

A Temporal Analysis of Vegetation Dynamics and Community Perceptions of Buxton

Woods

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Abstract

Buxton Woods is one of the largest tracts of contiguous maritime forest on the Atlantic Coast and provides important ecosystem services and social benefits within the dynamic barrier island system of Hatteras Island, NC. This study characterizes the extent, rates, and reasons for change in the vegetation of Buxton Woods, as well as stakeholder perceptions of change in the Woods. The preservation of Buxton Woods as a designated North Carolina Coastal Reserve site started in 1988, and in the same year plots were established by the Carolina Vegetation Survey to sample vegetation composition and structure. Resampling three of the original vegetation plots in 2021 revealed distinct changes in the structure and composition of the vegetative community in Buxton Woods, including a shift to more herbaceous species and fewer large canopy trees. Each plot gained and lost species, however, overall species richness remained relatively constant since 1988. These changes could be due to a range of disturbances to the maritime forest such as wetter soils due to sea-level rise, canopy loss, saltwater inundation and damage from storm events, and disease. Analysis of eleven qualitative interviews with residents of Hatteras Island illustrates that key values of the Woods for recreation, sustenance and personal well-being contribute importantly to a sense of place. Interviews also offered accounts of changes in Buxton Woods that align with mechanisms suggested by the vegetative data, including canopy loss and storm impacts. The importance of Buxton Woods as a cultural and environmental asset suggests balancing community values with various management methods are crucial to its continued preservation for future uses.

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Introduction

Barrier islands are ever-changing and dynamic systems that form adjacent to the coast through the accumulation of sand, and natural forces such as waves, winds, tides, storms, and sea level change. The human and natural communities within these islands are influenced by and adapted to the shifting environmental conditions of barrier islands such as inundation by water, salinity, and exposure to wind. As coasts face increasing storm frequency and intensity, sea level rise, and other disruptions related to climate change along with increasing human inhabitation and development, the rate and extent of dynamic change may exceed the adaptive capacity of barrier islands. This could have detrimental impacts for the many diverse coastal ecosystems, such as estuaries or maritime forests, and the crucial ecosystem services they provide. Because of this, management of maritime forests is especially important, as their deterioration can negatively impact the natural and human communities that rely on them. Understanding which ecosystems are at risk for highly disruptive events is extremely relevant as coastal environments are under the constant pressure of the impacts of human development and severe storms. Failing to protect these coastal ecosystems can cause a loss of ecosystem services, resulting in a decrease in water quality and reduced coastal protection from floods and storm events (Barbier et al., 2011).

Buxton Woods, a maritime forest found on Hatteras Island on the Outer Banks of North Carolina, was established in 1988 by the State of North Carolina. The State purchased a 152-acre tract to establish the Buxton Woods Coastal Reserve, which has grown to nearly 1,000 acres and is protected as a dedicated state nature preserve. Even though Buxton Woods is protected, it has been historically altered by human activities and natural phenomena, and, like all barrier island ecosystems, it is undoubtedly continuing to change. In this study, we will explore the type,

extent, rates, and reasons for change in the vegetative communities within the maritime forest of Buxton Woods. We also examine residents' perceptions of the change in Buxton Woods within this relatively resilient and protected coastal social-ecological system.

Barrier Islands

Barrier islands are intricate systems influenced by coastal gradients, sea level change, wave energy, and available sediments (Stutz et al., 2011). Waves continually exert influence on the islands, principally through the movement of sand.

Vegetation influences island sediment distribution and vice versa. The feedbacks between vegetation and sediments produces unique vegetative communities and landscapes. Sandy beaches and dunes are characteristic ecosystems located on the ocean side while maritime forests and marshes are located on the estuarine side (Fig. 1). Each barrier island ecosystem supports different functions. Some ecosystems, like dunes, have high resiliency whereas others such as maritime forests, are adapted to be resistant against constant change.

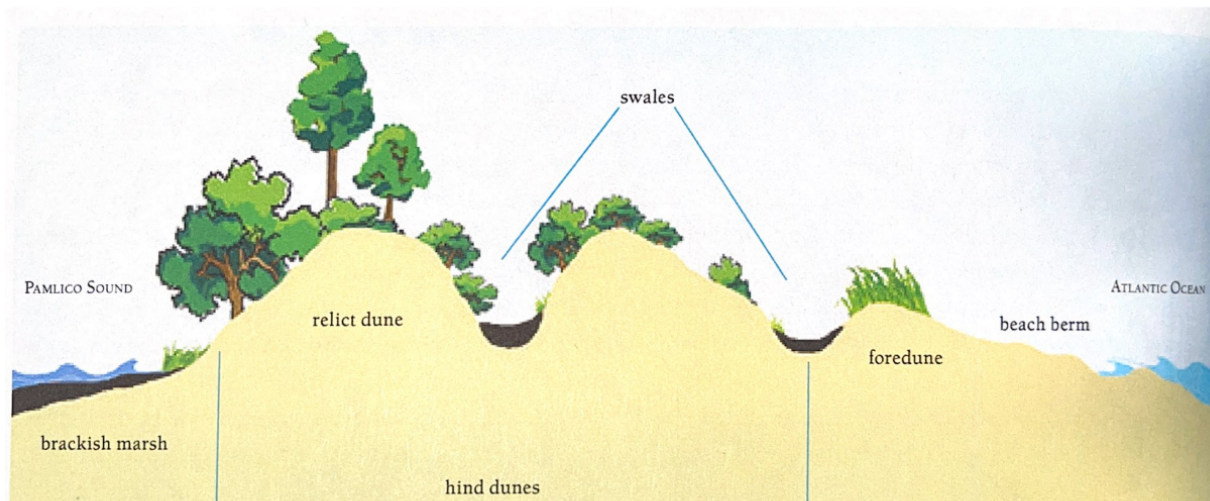


Figure 1. A Cross-Section of a Barrier Island (Faucette, 2020)

Maritime forests are late-successional ecosystems. Ecological succession is the process of ecological communities adapting and changing over time in response to natural or anthropogenic disturbances (Chang et al., 2019). Late-successional ecosystems contain more mature vegetative species with high resistance to disturbances which provide protection to the interior of the forest (Hansen, 2014). Maritime forests provide indispensable ecological services such as: erosion control, coastal protection, nutrient cycling, water purification, and habitat (Barbier et al., 2011). These ecological services occur within an ecosystem that is frequently exposed to disruptive events. Forest species are adapted to withstand the many stressors to which they are exposed. The forest canopy species are adapted to withstand high winds and salt spray and protect understory and landward vegetation that are themselves adapted to the sandy soil and limited freshwater supplies on barrier islands. Changes in the environmental stressors to which plants are exposed result in state changes of vegetation and changes in annual net primary production, species composition, evapotranspiration, and structural diversity within maritime forests.

The social-hydrological cycle provides an example of the pressures experienced by maritime forests from storms and anthropogenic effects. The social-hydrological cycle in maritime forests is complex, with reservoirs affected by various natural processes in the system. Water is naturally stored in reservoirs, including confined and unconfined groundwater aquifers, vegetation, surface water bodies such as interdunal ponds, and the atmosphere. Fluxes in the hydrological cycle are affected by several factors and have a variety of effects on the structure and composition of the forest. An influx of water in the freshwater lens caused by rain or sea-level rise can raise the water table, inundate low-lying areas, and influence sediment transport.

Natural Disturbances

Barrier islands are dynamic, but the different ecosystems that comprise them experience different frequencies and levels of disturbance. A notable indicator of a barrier island's resilience and resistance is biodiversity. Resilience is the amount of disturbance a system can tolerate without a state change (Zinnert et al., 2017). Resistance refers to the stabilization of sediments that creates a barrier to overwash and prevents landward migration of the barrier island (Zinnert et al., 2019). As an ecosystem's biodiversity increases, the resilience and resistance against catastrophic events such as severe storms and climatic change increases (Parlin et al., 2019).

Disruptive events, such as hurricanes and Nor'easters, can be detrimental to slow-growing vegetative species, such as live oak. However, they also allow for the succession of rapid-growing species such as loblolly pines to establish canopy cover after a disturbance (Schultz, 1997). This canopy cover provides protection for the interior trees of the maritime forest.

While disturbances are commonplace on barrier islands, hurricanes and overwash are an increasing problem for communities on developed barrier islands. Storm overwash results in landward migration of the barrier islands making coastal communities more vulnerable to flooding. The overwash moves sediments behind the frontal dune, where most houses are located. This erodes the shoreline in front of the houses and allows the tide line to move closer to the foundations. As a result, there has been an increased number of studies examining how barrier islands respond to hurricanes and other storm events to assess the vulnerability of nearby communities and coastal ecosystems to storm surge, waves, erosion and other storm variables (Plant and Stockdon, 2012).

Understanding the connectivity and processes of sediment transport across barrier island habitats is critical for improving predictions of island migration and coastal responses to sea-level rise and changes in storm activity. Vegetated dunes are more resistant to erosion than their unvegetated counterparts. Through processes above and belowground, they slow erosion and change the way barrier islands respond to disturbances (Feagin et al., 2015).

Species within maritime forests also have many adaptive mechanisms to withstand different ecological stressors. For example, *Carpinus caroliniana*, or ironwood, has adaptations to withstand moist soils, periodic flooding, and a variety of shade (Wildflower Center, 2021). Ironwood has roots that are spongy, so they can deal with hypoxia and inundation (Fire Effects Information System, 2021). Overall, ironwood and other forest species are able to deal with the changing conditions on barrier islands and within the maritime forests.

Sea-level rise is a factor that impacts the hydrological cycle of maritime forests. Masterson et al. (2014) conducted a study to research how groundwater systems react to increases in sea-level. They found sea-level rise can affect groundwater flow in barrier island aquifers by decreasing the duration of root-zone saturation and the thickness of the freshwater lens as the water table rises (Masterson et al., 2014). As the water table increases, it can indirectly influence how groundwater is released and result in flooding. Saltwater intrusion can also impact vegetation, affecting seed germination. Saltwater intrusion can be measured as total dissolved solids (TDS) or salinity. The inundation and altered sediment transport can impact the vegetation present, as plants are evolutionarily adapted to soil and hydrological conditions. Due to the varying water table, plants have adapted to develop resiliency.

