CHAPTER THREE
GROWTH AND PRESERVATION

Having, in the previous two chapters, considered the distribution of the various types of submerged forest, and the nature of the closest present-day analogues, it is possible to discuss the ways in which these forests could have grown and been preserved. This will be done before proceeding to a more detailed description of individual sites, since this will enable the whole range of theoretical possibilities to be considered for each forest, rather than attempting to deduce their history on the basis of assumed causes and effects, from the often limited, and possibly misleading evidence seen at individual sites.

Two separate environments must be considered; firstly that which allowed the growth of forest trees and possibly brought about their death, and secondly that which caused them to be preserved throughout the following millennia. There were undoubtedly many coastal forests which flourished during the earlier Holocene, and which left no trace, whilst on the other hand many well preserved peats, etc., were formed in environments unsuitable for trees.

It is necessary to consider what degree of change is necessary in an environment to convert it from one in which trees could grow to one in which decay was sufficiently inhibited to allow the remarkably good state of preservation typical of submerged forests. Such a change could clearly come about as a result of a rapid rise in water-table but this could be brought about in various ways, and other factors may be involved. Changes in the water-table may be more or less direct responses to changes in sea level, or they may be entirely unrelated to them.

Forest beds may have been formed on advancing or retreating coastlines, although they can clearly be exposed in the intertidal area as submerged forests, only if an overall retreat has occurred since the trees grew. The relationships between varying rates of sea level change and sediment supply must therefore, also be considered, as follows;
(1) Rising sea level, retreating coastline (sediment supply low).
(2) Rising sea level, advancing coastline (sediment supply high).
(3) Static sea level, retreating coastline.
(4) Static sea level, advancing coastline.
(5) Falling sea level, retreating coastline.
(6) Falling sea level, advancing coastline.
(7) Oscillating sea level, in particular a fall interposed in period of overall rise.

Other possible combinations seem to be very unlikely to produce submerged forests.

Considering the above in more detail:

(1) Rising sea, retreating coast.

The normal consequence of a rise in sea level will be a retreat of the coastline, and during the period of rapid rise, during the earlier Holocene, this retreat would be brought about by the progressive submergence of the tree-covered topography of pre-Holocene sediments. If this were gradual, then the forest edge would retreat up-slope, as trees at the seaward edge were killed, either by increasing salinity, by waterlogging as the freshwater table rose, or by burial under a coastal barrier which was pushed inland by the rising sea.

Woodland might be replaced directly by salt marsh, as the latter moved inland, or a belt (of width determined by the degree of relief) could develop, in which the woodland was converted firstly to carr and then to fen. If sediment supply were sufficiently great, the boles of the dead trees (and any fallen trunks) could be buried by salt marsh silts and clays before they rotted away. Unburied trunks would decay much more quickly.

It must be noted here that it is, no doubt, possible for estuarine or brackish-water sediments to be lain down on top of organic beds, even on a
retreating coastline (Figure 3.1). This would be more likely to occur when sea level was rising than when it was static, since such sediments would only accumulate as a result of inundations. The result of the accumulation of deposits, under these conditions, would be the formation of a basal forest bed, following the undulations of the pre-Holocene deposits, the higher levels being the more recent, and covered by salt marsh clays and silts, by fen peat, or possibly by dune sand or storm beach shingle.

Closed basins in the pre-existing surface would become lagoons, and trees which were growing there would be similarly killed and preserved. Such basins might be flooded, well before the normal tidal levels reached them, by extreme tides. The water would not drain away, when the tide fell, and trees would be killed. Valleys draining to the sea could be blocked at their seaward end, by shingle etc., and subsequently behave as basins.

If, in recent times, continued retreat of the coastline exposed the beds to wave-attack, the overlying sediment could be stripped off and the submerged forest bed revealed.

It is difficult to imagine that trees would be preserved for long periods simply by being inundated by the sea. Such trees would be killed, and then exposed in an intertidal area, where they would be susceptible to wave-attack, and to alternate wetting and drying, and also to breakdown by fungi, bacteria, boring molluscs, etc. They would be far more likely to disintegrate than at a site with a freshwater table determined by the same sea level, since here the probability of stagnant, anaerobic conditions would be higher.

