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FURTHER POLLEN STUDIES OF PEAT BOGS ON THE PACIFIC COAST OF OREGON AND WASHINGTON[1]

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INTRODUCTION

The moist climate of the Pacific Coast of Oregon and Washington and the progression of a post-Pleistocene marine cycle of a submergent shoreline has resulted in the formation of many freshwater ponds and subsequent hydrarch succession forming peat deposits. Many stages of hydrarch succession are to be found, from those in recently formed sand-dune lakes, supporting early submerged seres, to mature bogs covered with forests. This area lies beyond the limits of Pleistocene glaciation, but this geologic event has apparently been indirectly responsible for conditions favoring organic sedimentation during postglacial times. The nourishment of the continental ice sheet caused a lowering of sea level, which permitted down-cutting of streams emptying into the ocean. During deglaciation raising of sea level drowned the valley mouths of streams for many miles inland (Fenneman 1931). The marine cycle of submergence since then has resulted in the formation of several kinds of lakes, apparently with some chronological consistency. This is shown by the depth of the peat deposits, particularly on the margin of the larger lakes, formed in the blocked tributaries of the major streams. Ponding effected by movement of shore sand has taken place at later dates, and in fact is occurring continually along the coast, in the sand-dune zone. This includes embayment of small streams by spits and bars, blocking of small streams flowing parallel with the shore, and the formation of depressions by migrating sand dunes and possibly in some cases by deflation. Lakes formed in the tributaries of the larger streams at some distance from the ocean support the deepest peat deposits, and thus hold the probability of antedating those formed in the sand-dune zone. It is difficult to assign an age to these dune bogs, and an estimation must be based upon the depth of the peat and the average rate of deposition as determined by the average depth of the several profiles studied. Shifting of sand not only forms new depressions for potential hydrarch succession, but also buries bogs in varying stages of development. This is well shown by a stratum of fossil peat enclosed in terrace sands of a sea cliff near Newport, Oregon (Hansen & Allison 1942). The peat layer

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is overlain with 40 feet of sand which may be of either subaqueous or eolian origin. A record of forest succession from pioneer forests of lodgepole pine to climax forests of spruce and hemlock is revealed by pollen analysis of the sediments. Thus it can be seen that the chronology of coastal peat bogs is indefinite, with many different ages represented and considerable overlapping of their periods of recorded time.

LOCATION AND CHARACTERISTICS OF THE BOGS

This study is concerned with a series of six peat profiles extending from Hauser, Oregon, north to Hoquiam, Washington, a distance of about 265 miles. In order, beginning at the south, the peat profiles are located near the following towns: Hauser, Newport, and Gearhart in Oregon; Ilwaco, Grayland, and Hoquiam in Washington. Those located near Hauser, Newport, Ilwaco, and Grayland have been formed in shallow sand dune lakes within a mile or two of the ocean. The bog at Gearhart has developed in a small stream valley, somewhat inland from the sand-dune zone, and is the deepest of the profiles. That near Hoquiam lies near sea level on the north side of Grays Harbor, just west of the mouth of the Humptulips River. It apparently owes its origin to a eustatic rise in sea level, causing drowning of stream mouths. Several feet of mud underlying the organic sediments suggest tideflat conditions for some time before freshwater hydrarch plant succession began. The existence of estuarine conditions in this area further suggests this possibility. The bogs vary in depth, the deepest being 7 m. at Gearhart; those at Hauser and Newport, 1.0 m.; near Ilwaco, 2.8 m.; at Grayland, 2.1 m.; and that near Hoquiam, 4.4 m. The bog at Gearhart is underlain with silt and clay, and all the others except at Hoquiam are underlain directly with sand. In sand-dune bogs, the organic sediments are sharply defined stratigraphically from the underlying sand, with no gradation into silt, clay, and limnic peat, such as usually occurs in inland bogs, both in the glaciated and unglaciated regions. This is due to the presence of only sand adjacent to the ponds, which prevents the income of fine silts and clays before organic sedimentation gets under way.

