2350

ANCIENT MONUMENTS LABORATORY

REPORT

3125

SERIES/No CONTRACTOR

AUTHOR Peter D A Boyd 1980

TITLE an introduction to the Palaeoecology and Study of Estuarine deposits associated with archaeological sites

AN INTRODUCTION TO THE PALAEOECOLOGY AND STUDY OF ESTUARINE DEPOSITS ASSOCIATED WITH ARCHAEOLOGICAL SITES

By Peter D. A. Boyd

University of London - Institute of Archaeology

---

1. INTRODUCTION

This paper attempts to provide a brief introduction to the natural complexities of estuarine ecosystems and the relationships of Man with estuaries. It is, however, mainly concerned with introducing the range of biological remains which may be recovered from estuarine sediments associated with archaeological sites and problems associated with their study and interpretation.

The study is based on preliminary investigations by the author of estuarine deposits exposed on archaeological sites in the City of London excavated by the Department of Urban Archaeology of the Museum of London. The author has also drawn on his experience of fossil estuarine deposits (Boyd, 1973, 1974a, 1974b) and knowledge gained through his investigations of the modern and fossil fauna and flora of a number of rivers and their estuaries in Essex and elsewhere.

The range of archaeological sites situated on estuaries is large. Estuaries have formed a route for traders and invaders encouraging the development of trading settlements and defensive installations. The abundance of fish, shellfish and bird life supported by estuaries has encouraged the development of communities based on the cropping of these natural products. Salt-making has also been an important activity on the banks of estuaries as shown by the numerous 'Red Hills' by many (e.g. see de Brisay, 1975). Many of the world's major cities have developed on estuaries because of their importance as ports (e.g. London).

Estuarine deposits exposed in archaeological excavations will normally be sediments associated with the intertidal and supratidal zones. The remains of waterfront structures, boats and miscellaneous dumped materials will be associated with intertidal sediments and transgress onto supratidal deposits. Evidence of salt-making may be particularly associated with salt marsh deposits. Supratidal features including forest and archaeological remains may have become overlaid by intertidal and even sub-tidal sediments in an area which has been subjected to a rising mean sea level (e.g. see Akeroyd 1972 and Willcox 1975).

The accurate dating of sediments provided by artifacts and structures on an archaeological site offers tremendous opportunities for the palaeoecologist and on many sites he may also have the benefit of documentary records of the same date as the site to supplement or provide explanations for the results of his scientific investigations.

Study of biological remains from estuarine deposits associated with archaeological sites will broadly provide information for particular periods about:-

a) the indigenous fauna and flora of the estuary and its hinterland, and
b) biological remains of 'cultural interest comprising domestic and industrial rubbish of diverse origins dumped into the estuary by Man and providing information about trade, food, industries, diseases, etc.

The contents of this paper are intended to assist mainly with the recovery of information related to the first of these categories. The indigenous fauna and flora of the estuary and its hinterland reflect various environmental factors. Changes in the subfossil fauna and flora may provide information regarding the nature of environmental changes of significance to human communities living by or using the estuary.

SALINITY changes will be reflected by changes in the fauna and flora. Changes in salinity reflect changes in sea level or climate which may affect human activities in many ways.

POLLUTION also affects the fauna and flora and is of great interest as it is generally a direct result of human activities.

2. IMPORTANT CONCEPTS IN ESTUARINE ECOLOGY AND PALAEOECOLOGY

The volume of literature which has been written on almost every aspect of the study of estuaries is enormous and this reflects the complex nature of inter-relationships between water masses, sediments, organisms and other factors in estuaries. This paper does not attempt to cover every aspect of estuarine ecology or palaeoecology but attempts to introduce some of the most important concepts that will enable non-specialists to understand those aspects of estuarine ecology and palaeoecology which assist the interpretation of environmental conditions using assemblages of subfossil biological remains which may be observed in or recovered from estuarine deposits associated with archaeological sites.

The coverage of some topics is, of necessity, superficial but the references cited have been chosen to enable those interested to trace further information most easily. A number of general works contain a wealth of references as well as original work. The volumes edited by Hedgpeth (1957), Lauff (1967) and Nelson (1972) are particularly important collections of papers on physical, chemical, sedimentological, biological and economic aspects of estuaries. Each of the texts on estuarine biology and ecology by Green (1968), Remane and Schlieper (1971), McLusky (1971), Perkins (1974) and Barnes (1974) give emphasis to different aspects of their subject. Reineck and Singh (1975) provides an excellent introduction to the study of sedimentary environments including estuaries and Ager (1963), Brouwer (1967), Raup and Stanley (1971) and Schäfer (1972) provide valuable introductions to the study of palaeoecology.

Some of the main features of the physical environment which determine the distribution of living organisms in estuaries

Pritchard (1967) has defined an estuary as 'a semi-enclosed coastal body of water which has free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage.'

Estuaries may be divided into four categories based on their geomorphology:

a) Drowned river valleys (coastal plain estuaries)

b) Fjord-type estuaries

c) Bar-built estuaries

d) Estuaries produced by tectonic processes

The first type is the most common and most of the contents of this paper may be applied most directly to this type.

Salinity is only one of many chemical and physical factors that determine the distribution of organisms in estuaries but it is usually the most important single one. The variations of salinity within estuaries are therefore the basis for other classifications of estuaries and regions within them.

Salinity is expressed in terms of grammes of dissolved salts per kilogramme of water (i.e. parts per thousand, ‰). Sea water has an average salinity of about 35‰, while fresh water is most often defined as that having a salinity of less than 0.5‰. Some workers prefer to use chlorinity which is a measure of the concentration of chloride ions per kilogramme of water. Sea water has an average chlorinity of about 1.92% and fresh water has a chlorinity of 0.03% or less. The majority of ecologists and palaeoecologists use salinity to described the amount of 'salt'in water.

Pritchard (1955) described estuaries on the basis of water circulation patterns within them. He defined four types based on the relationships between outflowing 'fresh' water and inflowing 'salt' water.

In Type A, he recognised a two-layered, salt wedge system in which dense saline water moves upstream from the sea as a wedge beneath less dense fresh water flowing downstream. In such a situation the organisms living in or near the bottom sediments will experience much higher salinities than those living in the surface waters.

In Type B, the situation is similar but partial mixing occurs between the two layers. A vertical salinity gradient is formed rather than a sharp boundary between different salinities as in A.

In Type C, the estuary is vertically homogenous but there is a lateral gradient with a near vertical boundary between the more saline water flowing upstream and the less saline water flowing downstream. This effect is a product of Coriolus forces, the rotation of the Earth deflecting the inflowing sea water to one side (to the left of an observer looking seaward in the northern hemisphere).

In Type D, the estuary is vertically homogenous with a salinity gradient produced from fresh water to the sea. This is the situation palaeoecologists may be tempted to believe is the norm but it is not. However, the Thames approximates to this situation.

Even in estuaries of Type D the salinity gradient is not static and the zone of mixing (the gradient) will move up and down the estuary with each tide, move further up the estuary than 'normal' following a period of low rainfall in the summer and further down the estuary following high precipitation in the winter. Occasional tidal surges may have extreme effects and introduce very saline water far upstream.

A number of classifications of saline environments have been devised (see Remane, 1971) which provide useful descriptive terms for salinity controlled habitats where the salinity conditions are fairly stable in semi-enclosed seas like the Baltic, in inland seas and in coastal lagoons. "The Venice System" (1959) is one of the better known classifications which may be summarised as follows:-

Zone	Salinity ‰ (mean values)
Hyperhaline	More than 40
Euhaline	40 - 30
Mixohaline	(40) 30 - 0.5
(mixo) euhaline	More than 30 but less than adjacent euhaline sea
(mixo) polyhaline	30 - 18
(mixo) mesohaline	18 - 5
(mixo) oligohaline	5 - 0.5
Limnitic (fresh water)	Less than 0.5

It should be noted that other classifications use the terms oligohaline, mesohaline, and polyhaline in quite different ways and these terms should not be used without naming the classification employed. Such classifications are often used when estuarine conditions are described but the fluctuations and variations within estuaries make them difficult to apply.

Differences in salinity, substrate type and current velocity may be used to divide the length of an estuary into five zones (Carriker, 1967):-

i) Head - Where fresh water enters the estuary and salinity during high spring tides may reach a maximum of 5‰. Currents and substrate vary broadly and are dependant on the local geomorphology and geology.

ii) Upper Reaches - Muddy bottom deposits, slow movement of water and salinities roughly in a range of 5-18‰.

iii) Middle Reaches - Sandy mud bottom deposits, fairly fast currents and salinities from 18-25‰.

iv) Lower Reaches - Sandy mud to clean sand or gravel bottoms, fast currents and salinities from 25-30‰.

v) Mouth - Clean sand, gravel or rock bottom, very fast currents and salinities above 30‰.

There are also variations in salinity across an estuary because of changes produced by the tide coming in and going out. Estuaries are subjected to tides twice each day and the zone alternately covered and uncovered is known as the intertidal or littoral zone. The different amplitudes of spring and neap tides cause the period of exposure experienced by intertidal sediments to vary with the height on the shore. This and associated factors have encouraged the development of zones with characteristic sediments and characteristic communities of plants and animals. One may therefore recognise the following zones:-

a) Supratidal fresh water marsh

b) Intertidal salt marsh

c) Intertidal mud flat

d) Intertidal mixed flat (mud and sand)

e) Intertidal sand flat

f) Subtidal channels (with sand bars and coarser sediments)

The subtidal channels experience the greatest range of salinity as they carry the fresh water outflow of the river at low tide and carry water which may be as saline as the sea at high tide. The maximum and minimum salinities experienced by any particular length of channel will depend upon its distance along the estuary. The channels will also have the highest current velocities and are therefore characterised by the coarsest sediments.

The intertidal zones experience progressively weaker currents higher up the shore and the sediments are progressively finer in grade. The range of salinities experienced is generally less further up the shore. However, the surface of the salt marsh with its associated pools (salt pans) may experience elevated salinities during dry weather due to evaporation as much of the salt marsh is uncovered for several days between successive spring tides. The surface of the salt marsh may similarly experience low salinities during periods of heavy rainfall.

Although the surface of the sediments in any of the zones may experience fluctuations in salinity the interstitial water of the sediments below the surface may have a more stable salinity closer to the average salinity of the water mass than either extreme (see Reid 1930, Mangelsdorf 1967, McLusky 1971).

Evans (1965) is well worth reading for a detailed description of one example of an intertidal system of environments although it differs slightly from an estuarine intertidal system as it lacks some of the salinity variations and current regimes of a true estuary.

Some of the main features of living estuarine organisms, their behaviour and their occurrence which have special significance for the palaeoecologist.

Those aquatic organisms living on or in the bottom sediments (or solid rock where that forms the substrate) are called benthos and such organisms are said to be benthic or benthonic. They may be divided into those organims living on the substrate, the epibionts (epiflora and epifauna), and those living in the substrate, the endobionts (mainly infauna). Some benthic organisms are immobile and said to be sessile while those capable of movement are vagile. Pelagic organisms are those living in the water above the bottom deposits and include organisms capable of determining their position in the water by independent swimming movements, the nekton, and those organisms which are largely at the mercy of water currents for significant movements, the plankton. The plankton is divided into the phytoplankton or plant plankton and the zooplankton or animal plankton. The 'phytoplankton' of estuaries often contains a significant proportion of microscopic benthic algae which are maintained in suspension or repeatedly resuspended by water currents.

The terrestrial flora, the benthic flora and the phytoplankton are the producers of the estuary upon which most of its other life depends. Most of these are photosynthetic organisms which convert energy in the form of sunlight into chemical energy. The fauna may be divided, according to the means of obtaining nutrition, into the herbivores dependent directly upon plant life for food, the carnivores (predators) and parasites dependent on other living animals and scavengers which feed on the remains of dead organisms. Many carnivores are also scavengers and many estuarine animals are, in effect, omnivorous feeding on plant and animal material. Suspension feeders are animals which feed on detritus and suspended micro-organisms from the surrounding water. Deposit feeders are animals which feed upon the detritus deposited on the sediment with its associated micro-organisms. A large proportion of the estuarine fauna belongs to this and the former group. Most plants and animals and their organic products eventually become the substrates for bacterial and fungal decomposers (saprophytes) which are responsible for breaking down organic materials into inorganic substances which may be utilised by the producers. The preservation of biological remains is largely dependent upon the efficiency with which scavengers and decomposers destroy the remains of animals and plants reaching or already associated with the sediment. Wood (1965) provides a valuable account of the activities of these and other micro-organisms which play vital roles in the ecology of estuaries.

The estuarine flora and fauna may be divided into six components (see also Remane, 1971 and Green, 1968):-

1. The terrestrial component
2. The freshwater (limnobiotic) component
3. The marine component
4. The estuarine (brackish) component
5. The holoeuryhaline component
6. The migratory component

The terrestrial component includes some species that are tolerant of submersion and some that are not.

The freshwater component is restricted to waters of low salinity and may be divided into the stenohaline freshwater component (stenohaline limnobionts) which will not penetrate salinities greater than 0.5‰ and the euryhaline freshwater component (euryhaline limnobionts) some members of which will penetrate salinities greater than 8‰.

The marine component may be divided into the stenohaline marine component which will not penetrate salinities below 30‰ and the euryhaline marine component, some members of which will penetrate to salinities lower than 3‰.

The estuarine or brackish component comprises a limited number of species which are restricted to brackish water (say between 18‰ and 5‰) and penetrate neither fresh nor fully saline water.

