Presettlement Fire Regime and Vegetation Mapping in Southeastern Coastal Plain Forest Ecosystems

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Abstract—*Fire-adapted forest ecosystems make up 95 percent of the historic Coastal Plain vegetation types in the Southeastern United States. Fire suppression over the last century has altered the species composition of these ecosystems, increased fuel loads, and increased wildfire risk. Prescribed fire is one management tool used to reduce fuel loading and restore fire-adapted species, but little information exists on the presettlement extent and location of fire-dependent ecosystems at a level of detail useful to guide land management decisions at the local spatial scale. In an effort to close this knowledge gap, the principles of landscape fire ecology have been applied to develop a detailed presettlement fire regime map for ~200,000 acres of Coastal Plain ecosystems. Factors evaluated include the effects of fire compartment size in the original landscape, fire barriers, fire filters, prevailing wind direction during fire season, topographic and soil factors affecting fire intensity, fire frequency, fire spread, and fire effects on vegetation. The fire regime map was then combined with remnant fire-adapted vegetation surveys, historic aerial photography, digital elevation models, and soil survey information to create a map of presettlement vegetation. This map is being used to develop prescribed burning plans that restore original fire regimes, guide the use of prescribed fire as a management tool, restore fire-adapted vegetation structure and understory species diversity for threatened and endangered species, and enhance ecosystem sustainability.*

Introduction

Ninety-five percent of the forest, shrubland, and grassland ecosystems of the Southeastern United States Coastal Plain have been shaped by the occurrence of fire (Frost 1995). Many of the plant species that inhabit these ecosystems are adapted to either withstand fire by growing rapidly to take advantage of reduced competition following fire events, or regenerate rapidly after fire. Longleaf pine (*Pinus palustris*) / wiregrass (*Aristida stricta*) is the most frequently cited example of a fire-adapted Coastal Plain forest ecosystem. Of the estimated 60 to 90 million acres of presettlement forests dominated by longleaf pine in the Southeast, less than 4 million acres of poor-quality second growth longleaf pine forest remain in the region (Harper and others 1997). Many of these continue to decline due to lack of prescribed fire, or prescribed fire applied at an inappropriate frequency.

In contrast to the mineral soils that support longleaf pine ecosystems, the Lower Coastal Plain of the Southeast has extensive areas of deep organic soil types that support marshes, canebrakes, pond pine (*Pinus serotina*) pocosins (evergreen shrub bogs with pond pine), Atlantic white cedar forests (*Chamaecyparis thyoides*), and nonriverine swamps (Fussell and others 1995). Fire is important in these ecosystems, and the range of fire intensities and

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frequencies is often much wider than those found in upland longleaf pine savannas. The effects of fire suppression in these lowland fire-adapted ecosystems are similar to those in other areas of the Southeast: conversion to less fire-adapted ecosystems; a loss of threatened, endangered, and other rare endemic species; and increased fire risk due to increasing fuel loads (Robertson and others 1998).

Many of these ecosystems occur on Federal lands, where land managers are expected to simultaneously provide wildlife habitat preservation and enhancement, endangered species protection, and wildland fire protection. In addition, Federal lands in the Departments of the Interior (USDI) and Agriculture (USDA) are required to manage lands for multiple uses that include recreation, grazing, forestry, and historic and cultural values. Department of Defense properties must be managed for the military mission. Forced to manage within these constraints, land managers can gain insight for the development and implementation of management strategies by examining the fire history of their land.

Several strategies have been applied successfully in parts of the United States to reconstruct fire history, including fire scar analysis and charcoal sediment analysis (NOAA 2007). Fire scar analysis is of limited usefulness in Southeastern Coastal Plain ecosystems on deep organic soils, because natural fire regimes in these locations began to deviate early after settlement (~1600 AD), predating any surviving tree. Typically, these ecosystems have experienced either catastrophic stand-replacing fires or clear-cut harvesting, destroying the old trees needed for fire history reconstruction. Charcoal sediment analysis is not accurate enough to determine fire regimes in frequent fire regions, and fire regimes detected by this method cannot be mapped spatially at a scale small enough for local management.