Human Influences

Along the coast, issues caused by climate change and increased human development are more pronounced, foreshadowing the future of barrier islands. Between 1998 and 2011, almost 40% of North Carolina's maritime forests were lost due to human development and other economic uses (Jones et al., 2013). Barrier islands naturally migrate landward through sediment transport, mainly through overwash processes to maintain elevation above sea level. However, this process is now prevented due to construction of artificial dunes that protect roads and residential and commercial developments, cutting off sediment supply to critical ecosystems like maritime forests. Within maritime forests, historical uses have modified the vegetative composition. Maritime forests were a favorable place for development as they provided protection from storms (NC Coastal Reserve, 1996). In order to develop land, however, private lots were clear cut, disrupting the canopy and exposing interior trees to salt spray and other external forces. Humans also introduced non-native, hooved animals, such as wild horses, feral hogs, and cattle, which heavily influenced the vegetative diversity through grazing and trampling (Porter et al., 2014). In addition, development with impervious surfaces like roads, parking lots, and housing, increases runoff, reduces the groundwater recharge rate, and disrupts groundwater regeneration and storage, causing stress on freshwater resources that are already facing pressure, especially with the imminent effects of climate change (Akbarpour and Niksokhan, 2018). The loss of biodiversity as a result of these human activities decreases the resiliency of the maritime forest plant community, as well as its resistance to future events.

As maritime forests and barrier islands are ecologically and socio-culturally important, sustainable management practices are important to maintain the ecosystem services provided.

Protective measures need to be taken in order to ensure important natural resources are not damaged and overrun by anthropogenic forces.

The Outer Banks, Hatteras Island, and Buxton

The barrier islands comprising the Outer Banks of North Carolina were originally formed by deposition of sand through wind-driven tidal systems throughout the Holocene epoch (Moran et al., 2015). Hatteras Island is the easternmost barrier island on North Carolina's coast. This positioning has a large impact on the erosion and accretion of its shoreline. Buxton is in a very interesting position on the island as it experiences both. Its southern shoreline is an area of accretion because of its position to the west of Cape Hatteras, where there is reduced wave action and increased sediment deposition from longshore drift. On the other hand, Buxton's eastern shoreline is an area of high erosion. Between 1852 and 1998, Buxton experienced a net land loss of 4.1 meters per year, for a total of 594 (± 15) meters. One force driving changes to the estuarine shoreline is the closure of the Buxton Inlet in 1962. This prevented sand from being transported to the estuarine side. Between 1852 and 1998, it is estimated that Buxton experienced estuarine shoreline erosion at rates of 0.2 (± 0.4) meters per year (Smith et al., 2008).

The geologic formation of the Outer Banks, as well as unique interactions with people and geochemical cycles, allows for Buxton Woods' richness of plant and animal life throughout history (Touchette et al., 2012). Its location along the Outer Banks causes it to be a transitional area between northern and southern maritime forests, resulting in a unique vegetative community. The vegetative community in Buxton Woods is impacted by a variety of natural occurrences, one being ridge crest formations. Ridge crests are the remnants of previous Cape Hatteras coastlines. Neighboring a ridge crest in a maritime forest is oftentimes a swamp-like swale. The difference in elevation between a Buxton Woods ridge and swale is usually no more

than fifty feet, with the swale at sea level (Touchette et al., 2012). In Buxton Woods, the ridge crests consist of woodier and more dense vegetation, while the swales are inhabited by more water-tolerant vegetation.

Freshwater availability in Buxton Woods is also an important factor for human development on the barrier island. In the past, barrier island communities typically obtained their water from an unconfined aquifer also known as the freshwater lens. However, throughout the years, the water infrastructure experienced increased demand and barrier island communities adopted reverse osmosis as a new way to acquire water. The Buxton community obtains potable water through the Dare County reverse osmosis plant. Similarly, Ocracoke and Roanoke islands and the northern beaches of the Outer Banks also acquire their water through reverse osmosis. A study investigated how changes to the water infrastructure and management influence environmental conditions and change on Ocracoke Island (Pompeii, 2016). He found that the increased access to freshwater caused a boom in population and housing density on Ocracoke Island, which increased the amount of wastewater released into an uncontained aquifer (Pompeii, 2016). Similarly, elsewhere in the Outer Banks, improved access to freshwater through improvements in water infrastructure led to increased population and development.

Buxton Woods's significance as the largest remaining undeveloped maritime forest in North Carolina makes it an important study site to better understand natural and broader anthropogenic impacts of this changing ecosystem. This capstone will explore two research questions regarding the social-ecological system of Buxton Woods. The first research question is whether the vegetative community structure and composition in historical plots in Buxton Woods changed since 1988. To address the surrounding community's perspectives on Buxton Woods,

this capstone also investigates the uses, values, and perceptions of change of Buxton Woods, North Carolina among stakeholders and nearby residents.

Study Site

The Cape Hatteras National Seashore protects parts of three barrier islands: Bodie Island, Hatteras Island, and Ocracoke Island (Basic information, 2021). Our study location is on Hatteras Island with the focus on the town of Buxton and the Buxton Woods Reserve (Fig. 2). In 1987, the NC Coastal Reserve preserved approximately 818 acres in Buxton Woods. The Reserve manages approximately 12,000 acres of lands and waters at eight individual sites along the North Carolina ocean shoreline (NC Coastal Reserve, 1996). Buxton Woods contains one of the largest remaining maritime forests in North Carolina, consisting of one-fifth of total acreage of this ecosystem in the state (NC Coastal Reserve, 1996). Maritime forests are known for their diverse topography; composed of ridges and swales, and the varying elevations host an impressive biodiversity of plant and animal species.

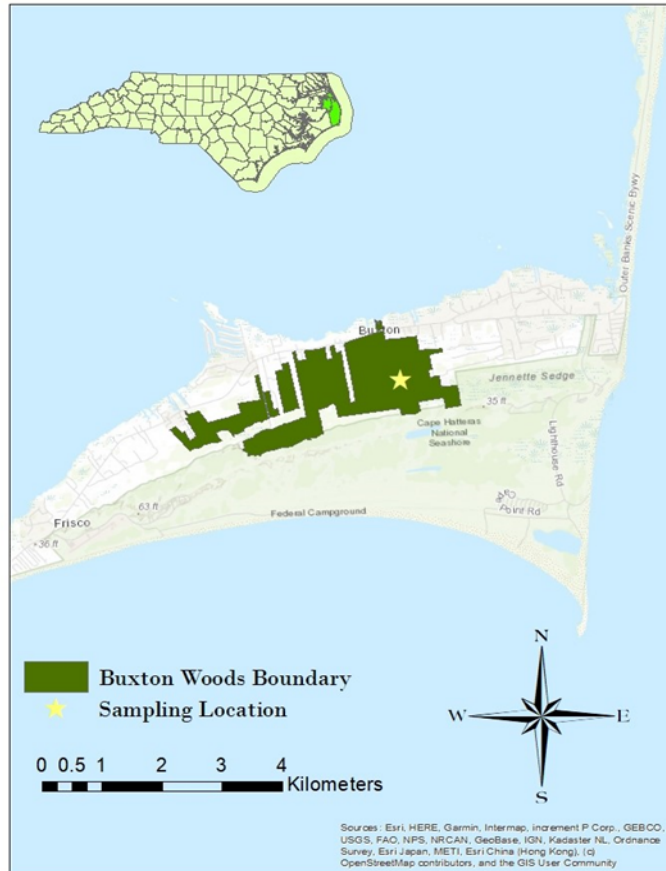


Figure 2. The location of the Buxton Woods Reserve on Hatteras Island, located between the towns of Frisco and Buxton in Dare County, on the Outer Banks of North Carolina. The reserve stretches south from N.C. Highway 12.

This study examined previously sampled plots from Peet et al. to observe the changes within the vegetative community from 1988 to 2021 (1988). We accessed the Carolina Vegetation Survey (CVS) plots in the Buxton Woods Reserve (Peet et al., 1988) by entering the woods through Old Doctor’s Road, Buxton, NC via four-wheel drive, and then walking to the sampling sites. These plots are within the largest contiguous area of the reserve and two out of the three plots are nearby dirt roads (Fig. 2). However, all the plots are relatively protected from development and extensive canopy destruction (Fig. 3). Plots were identified by GPS coordinates, and physical descriptions, noted with distances from roads and landscape features.

These plots were confirmed by location of conduits (metal rods) left in the ground by the original CVS researchers for resampling in the future.

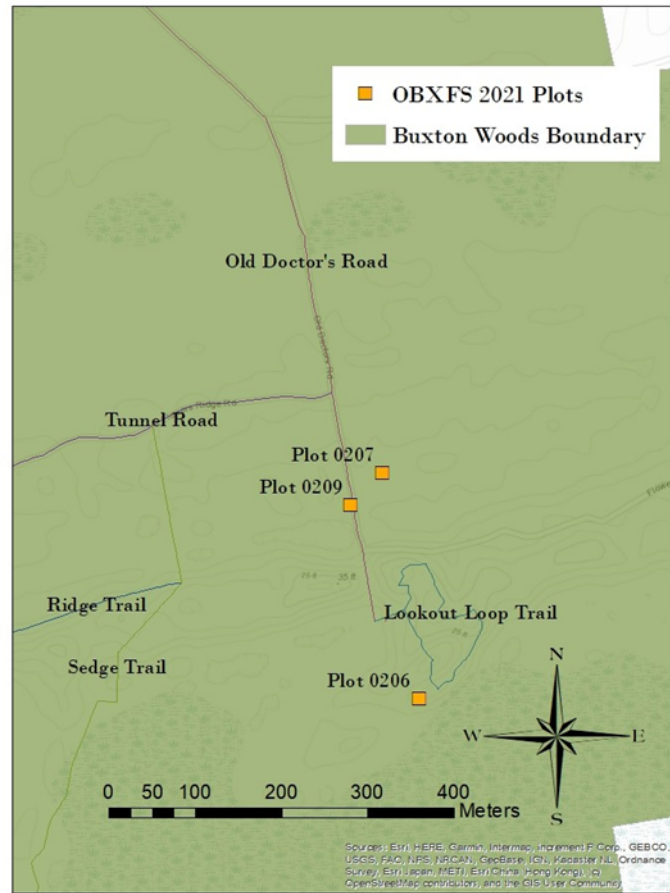


Figure 3. The location of the three plots sampled within Buxton Woods. Geospatial data was found through NC OneMap and NC Natural Heritage Program. ArcMap was used to plot GPS data and construct the map.

