ers during the spring months. Three small individuals less than 30 mm. in length were found 25 miles above brackish waters, but most were obtained closer to the sea. Recent work by Dexter Haven of the Virginia Fisheries Laboratory is establishing the importance of tidal estuaries as a croaker nursery ground.

Gobiosoma bosci (Lacépède), Naked goby.—Several gobies were collected in minnow seine samples up to five miles above brackish water in the Pamunkey River.

Paralichthys dentatus (Linnaeus), Summer flounder.—A single specimen was seined in the Pamunkey River five miles upriver from brackish water.

Trinectes maculatus (Bloch and Schneider), Hogchoker.—Hogchokers were common in the James, Pamunkey, Mattaponi, and Rappahannock rivers. Some were found 40 miles beyond brackish water. These fish were mostly small.

Summary and Conclusions

The transition from salt to fresh water in Virginia tidal estuaries is not abrupt. It is possible that very slight amounts of salt of marine origin may be present up to the head of tide, but these amounts become increasingly difficult to detect by conventional methods at increasing distances upstream. Small amounts of salt water may become detached from the main body of salt water and moved upriver by eddies (Donald W. Pritchard, personal communication). A series of salinity samples from the "fresh" tidal waters titrated with silver nitrate has indicated that salinities did not decline steadily until they reached the normal salt content of fresh water, but seemed to show small erratic differences. Most of the salinities reported here were obtained by hydrometer readings, which cannot be considered accurate below one part per thousand. It is possible, therefore, that slight traces of salt may be responsible for the ability of some marine species to survive in waters considered to be "fresh."

Some marine species are able to adjust themselves to life in "fresh" water. The degree of adjustment varies among the different species and age groups. In the five Virginia rivers considered, the marine fishes may be divided into three general groups: (1) fishes commonly found in fresh water both as young and adults, including mummichog, glassy silverside, Atlantic needlefish, and Mitchill's anchovy; (2) fishes that occur in fresh water usually only as young, including hogchoker, menhaden, spot, Atlantic croaker, silver perch, and gray squeteague; (3) fishes rarely taken either as young or adults, including spotted squeteague, winter flounder, Atlantic silverside, and naked goby. To this last category might be added the fourspine stickleback, *Apeltes quadracus* (Mitchill), reported by Raney (1950) in fresh waters of the Rappahannock River.

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EVIDENCE FOR THE RECENT ENLARGEMENT OF THE "BAY" LAKES OF NORTH CAROLINA[1]

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The almost inevitable fate of most lakes is extinction through the accumulation of autochthonous and allochthonous sediments and the lowering of the outlet level, if the lake has an outlet, with advancement in the physiographic cycle. Hundreds, and probably thousands, of the lakes owing their origin to the most recent ice sheet have become obliterated as basins, and a much greater proportion of the basins dating from earlier ice sheets have similarly been affected. Lake succession is generally conceived to be a unidirectional process, except in arid regions where the water surface depends largely on the magnitude of interior basin drainage. The latter basins can again contain lakes when conditions become suitable, whereas the glacial basins that have become filled with

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sediments can never again contain lakes, regardless of how much surface water is present.

Because of this ephemeral nature of lakes, it is most interesting when small bodies of water are discovered which have been in existence for a long period of time. Such are the lakes of the Carolina "bays" in Bladen County, North Carolina. Although none of these has a water depth greater than 12 feet, and nowhere do the non-arenaceous sediments extend deeper than 25 feet below water level, the basins have been in existence at least since early Wisconsin time (Frey 1953). The known rates of sedimentation have been as low as one inch in 730 years for the post-Wisconsin sediments at site Si-25 in Singletary Lake (Frey 1951).

Not only has the filling process been extremely slow, but there is evidence that it has not been harmonic: the lake areas have alternately contracted and expanded, even within the confines of their present sand rims. The lakes at present are in a phase of modest expansion.

General Description of the "Bay" Lakes

The bay lakes lie in oval basins, each surrounded more or less by a sandy rim, which is highest toward the east and southeast. The lake itself tends to be completely surrounded by organic soil (peat) except possibly at the southeast end where the lake comes closest to the sand rim. Along the eastern and southern quarters of the shore there tends to be a well-developed terrace of equilibrium, resulting in the shallowest littoral water anywhere in the lake. Along the northwestern shore, where, according to the aerial photographs, filling seems to have progressed most rapidly (Figure 1), the water is deepest, sometimes being four feet or more in depth right at the shoreline. The shore material in these localities is peat, bound together with roots of various kinds of bay shrubs. All of these morphometric features are described in detail for the various lakes in an earlier paper (Frey 1949).

