forests

The use of the Natural Vegetation Classification has shown that the two areas of submerged forests are composed of swamp, fen and wet woodland communities. Because of the way the data was used (on the basis of presence/absence rather than by quantification) it is not possible to ascertain which specific communities are present at each location.

In general, the dominant communities appear to be wet woodlands, W5 and tall-herb vegetation S24 at both Hightown and Wolla Bank and Anderby Creek. Although the communities present at each site are similar there is a fundamental difference in the developmental stage present at each site. Hightown seems to have suffered from several disturbance phases limiting the development of the woodland whilst at Wolla Bank and

Community	Overall	Peaty Sand	Compact Peat	Blue Clay	Lower Peat
A1	3	2	2	0	0
A2	3	0	2	0	0
A3	1	1	1	0	0
A4	6	0	1	0	0
A5	2	0	0	0	0
A6	3	1	1	0	0
A7	4	0	2	0	0
A8	8	2	4	0	0
A9	4	1	2	1	1
A10	3	0	0	0	0
A11	8	1	2	0	0
A12	3	1	1	0	0
A13	7	1	3	0	0
A14	1	0	0	0	0
A15	3	0	0	0	0
A16	1	0	0	0	0
A18	2	1	0	0	0
A19	2	0	1	0	0
A20	1	0	1	0	0
A21	5	1	2	0	0
A22	2	0	1	0	0
A24	2	0	1	0	0
Community	**Overall**	**Peaty Sand**	**Compact Peat**	**Blue Clay**	**Lower Peat**
S1	13	1	6	2	3
S2	6	1	3	1	1
S3	14	2	6	3	4
S4	17	3	9	2	4
S5	8	2	4	2	4
S6	9	2	3	2	3
S7	6	2	1	2	1
S8	11	2	5	2	3
S9	6	1	2	0	0
S10	4	0	2	1	0
S11	6	1	2	0	0
S12	12	4	5	3	3
S13	8	1	3	1	1
S14	11	2	5	1	3
S15	8	2	4	2	2
S16	2	2	0	1	1
S17	8	1	5	1	2
S18	10	2	5	1	3
S19	5	1	4	0	0
S20	6	1	4	1	2
S21	11	2	8	1	2
S22	5	1	2	1	0
S23	12	3	4	2	3
S24	22	2	9	2	4
S25	17	2	8	2	4
S26	10	2	6	2	4
S27	15	1	6	1	2
S28	6	3	3	2	2
Total Indicator taxa	26	6	26	5	11

Table 8.9b. Table showing the NVC Indicator Taxa Scores for Leasowe, Travis (1928) (For the names of the aquatic, swamp and tall-herb communities see Appendix II, tables II.2 & II.3)

Anderby Creek, there appears to be fewer disturbance episodes and the stands were allowed to develop to progress until the old growth stage had been reached.

8.8. Conclusions

The two submerged forests have a similar tree flora with the exceptions of the predominance of *Betula* sp. at Hightown and the presence of *Fraxinus excelsior* at Wolla Bank and Anderby Creek. The alder may be multistemmed and extending to 15m high, the birch would be of about this height. The ash and the oak will on the drier parts extending this dense canopy. The understorey at each exposure is also very similar.

In general, the mature woodland would be greatly influenced by the preceding swamp and fen vegetation, which can be assumed to be dominated by *Phragmites australis* due to its ubiquitous presence in the samples and may have had an appearance like those shown in figure 8.7 and plate 8.1. The understorey can be broken down into several elements. The first consists, of tussocks of sedge (at Wolla Bank, of *Carex remota*) and stools of *Osmunda regalis* (at Hightown). Associated with these tussocks would be the tall herbs which include *Phragmites australis*, *Eupatorium cannabinum*, *Filipendula ulmaria*, *Angelica sylvestris* and *Iris pseudoacorus*. In many cases, these tall herbs would be rooted in the sides and on top of the sedge tussocks, with *Iris* and *Phragmites* occurring between them. Mixed with the vegetation between the tussocks would be small herbs such as *Mentha aquatica*, *Hydrocotyle vulgaris*, and *Viola palustris*. Amongst the tall herbs, sprawlers such as *Solanum dulcamara* can be found and in some places this could become very abundant. Adding to this tangled field layer would be undershrubs such as *Rubus fruticosus* agg, which in the drier areas would make the woodland intractable.

In the more open parts of the woodland, *Phragmites* would be dominant but in some areas, especially the drier parts, shrubs and small trees such as *Frangula alnus*, *Prunus spinosa* and *Ilex aquifolium* may be present. In other areas, where the weight of the trees has caused the fen mat in which they are rooted to become depressed therefore lowering the woodland floor below the level of the watertable, species preferring this damper environment, such as

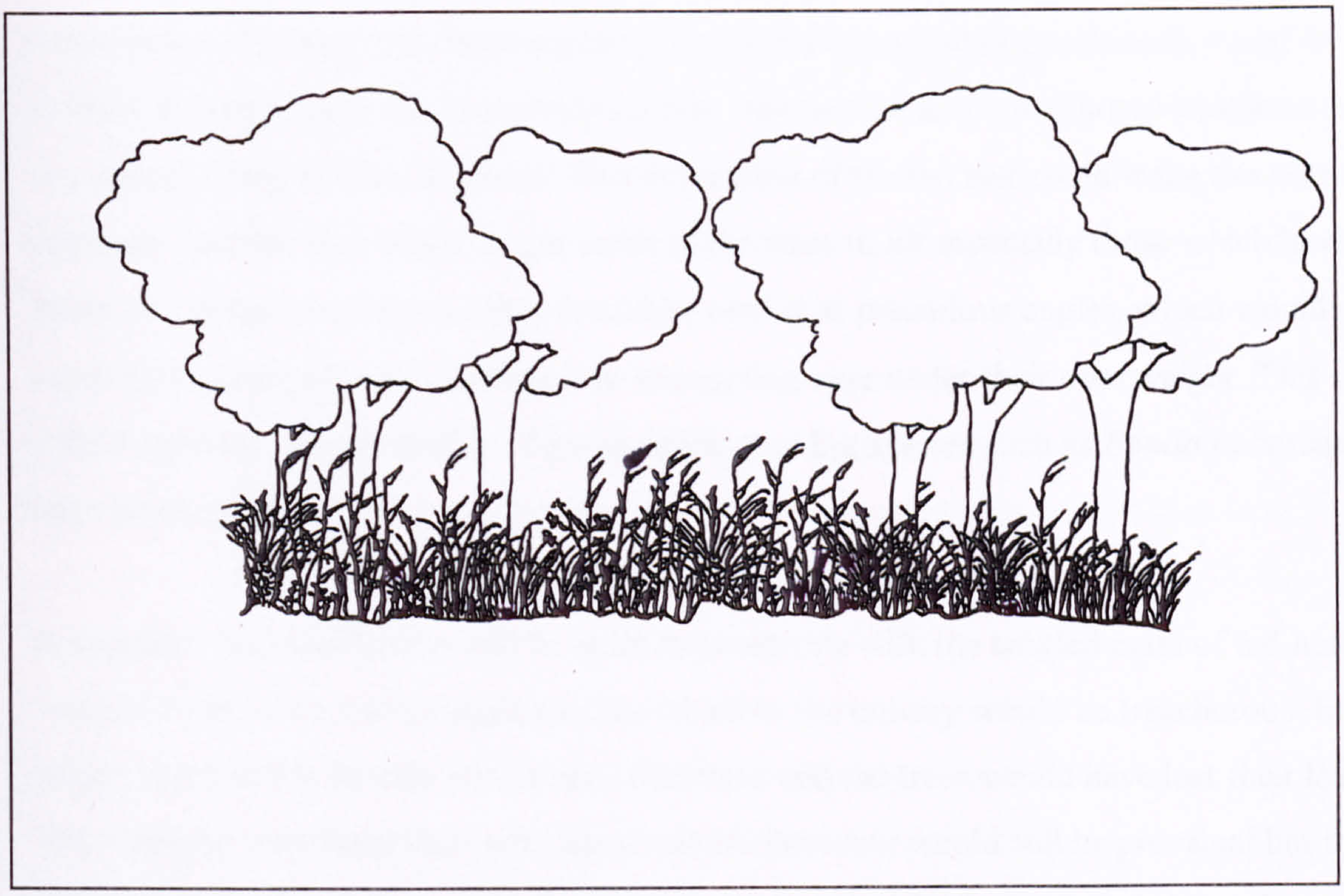


Figure 8.7. A stylised picture of a carr woodland (based on a W5 community) demonstrating how the submerged forests at Hightown, Wolla Bank and Anderby Creek may have appeared

Plate 8.1. Photograph of a modern day alder carr woodland (Chartley Moss, NNR, Staffordshire), demonstrating of how the submerged forests at Hightown, Wolla Bank and Anderby Creek may have appeared

Menyanthes trifoliata and *Potamogeton polygonifolius* and other pondweeds would be present. In some cases, these depressions may well be bare and could prove treacherous to any unsuspecting human or animal. This depression of the fen mat could make the peaty substrate unstable and would cause some of the trees to tilt especially those which have rooted on sedge tussocks and they would be resting at precarious angles, which would make them susceptible to windthrow or to toppling over under their own weight. This would open the canopy further allowing quick growing species such as *Betula pubescens* to become established.

In summer, the woodland would be quite impenetrable with the tangled mass of tall-herb fen vegetation and bare waterlogged patches which to the unwary would be treacherous. In winter, most of the species would have died back and the trees would have lost their leaves. The tussocky woodland floor with the stools of *Osmunda* would still be prevalent but the tall-herbs and *Phragmites* would have died back, leaving just the leafless, brittle stems standing which could still hinder penetration of the woodland. In most cases, the woodland floor would be flooded adding to the hindrance.

This type of woodland is capable of developing from open water within little more than a century (Lambert, 1951, 1965, Sinker 1962, Rodwell 1991a). Some stands which are considerably older (can be over 150 years, Rodwell 1991a) appear to be fairly stable and appear not to progress to drier carr types. Often the woodland can become moribund before the general peat surface has become dry which leads to collapsing trees and the sedge tussocks decaying which initiates the cycle of development again. This may explain the large number of trunks and stumps which appear throughout the profile of the submerged forest beds.

This type of woodland is usually found on wet to waterlogged organic soils, base-rich and moderately eutrophic in topogeneous and soligenous mires. They are often associated with fen peats in openwater transitions and flood-plain mires with a strong influence of calcareous groundwater and a periodic deposition of allochthanous material (usually in winter). The floristics and structure of the canopy and understorey are very much dependent on the availability of seed-parents and propagule dispersal. The field layer is often strongly influenced by the invaded fen vegetation (Rodwell, 1991a).

The general character of the two submerged forests are similar but there are local differences both in terms of development and species present. It may appear that the woodland at Hightown may have been more swampy which is probably due to being located on the western side of Britain, where rainfall is higher but is most likely due to the proximity of the River Alt (Travis 1920). The greater density of trees may also have caused the peat surface to become more depressed, therefore creating more shallow pools and helping to destabilise the trees, creating a disturbance which will allow the entrance and establishment of younger cohorts of trees. Large areas of Hightown may also have been dominated by *Osmunda regalis* casting a deep shadow on the woodland floor and in other areas by dense and tangled tall-herb vegetation.

At Anderby Creek and Wolla Bank, the lower density of trees may have resulted in a more open woodland allowing some of the trees to reach massive proportions, this localised increased weight may have depressed the peat surface to below the watertable and therefore causing the trees to become unstable and the field layer to be dominated by tall-herb fen and swamp communities. In other, drier areas species such as *Ilex aquifolium* and *Prunus spinosa* would be allowed to become established with a field layer again dominated by tussocks and tall-herbs and with seasonal flooding making the area impenetrable for most of the year. A possible reason for the appearance of fewer cohorts present on the east Lincolnshire coast maybe explained by the presence of an offshore spit (Swinnerton, 1931) which may have to some extent, sheltered the woodland from the more powerful storms.

Therefore, although the two submerged forests have a similar floristic composition, there are subtle differences in the developmental stages present at each of the exposures shown by the size and spatial distribution of the tree remains. A Hightown a multicohort stand is thought to be present created by frequent, though not severe disturbances, of which most are at the stem initiation or entering the stem exclusion stages. The older more regularly spaced stumps may represent the remains of the original invasion of the tall-herb vegetation by woody species and therefore may be at some later developmental stage. On the East Lincolnshire coast, the broader age distribution and the wider spacings of the tree remains has been interpreted as representing a woodland which has experienced fewer or less frequent disturbances permitting the stand to reach a later developmental stage. The density and basal area measurements for the three submerged forest exposures can also be explained by the developmental stage present at and the disturbance history of each exposure.

Chapter Nine

CONCLUSIONS

9.1. Introduction

The preceding chapters, (chapters two and three) have outlined previous research on submerged forest deposits and it has been evident that although the deposits in one way or another have been characterised to a certain extent, none of the past approaches have attempted to produce a characterisation which reflects the dynamic nature of woodlands. Chapters 4 and 7 show the methodology and the models used within this thesis to demonstrate that a more dynamic characterisation of these deposits is possible, and chapters 5 and 6 present the results of the two submerged forest exposures analysed in this thesis, one at Hightown on the Mersey Estuary and two separate exposures on the Lindsey Coast in East Lincolnshire. The two localities produced similar radiocarbon dates (with Wolla Bank and Anderby Creek producing dates of between 4865 ± 65 BP (OxA-5965) and 4480 ± 55 BP (OxA-5963) and Hightown, (Altmouth) producing a date of 4545 ± 90 BP Hv2679). Chapter 8 uses the data produced by the methodology and applies the models presented in chapter 7, producing a dynamic model of the woodlands present at these two submerged forest exposures, a comparison between the east and west coast deposits is also presented.

9.2. The records, origins and previous research on submerged forests (Chapter 2)

Submerged forests have been known for a long time around the coasts of Britain. The earliest record being by Giraldus Cambrensis in 1188 at Newgale, St. Bride's Bay, and have continued to be recorded through history up to the present day.

Since scientific interest in submerged forests began in the early-mid nineteenth century there has been vigorous debates concerning their origins. Arguments have ranged from the origins being due to the deluge, land subsidence and that they were not *in situ* deposits to the modern, generally accepted mechanism of Holocene eustatic sea level rise, although local conditions such as land subsidence via isostatic downwarping may be partly responsible.

The dating of submerged forests before the advent of radiocarbon dating and dendrochronology relied on the association of archaeological finds with the deposits. Most of the early recorded submerged forests were thought to be of a broad Neolithic date and this period was often referred to as the "Neolithic Submerged Forest Period."

A more accurate method of relative dating arrived with the development of pollen analysis and especially the work of Sir Harry Godwin, who using this method devised a sequence of pollen zones (I-VIII) which reflected the development of forest tree composition since the end of the Weichselian glacial period. The comparison of tree pollen spectra found within the deposits to those of the Godwin Pollen Zones enabled Godwin and other workers to establish that submerged forests could be found in a wide age band and the term "Submerged Forest Period" needed to be abandoned.

Later, using both dendrochronology and radiocarbon dating Heyworth (1978) was able to refine this, with the conclusion that although submerged forests have been formed throughout the Holocene with the earliest occurring around 10000 BP and the latest at 430-500 BP, the majority of the deposits could be dated to between 4000 and 5000 BP (Godwin Pollen Zones VIIa & VIIb). His reasoning for this wide range was due to the pattern of Holocene eustatic sea level rise linked with the variation of isostatic up/down-warping which occurs between the east and west coasts (see figure 2.2).