We sampled three plots (Fig. 3). Each plot was composed of one or more 10 x 10-meter modules ($100\text{ m}^2 = 1\text{ are} = 0.01\text{ hectare}$). Each plot had varying characteristics, including water saturation and topography. Our first sampled site was plot 0209, also known as the “Lowland Dune” to represent its topography characteristics. Plot 0209 was composed of 5 modules and was situated on flat, low-lying terrain. Our second sampled site was plot 0207, also known as “Swale.” It was located in a dune swale and was made up of one module. Plot 0207 was observed to have standing water present when compared to the rest of the plots due to it being in

a swale. Lastly, plot 0206, also known as the “Upland Dune” was located on a steep ridge. It was composed of 5 modules along the side of the ridge, parallel to the peak.

Natural Systems

Vegetation/Carolina Vegetation Survey Methodology

For our Buxton Woods vegetative study, we used the Carolina Vegetation Survey (CVS) protocol (Peet et al., 1988). The goal of the CVS methodology is to utilize a standard survey method with reliable data yield, to ensure standardization across data sets. The methodology is sufficiently flexible to be utilized in various vegetative communities, topographies, and soil conditions.

The methodology adhered to a modular approach to plot layout, where all plots (entirety of the area subject to study) were measured with one or more 10 x 10 m quadrats, called modules (Fig. 4). These modules allow consistent building blocks to be adapted to a specific area of study and an acceptable time frame of fieldwork.

For our survey, we collected data for three plots: 0209 on Aug 30th and Sept 10th, 0207 on Sept 2nd, and 0206 on Sept 10th. Plots 0209 and 0206 comprised five modules in a parallel line on the southernmost side of the plot origin (i.e. if we were facing the plot origin, our plots would be to our left in a straight line stretching into the woods). Plot 0207 comprised a single module. The corners of each module were demarcated with flags.

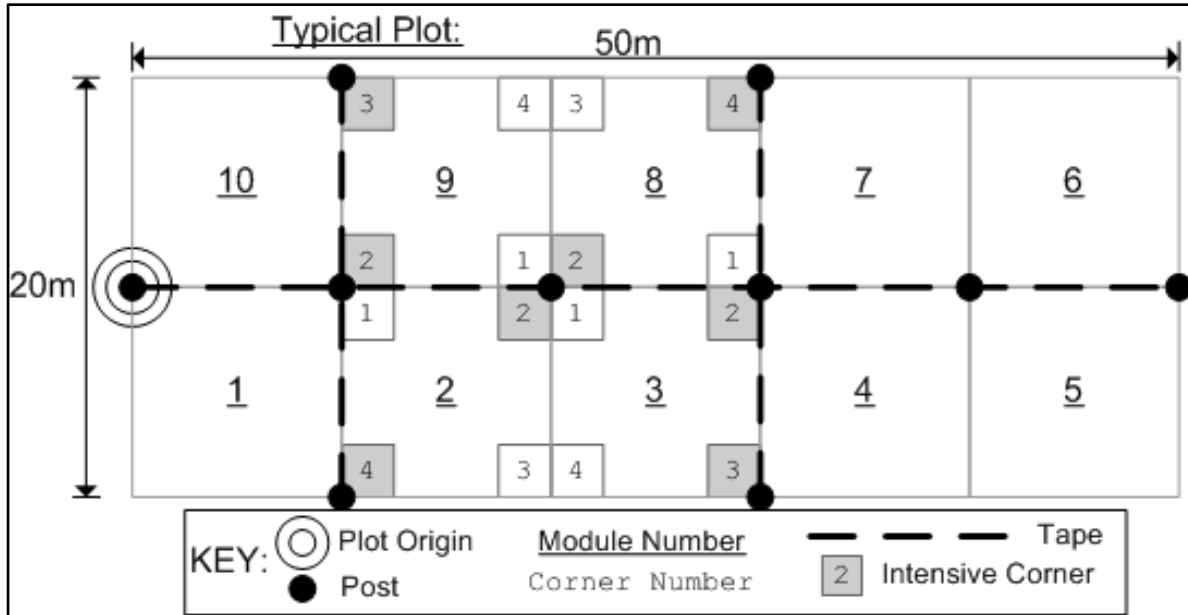


Figure 4. An example of a 10-module plot utilized for the CVS. The circle originating on the left is the first marker for establishing the plot and all measurements extend from this origin. There is a 10 m distance between each marker. Our plots consisted of module 1 for 0207 and modules 1-5 for 0209 and 0206 (Peet et al., 1988).

Vegetation

Two classes of vegetation data were collected and analyzed: cover and woody stems.

Suitable vegetation for data collection was determined if it had “presence,” meaning it had roots within the area of the quadrat in question, but not if it was rooted in another quadrat and grew to cover an adjacent quadrat.

A species “cover” is the amount of surface area obscured by parts of a given species. To determine ground surface area cover within the quadrats, a cover scale from 1 to 10 was utilized to easily assess cover between trace amounts (less than zero) to >95% (Fig. 5).

Cover Classes

Since **we can't measure cover to a high degree of accuracy, we use cover classes based on what the human eye can determine.** The cover classes are based roughly on doubling percents, since we can more easily tell 5% from 10% than 75% from 80%.

1 = trace	6 = 10-25%
2 = 0-1%	7 = 25-50%
3 = 1-2%	8 = 50-75%
4 = 2-5%	9 = 75-95%
5 = 5-10%	10 = >95%.

Figure 5. Cover classes were used to denote percent cover as a scale instead of strict percentages. The scale moved through values of 1-10 and constituted less than 1% to >95% (Peet et al., 1988).

Cover was quantified through two measures: total cover and strata. Total cover, per individual species, was the entire area within the quadrat where said species visually obscured the ground. Strata was measured in three height classes: tree (>5 m), shrub (0.5-5 m), and herb (0.0-0.5 m). The data sheets utilized to record field observations had historically observed species on the sheet (“resampling forms” provided by Peet for the CVS); if the species was present within the quadrat in question, it was marked with an “X” on the sheet. If it had not been observed before, field ID was performed for scientific name or it was categorized as Unknown1, Unknown2, etc. These unknowns were sampled for subsequent lab identification to ensure the species ID was correct. The cover for the overall quadrat was recorded using the scale aforementioned. For each species, the cover of strata in “tree,” “shrub,” and “herb” height categories were also recorded.

For example, if the cover team identified *Carpinus caroliniana* (American hornbeam) we would determine how much ground cover there was, as well as quantifying how much the species covered for “tree” height, “shrub” height, and “herb” height for the collective five quadrats. Considering that this species is a relatively large tree, an example quantification would

be Tree: 6, Shrub: 3, and Herb: 0, since this species would be found primarily at tree height, with maybe a sapling or two within the quadrat, and no presence at herb height.

The second data class utilized for vegetation were woody stems. Within each specified quadrat, the number of saplings and trees of each size class of each species that occurred and reached breast height were recorded; trees for this purpose, and for standardization, were labeled as “stems” henceforth. Breast height for this survey was standardized at 137.5 cm. A scale quantification was used to group and tally diameters (cm): 0-1, 1-2.5, 2.5-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, and 35-40 cm. If the diameter of the stem was larger than 40 cm, the exact diameter of the stem was recorded instead of using the scale. If multiple stems occurred from the same tree base, the largest stem out of the origin was recorded for diameter; the rest were not included within the data. Flagging tape was utilized to mark stems that had been recorded.

Taxonomic Standardization

Most of the species can be reliably identified vegetatively and species identification is largely consistent between observers. However, we did note a few instances where it was difficult to distinguish between two or more members of the same genus and where taxonomic determinations may have differed between observers. In analyzing data from several different observers and two different time periods, most instances involving taxonomic uncertainty in this dataset do not affect broad-scale trends in composition, structure, or species abundance. In instances of uncertainty, two or more similar species are merged into a taxonomic grouping. For example, the physical similarities of *Quercus hemisphaerica* and *Quercus laurifolia* (laurel and red oak, respectively) were near indistinguishable, so both species were coupled and labeled as the *Quercus* group. All other taxa were analyzed as originally determined, and nomenclature was updated to be consistent with Weakley (2020).

Natural Systems Results

Species Richness, Cover, and Composition

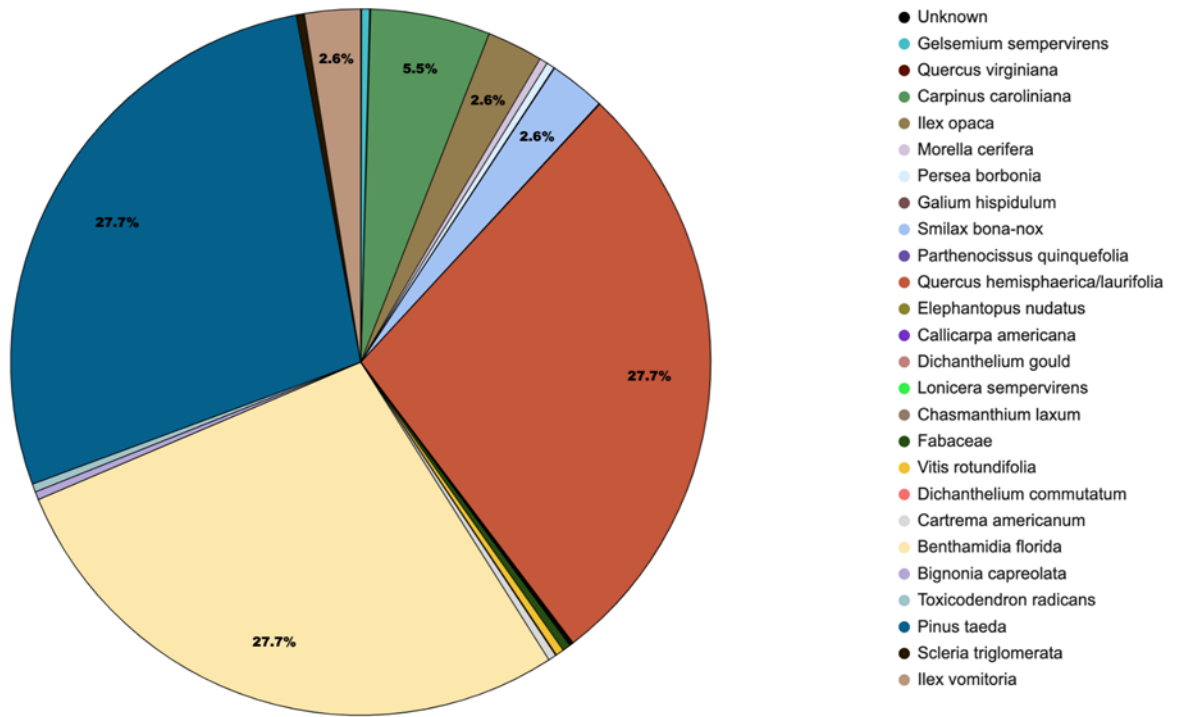
The species richness, cover and composition for each plot sampled in 1988 (Peet, 2013) and for this study resulted from analysis of the vegetative cover data. Across the three resampled plots, there were 44 species documented in 1988 and 47 species documented in 2021. Examining species richness of the individual plots, plot 0209 increased in species richness, going from 20 species to 31 species. Plot 0206 remained similar between sampling occasions, with a slight decrease from 26 to 25 species. Plot 0207 remained constant at 25 species on both sampling occasions (Table 1). While the general species richness was maintained across the 33-year period, the species richness and community composition for plot 0209 experienced a pronounced increase of more than a third additional species. The species that increased at plot 0209 were more salt and moisture tolerant and did not include numerous nor aggressive invasive species.