Cypresses (*Taxodium ascendens* Brongn.) occur in all the lakes at varying distances from shore in varying depths of water. Sometimes these cypresses occur in rather dense and apparently homogeneous stands, as at the south end of White Lake and the southeast end of Lake Waccamaw, but more frequently they are scattered and heterogeneous as to size. Occasional cypresses are found even along the northwest shore in water up to four feet deep. The lake sediments at these latter locations are entirely organic.

Methods

Several important aspects of this paper are based upon the ages of cypresses occurring in the lakes. These cypresses were sampled with a Djos 12-inch increment borer, kindly made available for this work by Mr. Rufus Page of the Bladen County State Forest. The very small cypresses in Lake Waccamaw were simply cut below water level with a machete, and suitable lengths of the trees were saved for analysis.

In the laboratory, the cores were prepared for examination according to the procedure described by Hawley (1941), which is apparently more or less standard in dendrochronology laboratories (Glock 1937). The cores were examined with a stereoscopic microscope at a magnification of 9 diameters.

Where the growth of the cypresses was rapid there was often a morphological change in the wood structure about ⅔ of the way through the growth increment of the particular year, which resembled the annual ring quite closely. Under conditions of rapid growth, these "mid-lines" could be distinguished from the true year marks quite readily. Where the growth was slower, however, as was the case in most cores of this series, such accessory marks if they occurred could not easily be separated from the true annuli by the gross methods employed. Just from the appearance of the cores, the author is inclined to believe that double rings did not form during years of very slow growth. An allowance of 10 per cent error should adequately take care of all such instances. In the several instances where two or three cores were obtained from the same tree, the age determinations usually differed by less than five per cent. Accuracy greater than this is not necessary for the purposes of the present study.

For those interested in dendrochronology, it might be pointed out that the cores of these lake cypresses do not seem to be favorable material for establishing a dendrochronology. There is a great individual variation from one cypress to another, and of course the situation is complicated by the expansion of the base of the trees. It is conceivable that the annual growth increment is governed primarily by hydrologic conditions rather than meteorologic, without their being too close a dependence of the hydrologic conditions on the meteorologic.

Argument

If it is agreed that cypresses can become established only on exposed surfaces (Demaree 1932, Wells 1942, Hall, *et al.* 1946), then the occurrence of these trees away from shore means that either: 1) the lake level at some time was low

FIG. 1. Aerial photograph of Singletary Lake, N. C., showing the typical oval shape and orientation of the Carolina bays. The dark area between the water and the white sand rim represents organic soil with its dense cover of vegetation. (USDA, Production and Marketing Administration.)

enough to permit the cypresses to become established in their present location, or 2) the cypresses were associated with a previous shore line but by subsequent erosion of the surrounding soil they were eventually isolated from the shore. Both processes have undoubtedly occurred.

Buell (1939) considered that the pond cypress is the principal pioneer in this particular hydrosere, becoming established during the low water levels of extreme dry seasons. The expanded bases and knees of established trees then form sites for the development of islands of typical "bay" shrubs and trees. These expand, coalesce, and form a solid organic surface, thereby obliterating the previously existing water area. Aiding in this process are the root systems and stolons of the "bay" shrubs growing along shore.

Although the pond cypress very likely is the first pioneer in this succession, the "islands" now present in the lakes represent portions of an original shore which have not yet been completely destroyed by erosion, rather than more advanced stages in the succession as described by Buell. Furthermore, the cypresses themselves although the pioneer plant in this hydrosere, are not advancing the succession under present conditions.