The holoeuryhaline component comprises a limited number of species which can live in fresh, brackish and sea water and some of which can also live under hypersaline conditions.

The migratory component spends only part of its life in the estuary and includes marine species of animals which enter the estuary for part of their life cycle to feed or spawn and those species which migrate through estuaries from the sea to freshwater to spawn (anadromous species) and those species which descend from freshwater to the sea to spawn (catadromous species).

Therefore the water body and underlying sediment in any particular region of an estuary will contain representitives of several of these components. It is the overlapping of salinity ranges required by different species of organisms that allows the probable salinity pertaining at the time of deposition of a sediment to be determined by the study of assemblages of sub-fossil remains from it.

It should however be recognised that palaeosalinity determinations based upon members of the subfossil infauna may differ from those based upon the epibionts or plankton. The infauna may reflect something close to the average salinity of the estuary water. Where salinity conditions are fairly stable, organisms seem able to tolerate more extreme conditions. 'Marine' organisms can penetrate further into lower salinities and 'freshwater' organisms can penetrate further into higher salinities than where the salinity conditions fluctuate.

However, there is more to the determination of palaeosalinities than consideration of the salinity range within which a species will live. Salinity also has a pronounced effect on the diversity of organisms in estuaries. The number of 'marine' species able to tolerate reduced salinities becomes smaller with decreasing salinity. Similarly, the number of 'freshwater' species able to tolerate increased salinities becomes smaller with increasing salinity. One might expect the minimum number of species (including all components) to occur in salinities midway between the salinities of freshwater and seawater. However, the 'marine' fauna and flora seem able to tolerate a greater salinity range than the 'freshwater' fauna and flora so that the 'species minimum' occurs between 5‰ and 7‰ (Remane 1971). Remane provides numerous examples comparing the diversity of organisms recorded from different salinities. The differences can be very striking and in several group of organisms the North Sea (with admittedly a wider range of habitats) supports approximately 50 times as many species as the brackish waters of the North Baltic.

However, as hinted at above, the low diversity of organisms in estuaries is not entirely due to salinity effects. The range of substrate types is generally low in estuaries, the sediments being predominantly muddy and this is probably a major reason for low diversities (McLusky 1971, Barnes 1974).

The phenomenon of reduced diversity tends to be accompanied by the development of large populations of the species able to exploit the available habitats (e.g. the development of extensive beds of the mussel _Mytilus edulis_ or the oyster _Ostrea edulis_). Although the estuarine environment is a stressful one, estuaries are capable of extremely high organic productivity.

An individual of any particular species may also show different reactions in different salinities. Therefore the interpretation of an assemblage of subfossil remains should not only be based on the particular species present or number of species but also on the characteristics of individual specimens.

Many 'marine' species of organisms which penetrate estuaries show a reduction in size of individuals related to the degree of reduction in salinity. This is particularly pronounced in molluscs (e.g. Mya arenaria and Mytilus edulis show a steady and enormous reduction in size, with the shell length at about 5‰ being about one third of that at about 30‰ salinity).

Some 'freshwater' organisms show a reduction in size with increasing salinity but it is not such a widespread or pronounced a phenomenon as the effect of reduced salinity on 'marine' organisms.

The thinning of shells or the reduction of other forms of calcareous 'skeletons' is also fairly common in 'marine' organisms living in reduced salinities and is a phenomenon exhibited by organisms ranging in complexity from foraminiferids to fishes.

Individual species may also exhibit other peculiarities (e.g. Eisma 1965 demonstrated a relationship between salinity and the number of ribs on shells of Cerastoderma (Cardium) edule).

While many plants and animals are capable of living quite happily in salinities at the edge of their range their reproductive abilities may be affected. Therefore, while seeds of plants or the larval stages of animals may enable a species to pioneer a habitat that population may be unable to maintain itself without repeated influxes of seeds or larvae unless they reproduce vegetatively. This effect upon the plants in particular has significance for the palaeoecologist who may depend upon the pollen or seeds of the plant to be preserved to recognise its remains. The phenomenon might also account for what are apparently autochthonous assemblages of organisms but all of the same size, (i.e. conditions one year might have been suitable for settlement of larval stages and subsequent growth but no juveniles will have been produced before senescence and death).

Where organisms suitable for human consumption are involved, attempts at cultivation may account for such assemblages.

The influence of Man upon the estuarine flora and fauna

Many human activities have affected the composition of estuarine biota or the abundance of individual components. Some of these activities have affected the biota intentionally while others have affected it by accident or in ways not originally intended.

Reclamation and the construction of waterfronts will have sealed intertidal and supratidal deposits and prevented the subsequent full zonal development of intertidal and supratidal deposits. The width of intertidal deposits will have been decreased and hence the range of habitats for aquatic and semi-aquatic organisms will have been reduced. However, the waterfront structures themselves may have enabled organisms to become established in the estuary which would otherwise be absent through the lack of solid substrates (i.e. timber or masonry). Sessile organisms such as sponges, bryozoans, barnacles and molluscs would have been particularly encouraged. Wood-boring organisms such as teredo worm (Teredo spp) or gribbles (Limnoria lignorum) may also be associated with the remains of waterfront structures or boats and such habitats, together with soft masonry, may also contain traces of piddocks (e.g. Pholas dactylus). Dumps of shells may also have provided habitats for other creatures unable to become established in mud.

Alien organisms have also been introduced into estuaries by Man, particularly during the last hundred years. Most of these introductions have been accidental having been brought into Britain with American seed-oysters imported for 'cultivation'. Such aliens include the molluscs Crepidula fornicata and Urosalpinx cinerea, the polychaete worm Clymenella torquata and the ostracod Sarsiella zostericola as well as the oyster Crassostrea virginica with which they came (see Cronin 1967, Kornicker 1975).

Man has also affected the fauna of estuaries by directly killing various components of it for food (particularly shellfish, fish and birds). It is clear from documentary evidence that overfishing was considered a problem even in medieval times in London and various laws were enforced concerning the removal of nets and traps from the Thames and the allowed use only of nets with a mesh of over 2 inches to prevent destruction of small fry and thus future fish stocks (Riley, 1868).

However, the unintentional destruction of life in estuaries by pollution has probably turned out to be a far greater problem.

Present day estuaries are subject to many types of pollution including many environmental poisons but in past centuries pollution would have been more limited in variety and extent and may be discussed under the following headings:-

a) Pollution by suspended and settled solids

b) Pollution by organic waste

c) Pollution by toxic substances

These divisions are chosen to provide a convenient framework for discussion of pollution in the past but it should be understood that they are inter-related and individual pollutants may affect the aquatic environment in all three modes.

a) Pollution by suspended and settled solids

Pollution of this type may act in one or more of six ways (Perkins, 1974). These are:-

1. Mechanical or abrasive action (e.g. clogging of gills and irritation of tissues).
2. Blanketing action or sedimentation
3. Reduction of light penetration
4. Availability as a surface for growth of bacteria and fungi
5. Adsorption and/or absorption of various chemicals
6. Reduction of temperature fluctuations

A wide range of inorganic and organic solids may cause such pollution and may act in other ways dependent on their composition, the effects of which will be superimposed on their effects as suspended and settled solids.

Benthic organisms are especially susceptible to pollution by suspended and settled solids. Sessile organisms, unable to move away from the pollution may be swamped and suffocated. Those members of the benthos able to move may be capable of moving away or be able to maintain their position relative to the surface of the sediment. Suspension feeders and any animals with gills are liable to be choked or suffer gill tissue damage by even moderate quantities of suspended solids in the water. Benthic macrophytes will also be choked by material collecting on the leaves and any part of the benthic flora will suffer from the decrease in intensity of light reaching them caused by suspended solids in the water. Phytoplankton growth may become limited to the top few centimetres of the water. As a result of this effect on the plant life of the estuary, any animal life dependent upon them will suffer even though they may not have been affected directly by the pollution.

b) Pollution by organic waste

Organic waste is subject to attack by the bacteria and fungi which cause decomposition. Dissolved oxygen is extracted from the water in the process and if large quantities of organic waste are deposited into the estuary, serious oxygen depletion can result. Anaerobic conditions may be produced which cause the death of a large proportion of or total anihilation of the aquatic fauna and flora.

Organic wastes are often described in terms of their Biochemical Oxygen Demand (B.O.D.) which is basically a measure of the potential of a particular type of waste to extract oxygen from the water.

Sewage is an important category of organic waste and for the present purpose can include animal dung and urine. It is a special case as it releases large amounts of plant nutrients to the water as it is broken down. Nitrates and phosphates are particularly important plant nutrients released and their increase constitutes the phenomenon of nutrient enrichment, or eutrophication. Moderate increases in plant nutrients (nutrient enrichment) through this process can be beneficial by encouraging phytoplankton and other plant growth with resultant increases in the animal populations directly or indirectly dependent upon the plants. This can be a direct benefit to Man through increased fish and shellfish production. However, at some times of year, nutrient enrichment may cause increased populations of dinoflagellates some species of which produce dangerous toxins which are concentrated by shellfish making consumption of the shellfish extremely dangerous and sometimes fatal.

The increase in phytoplankton and other plant growth caused by eutrophication results in a build up of dead organic material which has a high B.O.D. and leads to oxygen depletion. Excessive plant growth may also become a physical nuisance causing blocked channels and the accumulation of decomposing material on the banks of the estuary.

Therefore sewage causes pollution in several ways as the solid component acts like any suspended or settled solid and it has a high B.O.D.. The ammoniacal component also has an oxygen demand and is toxic in high concentrations and the release of nutrients can lead to the excessive production of organic matter with a high B.O.D. There can also be a health hazard due to the presence of pathogenic bacteria.

Prolonged anaerobic conditions will lead to the extinction of all life in the region affected except those micro-organisms which thrive in such conditions which include bacteria that reduce dissolved sulphates to hydrogen sulphide which is itself toxic. The extent of the region affected is likely to change according to the time of year and conditions are likely to be worst towards the end of a dry season with decreased freshwater flow and high summer temperatures. Any confinement of the channel or interference of flow through the construction of bridges or other structures in estuaries will normally exasperate the problem.

c) Pollution by toxic substances

Pollution of this type would probably have been uncommon in estuaries in previous centuries although heavy metal pollution may have arisen as a result of mining waste reaching estuaries. In small tributaries of estuaries the waste from industrial processes may have reached concentrations sufficient to be toxic. This might have included urine used in tanning and dyeing, the ammoniacal content of which is toxic.

General affects of pollution on the estuarine fauna and flora

The resistance of organisms to any pollution varies from species to species but some organisms in estuaries are close to the limits of their range regarding salinity and may be unable to cope with the additional stress imposed by pollution.

There is a tendency for the diversity of organisms in a specific habitat to be reduced by the effect of a pollutant or pollutants. The decrease in diversity with increasing pollution levels is often accompanied by the phenomenon of more resistant species being able to attain large populations as competition with other species is removed. If pollution is severe enough, however, the habitat will become barren.

This reduction in diversity due to pollution is therefore superimposed on what may already be habitats with low species diversity because of the stress of estuarine conditions. The diversity of species in such polluted estuarine habitats may therefore be very low.

Further details of the causes and effects of eutrophication and pollution in estuaries are provided by Hynes (1960), Abbot and Dawson (1971), Katz (1971), Zajic (1971) Hart and Fuller (1974) and Perkins (1974). O'Sullivan (1971) provides an excellent account of the effects of sewage pollution and Alabaster (1972) and Pearson (1972) provide useful information about the effects of suspended solids on aquatic life. National Academy of Sciences Symposium Volume (1969) contains a number of useful papers on eutrophication to which may be added Lund (1972).

The classic study on pollution in the Thames by the Department of Scientific and Industrial Research (1964) is of special value for all studies of the Thames and similar estuaries. It is supplemented in some ways by Barrett (1972) and the Royal Commission on Environmental Pollution (1972).

The cleaning up of the Thames and the return of birds, fish and other aquatic life is of great interest as it involves the reversal of the pollution process which started in Roman times. At certain times this century a 20 mile stretch of the Thames was completely devoid of oxygen due to pollution by sewage and other substances. The D.S.I.R. publication includes a brief history of pollution in the Thames from medieval times (based on documentary evidence) and the clean-up and return of life to the Thames is described by Harrison and Grant (1976) and Wheeler (1979).

Preliminary investigations by the author indicate that it should be possible to trace the development and effects of pollution in the Fleet and Thames from pre-medieval times onwards using the characteristics of subfossil assemblages of biological remains recovered from dated sediments.

Basic palaeoecological considerations

The organisms which characterise a given environment or sub environment comprise a biocoenosis. Only a proportion of these organisms will leave recognisable remains after their death preserved in the sediments associated with that environment or elsewhere. The subfossil or fossil remains preserved in a sediment comprise a thanatocoenosis. Organisms which are preserved within the sediment on or in which they lived are said to be autochthonous while any biological remains transported from elsewhere are said to be allochthonous. Many subfossil sediments will contain autochthonous and allochthonous components but others will contain assemblages which are virtually one or the other.

The subfossil remains will include:-

1) Hard skeletal parts such as shells, chitonous or calcareous carapaces, bones, teeth, siliceous diatoms.

2) Organic remains such as seeds, pollen, leaves, roots, dinoflagellate cysts, bryozoan statoblasts.

3) Bioturbation structures and other traces of burrowing or feeding worms, crustaceans, molluscs, etc.

4) Faecal pellets and coprolites.