The earliest research on submerged forests was only concerned with the trees where it was noticed that the majority of the trees were of a massive height and diameter and were very straight, suggesting that they grew in denser stands than they do today. Later research involved the analysis of the plant macrofossils (fruits, seeds, leaves etc.) from the deposits and was the first step towards the characterisation of the deposits themselves. The majority of the deposits were interpreted as being of a fen peat origin. The major contributor to this phase of research was Clement Reid which culminated in 1913 in a volume entitled 'Submerged Forests'.

Soon after this, the technique of palynology was developed and soon dominated the study of the submerged forest deposits, with macrofossil analysis reduced to providing subsidiary evidence. Pollen analysis up until recently, has still dominated the study of these deposits, although, in the 1920's C.B. Travis, working on the submerged forest deposits of the Mersey estuary had the foresight to use the macrofossil and microfossil evidence in conjunction to deduce the character of the submerged forest deposits in that area. Still, the characterisation of the deposits was concerned with the sedimentary matrix and was not considered with the tree remains, apart from species identification in order to determine the type of woodland.

The trunks and stumps of submerged forests have been used by several workers to determine the pattern of past wind storm events by studying the angle of fall of the trunks, others have used the tree remains, via dendrochronology to establish local pattern of Holocene sea-level rise.

In more recent years it has been realised that the archaeological and environmental record on parts of Britain's coast is being lost via erosion or industrial development without being recorded and analysed. This realisation prompted surveys in areas considered to be in danger, such as the Hullbridge Survey on the Essex Coast and the Severn Estuary Survey (e.g. at Goldcliff, Gwent). Other surveys have been part of bigger programmes which have been set up to increase the archaeological knowledge of certain areas, e.g. The Discovery Programme in Eire and especially the Shannon Estuary Survey. In all these surveys, submerged forests have been recorded and in some places planned (especially at Goldcliff) and have had archaeological structures such as trackways, fishtraps and buildings associated with them. In some cases the archaeological features are contemporary with the submerged forest deposits and in other cases are later. The realisation of the importance of the environmental context of archaeological sites has led to the analysis of the submerged forest deposits for biological evidence, and has led to the potential to characterise the submerged forests. However, this has progressed slowly and a more ecologically dynamic characterisation of the submerged forest deposits from these surveys has yet to be attained.

9.3. Methodology and Models (Chapters 4 and 7)

In this thesis, it is hoped that the methodology used will help to produce a more dynamic visualisation of the processes involved in the palaeoecology of two submerged forest deposits, one on the east Lincolnshire coast and one on the west coast in the Mersey estuary. From radiocarbon dating both woodlands were found to be of a similar age, (see above).

The methodology used in this thesis is a combination of the standard technique of plant macrofossil analysis and interpretation and developmental process forest models based on those developed by forest ecologists studying the primary and secondary forests of the United States of America.

The sampling methods used on the submerged forest deposits are standard. Samples from vertical profiles were taken from both locations with the exception of two horizontal monoliths taken from Hightown, in order to deduce the spatial variation across the exposure. Both deposits were mapped and the position of each trunk and stump recorded. The diameter of each stump and trunk was measured as was height and angle of fall for each trunk. Where preservation permitted, samples from the tree remains were taken for microscopic species identification.

In order to characterise the submerged forests sampled for this thesis a two pronged approach was used, whereby the ecological and the metrical data recorded from each location was processed via two different models and then combined to produce an overall characterisation. The ecological approach involved the classification of the plant macrofossil species into community types by using indicator species which were then grouped according to the National Vegetation Classification. The dominant community types present in each sample were considered to represent the sample. This allowed a visualisation of both the understorey and the type of woodland to be established.

The developmental model used in this thesis is dependent on the presence or absence of disturbance (major or minor) throughout the lifespan of the stand. It is assumed that in the case of submerged forests, the emergence of the surface above sea-level can be related to a major disturbance (i.e. no trees are present), which allows the development of a ground flora and finally a tree stand. The model then uses the presence or absence of minor or even major disturbances to track the development of the woodland/stand towards maturity. The metrical data recorded was processed via the developmental model, whereby the distribution of the stump/trunk diameters and girths were analysed alongside the spatial distribution provided by the mapped positions of the stumps and trunks. This was used to deduce the developmental stage (including the presence of phases of disturbance) each submerged forest had reached at the time of death.

There are problems associated with this approach, the main one being the possibility of diachronicity and therefore lack of contemporeneity across the deposit, this has been resolved partially by radiocarbon dating at Wolla Bank and Anderby Creek but has not been possible at Hightown. Even so, the presence of dead or dying trees do influence the character of the woodland, by providing more protected sites as well as being a source of nutrients for the seedling trees as they decompose. The use of tree diameters as a guide to the age of the trees is also full of pitfalls, as competition and other factors can create a range of diameters for trees of the same age. But modern forest ecologists have used diameter as a rough guide to age and this has been thought to be safe enough to use in this thesis. Another problem arises in the association of the organic deposits and the tree remains, are they contemporary or unrelated? The analyses in this thesis has shown that the majority of the tree species are found in the deposits as seeds and other plant macrofossils, suggesting that there is some connection between the tree remains and the organic deposits. This method is not entirely foolproof as taphonomy plays an important part in the preservation of biological material within deposits and therefore not all species may be represented. The use of radiocarbon dating of both the peats and the trees would help to resolve this problem.

Once the developmental model and the ecological model have been applied they are then combined to produce a more complete characterisation of the submerged forest by providing a detailed account of the undergrowth and its possible density and the developmental stage of the stand, and whether disturbances either minor or major have played a role in its development.

9.4. Application of models (Chapter 8) using the datasets (Chapters 5 and 6)

The application of this two pronged model to the two submerged forest localities showed that each deposit had a similar ground flora/understorey consisting of a tall-herb fen vegetation dominated by *Phragmites australis*, sprawling through this tall herbaceous vegetation were both *Rubus fruticosus* and *Solanum dulcamara* producing a thick tangled impenetrable mass. Closer to the ground, smaller herbs could be found and in wetter areas, aquatic species would be growing. The woodland floor would be very hummocky making it very difficult to keep a steady footing. In parts, shrubs would be present as part of the understorey. Although at Hightown, *Osmunda regalis* would form part of the understorey as well. The tree species varied between the sites. At Hightown the dominant tree was that of birch, with alder, oak and willow also being present but in smaller proportions. At both Wolla Bank and Anderby Creek, a more varied tree species list was present, which included oak, ash, willow and alder with a small quantity of birch.

The use of the stand model showed a difference between the two sites. At Hightown, the analysis of the stump diameter/girth distributions linked with the spatial distribution of the stumps and trunks showed that although constant regeneration occurred at Hightown this was only possible due to phases of minor disturbances causing trees to fall and therefore producing growing space for seedlings to become established. This held back the development of the stand which did not reach old growth stage, but the majority of the site was kept between stem initiation and stem exclusion stages. In areas where the older (larger diameter) trees were, an old growth character was attained. Therefore at Hightown a multicohort stand was formed by phases of minor disturbances, with a new cohort becoming established at each new disturbance and producing a mosaic across the site.

At Wolla Bank and Anderby Creek a different development pattern appears to have occurred. From the analysis of the diameter/girth distributions and the wider spatial patterning at both exposures it has been suggested that although more windblown trees are present, these have not fallen in any constant direction and therefore may have toppled due to the instability of the substrate. This lack of phases of disturbances has allowed the woodland to reach a later developmental stage of either understorey reinitiation (which may account for the smaller diameter trunks) or Old-growth stage, where the original trees were gradually being replaced by younger trees as they died.

Therefore, it has been possible by using this approach to establish that although both woodlands have a similar ground/understorey flora of a dense tangled herbaceous nature, with a lower ground flora which preferred a wetter environment than that provided by the hummocks of sedge and royal fern. The tree species did vary from site to site but by using the community type classification it could be deduced that they were basically of a similar fen carr woodland type. The use of the developmental model enabled the deduction that the woodland stand at Hightown was affected by several minor disturbances producing a multicohort stand which had only reached the stem exclusion phase in the majority of the stand, whilst at Wolla Bank and Anderby Creek, the lack of any disturbance permitted the stands to reach either Understorey reinitiation stage or Old growth stage.

It can be seen that although woodlands may be of a similar age and generally have a similar appearance with regards to species composition the presence or absence of disturbances can greatly influence the development and the structure of the stand.

9.4.1. Some interesting aspects of the submerged forest deposits

9.4.1.1 Earthworm cocoons

The presence of earthworm cocoons at Wolla Bank (Tables 5.6 and 5.7a & b) and at Hightown (Tables 6.6, 6.7 and 6.8) is of interest and Photograph 9.1 illustrates some of those recorded.

Cocoons contain the ova and spermatozoa of earthworms. These cocoons differ in shape with species (Evans and Guild, 1947; Edwards and Bohlen, 1996). The position of deposition is dependent on soil conditions. If very moist, they are deposited near the surface or deeper when the soil is dry, (Edwards and Bohlen, 1996). In the Northern Hemisphere. peak cocoon production occurs in the spring or early summer. Seasonal fluctuations of the soil climate can cause the number of cocoons produced by different earthworm species to vary from year to year (Evans and Guild, 1948; Gerard, 1967).

As it is possible to identify earthworm cocoons to species, it may be possible, in future, to identify the earthworm species present. This may in turn help, along with other environmental evidence, to determine the ecological conditions present at the time of the formation of the deposit. Changes in earthworm species composition may help to elucidate changes in the conditions of the deposit (or series of deposits) through time and in relation to the type of vegetation present. Recording the position of the earthworm cocoons within deposits may also help to determine water levels at the time of cocoon production.

The identification of earthworm cocoons needs to be evaluated in order to determine the importance of this extra line of evidence in helping to interpret the nature of the deposits in which they are found.

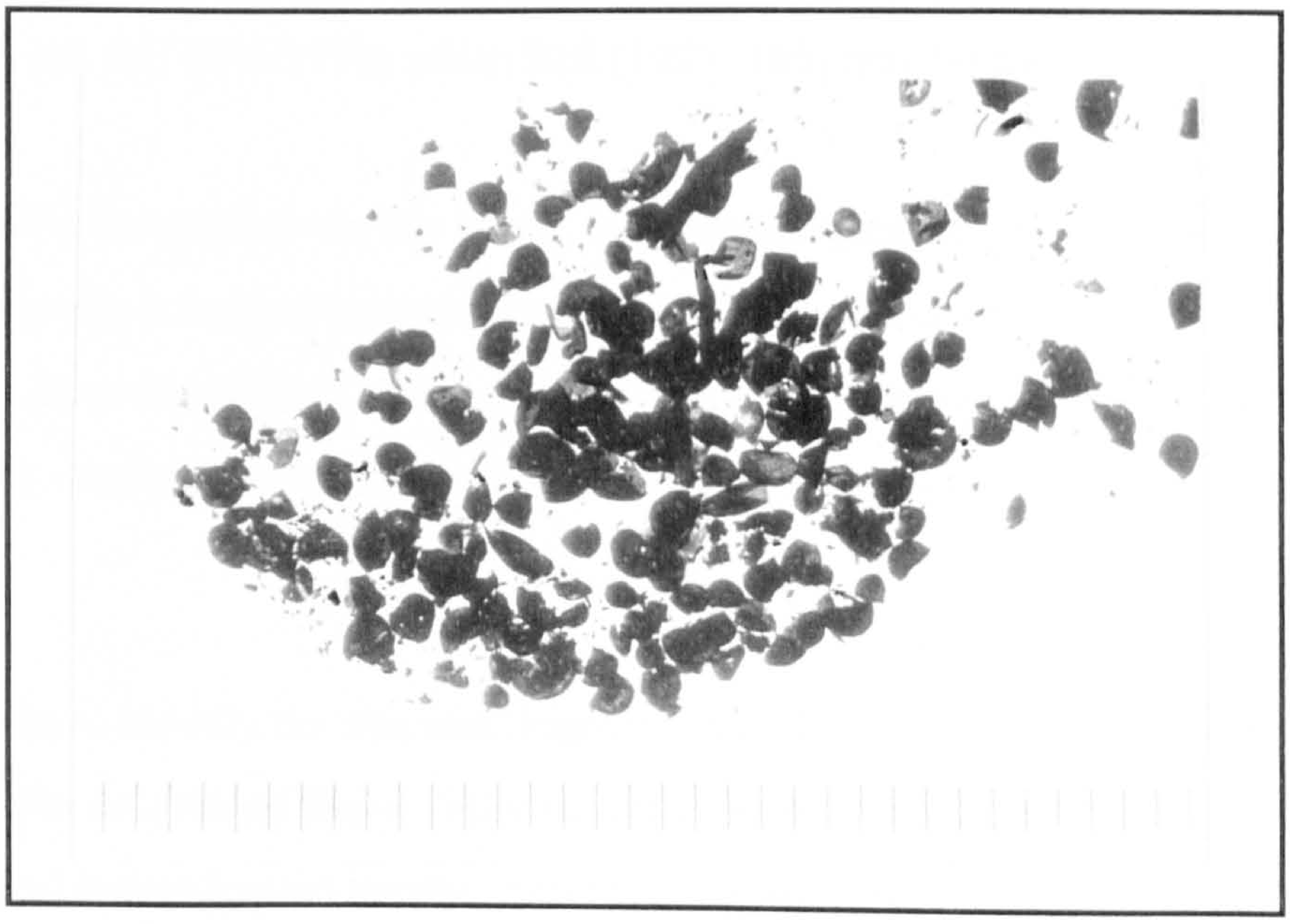


Plate 9.1. Photograph showing worm cocoons from Wolla Bank, East Lincolnshire (Scale in millimetres)

9.4.1.2. Charcoal fragments found at the peat and underlying clay interface

Fragments of charcoal were recorded at the junction of the base of the peat and top surface of the underlying clay at Wolla Bank (tables 5.6 and 5.7a & b) and at Hightown (table 6.6). The majority of the charcoal fragments recorded were from fractions retained above the 500μm sieve.

Charcoal fragments of this size are notoriously difficult to interpret (Smart and Hoffman, 1988) as they are very mobile and may not have been formed *in situ*. It is also difficult to determine whether or not the charcoal fragments are natural in origin, i.e. formed via forest fires or have an origin through anthropogenic activity, i.e. fires used for clearance or for some other activity such as cooking or artefact manufacture. It is not possible to determine whether or not a fire was caused by human activity from the palaeoecological data alone (Simmons and Innes, 1987; 396). And therefore it is important that the archaeological activity present in the study areas is considered before any informed interpretation can be made. A good example of this situation is at Goldcliff, Gwent, where in an area 800 x 300m, flints, chert and tuff flakes and bone are associated with a charcoal layer dated at c. 5440 - 5280 cal. BC (GU-2759) which Bell (1995; 135) may be Mesolithic clearance.

In both of the areas studied for this thesis, the archaeological record associated with the submerged forests is lacking (see sections, 5.6 and 6.8), therefore it is difficult to say if the charcoal has an anthropogenic or natural origin. It is only possible to state that fire occurred, but whether it occurred locally or some distance away is not possible to determine.