All the bogs are of the *Sphagnum* type. Portions of some of them have been drained and scalped for cranberry culture, which is an important industry along the coast of Oregon and Washington. The following species of plants are common to all the bogs; Labrador tea (*Ledum columbianum*), bog laurel (*Kalmia polifolia*), cranberry (*Vaccinium oxycoccus*), salal (*Gaultheria shallon*), sweet gale (*Myrica gale*), hardhack (*Spiraea douglasii*), skunk cabbage (*Lysichitum americanum*), cascara (*Rhamnus purshiana*), red alder (*Alnus rubra*), deer fern (*Struthiopteris spicant*), and yellow pond-lily (*Nymphozanthus polysepalus*). All bogs are in the climax stage and are being invaded by forest tree species. Generally, lodgepole pine

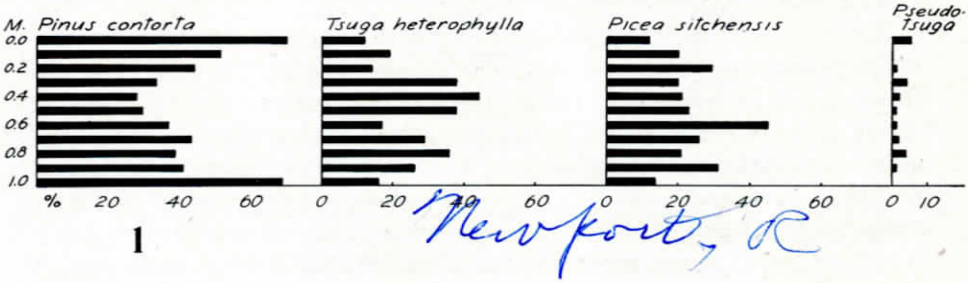
(*Pinus contorta*) is the pioneer and most abundant arboreal invader of the coast bogs, but occasionally Sitka spruce (*Picea sitchesis*) may be the initial invader. Other species that early encroach upon the climax bog are western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), and occasionally Douglas fir (*Pseudotsuga taxifolia*). Along the southern half of the Oregon coast, Port Orford cedar (*Chamaecyparis lawsoniana*) is found with lodgepole pine. The determining factor in the order of arboreal bog invasion seems to be the availability and proximity of the several species. Lodgepole pine is usually the most abundant species in the sand-dune zone, and is usually preponderant as a seed disperser onto the bog surface. Observations show that either Sitka spruce or western hemlock may be the first invader if their propagules are available. On the Newport bog, hemlock is abundant on the eastern part, but not on the western edge. This is evidently due to the presence of hemlock forests adjacent to the eastern margin of the bog, while the forests to the west are composed of lodgepole pine and spruce. The prevailing westerly winds are a further factor favoring lodgepole invasion, as the forests located windward to the site of the bogs are usually composed of a preponderance of this species. The abundance of lodgepole pine on climax bogs is reflected in the pollen proportions of the upper horizons of peat, and tends to distort the recorded composition of the adjacent forests.

FORESTS OF ADJACENT AREAS

All six bogs lie within the Humid Transition life area (Bailey 1936). A narrow zone, several miles in width from the ocean to the Coast Range along the coast of Oregon and Washington, is spoken of as the fog belt because of the heavy precipitation. The mean annual rainfall at stations nearest the site of the sediments of this study is as follows: Newport, 67 inches; Astoria, 76 inches; and Aberdeen, Wash., 81 inches. Although the coastal strip is a part of the area designated as the hemlock-cedar climax of the Coast Forest (Weaver and Clements 1938), cedar is of minor importance in the forest complex. The principal dominants of the fog belt forests are lodgepole pine, Sitka spruce, and western hemlock. As the first is not a climax species, the coastal strip forests may be classified as the spruce-hemlock climax. Lodgepole pine is usually the first arboreal invader of sand dunes after they have been somewhat stabilized by lesser vegetation. Thickets of lodgepole near the ocean shore are low and rounded owing to sand-shear caused by the abrasive action of landward-borne sand. Individuals are much misshapen, and often resemble the Krummholz form of trees at timberline. Occasionally a specimen of spruce is found in the thickets of lodgepole, but hemlock has not been observed under these conditions. Farther inland, lodgepole assumes a tall, straight form and dense thickets serve as a windbreak for other species. Leeward to the pine zone, and mixed with it to some extent, are spruce and hemlock. These species become progressively more abundant farther inland, lodgepole gradually thinning out because of its intolerance for shade. Still farther away from the ocean, Douglas fir enters the forest complex, while spruce becomes less abundant, gradually giving way to hemlock and Douglas fir. Hemlock in turn surrenders its predominance to Douglas fir in the Coast Range to the east. When the forests on the sand dunes are burned, lodgepole pine may regain its preponderance; or farther from the ocean Douglas fir often makes its appearance and become locally predominant until replaced by spruce and hemlock. Other forest tree species apparently within range of pollen dispersal to the site of the sediments are western white pine (*Pinus monticola*), lowland white fir (*Abies grandis*), noble fir (*A. nobilis*), and silver fir (*A. amabilis*). The most important broadleaf species are red alder, bigleaf maple (*Acer macrophyllum*), and black cottonwood (*Populus trichocarpa*).