Some sedimentary deposits are composed almost entirely of biological remains. They may be bioclastic deposits (e.g. allochthonous shell beds, sedimentary peats) or biogenic deposits which have formed in situ from the growth of organisms (e.g. autochthonous shell beds, marsh peat, bryozoan reefs).

Other biological remains will be associated with various types of sediments. However, the greatest variety of remains will be recovered from fine grained sediments. Coarser grained sediments (i.e. coarse sand and gravel) indicate conditions unsuitable for most estuarine organisms and currents which would have winnowed out less dense subfossil remains.

The maximum preservation of biological remains is found in sediments which have remained waterlogged since deposition. Remains composed of organic materials are preserved best in such conditions. In areas such as the Thames Estuary which have been subjected to a rising sea level these conditions have been produced. In areas of uplift where estuarine sediments have become sub-aerial the preservation of organic remains is less satisfactory.

In sediments with a high pH caused by the presence of abundant shelly material or precipitated calcium carbonate the organic material is frequently poorly preserved because decomposer activity is encouraged by alkaline conditions. Siliceous microfossils may also suffer solution in sediments with a high pH.

Calcareous remains are obviously preserved best where the sediment has a high pH and in sediments subjected to acidic post-depositional conditions all the original calcareous remains may be dissolved. The partial decomposition of abundant organic material in marsh deposits, in particular, can produce acid conditions and lead to the destruction of the calcareous remains of molluscs, foraminifera, ostracods, etc. However, sediments may become decalcified under many conditions, sandy sediments through which groundwater can freely pass being particularly susceptible. Decalcified sediments are quite common in fluviatile and estuarine sequences and may give the erroneous impression that the sediments were originally inimical to life or at least now totally unfossiliferous. However, such sediments may still contain organic, siliceous and agglutinated sub-fossil remains and trace fossils including mollusc 'burrows' which therefore provide evidence that decalcification has taken place as well as significant palaeo-ecological evidence.

It may be noted that in polluted environments which were inimical to life, reworked benthic or planktonic organisms may have been deposited and in other cases where the sediment alone was inimical to life the overlying water may have contained and deposited planktonic organisms or their remains into the sediment.

Care should be taken not to confuse the dumped remains of edible organisms, particularly molluscs, for material concentrated by sedimentalogical processes. Similarly, natural concentrations of mollusc shells associated with an archaeological site should not be taken for dumped material.

Any palaeoecological study of estuarine deposits should take the sedimentological features of the deposit into account. Such features include grain size, current bedding types and bioturbation features. These must be examined in situ on site and blocks of sediment should be collected for further examination in the laboratory. Each zone is characterised by particular current bedding and bioturbation features. Reineck (1967), Terwindt (1971), Raaf and Boersma (1971) and Reineck and Singh (1975) may be consulted for further details and excellent illustrations of the sedimentary structures to be found in tidal situations.

One should be familiar with the particular hydrographical idiosyncrasies of the estuary concerned before attempting the interpretation of deposits from it. The hydrographical features of the estuary may have changed during its history due to:-

1. Natural changes in its morphology through erosion and deposition.
2. Silting resulting from land erosion (following deforestation) or mining activities.
3. Changes in channel morphology brought about by Man through land reclamation, embanking, can alisation and dredging.
4. Obstructions of flow by bridges, tidal mills and other man-made structures.
5. Changes in relative sea-level brought about by tectonic activity and/or isostatic readjustment.
6. Changes in sea-level or fresh water influx due to climatic changes.

During the evolution of an estuary the gradual accumulation of sediment will allow the steady development of the sedimentary environments described above so that below any point on a supratidal or intertidal marsh one may find a sequence of sediments representing the stages of the succession leading to development of the marsh. Such a natural succession will continue to its climax (woodland) as long as the mean sea level is unchanging. However, during a period of transgression (rising mean sea level) sediments representing intertidal flats or even subtidal channels may be deposited on top of salt marsh, fresh water marsh or even climax vegetation deposits. During a period of regression (falling mean sea level) salt marsh, fresh water marsh and woodland will spread over older intertidal estuarine sediments.

Sedimentary sequences representing transgressive and regressive phases are features of estuaries. Devoy (1979) and Greensmith and Tucker (1971 and 1973) provide valuable contributions to the study of sedimentary sequences associated with sea level changes in the Thames Estuary area.

The origins of biological remains preserved in estuarine deposits

A sedimentary deposit collected from any point in an estuary may contain biological remains from a number of different sources and the various components of an assemblage may even differ widely in age. It is tempting to imagine that study of the biological remains from a series of sediments of the same age collected along a transect from the inner to the outer reaches of an estuary would automatically reflect any salinity gradient that existed in the estuary when the sediments were deposited.

However, the remains of freshwater organisms are readily transported downstream to be deposited in environments of higher salinity. It is also clear from many studies (e.g. Guilcher 1967, Prentice 1972) that much of the sediment found in estuaries is actually derived from the sea and may be transported many miles upstream from the estuary mouth. Therefore one may find subfossil material representing anomalously high salinities in estuarine sediments collected from the Middle and Upper Reaches of the estuary. One must therefore take great care to interpret the subfossil remains from estuarine deposits in terms of assemblages and not give any one category of subfossil material too much weight as an indicator of palaeosalinity or other environmental factor.

It is therefore essential to consider the possible sources of different components of any assemblage being studied, the physical conditions of individual categories and other factors.

A sediment may contain the remains of organisms that were:-

1) Members of the benthos preserved within the sediment with which they were associated in life.

2) Members of the living plankton or nekton in the water mass above the sediment in which their remains are preserved.

3) Members of the benthos in part of the sea, estuary or river some distance down-stream or upstream of the locality in which their remains have been preserved.

4) Members of the plankton or nekton in part of the sea, estuary or river some distance downstream or upstream of the locality in which their remains have been preserved.

5) Living in semi-aquatic or terrestrial habitats close to or at some distance downstream or upstream of the locality in which their remains have been preserved.

6) Part of or whose remains were part of the aerial plankton having no direct relationship with the estuary in which those remains have been preserved.

7) Parasites within the digestive systems of large populations of animals (particularly Man) whose faeces became deposited in the river or estuary.

8) Of more or less exotic origin dumped into the estuary by Man and which may include the remains of organisms originally gathered by Man from various regions of the estuary or distant geographical areas.

9) Already old when deposited in the sediment concerned, differing in age from the other biological remains in it by anything from a few decades to many millions of years and which originated in reworked estuarine or geological deposits.

3. TECHNIQUES EMPLOYED FOR RECOVERY OF BIOLOGICAL REMAINS

Poor sample treatment techniques can affect the composition of assemblages of subfossil remains recovered and may lead to erroneous or inaccurate interpretation of deposits being examined.

Some of the biological remains described below are not effectively recovered by many of the standard techniques employed for the recovery of biological remains from archaeological sites. In some cases fragile remains are destroyed by physical or chemical processes that are too violent and often where sieving techniques are employed the mesh sizes used are too large for the smaller 'microfossils'.

The author has found the following techniques to be effective in obtaining good recovery although each method has to be adapted to the characteristics of the sample being processed and the particular type of remains sought:-

1) Sieving with water using appropriate mesh sizes is used to recover the majority of the remains described below. Brass or stainless steel test sieves with the mesh sizes 63 micron, 125 micron, 250 micron, 500 micron, 1mm and 4mm are those most commonly used. It is rarely necessary to use all of these on one sample and the author prefers to use as few sieves as possible for each sample. The only sieve that is essential is the 63 micron one, the choice of others being dependent upon the grain size variation of the sediment and its biological inclusions.

Most estuarine sediments will break down in hot water without the use of chemicals that may be damaging to some biological remains. Samples may require soaking for several hours before sieving. It is best to remove the floating and less dense material before passing the denser material through the sieves. This is achieved by agitating the sample with water in a suitable container or by directing a water jet onto the sample in its container and repeatedly decanting off the floating and less dense material into another container or onto a 63 micron sieve until the sample has disintegrated completely and only the denser material is left.

Each fraction may then be passed through the appropriate range of sieves. This initial separation of the less or more dense fractions simplifies subsequent sorting and causes less damage to fragile material. It also prevents the loss of that material that floats which frequently occurs when sieves or containers are allowed to overflow. Such losses can easily occur and may lead to the almost total loss of some types of remains and the loss of the best preserved specimens of others from the sample.

When sieving has been completed preliminary examination of the fractions under a stereoscopic microscope while still on the sieves may show particles of sediment obscuring surface details or filling cavities of the remains. Each relevant fraction may be removed from its sieve, soaked in a very dilute solution of hydrogen peroxide for a few minutes and then washed on the sieve again. This treatment often cleans the specimens adequately but it may cause a few individuals of delicate molluscs, foraminiferids or other hollow forms to explode. For this reason use of hydrogen peroxide before sieving is usually avoided.

Each fraction is normally washed off its sieve onto absorbent paper and allowed to dry. Where fragile organic remains are concerned these are preserved in 70% alcohol and subsequently sorted while being kept moist. However, the majority of biological remains are most easily stored, sorted and identified when dry. Most remains are picked out from the residues with a moistened fine-tipped paintbrush and the smaller remains (those less than about 1mm across) are best placed directly into special micropalaeontological slides. Micropalaeontological slides and other containers with perspex tops are unsuitable for small microfossils because various problems arise with the static electricity associated with them.

Such sieving techniques will recover all organic, calcareous, siliceous, agglutinated, phosphatic and pyritic remains whose minimum dimensions are greater than the smallest mesh size used. It should be remembered that it is not the length but the smallest dimension that determines the retention of any elongated object in a sieve.

Material recovered by these methods will be normally studied by incident illunimation using a stereoscopic microscope with magnification up to x100 (higher magnifications will be required for critical identifications of the smallest remains).

2) Those organic remains whose dimensions fall within a range of less than 20 microns up to about 200 microns such as pollen, spores, dinoflagellate cysts and parasitic worm eggs require more complex techniques of preparation for study at high magnifications using transmitted light microscopy.

Palynological techniques commonly employed for pollen work are too violent for the recovery of many fragile algal remains. Indeed the use of sodium or potassium hydroxide and acetolysis mixtures is intended to remove everything but the sporopollenin of pollen and spores. The use of these chemicals should therefore be limited if algal and other fragile organic remains are sought.

The author uses techniques adapted from those evolved over several years by researchers in the Micropalaeontology Laboratory of the Geology Department at the University of Sheffield.

The sub sample size used depends upon the character of the sample (more being used for coarse grained or highly calcareous ones) but as a general rule sufficient is used to fill about one fifth of the container that is to be used for acid digestion. Samples are not allowed to dry out before processing. Polypropylene screw top jars (500 ml. capacity) are used with two small holes made in the screw-on lids to allow the gases generated during digestion to escape. The use of these jars through most of the process helps to prevent contamination.

Dilute hydrochloric acid is gradually added to the sample in the polypropylene jar to remove carbonates. When no further effervescence occurs on the addition of fresh acid the jar is topped up with distilled water, the contents stirred and after the sediment has settled (after several hours) the supernatent liquid is decanted off and the jar topped up with distilled water again. This procedure is repeated until the supernatent is no longer acid when tested with litmus paper.

The supernatent is then decanted off and hydrofluoric acid (about 30% concentration) is added with care to the contents of the jar. This procedure may have to be carried out in stages over a period of time because if too much heat is generated in the reaction the jar must be cooled in a cold water bath before continuing. When the reaction subsides more acid may be added and the jar placed in a hot water bath. The sample should be stirred periodically with a polypropylene stirring rod and the spent acid replaced with fresh acid after a day or two. After what may be several more days all the sand and silicates in the sample should have been dissolved.

The supernatent is then poured off, distilled water added and the contents of the jar mixed. After the organic 'ooze' has settled completely the supernatent is decanted off, the jar topped up with distilled water and the contents mixed again. This procedure is repeated until the supernatent is neutral when tested with litmus paper.

Full safety precautions must be used when using hydrofluoric acid including an efficient fume cupboard and a means of safely disposing of spent acid.

When neutrality has been achieved the organic ooze may be washed through a small brass or stainless steel sieve of about 200 micron mesh into a glass beaker or jar. The material retained in the sieve may be subsequently examined for seeds, macrospores, cuticles or other organic remains.

A portion of the material which passed through the sieve (having been left to settle) is deposited by pipette into a clean sintered glass Buchner funnel (porosity 5 - 10 microns) about half full of distilled water. The funnel is already fitted to a Buchner flask with a rubber suction bulb connected to it by rubber tubing. The suction bulb may be reversed to produce pressure and blow air through the filter funnel.

The procedures carried out in the filter funnel and subsequently are designed to remove any fluorides which may have been formed in the previous process, iron pyrites, other excessive mineral matter, amorphous organic matter and sometimes to lighten excessively dense pollen grains, etc. Periodically a small amount of the material should be examined on a microscope slide under a transmitted light microscope to monitor the procedures as no two samples are exactly the same in the way they respond.

Using the filter apparatus and the suction bulb for suction or reversed to blow air through the sample each process can be carried out without undue physical damage to the remains and with control of the length of time the remains are in contact with reacting chemicals. Filtering should never be allowed to progress to 'dryness' and the contents of the funnel should be kept moving by alternate 'blowing' and 'sucking', the latter being kept to a minimum. As some of the chemicals used can react with one another the Buchner flask should be emptied and rinsed with water as necessary. The sample itself is washed with distilled water between each chemical process.