If it is possible to identify the charcoal fragments and they correspond to the tree species identified in the submerged forest deposits, it may be possible to say that there is a high probability that it was formed locally. Although, whether the charcoal is of natural or anthropogenic origin still cannot be clarified.

9.5. Future developments

The methodology developed in this thesis works successfully but the model can be improved by the inclusion of more lines of evidence, and is presented in figure 9.1.

A more comprehensive sampling strategy would help to determine spatial variation throughout the exposure. Sampling across two perpendicular transects at two metre intervals (or closer if necessary) will pick up any variation across the site. The sampling procedure needs to follow that undertaken at Hightown, where a suite of vertical and horizontal profiles are sampled in order to recover as much of the spatial and temporal variation as possible. The positioning of samples is also important as has been realised at Wolla Bank, where two profile sections situated a metre apart showed a deep contrast in the number of plant remains contained in each sample, this was due to the first profile being located against a large alder stump. This has shown that a single profile from a deposit will not produce a complete picture of the variation across a site and therefore a more detailed sampling strategy is required. As well as a more comprehensive sampling of the deposits, more of the stumps and trunks should be sampled for species identification and for tree-ring analysis.

Apart from the detailed sampling strategy for plant macrofossils, other biological evidence should be studied, this should help to elucidate further the nature of the submerged forest.

The analysis of the insect remains will help to determine at what stage the woodland has reached, i.e. the presence or absence of dead or rotting wood, variation in shade density and the presence of pest species. The presence of pest species, i.e. those that eat leaves or perhaps the elm bark beetle will also help to determine if the trees could have been stressed and therefore more susceptible to insect and other disease attack, which could be classified as a disturbance. Certain insects are specific to certain tree species or a small suite of trees, if these insect species were present it would be possible to determine if that tree species was present, especially as the preservation of different tree species is variable with some being more resistant than others. The presence of molluscs could also be used to help determine and support the insect data to the types of environments present within the deposits.

Pollen analysis, may help to increase the understanding of which other species, not represented within the plant macrofossil level were present in the area and will help to produce a more multi-dimensional picture of the submerged forest deposits.

The use of tree-ring analysis would not just provide a floating chronology and age structure of the woodland, but could be used, via the study of the annual ring patterns to determine whether the trees were under constant or periodic stress and with the use of the other forms of evidence, what kind of stress. When the age structure of the wood is linked to the spatial distribution of the tree remains, it should be possible to determine the development of the woodland and the changes that happen through time. This information could then be used to produce a more accurate image of the development of each stand and to determine more accurately the nature, number and severity of each disturbance if present. The use of radiocarbon dating could then be used to determine the time of each disturbance, if dendrochronological dating was not possible (i.e. floating chronologies, as most of the trees present in this type of deposit are not suitable for producing chronologies).

It has been observed and well documented with support from radiocarbon dating (Bell & Neumann, 1997;98) and stated in this thesis (pages 69,152, 173, 256) that the seaward edge of the peat surfaces are eroded and may be older than those at the landward limits of the exposure. This may cause difficulties for the interpretation and reconstruction of the dynamic ecological processes occurring within the submerged forests.

Possible methods which may resolve this possible problem of diachronicity are outlined below. A series of radiocarbon dates from transects across the exposure from seaward to landward limits would provide an idea to the degree of diachronicity across the surfaces. This could be combined with a series of corings taken across the same transects in order to establish any changes in the depth of the submerged forest deposits. It may well be expected that the peat at the seaward edge would be thinner than that to landward. If the exposure is an island and being eroded by the sea on more than one side, it may be necessary to core and radiocarbon date along transects perpendicular to those from seaward to landward. This may help to reveal any diachronicity in that dimension.

Samples for macrofossil analysis along similar transects may also help to establish diachronicity. Firstly, by providing plant macrofossils for more accurate radiocarbon dating (via Atomic Mass Spectrophotometry - AMS). And secondly by detecting any changes across the deposit. The radiocarbon dating of the top and bottom of the peat along the transects may also pick up any changes in the time of initiation of the submerged forest deposits throughout the deposit.

Dendrochronological studies of suitable tree remains from the seaward-landward transects and those perpendicular may also provide evidence for diachronicity across the exposure as shown by Heywood (1978), although other factors may be responsible for the diachronicity other than erosion by the sea (Heyworth, 1978).

It is hoped that in future studies of submerged forests, the variety of methods outlined above may resolve any problems with diachronicity across the exposures.
Overall, this more detailed approach would have to be multidisciplinary and therefore may not be possible in the real world. Limitations such as the length of time the exposure is uncovered and the unpredictability of the exposure being uncovered over a long period of time need to be taken into consideration and therefore in some areas a compromise will need to be reached.

Although the approaches utilised in this thesis are of a palaeoecological nature, there is some application to archaeology. In studying and analysing these off-site deposits it becomes possible to put the archaeological material, either associated with or surrounding the these deposits into their environmental context and may give the archaeologist a perception of the landscape which could have potentially been utilised by the local human populations, as sources of food and timber.

The dense and impenetrable understorey and the unevenness of the ground underfoot of the submerged forests analysed in this thesis suggests that they may not have been exploited by the local population and this may explain the lack of artefacts and archaeological features associated with these deposits. In other cases where archaeological structures and artefacts are associated with submerged forests of a similar date, there may be some interaction between the submerged forests and the human population.

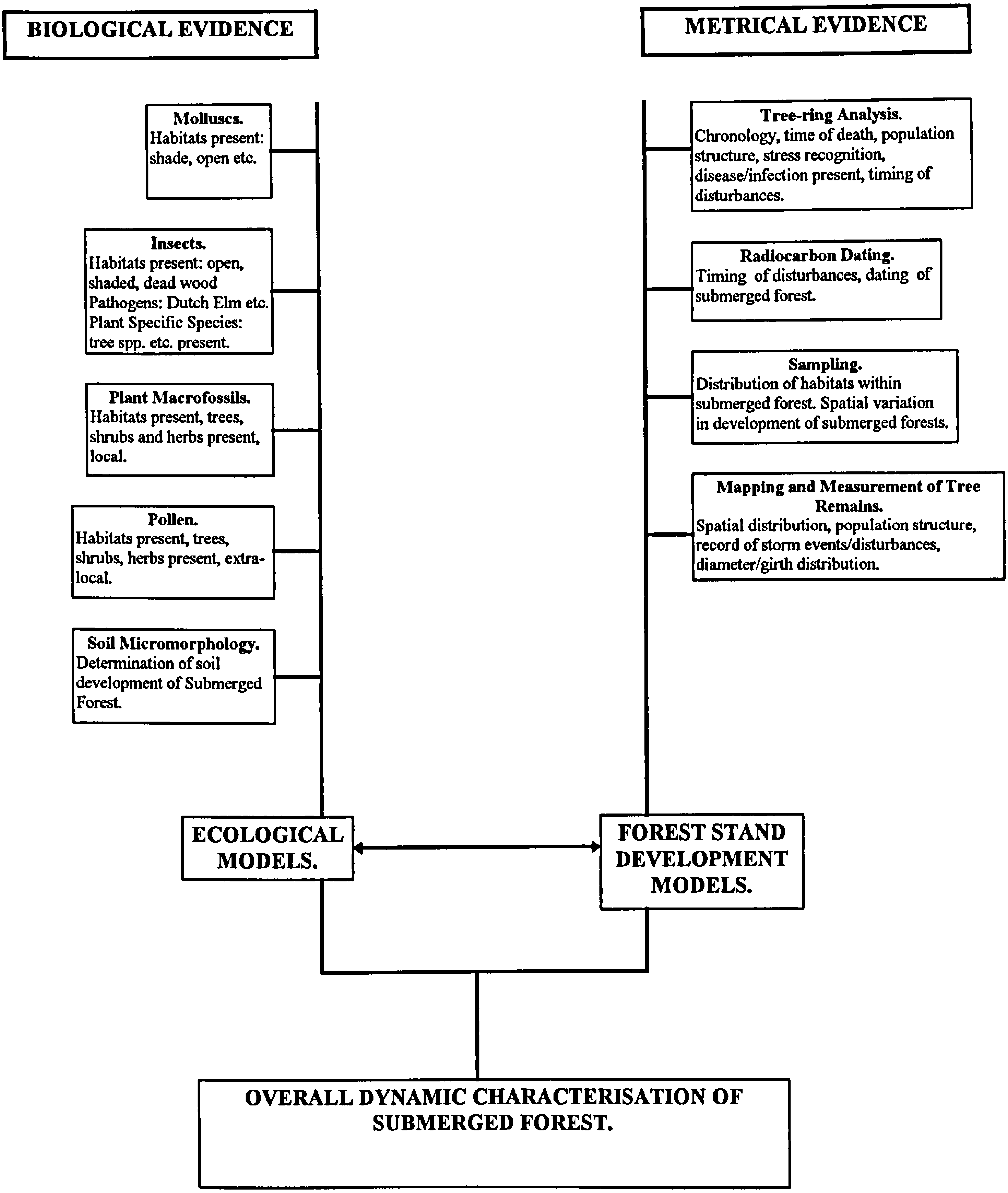


Figure 9.1. Diagram showing the use of Biological and Metrical Evidence via Ecological and Forest Stand Development Models in order to produce an overall dynamic characterisation of Submerged Forest Deposits

Appendix I

RAW DATA FROM THE SUBMERGED FORESTS

Diameter (cm)	no. of stump/exposure	Girth (cm)	Area cm2	Basal area m2/exposure	N ha-1	Basal area m2 ha-1
5	9	15.7	19.63	0.017667	46	0.090298
6	11	18.84	28.27	0.031097	56	0.158312
7	9	21.99	38.48	0.34632	46	0.1777008
8	13	25.13	50.26	0.065338	66	0.331716
9	12	28.27	63.61	0.076332	61	0.388021
10	22	31.41	78.53	0.172766	112	0.879536
11	12	34.55	95.03	0.114036	61	0.579683
12	17	37.69	113.09	0.192253	86	0.972574
13	12	40.84	132.73	0.159276	61	0.809653
14	11	43.98	153.93	0.169323	56	0.862008
15	13	47.12	176.71	0.229723	66	1.166286
16	13	50.26	201.06	0.261378	66	1.326996
17	11	53.4	226.98	0.249678	56	1.271088
18	11	56.54	254.46	0.279906	56	1.424976
19	8	59.69	283.52	0.226824	41	1.162432
20	15	62.83	314.15	0.471225	76	2.38754
21	2	65.97	346.36	0.069272	10	0.34636
22	8	69.11	380.13	0.304104	41	1.558533
23	11	72.25	415.47	0.457017	56	2.326632
24	10	75.39	452.38	0.45238	51	2.307138
25	5	78.53	490.87	0.245435	25	1.227175
26	6	81.68	530.92	0.318552	30	1.59276
27	2	84.82	572.55	0.11451	10	0.57255
28	6	87.96	615.75	0.36945	30	1.84725
29	2	91.1	660.51	0.132102	10	0.66051
30	9	94.24	706.85	0.636165	46	3.25151
31	1	97.38	754.76	0.075476	5	0.37738
32	1	100.53	804.24	0.080424	5	0.40212
33	3	103.67	855.29	0.256587	15	1.282935
34	1	106.81	907.92	0.090792	5	0.45396
36	4	113.09	1017.87	0.407148	20	2.03574
38	4	119.38	1134.11	0.453644	20	2.26822
40	2	125.66	1256.63	0.251326	10	1.25663
41	3	128.8	1320.25	0.396075	15	1.980375
42	2	131.94	1385.44	0.277088	10	1.38544
43	2	135.08	1452.01	0.290402	10	1.45201
45	1	141.37	1590.43	0.159043	5	0.795215
46	1	144.5	1661.9	0.16619	5	0.83095
48	2	150.79	1809.55	0.36191	10	1.80955
49	1	153.93	1885.74	0.188574	5	0.94287
50	2	157.07	1963.49	0.392698	10	1.96349
51	1	160.22	2042.82	0.204282	5	1.02141
53	1	166.5	2206.18	0.220618	5	1.10309
56	3	175.92	2463	0.7389	15	3 6945
61	1	191.63	2922.46	0.292246	5	1.46123
66	1	207.34	3421.19	0.342119	5	1.710595
187	1	587.47	27464.58	2.746458	5	13.73229
Total	298			14.554114	1511	72.451227

Table I.1. Table showing diameter, number of stumps per exposure, girth, basal area/exposure, number of stumps ha^{-1} and basal area ha^{-1} from the submerged forest at Hightown

Diameter (cm)	Stump reference no.
5	45 91 96 100 230 243 245 262 269
6	28 63 66 75 87 101 203 247 253 256 291
7	41 42 43 52 74 106 173 177 206
8	23 40 44 49 51 65 68 88 90 239 240 257 276
9	57 80 83 84 92 95 131 152 164 201 274 280
10	21 39 47 70 89 97 108 110 126 154 166 180 193 194 200 207 231 246 249 263 266 297
11	34 35 59 105 117 182 190 202 212 214 225 244
12	7 46 54 62 134 145 151 176 184 185 187 204 205 209 213 268 295
13	6 24 170 181 189 191 197 216 224 251 290 293
14	18 55 58 60 130 186 195 210 223 241 250
15	67 78 81 109 132 155 171 208 227 232 267 277 296
16	4 19 31 37 114 123 143 146 160 162 199 233 236
17	10 15 36 71 107 111 144 158 175 196 242
18	29 38 69 121 128 137 153 165 234 271 278
19	8 94 104 198 226 258 265 279
20	11 13 16 25 50 61 103 115 124 129 159 229 289 292 294
21	147 215
22	26 136 138 148 172 248 255 259
23	9 30 76 125 156 161 167 217 221 270 284
24	85 118 142 163 183 192 220 228 238 288
25	102 116 139 179 235
26	73 169 211 260 275 286
27	2 283
28	17 20 93 122 127 264
29	12 178
30	5 14 79 135 140 174 188 272 273
31	32
32	77
33	112 113 141
34	261
36	27 219 222 287
38	22 48 133 298
40	3 252
41	33 149 168
42	82 157
43	119 218
45	237
46	64
48	86 281
49	53
50	1 254
51	282
53	56
56	72 98 99
61	285
66	150
187	120

Table I.2. Table showing the diameters of stumps recorded at Hightown and the stumps associated with those diameter measurements

Stump Ref. No.	Diameter (cm)	Trunk length (cm)	Angle (°N)	Species
1	50			Decayed
2	27			Decayed
3	40	196	90	*Quercus* sp
4	16			Decayed
5	30			Decayed
6	13			Decayed
7	12			Decayed
8	19			Decayed
9	23			Decayed
10	17			Decayed
11	20			Decayed
12	29			Decayed
13	20			*Alnus* sp.
14	30	96	230	Decayed
15	17	63	15	Decayed
16	20			Decayed
17	28	270	180	Decayed
18	14			Decayed
19	16			Decayed
20	28			Decayed
21	10			Decayed
22	38			Decayed
23	8			Decayed
24	13			Decayed
25	20	96	100	Decayed
26	22			Decayed
27	36	136	80	Decayed
28	6			Decayed
29	18			Decayed
30	23			Decayed
31	16			Decayed
32	31	97	80	Decayed
33	41			Decayed
34	11			Decayed
35	11			Decayed
36	17			Decayed
37	16			Decayed
38	18			Decayed
39	10			Decayed
40	8			Decayed
41	7			Decayed
42	7			Decayed
43	7			Decayed
44	8			Decayed
45	5			Decayed
46	12			Decayed
47	10			Decayed
48	38			Decayed
49	8			Decayed
50	20			Decayed
51	8			Decayed
52	7			Decayed
53	49			Decayed
54	12			Decayed
55	14			Decayed
56	53			Decayed
57	9			Decayed
58	14			Decayed
59	11			Decayed
60	14			Decayed
61	20			Decayed
62	12			Decayed
63	6			Decayed
64	46			Salicaceae
65	8			Decayed
66	6			Decayed
67	15			Decayed
68	8			Decayed
69	18			Decayed
70	10			Decayed
71	17			Decayed

