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1. Introduction

The coastal plain vegetation of North Carolina has been the object of several studies in the last 50 years. The leading student of the coastal plain vegetation, B.W. WELLS, briefly outlined the major plant communities and their successional relations (WELLS 1928); in addition he has given detailed ecological descriptions of several of the more distinctive types of communities (WELLS 1946; WELLS and SHUNK 1928, 1931). However, until recently there has not been detailed analysis of a wide range of vegetation types found within a single area. The diverse wetland communities of the Green Swamp in the southern coastal plain have been described by KOLOGISKI (1977). The study presented here includes a wider range of vascular plant communities from hydric swamp to xeric sandhill vegetation, all found in a single section of Croatan National Forest. The areal extent of the communities is displayed in a vegetation map and their ecological relationships are discussed.

Acknowledgements

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1.1. *Study Site*

Croatan National Forest is an ideal study site because it is a centrally located area of public land with vegetation representative of the coastal plain of North Carolina. Croatan National Forest is located in the lower coastal plain south of the Neuse River estuary (Fig. 1). It occupies portions of Carteret, Craven, and Jones counties with U.S. 70 between New Bern and Morehead City traversing the eastern part. The National Forest is bounded on the north by the Trent River in addition to the Neuse, on the west by the White Oak River, on the south by N.C. 24 (Bogue Sound), and on the east by Harlowe and Clubfoot creeks.

