ABSTRACT

STALLINGS, KEVIN DURWOOD. Evaluation of Plant Populations Affected by Human Induced Disturbance in Aquatic and Terrestrial Ecosystems. (Under the direction of Dr. Robert J. Richardson and Dr. Danesha Seth Carley).

The influence of human induced disturbance on plant communities was reviewed through the development of extension documents and experiments for northeastern NC bridge sites and Pinehurst No. 2 Golf Course. One experiment within aquatic environments evaluated the influence of bridge footprints on submerged aquatic vegetation (SAV). A literature review was developed on light availability requirements for representative aquatic species, indicated how those species are affected by the absence of light, and reviewed management/evaluation techniques. The compilation of peer literature, in the Management of Aquatic Vegetation in the Southeastern United States, describes how aquatic plant management plans promote the growth of beneficial aquatic plants while attempting to reduce or eliminate unwanted “weedy species”. The aquatic species were divided into categories of algae, submerged, emergent, and floating species and their ecology described. Integrated pest management techniques were also included for the suppression of pest populations. An experiment was conducted between June 2012 and December 2013 to evaluate the amount of SAV present in northeastern NC watersheds near bridge sites, the effects of bridge footprints on freshwater streams, and determine if their height and orientation influenced the presence of SAV. Point intercept rake tosses along transects were used to assess the presence/absence of SAV at 16 representative bridges. Multiple water quality parameters were also measured. In combination with this survey two representative bridges were surveyed with SONAR to map SAV biovolume, depth, and soil hardness composition. The transect survey only found SAV at three bridges during the 2012 and 2013

seasons including the species *Ruppia maritima* L., *Ceratophyllum demersum* L., and *Najas minor* All. The SONAR survey found trace amounts of *Vallisneria americana* Michx. and [*Najas guadalupensi*s (Spreng.) Magnus]. The combination of techniques found limited SAV, precluding a concrete determination of footprint affects at these sites. A larger survey transect or pre-screening of bridges may be required for future research projects. Research and extension efforts were conducted in 2012 and 2013 at Pinehurst Golf Resort's No. 2 Course to characterize native vegetation, desirable adapted species, and invasive and undesirable weeds in the naturalized areas on the Pinehurst No. 2 site as the course transitioned through a renovation. From March 2012 to October 2012, 16 individual site visits for plant ID, cataloging, and photodocumentation resulting in ID booklets and a desired species list. In 2013, a plot survey protocol was employed to evaluate the vegetative community at Pinehurst No. 2 and how it compared to neighboring communities. The plot survey and species list combined found that approximately 39 families were represented on the course, with the most prominent being the Poaceae and Asteraceae, with 78% of the species identified as native to the lower 48 US States. To further aid in Pinehurst No. 2 management, a greenhouse experiment was conducted to evaluate the response of the native grass species *Aristida stricta* Michx. to plant growth regulators (PGRs) and fungicides commonly used for golf course management. Plants were treated with selected fungicides and PGRs and placed in a randomized complete block design. A quality indicator scale was employed in addition to measurements of height, base circumference, and dry weight to assess the chemical effects. Results indicated a manager has the option of using these types of herbicides, at high rates, with minimal impact to the bunchgrass *A. stricta*'s visual quality.

Evaluation of Plant Populations Affected by Human Induced Disturbance in Aquatic and Terrestrial Ecosystems

by
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DEDICATION

I dedicate this thesis to my father Dr. Stephen Durwood Stallings, Jr. He continues to be my inspiration for pursuing dreams and moving forward during the opportunities that life has to offer. My father was a veteran and served as a Lieutenant in The Korean War and later became the local physician for a small community in the Pilot-Zebulon area of North Carolina. Being the "country doctor" he made house calls and accepted fruits and vegetables as payment if that was all his patients could afford. I was a lucky child that my father was born in 1924 and retired when I was two years old to help raise me until his passing in May 2000. One of my dad's heroes growing up was Louis Pasteur who found a cure for a silkworm disease, anthrax, and rabies, in addition to inventing a process to keep milk from spoiling. From my dad's book collection I found a children's book that was bought for me about Louis Pasteur called *The Value of Believing in Yourself* with the following line at the end:

> "Of course, what you may decide to do in your own life may be very different indeed! But whatever you choose for yourself, let's hope it will make you happier…. Just like our good friend, Louis Pasteur."

BIOGRAPHY

Kevin D. Stallings was born January 24, 1986 and grew up in the small community of Pilot, North Carolina until age 14. After the passing of his father in 2000 he moved to Wendell, North Carolina with his mother, Jamie, and lived there until his graduation from East Wake High School in 2004. In 2008, Kevin received his B.S. in Biological Sciences and a minor in Environmental Toxicology from North Carolina State University in Raleigh, NC. During his undergraduate career he interned at Mote Marine Labs in Sarasota, Florida for the Sea Turtle Conservation and Research Program and traveled to Kunming, China and Hanoi, Vietnam through an Atlantic Coast Conference Summer Study Abroad Program. In 2010, Kevin graduated from the University of North Carolina at Wilmington with a M.A. in Environmental Studies and later pursued an M.S. program in Crop Science at his former alma mater North Carolina State University.

"Love the sea, the ringing beach, and the open downs. Keep clean body and mind" – Sir Frederick Treves (*The Dangerous Book for Boys*)

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CHAPTER 1

Overview of Aquatic Plants and Shading

North Carolina's Coastal Resources Commission designates Areas of Environmental Concern (AECs) and protects them from uncontrolled development. Areas of Environmental Concern cover almost all coastal waters and less than 3 percent of the land in the 20 coastal counties. Most submersed or submerged aquatic vegetation (SAV) is located within the Estuarine and Ocean System AEC, which includes the coast's broad network of brackish sounds, marshes, and surrounding shores. Within this AEC, certain coastal waters and submerged lands are designated Public Trust Areas. By law, every North Carolina citizen has the right to use these Public Trust Areas for recreational activities. The Handbook for Development in Coastal North Carolina (North Carolina Division of Coastal Management, 2012) defines Public Trust Areas as being:

- To the edge of the exclusive economic zone of North Carolina consisting of all waters of the Atlantic Ocean and the lands underneath, from the normal high water mark on shore to the state's official boundary three miles offshore;
- All navigable natural water bodies and lands underneath, to the normal high watermark on shore;
- All water in artificially created water bodies that have significant public fishing resources and are accessible to the public from other waters;
- And all waters in artificially created water bodies where the public has acquired rights by prescription, custom, usage, dedication or any other means.

Essentially, North Carolina's estuarine water AECs include oceans, sounds, tidal rivers, and their tributaries, which stretch across coastal North Carolina. Projects allowed in the estuarine system include navigation channels, docks, piers, bulkheads, boat ramps, groins, breakwaters, culverts, and bridges (North Carolina Division of Coastal Management, 2012) which may have the potential to change the overall ecology of an area and ultimately influence the growth of submerged aquatic vegetation.

Submersed aquatic vegetation

The North Carolina Marine Fisheries Commission and the Coastal Resources Commission define SAV habitat as:

> Those habitats in public and estuarine waters vegetated with one or more species of submerged vegetation such as eelgrass (*Zostera marina*), shoalgrass (*Halodule wrightii*), and widgeongrass (*Ruppia maritima*). These vegetation beds occur in both subtidal and intertidal zones and may occur in isolated patches or cover extensive areas. In either case, the bed is defined by the presence of above-ground leaves or the below-ground rhizomes and propagules together with the sediment on which the plants grow. In defining beds of submerged aquatic vegetation, the Marine Fisheries Commission recognizes the Aquatic Weed Control Act of 1991 (G.S. 113A – 220 et. seq) and does not intend the submerged aquatic vegetation definition and its implementing rules to apply or conflict with the non-development control activities

authorized by that Act" [MFC rule 15A NCAC 03I.0101 (20(A) and CRC rule 15A NCAC 07H.02.08(6)] (Deaton et al., 2010).

The North Carolina Coastal Habitat Protection Plan of 2010 defines SAV habitat as "bottom recurrently vegetated by living structures of submersed rooted vascular plants (i.e., roots, rhizomes, leaves, stems, propagules), as well as temporarily unvegetated areas between vegetated patches" (Deaton et al., 2010).

While various definitions exist, for the purposes of this report, SAV habitat is considered to include marine, estuarine, and riverine vascular plants that are rooted in sediment. There is an estimated 200,000 acres of SAV habitat in North Carolina (Deaton et al., 2010). These habitats occur along the entire east coast of the United States (North Carolina Division of Coastal Management, 2012). From 2006–2008 the first statewide aerial survey of SAV indicated 136,000 acres of observable SAV in the state, placing it third in aerial abundance behind Florida and Texas. Efforts to create an extensive SAV monitoring program are noted as challenging, considering the multi-dimensional biophysical complexity of the NC coastal ecosystems (Kenworthy et al., 2012).

Many species of fish and wildlife are directly dependent upon SAV for refuge, attachment, spawning, and food. Submerged aquatic vegetation also helps to stabilize shallow water sediments, reduces wave turbulence, and removes excess nutrients from the water column (PDEA, 2012). Within these systems there are high diversities of invertebrates and fish that benefit from the valuable ecosystem services provided by the primary producing vegetation and the enhanced water quality (Deaton et al., 2010). Aquatic plants also strengthen substrate-holding sediment in place and provide additional shelter for creatures that utilize the substrate (Ali, 2007).