Table I.3a.Table showing the diameter, trunk length, angle of fall and species identification of all tree remains recorded at Hightown

Stump Ref No.	Diameter (cm)	Trunk length (cm)	Angle (°N)	Species
72^	56		94 & 122	Salicaceae
73	26			Decayed
74	7			*Alnus* sp
75	6			Decayed
76	23			Decayed
77	32	65	19	Decayed
78	15			Decayed
79	30			Decayed
80	9			Decayed
81	15			Decayed
82	42			Decayed
83	9			Decayed
84	9			Decayed
85	24			Decayed
86	48	340	87	Decayed
87	6			Decayed
88	8			Decayed
89	10			Decayed
90	8			Decayed
91	5			Decayed
92	9			Decayed
93	28			Decayed
94	19			Decayed
95	9			Decayed
96	5			Decayed
97	10			Decayed
98	56			Decayed
99	56			Decayed
100	5			Decayed
101	6			Decayed
102	25			Decayed
103	20			Decayed
104	19			Decayed
105	11			Decayed
106	7			Decayed
107	17			Decayed
108	10			Decayed
109	15			Decayed
110	10			Decayed
111	17			Decayed
112	33			Decayed
113	33			Decayed
114	16			Decayed
115	20	243	173	Decayed
116	25			Decayed
117	11			Decayed
118	24			Decayed
119	43	650		*Quercus* sp
120	187			Decayed
121	18			Decayed
122	28	170	149	Salicaceae
123	16			Decayed
124	20			Decayed
125	23			Decayed
126	10			Decayed
127	28			*Quercus* sp.
128	18			Decayed
129	20			Decayed
130	14			Decayed
131	9			Decayed
132	15			Decayed
133	38			Decayed
134	12			Decayed
135	30			Decayed
136	22			Decayed
137	18			Decayed
138	22			Decayed
139	25			Decayed
140	30			Decayed
141	33			Decayed
142	24			Decayed

Table I.3b. Table showing the diameter, trunk length, angle of fall and species identification of all tree remains recorded at Hightown

Stump Ref. No.	Diameter (cm)	Trunk length (cm)	Angle (°N)	Species
143	16			*Betula* sp.
144	17			Decayed
145	12			Decayed
146	16			Decayed
147	21			Decayed
148	22			Decayed
149	41			Decayed
150	66			Decayed
151	12			Decayed
152	9			Decayed
153	18			Decayed
154	10			Decayed
155	15			Decayed
156	23			Decayed
157	42			Decayed
158	17			Decayed
159	20			*Betula* sp.
160	16			Decayed
161	23			Decayed
162	16			Decayed
163	24	33	120	Decayed
164	9			Decayed
165	18			*Corylus* sp
166	10			Decayed
167	23			Decayed
168	41			Decayed
169	26			Decayed
170	13			Decayed
171	15			Decayed
172	22			Decayed
173	7			Decayed
174	30			Decayed
175	17			Decayed
176	12			Decayed
177	7			Decayed
178	29			Decayed
179	25			Decayed
180	10			Decayed
181	13			Decayed
182	11			Decayed
183	24			Decayed
184	12			Decayed
185	12			Decayed
186	14			Decayed
187	12			Decayed
188	30			*Quercus* sp.
189	13			Decayed
190	11			Decayed
191	13			Decayed
192	24			Decayed
193	10			Decayed
194	10			Decayed
195	14			Decayed
196	17			Decayed
197	13			Decayed
198	19			Decayed
199	16			Decayed
200	10			Decayed
201	9			Decayed
202	11			Decayed
203	6			Decayed
204	12			Decayed
205	12			Decayed
206	7			Decayed
207	10			Decayed
208	15			Decayed
209	12			Decayed
210	14			Decayed
211	26			Decayed
212	11			Decayed
213	12			Decayed

Table I.3c. Table showing the diameter, trunk length, angle of fall and species identification of all tree remains recorded at Hightown

StumpRef No.	Diameter (cm)	Trunk length (cm)	Angle (°N)	Species
214	11			Decayed
215	21			Decayed
216	13			Decayed
217	23			Decayed
218	43			Decayed
219	36			Decayed
220	24			Decayed
221	23			Decayed
222	36			Decayed
223	14			Decayed
224	13			Decayed
225	11			Decayed
226	19			Decayed
227	15			Decayed
228	24			Decayed
229	20			Decayed
230	5			Decayed
231	10			Decayed
232	15			Decayed
233	16			Decayed
234	18			Decayed
235	25	100	185	Salicaceae
236	16			Decayed
237	45			*Betula* sp.
238	24			Salicaceae
239	8			Decayed
240	8			Decayed
241	14			Decayed
242	17			Decayed
243	5			Decayed
244	11			Decayed
245	5			Decayed
246	10			Decayed
247	6			Decayed
248	22			Decayed
249	10			Decayed
250	14			Decayed
251	13			Decayed
252	40			Decayed
253	6			Decayed
254	50	144		Decayed
255	22			Decayed
256	6			Decayed
257	8			Decayed
258	19			Decayed
259	22			Decayed
260	26			Decayed
261	34			Decayed
262	5			Decayed
263	10			Decayed
264	28			Decayed
265	19			*Betula* sp.
266	10			Decayed
267	15			Decayed
268	12			Decayed
269	5			Decayed
270	23	127	24	Salicaceae
271	18			Decayed
272	30			Decayed
273	30			Decayed
274	9			Decayed
275	26			Decayed
276	8			Decayed
277	15			Decayed
278	18			Decayed
279	19			Decayed
280	9			Decayed
281	48			Decayed
282	51			Decayed
283	27			Decayed
284	23			Decayed

Table I.3d. Table showing the diameter, trunk length, angle of fall and species identification of all tree remains recorded at Hightown

StumpRef. No.	Diameter (cm)	Trunk length (cm)	Angle (°N)	Species
285	61			Decayed
286	26			Decayed
287	36			Decayed
288	24			Decayed
289	20			Decayed
290	13			Decayed
291	6			Decayed
292	20			Decayed
293	13			Decayed
294	20			Decayed
295	12			Decayed
296	15			Decayed
297	10			Decayed
298	38			Decayed

Table I.3e. Table showing the diameter, trunk length, angle of fall and species identification of all tree remains recorded at Hightown

Diameter (cm)	N exposure^{-1}	Girth (cm)	Area (cm^2)	Basal area/exposure (m^2)	N ha^{-1}	Basal area (m^2 h^{-1})	Stump Ref. No.
9	1	28.274334	63.61	0.0063617	16	0.1052608	T5
10	2	31.415927	78.53	0.015708	33	0.2599049	T2 T6
14	1	43.982297	153.9	0.0153938	16	0.2547061	T4
20	1	62.831853	314.15	0.0314159	16	0.5198081	S1
24	1	75.398224	452.38	0.0452389	16	0.7485237	S3
25	3	78.539816	490.87	0.1472619	50	2.436667	S6 S11 T3
30	1	94.24778	706.85	0.0706858	16	1.1695686	T1
33	1	103.67256	855.29	0.0855298	16	1.4151777	S12
34	1	106.81415	907.92	0.090792	16	1.5022462	S4
35	1	109.95574	962.11	0.0962112	16	1.5919123	S5
40	2	125.66371	1256.63	0.2513274	33	4.158468	S9 S10
45	2	141.37167	1590.43	0.3180862	33	5.2630604	S2 S2a
55	1	172.7876	2375.83	0.2375829	16	3.935214	S7
100	1	314.15927	7853.98	0.7853981	16	12.995214	S8
150	1	471.2389	17671.46	1.7671459	16	29.23923	S1a
Total	20			3.9641395	325	65.590799	

Table I.4. Table showing diameter, number of stumps per exposure, girth, basal area/exposure, number of stumps ha^{-1} and basal area ha^{-1} from the submerged forest at Wolla Bank

Stump/trunk ref. no.	Date sampled	Diameter (cm)	Trunk length (m)	Angle(° N)	Species
Trunk 1	28/03/94	30	5.2	340	Alnus sp.
Trunk 2	28/03/94	10	3.2	345	Alnus sp.
Trunk 3	28/03/94	25	1.7	370	Salicaceae
Trunk 4	28/03/94	14	1	338	Alnus sp.
Trunk 5	28/03/94	9	1.5	8	Salicaceae
Trunk 6	28/03/94	10	1.1	356	Alnus sp.
Stump 1	28/03/94	20		20	Alnus sp.
Stump 2	28/03/94	45			Quercus sp.
Stump 1	29/03/94	150			Fraxinus sp.
Stump 2	29/03/94	45			Fraxinus sp.
Stump 3	29/03/94	24			Alnus sp
Stump 4	29/03/94	34			Fraxinus sp.
Stump 5	29/03/94	35			Salicaceae
Stump 6	29/03/94	25			Fraxinus sp.
Stump 7	29/03/94	55			Fraxinus sp.
Stump 8	29/03/94	100			Quercus sp.
Stump 9	29/03/94	40			Betula sp.
Stump 10	29/03/94	40			Alnus sp.
Stump 11	29/03/94	25			Alnus sp.
Stump 12	29/03/94	33			Alnus sp.

Table I.5. Table showing the diameter, trunk length, angle of fall and species identification of all tree remains recorded at Wolla Bank

Diameter (cm)	N exposure-1	Girth (cm)	Area (cm2)	Basal area/exposure (m2)	N ha-1	Basal area (m2 h-1)	Stump Ref No.
12	1	37 69	113 09	0.0113097	5	0 0533005	T37
14	1	43 98	153 93	0 0153938	5	0 725481	T10
15	5	47.12	176.71	0 088357	23	0 41641	T8 S24 S25 S28 S42
17	1	53 4	226 98	0 022698	5	0 1069714	S40
18	1	56.54	254.46	0.0254469	5	0 1199265	T15
19	2	59 69	283 52	0 0567058	9	0 2672438	T19,S36
20	7	62 83	314.15	0 2199113	33	1.0364008	T12 S16 S17 S22 S25 S26 S51
21	2	65 97	346 36	0 0692722	9	0.3264669	T14 T39
22	1	69 11	380 13	0 0380133	5	0.1791496	S21
25	3	78 53	490 87	0.1472622	14	0 6940192	T6 S13 S27
26	1	81 68	530 92	0 0530929	5	0 2502169	S20
27	1	84 82	572 55	0.0572555	5	0.2698345	S38
28	1	87.96	615.75	0.61575216	5	0.2901924	S44
30	2	94 24	706 85	0 1413716	9	0 6662579	T31 S41
34	1	106 81	907.92	0 090792	5	0 4278857	T1
35	1	109 95	962.11	0 0962113	5	0.4534259	S5
38	3	119 38	1134 11	0 3402342	14	1 6034602	S35 S43 T49
40	5	125.66	1256.63	0 6283185	23	2 9611476	S7 S18 S32 S33 S34
45	1	141.37	1590.43	0.1590431	5	0.7495404	S50
50	2	157 07	1963 49	0.392699	9	1 850717	S2 T4
52	1	163 36	2123.71	0 2123716	5	1.0008676	S30
54	1	169 64	2290.22	0.2290221	5	1 0793383	T47
55	1	172 78	2375 82	0 2375829	5	1 1196838	S9
60	3	188 49	2827 43	0 8482299	14	3 9975489	T45 S46 T48
80	2	251.32	5026 54	1.0053096	9	4 7378362	T3 T29
110	1	345 57	9503 31	0 9503318	5	4 4787361	S11
Total	51			6 1978114	236	29.209126	

Table I.6. Table showing diameter, number of stumps per exposure, girth, basal area/exposure, number of stumps ha^{-1} and basal area ha^{-1} from the submerged forest at Anderby Creek

Stump/trunk ref. no.	Date Sampled	Diameter (cm)	Trunk length (m)	Angle (° N)	Species
Trunk 1	28/04/94	34	4.98	95	Quercus sp.
Stump 2	28/04/94	50			Quercus sp.
Trunk 3	28/04/94	80	5.6	40	Quercus sp.
Trunk 4	28/04/94	50	4.05		Unsampled
Stump 5	28/04/94	35			Quercus sp.
Trunk 6	28/04/94	25	3.8	100	Unsampled
Stump 7	28/04/94	40			Alnus sp.
Trunk 8	28/04/94	15	2.25	20	Quercus sp.
Stump 9	28/04/94	55			Unsampled
Trunk 10	28/04/94	14	2.95	30	Quercus sp.
Stump 11	28/04/94	110			Quercus sp.
Trunk 12	28/04/94	20	2.89	40	Quercus sp.
Stump 13	28/04/94	25			Fraxinus sp.
Trunk 14	28/04/94	21	3.25		Quercus sp.
Trunk 15	28/04/94	18	1.65	56	Unsampled
Stump 16	28/04/94	20			Salicaceae
Stump 17	28/04/94	20			Unsampled
Stump 18	28/04/94	40			Alnus sp.
Trunk 19	28/04/94	19	2.14	28	Unsampled
Stump 20	28/04/94	26			Unsampled
Stump 21	28/04/94	22			Unsampled
Stump 22	28/04/94	20			Quercus sp.
Stump 23	28/04/94	20			Unsampled
Stump 24	28/04/94	15			Unsampled
Stump 25	28/04/94	15			Unsampled
Stump 26	29/04/94	20			Unsampled
Stump 27	29/04/94	25			Unsampled
Stump28	29/04/94	15			Unsampled
Trunk 29	29/04/94	80	1.23	20	Quercus sp.
Stump 30	29/04/94	52			Alnus sp.
Trunk 31	29/04/94	30	2.87	340	Quercus sp.
Stump 32	29/04/94	40			Quercus sp.
Stump 33	29/04/94	40			Unsampled
Stump 34	29/04/94	40			Quercus sp.
Stump 35	29/04/94	38			Unsampled
Stump 36	29/04/94	19			Unsampled
Trunk 37	29/04/94	12	1.36	58	Quercus sp.
Stump 38	29/04/94	27			Unidentified
Trunk 39	29/04/94	21	5.2	60	Quercus sp.
Stump 40	29/04/94	17			Quercus sp.
Stump 41	29/04/94	30			Salicaceae
Stump 42	29/04/94	15			Alnus sp.
Stump 43	29/04/94	38			Unsampled
Stump 44	29/04/94	28			Unsampled
Trunk 45	29/04/94	60	3.95	22	Fraxinus sp.
Stump 46	29/04/94	60			Quercus sp.
Trunk 47	29/04/94	54	5.28	60	Unsampled
Trunk 48	29/04/94	60	2.5	60	Unsampled
Trunk 49	29/04/94	38	8.83	30	Unsampled
Stump 50	29/04/94	45			Unsampled
Stump 51	29/04/94	20			Unsampled

Table I.7. Table showing the diameter, trunk length, angle of fall and species identification of all tree remains recorded at Anderby Creek