The U.S. Forest Service began acquiring property about forty years ago and

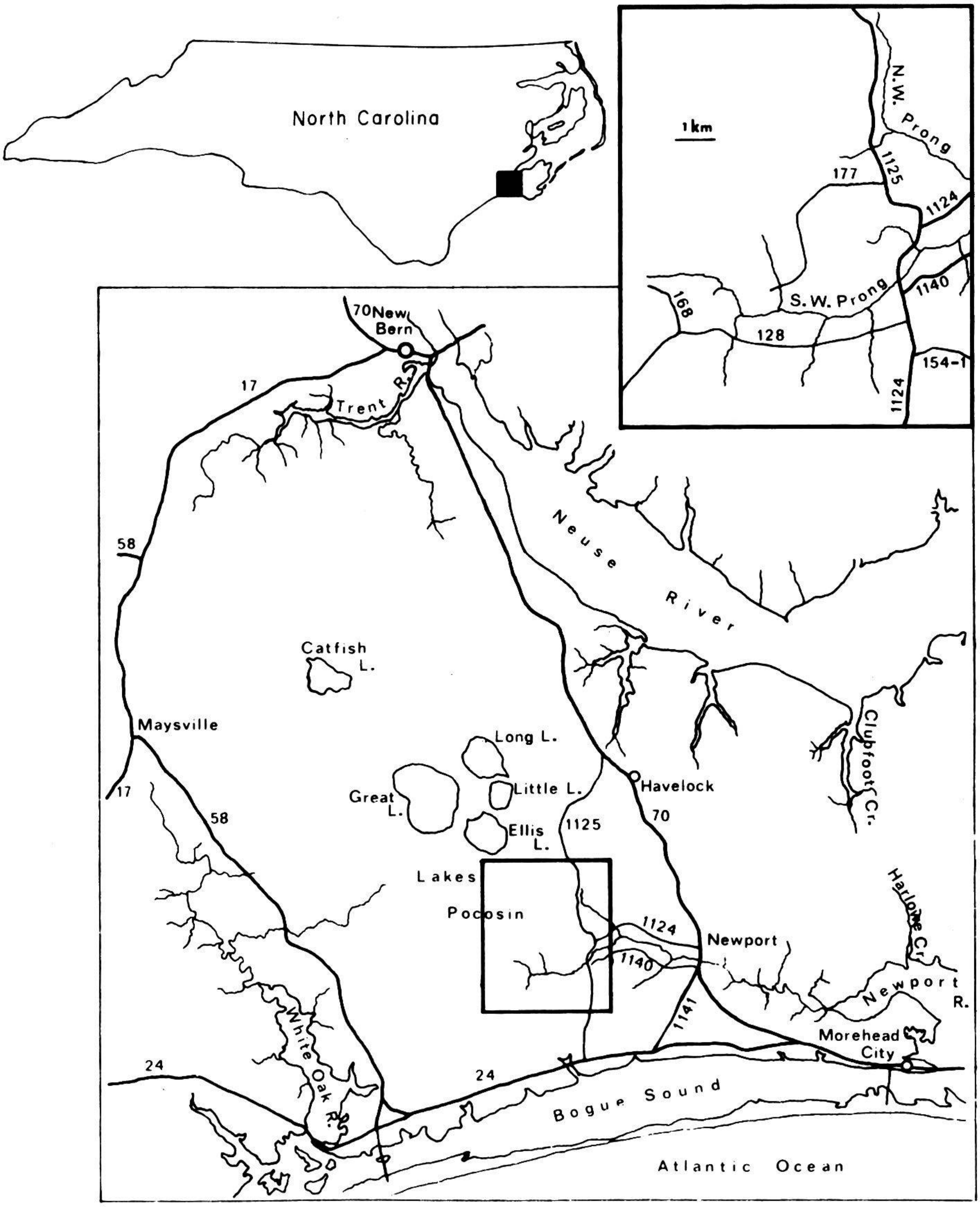

Figure 1. Location of study area (enlarged inset) within Croatan National Forest. Major highways and relevant minor roads are shown. U.S. highways: 17, 70; N.C. highways: 24, 58; County roads: 1124, 1125, 1140, 1141; Forest routes, unpaved: 128, 154-1, 168, 177.

now administers about 47,000 ha, somewhat less than half of which is managed for timber production. All of the productive forest land has been harvested at least once and most now supports second or third growth pine forest. Most of the nonproductive land is found in the center of the National Forest in a large expanse of shrub bog on organic soil known as Lakes Pocosin. This is one of many large areas of organic soil in the lower coastal plain of North Carolina which have an estimated total area of 600,000 ha (MAKI 1974).

The specific research area within Croatan National Forest was chosen because it contains representative examples of the major plant communities found in the coastal plain (exclusive of saltwater influenced communities). It is vegetated by shrub bog, loblolly and longleaf pine forest, and bottomland hardwood forest which together account for most of the natural vegetation of the coastal plain. The less common upland hardwood forest which is also found in Croatan National Forest could not be included because it was not available adjacent to a wide range of the more typical types.

The study area is a rectangular tract of about 7,050 ha lying southeast of Ellis Lake entirely within Carteret County (Fig. 1). The southern end is only about 3 km from the saltwater of Bogue Sound. The area is covered by the Masontown 7.5 minute topographic map and is bounded by 34°45' - 34°50'N and 76°55' - 77°W. The highest elevation is less than 13 m above mean sea level and most of the area is between 8 and 12 m elevation. The lowest points are about 3 m above sea level and are found along the two main streams which drain the area, the Southwest and Northwest Prongs of the Newport River.

There is a paved road running north-south through the eastern part of the research area with two others heading eastward parallel to the Southwest Prong. A number of unpaved Forest Service and private roads provide the access to much of the area.

The recorded land-use history of Carteret County dates from about 1700 when the first European settlements were founded. At that time, the forest of the better drained areas consisted mainly of *Pinus palustris* (longleaf pine), but there was some *Pinus taeda* (loblolly pine) in the less well-drained areas. The boggy areas supported only *Pinus serotina* (pond pine). Agriculture developed both for local consumption and for export, and a naval stores industry built up around the *Pinus palustris*. Lumber, tar, pitch, and turpentine were exported but by about 1900 supplies dwindled due to over-exploitation (PERKINS et al. 1938).

In eastern Carteret County in the large expanse of pocosin known as the Open Grounds, drainage and farming of the organic soils were attempted as early as the 1920's (DACHNOWSKI-STOKES and WELLS 1929). These early attempts failed but recently a large "agribusiness" has begun large scale conversion to row crops and pasturage for raising cattle.Conversion to agriculture appears to be the fate of much of the organic soil land of coastal North Carolina (CARTER 1975). Within the study area there has been no attempt to farm organic soils although west of Catfish Lake inside the National Forest boundary there is agricultural activity on privately owned organic soil.
Today most of the study area remains forested, although much is of non-commercial quality. Only about 7 % of the area is under conventional cultivation, mainly in soybeans, corn, and tobacco.

1.2. *Climate*

The climate of the North Carolina coastal plain is characterized by hot summers and cool winters with adequate moisture throughout the year; the region lies entirely within the humid mesothermal climate of Köppen (TREWARTHA 1954). Figure 2 is a climate diagram for the New Bern weather station which is about 35 km north of the study site and experiences similar weather patterns.
Precipitation shows a pattern of high summer rainfall with the months of July, August, and September receiving over one third the annual average of about 1400 mm. Summer rainfall often occurs in the form of brief afternoon thundershowers. Precipitation in the form of snow is recorded only in trace amounts in most years.
Lightning was historically a cause of natural fires and KOMAREK (1974) goes so far as to refer the southeastern coastal plain and piedmont to the "southern pine forest lightning fire bioclimatic region". Perhaps of greater significance is the frequent occurrence of periods of low rainfall in the fall and spring which coincide with the period of highest fire frequency. These fires, however, are at present largely man-caused.
Temperatures range from a July mean daily maximum of 33 ^{o}C and mean daily minimum of 20.5 ^{o}C to a January mean daily maximum of 14 ^{o}C and mean daily minimum of 1 ^{o}C. The highest temperature recorded at New Bern was 41 ^{o}C and the lowest was -13.5 ^{o}C for the period 1951-1960 (U.S. WEATHER BUREAU 1965). The mean length of the freeze-free period is greater than 240 days according to a