Submerged aquatic vegetation loss results in secondary impacts including the decline of waterfowl species that utilize the resource. As habitat disappears, waterfowl food decreases and water quality degrades. Invasive species entering new niches may also provide an added pressure, replacing many native plants and animals in regions of SAV loss (USEPA, 2013). Loss of SAV also increases erosion of buffered shorelines that dissipate wind and wave energy (HOW, 1991). In the Chesapeake Bay, SAV losses are closely tied to a decrease in water quality, an inhibition of native *Callinectes sapidus* (blue crab) recovery, and a decrease in *Cynoscion nebulosus* (speckled trout) (Moore and Orth, 2008).

North Carolina SAV

The dominant seagrass species along the North Carolina Coast is eelgrass (*Zostera marina* L). Eelgrass in North Carolina typically has two growing seasons; leaf expansion is most pronounced in the spring, and shoot production is more prolific in the autumn months (Burkholder et al., 1992, 1994; Mallin et al., 2000; Touchette and Burkholder, 2006).

North Carolina is the northernmost growing range for shoalgrass (*Halodule wrightii* Asch.) and home to the estuarine and marine SAV species widgeongrass (*Ruppia maritima* L.). In freshwater sounds and estuaries tapegrass (*Vallisneria americana* Michx), sago pondweed [*Potamogeton pectinatus* (L.) Borner], southern naiad [*Najas guadalupensis* (Spreng.) Magnus], clasping leaf pondweed (*Potamogeton perfoliatus* L.), and horned pondweed (*Zanichellia palustris* L.) are the predominant species (PDEA, 2012). There is slightly greater SAV species diversity in coastal riverine systems as compared to marine systems in North Carolina due to a lack of salinity stress (Odum et al., 1984; Ogburn, 1984). For a description of habitat requirements for 6 common SAV species found in North Carolina, refer to Table 1.

Threats to SAV habitat

Development along coastal environments and freshwater watersheds may decrease water quality, resulting in the complete loss of some seagrass meadows. Seagrasses growing in estuaries are particularly vulnerable to human activities and may be quickly changed through landscape modification. Dredging and filling activities were at one time considered to have the greatest detrimental impact on SAV. Water quality is further impacted by nutrient and petrochemical runoff from sources such as agricultural fields and urban environments, and the resulting phytoplankton blooms that reduce both the quality and the quantity of light (Ozretich, 2009) further damaging the vegetation. Coastal construction and hydrologic modifications to estuarine systems may change the chemistry and physical properties of water quality, ultimately having major impacts on SAV (Florida Fish and Wildlife Conservation Commission, 2013).

Bridge construction and replacement have resulted in SAV loss that has been extensively documented for the State of Florida (Fonesca et al., 1998). Uncontrolled construction sites within an estuary's watershed lead to elevated loads of suspended sediments that can possibly reduce the sunlight reaching seagrasses. Bridges in particular can have negative impacts on invertebrate density, taxa richness, dominant taxa, as well as trophic feeding groups when spanning brackish and saltwater marshes. Low bridges may also affect marsh food webs by reducing macrophyte growth and soil organic carbon, adversely impacting the density and diversity of benthic vertebrates (Broome et. al, 2005).

Of all human impacts, eutrophication and sediment turbidity have the most widespread impact on seagrasses. Eutrophication and increased turbidity reduce light over prolonged periods and can deplete SAV carbon reserves or, in cases of extreme light deprivation, anaerobic conditions may lead to sediment toxicity and more rapid mortality (Deaton et al., 2010; Ralph, 2006). Considerable SAV loss is thought to have occurred in Morehead City, NC, when the port's turning basins and access channels were dredged, given that nearby, similar yet undredged areas within Bogue Sound support healthy SAV (Deaton et al., 2005). Current state and federal regulations minimize impacts to SAV from permitted dredge and fill activities; particularly those associated with private development, and have helped to reduce the negative impacts of this threat (North Carolina Department of Natural and Environmental Resources, 2012).

In shallow conditions, seagrasses may be damaged by shipping traffic, accidental spills, and antifouling compounds. As reported in 'The Guidelines for the Conservation and Restoration of Seagrass in the United States and Adjacent Waters' (Fonesca et al., 1998) direct physical impacts from mooring scars, propeller scars, jet skis, and vessel wakes are a major source of seagrass habitat loss as well. Commercial shellfish harvesting also can cause considerable damage and local species elimination.

Environmental Stressors

Salinity is one abiotic factor that may change the health and vitality of SAV and ecological community characteristics, therefore, short-term and long-term environmental changes in estuaries create conditions inhospitable for SAV growth. North Carolina SAV species are divided into two communities that range from higher saline estuarine waters to lower salinity/freshwater ecosystems. Estuarine (high salinity) species common to North Carolina include eelgrass (*Zostera marina*), shoalgrass (*Halodule wrightii*), and widgeon grass (*Ruppia maritima*). Example low-salinity species include native wild-celery (*Vallisneria americana*), Eurasian milfoil (*Myriophyllum spicatum*), bushy pondweed (*Najas guadalupensis*), and sago pondweed (*Potamogeton pectinatus*) (Deaton et al., 2010). Ferguson and Wood (1994) review the ranges of salinity that commonly sustain North Carolina SAV species. Eelgrass has a salinity range of 10 to 36 parts per thousand (ppt) with an average of 26 ppt. Widgeongrass ranges from 0–36 ppt with an average of 15 ppt. Overall, the maximum salinity measurement for growth of high saline species is 36 ppt. Low salinity species such as wild celery, Eurasian milfoil, bushy pondweed, and sago pondweed require between 0–10 ppt with an average around 1–2 ppt (Ferguson and Wood, 1994; Kenworthy et al., 2012).

In systems where physiological and biological drivers play a role in the architecture of the habitat, SAV species are considered “ecosystem engineers” (Koch et al., 2001). In a stream setting, aquatic macrophyte presence is dictated by physical factors such as water flow and sediment movement. However, aquatic macrophytes also have the ability to influence physical processes by directly and indirectly altering channel roughness, velocity patterns, and sediment transport (Bunn et al., 1998; Pitlo and Dawson, 1990). Flow resistance from plants results in a lower mean velocity and consequently greater flow depths for the same discharge. Localized changes in water velocity have the potential to influence sediment transport. The macrophytes themselves may promote sediment deposition (Sand-Jensen, 1998).

One case study of seagrasses of the Indian River Lagoon in Florida indicates a 95 percent loss of SAV coverage in the last 20 years. Rey and Rutledge (2006) reported that reduced light transmittance through the water column is a major factor for the loss of seagrass coverage. In this scenario the reduction of sunlight usually starts at the deeper edge of beds, where the light reaching plants is marginal, and progresses towards shallower regions. Light penetration is impacted by absorption from other vegetation such as attached algae, floating phytoplankton, etc, other suspended and dissolved substances, changes in color due to dissolved organic materials, and eutrophication. Seagrass species most prominent in the Indian River region included turtle grass (*Thalassia testudinum* Banks and Soland. ex Koenig), shoal grass, manatee grass (*Syringodium filiforme* Kuetz.), Johnson’s sea grass (*Halophila johnsonii*), star grass (*Heteranthera zosterifolia*), paddle grass (*Halophila* *decipiens* Ostenf), and widgeongrass (Rey and Rutledge, 2006). In the Indian River Lagoon phytoplankton and algal blooms are often caused by increased nutrient loads from agricultural and residential fertilizers. These blooms may hinder seagrass growth by shading or blocking sunlight and render the estuarine floor unsuitable for regrowth of seagrass for extended periods (Kennish et al., 2008). Increased dissolved nutrients can also increase populations and density of light-blocking epiphytes (Rey and Rutledge, 2006), further impacting SAV growth.

In the mid-1980s, the Chesapeake Bay saw an unprecedented decline in SAV (Orth and Moore, 1983). Orth and Moore (1983) reported that areas with the greatest reduction in aquatic grass species coincided with the areas of greatest nutrient enrichment. Nutrients stimulated phytoplankton growth and periphyton growth on the leaf surface of eelgrass and other estuarine grasses resulting in reduced light availability to the plants. In areas of the Chesapeake Bay the loss of periphyton grazers may have also resulted in a larger density of periphyton growth, ultimately blocking sunlight and retarding photosynthesis in the plants (Orth and Moore, 1983).

Light effects on SAV

Light and light intensity reaching the leaves of aquatic vegetation is considered the most critical factor in maintaining healthy SAV habitats. The minimal light requirements of submerged aquatic plants are much higher than those from non-aquatic plants. Submerged aquatic vegetation requires light intensities that range from 4–29% (Dennison et al., 1993;

Hanson et al., 1987; Osmond et al., 1987). Shade tolerance and light-related morphological variations of some species may provide a competitive advantage in light-constrained situations, thereby influencing community structure (Barko and Smart, 1981; Lacoul and Freedman, 2006; Middelboe and Mareger, 1997). For example, estuaries shaded by riparian trees may be cooler and contain more dissolved oxygen. In these scenarios if tree cover is too dense the shade may completely eliminate submerged vegetation and other aquatic biota associated with them (Ali et al., 2011).