Hightown Monolith 2 (Vertical) 10/8/94						
Sample	6	5	4	3	2	1
Depth	0-5cm	5-10cm	10-14cm	14-18cm	18-22 5cm	22.5-27cm
Volume (cm^3)	300	400	400	400	400	400
Species						
Shrubs						
Frangula alnus				1f		
Waterside/margin						
Hydrocotyle vulgaris			1			
Mentha sp.				7		
Juncus sp seeds			1	3	181+2charred	
Isolepis setacea						125
Carex sp lentic	12	24	22+4f	41+5f	24+1charred	10+1f
Carex sp trig		1	2	1		
Phragmites australis rhizomes	common		rare	rare	common	common
Scrub/woodland						
Rubus fruticosus	2	4+1f	1	2+21f	1	
Solanum dulcamara			1		1f	
Aquatic						
Apium nodiflorum					1	
Alisma sp.			1			
Potamogeton coloratus			2+1f			
Open/disturbed						
Chenopodium sp.					6	1
Atriplex patula						1
Stellaria media						1
Coastal grassland						
? *Linum bienne*				2		
Poaceae	2			5	6(small)	8(small)
Miscellaneous						
Charcoal	5f		1f	9f	57f	100f
Buds, bud scales, leaf fragments			1bscale+1leaf f	4buds+1leaf f		
Leaf abscission plates	2		1	7		
?			1	3		2
Monocot stems/roots	common	abundant	rare			
Twigs & wood fragments	common	common	common	common	v. common	v. common
Cladoceran eggs			14	7		
Worm coccoons	8	16	22	36	35	90
Fungal sclerotia	1000's	100's	345	2	1	
Insect remains	common	common	common	common		
Modern marine molluscs	3					

Table I.8. Uncorrected scoresheet for the plant macrofossil analysis from the vertical section (monolith 2) from Hightown

Hightown Monolith 3 (Horizontal) 10/8/94		
Sample	bottom	top
Volume (cm^3)	200ml	200ml
Species		
Trees		
Betula sp.seeds	18	62
Betula sp. female cone bracts	2	10
Alnus glutinosa fruits	2	24
Shrubs		
Cornus sanguinea		3
Frangula alnus	3	11+23f
Scrub/woodland		
Rubus fruticosus	2+7f	3+5f
Rubus sp. prickles	3	10
Wet/pool/streamside		
Ranunculus flammula		2
Filipendula ulmaria		4
Angelica sylvestris		1
Lycopus europeus	5	3
Carex sp. lentic	271	387
Carex sp. lentic large		52+1f
Carex sp. trig	19	10
Carex sp. utricles		6
Aquatic		
Alisma sp.	1	
Potamogeton sp.	3	10
Miscellaneous		
Musci	rare	common
Poaceae	37+1f	27
Calyx unident	1	
Buds, bud scales, leaf fragments	common	v common
Twigs & wood fragments	v.common	v. common
Cladoceran eggs	4	38
Worm coccoons	6	8
Fungal sclerotia	167	33
Insect remains	common	common

Table I.9. Uncorrected scoresheet for the plant macrofossil analysis from the horizontal section (monolith 3) from Hightown

Hightown Monolith 4 (Horizontal) 10/8/94				
Sample	Bottom	Middle	Top	Top
Volume	850ml	525ml	300ml	200ml
Species				
Trees				
Betula sp.seeds	12			
Betula sp. female catkin scales	3			
Betula sp. bark				4f
Shrubs				
Crataegus/Prunus sp. thorns			1	
Frangula alnus	19+47f			
Aquatic				
Menyanthes trifoliata		4+13f	36+45f	1
Menyanthes trifoliata half seeds			48	
Potamogeton polygonifolius	208+62f	10+2f	1	
Waterside/margin				
Lychnis flos-cuculi		1f		1
Hydrocotyle vulgaris			2	
Iris pseudoacorus	1			
Carex sp. lentic (type 1)	261	34	5	4
Carex sp. lentic (type 2)	235	3		
Carex sp. trig	3	1		
Carex sp. utricules	7			
Phragmites australis rhizomes	common	v. common	v.v.common	24f
Peat bog				
Sphagnum sp. leaves	154	2		2
Sphagnum sp. branches	5			
Sphagnum sp. buds	6			
Bog/fen/damp woodland				
Osmunda regalis pinnule			1	
Osmunda regalis rhizome fragments		v. common	common	v.v.common
Osmunda regalis spores				3
Dryopteris type sporangia				129
Dryopteris type annulus fragments				185
Miscellaneous				
Poaceae	3(small)	3		
leaf & petal frags misc.	15			
Monocot stems/roots	v. common	common	v. common	common
Buds, bud scales, leaf fragments	9buds+21scales	1bud	1bud+1scale	
Twigs & wood fragments	common	v. common	v. common	
Daphne eggs		2		3
Worm cocoons	371	389	31	8
Fungal sclerotia	1	3	1	
Insect remains	v. common	v.common	common	common
Modern marine molluscs			9+7f	

Table I.10. Uncorrected scoresheet for the plant macrofossil analysis from the horizontal section (monolith 4) from Hightown

Wolla Bank Section 1 29/3/94							
sample	0-4.5cm	4.5-7.0cm	7.0-10cm	10-14.5cm	14.5-19.0cm	19.0-25.0cm	25.0-30.0cm
volume (cm^3)	300	150	300	400	150	400	300
Species							
Woodland							
Prunus spinosa	3+23f						
Rubus fruticosus	20+31f		5+12f	1+2f			
Wet Woodland							
Alnus wood	2		2				
Alnus twig		1					
Ajuga reptans				3			
Carex remota	4	1	105	52	1		
Woodland Miscellaneous							
Twigs 2-3mm diameter	86						
Twigs >3mm diameter	many						
Bark fragment				8	common		
Buds & bud scales	31	1	8				
Wetland/Aquatics							
Oenanthe aquatica	1						
Carex sp. trigonous	1						
Cyperaceae stem		1					
Phragmites australis rhizomes		12f	common				
Miscellaneous							
Fungal sclerotia				95	39		26
Charcoal fragments			1	65	23	15	13
tuber						1	
Pyritized wood							1
Insect remains	common	frequent	common	common		frequent	
Worm coccoons	1	1	18	18			
?	2						

Table I.11. Uncorrected scoresheet for the plant macrofossil analysis from the vertical section (section 1) from Wolla Bank

Wolla Carpark Section 2.						
Sample	0-3 5cm	3 5-7cm	7-8cm	8-10cm	10-14cm	14-17cm
Volume (cm³)	350	300	100	130	300	120
Species						
Woodland						
Betula sp. fruits	866	33	4	1	2	4
Betula pendula female cone scales	10					
Betula sp. female cone scales	31	2				
Ilex aquifolium	1	3				
Prunus spinosa	2+20f	3				
Rubus fruticosus agg	75 +293f	70+166f	24+158f	43+266f	1+2f	1
Rubus fruticosus prickles	286	89	3	6		
Rosaceae thorns		2				
Vaccinium myrtillus	2					
Solanum dulcamarra	27+9f	10+8f	1f	1+1f		
Wet Woodland						
Alnus glutinosa fruits	111	75+37f	1	2		
Alnus glutinosa female cones	15	15	1			
Alnus glutinosa female cone stalks		2+2 rachii				
Alnus glutinosa male catkins	132	3f			1f	
Alnus glutinosa male catkin scales		95	1	1		
Alnus glutinosa anthers	59	53				
Frangula alnus	4f					
Ajuga reptans					1	
Eupatorium cannabinum	13+3pappus frags		1			
Carex remota		112	108	77	18	
Dryopteris/Thelypteris sporangia	v. abundant	v abundant	few	few		
Osmunda type spore		1				
Woodland Miscellanea						
Wood fragments	common	common				common
Twigs				common	common	
Buds	frequent	v common				
Bud scales	frequent	v. common				
Wetland/Aquatics						
Ranunculus sceleratus		4				
Oenanthe aquatica	91+79f	19+18f				
Callitriche sp	364	78	1			
Lycopus europaeus	32+11f	9+26f				
Typha angustifolia/latifolia	1					
Phragmites australis rhizome	82	27f	23f	31+f		
Juncus spp.	661	1000's	226	618	1	
Carex sp (lentic)	7+2f	56+22f	20+70f	44+62f	10+2f	1
Carex sp. trigonus		1f				
Open/Disturbed/Grassland						
Ranunculus a/r/b		1				
Viola sp.					1	
Cirsium sp.	1	2				
Small Poaceae	5					
Poaceae indet.	2	1				
Poaceae culm node	1					
Miscellaneous						
Fungal sclerotia	8	14	15	100	1000's	251
Charcoal frags < 1mm	6	3	3	58	1000's	344
Moss stems and leaves	frequent	frequent	occasional			
Monocot stems/roots						v. common
Cyperaceae stem						
?	2					
Pyritized wood						
Pyritized roots and stems						
Pyritized culm nodes						
Insect remains	abundant	abundant	common	uncommon	uncommon	v. rare
Daphnia	134	abundant				
Worm coccoons	11	10+8f	23	22		
Flint >2mm						

Table I.12a. Uncorrected scoresheet for the plant macrofossil analysis from the vertical section (section 2) from Wolla Bank

Wolla Carpark Section 2.		
Sample	17-18cm	18-22cm
Volume	100	200
Species		
Woodland		
Betula sp fruits		
Betula pendula female cone scales		
Betula sp. female cone scales		
Ilex aquifolium		
Prunus spinosa		
Rubus fruticosus agg		
Rubus fruticosus prickles		
Rosaceae thorns	1	
Vaccinium myrtillus		
Solanum dulcamarra		
Wet Woodland		
Alnus glutinosa fruits		
Alnus glutinosa female cones		
Alnus glutinosa female cone stalks		
Alnus glutinosa male catkins		
Alnus glutinosa male catkin scales		
Alnus glutinosa anthers		
Frangula alnus		
Ajuga reptans		
Eupatorium cannabinum		1f
Carex remota		
Dryopteris/Thelypteris sporangia		
Osmunda type spore		
Woodland Miscellanea		
Wood fragments	rare	
Twigs		
Buds		
Bud scales		
Wetland/Aquatics		
Ranunculus sceleratus		
Oenanthe aquatica		
Callitriche sp.		
Lycopus europaeus		
Typha angustifolia/latifolia		
Phragmites australis rhizome		
Juncus spp		
Carex sp. (lentic)		
Carex sp. trigonus		
Open/Disturbed/Grassland		
Ranunculus a/r/b		
Viola sp.		
Cirsium sp.		
Small Poaceae		
Poaceae indet.		
Poaceae culm node		
Miscellaneous		
Fungal sclerotia	43	67
Charcoal frags.< 1mm	45	21
Moss stems and leaves		
Monocot stems/roots		
Cyperaceae stem	1f	
?		
Pyritized wood	3f	
Pyritized roots and stems	common	
Pyritized culm nodes		5
Insect remains	v rare	v v rare
Daphnia		
Worm coccoons		
Flint >2mm	1	2

Table I.12b. Uncorrected scoresheet for the plant macrofossil analysis from the vertical section (section 2) from Wolla Bank

Anderby Creek (N) 22/4/96				
Sample	0-4cm	10.5-7cm	10.5-13.5cm	13.5-17.0cm
Volume (cm^3)	600	425	200	400
Species				
Salt Marsh				
Suedea maritima seeds	52+311f	14+836f	1+120f	27+340f
S. maritima embryos	65	23	8	79
Limonium sp. flowers+calices	360	202+30f+4st+1a	34fl+4fruits	12
Triglochin maritima rhizomes	v. common			
Triglochin maritima fruits	168	61+24f	16	12
Triglochin maritima seeds		74+29f	16+7f	
Juncus gerardi	79	806+122f	384	50
cf *Puccinella* sp.				1
Woodland				
Betula sp. seeds	1	3	1	
Prunus spinosa			27f	
Rubus fruticosus		1	3+10f	12+37f
Rosaceae thorn				1
Solanum dulcamarra		1		
Bud scales	3		3+2buds	196
Wood fragments		10		
Bark			2f	
Wet Woodland				
Angelica sylvestris		1		
Eupatorium cannabinum		3f	8f	1f
Wetland/Aquatic				
Characeae oogonium		1		
Apium nodiflorum			2+1f	
Juncus sp.		173+18f		15
Carex sp. Trigonous			1	
Carex sp. utricle		1f		
Open/Disturbed/Grassland				
Potentilla sp.				1
Galium sp.				1
Poaceae	2	2	1	
Miscellaneous				
Fungal scleotia	6		42+17f	1082
Charcoal	6f	8f	121f	400+f
Culm node		1		
Leaf fragments			22	
Insect remains	v. common	frequent	frequent	rare
Unknown	4	15		12
Foraminifera	v.v. common	v.v. common	common	rare
?Fungal perithecae				8

Table I.13. Uncorrected scoresheet for the plant macrofossil analysis from the vertical section from Anderby Creek (N)

Appendix II

NATIONAL VEGETATION CLASSIFICATION DATA

Woodland Type	**Community**
W1	*Salix cinerea-Galium palustre*
W2	*Salix cinerea-Betula pubescens-Phragmites australis*
W3	*Salix pentandra-Carex rostrata*
W4	*Betula pendula-Molinia caerulea*
W5	*Alnus glutinosa-Carex paniculata*
W6	*Alnus glutinosa-Urtica dioica*
W7	*Alnus glutinosa-Fraxinus excelsior-Lysimachia nemorum*
W8	*Fraxinus excelsior-Acer campestre-Mercurialis perennis*
W9	*Fraxinus excelsior-Sorbus aucuparia-Mercurialis perennis*
W10	*Quercus robur-Pteridium aquilinum-Rubus fruticosus*
W11	*Quercus petraea-Betula pubescens-Oxalis acetosella*
W12	*Fagus slyvatica-Mercurialis perennis*
W13	*Taxus baccata*
W14	*Fagus sylvatica-Rubus fruticosus*
W15	*Fagus sylvatica-Deschampsia flexuosa*
W16	*Quercus* spp.-*Betula* spp.-*Deschampsia flexuosa*
W17	*Quercus petraea-Betula pubescens-Dicranium majus*
W18	*Pinus slyvestris-Hylocomium splendens*
W19	*Juniperus communis* ssp. *communis-Oxalis acetosella*
W20	*Salix lapponum-Luzula sylvatica*
W21	*Crataegus monogyna-Hedera helix*
W22	*Prunus spinosa-Rubus fruticosus*
W23	*Ulex europaeus-Rubus fruticosus*
W24	*Rubus fruticosus-Holcus lanatus*
W25	*Pteridium aquilinum-Rubus fruticosus*

Table II.1. Table showing the main Woodland types of the National Vegetation Classification (After Rodwell, 1991a)

Aquatic Type	Community
A1	*Lemna gibba*
A2	*Lemna minor*
A3	*Spiodela polyrhiza-Hydrocharis morsus-ranae*
A4	*Hydrocharis morsus-ranae-Stratiotes aloides*
A5	*Ceratophyllum demersum*
A6	*Ceratophyllum submersum*
A7	*Nymphaea alba*
A8	*Nuphar lutea*
A9	*Potamogeton natans*
A10	*Polygonium amphibium*
A11	*Potamogeton pectinatus-Myriophyllum spicatum*
A12	*Potamogeton pectinatus*
A13	*Potamogeton perfoliatus-Myriophyllum alterniflorum*
A14	*Myriophyllum alterniflorum*
A15	*Elodea canadensis*
A16	*Callitriche stagnalis*
A17	*Ranunculus penicillatus ssp. pseudofluitans*
A18	*Ranunculus fluitans*
A19	*Ranunculus aquatilis*
A20	*Ranunculus peltatus*
A21	*Ranunculus baudotii*
A22	*Littorella uniflora-Lobelia dortmanna*
A23	*Isoetes lacustris/setacea*
A24	*Juncus bulbosus*