generalized map (NELSON and ZILLGITT 1967); winter temperatures are moderated by the nearby Gulf Stream.

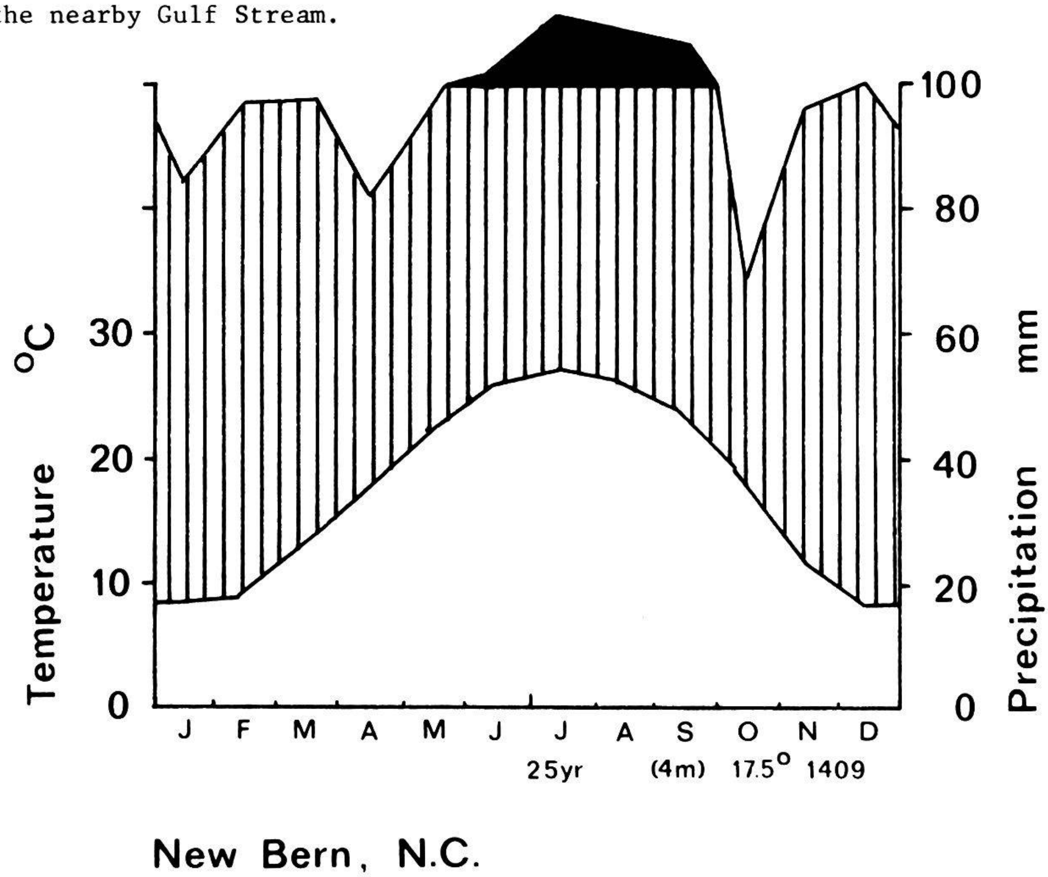

Figure 2. Climate diagram for New Bern, Craven County, N.C. Lower line represents mean monthly temperature (degrees C) and upper line represents mean monthly precipitation (in mm). In the solid black area the scale is reduced 1/10. (After WALTER and LIETH 1960).

The high winds associated with tropical storms are undoubtedly responsible for many of the windthrown trees in the area and for the unusual sight of *Pinus palustris* trees growing with their trunks at an angle greater than 30° from the perpendicular. These storms passed through the Croatan area approximately 20 times in the period from 1901 to 1955 (BRADLEY 1972).