Establishment of Cypresses on Exposed Lake Bottom at Low Water Levels

The present morphometry of the lake basins is such that a lowering of the water level by about a foot, as commonly occurs each year, does not expose any appreciable area of the lake bottom. A further lowering, however, first exposes bottom at the southeast end, where the extensive and shallow littoral shelf occurs. One might expect, therefore, that if cypresses were to become established on the lake bottom during periods of low water, they would be most likely to occur in this general area. There is evidence that this has occurred in White Lake and Waccamaw, and probably in Singletary Lake as well.

a. White Lake

Along the south shore of White Lake there is a rather dense stand of small cypresses extending out approximately 70 feet from shore, the outermost trees being in about 20 inches of water at average conditions (Figure 2). Because of the small diameter of the trees, ranging from about three to seven inches above the markedly expanded base typical of cypresses growing in water, one might be inclined to consider them fairly young trees. Cores taken with an increment borer, however, show that the age of these trees is remarkably uniform, the actual counts ranging from 125 to 158 years (Table I). Considering the close spacing of the annual rings, with an error in age determination of at least 10 per cent not unreasonable, particularly in the smallest trees, and the time required for the trees to reach the height at which the cores were collected, the actual age of these trees may well lie between 160 and 180 years. This would place their origin during or shortly after the Revolutionary period.

There is evidence that someone, possibly Col. William Bartram, operated a sawmill on White Lake during the decade or two after 1770. A channel was cut through the sand rim at the southeast end of the lake, and supposedly the lake level was lowered two feet during the logging activities.

Fig. 2. Part of the 70-foot wide homogeneous stand of cypresses at the south end of White Lake. These trees vary in diameter from 3 to 7 inches above their expanded bases.

The millrace is still evident at Melvin's Resort, and although the channel has been dry for many years, there are some cypresses present. The age of one of the three cypresses sampled (No. 13 in Table I) was about 160 years in each of two cores, or in other words the same as the cypresses in the lake. Since cypresses could not possibly become established on the xeric sand rim except where the water relations are artificially altered as in the sawmill channel, the age of this channel and hence of the sawmill extends back to the late 1700's. This is the time of Col. William Bartram, so that he may well have operated the sawmill. A map by Price and Strothers dated 1808 (reproduced in Harper 1942) designates the lake under discussion as Bartram's Lake.

The presence of stumps of logged cypresses at the northwest end of the lake about two feet below the present water level, and the presence of this extensive population of small cypresses at the southeast end in up to two feet of water, demonstrate that the lake level probably was lowered about two feet during these logging operations. Certainly there is little doubt that this stand of cypresses derives from this period and that they became established on exposed lake bottom.

It is noteworthy, however, that in this relatively long span of time no "islands" of bay vegetation have begun to form around the bases of the cypresses and there is no accumulation of peat; rather the bottom is entirely sand, as it is everywhere else on the littoral shelf. These cypresses are being thinned out gradually by natural processes, as evidenced by stumps and scraggly, weak individuals. Succession is not progressing but retrogressing. Conditions were initially favorable for establishment of the stand, but subsequently have not been favorable for the growth and further development of the sere. It is believed the factor primarily responsible for this condition is the wave action at the southeast end. Hence, the force which produces the conditions (the littoral shelf) most suitable for cypresses to become established during low water stages also makes it difficult for the trees to thrive after becoming established.

b. Lake Waccamaw

On the shallow littoral shelf at the southeast end of Waccamaw, likewise, there is a dense stand of cypresses which has become established at low

TABLE I. *Age and rate of growth of cypresses from the bay lakes in relation to depth of water and distance from shore*

Lake and date	Cypress number	Distance from shore (feet)	Depth of water (inches)	Height of core above bottom (inches)	Diameter at height sampled (inches)	Length of core (mm.)	Counted annual rings	Annual rings per mm.	Estimated age at height sampled
White 24 Aug. 48	1	70	20	49	5	47.4	142	3.0	145
	2	70	20	59	6	69.7	153	2.2	158
	3	70	19	58	6	61.2	139	2.3	142
	4	30	14	55	3¾	33.8	127	3.8	127
	5	30	14	56	4	44.2	144	3.3	144
	6	12	11	58	5¾	83.3	146	1.8	148
	7	8	14	61	7	80.0	138	1.7	138
	8	4	8	60	5¾	64.3	136	2.1	140
	9	9	8	52	3¼	27.7	129	4.7	129
	10	1	5	96	11	95.0	389	4.1	>500
	11	8	11	53	2¾	27.6	125	4.5	125
	12	In millrace		61	11	111.0	103	0.9	106
	13	"	"	61	9	100.0	160	1.6	160
	14	"	"	61	7½	75.4	47	0.6	50
Singletary 24 Aug. 48	15	80	13	67	9½	66.5	328	4.9	>500
	16	70	13	65	9	92.0	374	4.1	374
	17	80	17	67	11	~ 97.0	405	4.2	>500
	18	100	29	63	11	57.8	212	3.7	>500
	19	20	48	126	11	117.6	328	2.8	333
	20	15	46	122	14	129.7	317	2.4	>400
	21	30	46	108	23	170.9	304	1.8	>450
	22	12	46	118	13	~175.0	424	2.4	430
	23	25	48	100	13	127.6	271	2.1	277
	24	50	48	99	15	99.0	133	1.3	~250
	25	120	27	71	13	~140.0	458	3.3	491
Jones 15 Aug. 48	26	75	12	78	12	82.6	400	4.8	>650 ?
	27	75	12	60	12	116.3	417	3.6	435
	28	75	14	56	12	137.3	530	3.9	538
Salters 23 Aug. 48	29	15	12	60	14	132.8	96	0.7	99
	30	10	12	60	11	68.3	105	1.5	130
	31	30	14	60	10	122.7	66	0.5	68