The following processes are carried out in the Buchner funnel:-

a) Treatment with dilute hydrochloric acid (normally cold but hot if excessive fluoride present).

b) Treatment with concentrated nitric acid to remove iron pyrites and carry out brief oxidation of organic remains (less than a minute usually being adequate).

c) The washed contents of the funnel are transferred to a glass beaker, the funnel rinsed with a jet of water through the filter and the contents of the beaker returned to the clean funnel.

d) Treatment with very dilute sodium or potassium hydroxide (about 2% concentration) to remove finely divided amorphous organic material (less than a minute is usually adequate and more time or alkali that is too concentrated may destroy the more delicate organic remains).

e) A few drops of safranin stain are added to the funnel in the last stage of washing with distilled water while the contents are still slightly alkaline, the mixture allowed to mix for about a minute and then thoroughly washed with distilled water until excess stain has been removed and the material neutralised.

The contents of the funnel are then carefully transferred to a glass tube and allowed to stand or it may first be split into two fractions using a brass or stainless steel sieve, the mesh size selected being dependent upon the characteristics of the sample concerned. Any extraneous mineral matter can also be removed at this stage by gently swirling the contents of the funnel in a watch glass in the manner of 'panning' for gold.

The material transferred to the glass tube is allowed to settle and most of the supernatent removed with a clean pipette. The sediment is then mixed and a small quantity of this suspended material is transferred to a small quantity of glycerine jelly that has been allowed to melt in a small squat flat bottomed glass tube on a warm hotplate. The jelly and stained organic material are mixed and a small quantity of the mixture placed in the centre of a clean coverslip (No. 0 thickness) already warm on the hotplate.

In practice several coverslips are prepared at once on the hotplate and after the glycerine jelly mixture has been placed on them they are covered to prevent dust contamination and left for a few minutes to allow excess water to evaporate. Each coverslip is then inverted onto clean warmed slides in such a way that bubbles are excluded and the glycerine jelly just forms a fringe around the coverslip. The slides are left on the warm hotplate for several minutes to dry further and then removed to cool. Slides prepared in this way appear to last well without sealing if excess water has been removed adequately as subsequent shrinkage of the jelly with attendant 'bubble trouble' is largely prevented. If necessary the edges of the coverslip can be sealed with clear nail varnish.

The types of remains recovered in this way are studied using the best quality transmitted light microscope available with high power oil immersion objectives included and preferably phase contrast facilities (especially for dinoflagellate cysts and similar remains).

3) The processing of samples for siliceous microfossils such as diatoms and sponge spicules basically involves removal of carbonates and organic material from

the sediment and mounting of the siliceous material on microscope slides with a high refractive index mountant. All the processes are carried out in normal Pyrex laboratory glassware.

Very violent techniques and centrifugations are used by some workers but the author prefers to use the following procedures which seem to recover delicate forms as well as the more robust types and produce less fragmentation.

Dilute hydrochloric acid is added to a few grammes of sediment in a glass beaker or conical flask until no further effervescence occurs when fresh acid is added. The container is then topped up with distilled water, the contents mixed and then allowed to settle for several hours. The supernatent is removed, the container filled with distilled water, and the contents mixed again. After standing and removing the supernatent yet again sufficient dilute nitric acid is added to cover the sediment. The vessel with its contents is then heated in a water bath. The contents should be stirred repeatedly but care taken to prevent the contents being crushed between the stirring rod and the bottom or sides of the vessel. This treatment will remove iron pyrites which are often abundant in estuarine deposits, disaggregate the sediment further and initiate oxidation of organic material. The treatment may be continued for an hour or more but the period of time necessary will depend on the composition of the sample itself and the quantity being processed. Periodically, during this, as each other process small quantities of suspended sediment should be examined under a transmitted light microscope to monitor the effects of the treatment.

The acid mixture is removed from the water bath, allowed to cool, topped up with distilled water, mixed and the contents allowed to settle (at least three hours may be necessary). Small planktonic diatoms may be lost if insufficient time is allowed for them to settle out from suspension .

The supernatent is then removed, the container filled with distilled water again, stirred and allowed to stand. After decanting the supernatent the sediment is treated with dilute hydrogen peroxide until the organic material has been virtually eliminated. Effervescence should be checked with alcohol from a wash bottle. When oxidation is complete the container is topped up with distilled water, the contents mixed, allowed to settle and the supernatent removed. Washing with distilled water must be repeated several times to remove all soluble substances from the residue.

If sand is present in the residue this may be removed by placing the clean residue with a little water in a watch glass and swirling in the manner of 'panning' for gold referred to above. The clean microfossil-bearing residue may be pipetted into a glass tube.

Small quantities of siliceous suspension are pipetted onto clean coverslips (No. 0) on a cold or slightly warm hotplate. The quantity required is learnt with practice. A tiny amount of photographic wetting agent in the suspension encourages an even spread on the coverslips. The water is allowed to evaporate from the coverslips under a cover. When 'dry' the coverslips are heated on the hotplate for several minutes to ensure complete removal of water and then the hotplate allowed to cool slightly. A small quantity of a high refractive index mountant (i.e. R.I. of 1.7 or more)is placed on each coverslip and the coverslips inverted onto clean microscope slides (already warmed on the hot plate) in such a way as to exclude bubbles. The slides are left to dry on the hotplate for several minutes. Some mountants require curing in an oven for an extended period and subsequent sealing.

A transmitted light microscope with phase-contrast and dark-ground illumination and high-power oil immersion objectives of the best quality is essential for work with siliceous microfossils.

4) Methods of studying sedimentary structures including traces of biological activity in sediments are described by Bouma (1969) Carver (1971) and Farrow (1975) and good illustrations showing how effective such studies of sub-recent deposits can be are shown in Reineck and Singh (1975). The present author has only recently started experimenting himself with these techniques but preliminary results suggest that they may be particularly useful with sediments representing polluted conditions in which only worms were

living and in decalcified sediments from which burrowing molluscs and other calcareous remains have been dissolved.

Kummel and Raup (1965) is a valuable source of information on many types of palaeontological techniques.

4. THE BIOLOGICAL REMAINS AND THEIR VALUE IN PALAEOECOLOGICAL STUDIES

The variety of sources of biological remains entering estuarine deposits has already been indicated and the variety of biological remains that may be recovered is large. This part of the paper is intended to provide an introduction to each of the most important groups of organisms represented by subfossil remains, an indication of which recovery methods will yield these remains and a consideration of the possibilities and limitations of the remains as palaeoenvironmental indicators.

The study of some of the organisms mentioned is a matter for specialists and any preliminary identification of subfossil remains using publications cited or others should be confirmed (or otherwise) by comparison of the subfossil remains with modern reference material and/or expert assistance sought. In most cases, remains must be identified to the species level to be of palaeoecological value.

Many of the records of salinity extremes which 'freshwater' or 'marine' species will withstand come from observations of organisms living in the relatively stable salinity conditions of the Baltic. Work by Luther (1951) and others shows that the same species experiencing the fluctuating salinity conditions which are found in most estuaries have a more limited range. Therefore, salinity ranges of organisms derived from studies in the Baltic or similar areas should not be applied to subfossil remains from estuaries without care. Remane (1971) is an extremely valuable source of information on the salinity requirements of a wide range of organisms.

The biological remains will be discussed under the major headings (a) plant remains and (b) animal remains.

(a) Plant remains

For the purposes of discussion the plant remains likely to be found in estuarine deposits may be divided into:-

i) higher plant remains

ii) algal remains

While fungal spores and evidence of other thallophytes may be found they are not generally identifiable to species or of great value as environmental indicators.

Higher plant remains

Remains of bryophytes, pteridophytes and spermaphytes may be recovered. These may be macroscopic (vegetative remains, fruits and seeds) or microscopic (pollen and spores). In fact, many seeds are really 'microscopic' in practice and macrospores of pteridophytes are often included in descriptions of macroscopic remains.

Dickson (1970) provides a valuable introduction to the practical study of macroscopic plant remains. Beijerink (1947), Bertsch (1941) and Katz, Katz and Kipiani (1965) may be used to assist the preliminary identification of seeds and a few other macroscopic remains. Van Zeist (1974) and Wilson (1975) include good illustrations of the fruits and seeds of a number of coastal plants.

Godwin (1975) is an invaluable source of plant records from estuarine sites as well as other areas.

Faegri and Iverson (1975) and Moore and Webb (1978) provide introductions to the study of pollen and spores. A paper by Andrew (1970) is useful as it provides a means of checking whether particular plant species are identifiable from their pollen or spores. Although further work undertaken by various people since that paper was written has enabled a few more species to be distinguished by their pollen or spores it is still a useful guide.

Chapman (1960) and Ranwell (1972) are essential reading for a detailed treatment of the development and ecology of salt marshes. Green (1968) and Round (1979) provide introductions to the estuarine flora and Hepburn (1952) and Chapman (1964) provide introductory accounts of coastal plants and their ecology including those of estuaries. Luther (1951) is a particularly valuable source of information on salinity conditions withstood by higher plants. The difference in salinity range of various species under conditions of stable or fluctuating salinity is striking.

Pollen and spore assemblages may be difficult to interpret in estuarine sediments being readily transported downstream by the river, carried upstream by tidal currents, washed in by rain from the aerial flora or reworked from older sediments as well as containing a component coming from any autochthonous flora. The relative importance of various factors may be assessed however and allow pollen and spores to contribute information not obtained from other sources and may allow general changes in the vegetation of the estuary and its hinterland through time to be recognised.

Sediments examined in situ may reveal the remains of roots or rhizomes of various plants, some of which may be identifiable to species and obviously of particular value as they represent part of the autochthonous flora. Autochthonous peats or very organic horizons may overlie horizons containing 'roots' and yield not only valuable assemblages of fruits, seeds, leaves and other diagnostic remains but also evidence of mean sea level at the time of deposition. However, allochthonous peats composed of drifted plant material which may have been transported from several sources are not uncommon in estuarine sequences and may form in various positions in the intertidal zone.

Plant remains may be recovered representing the flora of supratidal levels, the upper tide flats (possibly salt marsh), the lower tide banks and sublittoral channels. The salinity conditions experienced by plants in these different zones will have been different so that palaeosalinity determinations based on the different components may also be different.

Algal remains

Algae are of great importance in estuaries as in every aquatic environment. However, the majority will not be preserved in sediments. Green seaweeds such as Enteromorpha and Ulva would never be preserved and even the tougher brown seaweeds such as Fucus and Ascophyllum are unlikely to be preserved in a form identifiable to species level. The red seaweeds include some calcareous forms and Corallina, Lithothamnion and Lithophyllum may be found in sediments associated with higher salinities.

Blue-green algae are quite important in estuaries but only those which precipitate calcium carbonate are likely to leave any remains. Some species form rounded or flattened onkolites by their growth and precipitation of calcium carbonate around fragments of shell or other objects. (c.f. Pentecost 1978 and see Wray 1978).

The algal remains most likely to be preserved in estuarine sediments are microscopic forms except for the charophytes.

Charophytes (Characeae)

The charophytes are atypical algae which superficially resemble higher plants in appearance. The majority of species form bushy plants in freshwater but a few species penetrate brackish water. Moore (1979) has provided an up-to-date review of the species diversity, ecology and distribution of Characeae in the British Isles and this may be supplemented by Moore (1976) for their occurrence in saline waters. One species, the rare *Lamprothamnium papulosum*, can survive in salinities as high as 30‰. Luther (1951) records several species of *Chara* penetrating at least 6‰ in the Baltic. The standard works on the British charophyte flora are those by Groves and Bullock-Webster (1920, 1924) and Allen (1950). The world flora has been examined in a monograph by Wood and Imahuri (1964, 1965).

Charophytes are most diverse and abundant in unpolluted environments. Eutrophication has caused the disappearance of many species in formerly rich habitats (Moore 1979). Changes in the diversity and abundance of subfossil remains may provide evidence of pollution.

Five genera are found in Britain grouped into two tribes, the Chareae (*Chara*, *Lamprothamnium* and *Nitellopsis*) and the Nitelleae (*Nitella* and *Tolypella*). Species of *Chara* and *Tolypella* precipitate calcium carbonate and contribute to the formation of marls. This capability has given charophytes as a whole the vernacular name 'stoneworts'.

The fruiting bodies of charophytes are known as oogonia. They are oval bodies with a distinctive spiral pattern. The shape, size, number of convolutions and details of sculpturing may be used to distinguish between genera. Horn af Rantzien (1959) suggests that in some cases at least subfossil oogonia may be identifiable to species level. The organic component of the oogonia is preserved under waterlogged conditions but in members of the Chareae an inner calcareous body is produced sometimes known to palaeontologists as a *gyrogonite*. These are the objects which most commonly represent charophytes in estuarine and other sedimentary deposits. Some oogonia may approach 1mm in length but a 63 or 125 micron sieve must be used to recover them as many are much smaller (and thinner in any case).

Charophyte oogonia are fairly common in estuarine sediments from the Fleet and Thames in London and although specific identifications have not yet been made, they are generally associated with other biological remains indicating fairly low salinities.

Diatoms

Diatoms are microscopic algae of great importance as 'producers' in aquatic environments. They are also found in terrestrial situations wherever sufficient moisture and light is present. They are the major component of the phytoplankton in freshwater, estuaries and the sea. They are also important members of the benthos in estuaries and the brown slime often seen covering areas of intertidal mudflats is composed of enormous numbers of diatoms. Many of these are motile but others are sessile being attached to water plants or other substrates. The 'plankton' of estuaries often contains many benthic forms suspended by tidal currents and fragments of suspended detritus frequently support colonies of sessile diatoms.