1.3. *Geology*

According to STEPHENSON (1912), the North Carolina coastal plain is composed of five marine terraces separated by scarps which represent the depositions of successively lower stands of the ocean. The sediments represent nearshore marine as well as estuarine and nearby river floodplain deposits. Croatan

National Forest is found almost entirely on the second lowest and therefore second youngest of these terraces, the Chowan formation, which corresponds to elevations of 7.5 to 14 m. The terrace is composed of a veneer of Quaternary sediments overlying Tertiary and Cretaceous sedimentary rocks which form a wedge increasing in thickness to the east and northeast (MIXON and PILKEY 1976).

MIXON and PILKEY (1976) provide the most recent treatment of the surficial geology of the Croatan area, including a map which covers the study site (Fig. 3). Their terminology and interpretations are followed here.

The research area shows relatively little relief. The northwestern third of the area is a very flat plain which is part of the large central bog (Lakes Pocosin) of the National Forest. The southeastern two thirds show a greater degree of relief but even here local changes in elevation are on the order of at most a few meters, and are greatest where downcutting by streams has occurred. These two geomorphologically differentiated areas are referred to by MIXON and PILKEY (1976) as the Newport Backbarrier Flat and the Newport Barrier respectively.

The Newport Barrier is a complex of old beach ridges and swales which run in a northeasterly direction toward the town of Newport. The parallel pattern is more pronounced just to the east of the research area and appears as striking bands of light and dark in aerial photographs (e.g., Fig. 3 in MIXON and PILKEY 1976) or as parallel contours on the Masontown and Newport topographic maps. The degree of relief is rather slight however, on the order of 1.5 m from ridge to swale. On the ground this pattern can be seen in cross section along county road 1141 and U.S. 70 south of Newport. The southwest-northeast trending ridge and swale topography is frequently interrupted by elliptical ridges of sand which probably represent the rims of Carolina bays (see later).

MIXON and PILKEY refer the Pleistocene sediments west of the Grantsboro scarp within their mapping area to the Flanner Beach formation. This formation corresponds closely to the area mapped as the Chowan formation by STEPHENSEN. MIXON and PILKEY avoid the use of the classic terrace formation terminology because the terraces as mapped over long distances may not represent valid stratigraphic units. The Flanner Beach formation is considered to be the deposition of a single transgressive-regressive cycle of the sea.