water levels. These trees are much younger than those in White Lake. The diameter of 22 trees at the height sampled (about 12 to 14 inches, which is also the depth of water) varied from 9 to 24 mm., with a mean of 15 mm. The apparent age of these trees as of 1949, based on a study of four cross sections from each tree, ranged from 5 to 15 years, with a mean of 11 years. There is a greater frequency toward the upper end of this age range. The cross sections of these young trees demonstrate clearly some of the errors that can readily occur in aging trees, apart from correctly recognizing and counting the annual rings. Some of the annual rings on various cross sections were present only part way around, and in other instances an annulus present on one cross section might be completely lacking on another cross section taken only an inch or two farther up or down the stem. These are problems that confront all dendrochronologists.

Considering the vertical growth of these trees to have been about three inches per year, most of the trees became established during the period 1931 to 1936, with minor amounts of seeding as late as 1939. It is known that the water level of Lake Waccamaw fluctuated greatly during this period. Only a makeshift dam was at the outlet to help control the minimum water level, and this dam washed out at least once during the period. Since the construction of a concrete dam at the outlet the annual fluctation in water level has been less, and there has been no further seeding of cypresses on the littoral shelf.

c. *Singletary Lake*

Singletary Lake is the only one of the bay lakes with large cypresses at any appreciable distance from shore at the southeast end of the lake (Figure 3). Trees number 15, 16, and 17 in Table I are from this region. Only number 16 yielded a complete core, with an age of 374 years. Trees 15 and 17 had rotten centers so that complete cores were impossible to obtain. Assuming the rate of growth was the same throughout as in the partial cores obtained, the total age of these trees would be considerably greater than 400 years, even allowing a 10 or 20 per cent error in counting the annuli.

If these trees became established when the lake bottom in this region was exposed, such exposure occurred a very long time ago and apparently has not been repeated within the past few hundred years, at least with the survival of any cypresses that may have become established. The cypresses present may be the remnants of much more extensive stands, such as those in White Lake and Waccamaw. Since, however, it is likely that these cypresses differ considerably in age they may be erosional remnants of the type to be described presently.

Again it should be noted that there is no tendency for any of these trees, in spite of their great age, to serve as foci for formation of islands of bay shrubs or for accumulations of peat. The bottom surrounding these trees is entirely sand.

Isolation of Cypresses from Shore by Erosion

On the other hand there is considerable evidence that many of the cypresses in the lakes were originally out of the water, and have since been isolated from the shore by erosional processes. The most direct evidence for this is the small "islands" of shrubs around the bases of some of the cypresses, which Buell regarded as evidence of progression in the succession, rather than the reverse as believed in the present paper.

One of these "islands" is shown in Figures 4 and 5. It consists of a cypress tree along the northeast shore of Jones Lake surrounded by a dense growth of *Cyrilla* and *Clethra*. A second live cypress is seen extending obliquely from the left side of this island, and a dead cypress projects from the right. The evidence for regarding this "island" as an outpost of the former shore is the following.

1. Cypresses growing in water tend to develop greatly *swollen bases,* such as those shown in Figures 3 and 6, which have obviously been in the water for a long time. Cypresses growing out of the water do not develop the swollen base to anywhere near this degree. The cypresses in this clump have only a slightly swollen base (hidden by the shrubs).