Table 1. Species richness by plot and overall, for 1988 and 2021.

	1988	2021
0206	26	25
0207	25	25
0209	20	31
All Plots	44	47

Although there was little change in species richness in plots 0206 and 0207 from 1988 to 2021, there were distinct changes in their community composition, which was also seen in plot 0209. In plot 0206, the most notable change was the increase in *Quercus hemisphaerica/laurifolia* (laurel oak) and *Ilex opaca* (American holly) and the decrease in *Pinus taeda* (loblolly pine), *Benthamidia florida* (flowering dogwood). *Benthamidia florida* was especially noticeable as its percent cover went from 27.7% to 0.0% (Fig. 6). In plot 0207, the most notable change was an increase in *Swida foemina* (swamp dogwood) and *Muscadinia rotundifolia* (muscadine grape) and a decrease in *Pinus taeda*, *Persea borbonia* (red bay), and *Berchemia scandens* (rattan vine). *Swida foemina* was especially noticeable as its percent cover went from 39.2% to 72.2% (Fig. 7). In plot 0209, the most striking changes were the increase in *Carpinus caroliniana* (ironwood), *Ilex vomitoria* (yaupon holly), and *Ilex opaca* and the decrease in *Benthamidia florida*, *Pinus taeda*, and *Quercus hemisphaerica/laurifolia* (Fig. 8). Like in plot 0206, *Benthamidia florida* decreased in plot 0209 to 0.0% from 16.5% cover observed in 1988.

1988 Cover - 0206
Upland Dune



2021 Cover - 0206
Upland Dune

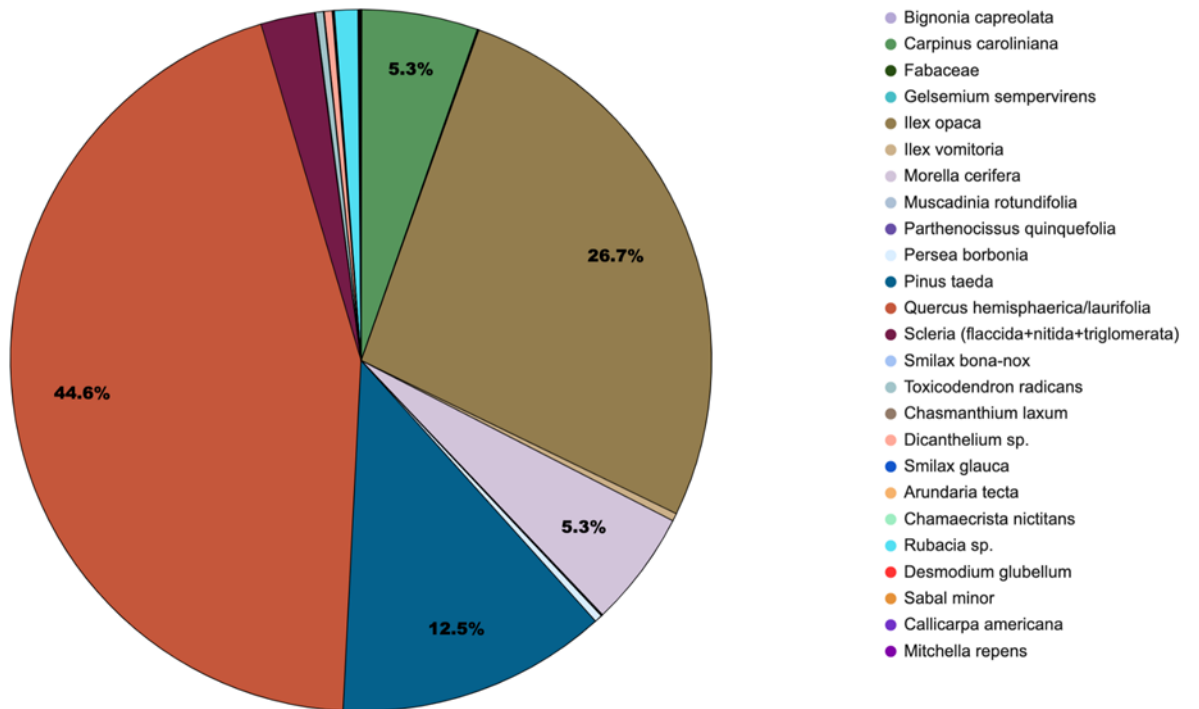
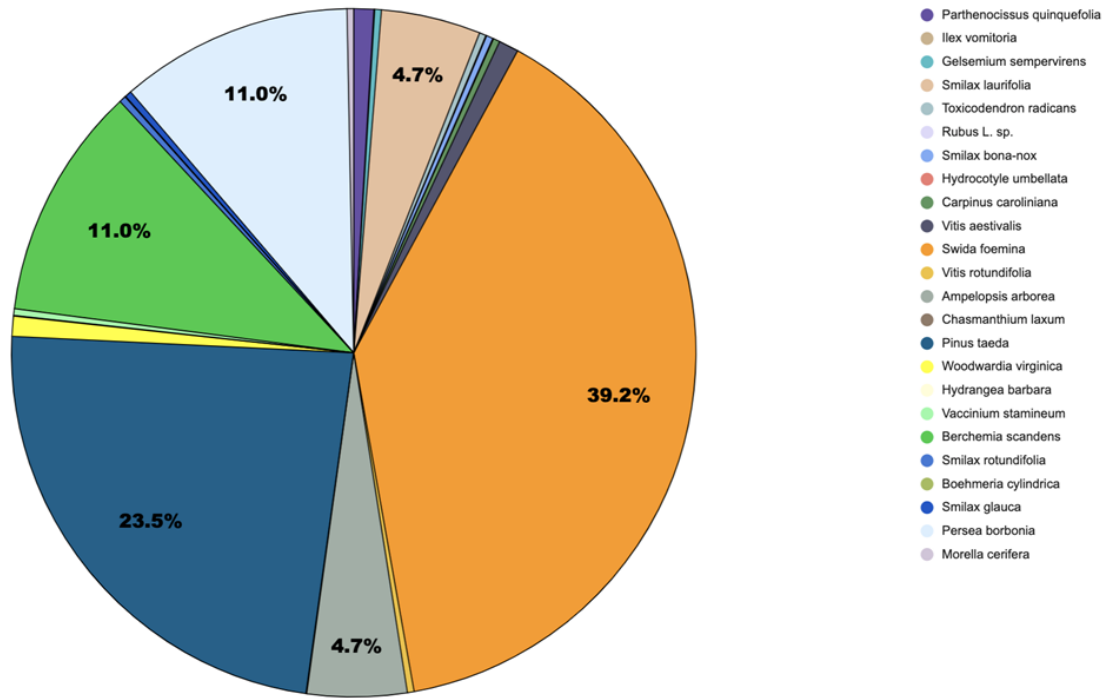


Figure 6. Cover data for plot 0206, “Upland Dune” in 1988 and 2021

1988 Cover - 0207
Swale



2021 Cover - 0207
Swale

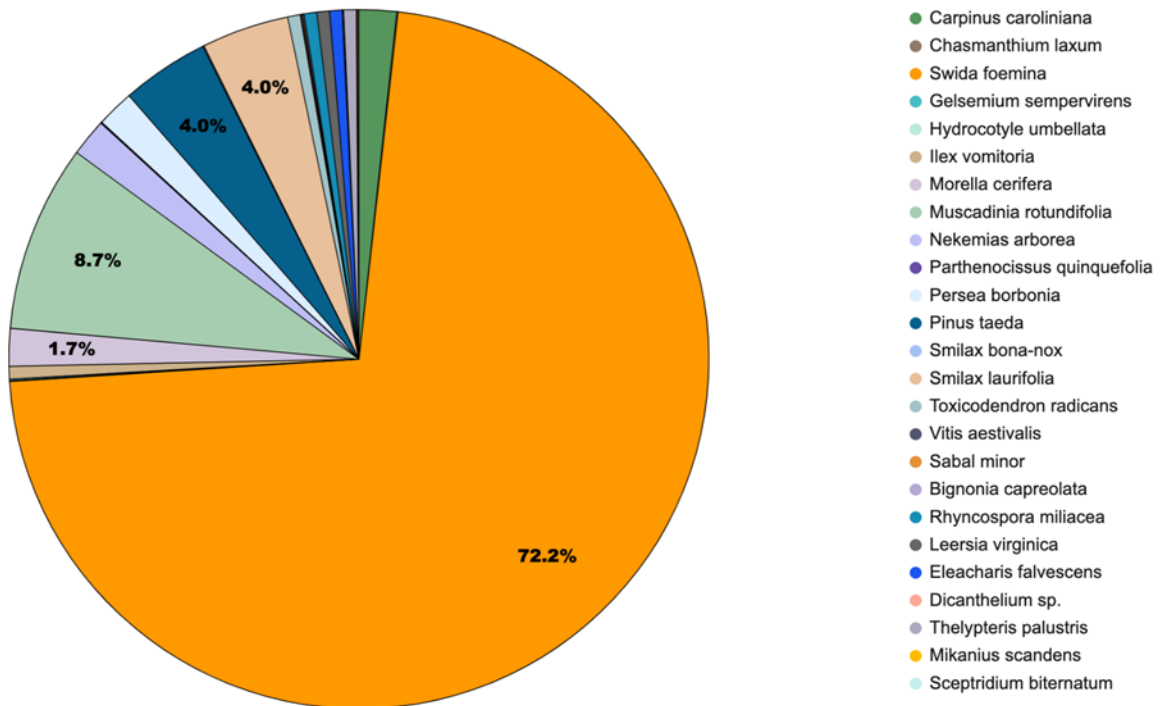
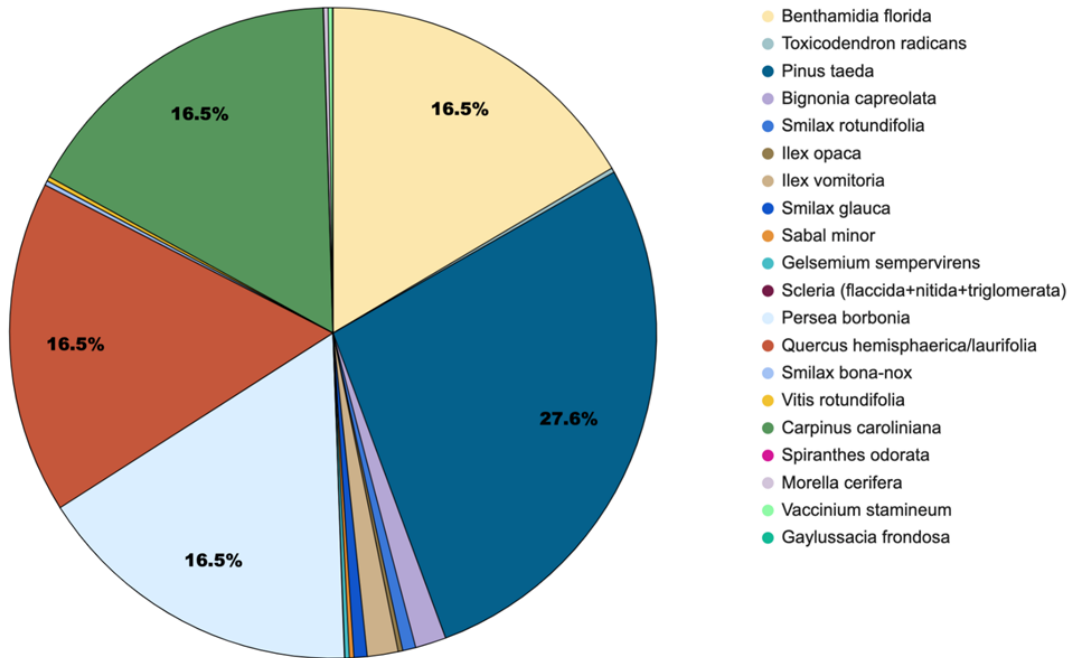