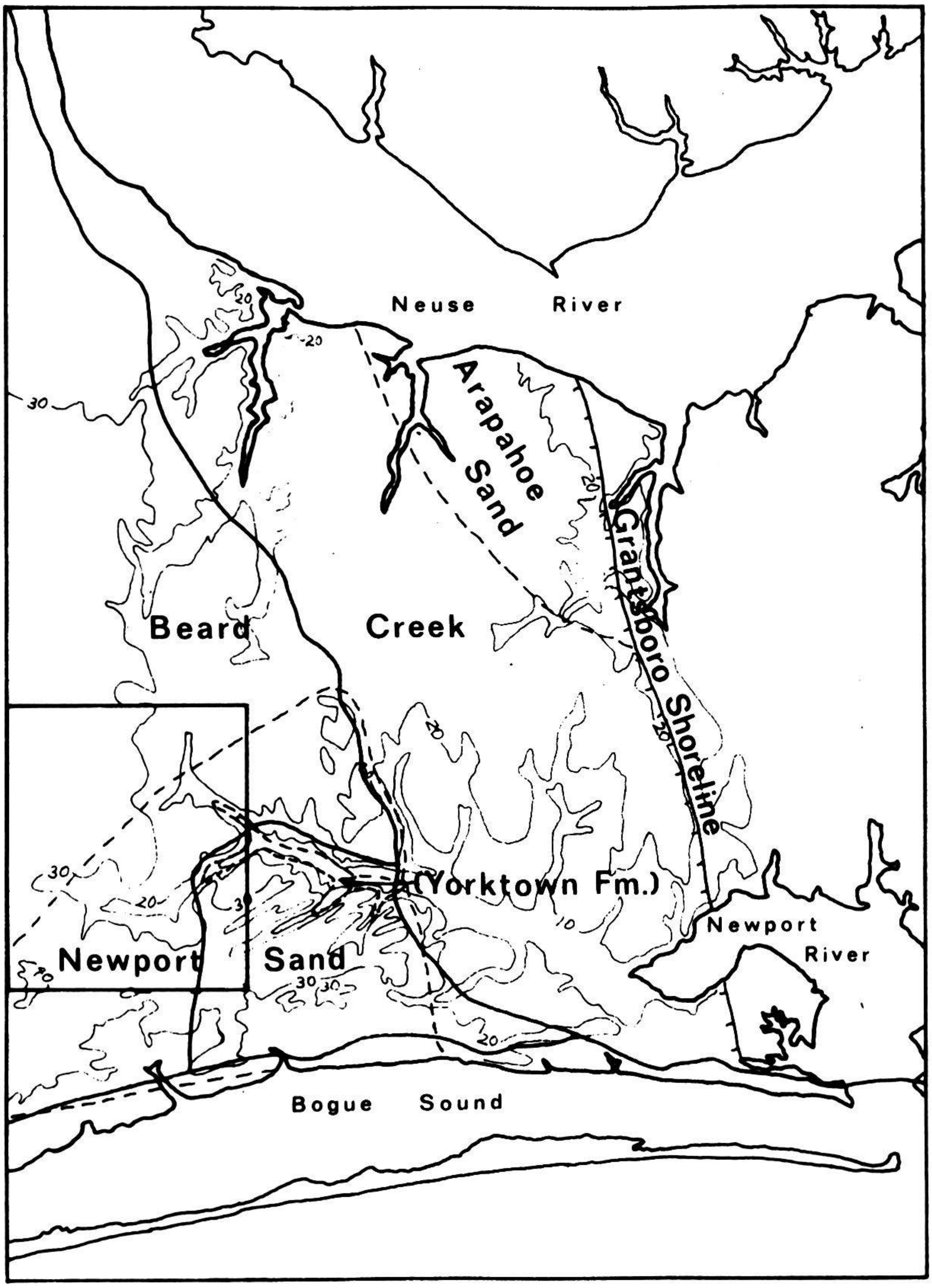

Figure 3. Geological map of the study area (small rectangle) and adjoining parts of Croatan National Forest. The area to the west of the Grantsboro shoreline is covered by Pleistocene sediments of the Flanner Beach formation, except for an area of outcropping of the Yorktown formation (Lower Pliocene and Upper Miocene) along the Newport River. The area of outcropping shown on the map is exaggerated. The Beard Creek and Newport Sand members of the Flanner Beach formation represent backbarrier flat and barrier deposits respectively. Ten foot contour intervals are shown completely only within the study area. (After MIXON and PILKEY 1976).

Within the Flanner Beach formation MIXON and PILKEY informally recognize three members or facies (Fig. 3). One of these, the Newport Sand member, is equivalent to the Pleistocene sediments of the Newport Barrier referred to above and a second is the Beard Creek member which represents the Newport Backbarrier Flat deposits. The third member, not found in the research area, is designated the Arapahoe Sand member. A tongue of the Beard Creek facies which separates the Newport and Arapahoe Sand facies is hypothesized to represent the former channel of the Neuse River.

The Newport Sand facies of the Flanner Beach formation is formed by the sandy sediments of the ridge and swale dune complex. The sediments are well-sorted to moderately well-sorted quartz sands which locally contain fine quartz and chert pebbles. The nonfossiliferous sands range in depth from 3 m or less where they integrade with the finer sediments to the northwest to about 12 m at the south near Bogue Sound. The ridge and swale complex is inferred to be beach deposits of a previous coastline of the mainland or of a barrier island.

To the northwest, the sandy deposits merge with the finer sediments of the Beard Creek member. The flat topography and the presence of clayey and silty sand, and smaller amounts of silt and clay, which today underlie the mantle of peat, indicate that this facies was a backbarrier region where deposition took place in the lower energy environment of an estuary or lagoon located landward of the Newport Barrier.

The elevations of the Newport Barrier and Backbarrier Flat correspond closely to those of a similar geomorphological structure described by THOM (1967) for South Carolina; MIXON and PILKEY note that a sea stand of 10.5 m in South Carolina has been dated at 147,000 ± 13,000 years before present.

The only pre-Quaternary rocks which outcrop in the research area belong to the Yorktown formation of late Miocene or Pliocene age. The deposits outcrop in very narrow areas along the Newport River and its tributaries, and the extent of the outcropping has been exaggerated on the map (Fig. 3). The Yorktown formation is composed of fossiliferous clayey sands and clays.

Carolina bays are a distinctive feature of the Carolina coastal plain and have inspired many suggestions and debates as to their origin. They are shallow elliptical depressions surrounded by a low sand rim and either contain standing water as some of the Bladen Lakes or more frequently are filled with accumulated peat supporting pocosin or "bay" vegetation (BUELL 1946). In addition to their regular outlines they are unusual in that they are regularly oriented on a northwest-southeast axis. Within the research area south of forest route 128 a number of partial rims of Carolina bays are distinguishable as curved "islands" of longleaf pine in a "sea" of pocosin (Fig. 5*). THOM (1970) did extensive work on the geomorphology of Horry and Marion Counties, South Carolina, which contain many well-developed Carolina bays. The following quote is from his paper:

> The hypothesis which has developed from this study is that Carolina bays are the result of the expansion of shallow water bodies. These water bodies were initially deflation hollows within dune fields, or depressions on poorly drained interfluves, or lake basins at the contact between two river terraces. Under the influence of strong unidirectional winds from the southwest, the bays expanded laterally with a northwest-southeast elongation. Sandy rims developed as beaches on the leeward side and at the ends of these shallow lakes .... No specific evidence has been found requiring in any theory of bay formation the effect of solution, artesian flow, slumping, periglacial conditions (for example, permafrost or thermokarst), meteor impact, gyroscopic eddies or spawning fish.