Considerable thought has been given to why SAV often occurs in one area but is absent just a few meters away. One possible reason is the light levels are adequate in one location but other parameters such as wave energy and sulfide concentration are excessive. In areas where light attenuation remains the key factor defining SAV habitats, the plants are largely restricted to shallow areas. These shallow areas are not the most suitable conditions because they have the highest wave energy levels and sediment resuspension is likely. Thus, aquatic environments presently most favorable to SAV growth from the perspective of light are also the least favorable from the perspective of waves and tides (Koch, 2001). For a description of light requirements for 6 common SAV species found in North Carolina, refer to Table 2.

Shading and SAV

Light transmitted through the atmosphere is modified by atmospheric absorption and scattering before reaching the surface of a water body. At the water's surface sunlight may be reflected or transmitted across the air-water interface. The water and its constituents further modify light entering into the water through absorption, scattering, and fluorescence before the light reaches submerged plants. The modified sunlight allows photosynthesis by seagrass meadows, macro-algal beds, coral reefs, and benthic micro-algal mats (Zimmeran, 2006). Knowledge of the interaction between light and plant canopies is also crucial for quantification of vegetation abundance and distribution by remote sensing (Zimmerman, 2006).

Submerged aquatic vegetation may provide a strong optical signature that can be tracked using satellites and remote sensing (Zimmerman, 2006) in areas where high quality imagery exists and water quality conditions are adequate. In much of North Carolina it is difficult to estimate SAV abundance due to low-resolution imagery or poor water quality (Kenworthy et al., 2012). In general, remote sensing systems may provide detailed maps of benthic species/ and or habitats, as well as information on the biophysical and possibly psychological condition of seagrasses (Dekker, 2006).

In the Great Bay estuary of New Hampshire and Maine, *Z. marina* (eelgrass) was transplanted in outdoor mesocosms and placed in four difference levels of in situ surface irradiance (SI). Neutral density screening provided different levels of photosynthetically active radiation for the mesocosms. The study demonstrated that 11% SI is inadequate for long-term eelgrass survival and causes 81% mortality of plants. Plants were found to be light limited at 34% SI and below but could persist at light levels 58% SI and above (Ochieng et al., 2010).

Repeated, lengthy periods of light-deprivation are a likely cause of mortality in sensitive species. In research by Biber et al. (2009) eelgrass and shoalgrass were subjected to a matrix of light-deprivation events followed by recovery periods to mimic acute shading events. As light-deprivation periods increased in duration and frequency, individuals of both species and specific life stages produced fewer or no new vegetative shoots. Plants with the highest rate of survival were treatments where light-deprivation was followed by a recovery interval of at least the same duration (Biber et al., 2009).

To evaluate shading, Collier et al. (2012) exposed species of SAV to high (66%), moderate (31%), low (14%), and very low surface light (1%) conditions for 102 days. In a shaded environment with only 1% surface light, the Indo-West Pacific seagrasses (*Cymododoeca serrulata* (R. Brown) Ascherson & Magnus, Halodule uninervis (Forsskal) Ascherson, *Thalassia hemprichii* (Ehrenberg) Ascherson, and *Zostera mulleri* Irmisch ex Ascherson) responded by first exhibiting metabolic changes and the production of new, altered tissue. All species exhibited shoot die off after 46 days and complete loss of shoots after 133 days (Collier et al., 2012). Shoot mortality responses were slower in the low light conditions (14%) than the very low light treatment conditions (1%); therefore efforts to minimize water quality degradation could be of benefit for these habitats.

The vertical distribution and resource allocation of *Ruppia maritima* (widgeongrass) were studied in the Patos Lagoon estuary in Brazil (Costa and Seeliger, 1989). The study included plants at water depths ranging from 0.10 m to 1.30 m. Vegetative shoot numbers and biomass were greatest at 0.40 m. The number of shoots, as well as vegetative biomass decreased with depth to 0.70 m. Below 0.70 m, *Ruppia* plants were absent.

Another study by Gordon et al. (1993) on a SAV species common in Australia, demonstrated a pronounced effect from long term shading on a *Posidonia sinuosa* Cambridge & Kuo meadow. *P. sinuosa* was covered with a shade cloth that gave 80–90% shading for between 148 to 393 days. Reductions in shoot density and primary productivity were more pronounced when the shade period extended from 148 days to 393 days. The negative effects of shade on shoot density, leaf density, and primary productivity persisted for several months after removal of the shade cloth. The study suggests there is long-term damage to the seagrass meadows due to prolonged shading.

Measurement of SAV

Seagrass environments are characterized by certain physical conditions such as temperature, salinity, currents, waves, turbulence and light. These parameters have the potential to affect vegetation on both a small scale (molecular and physiological) and a very large scale (ecosystems as well as global) (Koch and Verduin, 2001). Various methods are used to analyze the distribution and abundance of SAV in these environments. In freshwater and marine environments, field methods generally include qualitative observations and quantitative transect sampling (Rodusky, 2005). Direct sampling of submerged plants is usually conducted from a boat or in the water. Common tools for assessment include corers, rakes, and grapnel; all are commonly used from boats. A long-handled, double headed garden rake is another effective tool used to sample SAV. In turbid waters of the Mississippi River, visual inspection of SAV was found to only detect 27% of present species while raking retrieved on average 70% of the total species (Yao, 2011). This method is effective when determining abundance but not as useful for cross–species comparisons unless the efficiency of the rake has been determined for each species being compared (Yao, 2011).

Acoustic methods for SAV detection have been shown to be effective for quantifying spatial distribution, coverage, and canopy height of seagrass meadows. Paul et al. (2011) described the use of the Star Information System (SIS) for high frequency profiling using a single sonar beam that records an acoustic image of the water column and the underlying seabed to collect quantitative data. This method is also useful for monitoring a meadow's health and changes over time.

Landsat satellites provide high-resolution imagery for the management of SAV. Landsat 7 Enhanced Thematic Mapper Imagery has been used to compare spectral variations between submerged aquatic vegetation and non-vegetated bare substrate along transects in Lake Pontchartrain in Louisiana (Cho, 2007). Landsat imagery was used to demonstrate that reflectance can be altered with depth and presence of SAV. Using the ratios of two consecutive visible light bands Cho (2007) was able to demonstrate an alternative means to study long-term changes in SAV shore distribution.

Geographic Information Systems (GIS) provides the means to visualize, interpret, and understand relationships in SAV environments. Fleming et al. (2012) states "Spatial technology is now prolific in universities and management agencies, presenting a unique opportunity for researchers to apply the current state of knowledge regarding the fundamental niche of macrophytes to the development of spatially explicit tools that can actually be applied by management personnel to enhance re-establishment efforts." Fleming also suggests this technology can enhance macrophyte re-establishment projects.

Three methods for sampling submersed aquatic vegetation in shallow lakes were tested by Rodusky et al (2005); 2 were boat-based and 1 was water-based. This research assessed the capabilities of a ponar dredge, oyster-tong rake, and a PVC quadrat frame deployed by a diver in Lake Okeechobee, Florida. The authors concluded that the boat-based rake method was a suitable replacement for the previously used ponar dredge and quadrat methods, when water-based measurements are not considered practical (Rodsuky et al., 2005).

Neckles et al. (2012) integrated a three-tiered hierarchical framework for seagrass monitoring in the northeastern United States. Little Pleasant Bay, MA, and Great South Bay, NY were monitored at multiple spatial scales and sampling intensities. The three-tier approach is described as:

- Tier 1 monitoring – Existing mapping programs providing large-scale information on seagrass distribution and bed sizes.
- Tier 2 monitoring – Quadrat- based assessments of seagrass percent cover and canopy height at permanent sampling stations following a spatially distributed random design.

- Tier 3 monitoring – High-resolution measurements of seagrass condition (percent cover, canopy height, total reproductive shoot density, and seagrass depth limit) at a representative index site in each system.

The three-tiered approach allowed for a better understanding of seagrass status and trends at multiple scales and provided a comprehensive review of ecological conditions. Tier 1 provided information on long-term changes to seagrass distributions at a bay-wide scale. Tiers 2 and 3 monitoring of bays with known seagrass distributions allowed for higher resolution results that were useful for understanding mechanisms of change. Projects of this magnitude are designed to provide the information necessary for resource managers to make conservation decisions (Neckles et. al, 2012).

Measurement of light

In most aquatic environments, light is a limiting factor for submerged vegetation. In reference to light, Ozretich (2009) states,

> "Light is a fundamental requirement for seagrasses. The energy derived from photons is used to reduce carbon dioxide and fuel the biosynthesis of carbohydrates that make up the bulk of these plants, amino acids and lipids. Without light consisting of a sufficient quantity of photons of wavelengths overlapping the absorption spectra of seagrass' photosynthetic pigments, insufficient carbon dioxide will be fixed to fulfill the plant's respiratory needs resulting in the plant's death or failure to growth or reproduce (Ozterich 2009)."

Light availability in aquatic habitats is studied quantitatively with photometers as fluxes or Joules, or as relative transparency using a Sechhi disc or a spectrophotometric index (Lacoul and Freedman, 2006). In larger scale studies of lentic ecosystems, gradients of turbidity and or transparency are important predictors of the distribution and abundance of aquatic plants, while in streams and rivers shading by a riparian canopy may also be an important factor (Lacoul and Freedman, 2006a; Lacoul and Freedman, 2006; Mackey et. al., 2004).