A third technique for determining fire history is to apply the principles of landscape fire ecology at a local scale. Using available local data sets, weather patterns, and current knowledge of fire behavior, the local landscape may be broken up into a series of fire compartments. A fire compartment is a unit of the landscape with no natural firebreaks, such that an ignition in one part would be likely to burn the whole unit unless there was a change in the weather or fuel conditions. Within each fire compartment on the landscape, an associated mean fire interval and range of variation may be determined (Frost 1995). Factors such as fire barriers, prevailing wind direction, topography, hydrology, and vegetation determine this interval and range within a specific compartment. Using field surveys for remnant vegetation, historical land survey documents, and photography, maps can be developed at a fine level of detail depicting the most likely distribution of fire regimes and fire-adapted vegetation communities in the presettlement landscape (Frost 2000). These maps may be used to guide land management decisions, determine areas for threatened and endangered species recovery, establish ecological endpoints, or guide ecological restoration efforts. Here, we apply the principles of landscape fire ecology to map the presettlement fire regimes and vegetation of Dare County, North Carolina.

Methods

Site Description

The mainland of Dare County, North Carolina, provides an outstanding example of several fire-adapted ecosystems in proximity to one another. Nearly 200,000 acres in Dare County are managed by the U.S. Fish and

Wildlife Service and the U.S. Air Force. The Dare mainland is a peninsula, 14 miles across, bordered on the north by the Albemarle Sound, on the east and south by the brackish Pamlico and Croatan Sounds, and on the west by the freshwater Alligator River. The long axis of the peninsula extends 29 miles from north to south. The Outer Banks barrier island chain provides protection from the Atlantic Ocean some 20 miles to the east. Though there are two small tidal creeks on the peninsula, there is virtually no relief, and elevations range from slightly below sea level to 4 ft above sea level. Areas below sea level are typically located in and around agricultural fields. The absence of topography means that the vegetation on the Dare mainland is shaped primarily by two major natural factors: fire and salinity.

Soils

A digital soil data layer for Dare County was obtained from the USDA Natural Resource Conservation Service (NRCS). These data layers are digital representations of USDA county soil surveys that contain a soil classification established through field work and aerial photography. Each polygon in the data layer is associated with detailed information describing physical characteristics of the soil, the type of terrain it is commonly found in, as well as potential vegetation types. The soil layer becomes the base map for classifying presettlement vegetation.

Remnant Vegetation

Vegetation survey information for fire adapted plant species and communities were grouped by soil series in the Southeastern United States, including Dare County (Frost 2000). This survey information was used for preliminary mapping of vegetation. Special attention was afforded to vegetation species that are considered to be highly fire adapted, or plant species that are remnants of fire-adapted vegetation communities displaced by fire suppression, such as pitcher plants (*Sarracenia* ssp.), wiregrass (*Aristida stricta*), and canebrake (*Arundinaria gigantea*). In some cases, downed logs and plant remains that have been buried in organic soil are preserved and can be identified. These provide clues to determine what vegetation may have previously occupied a converted site. On rare occasions, old individual trees may have fire scars that can be used to age past fires.

A second source used to delineate presettlement vegetation is a series of aerial photography taken in 1932 depicting the entire Dare County mainland. Because effective fire suppression was not possible in Dare until after the establishment of internal roads in the 1960s, these images are representative of the fire-shaped landscape. The photo series was digitized using a high-quality desktop scanner and orthorectified using a second-degree polynomial rectification procedure. Images were then stitched together to form a seamless mosaic of the peninsula. From this mosaic, vegetation types and fire patterns were identified and used to further refine the base map. Finally, all vegetation data were recorded by soil type and then plotted on a map for a rough first draft of presettlement vegetation. Using information from the soil map, vegetation plots, and historical photography, a first draft of presettlement vegetation was digitized into a GIS database.

Historical Maps

A third source of information was historical timber surveys and older maps collected from former forest industry owners and the U.S. National Archives. These maps have descriptions of the forest landscape and show the locations of remnant timber stands and place names that include natural history clues.

Topography

Digital Elevation Models (DEMs) for eastern North Carolina were developed beginning in 2000 using Light Detection and Ranging (LiDAR) technology, a highly accurate method of measuring elevations on Earth's surface. These models were used to develop a topographic map showing 1 ft isopleths of elevation change across the peninsula (fig. 1). Because elevation corresponds closely with moisture regime and vegetation type, these data were used to further refine the presettlement vegetation map.