For further discussion of problems in Carolina bay formation and references to some of the above mentioned alternatives the reader is referred to THOM (1970).

Numerous small depressions which are not Carolina bays are present in the research area south of country road 1140, within the Newport Barrier region of MIXON and PILKEY. The depressions range in size from tiny pits about 4 m in diameter to those large enough to be visible on standard aerial photographs. Some of the larger depressions apparently contain permanent or semi-permanent ponds whereas the small ones only contain water after heavy rains, if ever. The origin of the depressions is probably due to a coastal dune process inasmuch as they occur in the Newport Barrier region. However, the steepness of the slope of the depressions and the almost circular outline of some of the smaller ones seems appropriate to solution holes. THOM (1970) describes water-filled depressions in the outer coastal plain of South Carolina which appear to be the result of dissolution of underlying calcareous strata. Dr. Walter WHEELER (pers. comm.) of the UNC Geology Department feels that solution hole formation is unlikely in the study area because rock capable of dissolution is found too deep beneath the Pleistocene sediments. Regardless of how they were

* in the pouched back-cover.

formed, the ponds in some of the larger depressions are noteworthy in that they contain a number of interesting vascular plants.

1.4. *Soils*

The soils found in the research area are to a large degree the result of the Quaternary geology, including topography, of the surficial deposits. In addition, the climate and vegetation have had primary influence on pedogenesis.

The parent material of the soils is in all cases unconsolidated coastal plain sediments. The mineral soils range in texture from sands to clays. The topography of the area is generally very flat due to the nature of the depositional process, and this has profound influence on the hydrology. Broad flat areas, especially of finer sediments, tend to be poorly drained, and this situation is here aggravated by the low elevation. Downcutting by the two major streams improves the drainage of only a small portion of the area. In contrast to the poorly drained soils there also exist much smaller areas of excessively-drained soils where deep deposits of sands from old dune systems are found.

The climate of the area influences both the physical-chemical processes and the biotic factors involved in soil development. Precipitation greatly exceeds evapotranspiration and this excess rainfall has a number of effects on soil genesis. Percolating rainfall coupled with relatively warm temperatures has served to leach nutrient cations from the soil and saturate the exchange complex with acidic species. The result is nutrient-deficient soils with low pH.

Soil is not only an important determinant of the type of vegetation found in an area, but in turn is influenced by the vegetation which it supports. Podzolization is a process characterized by the leaching out of organic matter and/or iron and aluminium from the upper part of the soil profile (A2 horizon) and the deposition of the leached material in the layer below (Bh horizon) (BUOL et al. 1973). Podzolization in quartzose sand is apparently favoured by certain types of vegetation which produce acid litter, including ericaceous species and the genera *Pinus* and *Quercus* (ETHERINGTON 1975).

In the southeastern coastal plain spodosol profiles develop in sandy sediments with water cables at or near the surface during part of the year. These soils are the aquods or ground-water podzols. DANIELS et al. (1976) have studied the spodic horizons (Bh) of North Carolina soils in the Leon and related series. The spodic layers appear as dark brown to black layers composed of sand impregnated with organic matter,with almost no iron and little aluminium present. Apparently organic matter in the form of fulvic acids is released from the litter and the organic matter in the A1 horizon and is carried downward by percolating rainwater. The organic acids are then precipitated by some undetermined mechanism in the Bh horizon. That large amounts of organic acids are leached through these coastal plain soils is obvious from the tea color of the streams draining them.

The spodic horizon is often credited with slowing drainage (PERKINS et al. 1938) or even perching the water table (THOM 1970) and is commonly referred to as a hardpan. However, DANIELS et al. (1976) report that the water table moves freely through the Bh of soils in New Hanover County, North Carolina.