Aquatic plants' maximal survival depth increases as light penetration increases. The minimal requirements for SAV survival can be determined from simultaneous measurements of the maximal depth limit for SAV and the light attenuation coefficient, which quantifies the rate at which light is attenuated as a result of all absorbing and scattering components of the water column (CSRIO, 2013).

In aquatic environments, light is often measured using a device called a Secchi disc. This is a round, black and white 30-centimeter disc that is lowered through the water until the distinction between quadrants is no longer visible to the naked eye (Dennison et al., 1993). This method is widely used throughout the world because it is simple, quick, cheap, and applicable to many different environments. After the measurement of depth, a conversion factor between Secchi and the light attenuation coefficient is used. "The conversion factor is the percentage of incident light (photosynthetically active radiation [PAR] = 400 to 700 nm) that corresponds to maximal depth penetration of submersed aquatic vegetation and is determined using a negative exponential function according to the Lambert – Beer equation [empirical relationship between the absorption of light and the properties of the material the light is traveling through]" (Dennison et al., 1993). Secchi measurements are robust, and if taken carefully can be successfully compared across most atmospheric and sea surface conditions. A limitation to the Secchi depth is that most seagrasses grow in very clear water where sediment bottom is clearly visible from the surface or in shallow, turbid regions, often with high tannin concentrations flowing off swamp habitats (Carruthers et al., 2001).

Another cited method measures light using photosynthetic photon flux density. Photosynthetically active radiation (PAR), wavelengths of 400–700 nm of the light spectrum that is utilized by plants for photosynthesis, is measured in photosynthetic photon flux density (PPFD). Photoelectric light meters are used to measure light as moles of quanta between 400–700 nm in *u*mol quanta. Sensors may measure 2π (direct light) or 4π (direct as well as scattered) types of light and are used for monitoring as well as direct comparison between sites. Continuous light monitoring may be achieved using a data logger that provides long-term information to indicate strong seasonal patterns in surface irradiance. Long-term continuous modeling is the most accurate method for determining seagrass minimum light conditions (Carruthers et al., 2001). Researchers understand that maintaining adequate light penetration to the depth limit of an existing seagrass bed is a minimal requirement for preservation.

Introduced solution to loss of sunlight

In a 2004 study, researchers attempted to use glass prisms to reduce the impact of shading to submerged aquatic vegetation. The prisms were placed on experimental boat docks in the St. John's River of Florida to increase photosynthetically active radiation to *Vallisneria americana* located beneath the docks. Post-construction revealed no significant difference in SAV percent cover between dock treatments. Submerged aquatic vegetation decline was noted for both control and experimental dock treatments. The researchers concluded prisms do not provide enough additional light to be biologically significant or adequate enough to counteract effects from larger-scale environmental stressors (Steinmetz et al., 2004).

Site restoration and mitigation

In April 2010, the feasibility of widgeongrass restoration was explored in the Caloosahatchee Estuary of the Gulf Coast of Florida. Bartleson (2010) reported water column light attenuation was a significant factor affecting the production of SAV in the estuary. High sediment silt-clay content and high turbidities result in higher total suspended solids (TSS). Higher TSS during wind events also results in reduced light availability. One solution for the loss of SAV is the development of exclosures, areas protected by a fence, to jump start SAV in the region. In one study, the exclosures had a 3 m diameter base and plastic mesh up to 1 m high which prevented grazing (Bartleson, 2010). The intact exclosures were successful and allowed plant densities to increase for widgeongrass. The exclosures provided the secondary benefit of widgeongrass flowering and fragmenting in a protected area. Propagation of new plants increased in the surrounding area through seeding or fragmentation. Reduction of surface runoff and agricultural discharges is also recommended to improve water clarity and reduce epiphytic algal growth (Bartleson, 2010).

In North Carolina a protocol was developed by the North Carolina Department of Transportation (NCDOT) for compensatory mitigation of impacts to SAV from NCDOT projects. The protocol's developing task force was formed because:

- SAV mitigation is not at all like traditional terrestrial wetland and stream mitigation.
- All potential SAV sites are likely within public trust waters and not privately owned.
- Traditional wetland and stream mitigation site searches would be ineffective for SAV mitigation.
- Searches and identification of potential SAV restoration sites must be a coordinated effort with all agencies and organizations with a vested interest in this resource (PDEA, 2012).

This protocol applies to SAV impacts from the NCDOT highway projects in any county that is covered under Coastal Area Management Act. Under the guidelines the NCDOT must appropriately design projects to minimize impacts to SAV communities, and jurisdictional waters. Projects must also utilize aerial photography of the proposed project area and off-site locations to determine possible off-site restoration projects (PDEA, 2012).

To adequately satisfy the desires of the NCDOT task group, restoration efforts must be developed to restore damaged SAV communities or create new communities. The restoration efforts must have multi-agency coordination in the identification, selection, and implementation of a project. Restoration may be performed on-site in kind (restoration of SAV communities within or near project corridor), off-site in kind (at a distance), or off-site out of kind (restoration projects in different biogeographical locations) (PDEA, 2012). Projects may also choose to enhance existing communities (ex. upland buffers) or perform non-traditional mitigation. Non-traditional mitigation includes large extent aerial photography, water quality surveys, customized SAV research, education/outreach, and restoration or enhancement of other environmentally sensitive areas (PDEA, 2012). In some cases maintenance-dredging projects are often considered exempt from mitigation requirements, although in instances of very long dredging cycles these actions are sometimes implemented to minimize immediate impacts (Fonesca et al., 1998).

Concluding Statements

- Areas of Environmental Concern (AECs) are designated by the North Carolina Resources Commission. Most submerged aquatic vegetation is located within the Estuarine and Ocean System AEC which is the coast's broad network of brackish sounds, marshes, and surrounding shores.
- Submerged Aquatic Vegetation (SAV) is "bottom recurrently vegetated by living structures of submersed rooted vascular plants, as well as temporarily unvegetated areas between vegetation patches (Deaton et al., 2010). These "ecosystem engineers" provide refuge for fish and wildlife, reduce wave turbulence, increase water quality, and strengthen sediment substrate.
- Common North Carolina SAV species include coon's tail (*Ceratophyllum demersum*), shoalgrass (*Halodule wrightii*), sago pondweed (*Potamogeton pectinatus*), widgeongrass (*Ruppia maritima*), wild celery (*Vallisineria americana*), and eelgrass (*Zostera marina*).
- Humans pose a significant threat to the SAV habitat due to construction and other influential activities that cause shading.

- Light and light intensity reaching the leaves of aquatic vegetation is considered the most critical factor in maintaining healthy SAV habitats. It is estimated that 15–25% of surface light is the minimal light requirement for many SAV species.
- SAV is measured via direct sampling (rake) or indirectly with the use of acoustics, satellites, or geographic information systems.
- Light is measured in aquatic environments quantitatively with the use of photometers as fluxes or Jourles, or as relative transparency using a Secchi disc or a spectrophotometric index. In plant research photosynthetically active radiation (PAR), wavelengths of 400–700 nm of light spectrum, is measured in photonsynthetic photon flux density (PPFD).

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Table 1.1. General habitat requirements for common species of submerged aquatic vegetation (SAV) in North Carolina.

Species (Scientific, common)	Description	Reference
Ceratophyllum demersum L. (coon's tail)	• Submerged aquatic plant with no roots • Free-floating • Occurs in the entire US • Leaves are arranged in whorls on the stem	Center for Aquatic and Invasive Plants, 2012
Halodule wrightii Asch. (shoalgrass)	• Range is from North Carolina south through Florida and the Gulf of Mexico, to the Caribbean and South America • Grows in sheltered or exposed areas of low intertidal and subtidal zones in sand and mud substrates • Leaves are normally 1.5–13 inches in length • In shallow water, 2 feet depth, it often forms extensive meadows	Smithsonian, 2012

Potamogeton pectinatus L. (sago pondweed)	• Aquatic herbaceous plant up to 3 feet tall
	• Region extends throughout the entire United States
	• Waterfowl utilize sago pondweed as a food source
	• Controls erosion
	• Reproductive strategy
	    ○ Tubers for short term perennation and short distance dispersal
	    ○ Seeds for long term dormancy and long distance dispersal
		Casey, 2010; Madsen and Adams, 1988

Table 1.1. Continued

Ruppia maritima L. (widgeon grass)	• Completely submerged perennial plant • Stems may reach up to 3 feet long • Provides habitat for many micro and macro invertebrates • Used as a food resource by many duck species • Flowers during the summer and the fruiting period is from July to October	Aquaplant, 2012; Rhode Island Coastal Resources Management Program, 2000
Vallisneria americana MichX. (wild celery)	• Spreads by runners and forms tall underwater meadows • Two biotypes: one narrow leaf and one wide leaf • Helps to reduce erosion • Waterfowl utilize wild celery as a food source	Center for Aquatic and Invasive Plants*, 2012; Northern Prairie Wildlife Research Center, 2012
Zosetra marina L. (eelgrass)	• Range is Greenland to North Carolina and reaches a height of 4 feet • Grows in shallow bays and coves, tidal creeks, and estuaries • The long leaves of grass are often covered with tiny marine plants and animals • Over the past 70 years, approximately 90% of all eelgrass throughout its range has been destroyed	Epifanio, 2008

Table 1.2. Light requirements for common species of submerged aquatic vegetation (SAV) in North Carolina.