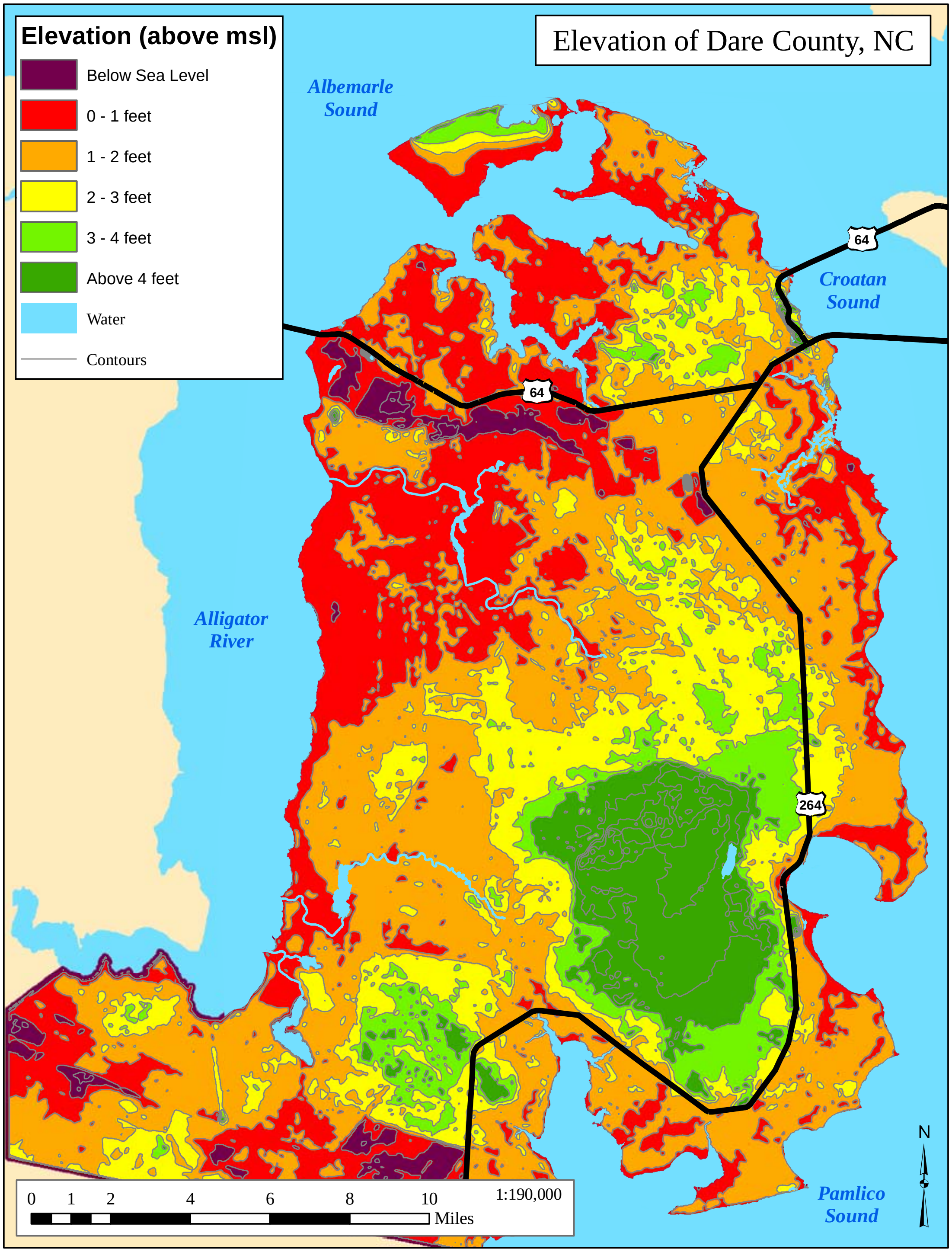

Figure 1—Color-coded topographic map for Dare County. Nearly the entire county is below 5 ft above sea level. The low pocosin dome (dark green), an area where peat has built up over time to rise slightly above the surrounding land, is clearly visible in the southeast.

Fire Regime Map Creation

All fire indicator species and communities were plotted over the soil map to generate a first draft of presettlement fire regimes. In areas where data were scarce, it was useful to construct general fire frequency gradients over a larger area that included the study area. Because vegetation and fire interact in a complex mechanism of feedback, frequent fire plant communities and infrequent fire plant communities are rarely found to abut one another directly; usually a gradient exists between extremely different communities. Landscape features that affect the spread of fire were determined and considered with respect to the prevailing winds during fire season. Hydrology data were used to identify barriers to fire spread, including nonflammable vegetation types and bodies of water. This knowledge is used to delineate isopleths between areas of similar fire frequency, where the lines form the boundaries between compartments with equal fire frequencies. The effect is similar to that of a contour map; the contours represent different fire-return intervals rather than elevation.