Another important way in which vegetation interacts with abiotic factors is in the process of paludization (BUOL et al. 1973), the accumulation of surface deposits of organic matter. This process might well be regarded as a geologic phenomenon as a pedogenic one. The accumulation of organic material occurs when the rate of litter production outstrips the rate of litter decomposition. The rate of decomposition is slowed down by a number of factors, especially waterlogging which creates anaerobic conditions which inhibit the activity of decomposer organisms. The low soil pH and paucity of nutrients also limit microbial activity. It should be noted that the peat formation here is due largely to accumulation of litter from trees and shrubs and not to a significant extent the presence of *Sphagnum*.

As accumulations of organic matter build up they tend to reinforce those conditions responsible for their formation. Much of Croatan National Forest is covered with peat deposits over 40 cm deep, and these constitute the histosols of the current U.S. soil taxonomy. The Lakes Pocosin in the center of the National Forest, which includes the research area, constitutes a raised bog (HEINSELMAN 1963). Organic matter accumulation began on a poorly drained, flat to concave, land surface and has continued to the point that the thickness of the peat deposits is often greater than one meter and the bog surface is highest in the center where the organic matter is assumed to

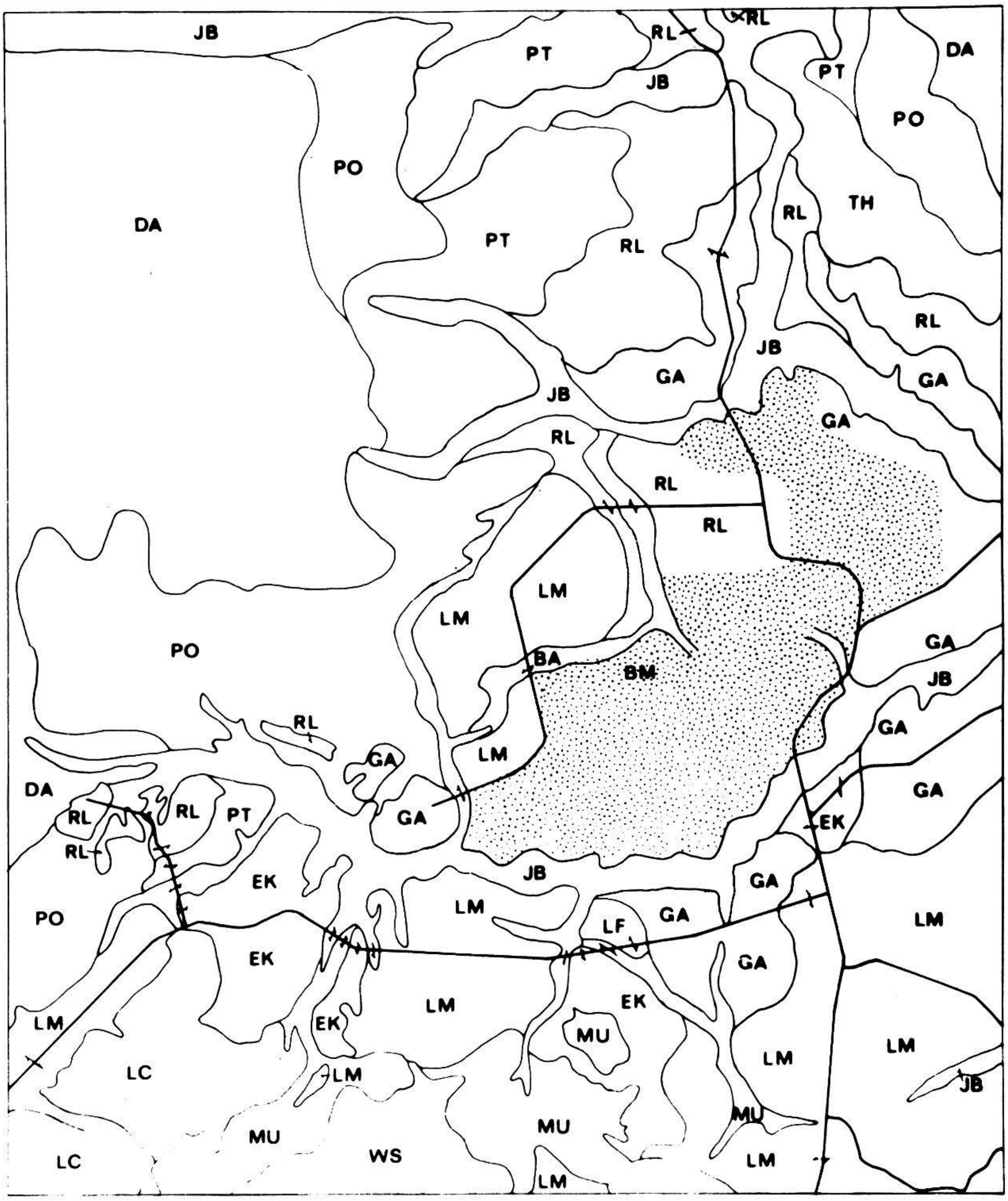

Figure 4. Soil map of the study area. The stippled area is inadequately mapped. Mapping unit descriptions are given in SNYDER (1978). The map was compiled from preliminary photomaps of a Forest Service soil survey (GREEN 1978).