2. The cypresses in the lake tend to have two *horizontal marks* on their bases at distances above the water level which are the same for all the trees (Figure 6). These marks are more prominent on the lakeward side of the tree than on the shoreward side. They do not occur on the trees growing on shore. The author's interpretation of these particular marks is that they are abrasion features formed during two particular high

Fig. 3. Ancient cypresses on the littoral shelf at the southeast end of Singletary Lake. Note the several pines growing at the edge of the water apparently being cut away from the shore by wave action.

FIG. 4. A cypress "island" in Jones Lake about 15 feet from shore.

water periods. Because high water occurs in the early part of the year, it is believed these marks possibly resulted from fractured ice moved by a strong wind. Regardless of their origin, however, they occur at corresponding levels on trees in the water but do not occur on trees out of the water. The cypresses in this island (and the cypresses in similar islands elsewhere) do not have these abrasion marks on their bases.

3. The general aspect of the tangled mass of roots around the base of this island is one of *degradation* rather than aggradation. Many of the roots are bare without any soil around them at all. The roots in the water away from the island belong to the two living cypresses in this island, and are similar in aspect to the roots surrounding the other cypresses in the lakes (Figure 6). Normally these roots are under water; the photographs were taken at such an extreme water stage that sponges on these roots, for example, were three inches *above* the water surface at this time

FIG. 5. Closer view of the base of the cypress "island" in Figure 4, showing the exposed roots of the cypresses and bay shrubs and the general aspect of degradation.

(August 15, 1948). No appreciable portion of the littoral shelf was exposed even at this low water level.

4. The great tangle of *cypress roots* in the water may be another indication that erosion has occurred. Cypresses ordinarily form an extensive horizontal root system beneath the ground surface. Photographs in the paper by Brown (1943) show the soil washed away from around the roots of cypress trees, giving an aspect somewhat similar to that around the island. By contrast, the cypresses at the south end of White Lake (Figure 2), which are known with some certainty to have been established at a low water level, do not have similar extensive root systems in the water.

This particular island was 15 feet from the present shoreline. Other islands are at a somewhat greater distance, and a few are barely separated from the shore. The latter applies to cypress No. 10 from the south end of White Lake. It should be mentioned that these accumulations of shrubs around the bases of the trees are not common. Usually the trees are completely isolated from any other vegetation except the *Sphagnum* and *Fontinalis* on their roots in the water, or the occasional liverworts on their boles.

Other Evidence for Shoreline Erosion

Realizing that erosion has occurred, there are some features of these lakes that can be best explained on the basis of such erosion.

1. Along the eastern shore of Jones Lake just north of the outlet there are three small scallops or indentations of the shoreline. Paralleling the two upper scallops almost exactly and at a distance of approximately 75 feet from shore is a row of ancient cypresses, about 15 in number. A considerable number of these cypresses is shown in Figure 6. Each of the trees is surrounded by an extensive root system in the water (exposed in the photograph because of the extremely low

FIG. 6. Part of the row of cypresses paralleling shore in Jones Lake. The abrasion marks on the expanded bases are readily visible, as are also the extensive systems of roots in the water, here exposed at very low water level.

water level). The butts of all these trees are greatly expanded, but there are almost no "knees" of the type usually occurring in aquatic cypresses. It will be observed in Figure 6 that there is no island development around these trees, even though such development ought to be encouraged rather than discouraged by these extensive aquatic root systems.

The question is, has this row of cypresses paralleling the shore originated through establishment at a very low water level, or has it originated through isolation by erosion from a previous shoreline? The evidence seems to favor the latter view.

Borings obtained from three of these trees (numbers 26-28 in Table I) reveal that although all the trees are very old, they are probably not the same age. The cores for trees 27 and 28 were reasonably complete, so that depending on the accuracy with which the annual rings were interpreted and counted, the ages should be roughly the order of magnitude shown in Table I, with the addition of the number of years necessary for each tree to reach a height of about five feet above the present ground level. Cypress number 26, however, had a hollow center, necessitating an extrapolation by more than a third of the counted number of annuli to obtain the estimated total age.

Granting that these trees are not the same age but differ by perhaps 50 to 200 years, their present linear arrangement paralleling the shore is more logically the result of erosion of a previous shoreline, where conceivably cypresses could become established almost every year, than the result of the purely coincidental alignment parallel to shore through establishment over a number of very low water stages occurring within a time span of a couple hundred years.