Feedback into Vegetation Map

The vegetation and fire frequency maps were compared, and areas were identified that needed further investigation. These included areas where fire-infrequent species were identified in fire-frequent compartments, or areas where gradients between infrequent fire and frequent fire appeared very steep. Collaborative discussions between the authors were used to resolve discrepancies when they were found, and both maps were adjusted using GIS editing tools.

Historical Document Validation

Final examination of the maps was done using historical documents from multiple sources. For Dare County, these sources included land grant documents from the 18th century and early survey plats (fig. 2) with witness trees and descriptions of vegetation. Personal accounts and newspaper articles were collected describing logging work from the late 19th century. In several cases these sources were used to adjust vegetation and fire frequency polygons.

Results

Presettlement fire regimes are displayed in figure 3. The largest fire frequency class had a mean fire interval of 4 years, and comprised 63,468 acres (32.5 percent) of the Dare County mainland where frequent-fire marsh vegetation along the eastern shoreline promoted the spread of fire into the peninsula interior under hot, dry conditions. The second-largest fire frequency class had a mean fire return interval of 25 years, and covered 35,116 acres (18 percent) of deep, wet peat soils toward the western interior portion of the peninsula. Transition areas are represented by the 6-year and 9-year fire return interval classes. These areas were narrow when wet soils forced a steep fire gradient and were wider where broad lenses of mineral soil promoted drier conditions. The smallest fire frequency class had a mean fire return interval of 2 years, and occurred on 1,192 acres (0.6 percent) of upland in the northeast of the county, where drier upland fuels and continuity with large areas of frequent-fire marsh, canebrake, and pocosin upwind to the south and southwest combined to raise fire frequency. All presettlement fire frequencies are listed in table 1.