Table II.2. Table showing the main Aquatic Communities of the National Vegetation Classification.
(After Rodwell, 1995)

Swamp and Tall-fen Type	**Community**
S1	*Carex elata* swamp
S2	*Cladium mariscus* swamp & sedge-beds
S3	*Carex paniculata* swmp
S4	*Phragmites australis* swamp and reed-beds
S5	*Glyceria maxima* swamp
S6	*Carex riparia* swamp
S7	*Carex acutiformis* swamp
S8	*Scirpus lacustris* ssp. *lacustris* swamp
S9	*Carex rostrata* swamp
S10	*Equisetum fluviatile* swamp
S11	*Carex vesicaria* swamp
S12	*Typha latifolia* swamp
S13	*Typha angustifolia* swamp
S14	*Sparganium erectum* swamp
S15	*Acorus calamus* swamp
S16	*Sagittaria sagittifolia* swamp
S17	*Carex pseudocyperus* swamp
S18	*Carex otrubae* swamp
S19	*Eleocharis palustris* swamp
S20	*Scirpus lacustris* ssp. *tabernaemontani* swamp
S21	*Scirpus maritimus* swamp
S22	*Glyceria fluitans* water-margin vegetation
S23	Other water-margin vegetation
S24	*Phragmites australis-Peucedanum palustre* tall-herb fen
S25	*Phragmites australis-Eupatorium cannabinum* tall-herb fen
S26	*Phragmites australis-Urtica dioica* tall-herb fen
S27	*Carex rostrata-Potentilla palustris* tall-herb fen
S28	*Phalaris arundinaceae* tall-herb fen

Table II.3. Table showing the main Swamp and Tall-herb fen Communities of the National Vegetation Classification (After Rodwell, 1995)

Overall	10-14cm	14-18cm	18-22.5
Rubus fruticosus L.	*Rubus fruticosus* L .	*Rubus fruticosus* L.	*Rubus fruticosus* L.
Frangula alnus Mill.	*Hydrocotyle vulgaris* L.	*Frangula alnus* Mill.	*Apium nodiflorum* (L.) Lag.
Hydrocotyle vulgaris L.	*Solanum dulcamara*	*Mentha* L. *sp.*	*Solanum dulcamara* L.
Apium nodiflorum (L.) Lag.	*Alisma sp.* L.	*Juncus* L. *sp.*	*Juncus* L. *sp.*
Solanum dulcamara L.	*Potamogeton coloratus* Hornem.	*Phragmites australis* (Cav.) Trin. ex Steud.	*Phragmites australis* (Cav.) Trin. ex Steud.
Mentha L. *sp.*	*Juncus* L. *sp.*		
Alisma L. *sp.*	*Phragmites australis* (Cav.) Trin. ex Steud.		
Potamogeton coloratus Hornem.			
Juncus L *sp.*			
Phragmites australis (Cav.) Trin. ex Steud.			

Table II.4a. Table of Taxa at Hightown, vertical section used in the NVC analyses

Overall	Lower	Upper
Ranunculus flammula L.	*Betula* L. sp.	*Ranunculus flammula* L.
Betula L. sp.	*Alnus glutinosa* (L.) Gaertn.	*Betula* L. sp.
Alnus glutinosa (L.) Gaertn.	*Rubus fruticosus* L.	*Alnus glutinosa* (L.) Gaertn.
Filipendula ulmaria (L.) Maxim.	*Frangula alnus* Mill.	*Filipendula ulmaria* (L.) Maxim.
Rubus fruticosus L.	*Lycopus europaeus* L.	*Rubus fruticosus* L.
Cornus sanguinea L.	*Alisma* L. sp.	*Cornus sanguinea* L.
Frangula alnus Mill.		*Frangula alnus* Mill.
Angelica sylvestris L.		*Angelica sylvestris* L.
Lycopus europaeus L.		*Lycopus europaeus* L.
Alisma L. sp.		

Table II.4b. Table of Taxa at Hightown, Monolith 3 used in the NVC analyses

Overall	Lower	Middle	Upper
Osmunda regalis L.	*Betula* L. sp.	*Lychnis flos-cuculi* L.	*Hydrocotyle vulgaris* L.
Betula L. sp.	*Frangula alnus* Mill.	*Menyanthes trifoliata* L.	*Menyanthes trifoliata* L.
Lychnis flos-cuculi L.	*Potamogeton polygonifolius* Pourr.	*Potamogeton polygonifolius* Pourr.	*Potamogeton polygonifolius* Pourr.
Frangula alnus Mill.	*Phragmites australis* (Cav.) Trin. ex Steud.	*Phragmites australis* (Cav.) Trin. ex Steud.	*Phragmites australis* (Cav.) Trin. ex Steud
Hydrocotyle vulgaris L.	*Iris pseudoacorus* L.		
Menyanthes trifoliata L.			
Potamogeton polygonifolius Pourr.			
Phragmites australis (Cav.) Trin. ex Steud.			
Iris pseudoacorus L.			

Table II.4.c. Table of Taxa at Hightown, Monolith 4 used in the NVC analyses

Overall	**Dk. Peaty sand**	**Peat & Forest Bed**	**Dk. Sandy Horizon**	**Blue clay Horizon.**
Osmunda regalis L.	*Nymphaea alba* L.	*Huperzia selago* (L.) Bernh. ex Schrank & Mart	*Thalictrum flavum* L.	*Potentilla sterilis* (L.) Garcke
Pinus sylvestris L.	*Nuphar lutea* (L.) Sm.	*Osmunda regalis* L.	*Alnus glutinosa* (L.) Gaertn.	*Ruppia maritima* L.
Nymphaea alba L.	*Quercus robur* L.	*Polypodium vulgare* L.	*Rubus fruticosus* L.	*Ruppia cirrhosa* (Petagna) Grande
Nuphar lutea (L.) Sm.	*Betula pendula* Roth	*Thelypteris palustris* Schott.	*Oenanthe aquatica* (L.) Poir.	
Myrica gale L.	*Chenopodium album* L.	*Athyrium felix-femina* (L.) Roth	*Ruppia maritima* L.	
Quercus robur L.	*Atriplex patula* L.	*Dryopteris cristata* (L.) A. Gray	*Ruppia cirrhosa* (Petagna) Grande	
Betula pendula Roth	*Potentilla anserina* L.	*Pinus sylvestris* L.		
Alnus glutinosa (L.) Gaertn.	*Myriophyllum spicatum* L.	*Myrica gale* L.		
Corylus avellana L.	*Hydrocotyle vulgaris* L.	*Quercus robur* L.		
Chenopodium album L.	*Mentha aquatica* L.	*Betula pendula* Roth		
Atriplex patula L.	*Alisma plantago-aquatica* L.	*Alnus glutinosa* (L.) Gaertn.		
Stellaria palustris Retz.	*Potamogeton gramineus* L.	*Corylus avellana* L.		
Viola palustris L.	*Juncus* L. spp.	*Atriplex patula* L.		
Salix cinerea L.		*Stellaria palustris* Retz.		
Salix aurita L.		*Rumex acetosa* L.		
Salix repens L.		*Tilia* L. sp.		
Potentilla anserina L.		*Viola palustris* L.		
Myriophyllum spicatum L.		*Salix cinerea* L.		
Ilex aquifolium L.		*Salix aurita* L.		
Hydrocotyle vulgaris L.		*Salix repens* L.		
Menyanthes trifoliata L.		*Myriophyllum spicatum* L.		
Mentha aquatica L.		*Ilex aquifolium* L.		
Hippuris vulgaris L.		*Sium latifolium* L.		
Potamogeton gramineus L.		*Menyanthes trifoliata* L.		
Juncus articulatus L.		*Scutellaria* L. sp.		
Juncus L. spp.		*Hippuris vulgaris* L.		
Carex paniculata L.		*Juncus articulatus* L.		
		Carex paniculata L.		

Table II.5a Table of taxa from Travis's 1926 study of Hightown used in the NVC analyses

Overall	**Peaty sand**	**Compact peat**	**Blue clay**	**Lower peat**
Pinus sylvestris L.	*Urtica dioica* L.	*Osmunda regalis* L.	*Polypodium vulgare* L.	*Pinus sylvestris* L.
Ranunculus flammula L.	*Atriplex prostrata* Boucher ex DC.	*Athyrium felix-femina* (L.) Roth	*Betula pendula* Roth	*Urtica dioica* L.
Urtica dioica L.	*Menyanthes trifoliata* L.	*Pinus sylvestris* L.	*Viola* L. sp.	*Quercus robur* L.
Quercus robur L.	*Mentha aquatica* L.	*Ranunculus flammula* L.	*Solanum dulcamara* L.	*Betula pendula* Roth
Betula pendula Roth	*Zannichellia palustris* L.	*Ulmus* L. sp.	*Schoenoplectus lacustris* (L.) Palla	*Corylus avellana* L.
Alnus glutinosa (L.) Gaertn.	*Schoenoplectus lacustris* (L.) Palla	*Quercus robur* L.		*Atriplex prostrata* Boucher ex DC
Corylus avellana L.		*Betula pendula* Roth		*Prunus spinosa* L.
Atriplex prostrata Boucher ex DC		*Alnus glutinosa* (L.) Gaertn.		*Lycopus europaeus* L.
Stellaria media (L.) Vill		*Corylus avellana* L.		*Eupatorium cannabinum* L.
Viola palustris L.		*Atriplex prostrata* Boucher ex DC		*Schoenoplectus lacustris* (L.) Palla
Rubus fruticosus L.		*Stellaria media* (L.) Vill		*Phragmites australis* (Cav.) Trin. ex Steud.
Potentilla anserina L.		*Tilia* L. sp.		
Prunus spinosa L.		*Viola palustris* L.		
Hydrocotyle vulgaris L.		*Rubus fruticosus* L.		
Apium nodiflorum (L.) Lag.		*Potentilla anserina* L.		
Lycopus europaeus L.		*Hydrocotyle vulgaris* L.		
Hippuris vulgaris L.		*Apium nodiflorum* (L.) Lag.		
Cirsium palustre (L.) Scop.		*Lycopus europaeus* L.		
Eupatorium cannabinum L.		*Hippuris vulgaris* L.		
Alisma plantago-aquatica L.		*Cirsium palustre* (L.) Scop.		
Zannichellia palustris L.		*Alisma plantago-aquatica* L.		
Eleocharis palustris (Link) Schult.		*Zannichellia palustris* L.		
Schoenoplectus lacustris (L.) Palla		*Eleocharis palustris* (Link) Schult.		
Cladium mariscus (L.) Pohl		*Cladium mariscus* (L.) Pohl		
Phragmites australis (Ca.) Trin. ex Steud.		*Phragmites australis* (Ca.) Trin. ex Steud.		
Sparganium natans L.		*Sparganium natans* L.		

Table II.5b. Table of Taxa from Travis's 1929 study of Leasowe used in the NVC analyses

Overall	**0-4.5cm**	**7-10cm**	**10-14.5cm**
Alnus glutinosa (L.) Gaertn.	*Alnus glutinosa* (L.) Gaertn.	*Alnus glutinosa* (L.) Gaertn.	*Rubus fruticosus* L.
Rubus fruticosus L	*Rubus fruticosus* L.	*Rubus fruticosus* L.	*Ajuga reptans* L.
Prunus spinosa L.	*Prunus spinosa* L.	*Carex remota* L.	*Carex remota* L.
Oenanthe aquatica (L.) Poirr.	*Oenanthe aquatica* (L.) Poirr.	*Phragmites australis* (Cav.) Trin. ex Steud.	
Ajuga reptans L	*Carex remota* L.		
Carex remota L.			
Phragmites australis (Cav.) Trin. ex Steud.			

Table II.6a. Table of Taxa from Wolla Bank, Section One used in the NVC analyses

Overall	**0-3.5cm**	**3.5-7.0cm**	**7.0-8.0cm**	**8.0-10.0cm**	**10.0-14.0cm**
Osmunda regalis L.	*Betula pendula* Roth.	*Osmunda regalis* L.	*Betula* L. sp.	*Betula* L. sp.	*Betula* L. sp.
Ranunculus subgenus *Ranunculus*	*Betula* L. sp.	*Ranunculus* subgenus *Ranunculus*	*Alnus glutinosa* (L.) Gaertn.	*Rubus fruticosus* L.	*Viola* L. sp.
Ranunculus scleratus L.	*Alnus glutinosa* (L.) Gaertn.	*Ranunculus scleratus* L.	*Rubus fruticosus* L.	*Solanum dulcamara* L.	*Rubus fruticosus* L.
Betula pendula Roth.	*Vaccinium myrtillus* L.	*Betula* L. sp.	*Solanum dulcamara* L.	*Juncus* L. spp.	*Ajuga reptans* L.
Betula L. sp.	*Rubus fruticosus* L.	*Alnus glutinosa* (L.) Gaertn.	*Eupatorium cannabinum* L.	*Carex remota* L.	*Juncus* L. spp.
Alnus glutinosa (L.) Gaertn.	Prunus spinosa L.	*Rubus fruticosus* L.	*Juncus* L. spp.	*Phragmites australis* (Cav. Trin. ex Steud.	*Carex remota* L.
Viola L. sp.	*Ilex aquifolium* L.	*Prunus spinosa* L.	*Carex remota* L.		
Vaccinium myrtillus L.	*Frangula alnus* Mill.	*Ilex aquifolium* L.	*Phragmites australis* (Cav.) Trin. ex Steud.		
Rubus fruticosus L.	*Oenanthe aquatica* (L.) Poir.	*Oenanthe aquatica* (L.) Poir.			
Prunus spinosa L.	Solanum dulcamara L.	*Solanum dulcamara* L.			
Ilex aquifolium L.	*Lycopus europaeus* L.	*Lycopus europaeus* L.			
Frangula alnus Mill.	*Cirsium* Mill. sp.	*Cirsium* Mill. sp.			
Oenanthe aquatica (L.) Poir.	*Eupatorium cannabinum* L.	*Juncus* L. spp.			
Solanum dulcamara L.	*Juncus* L. spp.	*Carex remota* L.			
Ajuga reptans L	*Typha* L. sp.	*Phragmites australis* (Cav.) Trin. ex Steud.			
Lycopus europaeus L.					
Cirsium Mill. sp.					
Eupatorium cannabinum L.					
Juncus L. spp.					
Carex remota L.					
Phragmites australis (Cav.) Trin. ex Steud.					
Typha L. sp.					

Table II.6b. Table of Taxa from Wolla Bank, Section Two used in the NVC analyses

Appendix III

A PLANT MACROFOSSIL INVESTIGATION OF A SUBMERGED FOREST

A Plant Macrofossil Investigation of a Submerged Forest

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Introduction

It is accepted that the forest formed a major component of the environment of prehistoric cultures and was an important resource, whether as a source of foodstuffs, of timber or of browse. Evidence for what the forest looked like and how its character might have affected exploitation has, however, been derived from on-site evidence, such as plant macrofossils, including charcoal from post-holes and off-site palynology.