FOREST SUCCESSION

Although the general forest physiognomy of the coastal strip in which the peat profiles are situated is more or less homogeneous, the recorded forest succession for the period represented varies somewhat in the several areas. This may be due to the different ages of the bogs, the varying forest composition and stages of succession during initial sedimentation, the different trends of forest succession because of differences in topography, varying degrees and periods of sand movement, and the position of the bog in relation to sand dunes, the ocean, prevailing winds, and the adjacent forests. Perhaps the most important factor that influences forest succession and tends to interrupt the normal succession along the Oregon and Washington coast is sand-dune movement. Periodic shifting of dunes may bury forests in various stages of succession, from the pioneer forests of lodgepole pine to more mature forests of spruce and hemlock. The first are more prone to be destroyed because of their proximity to the ocean and their establishment on less stabilized soil than the climax forest. The destruction of the lodgepole forests is perhaps more readily reflected in the pollen profiles than the climax forests, because the bogs usually lie leeward to the pine zone. Thus, fluctuations in the pollen profiles of the several species, when contrary with one another, or one group with another, may denote relative rather than actual changes of the recorded species. One can assume that fluctuations in pollen profiles of coast bogs are probably more often a result of changes in the actual abundance of lodgepole pine, rather than in spruce or hemlock. The location of pine forests, largely windward to the bogs, and the greater amount of pollen produced by this species undoubtedly cause over-representation by its pollen. The maturation of lodgepole pine at a much earlier age than the other species gives it more maneuverability in an unstabilized dune area. Not only is it better adapted to invade newly formed dunes, but it is also better able as a forest to recover after, or even during, its destruction by burying or fire than spruce or hemlock, which require many years before attaining seed-bearing age. Spruce and hemlock forests producing relatively



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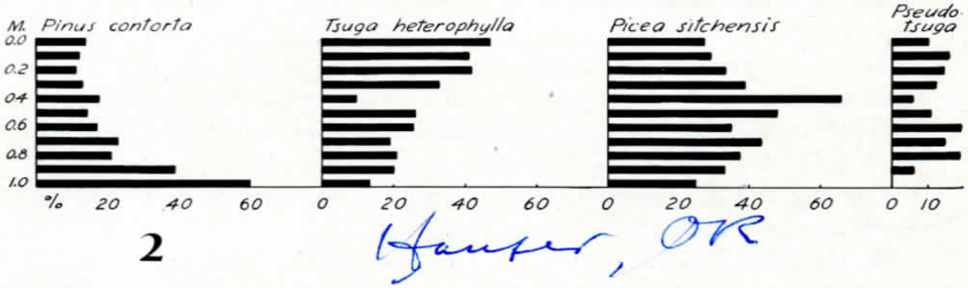

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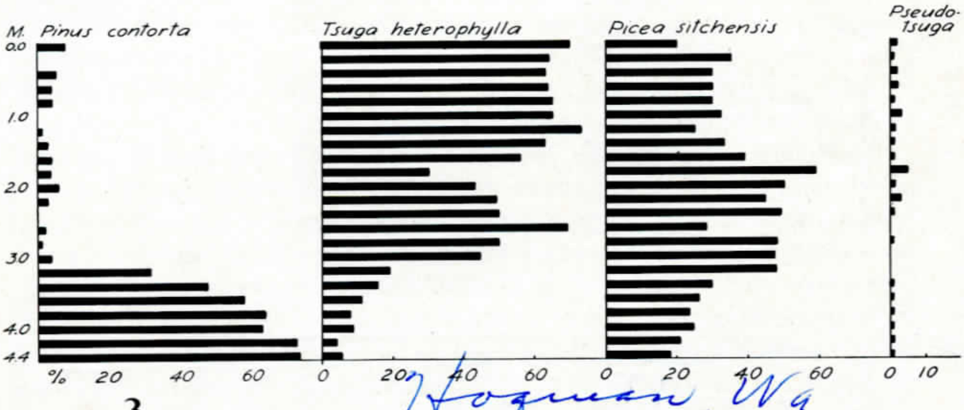

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FIG. 1. Pollen profiles, Newport, Oregon. FIG. 2. Pollen profiles, Hauser, Oregon. FIG. 3. Pollen profiles, Hoquiam, Washington.

less pollen and lying largely leeward to the bogs are probably generally under-represented in the pollen profiles.