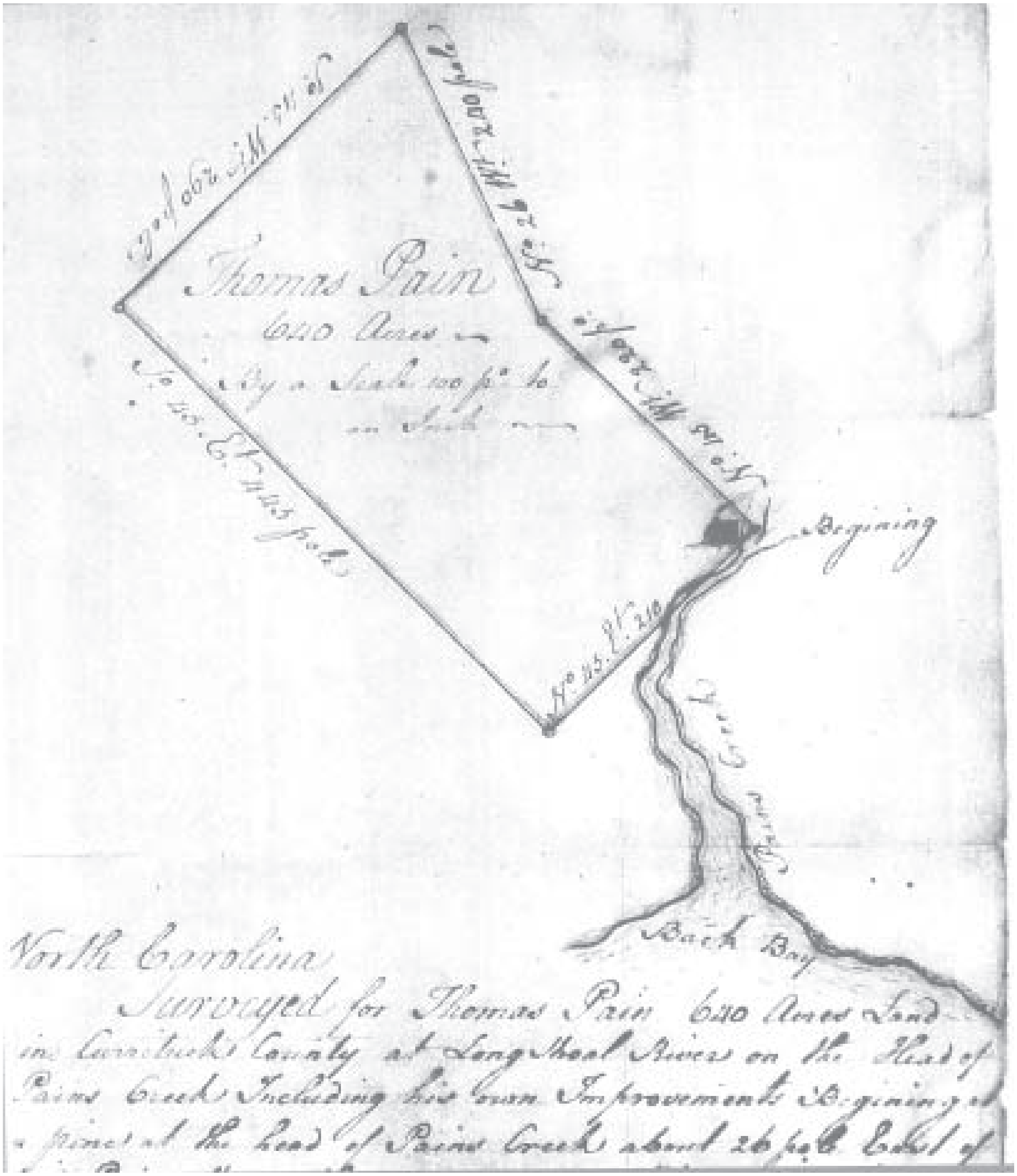

Figure 2—1765 land grant survey for Thomas Pain, the first settler on Pains Bay, southeastern Dare County, just north of Long Shoal River. The portion of interest for agriculture was a pine ridge near the center of the tract. Beyond the pine ridge to the northeast, the land was described as "the Desart," referring to treeless canebrake and pyrophytic (fire-maintained) low pocosin with sparse pond pine. Sea level rise over the intervening 240 years have converted the original house site to a brackish marsh today.