Species (Scientific, common)	Light responses	Reference
Halodule wrightii Asch. (shoalgrass)	• Light attenuation coefficient (Kd) - 0.93 • Minimal light requirement – 17.2%	Dennison et al., 1993
Potamogeton pectinatus L. (sago pondweed)	• Responds to shading by increasing its location of available carbohydrate to the tubers • Tuber initiation occurs under long day conditions and not controlled by daily photon flux density	Dijk and Vierssen, 1990
Ruppia maritima L. (widgeon grass)	• Light attenuation coefficient (Kd) – 3.57 • Minimal light requirement – 8.2%	Dennison et al., 1993
Vallisneria americana MichX. (wild celery)	• Minimal light requirement – 10%	Kimber et al., 1995
Zostera marina L. (eelgrass)	• Light attenuation coefficient (Kd) - 0.28 • Minimal light requirement – 29.4%	Dennison et al., 1993; Duarte, 1991

CHAPTER 2

Management of Aquatic Vegetation in the Southeastern United States

Journal of Integrated Pest Management
Profiles Section

Stallings et al.: Management of aquatic vegetation in the Southeastern United States

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Management of Aquatic Vegetation in the Southeastern United States

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Abstract

Key Words: Aquatic, Management, Plans, Practices, Weed, Integrated Pest Management

Aquatic vegetation is managed throughout the Southeastern United States with the guidance of state and Federal aquatic plant management plans. These plans often suggest ways to promote the growth of beneficial aquatic plants while attempting to guide the reduction and elimination of unwanted “weedy species.” Aquatic species are divided into the categories of algae, submerged, emergent, and floating species and this classification is based on the morphology and growth habit of the identified species. These species are surveyed using multiple research techniques designed to identify and manage the resource based on the needs of the stakeholder. Management practices can be subdivided into physical, mechanical, biological, and chemical control to reduce or eliminate an undesirable weed species. This document reviews current literature related to management of aquatic plants and provides an overview of problematic aquatic weeds in the Southeastern United States.

Estuaries and river systems throughout the Southeastern United States are inhabited by a great diversity of aquatic vegetative species. These species fall into the categories of algae, submersed aquatic, emergent, or floating. The nine states in this region (Alabama, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia) each have unique ecological resources that are managed with the cooperation of stakeholders through the development of invasive species management programs. Management programs may include aquatic nuisance species task forces, direct implementation of management protocols by a state government, or the creation of a comprehensive aquatic species management plan. In 2011 a review of aquatic species management activities was incorporated into the Southeastern US Aquatic Weeds Crop Profile (excluding Florida due to its diverse and unique aquatic resources). The document acts as an educational resource for policymakers, managers, and the public at large (see Richardson et al. 2013).

In the past few decades, the concept of integrated pest management (IPM) became widely accepted as the most cost effective approach to aquatic weed control. States began to enact programs such as aquatic nuisance species (ANS) management plans for aquatic plant management. For example, the state of Georgia developed a method for "coordinating all state aquatic nuisance species efforts through collaboration and full communication among agencies and organizations." Their primary goal is to prevent the introduction of additional aquatic nuisance species and minimize the spread and impacts of existing ANS populations on native species, environmental quality, human health and the economy" (GDNR 2009). Many other states (e.g. Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina, Tennessee, and Virginia) have similar plans for their aquatic plant management activities that set priority goals based on their specific environments and aquatic pest pressures. These plans provide a resource of networks that may be contacted before, during, and after the implementation of an aquatic pest management strategy.

Ecology

Classifications of aquatic plants

Algae. Algae include several problematic species in the southeast that range in size from microscopic single-cell to multi-cellular to macro-algae that resemble other submersed aquatic weeds. Planktonic algae produce the majority of dissolved oxygen in ponds which is essential for fish survival (Shelton and Murphy 1989; Whetstone 2004). Common examples include species in the *Chlamydomonas* and *Chlorella* genera.

Submersed aquatic plants. These colonies and filaments are rooted to the sediment and grow through the water column and may emerge above the water surface (Lembi 2003). Habitat for submersed aquatic vegetation (SAV) includes marine, estuarine, and riverine systems. Common examples of SAV in the southeast include naiad (*Najas minor* All.), Eurasian water-milfoil (*Myriophyllum spicatum* L.), hydrilla (*Hydrilla verticillatta* L.) and coontail [*Ceratophyllum demersum* (Figure 2.1)].

Floating aquatic plants. Many of these plants may be divided into the categories of free-floating or rooted-floating based on plant connection or lack of connection to the substrate (Lembi 2003). Floating plants may completely cover the water surface consequently shading out plants lower in the water column. Common plants in this category include duckweed [*Lemna minor* L. (Figure 2.1)], water hyacinth [*Eichornia crassipes* (Mart.) Solms], and watermeal (*Wolffia* spp.).

Emergent aquatic plants. Category includes grass and broad-leaved plants that are rooted in substrate but have stems, leaves, and flowers that extend above the surface of the water (Whetstone 2004). Common emergent plants, often found along the shoreline, include waterlily (*Nymphaea odorata* Ait) and alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb]. (See Figures 2.3 and 2.4 for examples.)

Benefits of aquatic vegetation

Many species of fish and wildlife are directly dependent on aquatic vegetation for refuge, attachment, spawning, and food (Rozas et al 1998). The larger macrophytes in particular provide habitat and shelter for fish, fish-eating predators, waterfowl and other wildlife. Submerged aquatic vegetation also produces oxygen through photosynthesis and provides the necessary oxygen for aquatic fauna to thrive (Krull 1970, Lembi 2003, Rozas et al. 1998). Aquatic plants will bind to shallow water sediments, reduce wave turbulence, and remove excess nutrients from the water column (PDEA 2012, Smart et al. 1998). Aquatic plants benefit shorelines by strengthening substrates and holding sediment in place which reduces shoreline movement. The protected bottom sediments may also provide additional shelter for organisms that utilize the substrate (Ali 2007). Aquatic plant life can also add aesthetic appeal to a particular water body along shorelines, in the backyard, or in retention ponds in urban areas (Lembi 2003).

Environmental stressors contributing to loss of aquatic vegetation

Short-term and long-term environmental changes in estuaries, freshwater bodies, and streams can be inhospitable for aquatic plant growth and ultimately affect the health of the ecosystem. An ideal aquatic habitat is one that allows for vegetation to thrive and has suitable biotic conditions. Biotic factors that may affect aquatic plant growth include epiphytes (plants that grow upon other plants), pathogens/diseases, and competition from other vegetation which will ultimately determine dispersal and establishment of a specific species. A change in any of these factors may limit growth or result in the elimination of a species from an area or system (Davis 1990).

Aquatic vegetation, especially SAV, may be considered an "ecosystem engineer" because it plays a vital role in the architecture of the habitat (Koch et al. 2001). Abiotic factors such as water flow and sediment may ultimately determine the spread and viability of these plants. Sunlight also plays a key role in the health of aquatic ecosystems by providing the necessary energy for aquatic vegetation to transform carbon dioxide and inorganic materials into carbohydrates and proteins through photosynthesis (FWS 2013). Invasive species, such as hydrilla, sometimes dominate local systems such that biodiversity and habitat heterogeneity are severely altered. One concern is the overabundance and aggressiveness of an individual species shading the water column and reducing the presence of other less-aggressive, and often native, species. Major algae blooms may hinder seagrass growth by blocking sunlight and render the estuarine floor unsuitable for regrowth of seagrass (Kennish et al. 2008), as well as dramatically reducing available oxygen to aquatic flora and fauna. Increased dissolved nutrients can also increase populations and density of light-blocking epiphytes (Rey and Rutledge 2006) further impacting the growth of other aquatic plant species in the water column.

The loss of a diverse aquatic plant population results in secondary impacts including the decline of waterfowl species. As habitat disappears, species waterfowl depend on as food decreases and water quality degrades. Invasive species entering new niches may also provide added pressure by replacing many native plants and animals in regions of SAV loss (USEPA 2013). The loss of SAV also increases erosion of buffered shorelines due to reduced dissipation of wind and wave energy (HOW 1991).

Management for nuisance aquatic vegetation

State management plans

Each Southeastern state is unique in their management of SAV and representation from local stakeholders. Management plans often define the criteria for determining if a plant is considered a weed, native, or invasive plant. In many cases when aquatic plants begin to flourish and affect human activities negatively (e.g. swimming, fishing, navigation, irrigation), they are considered a weed and management may be pursued to reduce the impact on the local economy or to protect ecological benefits of the water resource (CAST 2014). For each state management strategies may incorporate mechanisms for the PAMS approach (Prevention, Avoidance, Monitoring, and Suppression) of aquatic pests. Once an undesirable species becomes established suppression techniques may include cultural, physical, biological, and chemical control options based on the situation/scenario (see Regional IPM Centers 2013).

Integrated management options of aquatic weeds include physical, mechanical, biological and chemical suppression practices and methodologies and chosen based on the needs or goals of the stakeholders. Some form of control is often considered necessary when dense mats of aquatic plants interfere with recreation and/or threaten wildlife (CAST, 2014). An overabundance of plants may also restrict water flow, cause oxygen depletion, and result in fish kills (Getsinger et al. 2014, CAST 2014). Dense plant growth may also provide too much cover, preventing predation, and leading to stunted sport fish populations (Helfrich et al. 2009). Areas that are in the vicinity of an overly vegetated waterway may experience higher populations of mosquitoes (due to retarded water flow), foul taste and odor in the water supply, and lower property values (Lembi 2003). The most problematic weedy species in the Southeastern United States are listed in Table 2.1 of this document.