Diatoms have two great attributes as far as the palaeoecologist in concerned. Firstly, they are good environmental indicators, individual species being fairly specific in their requirements. Secondly, the cell wall is largely composed of silica forming a box known as the frustule made of two valves so that complete frustules or separate valves are resistant to solution (except in highly calcareous conditions).

A fairly recent monograph (Werner 1977) contains a number of valuable papers reviewing the classification, biology and ecology of diatoms. The literature on diatoms is vast but scattered and the most important publications are not readily available. However, Hendey (1964) provides a good introduction to diatoms in general and good illustrations of estuarine and marine forms from Britain. Bourrelly (1968) provides a good introduction to the freshwater forms which will be encountered in estuarine deposits. However, the major works by Hustedt (1927-1966), Cleve-Euler (1951-3) and van Werff and Huls (1958-74) should be consulted for the most detailed accounts of the diatom flora of Europe and its ecology. Smith (1853, 1856) and Van Heurck (1896) still have their value and Remane (1971) and Perkins (1974) include data on salinity and other environmental requirements of diatoms not published or readily available elsewhere.

Several species of diatoms tend to vary in size and shape according to the salinity conditions. All species, however, have a wide size range as their method of asexual reproduction leads to a decrease in size of a proportion of the population until a point is reached at which a form of sexual reproduction takes place to prevent the diminution in size from progressing too far. Therefore any assemblage of diatom frustules will contain small individuals and only measurements of a suitable number of valves will indicate whether there is an ecologically significant diminution of size in the population of a species as a whole.

While eutrophication may lead to increased populations of planktonic and benthic diatoms, severe pollution by suspended material will tend to destroy the benthic flora and limit the phytoplankton by decreasing the light penetration. However, pollution affecting the benthos will cause the proportion of planktonic diatoms in the sediment to increase. This seems to be the case with medieval and post-medieval sediments from the Thames and Fleet examined by the author. Preliminary analysis also indicates a general decline in diversity with increasing pollution.

Jansma has used diatom analysis in environmental work on sediments associated with archaeological sites and in identifying the source of clays used for making pottery (Jansma 1975, 1977 and this volume). Burckle (1978) provides an introduction to the use of marine diatoms in stratigraphic palaeontology and palaeoecology but is mainly concerned with oceanic deposits.

Devoy (1979) has employed diatom analysis in the study of sea level changes in the Thames Estuary.

The larger diatoms may be recovered in the course of wet sieving on the 63 micron sieve if care has been taken. However, the special techniques described for siliceous remains should normally be employed for the recovery of diatom assemblages.

Dinoflagellates

Dinoflagellates are microscopic algae which are primarily members of the plankton in freshwater, estuaries and the sea. They are second only to diatoms in the sea in their importance as 'producers'. Lebour (1925) may be consulted for an account of the dinoflagellate flora of British coastal waters. LACKEY (1967) AND Perkins (1974) discuss several aspects of the occurrence and significance of dinoflagellates in estuaries. Certain species produce toxins and occasionally their numbers increase to such an extent under conditions of nutrient enrichment that 'red tides' are produced which cause mass mortalities among fish and contaminate molluscs in which the toxins become concentrated (without necessarily killing them). Such molluscs may cause the death of large numbers of birds and sometimes Man if they are eaten.

The motile stage of dinoflagellates is rarely preserved but the 'resting bodies' or cysts which many species produce are often abundant in estuarine and marine sediments. The author has found them to be very abundant in phytoplankton collections made at certain times of year in the Blackwater and Crouch estuaries.

The author has also recovered well preserved dinoflagellate cysts from medieval and post-medieval Thames and Fleet sediments but, strangely, the best preserved ones have been clearly reworked from the London Clay and Cretaceous sediments. The subfossil ones are often less robust and seem to take up stain less readily.

Williams (1978) provides an excellent introduction to the study of dinoflagellate cysts but fails to note the work by Reid (1972, 1974, 1975) which is of particular value to those concerned with subfossil cysts and their distribution around the British Isles. Unfortunately, not all dinoflagellates produce cysts, including species of the important genus Ceratium, and not all cysts have been linked to their parent species.

Dinoflagellate cysts will be recovered by the special palynological techniques described. However, their identification should only be attempted by those familiar with the fossil dinoflagellate flora as well. Dinoflagellate cysts may provide valuable palaeoecological information in the future but studies are at an early stage of development.

Other microscopic algae

Species of Pediastrum are the most common planktonic algae after dinoflagellates recovered in 'palynological' preparations of estuarine sediments. However, they are often rather 'thin' and fragile compared with dinoflagellate cysts and may be destroyed by palynological techniques that are too violent. They live in salinities up to about 5‰ (Remane 1971). Sulek (1969) discusses the taxonomy of the genus and provides illustrations of the species.

Colonies of Botryococcus, another freshwater planktonic alga, may also be fairly common in palynological preparations.

Silicoflagellates have been recovered by the author from estuarine sediments in London. Living forms can be abundant in the plankton of estuaries but unfortunately the genera represented in London, Dictyocha and Distephanus and their species, have long stratigraphic ranges so that it is difficult to tell whether they are subfossil or fossil forms reworked from the London Clay. Haq (1978) provides a good introduction to the group. Being siliceous, they are most likely to be found in diatom preparations.

(b) Animal remains

The variety of animal remains to be recovered from estuarine deposits is large and ranges from microscopic protozoans to the skeletal remains of whales.

Schäfer (1972) is essential reading for anyone concerned with the ecology and palaeoecology of 'marine' animals and is equally applicable to many components of the estuarine environment.

Thecamoebae

Thecamoebae (sometimes known as testaceans) are testate rhizopod protozoans that are almost entirely confined to freshwater habitats and the lower salinity regions of estuaries.

Species found in estuaries are mainly those with organic tests (e.g. Arcella spp.) or with agglutinated tests made of sand grains, diatoms and other particles cemented together (e.g. Difflugia spp.). Other species possess more delicate tests composed of siliceous plates or scales. They are all members of the benthos.

Murray (1968a) recorded data on the chlorinity requirements of several species that may be found in estuaries.

The most complete work on the British fauna is still that by Cash, Wailes and Hopkinson (1905-1921) although out of date in some respects. Deflandre (1959) provides a useful introduction to the group and Corbet (1973) is well worth consulting although primarily concerned with species from *Sphagnum*.

The larger species with agglutinated or organic tests will be recovered by sieving but organic tests will be recovered in 'palynological' preparations as well. The species with siliceous scales or plates, however, will normally pass through the 63 micron sieve, are also destroyed by hydrofluoric acid and they will normally disintegrate in the preparation of samples for siliceous remains. The presence of the small siliceous types may be ascertained by examining material passing through the 63 micron sieve.

Foraminiferids

Foraminferids are also testate rhizopod protozoans. They are primarily a marine group but some species penetrate to very low salinities in estuaries. Although planktonic foraminiferids are important in tropical waters, only the benthic foraminiferids are common in British coastal waters. They are extremely useful indicators of salinity and estuaries support characteristic assemblages.

Murray (1968b and 1973) has described the characteristics of estuarine assemblages. Schafer (1970) has studied the effects of pollution upon foraminiferids in a Canadian estuary.

The identification of subfossil specimens may be attempted utilising Murray (1971) and Murray (1979) but considerable care should be taken as reworked fossil specimens can be very common in estuaries and investigators without knowledge of fossil faunas should have provisional identifications checked by a specialist. Medieval estuarine sediments from London examined by the author yield not only medieval foraminifera but also large numbers of well preserved Cretaceous and Tertiary forms.

Agglutinated or calcareous tests of foraminiferids will be recovered by sieving (juveniles may pass through the 63 micron sieve) but the organic linings will also be recovered in palynological preparations. The latter can only rarely be identified to species but may be significant in sediments that have been decalcified removing the normal evidence for calcareous and many agglutinated remains of value in recognising saline influences.

Tintinnids:

Tintinnids are ciliate protozoans which secrete a vase-like lorica into which the body can be withdrawn. The lorica is organic but in many species this is covered by small mineral particles, diatoms or sponge spicules. They are primarily marine planktonic organisms but they are frequently abundant in the plankton of estuaries and their lorica can be concentrated in fine grained sediments. The author has found that tintinnids can become a dominant component of the zooplankton for periods during the summer in the Blackwater and Crouch estuaries.

Work by Lafon, Durchon and Saudray (1955) on the plankton of some stable brackish habitats suggests that tintinnids could be useful salinity indicators.

The majority of species will pass through a 63 micron sieve and may only be recognised in palynological preparations. However, the larger species (e.g. Tintinnopsis campanula) may be recovered by wet sieving. A number of species of tintinnids which are found in British coastal waters are illustrated and described by Newell and Newell (1963) who also provide references to more specialist works.

Sponges:

Sponges are simple multicellular animals which possess a skeleton consisting of either a network of organic fibres or inorganic spicules embedded in the tissues. These spicules are calcareous or composed of silica and become scattered on the death and decomposition of the sponge. Spicules may be recovered in the course of wet sieving but may be abundant in diatom preparations.

Marine sponges include species whose spicules have a variety of basic shapes. However, these spicules cannot generally be attributed to particular species as the manner in which the spicules are arranged in the animal and the morphology of the whole sponge are vital factors in the identification of species. Bowerbank (1864) provides illustrations showing the range of spicule types found in British sponges.

Tetraxon spicules are frequently encountered in sediments representing higher salinities but these could be attributed to one of several marine species. They can therefore only be used to help support other evidence and may sometimes be reworked from much older sediments.

At the low salinity end of an estuary the problem is more straightforward as only two species of freshwater sponges can be expected. Spongilla lacustris and Ephydatia fluviatalis. Both species have smooth, slightly curved monaxon spicules but Spongilla lacustris also produces smaller monaxon spicules with a rough surface. Therefore, if the smooth monaxons are found with the smaller rough-surfaced monaxons S. lacustris must be represented with or without E. fluviatalis.

If only smooth monaxons are present in sediments thought to represent low salinities from other evidence, E. fluviatalis is indicated. Several marine species also possess monaxon spicules but would not be found without more complex spicule types. Remane (1971) states that E. fluviatalis extends into waters of about 6-7‰ salinity and implies that S. lacustris is not found in salinities above 3‰ salinity. Harrison (1974) provides further information on the ecology of both of the cosmopolitan species including their tolerance of pollution as well as salinity. Ephydatia fluviatalis appears to be fairly resistant to particulate pollution and eutrophication.

Spicules of E. fluviatalis and S. lacustris are abundant in some sediments from the Fleet and Thames on sites in London and preliminary investigation of differences in areal and temporal distribution suggest that these differences may reflect changes in salinity and pollution.

Incidentally, many mollusc shells from higher salinities, particularly those of the oyster Ostrea edulis, will be found to be riddled with borings made by the sponge Cliona cellata.

Bryozoans

Bryozoans ("moss -animals") are often known as Ectoprocts or Polyzoa in older publications. The phylum Bryozoa includes freshwater as well as marine species although it is primarily a marine group. Ryland (1970) provides a useful introduction to the biology of the phylum as a whole.

The freshwater species do not possess any resistant 'skeleton' capable of being preserved but most of them do produce organic-walled reproductive bodies called statoblasts which are characteristic for each genus and may be attributed to particular species in several cases. Allman (1856) first described the British freshwater fauna but several of the British species are described by Rogick (1959) and Pennak (1978). Lacourt (1968) provides a valuable up-to-date monograph treatment of the freshwater bryozoans. Bushnell (1974) examines the pollution ecology of several species that occur in Britain.

The genus Plumatella includes species that are the most resistant of freshwater bryozoans to pollution (Ryland, 1970) and some species penetrate into brackish waters. Statoblasts of Plumatella spp are quite common in estuarine deposits from London sites and preliminary studies suggest that they may prove useful in identifying changes in salinity and pollution.

A number of marine bryozoans penetrate into brackish waters, the diversity of species decreasing as the salinity decreases. Ryland (1970) describes the salinity requirements of several species. Membranipora (Electra) crustulenta has been recorded from salinities as low as 2‰ . It is capable of forming reefs in brackish water Remane (1971). 'Marine' species do not produce statoblasts but the majority produce calcareous 'skeletons'. However, Victorella pavida, a characteristically brackish water species, produces neither calcareous remains nor statoblasts.

Identification of the remains of 'marine' species may be attempted by the use of Hincks (1880) supplemented by Ryland (1969) and the keys provided by Ryland (1974), Ryland and Hayward (1977) and Ryland and Hayward (1979).

Both the statoblasts of 'freshwater' species and the calcareous remains of 'marine' species will be recovered by sieving.

Benthic worms:

Polychaetes, nematodes and other 'worms' are extremely important members of the fauna of estuaries. They are widely used in the classification of specific habitats within modern estuaries and in the recognition of changes in habitats due to pollution.

Unfortunately, however, few 'worms' have hard parts by which they may be recognised in the subfossil state in estuarine sediments. Scolecodonts (the jaws of certain polychaete worms e.g. Nereis) and calcareous tubes of worms such as

Spirobis and *Pomatoceras* may be found in the course of sieving. Sometimes the burrows of other worms such as *Arenicola* may become encrusted with iron hydroxide and have sufficient strength to be retained by a sieve. Small scolecodonts and fragments of polychaete bristles may be quite common in palynological preparations. Worm eggs, mostly unidentifiable, may also be common in such preparations. The organic cocoon cases of leeches may be found in low salinity deposits by sieving.