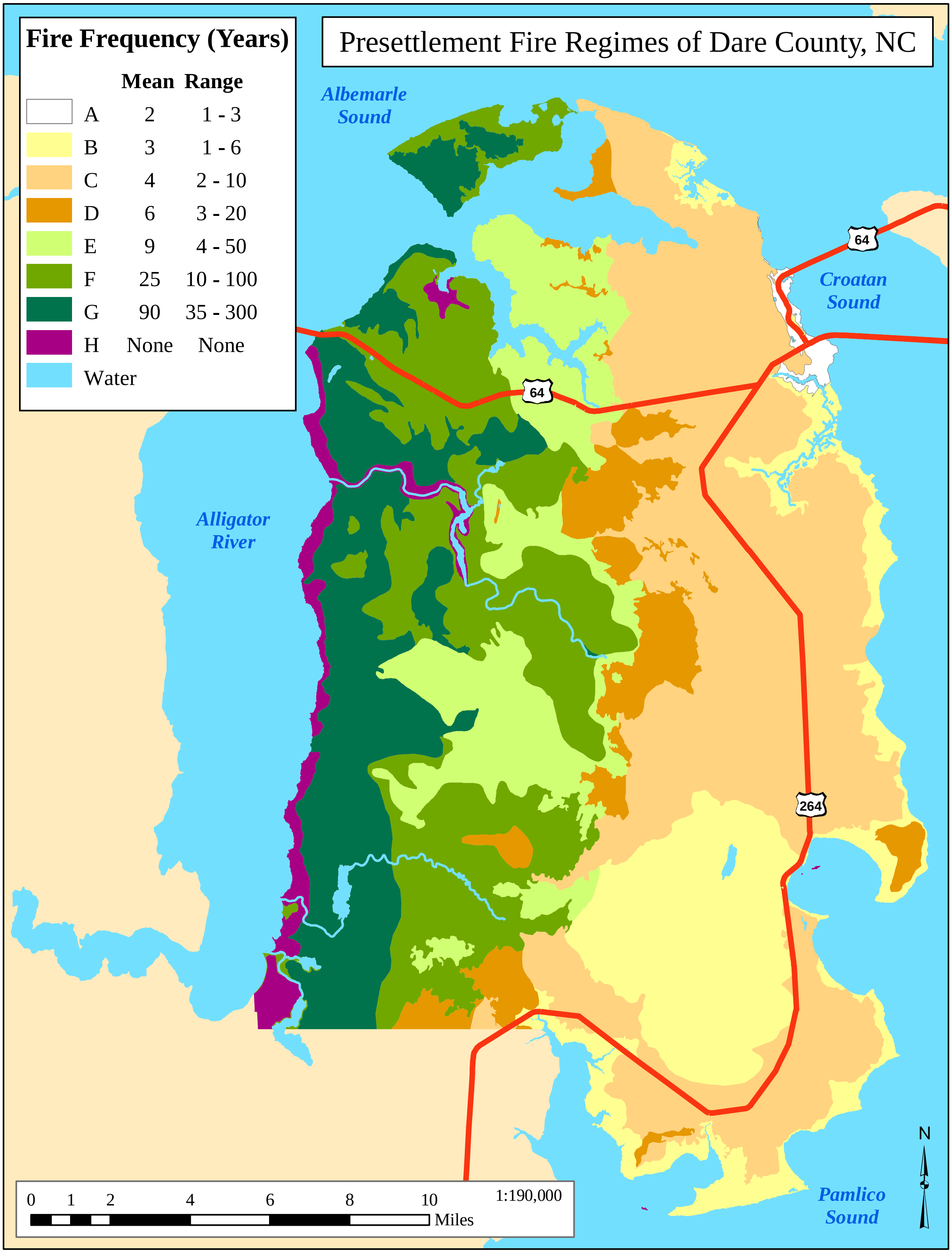

Figure 3—Fire regime maps, using cool colors to represent long fire intervals and warm colors for more frequent fire intervals (roads superimposed for reference).

Presettlement vegetation is displayed in figure 4. The largest two classes were the fire-frequent canebrake (33,823 acres) and pond pine pocosin (38,445 acres) vegetation types, which occur on the eastern portion of the peninsula. These are fire-dependant vegetation communities with similar, sparse pond pine overstories. Pocosin vegetation refers to an understory dominated by the shrubs little gallberry (*Ilex glabra*), big gallberry (*Ilex coriacea*), fetterbush (*Lyonia lucida*), and pepperbush (*Clethra alnifolia*). Canebrake refers to an understory dominated by the herbaceous giant cane (*Arundinarea gigantea*). Typical pond pine/canebrake is found in parts of the peatland landscape where fire frequency runs from 2 to 6 years. With fire intervals between 7 and 12 years, some pocosin shrubs become established, and the community consists of alternating canebrake and pocosin, with cane dominant for a few years after a fire and pocosin shrubs becoming increasingly prominent toward the end of the interval. With longer fire intervals, pond pine/canebrake is replaced by pond pine/pocosin. Fire-infrequent vegetation classes Atlantic white cedar (26,681 acres) and peatland long fire interval pyromosaic (31,349 acres) dominate on the western side of the peninsula under fire interval classes F (10 to 100 years) and G (35 to 300 years). Position in the fire landscape along with less flammable litter-layer fuels contribute to a reduction in fire frequency in these areas. Fires carried easily by the frequent fire fuel types

Table 1—Presettlement fire frequencies of Dare County.

Fire frequency class	Mean fire interval (years)	Estimated historic range of variation (90% of fires) (in years)	Acres	Percent of total
A	2	1 - 3	1,192	1
B	3	1 – 6	28,727	15
C	4	2 – 10	63,468	32
D	6	3 – 20	12,484	6
E	9	4 – 50 depending upon vegetation type and location in the landscape	21,993	11
F	25	10 – 100 depending upon vegetation type and location in the landscape	35,116	18
G	90	35 – 300+ depending on landscape position along the fire frequency gradient	26,357	14
H	None	Nonflammable, tidal cypress-tupelo swamp	4,712	2
W	Water		1,239	1