Integrated pest management practices for aquatic weeds

It is important to note that the practice of IPM is site-specific in nature, with individual tactics determined by the particular pest/environment scenario. Where appropriate, each site should have in place a management strategy for Prevention, Avoidance, Monitoring, and Suppression of pest populations (the PAMS approach). For any IPM suppression or control method to be effective, a manager must accurately identify of the problem weed. Assistance in weed identification is accessible through local cooperative extension offices and a number of online resources.

Cultural suppression practices. Many methods for cultural control exist and may be utilized in the removal or reduction of aquatic weeds through modifying the environment to make conditions less suitable for weed growth (Whetstone 2004). Aeration, for example, circulates and adds oxygen to a water column, enhancing ammonium nitrogen removal (Jamieson et al. 2003). Aeration devices incorporate electric or solar power mixers that reduce available phosphorous, resulting in less algal growth. Physical control may also reduce or enhance available light in the water column. Benthic barriers and Environmental Protection Agency registered dyes may limit light penetration through shading (Richardson 2008).

Physical suppression practices. When applicable, cutter and shredding barges may destroy vegetation and allow the plant material to flow downstream or to more saline environments. Due to the concern of continued spread and reproduction after shredding, mechanical harvesters and removers are the most recommended and widely used type of equipment for mechanical control in the United States. Harvesters have the advantage of storing cut vegetation in a storage bay for disposal at a later time, however, may be expensive and non-selective between desirable and undesirable species (Madsen 2000; Gettys et al. 2009). Hand pulling is another method that is also effective to dislodge an entire weed from substrate to prevent vegetative regrowth. With many aquatic plants being perennial it is important to remove above/below ground vegetative material to prevent the sprouting of new shoots after management. After removal plant material may be used as a fertilizer or mulch in gardens or as land-fill (Lembi 2003). In some scenarios, large scale drawdown or a lowering of water levels will directly expose aquatic plants to environmental factors such as freezing temperatures, dry conditions, strong wind action, and bottom sediment compaction (Helfrich et al. 2009) or indirectly modify substrate (Bornette and Puijalon 2011).

Biological suppression practices. Biological control is divided into the two subcategories classical and non-classical. In the classical method, a natural enemy (e.g. insects, fish, and pathogens) is introduced from the nonnative invasive plants' native range in an attempt to reduce the dominance that invasive species has in the ecosystem. An example of this method is the release of an insect species that will feed-on targeted aquatic vegetation over a long period of time (refer to UF IFAS 2013). One such example is the *Bageous hydrillae*, a small Australian weevil that feeds on hydrilla in its native environment. This and other weevil species have been used in the U.S. for hydrilla management, but generally with limited success (Madsen 2000). The non-classical biocontrol method incorporates mass rearing and the periodic release of naturalized nonnative aquatic weed biocontrol agents to increase the effectiveness of control. An example of this method is the enhanced rearing and release of Chinese grass carp (*Ctenopharyngodon idella* Val.) for reduction of nuisance aquatic vegetation (Hanlon et al. 2000). Grass carp can be problematic in uncontained systems. Since they do not feed selectively on nuisance vegetation, grasscarp can also consume non-target vegetation.

Chemical suppression practices. Chemical pesticides are an important tool in IPM programs, and in some cases, the use of herbicides to suppress aggressive nuisance vegetation will remain necessary. However, herbicides should be applied as a last resort in suppression systems using a sound integrated pest management approach. Registered chemicals can be used to manipulate or control undesirable aquatic vegetation and can be very effective when used as directed by the label (Masser et al. 2013), but the available products generally kill all the plants, rather than just the targeted vegetation (Hershner and Havens 2008). When making repeated applications, it is always advised to rotate herbicides (use herbicides with different modes of action) due to a growing number of cases where aquatic plants are developing herbicide resistance, and never exceed the rates recommended for a specific label (Masser et al. 2013; Whetstone 2004). Effects of herbicides are strongly influenced by their toxic mode of action and their method of application (Todd and Suter 2013; Kaufman and Kaufman 2013) and either target a specific species or provide for a broad spectrum of control.

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Table 2.1. Problematic aquatic weed species of the Southeastern United States (Developed from Richardson et al. 2013)

Species (Scientific, common)	Impacts	Reference
Alternanthera philoxeroides (Mart.) Griseb. (Alligatorweed)	• Complete coverage of waterways, drains, and water intake valves • Increased risks of flooding • Limitation on light penetration • Recreational access hindered	(USGS 2011 *Alternanthera philoxeroides)* (UF IFAS 2008 Alligatorweed)
Egeria densa Planch. (Brazilian waterweed)	• Displacement of native vegetation and degradation of wildlife habitat • Limitation on recreational activities • Increased sedimentation • Retarded water flow	(Morgan 2009) (University of Maine Coop 2004)
Eichhonrnia crassipies (Mart.) Solms. (Water hyacinth)	• Clogged waterways • Limitation of recreational activities • Block sunlight • Increase eutrophication • Enhanced evaporation of water bodies (Check citation)	(Jacono et al. 2007) (Ramey 2001b)
Hydrilla verticillata (L.F. Royle) (Hydrilla)	• Aggressive and competitive weed that forms dense mats reducing light penetration • Decrease in oxygen levels resulting in fish kills • Reduction of sportsfish weight and size • Limitation of recreational activities	(Jacono et al 2008)
Landolita punctata (G. Mey.) D.H. Les & DJ Crawford (Dotted Duckweed)	• High rate of vegetative propagation that may outcompete native species	(Jacono 2002)
Myriophyllum spicatum L. (Eurasian water-milfoil)	• Shading of other species • Reduced water quality • Inhibition of recreational activities • Reduction of invertebrates	(Collete et al. 2008) (Ramey 2001a)

Table 2.1. Continued

Najas minor All. (Naiad)	• Inhibits growth of aquatic macrophytes • Inhibition of recreational activities	(Cao 2009) (Stratford and Hoyle 2011)
Salvinia molesta Mitchell (Giant salvinia)	• Shading of underwater plants • Oxygen depletion	(Howard 2008) (US IFAS 2011)

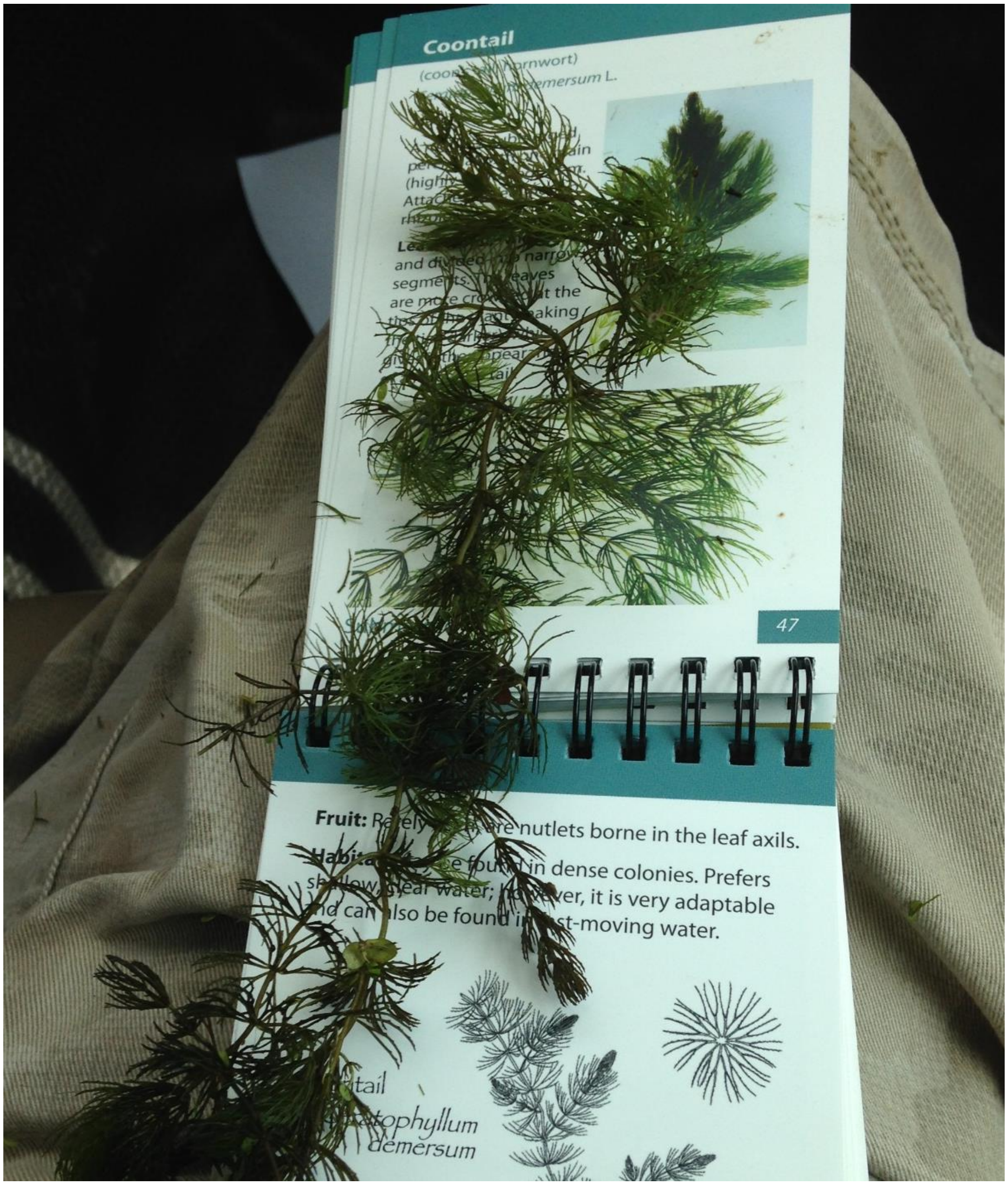

Figure 2.1. *Ceratophyllum demersum* (coontail, submerged aquatic species)

Figure 2.2. *Lemna minor* (duckweed, floating) near Elizabeth City, North Carolina.