Trace fossils of worms are much more obvious in many estuarine sediments but require examination of the sediment in situ or in carefully collected blocks of sediment (see Schäfer, 1972, Bouma, 1969 and Reineck and Singh, 1975). Examination of trace fossils of benthic worms is likely to provide more valuable ecological evidence than those fragments obtained by sieving or other processes.

Worms such as *Tubifex* which are so important in enriched estuaries are only likely to be recognised as trace fossils in subfossil sediments.

Several important species can withstand a wide range of salinities (e.g. *Nereis diversicolor* will survive in salinities as low as 4‰ in normal conditions or lower in stable environments and *Tubifex tubifex* will survive up to about 16‰ (Remane 1971).

The shells of molluscs from higher salinities particularly those of the oyster *Ostrea edulis*, the cockle *Cerastoderma* *(Cardium) edule* and the mussel *Mytilus edulis* may contain the U-shaped borings of the polychaete *Polydora ciliata*. These appear oval on the surface rather than round as in those of the boring sponge, *Cliona*.

Parasitic worms:

The eggs of worms parasitic in Man and domestic animals may reach estuarine sediments in large numbers with human faeces and stable refuse. Estuaries associated with large urban settlements (e.g. London) have been the recipients of enormous quantities of human waste.

The author has found the eggs of two species of nematode *Trichuris (Trichocephalus) trichiura* and *Ascaris lumbricoides* to be particularly common in faecal material from latrine and cess-pits on archaeological sites in the City of London and these eggs also occur in sediments of the Fleet and Thames. Preliminary investigations suggest that the relative abundance of these eggs in different parts of a sedimentary sequence may provide evidence of changes in degree of pollution due to human waste.

These eggs will be recovered in palynological preparations. Eggs of the two species referred to above will pass through a 63 micron sieve. Details about the life histories of these worms and their social significance may be obtained from one of many books on Human Parasitology (e.g. Chatterjee 1976, Muller, 1975).

Cladocerans:

Cladocerans are small crustaceans frequently known as 'water-fleas' due to their jerky swimming movements and Daphnia is a familiar genus. They are primarily a freshwater group although species do occur in estuaries and the sea.

While the delicate carapaces are preserved in pond and lake sediments and have been of value in palaeoecological studies they are less likely to survive in sediments deposited by moving water. However, many species form a special resistant resting body inside the carapace at a particular time of year or when conditions become unsavoury for the swimming stage. These resistant bodies are called 'ephippia' and may be quite common in freshwater sediments and in the low salinity regions of estuaries. They frequently occur in Fleet and Thames sediments from London.

These ephippia have distinctive shapes which differ from one group of Cladoceran species to another but they may not be identifiable to species. While keys exist for the free-swimming forms with illustrations of some ephippia (e.g. Scourfield and Harding 1966, Brooks 1959) the author is not aware of a key for ephippia although descriptions of ephippia for individual species are scattered through the literature. They may be identifiable from reference collections.

Ephippia are recovered by wet sieving but as they frequently float special care must be taken to prevent their loss during processing.

Their relative abundance in different parts of a sedimentary sequence may provide evidence for general water quality and freshwater influence. If species can be identified they may provide more precise information.

Ostracods:

Ostracods are small bivalved crustaceans which are among the most useful of organisms in palaeoecological studies of aquatic environments. The calcified paired or separated valves of their carapaces are often very common in freshwater, estuarine and marine sediments.

They are a useful group because individual species have quite specific environmental requirements. Salinity is the main factor determining the distribution of different species in estuaries and Neale (1965) lists the salinity requirements of many British species.

However, like many other microfossils, ostracod valves are readily transported into sedimentary environments which are not the natural habitat for the living organisms. Kilenyi (1970) describes the problems caused by reworked valves in studies of ostracod assemblages from the outer part of the Thames estuary. Kilenyi has also discussed other basic problems of ostracod palaeoecology (Kilenyi 1971).

Preliminary investigations by the present author on London sites indicate that ostracod assemblages from the Fleet and Thames reflect changes in salinity and pollution but reworked valves are also common. Valves showing signs of wear and of a limited range of size suggest transported specimens but it is frequently necessary to have a fairly intimate knowledge of the ontogeny and ecology of the species involved to understand an assemblage. The presence of juveniles as well as adults of a species in an assemblage is a fairly good indication that the species was living in or close to the sediment being studied.

Many ostracod species exhibit more or less pronounced sexual dimorphism, the immature instars are frequently quite different in appearance to the adults and some species change their morphology with changes in salinity. The study of ostracods is therefore not without pitfalls for the unwary.

Van Morkhoven (1963) and Bate and Robinson (1979) provide valuable introductions to the study of fossil ostracods and include illustrations of many species which are still part of the British fauna. Sars (1922-1928) and Klie (1938) provide the most complete descriptions of the Recent fauna of North West Europe although descriptions of new species and old species redescribed are scattered among more recent publications. Unfortunately, many descriptions of species emphasise the soft parts which are not generally preserved in sediments so that it is necessary to have access to a reference collection to enable comparison of subfossil carapaces with Recent ones to be undertaken with difficult species.

Ostracods are usually recovered from a sediment by wet sieving but ostracods from low salinities have less heavily calcified carapaces than those from high salinity environments and it is wise to examine blocks of sediment under a stereoscopic microscope in addition to examining the residues from wet sieving to ascertain whether fragile valves are being destroyed during sieving. Individual specimens may be excavated carefully on the block using mounted needles and a small brush and transferred to micropalaeontological slides.

Other crustaceans

Remains of barnacles, crabs, gribbles and perhaps also other crustaceans may be recovered from estuarine deposits.

The articulated or isolated calcareous plates of barnacles (cirripedes) may be common in estuarine deposits attached to solid substrates (including archaeological structures) or dispersed in the sediment. The species most likely to occur in estuaries are Semibalanus (Balanus) balanoides, the common acorn barnacle, which penetrates to salinities as low as 12‰ in regions of stable salinity and Balanus improvisus which penetrates salinities as low as 2 or 3‰ (Green, 1968). The distribution of barnacles in estuaries may be determined by the requirements of the planktonic larvae rather than the adult (e.g. the nauplii of S. balanoides are apparently killed by salinities lower than 12‰). Whereas S. balanoides is mainly found in the intertidal zone, B. improvisus is mainly found below low tide level (Schäfer 1972).

Various crabs may occur in the higher salinity regions of estuaries but the shore crab, Carcinus maenus, is the only crab which penetrates the lower salinity regions of estuaries. It will survive permanently in salinities as low as 6‰ (Green 1968). Various parts of the carapace or exuviae (moults) may be preserved under favourable circumstances but they often tend to break up in the sediment.

Prawns of various types are important members of the estuarine fauna but are rarely preserved as the carapaces or exuviae are delicate and likely to be broken up by sedimentary processes or the activities of scavengers.

Burrows of the wood-boring crustacean, the gribble, Limnoria lignorum, may be found in the timber of waterfront structures or boats on archaeological sites. Richards (1969) seems to infer that Limnoria, in common with most other marine wood-borers, does not occur in salinities lower than 9‰.

Insects

This group of anthropods is extremely important in freshwater habitats but only a handful of species are associated with the sea. However, a number of insects live successfully in estuaries some of which are basically terrestrial associated with salt marshes but others that are aquatic insects living in brackish water habitats (see Green 1968).

Among the most likely to leave identifiable subfossil remains are the beetles (Coleoptera), the water bugs (Hemiptera Heteroptera) and caddis-fly larvae (Trichoptera).

Green (1968) discusses the occurrence of a number of species of beetles to be found in estuarine habitats. Sutcliffe (1961) observed the dytiscid Colymbetes fuscus living in pools with an average salinity between 18 and 23‰ (rising occasionally to 30‰).

Sigara stagnalis is the most successful water bug in estuaries and may be found in salt marsh pools with salinities up to 25‰. Notonecta viridis is another common water bug in brackish waters. Although the exoskeletons of bugs are not quite so robust as those of beetles they may be recovered under suitable conditions.

Many caddis-fly larvae construct protective cases made of sand grains, small shells or plant fragments. The cases are often identifiable to the species and those made of sand grains or shells may be preserved in sediments from the lower salinity regions of estuaries. Only one species, Limnephilus affinis can be considered to be a well established brackish water animal. Sutcliffe (1960) observed this species surviving 26‰ for several months and able to complete their life cycle in a salinity of 17‰. However, this species mainly uses vegetable matter for its case so is unlikely to be preserved.

Remains of insects may be recovered from suitable sediments by wet sieving.

Echinoderms

The majority of echinoderms (echinoids, asteroids, ophiuroids, crinoids, holothuroids) are strictly marine animals but some penetrate brackish water. Brattström (1941) provides valuable data on the salinity ranges of different species. A salinity of 15-20‰ is the limit for most echinoderms. The starfish Asterias rubens will penetrate salinities as low as 9‰ in the Baltic.

Echinoderms show a decrease in size with reduced salinities so that in those cases where identifiable remains are preserved it may be possible to recognise this phenomenon.

Schäfer (1972) discusses the different modes of preservation of echinoderms. All have calcareous skeletal elements most of which may be identified to the class but probably only those of the echinoids (sea-urchins) may be identified to species level (Mortensen 1938).

Spines and fragments of echinoids are often found in estuarine sediments and the author has found them in sediments in London. In some cases their presence may be accounted for by upstream sediment transport or material associated with dumped edible mollusc shells.

Echinoderm skeletal elements may be recovered by wet sieving.

Molluscs

Molluscs are tremendously important in most aquatic environments and estuarine deposits will contain freshwater, brackish and marine components. The diversity of gast ropod and bivalve molluscs occurring in estuaries is often reduced but they frequently form enormous populations (e.g. the small gastropod Hydrobia ulvae typically forms populations of 42,000 per square metre in estuarine mud flats (McLusky, 1972)).

Yonge and Thompson (1976) provides an excellent introduction to the biology and ecology of 'marine' molluscs. The species of 'marine' bivalves to be found in Britain are described by Tebble (1966) and the freshwater ones by Ellis (1978). The aquatic gastropods are covered by Macan (1960), McMillan (1968), Beedham (1972) and Graham (1971). Muus (1967) may be consulted for details of Hydrobiids and other estuarine molluscs. Terrestrial gastropods which may be associated with estuaries are described by Kerney and Cameron (1979). Boycott (1936), Muus (1967), Green (1968), Remane (1971) and Perkins (1974) provide much useful information concerning salinity requirements and other ecological data concerning estuarine molluscs. Schäfer (1972) is essential reading for a discussion of the palaeoecology of molluscs. Fuller (1974) and Harman (1974) provide information on the effects of pollution upon 'freshwater' molluscs as well as on their general ecology.

The behaviour of a species will clearly determine the effects of salinity fluctuations and pollution upon it and thus its use as a palaeosalinity and palaeopollution indicator.

While some estuarine molluscs such as oysters (e.g. Ostrea) and mussels (e.g. Mytilus) are sessile attaching themselves to suitable substrates, others such as winkles (Littorina spp), hydrobiids and 'freshwater' snails move actively over macrophytic vegetation, sediments and other substrates. Many others such as cockles (e.g. Cerastoderma), Scrobicularia and freshwater mussels (e.g. Unio spp) burrow within the sediments. Piddocks (e.g. Barnea spp) gradually bore deeper into peat, soft rock, wood or other suitable substrates as they grow but they do not move about whereas teredo 'worms' (e.g. Teredo navalis) are active wood borers actually feeding on the timber. Most of the molluscs occurring in estuaries are deposit or suspension feeders relying to a great extent on detritus and associated micro-organisms as their food source but some gastropods are grazers and some are carnivores which 'drill' holes through the shells of other molluscs and consume the contents. Many bivalve valves from subfossil assemblages have a small round hole close to the umbo caused by these gastropods (mainly in higher salinities).

The lower the salinity conditions experienced the smaller the maximum size to which many marine molluscs will grow and some freshwater molluscs show a similar size reduction in brackish water (see Remane 1971).

The importance of many molluscs as a source of food has made their shells one of the most abundant types of biological remains on archaeological sites. They are therefore a common contaminant of estuarine deposits associated with archaeological sites and care should be taken to ensure that salinity determinations are based on autochthonous mollusc assemblages, molluscs of no economic value or other categories of biological remains as the shells of edible species may have been originally collected from a distant source.

Disarticulated valves, shells showing signs of wear and shells all of a similar size tend to indicate assemblages reworked by sedimentary or human agency. Valves of bivalves or shells of gastropods may have a preferred orientation in the sediment due to current action. Molluscs with articulated valves in life position with, perhaps, associated epifauna on the shells of sessile or shallow burrowing forms and with juvenile shells as well as adults are among the indications of an autochthonous fauna.

The study of molluscs from estuarine sediments should therefore not rely entirely upon shells recovered by sieving samples of sediment but the molluscs should be studied in situ before collection. Adults of most molluscs will be retained in a 500 micron sieve if sediment is processed but juveniles of small species will pass through. The larger species will require collecting individual shells by hand on site in addition to collecting bulk sediment samples for subsequent processing otherwise the numbers of individuals of large species will be insufficient for statistical analysis.

Other invertebrate animal remains

'Palynological' preparations may contain various components not already discussed. Some may be readily identified when they occur (e.g. rotifers such as *Keratella*) but many are the eggs of a vast variety of invertebrates (e.g. copepods) most of which cannot be identified. Many invertebrate eggs are also recovered in the course of wet sieving.