Figure 7. Cover data for plot 0207, “Swale” in 1988 and 2021

1988 Cover - 0209
Lowland Dune



2021 Cover - 0209
Lowland Dune

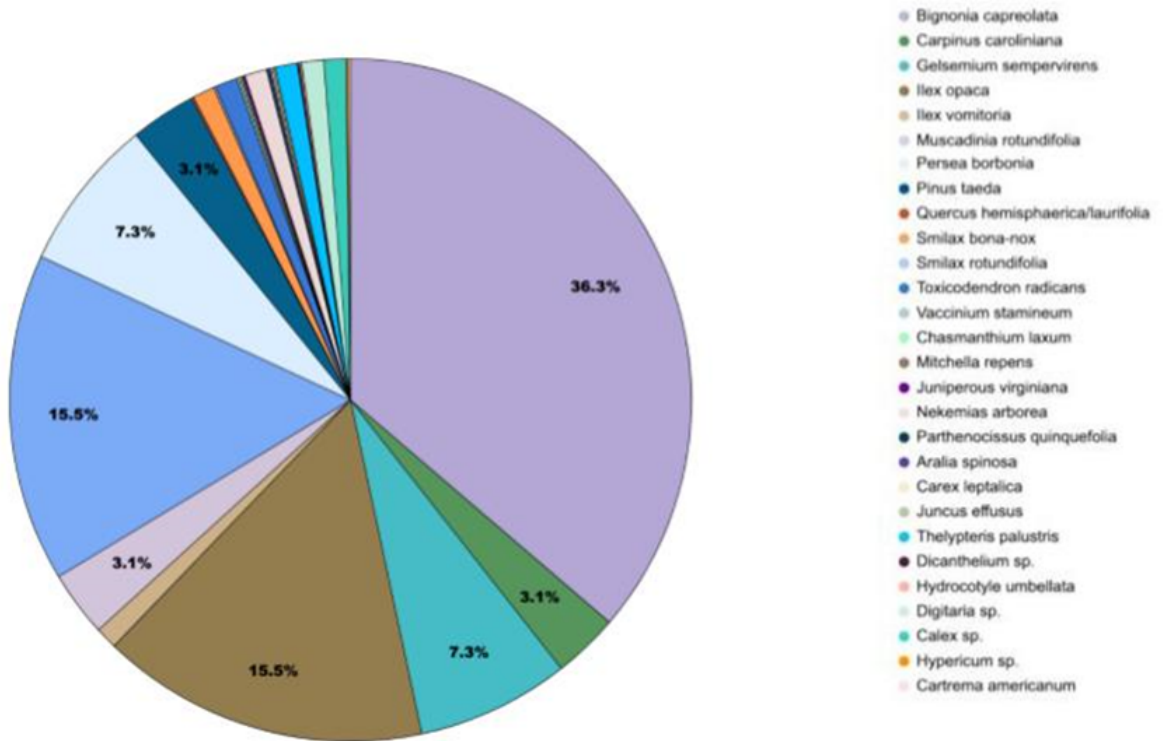


Figure 8. Cover data for plot 0209, “Lowland Dune” in 1988 and 2021

Further exploring community composition, each plot gained and lost species from 1988 to 2021. Across all plots, from 1988 to 2021, 11 species disappeared, and 20 new species appeared. Plot 0206 lost 6 and gained 5 new species. Plot 0207 had a net change of zero since it lost 7 species and gained 7 species. Plot 0209 lost 4 species and saw the greatest increase in new species with 11 (Table 2). Across all three plots, the plants that were no longer present in 2021, all had little tolerance to saltwater inundation and salt spray. Among the species lost were *Berchemia scandens*, *Woodwardia virginica* (southern live oak), and *Ampelopsis arborea* (peppervine). Of the 20 new species present in 2021, most were herbaceous: 16 herbaceous, 2 trees, and 2 vines. However, of the 20 new species, only one was found at a cover class greater than 2. *Rubicia sp.* was found at cover class 3. Therefore, the new species were not found in great quantities.

Table 2. The number of species lost and gained in each plot and overall between 1988 to 2021.

	Lost from 1988	Gained in 2021
0206	6	5
0207	7	7
0209	4	11
Total	11	20

Forest Structure

Changes to forest structure are marked by differences in relative abundance and average cover of growth forms as well as woody stem data. A relative balance of herbaceous, tree, and vine species was recorded in 1988, with each category having 16, 12, and 15 species, respectively. We did not categorize the one unknown species found in 1988. We observed a shift in this balance in 2021, with 24 herbaceous species along with 11 tree and 12 vine species (Table 3). Average cover among these categories remained similar for plots 0206 and 0207, with woody

species comprising just over 90 and 80% of cover respectively. In plot 0209, herbaceous and vine species increased in average cover between sampling occasions, with woody species decreasing from just over 90% to just over 80% (Table 4). These data support a shift in plot 0209 to a more herbaceous plant community within Buxton Woods.

Table 3. Classification of species into three categories (herbaceous, tree, and vine species) for 1988 and 2021. One unknown species was not classified from 1988.

	1988 (1 unknown species)	2021
“Herbaceous” Species	16	24
“Tree” Species	12	11
“Vine” Species	15	12

Table 4. The average cover of growth forms with two categories as woody stems (1) and the combined cover of herbaceous and vine species (2) for 1988 and 2021.

	1988	2021
0206	Over 90% woody stem	Over 90% woody stem, about the same
0207	Over 80% woody stem	Over 80% woody stem, about the same
0209	Over 90% woody stem	Over 80% woody, a slight decrease; a correlated slight increase in herbs and vines

There was an overall increase in woody stems, from 91 recorded in 1988 to 132 recorded in 2021. Plots 0206 and 0207 saw small changes to stem counts; plot 0206 increased from 34 to 37 and plot 0207 increased from 12 to 13. Nearly all of the increase in stem count was found in plot 0209, which had 42 stems in 1988 compared to the 85 we recorded in 2021 (Table 5).

Large shifts were observed in the size classes of stem data. In 1988, 44 stems were recorded below 2.5 cm dbh (saplings), 32 were found between 2.5 and 30 cm dbh (mid-size stems), and 15 were found above 30 cm dbh (large stems). In 2021, 38 stems were recorded

below 2.5 cm dbh, 89 were found between 2.5 and 30 cm dbh, and 5 were found above 30 cm dbh. Saplings decreased from just under one-half of all stems in 1988 to just under one-third in 2021. Mid-size stems increased from about one-third of stems in 1988 to two-thirds in 2021. Large stems decreased from about one-sixth of stems in 1988 to under 4% (1/25) of stems in 2021. All three plots had a majority of stems found as saplings in 1988, which shifted to a majority in mid-size stems in 2021. Plot 0209 displayed a noticeable loss of large stems, from eight in 1988 to only one in 2021 (Table 6). These data support the maturation and aging of stems as well as the loss of potential canopy trees reflected by declines in large stem counts.

Table 5. The total number of woody stems of all sizes recorded in each plot and across all plots for 1988 and 2021.

	1988	2021
0206	37	34
0207	12	13
0209	42	85
All Plots	91	132

Table 6. Stem size distribution by plot and overall across saplings (<2.5 cm), mid-size stems (2.5-30 cm), and large stems (>30 cm) for 1988 and 2021.

	1988			2021		
	<2.5 cm	2.5-30 cm	>30 cm	<2.5 cm	2.5-30 cm	>30 cm
0206	16	14	7	12	19	3
0207	10	2	0	3	9	1
0209	18	16	8	23	61	1
All Plots	44	32	15	38	89	5

Natural Systems Discussion

Overall, the most noticeable changes influencing the trends observed across plots, were observed in plot 0209, including the largest loss of large stems between 1988 to 2021 and the largest shift of stems from 0.5-1.75 cm dbh to 0.5-12.5 cm dbh within the plot. Species richness remained the same between both surveys conducted 33 years apart. Richness contributes to ecosystem stability and resiliency in the face of disturbances, namely storm events, increase in saline conditions, and a rise in the freshwater lens within the maritime forest.