Figure 2.3. *Alternanthera philoxeroides* (alligatorweed, emergent), *Lemna minor* (duckweed, floating), and *Myriophyllum aquaticum* (parrotfeather, emergent) species interspersed.

Figure 2.4. *Pontederia cordata* (pickelerweed, emergent species) in the foreground near a boat ramp.

CHAPTER 3

The Influence of Bridge Footprints on the Growth of Submersed Aquatic Vegetation

Introduction

Human induced disturbance along coastal and freshwater watersheds, namely human population expansion and upland development, is historically caused by submersed aquatic vegetation (SAV) losses in the United States (Haramis and Carter, 1983; Short and Wyllie-Echeverria, 1996). Bridge construction and replacement has resulted in SAV loss that has been extensively documented for areas of the United States, and is especially well documented in Florida (Fonesca et al., 1998). Bridge related effects upstream may include levees and culverts that reduce flooding of the riparian zone, grade degradation, and channelization. Downstream grade changes at a bridge may result in local scour that alters sedimentation and deposition processes (Brown, 1982; Forman and Alexander, 1998). Environmental changes to the fixed stream or local freshwater watershed may alter flow rates, pool-riffle sequences, and scour, which typically reduce habit-forming debris and aquatic organisms (Forman and Alexander, 1998). Construction sites also create elevated loads of suspended sediments that can possibly reduce sunlight reaching SAV. Bridges in particular can have negative impacts on invertebrate density, taxa richness, and dominant taxa, as well as trophic feeding groups when spanning brackish and saltwater marshes (Broome et al., 2005). Low bridges may also affect marsh food webs by reducing macrophyte growth and soil organic carbon, adversely impacting the density and diversity of benthic vertebrates (Broome et al., 2005).

Submersed aquatic vegetation plays a vital role in both marine and freshwater ecosystems, providing spawning sites, sanctuary from predators and habitat structure needed by many aquatic species (Smart et al., 1996). In many cases, SAV presence improves water quality through reduction of sedimentation, nutrient removal, and oxygen production. The excellent nutrient assimilation, ability to increase microbial decomposition rates, and the prolific growth potential of these species are all factors that have lead many countries to incorporate SAV into their waste water management practices (Brix and Schierup, 1989; Srivastava et al., 2008). Submersed aquatic vegetation is also able to absorb wave energy, which helps to reduce sedimentation and maintain the integrity of underwater channels because the frictional the drag of water flowing over the leaves and stems allows sediment to settle out of the water column (Deaton et al., 2010). Federal and state watershed managers in the United States develop mitigation programs to replace SAV communities that are disturbed by human development projects for ecosystem enhancement and to improve water quality (Srivastava et al. 2008).

In North Carolina, SAV is regulated by the US Army Corp of Engineers and the Department of Environmental and Natural Resources (NCDENR). Within NCDENR the North Carolina Ecosystem Enhancement Program makes watershed plans (NCEEP, 2013) and determines the required mitigation offset for the anticipated loss of submersed aquatic vegetation due to a construction project or practice. In the case of bridge design, changing a project may reduce the impact of the bridge footprint on submersed aquatic vegetation, ultimately reducing mitigation costs to an organization such as the North Carolina

Department of Transportation (NCDOT), which manages bridge construction over waterways throughout all 100 counties in North Carolina (NCDOT, 2013).

For SAV abundance and evaluation, satellite imagery is limited by image resolution, water quality (Kenworthy et al., 2012), and expense. These limitations affect research in North Carolina freshwater estuaries. For areas of northeastern NC, extensive research has been performed on estuaries such as the Albemarle Sound, but there is limited information on freshwater rivers and streams in the same region. Most data near roadways for freshwater sites in the state is collected by the North Carolina Department of Transportation, which performs plot surveys to identify SAV through environmental water quality surveys (NCDOT, 2013). Further research is required to evaluate how SAV may be affected by bridge structures and footprints in the Northeastern part of North Carolina.

Our objectives were to determine the distribution of SAV present near representative northeastern NC bridge sites, the effects of the bridge footprint on streams, and to determine if bridge height and orientation impacted the presence of SAV.

Methods

Experimental Design and Study Bridge Selection (Primary Survey). The initial population of potential bridge study sites was selected through the use of Google Earth® and the NCDOT Bridge Database in ARCGIS. The region of interest, an area north and east of Williamston, NC to South Mills, NC was reviewed for possible bridge locations (all within the Coastal Plain of North Carolina). The area was chosen because many bridges in the region will undergo maintenance and replacement requiring the North Carolina Department of Transportation to mitigate for the loss of SAV. Bridge locations were characterized based upon height, directional orientation, and location, then divided into sampling categories of short (< 12 meters), tall (≥ 12 meters), North/South, and East/West. After a preliminary survey was performed in winter 2012, a subsample of 16 bridges was chosen, based upon an even distribution between categories, accessibility for sampling, and location (See Table 3.1 and Figure 3.1). Data collected included submersed aquatic vegetation presence/absence and identification, water quality (Secchi depth, pH, temperature, and dissolved oxygen), available light (Photosynthetically Active Radiation availability), and bridge characteristics (Table 3.2).

Geographic location. All stream and river study bridges were located in the North Carolina counties of Bertie, Camden, Perquimans, Pasquotank, Perquimans, and Washington. Watersheds included the Albemarle, Chowan, Pasquotank, Roanoke, and Tar-Pamlico. Gage height, rainfall per month, and temperature from January 2012 to December 2013, for the Northeasthern NC region, may be seen in Table 3.3 (National Climatic Data Center, 2014; USGS, 2014).

Study Bridge Assessment. The bridge footprint was determined to include any area of shoreline that was heavily impacted by the presence of stone riprap or other necessary control measures for erosion prevention (Van Zyl Environmental Consultants CC, 2011). Bare soil was also considered part of the footprint. The bridge footprints ranged from 4 m to 32 m, on either side, based upon the bridge characteristics. Bridge-specific characteristics that may be seen in Table 3.2 include bridge descriptors (height, width, length, and footprint width), footprint impact variables, and a noted species list.

From June 2012 to December 2013, bridge sites were surveyed once per month along a perpendicular shoreline transect starting from the center of the bridge moving outward at 8 m intervals to 40 m. The 40 m distance was outside of the defined footprint for all bridges and was considered to be the control sample point. In total, our sample area had a total linear distance of 80 m at each bridge. At each 8 m transect point, a rake was thrown twice to assess the presence/absence of submersed aquatic vegetative species and any vegetation collected was identified to species and recorded. The percentage of abundance was then calculated based on the number of transect points that had presence of a specific species out of 12 total points, then multiplied by 100. From December 2012 to December 2013, a visual survey was also performed from each transect point for the presence/absence of species until the completion of the project in December 2014. At each transect point a researcher scanned for any visible SAV, perpendicular to the shoreline, as far as easily distinguishable. The visual percentage of abundance was then calculated similar to the rake transect method. If accessibility was hindered by environmental conditions it was noted in the log.

For the survey period from June 2012 to December 2013, water quality measures were documented during each survey. These measures included pH, dissolved oxygen (DO), and temperature through the use of a YSI 556 Multiparameter System unit (YSI Incorporated, Yellow Springs, Ohio). Photosynthetically Active Radiation (PAR) was also measured every foot from the surface until the unit reached a measure below 100 with the use of a Licor LI-192SA Underwater Quantum Sensor (Fondriest Environmental, Fairborn, Ohio). A measure of Secchi depth was also performed during this period. Beginning December 2012 conductivity was measured.

Secondary Survey. On July 30, 2013 a secondary SONAR survey was performed using a Lowrance™ HDS 7 SONAR (Lowrance™, Tulsa, Oklahoma) system at bridge F (Highway 32) and bridge G (Highway 17). The bridges were chosen based on the minimal depth requirements of the SONAR equipment and travel distance between bridges for a single day survey. The survey instrument, Lowrance™ HDS 7 unit, collected raw acoustic data from transects, at roughly 20m intervals using a small watercraft that ran perpendicular to the bridges. Throughout the survey the boat went no faster than 6 miles per hour.

SONAR log information was recorded to assess data for the bathymetric and biovolume components of the survey. After the survey was completed the data was submitted to Contour Innovations, LLC for processing, via a kriging algorithm, to statistically smooth data between transects for SAV biovolume, depth, and soil hardness composition (ciBiobase, 2014). Data acquired were later loaded into ArcGIS and the Geostatistical Analysis Tool IDW interpolated biovolume, depth, and soil hardness for a specified polygon within the survey areas. SONAR survey methods are limited to only identifying the possible presence of vegetation, therefore ground truthing with the rake method was utilized for species observation and identification.