The problem with the first type of evidence is that it tells us nothing of how representative the selected tree sizes and species were of the actual forest trees. Whilst pollen analysis provides evidence for which species of trees were growing in a particular area at a particular time and provides a rough guideline to the proportions of each species, this has to be qualified by recognizing that certain species would be underrepresented whilst others, such as pine (*Pinus* sp.), might have travelled from greater distances. Therefore, palynology linked with on-site plant macrofossil evidence cannot tell us about the proportions of particular species, and their distribution or age structure within the forest. For example, was hazel, with its supply of nuts, one of the most frequent food resources recovered from archaeological sites, scattered evenly throughout the forest or was it concentrated in certain areas? The answer is important as it would have affected the distribution of past exploitation and thus the distribution of archaeological artefacts.

Submerged forests would seem to provide an opportunity to answer this and other questions.Their existence has been known for centuries and the tree remains within them have been used in archaeological science for dendrochronology and the investigation of sea-level changes. This present work, intends to use the plant macro-fossil remains (tree stumps, leaves, seeds, and so on) in these deposits to reconstruct the ecological structure of the forest and its floor. Mapping and recording the size of the tree remains may give an indication of the quantity and frequency of timber which could have been utilised for building structures and monuments. Analysis of the distribution of tree size groups, may help detect selective felling, which may be represented by the presence of stands containing trees of a similar age. Therefore, evidence of the past conditions contained within the submerged forest exposures may help to elucidate the character of the woodland which may have been utilised by the local communities.

This paper describes data from the submerged forest at Hightown, Lancashire. Work at Hightown is still in progress and therefore, preliminary results are presented.

Submerged Forests

The presence of submerged forests around the coasts of the British Isles has been known for a long time and have been described by authors earlier this century, (Reid 1913; Wright 1937). This earlier work has been summarised by recent workers in the course of their further studies (Heyworth 1978; Huddart and Tooley 1972; Huddart *et. al.* 1977; Tooley 1978, 1979).

Submerged forests, consist of tree stumps, fallen trunks and branches which appear to have been preserved *in situ*. Surrounding these stumps there is usually a deposit of peat, this combination of tree remains and peat has been often referred to as the 'forests beds'. Early work (Fleming 1822; Godwin-Austen 1865; Lucy 1877; Keeping 1878; Prevost *et al.* 1901 and Reid 1913) assumed that the deposits had been preserved by land submergence or a general rise in sea level. The origin of these deposits is now generally accepted to be due to eustatic sea-level rise.

The original work on submerged forests concerned the analysis of the plant macrofossil content, in order to establish biostratigraphical relationships. With the advent of pollen analysis, (Erdtmann 1929; Godwin 1940), submerged forests provided an ideal opportunity to develop and improve palynology (Godwin 1940, 1943). Within these pollen studies, the macrofossil content was only mentioned in passing and the tree species present noted for comparison with the pollen record.

Later work, (Campbell and Baxter 1979; Heyworth 1978) concentrated on the use of the tree stumps as a source of dating via radiocarbon and dendrochronology. Other workers have used submerged forests as indicators of sea-level change, (Tooley 1978, 1986; Heyworth 1978, 1986). Previous exercises in mapping submerged forest exposures has been by researchers interested in the palaeoclimate of the British Isles, (Taylor 1973; Allen 1992a, 1992b; Bibby 1940), whereby the position and angle of fallen trunks has been used to determine the frequency and general direction of past storm events such as hurricanes. Even in these studies no overall plans of the trees *in situ* were ever produced.

The Submerged Forest at Hightown, Lancashire

The largest exposure of the submerged forest at Hightown, is situated between the Sailing Club and the course of the River Alt (Grid reference SD295028) (fig. 1) and covers an area of approximately, 70 metres by 150 metres. The most densely populated expanse of the exposure covered an area of approximately 60m × 45 m and was mapped for this study in August 1994. The Alt river is constantly changing its course (Travis 1920) and has cut into the submerged forest deposits which occur along its landward (west) bank. This erosion and undercutting has lead to large chunks of the deposits being dislodged providing a cliff of about 1.5 m. This cliff reveals a complete section of the submerged

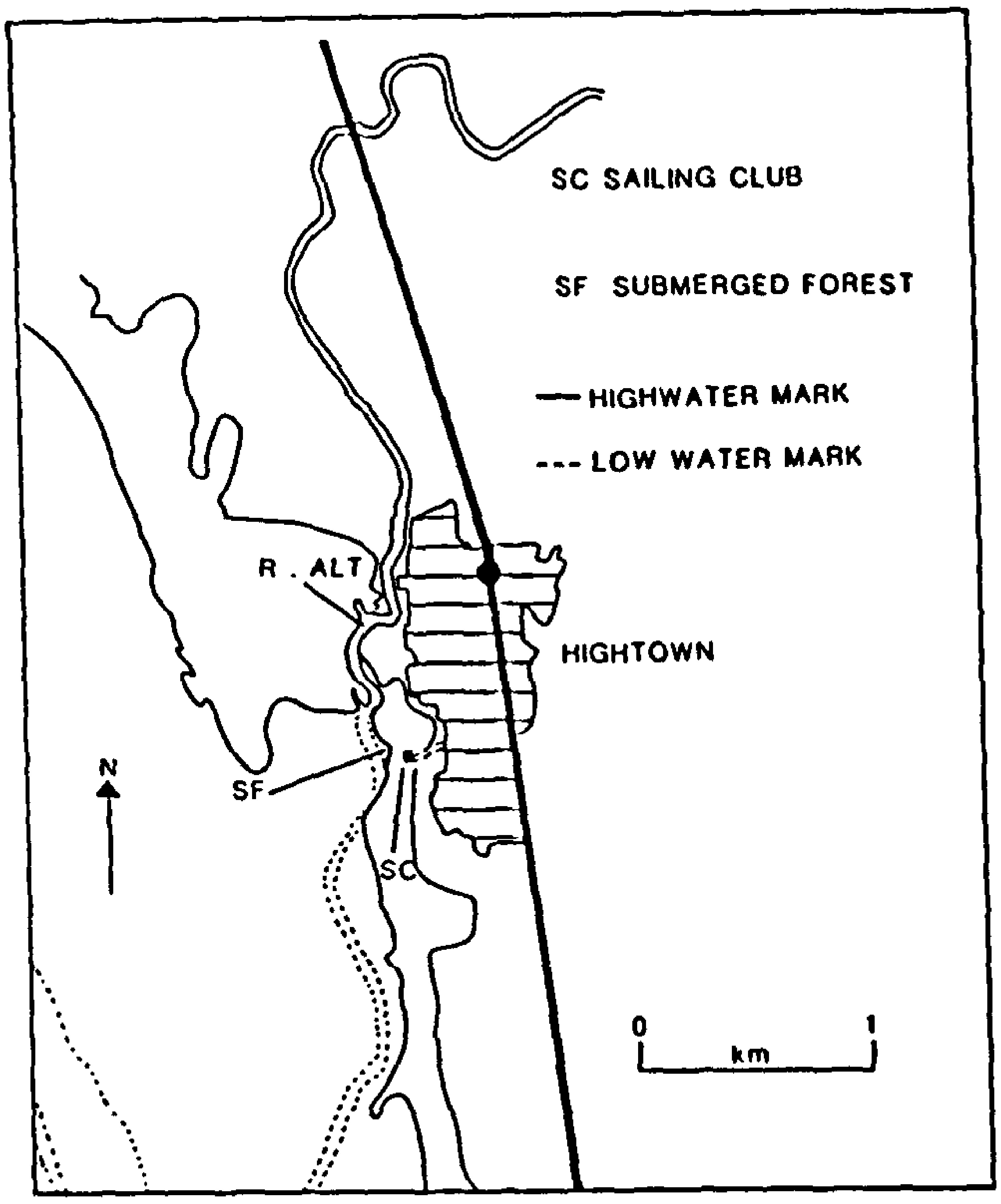

Figure 1. Location of submerged forest at Hightown.

forest and underlying deposits. The most noticeable feature of this section is that the stumps present in the forest beds appear to be rooted in the underlying blue clay.

Travis (1926), described the submerged forest deposits at Hightown as consisting of peat which varies in depth from 20 cm to 1.2 m, averaging between 45–53 cm, this is overlain by a dark coloured peaty sand 45 cm – 1.5 m thick which forms the base of the sand dunes. The peat bed rests on a bed of grey sand and laminated blue clay which on the foreshore is visible for a thickness of between 30 cm – 1.2 m. The upper surface of the Peat and Forest Bed was determined to be 3.1–3.6 m above O.D.

Travis (1926) examined the upper layers of the forest bed which contained small fragments of carbonised wood, grass stems, small twigs, and seeds of bog bean (*Menyanthes trifoliata*). In other places, the upper peat was laminated and spongy when sodden with sea-water and composed of decayed fibres, stems, leaves of grasses and sedges with layers of sallows, (*Salix* spp.) bog myrtle (*Myrica gale*) and bogbean as well as remains of the royal fern (*Osmunda regalis*). Travis (1926) stated that 'lower down the profile, the peat is dark brown in colour and becomes more compact and often woody in nature, with a well humified matrix. It contains a great abundance of twigs, branches, pieces of bark, mostly silver birch, (*Betula* sp.) together with numerous stools and prostrate trunks. At the base of the peat 20–30 cm above the sand and clay interface very little in the way of plant remains were preserved.'

The upright stools of the larger trees varied in size from 30 cm to 91 cm and in one case 1.8 m in diameter (Travis, 1926). The prostrate trunks as measured by Travis (1926) were between 1.8–3.6 m in length. It was common to find stools of trees, 60 cm in diameter, strongly rooted at the actual junction of the peat and underlying sediments. In many cases the roots could be seen to penetrate the clay and sand proving that the trees grew *in situ*. The trunks lie at all depths in the peat and prostrate trunks can be found to overlie and cross each other at all angles but mainly between the north-east and north-west.

Species	*Type of remain*
Pinus sylvestris	bark, wood
Pinus sp.	pollen
Myrica gale	cones, seeds, leaves
Quercus sp.	bark, wood, acorns, pollen
Betula sp.	bark, wood, pollen
Alnus glutinosa	cones, seeds
Corylus avellana	wood, nuts, pollen
Tilia europaea	pollen
Salix cinerea	leaves
Salix aurita	leaves
Salix repens	leaves
Salix sp.	pollen, wood
Ilex aquifolium	leaves

Figure 2. Table showing trees and shrub species with fossil remain type identified at Hightown (Travis 1926)

Travis found the timber in various stages of decay, but often internally sound. The twigs and branches show the effects of compression. The larger trees were of oak and birch, the latter being particularly abundant,being readily identified by the characteristic silvery bark. These observations of Travis are still pertinent today, except that the large expanses of the submerged forest recorded by Travis have been eroded away and the tree stumps are in a more decomposed state. The trees and shrubs identified by Travis can be seen in figure 2.

Pollen analysis (Tooley 1978, 1986), of these deposits shows a dominance of tree taxa, along with a smaller proportion of herb taxa. The proportion of hazel (*Corylus*) appears to be constant throughout the profile within a smaller shrub component. Very few aquatic taxa were represented in the analysis. This assemblage has been interpreted as being representative of a succession towards an Alder-Willow carr (*Alnus-Salix*) with alder buckthorn (*Frangula alnus*), purple loosestrife (*Lythrum salicaria*) and woody climbers such as bittersweet (*Solanum dulcamarra*) which formed within a tidal flat and lagoonal zone, the peat at the Alt Mouth (at + 3.1 m O.D) produced a radiocarbon date of 4545±90 B.P. (Tooley 1976, 1978).

Methodology

As noted above, there has been very little palaeoecological characterisation of submerged woodland. In order to obtain the maximum amount of information preserved within a submerged forest, several steps need to be undertaken.

The first involves a detailed recording of the position of each exposed stump, trunk and fallen branch within a specified area. The distances to the centre of each exposed stump were noted. Along with the position of each stump, branch and trunk, maximum diameters for each individual were recorded.The orientation of fallen trunks was also noted, in order to detect any dominant direction of wind blow as recorded at other sites such as those in the Severn estuary (Allen 1992a, b). Wood samples for species

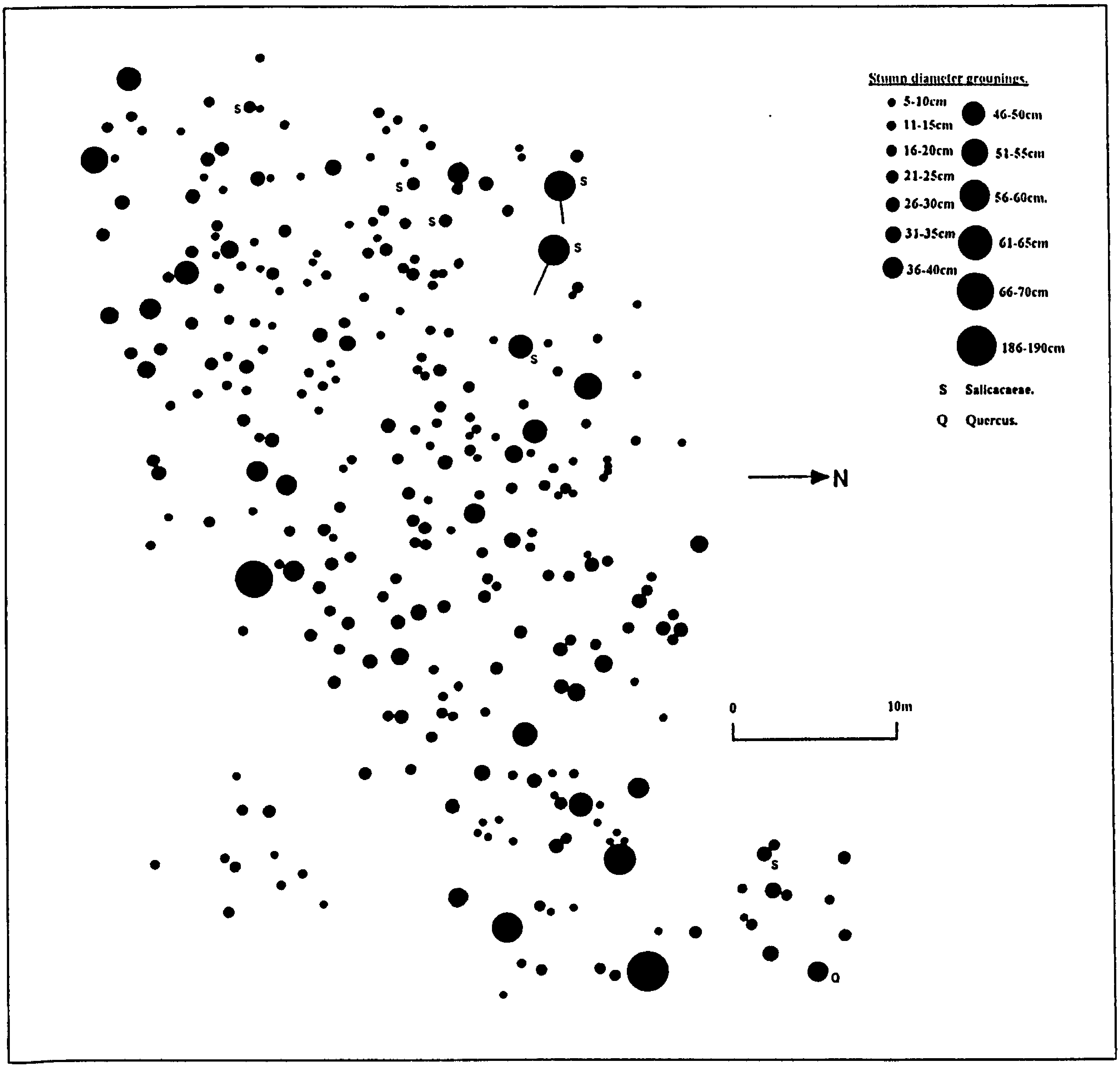

Figure 3. Distribution of all stump diameter groupings at Hightown, 1994.

identification were taken where preservation permitted. Samples of the surrounding peat and sediments were also taken, both as vertical monoliths through the profile and as horizontal monoliths from different parts of the exposure in order to pick up any local variation in the forest floor. The Ordnance Datum of the exposure was also recorded.