Of the 20 new observed species across the plots, all were native species except for the observed trace amounts of two grass species found in the lowland dune plot, plot 0209: *Carex elata* and *Digitaria sp.* Although non-native, their low presence indicates invasive species are not a driver of change within the plots.

Based on the trends of change, the overarching mechanism for the vegetative shift may be explained by natural succession and disturbance. Disturbances to the maritime forest can be expected as a result of sea level rise or loss of the protective forest canopy for construction of trails, roads, and structures, and storm events. The resulting changes in moisture content within the forest and penetration of the protective canopy layer by winds and saltwater spray can change the community composition and structure. Maritime forests are resilient ecosystems and have adapted to high rates of disturbances; the resultant vegetation changes and observances of forest succession are natural processes that occur in healthy forest ecosystems. It is not unusual to encounter the rise and fall in the presence and abundance of different plant species as a result of changing environmental conditions on barrier island ecosystems.

Noted observations in the shift of plant communities from water intolerant to more water tolerant species suggests an increase in soil moisture. The long-term ocean-side NOAA

observing location in Duck, NC, has measured a relative sea level trend increase of 4.79 millimeters/year with a 95% confidence interval of +/- 0.62 mm/yr based on monthly mean sea level data from 1978 to 2020 (which is equivalent to a change of 1.57 feet in 100 years) (NOAA, 2020). As sea level rises, the dense layer of saltwater pushes the less-dense layer of freshwater, contained within the aquifer under Buxton, further up within the soil column, resulting in higher water levels within the forest. This potential mechanism was supported by the increase in hydrophilic plants in plot 0207 like the increase of *Swida foemina* (swamp dogwood) presence from 39.2% in 1988 to 72.2% in 2021. Additionally, the decline of water-intolerant species, such as *Pinus taeda* (loblolly pine) and *Persea borbonia* (red bay) in 0207, support this conclusion. Similarly, plot 0209 documented a decrease in hydrophobic plants like *Pinus taeda* (loblolly pine), *Cornus florida* (flowering dogwood), and oaks as well as an increase in hydrophilic plants such as *Ilex vomitoria* (yaupon holly) and *Ilex opaca* (American holly). Additional studies on the relationship between soil saturation and vegetative communities indicate 22-25 cm elevation differences can entirely shift structures from emergent marsh landscapes to shrub swamp areas (Rheinhardt and Faser, 2001).

Although sea level rise is influencing vegetative community shifts in Buxton Woods, there does not appear to be recent saltwater intrusion of the plot locations, supported by total dissolved solid (TDS) concentrations from surface groundwater well data (Buxton Woods, wells 6 and 7) received from the Dare County Water Department (personal communication, Nov.30, 2021). While the wells were within Buxton Woods, they were approximately 1 km away from our sampling locations. There was a decrease in (TDS) within the wells from 2001 to 2021 from 624 mean TDS (ppm) and decreasing to 427 mean TDS (ppm). The decrease in TDS further supports that succession and the observed decrease in the presence of salt-tolerant plants are not

caused by recent saltwater intrusion of the freshwater aquifer (since 2001 as this was the earliest date recorded for Buxton TDS data), but could have been due to previously introduced salt (ie. Hurricane Emily in 1993). However, due to the distance between the well site and the sampling locations, the well data is a potential data limitation. Future research into the spatial and temporal patterns in groundwater salinity is encouraged.

A secondary driver of change could be penetration of the canopy layer through removal of large woody species like *Quercus virginiana* (southern live oak) from the forest ecosystem. Airborne pollutants and airborne salts can infiltrate the canopy and cause a disproportionate impact on species not adapted to introduced salt and pollutants. Plot 0209 showed the highest rates of change in terms of species composition and stem count. Increasing the amount of salt spray in an environment decreases the presence of salt sensitive plants; 9 of 11 plants that disappeared from the plots had little or no inundation or salt spray tolerance. This plot was located closest to Old Doctors Road, the road utilized to access the plots and is utilized for NC Coastal Reserve maintenance. However, canopy breakage also enables more sunlight to penetrate into lower levels of the forest. The sunlight benefits understory herbaceous and vine species that would otherwise be outcompeted by previously established trees; this trend was also observed in 0209 where herbaceous and vine species were more abundant in 2021 when there was less canopy cover.

Another driver of change for Buxton Woods may be storm-associated overwash and saltwater intrusion. Storm events such as Hurricane Emily in 1993 and Hurricane Dorian in 2019 were the most influential storm events on Buxton Woods within the last two decades. Along with wind-driven salt spray, overwash events from storms can deposit large amounts of salt within the maritime forest. Once present within the soil, salt will sit where deposited until flushed out by

freshwater processes, which can take over a year to occur in sandy soil (USDA, 2020). Salt impacts on vegetation accumulate when there is a high water table and water sits on top of the soil. When the freshwater evaporates, it leaves salt within the soil instead of being flushed out of these systems. On a barrier island where overwash events occur multiple times a year, salt can be continuously deposited within the soil, reducing the viability of salt intolerant plants within these areas (USDA, 2020).

Additional mechanisms of change in maritime forests include herbivory and disease. In a similar study of vegetative change in a maritime forest on Bald Head Island in North Carolina, Tessel and Peet found herbivory and disease to be large contributors to a loss in species richness (Tessel and Peet, working draft 2021). Unlike Tessel and Peet, we did not find that they were likely causes of change. *Odocoileus virginianus* (white tailed deer) occupy Hatteras Island and Buxton Woods and their grazing can create biodiversity and productivity concerns for maritime forest preservation (Sherrill et al. 2010). However, in our forest cover data, we saw cover by herbaceous species stay constant in plots 0206 and 0207 and increase in plot 0209 since 1988 (Table 2). In further support, we saw an increase in herbaceous species to make up 24 of the 47 total species present, suggesting that herbivory by *Odocoileus virginianus* (white-tailed deer) is not a large threat to herbaceous species in Buxton Woods.

Disease is another mechanism of compositional and structural change in maritime forests, and there has been historical documentation of its impacts on Buxton Woods. According to the National Parks Service Natural Resource Condition Assessment for the Cape Hatteras National Seashore, maritime forests, including Buxton Woods, are susceptible to several pests and pathogens. In the recovery from Hurricane Emily, Buxton experienced a *Dendroctonus frontalis* (native pine beetles) outbreak (Nadeau et al. 2021). While *Dendroctonus frontalis* (native pine

beetles) are not normally an issue across the Outer Banks, outbreaks can occur amongst trees stressed or damaged by storms. This known outbreak supports our finding of a loss in *Pinus taeda* (loblolly pine) from 27.6% in 1988 to 7.2% in plot 0209. Laurel wilt disease (LWD) is a fungus (*Raffaelea lauricola*) that kills *Persea borbonia* (red bay) and other members of the laurel family. While LWD is present across southeastern North Carolina, it has not been detected on the Cape Hatteras National Seashore (Nadeau et al. 2021). *Lymantria dispar* (gypsy moth) is a non-native moth that causes extreme defoliation and makes a tree more susceptible to other stressors. *Lymantria dispar* (gypsy moth) caterpillars typically nest in oaks, but also feed on pines, red cedars, and hardwoods. *Lymantria dispar* (gypsy moth) are present in Buxton Woods and the northeastern region of the woods has been subject to ground and aerial treatments for the moths in 2016 and 2018 (Nadeau et al. 2021). The presence of *Lymantria dispar* (gypsy moth) could contribute to a decrease in oak species from 16.5 to 3.1%, as well as decreases in *Pinus taeda* (loblolly pine) from 27.6 to 7.2%, and *Benthamidia florida* (flowering dogwood) from 16.5 to 0% in plot 0209. We did not observe *Lymantria dispar* (gypsy moth) activity, which is typically highly visible, in our plots, but it is a pest of concern for these species.

It is also worth considering potential errors in plot relocation in our 2021 sampling. Even slight inconsistencies could have led to the inclusion and/or exclusion of certain vegetation. GPS coordinates were provided and were cross checked with handwritten notes to ensure the correct conduits were found. In addition to plot mislocation, differences between observers could have impacted cover estimation, especially as the CVS method requires observer discretion for vine and canopy coverage.

In our work, we were able to resample 3 of the 8 plots established in 1988. Given our sample size, we collected data at great depth, completing a thorough resampling using the

Carolina Vegetation Survey method. We set out to collect data of a high quality that could be built upon in future research.

Human Dimensions

Interview Methods

Collecting qualitative data provided insight into the community values and perceptions of change in Buxton Woods. We chose a qualitative approach with several subjects to gather a foundation of detailed information in our area of study. Eleven students individually conducted a one-on-one, semi-structured interview, except for a joint interview conducted with a married couple. The interviews were conducted from Sept. 22nd to Nov. 1st, 2021. The semi-structured nature of our interviews permitted interviewees flexibility in their individual responses. Our interviews covered four key themes. First, we asked interviewees to talk about their personal history with the Outer Banks, specifically regarding the community of Hatteras Island and Buxton Woods. Second, we asked about the public sentiment concerning the preservation of Buxton Woods in the past and currently. Third, we inquired about how the uses for Buxton Woods have changed over time, both on a personal and community level. Lastly, we asked interviewees about changes they saw in the environment of the Woods.

The first interviewees were suggested by colleagues of the Coastal Studies Institute as people of interest. Interviewees were community members of Buxton or Hatteras Island, with some being involved in the preservation of Buxton Woods through the Friends of Hatteras Group. Subsequent interviewees were identified using snowball sampling. In this practice, we received recommendations from the first interviewees of individuals with valuable knowledge of Buxton Woods and its preservation. Interviewees were contacted by students via phone, email, or text message to schedule an interview meeting time. Interviews spanned an average of sixty-nine

minutes, ranging from roughly a half an hour to an hour and forty-five minutes. Seven interviews were conducted in person at a private meeting space, two were conducted over the phone, and two were conducted via Zoom, a proprietary video-teleconferencing software. The interviews were one-on-one with the intentions of making interviewees feel comfortable speaking with students about controversial or personal topics.

All interview audio was recorded, and audio files were saved and transcribed for later analysis. After completing the qualitative data collection, we began the human dimensions analysis using the NVivo v.11 coding software. Coding is the process of breaking down an interview into categories based on different subjects of our research. These categories are also known as codes. Through the process of coding, we identified explicit concepts across all of our extensive qualitative data for comparison with our natural systems data. Four major themes were addressed in our codebook: the uses, values, and preservation process of Buxton Woods, as well as the surrounding community of Hatteras Island. All transcribed interviews were coded using this codebook. Creating a unanimous codebook for our research allowed us to identify quotes across all interviews about a specific topic. Codes were queried to make connections between our natural systems and human dimensions data. All qualitative data collection and analysis followed IRB (International Review Board) standards.