In the case of forest beds which now seem to be simply submerged, with no cover of later sediment, e.g. the North Sea "moorlog" (Godwin, 1943) and the woody peat found on the sea bed in Cardigan Bay, the tree remains would seem to have been incorporated into peat beds which were compacted before submergence; the trees are not simply a drowned forest.

(2) Rising sea, advancing coast.
Fig. 3.1 Sequence of events leading to the burial of peats by clays, etc., on a receding coastline, when erosion of the beds might be expected.

Fig. 3.2 Formation of peat beds at progressively higher levels, on an advancing coastline, during a period of rising sea level.

Fig. 3.3 Formation of intertidal forest bed, with no change in sea-level, as a result of retreat of the coastal barrier, and gravitational compaction.
Whilst, in the earlier part of the Holocene, when sea level rise was very rapid, almost all coastal areas would have undergone progressive submergence, it is likely that, as the rate of rise slowed somewhat, advance of the coastline could have occurred when the supply of sediment was sufficiently great. In this case, a salt marsh, or a storm beach or dune system would have moved seawards and, at the same time, risen with sea level. In the areas of slacks, fens or lagoons behind the coastal barrier, peat growth, impelled by the rising water table would be rapid. The peat-forming vegetation would, at any one time, be in a more or less horizontal plane, but the start of peat formation, at the seaward edge, would be progressively later as the coastline advanced, so that the base of the peat would slope upwards to the sea, forming a basin, infilled by peat (Figure 3.2).

The combination of an advancing, or even a stationary coastline, and rising sea level would clearly be one of a somewhat unstable equilibrium. In many instances, the position of the coastline would be largely determined by headlands, or other features of the pre-existing topography, so that there would be a considerable inertia in the system, which would eventually be overcome either by the steady rise of sea level, or by a catastrophic event, the position of the coastal barrier being suddenly moved to a new position of relative stability. This would probably be the fate of most advancing or stationary barriers when sea level rise was rapid. Over-topping or breaching of the barrier would allow flooding of the basin behind it, laying down silts and clays on top of the peat layers. Inlets or lagoons, etc., would therefore, be infilled by intercalated peats and clays, and the coastline would, in effect advance, even at times of rising sea level. A basal peat, following the floor of the basin might be found together with the horizontal peats (Figure 3.2).

Conditions suitable for trees would be unlikely in this situation, except at the landward edge of the basin, where a raised bog might also develop, and the trees in this position would be less susceptible to subsequent exhumation by the sea, and exposure in the form of submerged forests. This
exposure could, of course, occur only if the advance of the coastline were subsequently reversed. Many potential submerged forest beds are now preserved as buried forests, well inland.

The growth of trees might have been possible near to the coastal barrier during relatively brief intervals, and their remains could be preserved in the intercalated peats. The trees growing on the earlier surface immediately before tidal effects were felt, might also be preserved, at the base of the peat and clay infill.

(3) Static sea level, retreating coast

With no rise in sea level, there would be no consequent rise in the fresh water table in coastal areas, and peat growth above the general surface would occur only by the development of raised bogs. Trees would not as a rule, therefore, be killed and preserved by the development of fen peat round them. Lagoons, etc., would be gradually infilled, however, and trees could then grow on the resulting bog surface and be subsequently overwhelmed and preserved in Sphagnum peat. These trees could, without any change in sea level, be buried by a retreating storm beach, or by dunes, which could cause a considerable degree of compaction of the peats (see below, this Chapter) so that when the barrier was pushed back still further, leaving the peats on its seaward side, the trees would be at a level below that of high tides (Figure 3.3).

Trees which grew on mineral soils could similarly be preserved by Sphagnum peat spreading onto them from an adjacent bog, or by burial under a coastal barrier, and could also be subsequently exposed as submerged forest beds, although, as the extent of compaction would be much less than with a peat substrate, the forest bed would be virtually at its original level, and be reached only by highest tides.