Vertebrates

Although birds, fish and other vertebrates are important members of the fauna of estuaries they are of limited value to the palaeoecologist concerned with interpreting the conditions pertaining within an estuary at any one time in the past.

A few species of fish will inhabit fairly specific regions of an estuary but many only spend part of their life in the estuary. Some marine species move into estuaries to feed or spawn. Other species move into freshwater from the sea through the estuary to spawn (anadromous species, e.g. Salmon) while others move out of freshwater through the estuary into the sea to spawn (catadromous species, e.g. Eel). Some species are found throughout the estuary (e.g. Flounder). Many of the most abundant birds in estuaries are migratory and waders and wildfowl may migrate hundreds or thousands of miles each year. Green (1968) provides a useful account of the vertebrate fauna of estuaries.

Vertebrates are preserved less frequently than the invertebrate and plant remains already discussed. When skeletal remains are recovered they are usually of limited value either because they are fragmentary and may be unidentifiable or because of the behaviour of vertebrates in estuaries. Remains are less common than in other groups because dead fish, birds or mammals are usually consumed or their remains widely scattered by scavengers soon after death. This will even be so for small whales which having entered an estuary by accident become trapped or stranded. Man would have made short work of such whales in the past. Schäfer (1972) provides a valuable account of the type of remains marine vertebrates may leave and their mode of occurrence in sediments. Dumped vertebrate remains including those of estuarine fish and birds collected from a distant source may also be quite abundant in estuarine deposits associated with archaeological sites.

5. CONCLUSION

The study of estuarine sediments from archaeological sites in London was not undertaken until recently and before then changes in relative sea level could only be estimated by comparing the present-day levels of waterfront structures with ordnance datum (e.g. see Willcox 1975). However 'sea level' in London has been affected by extensive reclamation since Roman times with resultant narrowing of the channel. The erection of a stone built London Bridge in 1209 clearly caused considerable changes to the tidal regimes above and below the bridge with differences in effective tidal amplitude, differences in current influences and differences in the maximum salinity experienced and the degree of fluctuation in salinity. Preliminary studies on the fauna and flora show this to be so. Differential compaction of sediments associated with waterfront structures makes measurements concerning the levels of those structures in the past relative to sea level hazardous.

Palaeosalinities provide information of a different type which may reflect factors other than relative sea level. Important though sea level changes have been in the history of London and similar sites it has frequently been the characteristics of the water and its fauna and flora that have been of greater significance to the everyday life of the human community.

The Thames was a major source of water for drinking and other domestic uses until medieval times when a combination of high salinities and pollution encouraged the City to pipe fresh water in from wells and springs on the outskirts of London. Salinity changes and pollution also affected other activities based on the Thames and its tributaries and it became a serious health hazard. Documentary records give part of the story but it is only through scientific studies of the type which I have introduced in this paper that we shall be able to examine the ways in which an estuary has affected human activities during its history and the effects which Man has had on the estuary and its fauna and flora.

There are problems in the interpretation of subfossil remains as I have outlined but acquaintance with the problems will generally enable an assessment to be made of the significance of any particular assemblage.

A detailed account of the subfossil fauna and flora of estuarine deposits from London and their palaeoecological significance is in preparation.

6. REFERENCES

Abbot, W. and Dawson, C. E. 1971 — Physical, Chemical and Biological Characteristics of Estuaries. In: Ciaccio 1971 pp 51-140.

Ager, D. V. 1963 — Principles of Palaeoecology. McGraw-Hill Book Co., New York.

Akeroyd, A. 1972 — Archaeological and historical evidence for subsidence in Southern Britain. Phil. Trans. Roy. Soc. Lond. 272, 151-169.

Alabaster, J. S. 1972 — Suspended solids and fisheries. Proc. Roy. Soc. Lond. B. 180, 395-406.

Allen, G. O. 1950 — British stoneworts (Charophyta). Haslemere Educ. Mus.

Allman, G. J. 1856 — A monograph of freshwater Polyzoa. Ray Soc. London.

Andrew, R. 1970 — The Cambridge Pollen Reference Collection. In: Walker and West, 1970, pp 225-231.

Barnes, R. S. K. 1974 — Estuarine Biology. Studies in Biology, No. 49. Arnold, London.

Barrett, M. J. 1972 — Predicting the effect of pollution in estuaries. Proc. Roy. Soc. Lond., B, 180, 511-520.

Bate, R. H. and Robinson, E. 1979 — A stratigraphical index of British Ostracoda. Special publication No. 1. British Micropalaeontological Society. Seel House Press, Liverpool.

Beedham, G. E. 1972 — Identification of the British Mollusca. Hulton Educational Publications Ltd.

Beijerink, W. 1947 — Zadenatlas der Nederlandsche Flora. Wageningen, Veenman.

Bertsch, K. 1941 — Früchte und Samen. Handbücher der praktischen Vorgeschichtsforschung I. Stuttgart, Ferdinand Enke.

Bouma, A. H. 1969 — Methods for the study of sedimentary structures. Wiley-Interscience, New York etc.

Bourrelly, P. 1968 — Les Algues d'Eau Douce, Tome II, 241-399, 413-415.

Bowerbank, J. S. 1864 — A Monograph of the British Spongiadae Vol. I. Ray. Soc. London.

Boycott, A. E. 1936 — The habitats of freshwater Mollusca in Britain. J. anim. ecol., 5, 116-186.

Boyd, P. D. A. 1973 — An assemblage approach to the study of microfossils from the Middle Jurassic of the Inner Hebrides. Palaeontological Assoc. Circular (Abstract).

Boyd, P. D. A. 1974a The micropalaeontology of the Middle Jurassic of the Inner Hebrides. Brit. Micropal. Group Circular No. 9 (Synopsis).

Boyd, P. D. A. 1974b Organic-walled microplankton and other microfossils as palaeosalinity indicators in the Middle Jurassic of the Inner Hebrides. Palaeontological Assoc. Circular 78a (Abstract).

Brattström, H. 1941 Studien über die Echinoderman des Gebietes zwischen Skagerrak und Ostee, besonders des Öresundes usw. - Undersökn över Oresund 27, Lund, 1-133.

Brisay, K. W. de 1975 The Red Hills of Essex. In: de Brisay and Evans, pp 5-10.

Brisay, K. W. de and Evans, K. A. (eds) 1975 Salt. The study of an Ancient Industry. Colchester.

Brooks, J. L. 1959 Cladocera. In: Edmondson, 1959, pp 587-656.

Brouwer, A. 1967 General Palaeontology. Oliver and Boyd Ltd. Edinburgh.

Burckle, L. H. 1978 Marine Diatoms. In: Haq and Boersma, 1978, pp 245-266.

Bushnell, J. H. 1974 Bryozoans (Ectoprocta). In: Hart and Fuller, 1974, pp 157-192.

Carver, R. E. 1971 Procedures in sedimentary petrology. Wiley-Interscience, New York.

Carricker, M. R. 1967 Ecology of Estuarine Benthic Invertebrates: A perspective. In: Lauff, pp 442-487.

Cash, J., Wailes, G. H. and Hopkinson, J. (1905-1921) The British Freshwater Rhizopoda and Heliozoa, I-V. Ray. Soc., London.

Chapman, V. J. 1960 Salt Marshes and Salt Deserts of the World. Plant Science Monographs. Leonard Hill (Books) Ltd., London.

Chapman, V. J. 1964 Coastal Vegetation. Pergamon, Oxford and London.

Chatterjee, K. D. 1976 Parasitology (Protozoology and Helminthology) in relation to Clinical Medicine. Eleventh edition, Calcutta.

Ciaccio, L. L. (ed) 1971 Water and Water Pollution Handbook Vol. I. Marcel Dekker, inc., New York.

Cleve-Euler, A. 1951-3 Die diatomeen von Schweden und Finnland. Kungl. Svens. Vetensk. Akad. Handl. (Ser. 4) 2, 139-163; 3, 144-153; 4, 150-158; 4, 240-255.

Corbet, S. A. 1973 An illustrated introduction to the Testate Rhizopods in Sphagnum, with special reference to the area around Malham Tarn, Yorkshire. Fld. Stud., 3, 801-838.

Cronin, L. E. 1967 The role of Man in estuarine processes. In: Lauff, pp 667-689.

Deflandre, G. 1959 Rhizopoda and Actinopoda. In: Edmondson, 1959, pp 232-264.

Department of Scientific and Industrial Research 1964 Effects of polluting discharges on the Thames Estuary. W.P.R. Technical Paper No. 11, London, H.M.S.O.

Devoy, R. J. N. 1979 Flandrian sea level changes and vegetational history of the Lower Thames Estuary. Phil. Trans. Roy. Soc. Lond. B., 285, 355-410.

Dickson, C. A. 1970 The study of plant macrofossils in British Quaternary Deposits. In: Walker and West, 1970, pp 233-254.

Edmondson, W. T. (ed) 1959 Freshwater Biology. 2nd edition. (Ward and Whipple). John Wiley and Sons inc., New York.

Eisma, D. 1965 Shell-characteristics of Cardium edule as indicators of salinity. Netherlands J. Sea Res., 2, pp 493-540.

Ellis, A. E. 1978 British Freshwater Bivalve Mollusca. Synopses of British Fauna (New Series) No. 11. Linn. Soc. Academic Press.

Evans, G. 1965 Intertidal flat sediments and their environments of deposition in the Wash. Quart. J. Geol. Soc. Lond., Vol. 121, pp 209-245.

Faegri, K. and Iversen, J. 1975 Textbook of Pollen Analysis. 3rd edition. Blackwell Scientific Publications, Oxford.

Farrow, G. E. 1975 Techniques for the Study of Fossil and Recent Traces. In: Frey, 1975, pp 537-554.

Firth, F. E. (ed) 1969 The Encyclopedia of Marine Resources. Van Nostrand Reinhold Co., New York.

Fott, B. (ed) 1969 Studies in Phycology. E. Schweigerbart'sche Verlagsbuchhandlung. Stuttgart.

Frey, R. W. (ed) 1975 The Study of Trace Fossils. Springer-Verlag, New York.

Fuller, S. L. H. 1974 Clams and Mussels (Mollusca: Bivalvia). In: Hart and Fuller, 1974.

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

Graham, A. 1971 — British Prosobranch and other Operculate Gastropod Molluscs. Synopsis of British Fauna (New Series) No. 2. Linn. Soc. Academic Press.

Green, J. 1968 — The Biology of Estuarine Animals. Sidgwick and Jackson, London.

Greensmith, J. T. and Tucker, E. V. 1971 — The effects of late Pleistocene and Holocene sea level changes in the vicinity of the river Crouch, East Essex. Proc. Geol. Ass., 82, 301-322.

Greensmith, J. T. and Tucker, E. V. 1973 — Holocene transgressions and regressions on the Essex coast outer Thames estuary. Geol. en Mijnb., 52, 193-202.

Groves, J. and Bullock-Webster, G. R. 1920, 1924 — The British Charophyta Vol. I (1920) and II (1924). Ray Soc. London.

Guilcher, A. 1967 — Origin of Sediments in Estuaries. In: Lauff, 1967, pp 149-157.

Harman, W. N. 1974 — Snails (Mollusca: Gastropoda). In: Hart and Fuller, 1974

Harrison, F. W. 1974 — Sponges (Porifera: Spongillidae). In: Hart and Fuller, 1974, pp 29-66.

Harrison, J. and Grant, P. 1976 — The Thames Transformed: London's River and its Waterfowl. Deutsch, London.

Hart, C. W. Jr., and Fuller, S. L. H. (eds) 1974 — Pollution Ecology of Freshwater Invertebrates. Academic Press, New York and London.

Haq, B. U. 1978 — Silicoflagellates and Ebridians. In: Haq and Boersma 1978, pp 267-275.

Haq, B. U. and Boersma, A. (eds) 1978 — Introduction to Marine Micropalaeontology. Elsevier, New York.

Hedgepeth, J. W. 1957 — Treatise on Marine Ecology and Palaeoecology. Vol. 1, Ecology. Memoir, 67, Geol. Soc. Am.

Hendey, N. I. 1964 — An introductory account of the smaller algae of British coastal waters, Part V. Bacillariophyceae (Diatoms). Fish. Invest. Lond. Ser., 4, H.M.S.O. London.

Hepburn, I. 1952 — Flowers of the Coast. New Naturalist, Collins, London.

Heurck, H. van 1896 — A treatise on the Diatomaceae. Transl. W. E. Baxter, London.

Hincks, T. 1880 — A history of the British marine Polyzoa. London.

Horn Af Rantzien, H. 1959 — Recent charophyte fructifications and their relations to fossil charophyte gyrogonites. Ark. Bot., 4, No. 7, 165-332.

Hustedt, F. 1930-1966 — Die Kieselalgen Deutschlands, Österreichs und der Schweiz unter Berucksichtigung der übrigen Länder Europas sowie der der angrenzenden Meeresgebiete. In: L. Rabenhorst, Kryptogamen-Flora von Deutschland, Österreich und der Schweiz, Bd. 7, Tl. 1, Leipzig, 1930; Autorisierter Nachdruck New York-Weinheim, 1962; Tle. 2-3, Leipzig, 1959-1966.

Hynes, H. B. N. 1960 — The Biology of Polluted Waters. Liverpool University Press.

Jansma, M. J. 1975 — Quantitative Diatom Analysis as an Archaeological Aid. Hydrobiological Bulletin (Amsterdam) Vol. 9, 2, pp 87-88.