Clearly, reconstruction relies on the assumption that all of the exposed stumps are contemporary. Whether or not this is the case can only be determined by extensive cross-matching of the tree-rings of the stumps. This has not been possible at Hightown due to the fact that most of the stumps are too decomposed to allow analysis. However the location of the stumps in the field suggest that they are contemporary.

Results

Figure 3 shows the overall distribution of the stump diameter groups of the 298 stumps and trunks recorded in the survey area at Hightown, near the Alt Mouth. As can be seen there is no apparent pattern in the distribution of the groupings.

The measurement of the diameter of tree trunks is a standard method for estimating the age of modern trees, this is usually measured at breast height. Since none of the trees in the submerged forest survive to breast height, the diameter of the stumps has been taken to represent the relative ages of the trees. Data from the measurement of modern trees has shown that there is a correlation between diameter at ground surface with diameter at breast height (Wilkinson, unpublished) and therefore, this measure can be used to age the trees. From the histogram in figure 4, it can be seen that the 5–10 cm, 11–16 cm and 16–20 cm diameter groups appear to dominate the distribution, with numbers decreasing with the increase in stump diameter. When the diameters are translated into relative ages, the submerged forest at Hightown appears to be dominated by young trees, with

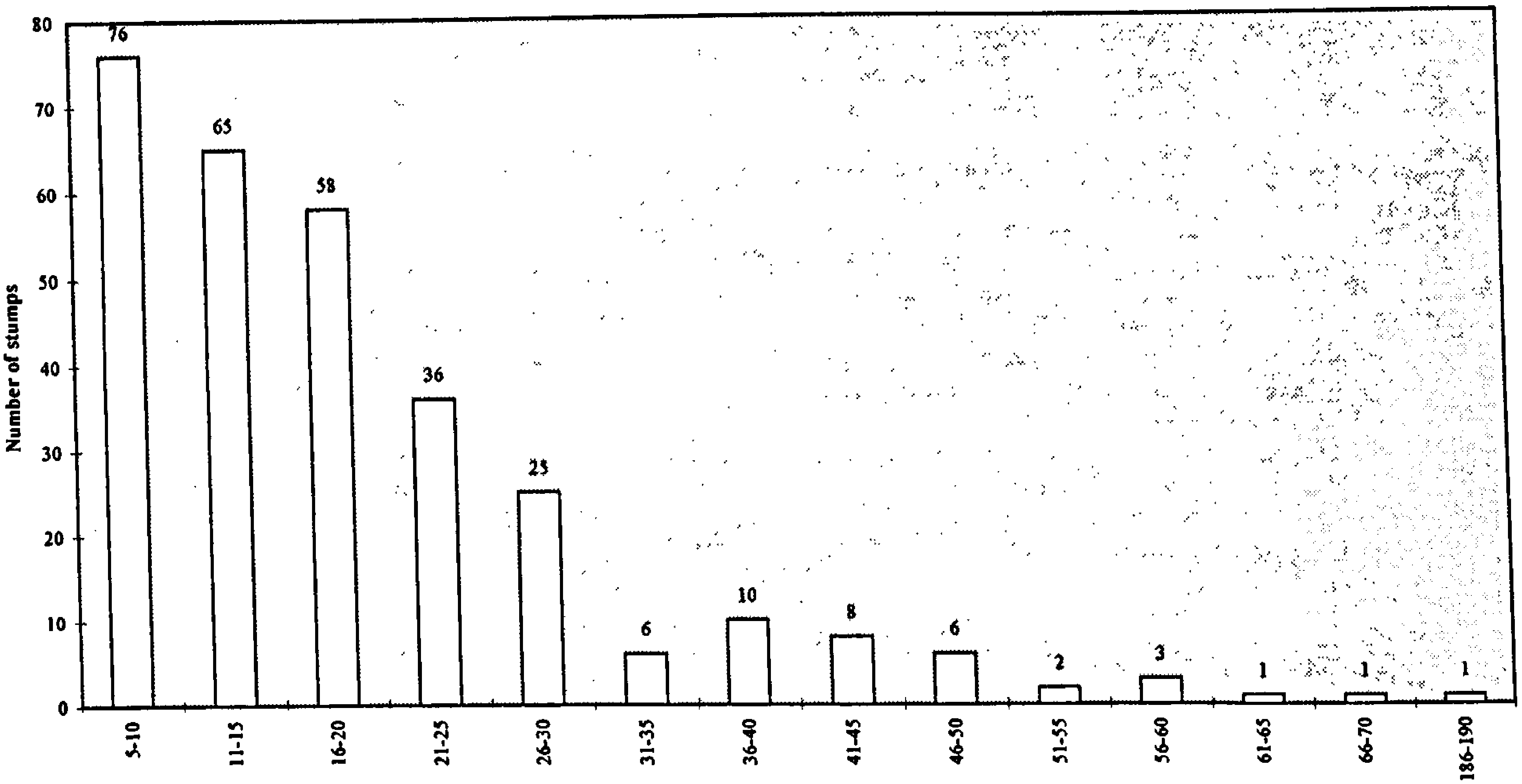

Figure 4. Number of stumps per diameter group at Hightown, 1994.

some middle aged ones and few mature trees, which are widely distributed.

The actual age of each stump cannot be determined via this method as growth rate (and therefore increase in diameter) is controlled by many factors such as climate, soil,and nutrient conditions as well as the level of the watertable. These factors can vary greatly over the lifetime of the tree and therefore directly influence the amount annual growth. Therefore, this method can only provide a relative age structure of the submerged forest which is sufficient for this study.

In figure 3, small clumps of four or five trees can be seen, which may represent the replacement of a fallen larger tree, some of the larger diameter trunks appear to be associated with smaller diameter stumps which may represent competition between individuals whereby only one of the clump of saplings is capable of filling the gap in the canopy and therefore restricting the growth of the others. Unfortunately, due to the preservation conditions at Hightown, the determination of whether the larger stump is of the same date and species as the smaller ones is not possible.

Eight stumps were sampled for identification, seven were of possible willow, *Salix* sp. and one of oak, *Quercus* sp. Figure 5 shows the distribution of the species across the diameter groups. Only two samples showed any evidence of distortion due to compression. It should be noted that *Betula* sp., (identified by the ubiquitous presence of the characteristic silver bark) was observed to be the dominant tree species present, but was too decomposed to sample. The identification of the wood species was undertaken at the Pitt-Rivers Laboratory, McDonald Institute of Archaeological Research, University of Cambridge, and employed the standard methods required to identify wood samples as stated in Jane (1962) and Schweingruber (1982).

With the identification of the stumps it can be seen that the larger diameter stumps are not of birch but most likely to be of either willow or oak. From wood identifications alone it is not possible to determine which species of willow is represented. The macrofossils identified by Travis (fig. 2) suggests that they could be either *Salix aurita* or *S. cinerea*, but other species should not be ruled out as these two species are nowadays recorded as shrubs rather than trees, although *Salix cinerea* can be found as a small tree.

Discussion

Peterken, (1993: 4–5) states that modern virgin stands usually have an irregular canopy and a more-or-less even spread of age classes of all species throughout the stand, but in practice this appears to be rare. With submerged forests it is difficult to determine the structure of the canopy but some idea of the age classes within the area exposed can be obtained and it can be seen that there is no even spread of individuals across the age (diameter) groups represented in the exposure (figs 3 and 4). Most modern virgin stands contain a component of trees of similar age, ranging from completely even-aged stands to mixed aged stands in which one or two age classes are over-represented, this appears to be the case at Hightown. The age structure of modern forests is largely determined by the periodicity of regeneration. Even aged stands develop after natural and sometimes artificially

Species	*Stump diameter group*	*No. of samples*
Salicaceae ?*Salix* sp.	21–25 cm	3
Salicaceae ?*Salix* sp.	26–30 cm	1
Quercus sp.	41–45 cm	1
Salicaceae ?*Salix* sp.	46–50 cm	1
Salicaceae ?*Salix* sp.	56–60 cm	2

Figure 5. Table showing species identification and diameter groups.

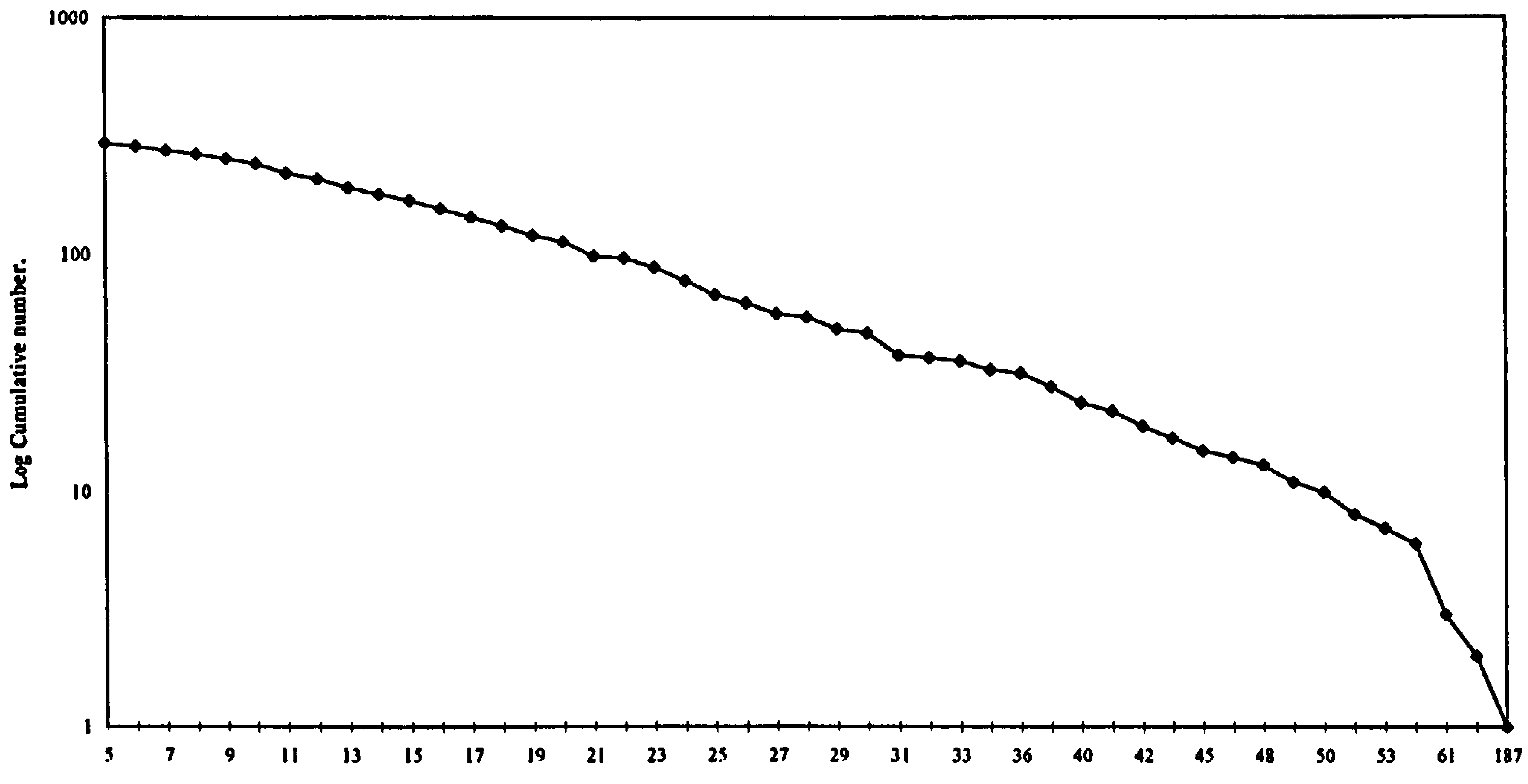

Figure 6. Cumulative stump diameter distribution of all individuals recorded at Hightown, 1994.

induced catastrophes, such as fire,wind, inundation or selective felling. The subsequent stand may last for a long period of time.

The overall picture from the mapping of the tree stumps and trunks exposed at Hightown is of a forest which consists mainly of small diameter birch trees with few large diameter trees which could have been utilised for timber, although the majority of the larger stumps identified were in fact of willow, with only one being of oak. There appears to be very little evidence to suggest an expanse of trees of similar age as shown by figure 6. The presence of a plateau at any stage of the curve showing the distribution of the individual diameter sizes as a cumulative number on a log scale would indicate a large number of trees of similar age suggesting an occurrence or succession of catastrophic events whether natural or artificial, such as hurricanes or selective felling. This, associated with the map (fig. 3) is most likely to represent constant regeneration and replacement of individual trees through time. It is difficult to ascertain over what time period this regeneration takes place, as dating has yet to be carried out.

Two aspects of these initial results are directly relevant to archaeology. Firstly, the size of the trees and their distribution shows that 'wildwood' was not wholly composed of massive trunks just waiting to be cut down and incorporated into monuments. From the results shown here, the latter would have required selective extraction over a large geographical area. Secondly, it would have been easier for prehistoric populations to have cut down the majority of the smaller trees growing between the 'forest giants'. If this occurred, then by the end of the Neolithic there could have been areas where larger trees predominate over smaller ones. These clearances would have produced irregular clearings which could have been exploited for agriculture.

Conclusions

Submerged forests have been known to exist around the coasts of Britain for a very long time (Reid 1913). They are formed at different times throughout geological time right up to the present day and preserve many different woodland types on a variety of substrates. In previous studies, submerged forests have been used to provide evidence for changes in past weather patterns as records of catastrophic events such as hurricanes. Through pollen analysis they have been used to determine forest composition, although rarely through analysis of the tree remains themselves. Submerged forests have also provided plentiful material for dendrochronological and radiocarbon dating.

From the methodology outlined in this paper, it has been shown that from the wealth of material preserved, it is possible to reconstruct the population structure of a submerged woodland at the time of death. This, along with the study of the plant macrofossils preserved within the deposits allows a characterisation of the woodland type that existed in the past. Although, the main problem to this approach is in determining whether the stumps exposed are of a contemporary age and even without closely dated material, the results from this study suggest that the submerged forest at Hightown did not suffer from catastrophic events either in the form of hurricanes or from management practices such as selective felling. Therefore, it can be concluded that this woodland was not exploited, in terms of timber production, although it may have been utilised as a wild food resource.

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