The similarity in the composition of the peat of the six profiles suggests about the same rate of deposition. The profile near Gearhart, being the deepest, would also represent the greatest period of time for its deposition. Its location and method of formation also indicate a greater possible age, and it is the only profile that seems to hold the potentiality of representing most or all of postglacial time. The trends of adjacent forest succession as recorded in the profile seem to substantiate this theory.

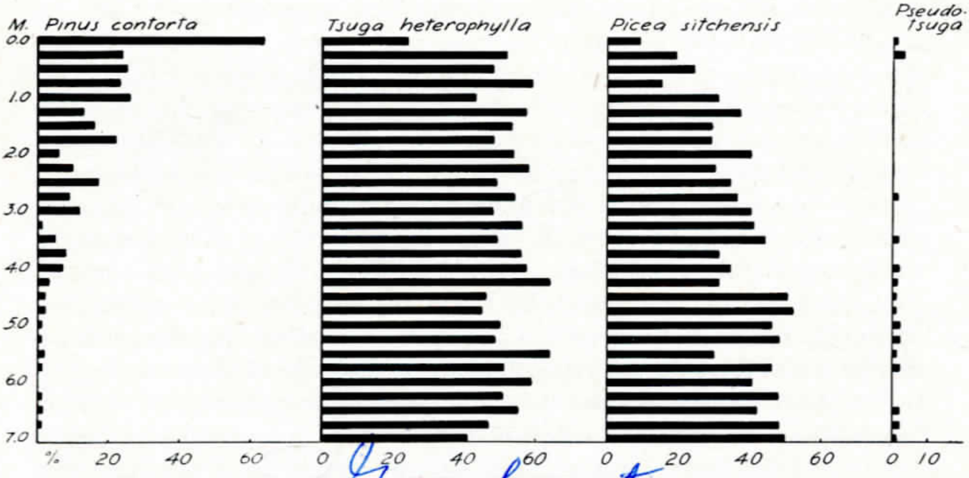
Three of the profiles, those at Newport, Hauser, and Hoquiam reveal a preponderance of lodgepole pine in the lower levels (figs. 1, 2, 3). This is also shown in two sand-dune bogs farther south on the Oregon coast, near Bandon and Marshfield (Hansen 1943). Lodgepole pine has generally been the pioneer postglacial invader in the Pacific Northwest, especially in the glaciated region. In these areas, however, forest succession started anew as the ice retreated, whereas the coastal strip of Oregon and Washington was probably forested during the glacial period with the present day species. In the Hauser profile lodgepole pine is recorded as having gradually declined from 60 per cent at the bottom to 14 per cent at the top. At Newport, lodgepole declines from its maximum of 69 per cent at the bottom to its minimum of 28 per cent at 0.4 m., and then increases to 66 per cent at the surface. The resurgence of lodgepole at the surface reflects its invasion of the bog and its abundance in sandy areas west of the bog. Lodgepole is not so abundant adjacent to the Hauser bog, and the surface has been scalped for cranberry culture, with the elimination of much of the source for its pollen.

In the Hoquiam profile, lodgepole is recorded to its maximum of 74 per cent at the lowest horizon, from which level it abruptly declines to only 4 per cent at 3 m., and then fluctuates between nothing and 8 per cent to the top. There is less dune area in this vicinity, much of the adjacent region consisting of low swampy ground forested with hardwood species, and gravelly knolls covered with climax forest.

In the other three profiles, lodgepole is recorded to less than 15 per cent at the lowest horizons, but shows slightly different trends upward in the profiles. At Gearhart it shows a general increase upward, to reach its maximum of 63 per cent at the surface (fig. 4). The accelerated increase in more recent time marks its invasion of the bog. Apparently the Gearhart bog had its inception when the adjacent forests existed in the climax stage. Since that time, the major trend of pine has been its more recent encroachment upon the bog. A similar situation apparently was present in the vicinity of a 12 m. profile farther south, near Florence, Oregon (Hansen 1941). Here, in an area inland from the sand-dune zone, climax forests of spruce and hemlock also existed when sedimentation was begun. In the Ilwaco profile, pine is revealed as having fluctuated considerably during the period represented (fig. 5). It

Explanation of figures 4–6

FIG. 4. Pollen profiles, Gearhart, Oregon. FIG. 5. Pollen profiles, Ilwaco, Washington. FIG. 6. Pollen profiles, Grayland, Washington.