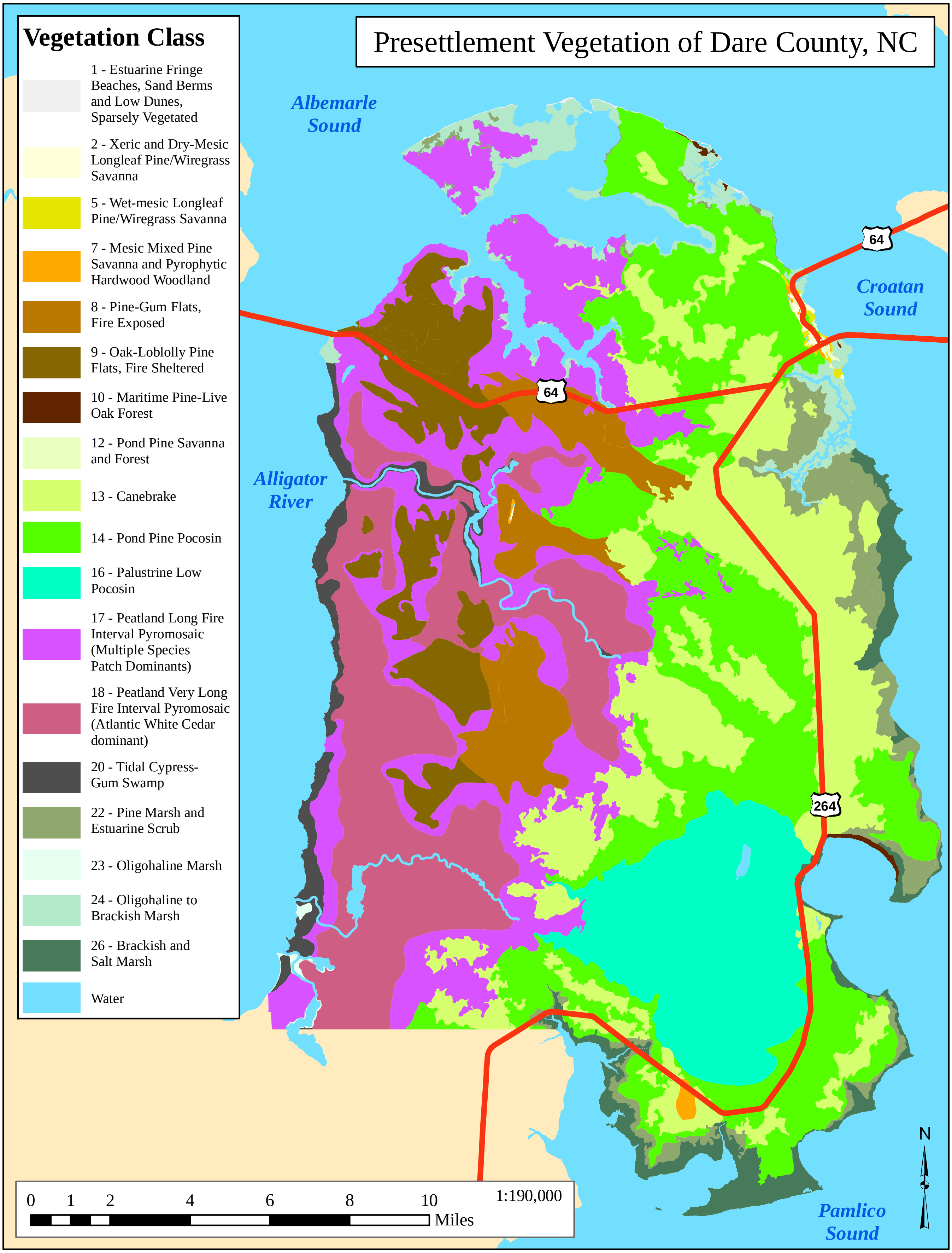

Figure 4—Presettlement vegetation map. Frequent fire vegetation types form bands along the eastern side of the peninsula, with vegetation becoming less frequently burned from east to west (roads superimposed for reference).

on the eastern side of the peninsula have little access to the western forests. Fires can approach only from the east and southeast, while any fires carried on the prevailing southwest winds are blocked by small lakes, streams, and the nonflammable band of cypress-gum along the Alligator River. Moderate fire return interval vegetation types such as oak-pine flats (11,977 acres) and pine-gum flats (9,756 acres) occur at the transition zones between frequent and infrequent fire regimes. These vegetation communities are largely missing in the current landscape due to site conversion for plantation forestry and agriculture. All presettlement vegetation types are listed in table 2.

Discussion

The pronounced east-west fire frequency gradient on the Dare County peninsula is driven by salinity. The brackish water along the eastern margin sustains flammable saltmeadow cordgrass (*Spartina patens*) / saltgrass (*Distichlis spicata*) and black needle rush (*Juncus roemarianus*) marshes, which form a continuous wide shoreline band stretching some 50 miles (80 km) from the Albemarle sound, down the length of mainland Dare, to the Pamlico sound at the bottom of the peninsula. This fire corridor graded into flammable canebrake immediately to the west. The boundary between brackish marsh and salt-intolerant canebrake likely occurs at the western limit

Table 2—Presettlement vegetation of Dare County.