The storm beach, pushed inland by the sea, is very likely to block the mouth of a river, and cause ponding-up of drainage water. This could kill trees by waterlogging, and preserve them, without any rise in sea level, and
the coastal barrier could subsequently pass over them, exposing them as a submerged forest on the foreshore. Catastrophic breaching or overtopping of the storm beach could have a similar result, either through a rising water table, or the increase in salinity. Godwin (1943) cites the example of a site in the Norfolk Broads, many miles from the sea via the meandering river channel, but close to it in a straight line, where breaching of the coastal barrier flooded an area hitherto completely isolated from the influence of the sea. The depth of flooding which would, under natural circumstances occur, appears however to be somewhat exaggerated, since it is based on the supposition that the amplitude of the tidal wave will be diminished as it passes up-river, so that the water level inland will be near to mean sea level. But this does not take into account the gradient needed to allow the escape of drainage water to the sea. This gradient varies, of course with the state of the tide, and the determination of the "average" sea level which controls the level of the river in its tidal reaches is very complex; depending on the tidal range, the form of the river channel and of its mouth, the volume of freshwater discharge, etc.

In the Somerset Levels, the lowest areas, which are well inland, are virtually at the water-table, that is, at river level, at a height of c. 2.1 m O.D. The surface level of the coastal clay belt (see Kidson and Heyworth, 1973 and 1976) is at c. 6 m O.D. However, the low inland level is only maintained by an elaborate system of sluices and pumping stations, and has been gradually lowered over the centuries (Williams, 1970) as increased drainage has caused the underlying peat to shrink, lowering the surface, and requiring even greater effort to avoid flooding. If artificial drainage were to stop, then the water-table in the inland area would rise to probably 4 or 5 m O.D., and eventually peat would grow up to this level also. If Godwin's hypothesis were correct, then the flow in the river would consist only of the same water moving upstream at high tide and downstream at low tide, with the gradient being reversed, and no net outflow. It follows that, only in areas
with a very small tidal range can the inland river level approximate to that of mean sea level. Nevertheless, it is still quite possible for breaching of the coastal barrier, in the situation described, to produce dramatic effects on the inland vegetation, since extreme tides can be well above the freshwater level.

Consideration of the above points shows that there are many ways in which a buried forest bed could be formed at a time of static sea level, and could later be exposed on the beach as a submerged forest bed, giving the impression that a rise in sea level had been responsible.

(4) Sea level static, coast advancing

There are two main ways in which the coastline can advance when sea level is static. Firstly a coastal barrier can build out in a seaward direction, as e.g. the dunes on the South Lancashire coast (Ainsdale, etc.) or the shingle complexes of Bridgwater Bay, Somerset (Kidson, 1960). In these and similar cases the landward dunes or ridges become fixed and vegetated, and seaward extension requires new material to be brought in from elsewhere; the earlier barriers do not themselves move seawards, and the whole complex becomes wider. Low-lying areas of slacks or lagoons behind the coastal barrier will be infilled by peat, and buried forest beds may be preserved there, to be exhumed during a later retreat of the coastline, and exposed as a submerged forest. This area of peat formation will not, however, move seaward as the coastline advances, since it is bounded by the earlier barrier.

The second way in which the coastline can advance is by the development of an increasingly extensive salt marsh in front of the earlier storm beach. Good examples of this type of development are seen in Morecambe Bay, Lancashire. The tidal cover of the landward areas of the salt marsh becomes less and less frequent, and eventually trees may colonise the marsh, probably spreading from the fens or mosses present in the inlets of the earlier coastline. Slight changes in the tidal regime or in the positions of drainage channels in the
marsh could render these areas unsuitable for trees, which might be killed and preserved by increased accumulation of salt marsh clays and silts around them. It is also possible that a new barrier could develop at the outer edge of the marsh, resulting in the ponding up of freshwater, and the conversion of the salt marsh to fen or carr. A subsequent small rise in sea level would suffice to bring the resulting peats to a position where they might be exposed as submerged forest bed.