Human Dimensions Results

Maritime forests provide important resources to the way of life of the people living near them. Buxton Woods is impacted to varying degrees by a range of diverse human uses. It is important to contextualize the relationships between individuals, their quotes, and Buxton Woods. Our interviews with Hatteras Island residents and members of Friends of Hatteras Island

revealed three key themes around perceptions of Buxton Woods. The three themes are: Benefits and Significance of Buxton Woods, Disturbances and Impacts, and Perceptions of Management.

Theme 1: Benefits and Significance of Buxton Woods

Throughout history, Buxton Woods has been a cultural cornerstone to the people living on Hatteras Island. In the past, the Woods provided protection for homes from the elements, and resources in the Woods gave subsistence value through hunting, trapping, fishing, and grazing livestock.

Buxton Woods was exploited to provide resources for industry. Beginning in the 1700s, live oaks were logged excessively for shipbuilding due to the curved shape of their limbs (Couch 1994). This historical use was mentioned by several of our interviewees, who claimed that it resulted in a shift in forest composition away from a live oak-dominated ecosystem.

“By the 1830s, most of the big, huge live oaks had been logged out of here for only one shipyard. So that just shifted the whole diversity of the woods.”

Prior to European settlement, the composition of Buxton Woods was mostly oak trees, but after logging, the woods became overwhelmingly composed of pine trees (Couch, 1994). This change in forest composition was intensified and continued by other historical uses, such as livestock grazing in the Woods. Several interviewees mentioned the livestock uses of Buxton Woods until local laws required animals to be contained.

“Supposedly years ago, the whole island had so much livestock that they just cleared out the Woods immensely. You know, I mean, they were just free-roaming cows and everything, I guess.”

The appetites of grazing species had an immense impact on Buxton Woods’ vegetative diversity

as they ate away the understory and brush, limiting oak regeneration and accelerating wind erosion. The termination of livestock grazing and logging will likely allow oak trees to outcompete pines in the future. Left undisturbed by human impacts, the forest will eventually return to the original oak-dominated system it once was (Couch, 1994).

The history of Buxton Woods as a resource for food, development, and industry contributed to its value for residents up to the present day. Over time, these uses have shifted, but the Woods continue to be an element of the ecosystem that brings the community together through shared values and uses. All of the interviewees were asked how they used Buxton Woods, and various responses were gathered. There were many overlaps, indicating that Buxton Woods provides many different recreational and extractive values for both residents and visitors.

“Hunting, fishing, walking, horseback riding... many local folks have a real relationship with Buxton Woods and understand that it is just an ancient, ancient part of the Outer Banks, and appreciate that.”

Because Buxton Woods is considered to be “ancient”, it has provided substantial time for people living on Hatteras Island to develop a sense of place within the Woods. The diversity of benefits and uses that Buxton Woods provides results in a connection between the community and the forest and enforces that sense of place concerning the Woods. The majority of interviewees described Buxton as a small town with a close-knit nature.

“There was a great sense of community. Living in a small village, everybody knows each other.”

One of the reasons why there has been such a close-knit community in Buxton is that there were limited points of access to Hatteras Island. The isolation of Hatteras Island enhanced residents’

sense of place and change in the accessibility of Hatteras Island led to change within the community.

“Well, primarily what's happened... is the fact that it's become such an incredible tourist attraction. When there was no bridge and you had to take a boat to get over here and you had to drive down the sand to get to any of the towns... it was much quainter, much more localized...”

The development of The Herbert C. Bonner Bridge in 1963 led to increased movement of people between Hatteras Island and the rest of the Outer Banks. As access increased over time, it decreased Hatteras Island's isolation, impacting the sense of community and its composition.

While the sense of community has changed over time, the sentiments towards Buxton Woods have remained constant. Each interviewee was asked, “What does Buxton Woods mean to you?”

“It's kind of the heartbeat of this island in a way.”

“It's an escape area. I can walk for thirty minutes, an hour, and just get my head in perspective.”

“Everything.”

There were various responses, but the words used to describe its meaning all fell in the vein of sentimental. These meanings are derived from historical uses and values that have either carried over or given way to new meanings. In either case, the uses and values of the present build upon those of the past to develop a rich sense of place and attachment to Buxton Woods. Buxton Woods historically and contemporarily has provided immeasurable benefits through various

ecosystem services and through value for human well-being.

Theme 2: Disturbances and Impacts

Interviewees described that environmental and developmental pressures contributed to changes in Buxton Woods. The key drivers of this change mentioned were disruption of the canopy, accessibility, salt intrusion, and storm events.

One crucial driver of change our interviewees provided was the disruption of the canopy. To develop homes and infrastructure, areas of forest need to be cleared. This opens the interior of the forest to elements such as salt and wind, which damage vegetation.

“The interior trees are more protected [by the canopy] and now there's been so many homes built despite the legislation of minimal lot clearing in Buxton Woods. It still makes an entry. It allows the interior wind to get in there and salt. And so, the dome of that canopy is not as impervious to salt like it used to be. And so your interior trees are now suffering like the perimeter trees.”

Increased development pressure on the edges of Buxton Woods through housing and roads has resulted in the spreading and thinning of the overhead canopy, exposing the inner layers of Buxton Woods to external disturbances. These external disturbances include salt spray and high winds, which can have adverse effects on the health of the forest. The presence of these disturbances in the Woods caused some interviewees to perceive further development around or in Buxton Woods as a major threat to the integrity of the Woods.

Another crucial driver of change is the issue of accessibility in Buxton Woods, which can also impact canopy structure and general forest health. Interviewees described how past and future changes to the accessibility of the Woods could alter the structure of Buxton Woods. They shared both negative and positive outlooks on increased accessibility. On the negative side,

interviewees believed expanded accessibility increases human impacts on Buxton Woods.

“I know, I don't want to see visitor kiosks, I don't want to see easier access... it needs to be left alone.”

Some interviewees expressed concern about increased human influences of the Woods as human presence in Buxton Woods disrupts the natural structure and processes of the Woods. Increased accessibility to the Woods would draw more people in, and an increase in human traffic could benefit from additional development of trails, signs, and cutting down of vegetation for footpaths and space for parking.

On the other hand, other community members described increased accessibility as a potentially positive change for Buxton Woods.

“We took a walk on the nature trail... They have little plaques that explain everything, which is very good.”

“Making [Buxton Woods] have a purpose. Making it enjoyable.”

These community members recognize increased accessibility as an opportunity for education, research, and the development of more eco-friendly attitudes as people can become more connected to a natural area. Increased use and access of Buxton Woods can provide more support for protection and management as more people are interested in preserving that use area.

With or without increased accessibility, interviewees indicated there is potential for tourists to use the Woods more frequently. Many interviewees perceived a notable change in the number of tourists over the years, leaving some hoping to limit outsiders to keep the Woods a “nice kept secret”.

“I would not want to see brochures at every visitor contact station saying, go visit Buxton Woods. No, it's nice, we kept it a secret.”

“There's just more [tourists] here... it's a double-edged sword, you know, you can make a living a little better, but you have to put up with more people”

“That's what's changed. We became a tourist destination. That's our primary input now is just the tourists.”

The views held on increased tourism depend on the values of the interviewees. For the interviewees who disapproved of more access, a key value of Buxton Woods was the escape it provided. The increase in visitors to the Woods detracts from the value as they cannot escape to the Woods if that is where all the people are. Those who viewed increased tourism positively, however, placed more value on the benefits to the local economy and environmental education. The tradeoff of accessibility versus preservation and the role of tourism in the Woods is an issue that needs to be explored further with community input regarding management.

Salt also disrupts ecosystem services through the intrusion of saltwater into the aquifer under Buxton Woods.

“Whereas you can see where water has saltwater has intruded into the early parts of the forest, and you can start to see the deaths of some of our live Oaks and the bigger trees and things that can't take the salt...”

Saltwater intrudes upon the underground aquifer through processes including storm surge and the rising of the freshwater lens. This shifts the vegetative composition, and causes an imbalance between inland freshwater systems, as further discussed in the natural system results. The aquifer

was an essential aspect of the preservation of Buxton Woods, as it was used to provide clean water to the surrounding communities. In the past, a threat to the aquifer not only disrupted the natural system but also majorly impacted the community overall, as discussed by our interviewees. Today, the aquifer has value as it was the main driver of preservation and is essential to the health of the ecosystem.

Interviewees cited severe storms and weather events as the most powerful drivers of change in Buxton Woods. Many of our interviewees talked specifically about Hurricane Emily in 1993 as the most destructive singular event Buxton Woods has faced.

“I feel like after Hurricane Emily in ‘93, the Woods and my husband and I on our property sustained the greatest tragedy that I have lived through in Buxton Woods. Especially the loblolly pines, the big pines, they snapped off.”

“[Hurricane Emily] was just awful, it was a real awakening.”

Hurricane Emily was an “awakening”, as it showed people living on Hatteras Island the kind of extreme weather events that can occur. Interviewees mentioned impacts like the snapping of pine trees, uprooting of live oaks, and introduction of salt through storm surge. Severe storms and weather events can dramatically alter the landscape and the structure of Buxton Woods as extreme winds and storm surges disrupt the natural ecosystems.

The environmental and developmental pressures discussed by the interviewees show a diverse collection of perceptions regarding the changes impacting Buxton Woods.

Theme 3: Perceptions of Management

Our community members discussed many important values of the Woods and expressed concern about perceived drivers of change in Buxton Woods. The vulnerability of these highly

valued Woods to these threats depends on the management and preservation efforts in Buxton Woods.

The creation of Buxton Woods Coastal Reserve began with the establishment of the Friends of Hatteras Island group, a grassroots nonprofit organization with goals to prevent development inside Buxton Woods.

“...so that started this core group to do the normal things of contacting legislators. [We] would have meetings and have hydrologists come and speak about the Buxton woods aquifer and the need to protect it.”

Friends of Hatteras Island was essentially composed of community members who felt obligated to protect Buxton Woods from being cleared. Developers were looking to establish a golf course on Hatteras Island, which several interviewees who were involved with Friends of Hatteras Island discussed.

“[There was] a proposed golf course in the middle of Buxton Woods, on top of our sole source of potable water.”