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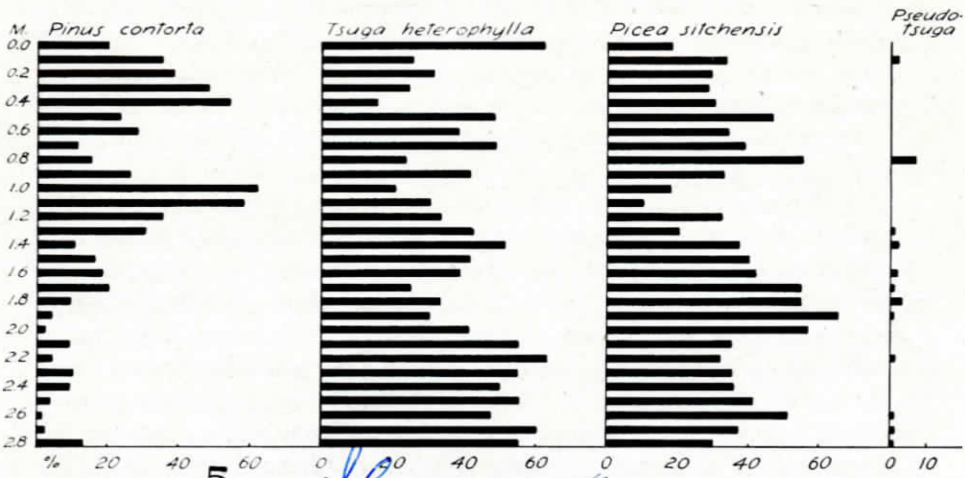
Gearhart



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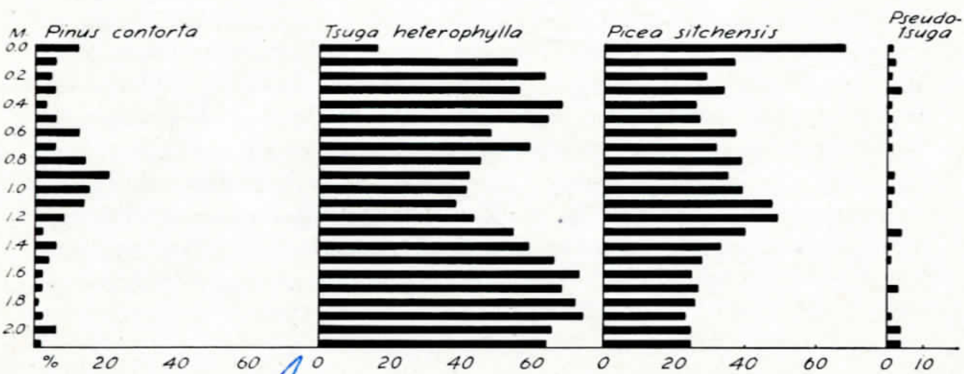
Ilwaco, WA



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Grayland, Wash

is recorded as 13 per cent at the bottom, fluctuates between 1 and 20 per cent to 1.4 m., and sharply increases to its maximum of 62 per cent at 1 m. It then abruptly declines to 11 per cent at 0.7 m., followed by a marked increase to 54 per cent at 0.4 m., and then a final decline to 20 per cent at the top. These marked trends evidently record extensive and periodic dune movement, burying forests of lodgepole on one hand, and providing new areas for its invasion on the other. The Ilwaco profile is located in the most extensive dune area of the six bogs, at the mouth of the Columbia River. Here the strong winds follow up the Columbia, causing movement of sand from both the west and the south. The vast Long Beach spit extends for 15 miles to the north. The presence of large bog areas in this region has probably been responsible also for lodgepole pine fluctuation. Invasion of bogs occurred at various times, as they reached the climax stage, and such invasions are undoubtedly represented in the pollen profiles by an increase in pine pollen. The presence of charred peat at 1.0 m. suggests that fire may also have been a factor in the abrupt increase of pine to its maximum at this horizon. In the Grayland bog pine is recorded as only 2 per cent at the lowest level, from which point it increases to its maximum of 21 per cent at 0.9 m. (fig. 6). It declines to 6 per cent at 0.1 m. and then increases to 12 per cent at the top. The latter increase reflects its limited encroachment upon the bog in recent time. Both the Ilwaco and Grayland bogs apparently had their initiation when climax forests existed in their vicinity.