There is, of course, no sharp dividing line between an imperceptibly rising sea level and a very slowly rising one, and the pattern of development described above could occur during a period of slow rise, which if continued, could perhaps, because of the diminution of sediment supply, submerge the previously emerged areas. Regressions and transgressions could result from the same rate of rise.

(5) Sea level falling, coast retreating.

It is possible, in a high energy environment, for a retreat of the coastline to occur even if sea level is falling. With an imperceptibly slow rate of fall, this retreat could go on for long periods; with a rapid rate of fall the period would be limited, since wave energy would be dissipated in the increasingly shallow sea.

As sea level fell, areas previously occupied by fen or bog would, as a result of the falling water table become suitable for tree growth. The margin of the woodland would then move towards the sea. If at the same time, a coastal barrier were being pushed inland, it is probable the trees would be buried by shingle or by dune sand, and even that the woodland itself would be subjected to wave-attack, roots and branches being incorporated in contemporaneous storm beach material. This phenomenon has been noted at a number of sites and is worthy of particular attention, since there are very few present day sites in Britain where mature trees are found near to an active storm beach.
(6) Falling sea level, advancing coastline.

This is obviously a more likely combination than the previous one. A falling sea level, would in general, allow salt marsh vegetation to colonise areas of the beach slope, which previously experienced too great a degree of submergence, whilst the landward edge of the salt marsh would also move towards the sea, followed by a fresh water zone, and probably woodland. Trees would colonise areas at progressively lower levels, reversing the pattern of rapid sea level rise, when the woodland margin was pushed back up the earlier slopes. However, there is an important difference between the two situations, since the falling sea would not preserve the woodland in its wake. Trees which grew on areas previously below high tide level would not be preserved when they died; they would simply decay and disappear as in any other normal forest. If woodland spreading down a beach slope were preserved it would show a very characteristic pattern, in that the lower trees would be more recent than the higher, unlike the general rule for the vast majority of sea level related organic deposits from the Holocene, that is; the higher the bed the more recently it was formed.

There seems no obvious way, however, in which trees in this situation would be preserved. Even if living trees were found to be growing on a Holocene salt marsh deposit, it would be difficult to prove that this was not simply the result of local changes in the coastline. It is therefore unlikely that evidence of this pattern of colonization, as a result of falling sea level, will be found. If a subsequent rise in sea level occurred, then some trees would be preserved.

(7) Oscillating sea level; fall interposed in general rise.

If the fall in sea level (described under 6) were followed by a rise, then the lowest point reached by the trees as they colonised the beach slope, would very soon be rendered unsuitable for trees once more, as the water-table rose. Higher trees would be killed and preserved by continuing sea level rise, exactly as during the formation of the basal peat (as described under 1).
At such sites the preserved evidence of a fall followed by a rise would, therefore, be a sloping forest bed equivalent to the basal peat, but resting on the earlier salt marsh clays or silts, rather than the pre-Holocene deposits. Other substrates uncovered by the falling sea would, of course, also be available for colonization by trees. The most recent trees would, again, be the highest. At the lower limit of the bed, marking the turning point in sea level, from fall to rise, there would be a zone without trees, or with only very short-lived specimens, since the period during which this level was free from marine influence would be short. The effects of sea level changes on the ages of the trees is discussed further in Chapter Eight.

It has been implicit in the work of several authors, e.g. Tooley (1974), that a rise in relative sea level will bring about a transgression, whilst a fall of sea level will cause a regression.

This may not always be the case, so that an oscillation in sea-level could occur, whilst the coastline was continuously advancing or retreating, the behaviour during the rising and falling phases and intermediate stands being as described above, under 1 to 6.

If, for example, the rise-fall-rise sequence occurred at a site with abundant sediment supply, the advance of the coastline might be continuous throughout, especially if the rate of rise were only moderate. In this case, low-lying areas would be formed behind the coastal barrier, when sea-level began to rise once more. Extensive lagoons could be developed in this way, and these would be likely to undergo rapid infilling by peats, driven by the rise in water level.