BA = Bayboro
BM = Baymeade
DA = Dare
EK = Echaw-Kureb
GA = Goldsboro-Autryville
JB = Johnston-Muckalee
LC = Leon complex
LF = Leaf
LM = Leon-Murville
MU = Murville
PO = Ponzer
PT = Pantego
RL = Rains-Lynchberg
TH = Torhunta
WS = Wasda

Table 1. Taxonomic classification of soil series.

Series	Taxonomy	
Autryville	Arenic Paleudult	: loamy, siliceous
Bayboro	Umbric Paleaquult	: clayey, mixed
Baymeade	Arenic Hapludult	: loamy, siliceous
Dare	Typic Medisaprist	: dysic
Echaw	Entic Haplohumod	: sandy, siliceous
Goldsboro	Aquic Paleudult	: fine-loamy, siliceous
Johnston	Cumulic Humaquept	: coarse-loamy, siliceous
Kureb	Spodic Quartzipsamment	
Leaf	Typic Albaquult	: clayey, mixed
Leon	Aeric Haplaquod	: sandy, siliceous
Lynchberg	Aeric Paleaquult	: fine-loamy, siliceous
Muckalee	Typic Fluvaquent	: coarse-loamy, siliceous
Murville	Typic Haplaquod	: sandy, siliceous
Pantego	Umbric Paleaquult	: fine-loamy, siliceous
Ponzer	Terric Medisaprist	: loamy, mixed
Rains	Typic Paleaquult	: fine-loamy, siliceous
Torhunta	Typic Humaquept	: coarse-loamy, siliceous
Wasda	Histic Humaquept	: fine-loamy, mixed

Table 2. Outline of soil series.

Mineral Soils of Uplands					
	Well drained	Moderately well drained	Somewhat poorly drained	Poorly drained	Very poorly drained
Fine-loamy	--	Goldsboro	Lynchberg	Rains	Pantego/ Wasda[1]
Loamy	Autryville[2]	--	--	--	--
Coarse-loamy	--	--	--	--	Torhunta
Clayey	--	--	--	Leaf	Bayboro
With spodic horizons	Baymeade[3]/ Kureb[4]	Echaw	--	Leon	Murville

Floodplains		Histosols	
Sandy loam	Muckalee	Organic surface 40-130 cm	Ponzer
Muckey loam	Johnston	Organic surface >130 cm	Dare

1 = with histic epipedon, 2 = with arenic surface, 3 = with Bh over argillic, 4 = excessively drained.

be the thickest. It is hypothesized that the 5 lakes in Croatan National Forest were actually formed by deep burning of the peat during severe drought (WELLS and BOYCE 1953).

Although soils with surface horizons of peat less than 40 cm thick are not classified as histosols they form an important part of the peatland landscape. For example, Wasda soils have histic epipedons which are not thick enough (less than 40 cm) to be called histosols. Most of the soil south of forest route 128 is spodosol with highly organic surface layers (Murville series) which make it ecologically part of the bog system.

The soils of Carteret County were last mapped in 1935 (PERKINS et al. 1938), long before the current soil taxonomy was formulated. A new county soil survey is currently in progress but is not yet available. However, the Forest Service has completed a reconnaissance soil survey of Croatan National Forest and the soil map (Fig. 4) was compiled from the photomaps produced in that survey. The mapping units are somewhat more broadly defined than those of a standard county soil survey but they provide sufficient resolution for soil-vegetation correlations. Table 1 gives the taxonomic classification of the soil series included in the mapping units, and Table 2 differentiates the series in a brief outline. A brief description of each of the mapping units is given in SNYDER (1978).

2. Methods

2.1. *Vegetation*

2.1.1. *Sampling*

The object of study within the circumscribed research area is the "natural vegetation". This excludes agricultural and residential areas and as defined here also excludes pine plantations in which evidence of site manipulations such as bedding is visible. Disturbed areas such as logging roads and plowed fire lines where the soil had been bared were not studied, but sites which had been prescription burned were included. Much of the *Pinus palustris* land has been cut in the last few years, but if there was evidence of regeneration and the ground cover appeared undisturbed it was considered natural vegetation.