A further fact opposed to the latter conclusion is that the bottom configuration of the lake while very regular is not so precise that if the lake level were lowered say 2 feet the new shoreline would parallel with any exactness the minor indentations of the present shoreline.

2. The south and southeast shores of Black Lake are very irregular, with many narrow tongues of cypresses and bay vegetation extending out from shore, forming numerous small embayments of the lake measuring from 50 to 100 or 150 feet across. The vegetation in these small peninsulas is growing in organic soil which extends above the water level, and again the over-all aspect is one of degradation (as in Figure 5). In

addition there are quite a few cypresses completely isolated from shore, with no "islands" of bay shrubs surrounding their expanded bases. It is the author's opinion that these features in Black Lake have resulted from the erosion of a previous shoreline more centrally located than the present one.

3. The occurrence of cypresses in water as deep as four feet along the *northwest* shore of these lakes is difficult to explain except by isolation by erosion from a previous shore. A drop of water level of four feet would be extremely rare in occurrence, and with less extensive lowering of lake levels the cypresses would become established along other shores. As already mentioned, the shallowest water is at the southeast end of these lakes, and the littoral water tends to increase in depth as a function of distance away from the southeast end, both in a clockwise and a counterclockwise direction, reaching its maximum along the northwest end. This statement does not hold true for Waccamaw, because in this lake the organic filled-in portion of the basin at the northwest end has become isolated from the extant lake by deposition of sand. Even so, however, the bottom drops off much more rapidly here than toward the southeast end.

The cypresses were studied more intensively in Singletary Lake than in any of the others. A complete circuit of the lake was made, beginning at the southeast end. It was difficult to locate cypresses without hollow centers or without layers of rotting wood, either of which conditions yielded an incomplete core.

Cypresses 19 to 22 in Table I occurred within a lineal distance of 500 feet along the extreme north shore of the lake. Although these trees are all in water four feet deep, number 19 is definitely younger than the rest. Moreover, number 20 is surrounded by a residual island of bay vegetation and peat, which appears to have been quite recently isolated from the shore. The base of this tree was much less expanded than those of adjacent trees in the water without such an island of shrubs.

Cypress 21 is one of the largest in the lake, and its estimated age was also very great. The largest cypress in the lake, growing along the southwest side in 51 inches of water 80 feet from shore, had a diameter of 27 inches approximately 9 feet above the lake bottom. A satisfactory core could not be obtained, but examination of the fragments indicated as slow a rate of growth as in the other trees of this region.

Cypress 23 and 24 are interesting in that although the trees are growing in four feet of water, their ages are much smaller than those of the cypresses at the north end. Number 23 is particularly interesting in that although 25 feet from the present shore line, the basal portion of the trunk is charred by fire. The present vegetation of the adjacent shore consists of shrubs, and it is inconceivable how even an intense fire in such vegetation could produce charring 25 feet away. Either this cypress was much closer to the shore at the time of the fire, or perhaps it was surrounded by an island of bay shrubs, which has disappeared since the fire. It is extremely doubtful that this tree became established in its present relation to the shoreline as a result of a lowering of the lake level by four feet.

4. It is known to be true for Singletary, Jones, White, and Waccamaw (and presumably for Salters and Black lakes as well) on the basis of reliable testimony that only a short distance below the sand of the littoral shelf particularly along the east and southeast shores are *tree stumps in situ*. The author has observed these personally only in White Lake and Singletary Lake. The species of trees represented are not known, but it is very likely that many of them are cypresses.

Regardless of whether these trees became established at low water levels away from shore or were originally part of shore and then later became isloated by erosion, they provide additional evidence that the successional sequence which bring about encroachment upon and gradual obliteration of the lake area has been retrogressing rather than progressing.

Discussion

Buell's (1939) concept concerning the role of the pond cypress as the pioneer in the hydrosere of these lakes is probably correct, and likewise the accumulation of "islands" of bay shrubs and organic soils around the bases of these trees. On the other hand, there is evidence from the pollen analysis of the sediments of a number of these bays (Frey 1953) that in the filling process accumulation of sediments offshore may have been of relatively greater importance than marginal encroachment of vegetation.

Pollen of all the vegetational components of a region do not turn up in a pollen diagram, at least in frequencies corresponding to the actual occurrence of the plants. One, therefore, must seek out any bits of evidence which seem to indicate trends. In the pollen diagrams from filled-in regions, there seems to be a distinct stratigraphic sequence of peaks of cypress, tupelo (*Nyssa*), *Sphagum,* and composites—*Ilex,* in that order beginning with the post-glacial broadleaf maximum.