Jansma, M. J. 1977 — Diatom analysis of pottery. Ex Horreo, Vol. IV, pp 77-85, University of Amsterdam.

Katz, M. 1971 — The effects of pollution upon aquatic life. In: Ciaccio, 1971, pp 297-326.

Katz, N. J., Katz, S. V. and Kipiani, M. G. 1965 — Atlas and Keys of fruits and seeds occuring in the Quaternary deposits of the U.S.S.R. (in russian). Moscow, Nauka.

Kerney, M. P. and Cameron, R. A. D. 1979 — A Field Guide to the Land Snails of Britain and North-west Europe. Collins, London.

Kilenyi, T. I. 1970 — The problems of ostracod ecology in the Thames estuary. Symp. Morph. Taxon. Ecol. Recent Ostracoda. Edinburgh, 1968.

Kilenyi, T. I. 1971 — Some basic questions in the palaeoecology of ostracods. Paléoécologie des Ostracodes (H. J. Oertli, ed.) Bull. Centre de Recherches Pau. S.N.P.A., Vol. 5, pp 31-44.

Klie, W. 1938 — Ostracoda, Muschelkrebse. In: F. Dahl (ed) Die Tierwelt Deutschlands und der Angrenzenden Meeresteile nach ihren Merkmalen und nach ihrer Lebensweise, 34 (3) 1-230.

Kornicker, L. S. 1975 — Spread of Ostracodes to Exotic Environs on Transplanted Oysters. In: Swain, 1975, pp 129-139.

Kummel, B. and Raup, D. (eds) 1965 — Handbook of Palaeontological Techniques. W. H. Freeman and Co., San Francisco.

Lacourt, A. W. 1968 — Monograph of the freshwater Bryozoa - Phylactolaemata. Zool. Verh., Leiden, 93, 1-159.

Lackey, J. B. 1967 — The microbiota of estuaries and their roles. In: Lauff, pp 291-302.

Lafon, M., Durchon, M. and Saudray, Y. 1955 Recherches sur les cycles saisonniers du plankton. Ann. Inst. Oceanogr., 31(3), 126-230.

Lauff, G. H. ed. 1967 Estuaries. Am. Ass. Advmt. Sci., Publ. No. 83, Washington, D.C.

Lebour, M. V. 1925 The Dinoflagellates of Northern Seas. Marine Biological Association, Plymouth.

Lund, J. W. G. 1972 Eutrophication. Proc. Roy. Soc. Lond. B., 180, 371-382.

Luther, H. 1951 Verbreitung und Ökologie der Höheren Wasserpflanzen in Brackwasser der Ekinäs-Gegund in Südfinnland. I, II. Acta Bot. Fenn., 49, 1-231; 50, 1-370.

Macan, T. T. 1960 A key to the British fresh and brackish water gastropods with notes on their ecology. Scientific Publication No. 13, Freshwater Biol. Assoc.

Mangelsdorf, P. C. Jr. 1967 Salinity measurements in Estuaries In: Lauff, 1967, pp 71-79

McLusky, D. F. 1971 Ecology of Estuaries. Heinemann Educational Books Ltd., London.

McMillan, N. F. 1968 British Shells. Wayside and Woodland Series. Warne, London.

Moore, J. A. 1976 Charophyceae. In: Parke and Dixon, 1976 pp 570-571

Moore, J. A. 1979 The current status of the Characeae (stoneworts) in the British Isles. Watsonia, 12, 297-309.

Moore, P. D. and Webb, J. A. 1978 An illustrated guide to Pollen Analysis. Hodder and Stoughton, London.

Morkhoven, F. P. C. M. Van 1963 Post-Palaeozoic Ostracoda - their morphology, taxonomy and economic use. 2 vols. Elsevier, Amsterdam.

Mortensen, Th. 1938 Uber die stratigraphische Verwendbarkeit der mikroskopischen Echinodermen-Reste. Senckenbergiana, 20, 342-345, Frankfurt a.M.

Muller, R. 1975 Worms and Disease. A Manual of Medical Helminthology. Heinemann, London.

Murray, J. W. 1968a The living Foraminiferida of Christchurch Harbour, England. Micropalaeontology, Vol. 14, No. 1, pp 83-96.

Murray, J. W. 1968b Living foraminifera of lagoons and estuaries. Micropalaeontology, Vol. 14, No. 4, pp 435-455.

Murray, J. W. 1971 An Atlas of British Recent Foraminiferids, Heinemann Educational Books, London.

Murray, J. W. 1973 Distribution and Ecology of Living Benthic Foraminiferids, Heinemann Educational Books, London.

Murray, J. W. 1979 — British Nearshore Foraminiferids Keys and Notes for the Identification of the Species. Synopses of the British Fauna (New Series) No. 16. Linnean Society of London and Estuarine and Brackish water Sciences Association :. Academic Press.

Muus, B. J. 1967 — The fauna of Danish estuaries and lagoons. Meddelelser fra Danmarks Fiskeri-Og Havundersogelser, New Series, Vol. 5, pp 1-316.

National Academy of Sciences, 1969 — Eutrophication: Causes, Consequences, Proceedings of an International Symposium, N.A.S., Washington.

Neale, J. W. 1965 — Some factors influencing the distribution of recent British Ostracoda, Publ. Staz. Zool. Napol. 33 suppl. pp 247-307.

Nelson, B. W. (ed) 1972 — Environmental Framework of Coastal Plain Estuaries. Memoir 133, Geol. Soc. Am.

Newell, G. E. and Newell, R. C. 1963 — Marine plankton - a practical guide. Hutchinson Educational London.

O'Sullivan, A. J. 1971 — Ecological effects of sewage discharge in the marine environment. Proc. Roy. Soc. Lond. B., 177, 331-351.

Parke, M. and Dixon, P. S. 1976 — Check-list of British marine algae - 3rd edition. J. mar. biol. Am. U.K., 56, 527-594.

Pearson, T. H. 1972 — The effect of industrial effluent from pulp and paper mills on the marine benthic environment. Proc. Roy. Soc. Lond. B., 180, 469-485.

Pennak, R. W. 1978 — Freshwater Invertebrates of the United States. 2nd edition. Ronald Press, New York.

Pentecost, A. 1978 — Blue green algae and freshwater carbonate deposits. Proc. Roy. Soc. Lond. B., 200, 43-61.

Perkins, E. J. 1974 — The Biology of Estuaries and Coastal Waters. Academic Press, London and New York.

Prentice, J. E. 1972 — Sedimentation in the inner estuary of the Thames, and its relation to the regional subsidence. Phil. Trans. Roy. Soc. Lond. A; 272, 115-119.

Pritchard, D. W. 1955 — Estuarine circulation patterns. Proc. Amer. Soc. Civil. Engin., 81 (717) pp 1-11.

Pritchard, D. W. 1967 — What is an Estuary: Physical Viewpoint. In: Lauff, 1967, pp 3-5.

Raaf, J. F. M. de and Boersma, J. R. 1971 — Tidal deposits and their sedimentary structures. Geol. en Mijnb 50(3) pp 479-504

Ranwell, D. S. 1972 — Ecology of Salt Marshes and Sand Dunes. Chapman and Hall, London.

Raup, D. M. and Stanley, 1971 — Principles of Palaeontology. W. H. Freeman & Co., San Francisco.

Reid, D. M. 1930 — Salinity interchange between seawater in sand and overflowing freshwater at low tide. J. mar. biol. Ass. U.K., 16, 609-614.

Reid, P. C. 1972 — Dinoflagellate cyst distribution around the British Isles. J. mar. biol. Assoc., U.K., 52, 939.

Reid, P. C. 1974 — Gonyaulacean dinoflagellate cysts from the British Isles. Nova Hedwigia, 25, 579.

Reid, P. C. 1975 — A regional sub-division of dinoflagellate cysts around the British Isles. New Phytol., 75, 589-603.

Reineck, H. E. 1967 — Layered Sediments of Tidal Flats, Beaches and Shelf Bottoms of the North Sea. In: Lauff, pp 191-206.

Reineck, H. E. and Singh, I. B. 1975 — Depositional Sedimentary Environments with reference to Terrigenous Clastics Springer-Verlag, Berlin, Heidelberg, New York.

Remane, A. 1971 — Ecology of brackish water. In: Remane and Schlieper, 1971, pp 1-210.

Remane, A. and Schlieper, C. 1971 — Biology of Brackish Water. 2nd revised edition. Schwiezerbart'sche, Stuttgart.

Richards, B. R. 1969 — Marine Borers. In: Firth, 1969, pp 377-380.

Riley, H. T. 1868 — Memorials of London and London Life in the 13th, 14th and 15th Centuries. Longmans, Green & Co., London.

Rogick, M. D. 1959 — Bryozoa. In: Edmondson, 1959, pp 495-507.

Round, F. E. 1979 — Botanical aspects of estuaries. In: Severn, Dineley and Hawker, 1979.

Royal Commission on Environmental Pollution 1972 — Third Report: Pollution in some British Estuaries and Coastal Waters. H.M.S.O. London.

Ryland, J. S. 1969 — Supplement to Hincks. Bull. Br. Mus. Nat. Hist. (Zool.), 17, 207-260.

Ryland, J. S. 1970 — Bryozoans. Hutchinson University Library, London.

Ryland, J. S. 1974 — A revised key for the identification of intertidal Bryozoa (Polyzoa). Field Studies, 4.

Ryland, J. S. and Hayward, P. J. 1977 — British Anascan Bryozoans. Syn. Brit. Fauna (New Series) No. 10, Linn. Soc. Academic Press.

Ryland, J. S. and Hayward, P. J. 1979 — British Ascophoran Bryozoans. Syn. Brit. Fauna (New Series), No. 14, Linn. Soc. Academic Press.

Sars, G. O. 1922-1928 An account of the Crustacea of Norway, IX, Ostracoda, Bergen, 277pp.

Schafer, C. T. 1970 Studies of benthonic Foraminifera in Restigouche Estuary: 1. Faunal distribution patterns near pollution sources. Maritime Sediments, 6, 121-34.

Schäfer, W. 1972 Ecology and Palaeoecology of Marine Environments. Oliver and Boyd, Edinburgh.

Scourfield, D. J. and Harding, J. P. 1966 A Key to the British Species of Freshwater Cladocera. Scientific Publication, No. 5. Freshwater Biological Association.

Severn, R. T., Dineley, D. and Hawker, L. E. 1979 Tidal Power and Estuary Management. Colston Papers, No. 30. Scientechnica, Bristol

Smith, Wm. 1853-56 A synopsis of the British Diatomaceae, Vol. 1, 1853; Vol. 2, 1856, London.

Sulek, J. 1969 Taxonomische Übersicht der Gattung Pediastrum Meyen. In: Fott, 1969, pp 197-261.

Sutcliffe, D. W. 1960 Observations on the salinity tolerance and habits of a euryhaline caddis larva, Limnephilus affinis Curtis (Trichoptera: Limnephilidae) Proc. Roy. Ent. Soc. Lond., A35, pp 156-62.

Sutcliffe, D. W. 1961 Salinity fluctuations and the fauna in a salt marsh with special reference to aquatic insects. Trans. Nat. Hist. Soc., Northumb. Durh., 14, pp 37-56.

Swain, F. M. (ed) 1975 Biology and Palaeobiology of Ostracoda. Bull. Am. Palaeontology, Vol. 65, No. 282.

Tebble, N. 1966 British bivalve seashells, London: British Museum (Natural History), 212pp.

Terwindt, J. H. J. 1971 Lithofacies of inshore estuarine and tidal-inlet deposits. Geol. en Mijnb. 50(3) pp 515-526

Venice System. 1959 Symposium on the classification of brackish waters, Venice, April 8th-14th, 1958. Arch. Oceanog. Limnol., 11, suppl. pp 1-248.

Walker, D. and West, R. G. 1970 Studies in the vegetational history of the British Isles. Cambridge University Press.

Werff, A. van der and Huls, H. 1958-74 Diatomeënflora van Nederland (1-10). A. van der Werff, Westzijde 13a, De Hoef (u.), The Netherlands.

Werner, D. (ed) 1977 The Biology of Diatoms. Bot. Monographs, Vol. 13, Blackwell Scientific Publications, Oxford.

Wheeler, A. 1979 The Tidal Thames. The history of a river and its fishes. Routledge and Kegan Paul, London.

Willcox, G. H. 1975 Problems and possible conclusions related to the history and archaeology of the Thames in the London region. Trans. London and Middlesex Arch. Soc., 26, 285-292.

Williams, G. L. 1978 Dinoflagellates, Acritarchs and Tasmanitids. In: Haq and Boersma, 1978, pp 293-326.

Wilson, D. G. 1975 Plant Remains from the Graveney Boat and the Early History of Humulus Lupulus L. in W. Europe. New Phytol., 75, 627-648.

Wood, E. J. F. 1967 Microbiology of Oceans and Estuaries. Elsevier, Amsterdam.

Wood, R. D. and Imahori, K. 1964-65 A revision of the Characeae. 1, Monograph (1965). 2, Iconograph (1964).

Wray, J. L. 1978 Calcareous Algae. In: Haq and Boersma, 1978, pp 171-187.

Yonge, C. M. and Thompson, T. E. 1976 Living Marine Molluscs. Collins, London.

Zajic, J. E. 1971 Water Pollution. Disposal and Reuse, Vol. I. Dekker, New York.

Zeist, W. Van 1974 Palaeobotanical studies of settlement sites in the coastal area of the Netherlands. Palaeohistoria, 16, pp 226-371.