The climax species, spruce and hemlock, show considerable fluctuation in all profiles. Most of these fluctuations are opposed to each other, rather than to that of pine, because the latter reveals many trends that are neither opposite nor similar to those of hemlock and spruce, either collectively or as to individual species. An increase in spruce and hemlock from the bottom to half-way up in the profile is contrary to pine decrease. A continued sharp rise in spruce to 66 per cent at 0.4 m., however, is contemporaneous with a decline of hemlock, and pine shows a slight increase to this same level (fig. 2). A sharp reversal of trends for spruce and hemlock from this horizon to the surface denotes continued competition between these species, as lodgepole remains constant. In the Newport profile, spruce and hemlock trends are opposed at every level except from the bottom to that immediately above (fig. 1). The trend of lodgepole pine apparently has been independent throughout the entire period represented. In the Gearhart bog, again the recorded trends of spruce and hemlock have been largely contrary to each other, with the latter predominant throughout, while lodgepole reflects only its invasion of the bog itself (fig. 4). The Ilwaco profile discloses several short period fluctuations of all three species (fig. 5). Some involve spruce and hemlock fluctuating oppositely to lodgepole, others concern contrary trends of spruce and hemlock, and still others denote fluctuations of lodgepole contrary to either spruce or hemlock. The major fluctuations of pine suggest accelerated dune movement, first burying pine forests, then supporting pine invasion, and finally replacement of pine with spruce and hemlock as stabilization of edaphic conditions progressed. The occurrence of charred peat at 1 m., the level of pine maximum, suggests the possibility of fire as having been instrumental in the development of this trend. The pollen-bearing sediments at Grayland also were apparently inaugurated when the adjacent forests existed in the climax stage (fig. 6). The trends of spruce are largely the converse of hemlock, whereas those of lodgepole seem to be independent. From its initial predominance, hemlock declines whereas spruce increases to 1.1 m., then their trends are reversed to the horizon immediately below the surface, where hemlock again decreases and spruce increases to the top, the latter being preponderant. There are several possible events suggested by these trends. Fire may have destroyed the hemlock forests, increasing the relative abundance of spruce and pine. Sand dune movement may have permitted an increase in spruce and pine. A third possibility for spruce expansion is its invasion of other climax bog areas in the vicinity. The resurgence of hemlock from 1.1 m. to immediately below the surface suggests normal forest succession. The final increase of spruce at the expense of hemlock may mark the invasion of spruce on the bog. In the Hoquiam sediments, the trends of spruce and hemlock are opposed throughout the profile. Hemlock reveals an increase from 6 per cent at the bottom to 71 per cent at 2.6 m., with spruce remaining constant. Then with several minor fluctuations, hemlock attains its maximum of 73 per cent at 1.2 m. and spruce declines to 25 per cent at the same level, and then both species remain generally constant to the top (fig. 3). Dune movement has apparently played a minor role in forest succession in this region, the expansion of lodgepole pine to 21 per cent at 0.9 m. after its initial decline being the only period indicating unstabilized edaphic conditions.

Other forest tree species are only sparsely and sporadically represented. In the Hauser profile, Douglas fir is recorded as high as 20 per cent, and closely follows the trends of hemlock, while in the others it has a limited representation and not at every horizon. The bogs are located windward to the Douglas fir forests of the Coast Range. Other species recorded are western white pine, lowland white fir, noble fir, and silver fir. A non-indicator of adjacent forest succession consistently represented by its pollen in appreciable proportions is red alder. Species confined largely to the bogs, which provide abundant pollen at various levels, are myrtle, willow, maple, several species of Ericaceae, sedge, yellow pond-lily, and cattail. The pollen proportions of these species mark the development of hydrarch succession from submerged to climax seres.

There seems to be little evidence for climatic trends in the pollen profiles of the several species represented. There probably have been slight climatic changes during the post-Pleistocene along the coast of Oregon and Washington, because of the moderating influence of the ocean. The principal factor influencing forest succession has probably been sand movement. The inland movement of sand modifies and retards the rate of forest succession, and in some cases terminates it by burying forests. The formation of spits and bars and the building up of the beach provide primary areas for succession. Periods of extensive sand movement may reflect climatic changes farther inland, bringing about increased wind velocity for periods of time sufficient to cause considerable shifting of sand. Eustatic changes in sea level may also be reflected by increased sand movement. Emergence of land may have provided more eolian material and new areas suitable for primary forest succession. There apparently are many complex variables involved in initiating sand movement and the forest succession which it controls to a large extent. Most of these seem to be intangible as far as their application to interpretation of pollen profiles is concerned.

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