Vegetation type	Acres	Percent
Estuarine fringe beaches, sand berms and low dunes, sparsely vegetated	130	0.1
Xeric and dry-mesic longleaf pine/wiregrass savanna	197	0.1
Wet-mesic longleaf pine/wiregrass savanna	161	0.1
Mesic mixed pine savanna and pyrophytic hardwood woodland	347	0.2
Pine-gum flats, fire exposed	9,756	5.0
Oak-loblolly pine flats, fire sheltered	11,977	6.1
Maritime pine-live oak forest	223	0.1
Pond pine savanna and forest	160	0.1
Canebrake	33,823	17.3
Pond pine pocosin	38,445	19.7
Palustrine low pocosin	18,560	9.5
Peatland long fire interval pyromosaic	31,349	16.1
Atlantic white cedar	26,681	13.7
Tidal cypress-gum swamp	3,726	1.9
Pine marsh and estuarine scrub	6,812	3.5
Oligohaline marsh	288	0.1
Oligohaline to brackish marsh	5,387	2.8
Brackish and salt marsh	6,023	3.1
Water	1,247	0.6
Total	**195,291**	

of storm overwash. In contrast, on the west side, nonpyrophytic cypress-gum swamp fringes the fresh waters of the Alligator River in a narrow band. The short fire interval marsh and cane communities of the eastern side and the nonflamable river swamp on the west comprise the extremes of a cross-peninsula fire frequency gradient. Between these extremes, a kilometer wide swath of canebrake graded into pocosin vegetation where fire frequency was low enough to allow the development of a dense shrub understory. To the west of the pocosin vegetation, a large-scale patch mosaic of wooded wetland ecotypes occurred at decreasing fire intervals. This mosaic was made up of pocosin, pond pine forest, black gum (*Nyssa biflora*) forest, pond cypress (*Taxodium ascendens*), loblolly bay (*Gordonia lasianthus*) forest, and Atlantic white cedar. Fire-exposed pine-gum and fire-sheltered oak-pine forests occurred on mineral soil lenses in the peninsula's interior. The patch mosaic was bounded on the west by a relatively narrow band of cypress-gum swamp, only 100 to 300 m wide, along the Alligator River.

A certain amount of uncertainty is inherent in the construction of presettlement maps. The polygons delineated represent our best estimate of the locations of specific fire-adapted communities and fire regimes. In many cases these estimates are confirmed by 1934 aerial photography, land grant documents, and historic maps, but it is important to realize these sources have limited spatial accuracy. This form of mapping does not lend itself to quantitative accuracy assessment, and the resulting maps should not be regarded as truth. Instead, they represent a snapshot of the many likely fire and vegetation patterns that have existed since these communities became dominant nearly 5,000 years ago.

No ecosystem is static, and many things have changed over the 400 years since European settlement, including extensive logging of Atlantic white cedar and loblolly pine, conversion of hardwood forests on mineral soils to agricultural fields, widespread alteration of hydrology, changing climate, and rising sea level. The changes dictate that these presettlement vegetation and fire regime maps should not be used to demonstrate what the current landscape should look like, but rather used as background information for managing existing vegetation. For example, special attention may be appropriate for the oak-pine and pine-gum forest types. These forest types occupied a moderate-frequency fire niche in the landscape that is currently not replicated by fire or management activity in Dare County. Frequent-fire vegetation communities such as low pocosin and canebrake are much smaller than they would have been in the presettlement landscape. At the present, 43 percent of presettlement extent of low pocosin and no pure canebrake communities remain. On the western portion of the peninsula, fire-intolerant vegetation types are now encroaching into what were once areas of low- and mid-frequency fire. This encroachment reduces habitat for threatened and endangered species, particularly the red-cockaded woodpecker, which inhabits open, frequently burned pond pine woodland ecosystems. Active management to increase the acreage of pond pine woodland burned would benefit these species.

These techniques may be useful throughout the Southeastern United States, where other techniques for establishing presettlement fire regimes and vegetation composition have proven less useful. The GIS datasets used in this analysis are freely available through online Federal data distribution Web sites, and historic documents may typically be obtained from State and Federal archives. Other sources of information, including historic aerial photography and maps, may be obtained from local land management offices, former landowners, and local history societies.

Conclusions

The principles of landscape fire ecology were applied to construct a map of presettlement fire regimes and presettlement vegetation in Dare County, North Carolina. In an area of the country where traditional fire history reconstruction techniques such as fire scar chronologies are not available, these techniques provide a method to create a useful product for the land manager. These presettlement maps should serve as a useful guide for prescribed fire management, restoration ecology, and ecosystem management planning for the current and future ecosystems of Dare County.

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