The threat of contamination of the aquifer and potential impacts to the hydrology of the island were huge concerns, spurring action in community members. However, this desire to protect Buxton Woods and impose regulations was not unanimous across the community.

While they aimed to protect a valuable ecosystem, it received considerable backlash from the community. Residents were accustomed to the unadulterated use of Buxton Woods and had concerns that any management would overregulate their use of the Woods. One interviewee paraphrased a common sentiment regarding Buxton Woods during its initial preservation.

“And there was always this [sentiment that] we're the natives. We have more say, you know, this is our island. Don't tell us what to do. It's some real basic human

behavior.”

Some residents were upset newcomers were coming in and making decisions they felt had nothing to do with them when the residents would be the ones most impacted by regulation. Due to this concern by some residents, interviewees recalled experiencing threats and being berated by other community members for their alleged overregulation of a common use area.

“...there was some heated times... Some people tried to villainize the people involved with it...”

“Well, I didn’t get invited to weddings anymore... It was bad.”

“It got really heated... [friends] started screaming at us... we had a number of public hearings... and they were all very stressful.”

The Friends of Hatteras Island group endured considerable hostility from community members with diverging opinions to ensure Buxton Woods was established and protected by the NC Coastal Reserve. Interviewees involved with Friends of Hatteras Island were asked how they felt about the group’s success regarding the preservation of Buxton Woods.

“It was a fight well fought and was just very near and dear to us on many levels...”

“I’m very proud of all of us. [Friends of Hatteras Island was a] huge accomplishment of my life really.”

“I think in time, more people got to the understanding that the preservation of the woods was a preservation of us, and living here.”

The original members of Friends of Hatteras Island expressed great pride and felt gratification from the preservation of Buxton Woods as an essential feature on Hatteras Island. In preserving Buxton Woods, the NC Coastal Reserve balanced historical uses of the woods with limits on who can use the woods and how.

To allow people to use the Woods, management is needed to maintain trails, roads, signs, and other aspects of accessibility. The NC Coastal Reserve's management plan aims to protect natural ecosystems for the public to have access to areas that maintain the natural heritage and traditional uses. These sites are also utilized for research and educational opportunities to enhance knowledge surrounding coastal areas and processes, improving future management efforts (NC Coastal Reserve, 1996). Preservation is required to maintain the personal and environmental values people hold, but our interviewees reflected varying opinions of how Buxton Woods is currently managed.

Although there are management efforts in place, some of our interviewees perceived an absence of management.

"I don't even know how they're managed anymore."

"[Management has] been great. I don't ever see them."

One reason for the perceived lack of management might be due to the limited workforce of the NC Coastal Reserve. The site manager for Buxton Woods also manages two other maritime forests on the Outer Banks: Kitty Hawk Woods and Currituck Banks. For those who value the isolation and wilderness of the Woods, this lack of management is viewed positively. But for those who want easier access, there are concerns about the absence.

Interviewees cite a lack of maintenance of trails and roads that restricts some uses of the

Woods as it makes it difficult or less appealing to access the Woods. One of the main uses of the Woods is for walking or hiking, and many interviewees expressed the desire to have the trails be better maintained.

“That is a problem with the [North Carolina] Coastal Reserve; they don't have anyone on staff that can maintain the trails and they're narrow... Some people are afraid of ticks and snakes and all of that... there's beautiful trails, but they're very narrow.”

There are many great trails to utilize in the Woods, however, there are also many snakes and ticks in the woods. The narrow trails make it difficult to avoid snakes or ticks, making them less suitable for casual visitors.

Several interviewees stated their concern with the accumulation of dead organic matter on the forest floor potentially catching fire.

“My greatest concern is fire. The Woods are a tinderbox.”

“But you know, what fire would do the Woods good right now. It would clean out the underbrush and it wouldn't be that bad.”

Some residents said they were willing to pay a \$300 permit for the North Carolina Forestry Service to come in and perform a control burn near their property. But according to an interviewee, the Forestry Service allegedly declined out of fear that the fire could get out of hand, furthering the notion that fire is a great threat to the Woods. The development of a fire management plan could relieve some of this stress by addressing specific community concerns.

Another concern with management in Buxton Woods can be attributed to the interviewees' opinions on the state of the roads within the Reserve. Some felt there was not

enough being done by the management entities in Buxton Woods to ensure the roads were usable.

“The road is not, in my opinion, what it should be with as much public use as it has.”

Some interviewees live on small tracts of the Woods, which were mainly developed before the preservation effort of the Friends of Hatteras Island group. These individuals mentioned they often have to maintain the vegetation growing on the sides of the roads, as they are essentially in their driveway, and would not be maintained otherwise.

Each interviewee was asked what they see in the future for the Woods, how they hoped it would be preserved, or what changes they would like to see. This gave context for how members of the community want the area to be valued or managed over a longer period of time.

“I think there still needs to be more building between the community and the [North Carolina] Coastal Reserve on the value of it.”

“I don't want them to mess with it at all. Lock it up tighter.”

“...I don't know what the possibilities are for as far as expanding [development]... but I would hope it continues to be preserved...”

“I think local folks have become kind of protective of Buxton Woods because they do understand its value to our lives here.”

While all our interviewees want continued management, they held differing views on what this management should look like. Some want the community to be more involved in the use of Buxton Woods, and some want the uses of the Woods to be restricted even further. Overall, the

woods have undeniable value to the lives of residents in Buxton. The differing viewpoints, and the tradeoffs between them, need to be considered in future management decisions to ensure community needs are balanced with ecological preservation.

The overarching consensus among interviewees is that the Woods are critical to the social and environmental health of Hatteras Island and its preservation is paramount. The community's values suggest the management of Buxton Woods should reflect the connection between the people and the Woods so the integrity of the forest is preserved for the foreseeable future. Taking into account the existing landscape of varied opinions with new management implementations in Buxton Woods could be a productive way of making sure the values and needs of the community are met.

Limitations

Like any other study, we faced some limitations in our qualitative analysis of human dimensions. We had a small sample size of eleven interviews, all of whom were found through recommendations by community members. This reflected our goal of having in-depth results about perceptions of Buxton Woods. The small sample size, however, means the results from interviews cannot be interpreted as representative of the whole community of Buxton, NC.

Conclusions

Barrier islands are dynamic coastal systems influenced by various forces including waves, winds, tides, storms, and sea level change. Maritime forests are late-successional ecosystems that form on barrier islands and provide many ecosystem services to areas they occupy. Maritime forests and their vegetative communities provide erosion control, contribute to nutrient cycling, and are valuable habitat for a wide diversity of species. In addition, these

ecosystems often house and maintain resources humans rely upon, such as freshwater and space for recreation. These ecosystems are largely resilient to disturbances but are also very dynamic due to developmental and environmental influences. Using the collection of natural data while applying the Carolina Vegetation Survey method, we were able to document how the vegetative community and forest structure of Buxton Woods has changed over a 33-year period.

We saw changes to the vegetative community since 1988 marked by the rise and decline of several species. We observed reductions in cover of *Benthamidia florida* and *Pinus taeda*, and increases in *Swida foemina*, *Ilex opaca*, and *Ilex vomitoria*. Species richness increased from 44 to 47 species, but composition changed, and we observed 11 lost and 20 gained species. Among the gained species, 16 were herbaceous, supporting an overall change to a more herbaceous forest composition and cover. Stem counts increased from 91 to 132 between sampling periods and small decreases in saplings and large stems were accompanied by large increases in mid-size stems. All plots had a majority of stems found as saplings in 1988, shifting to a majority as mid-size stems in 2021. We also found a decrease in large stems mostly driven by a decrease from 8 to 1 stems in plot 0209.

There are many disturbances influencing Buxton Woods and changes we observed. A broad mechanism that explains changes is the succession of maritime forests. Succession occurs as natural events, including the resident vegetation, change the conditions of the environment and allow new species to arise and outcompete old ones. An increase in soil moisture from sea-level rise is supported by the rise of species that can tolerate wetter soils. Another disturbance is disease. The known presence of pine beetles and gypsy moths show that disease is also a likely factor in the decline of some species, such as loblolly pines and flowering dogwood.

Some of these disturbances were also noticed by our interviewees, such as saltwater intrusion. Our interviewees perceived threats of saltwater intrusion in the decline of species that cannot tolerate saline conditions. Our natural data reflected a loss of species intolerant to salt, with intrusion as a possible factor. Another disturbance is storms and our interviewees specifically talked about the great damages sustained by Hurricane Emily in 1993. These storms can damage vegetation and contribute to thinning of the protective canopy, a point both noted by our interviewees and supported by decreases in large stems in our natural data.

These integrated conclusions add value to our work for use in management and this is further explored by our qualitative data. Our interviewees noted the mutual goals of preservation by Friends of Hatteras Island and the NC Coastal Reserve have made the protection of the Woods possible. Among the interviewees, there is an agreement that management is necessary, but some had conflicting perceptions of the role of management with accessibility of trails. By using insights from our natural science data, we can reconcile tradeoffs between increasing or maintaining access. Increased access and construction of trails requires trimming of trees and direct disruption to the canopy. Our natural data shows that in plot 0209, which is closest to the road, experienced the largest decrease in large stemmed canopy trees. These and other integrations provide value to managers looking to incorporate community perspectives and ecosystem ecology. It will be helpful in addressing other management concerns noted by our interviewees, such as the need for a fire management plan.

Beyond management, there are various avenues for future research. Our groundwater salinity data came from nearby wells in Buxton Woods but not specifically in our plots; future research could evaluate water sourced directly from the plots. In addition, other variables such as soil characteristics and water quality could be considered. A community presentation

incorporated feedback and suggestions for future research. One suggestion was in exploring the use of fire as a management tool in Buxton Woods. A suggestion was also taken to include more quantitative data in our human dimensions component, such as quantifying ecosystem services of Buxton Woods. Another suggestion involves a focus on vertebrates and invertebrates, specifically changes to their location and composition and potential impacts on Buxton Woods. A final community suggestion involved the connectivity of the Reserve, with a focus on those areas of the Reserve where sections of unprotected land cut into the connected whole. These and other avenues of research will find value in referencing our work.

Overall, our project provided an in-depth view of changes in Buxton Woods and some community perceptions of that change. Barrier islands and maritime forests are dynamic systems and Buxton Woods is no exception. Our natural science data quantifies the changes that have occurred and integration with our qualitative data adds support to our conclusions. Our study contributes to the larger conversation about resilience, succession, and changes within maritime forests on barrier islands. Its depth has great value for future research, and it will be useful for the continued management of Buxton Woods.

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