It was concluded that this sequence reflected a progressive reduction in duration of hydroperiods. Such a reduction could result from decrease in water depth through accumulation of sediments, decrease in moisture entering the basin (almost entirely direct precipitation), or increase in loss of water from the basin by subsurface leakage and surface drainage.

For reasons as yet unknown, the rate of sedimentation in the extant bay lakes has been extremely slow, so that the hydroperiod of the offshore areas is continuous, and the hydroperiod even of the littoral areas is almost continuous. Those cypresses which do become established in the latter areas during the very infrequent interruptions of the hydroperiod find conditions difficult for maintaining themselves (as evidenced by very slow growth rates) and do not provide a satisfactory base for development of more complex communities. Moreover, at times such as the present, their role is minimized even further by the actual reversal of successional trends through erosion of the organic shores. It is interesting that Wells and Boyce (153) have recently arrived at the same conclusion regarding erosion, independently of the present author.

If peripheral expansion of the lake areas is occurring under present conditions, there is no reason to believe that it may not also have occurred at various times in the past when conditions were suitable, and very likely at greater rates than at present. The author conceives of these lakes as having undergone an areal expansion and contraction at various times during their ontogeny. This concept has an important bearing on two matters relating to the final understanding of the origin and ontogeny of these basins.

First, it has pointed out by the author (Frey 1953) that although the regional pollen succession was definite and readily capable of correlation from one basin to another, yet there were instances (particularly in Little Singletary Lake and White Lake) when the typical succession of pollen types was somewhat masked and obscured by considerable frequencies of "extraneous" pollen grains. Such "mixing" is believed to have resulted from phases of erosion similar to the present at various times in the past. Erosion brings about a redistribution over the lake bottom of pollens and spores deposited during earlier phases of contraction of lake area (or prolonged periods of lowered lake level). It is necessary, therefore, to be aware of this phenomenon and be alert for vidence of it in interpreting pollen diagrams from the Carolina bays.

Second, adherents of the meteoric hypothesis as to the origin of these oval depressions in the Atlantic Coastal Plain conceive of the process of basin filling as being undirectional: the basins were formed essentially in their present shapes and orientation, and these have persisted unaltered to the present with the exception of the accumulation of sediments (Prouty 1952). Instances where the highly regular outline of one bay is cut into by that of another bay, in the same way as during a lunar eclipse the earth's shadow appears to be taking a bite out of the moon, are explained by two meteorites striking the earth successively within a short distance of one another. The meteorite striking last would produce the basin having the completely regular outline which would appear to be taking a "bite" out of the slightly earlier basin. A contrary view that such intersections of bays may have resulted from particularly active phases of erosion in certain of them is suggested by the findings of the current study. Such a conclusion had already been reached by Johnson (1942) as a logical consequence of his multiple factor hypothesis conceiving the origin of the Carolina "bays."

Summary

Evidence based chiefly on the age and morphologic features of cypresses growing away from shore and on the degraded appearance of the peat along shore and in isolated "islands" surrounding some of these cypresses suggests strongly that the lake areas have been undergoing a modest phase of erosional expansion during at least the past 500 years. The author considers it likely that similar or even more extensive expansions, alternating with phases of filling and contraction, have occurred at various times in the ontogeny of these basins.

Such periods of erosion are important in the pollen and spore succession of the sediments in bringing about a mixing of microsfossils from earlier periods with those currently accumulating during such periods of erosion. Aggressive expansion of particular bays is also an alternate explanation for the interruption of the otherwise regular oval outline of one bay by that of another bay.

Succession in this hydrosere may well follow the pattern outlined by Buell (1939) of pioneer cypresses accumulating islands of shrubs around their bases, aided by a marginal encroachment of bay shrubs. The present author believes that accumulation of offshore sediments eventually permitting extensive interruptions of the previously continuous hydroperiod with only a moderate low-

ering of the water level, would be a more likely early stage in the succession than the direct advancement of cypresses into deep water.

The extensive filling of these lakes, which on the basis of the Singletary Lake pollen analyses (Frey 1951, 1953) has occurred largely since the broadleaf maximum in post-glacial time, has been more rapid at the northwest end than elsewhere. The present phase of erosion is involving the entire shoreline.

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