Results/Discussion

During the primary survey, from June 2012 to December 2013 vegetation was found at only three bridges. Species recovered using the rake and visual surveys included *Ceratophyllum demersum* L., *Ruppia maritima* L., *Najas guadalupensis* (Spreng.) Magnus and *Utricularia* sp. (Tables 3.4 and 3.5). Bridge P had the greatest abundance of SAV recovered with both *C. demersum* and *N. guadalupensis* present. The bar graph in Figure 3.2 indicates *C. demersum* from July to August of 2012 and December to May of 2013 for bridge P.

Bridges in closer proximity to the Albemarle Sound (bridges H or P) were more likely to have vegetation than bridges upstream. The key difference between bridges H and P and the other representative bridges is these two they are not located in completely freshwater riverine/stream systems that may be affected by increased water speeds in wetter seasons of the year, such as the fall. Brackish water may promote the growth of certain species of SAV and *R. maritima* could possibly grow in a dynamic system such as bridge H because it tolerates a salinity range of 0 to 36 ppt (Ferguson and Wood, 1994). All other bridges were freshwater except for bridges E, F, and G which had salinity of approximately 1 ppt and K which had an average salinity of approximately 2 ppt. Bridge K, even though it had a higher salinity value, had a footprint that was heavily impacted by human disturbance including seawalls, riprap, and a rocky substrate within a canal-like system which will reduce aquatic plant abundance (Radomski and Goeman, 2001).

Bridge P consistently had the highest abundance of *C. demersum* until June 2013 which coincided with a peak of gage height of 6.07 meters for June and 6.36 meters (Table 3.3) for July 2013. The peaks in gage height were likely associated with the average rainfall of 7.92 inches for June 2013 for the study region. In some instances intense disturbance, such as extreme precipitation, can destroy macrophyte communities through the process of scouring (Lacoul and Freedman, 2006). As water levels rose during this time period an increase in water momentum may have removed or inhibited the growth of *C. demersum* through the scouring process. Also as water levels increased and possibly became more turbid there was likely a decrease in light availability for the system further limiting the capacity for the growth of *C. demersum*. As stated in Lacoul and Freedman (2006) gradients of turbidity and/or transparency are important predictors of the distribution and abundance of aquatic plants.

Bridge F differs from other bridges in the survey due to its location within the Albemarle Sound. As seen during the transect survey, vegetation was present but never rooted along the 80 meter transect. One possible reason is the rip rap for this location extended 30 meters to the west and sandy beach comprised an area 40 meters to the east, possibly not allowing for a stable substrate that submersed aquatic vegetation requires for establishment. The sandy bottom at this bridge is constantly shifting due to wave action (white caps made it difficult to sample throughout year). According to Koch (2001) growth and distribution of submersed aquatic vegetation may be limited by high wave energy like that documented for bridge F. If this site were more stable, with less wave action, it may allow for the growth of submersed aquatic vegetative species such as *V. americana* and *N. guadalupensis* that were found at bridge G during the secondary survey.

In an attempt to capture a more substantive amount of data related to the growth of submersed aquatic vegetation, we employed a SONAR system July of 2013. The July 2013 survey of bridge F (Highway 32) and bridge G (Highway 17) showed only a small amount of vegetation. At bridge G (Figure 3.3) a trace amount of *Vallisineria americana* Michx. and *N. guadalupensis* was confirmed via rake collection. Of the 6 waypoints that had submersed aquatic vegetation, 83% were *V. Americana* and 83% contained *N. guadalupensis*. When bridge F was sampled, no submersed aquatic vegetation was found. From the primary transect survey data from June 2012 to December 2013 vegetation such as *Myriophyllum spicatum*, *Zannichellia palustris,* and *N. guadalupensis* was consistently found along the riprap or on the shoreline during observations of the general area, but these fragments were not rooted for bridge F and bridge G. Relative water depth and soil composition for these bridges are included in Figures 3.4 to 3.7.

The SONAR survey further confirmed a small amount of vegetation for bridge F and bridge G, which corresponds to the findings of the transect method. For bridge G we found a trace amount of *V. americana* and *N. guadalupensis* but not enough to be considered a substantial SAV bed where one could visually see the impact of the bridge structure. Conditions for bridge F and bridge G (figures 3.4. and 3.6) water depths were suitable for plants such as *N. guadalupensis, V. americana* or *R. maritima,* which all can range in depth from 0 to 14.5 ft , with *V. americana* typically occurring from 3.3 to 6.6 ft (Adair et al., 1994;

Blanch et al., 1998, Kantrud, 1991). The areas in the depth range had recorded soil hardness percentages between 33 to 50% for bridge F and 30.5 to 50% for bridge G as seen in Figures 3.5 and 3.7.

The primary survey data was limited due to the absence of vegetation at any but 3 bridges during the May 2012 to December 2013 survey period. This result is inconclusive to determining if bridge height and orientation impacted the presence of SAV, however, we do have some indication that SAV is more likely distributed in more saline environments and not freshwater streams for the region. For future research a sampling universe of bridges should be prescreened from May to July to ensure the presence of vegetation before a subsequent sampling period. At bridge survey sites a further control distance (beyond 40 meter) would ensure that we are completely outside the impact of bridge characteristics that could increase sedimentation and reduce light availability of species. For the current sampling population of bridges, advised research may include a screening with the sonar methodology or rake method sampling up to a half mile upstream or downstream of the bridge footprint. This data would further indicate whether the limited vegetation was due to localized environmental or human disturbance or the entire watershed is limited in vegetation abundance.

For the management protocols of SAV it will be beneficial to determine mitigation level on a project by project basis as currently implemented by the NCDOT (NCDOT, 2013). Human development can have deleterious effects on vegetation abundance (Radomski and Goeman, 2001) and with the variability of the bridge footprints individual bridge studies, pre and post project, will need to continue to evaluate how much vegetation is lost due to a bridges replacement or construction project. In northeastern NC freshwater streams may not require as much mitigation offset as more saline environments and estuaries in coastal counties. Future research is needed to map freshwater streams, evaluate disturbance impacts, and observe water quality to help managers determine which SAV species may thrive if a mitigation project were placed on site (Dennison et al., 1993).

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Table 3.1. List of bridge sites for the survey period from June 2012 to December 2013.

	COUNTY	ACROSS	LATITUDE	LONGITUDE	ORIENTATION	TALL/SHORT
A	BERTIE	ROANOKE RIVER	35.8597	77.0399	N/S	TALL
B	WASHINGTON	CONABY CREEK	35.8961	76.7060	N/S	SHORT
C	BERTIE	ROAN.MID.&CASHIKE	35.9141	76.7218	NE/SW	TALL
D	BERTIE	CASHOKE CREEK	35.9385	76.7432	N/S	SHORT
E	TYRRELL	SCUPPERNONG RIVER	35.8778	76.3374	E/W	SHORT
F	WASHINGTON	ALBEMARLE SOUND	35.9840	76.5086	N/S	TALL
G	BERTIE	CHOWAN RIVER	36.0475	76.6957	NE/SW	TALL
H	PERQUIMANS	PERQUIMANS RIVER	36.1893	76.4560	N/S	TALL
I	PERQUIMANS	PERQUIMANS RIVER	36.1941	76.4664	E/W	SHORT
J	PERQUIMANS	LITTLE RIVER	36.2440	76.3305	N/S	SHORT
K	PASQUOTANK	CHARLES CREEK	36.296	76.2174	E/W	SHORT
L	PERQUIMANS	PERQUIMANS RIVER	36.2841	76.5452	E/W	SHORT
M	PASQUOTANK	KNOBBS CREEK	36.3157	76.2242	N/S	SHORT
N	CAMDEN	JARVIS CREEK	36.4409	76.3141	N/S	SHORT
O	PASQUOTANK	PASQUOTANK RIVER	36.4217	76.3423	N/S	SHORT
P	PASQUOTANK	BR.OF NEW BEGUN CREEK	36.2075	76.1600	E/W	SHORT

*****Bridges with height from crown to bed of ≥ 12 m were considered tall.

Table 3.2. Bridge descriptions including footprint impact variables and noted species list for 16 representative bridges in northeastern, NC. Bridges selected based on location, orientation, height, and accessibility.

Bridge	Description	Footprint Impact Variables	Noted Species List
A	Height (m): 25.0 Width (m): 10.8 Length (m): 279.0 Footprint width (m): 82.0	• Stone Riprap • Culvert • Boat Ramp (Close proximity)	• Shoreline turfgrass • *Alternanthera philoxeroides* • *Lemna minor* • *Polygonum hydrdopiperoides*
B	Height (m): 8.2 Width (m): 10.3 Length (m): 73.5 Footprint width (m): 23.3	• Bare soil	• *Lemna minor* • *Nymphaea* sp. • *Pontederia cordata* • *Scirpus sp.* • *Typha sp.* • *Utricularia sp.*
C	Height (m): 25.3 Width (m): 10.3 Length (m): 1780.3 Footprint width (m): 30.3	• Modified landscape (erosion prevention) • Bare soil	• *Phragmites australis* • *Pontederia cordata* • *Saggitaria* sp.
D	Height (m): 7.62 Width (m): 10.3 Length (m): 92.0 Footprint width (m): 30.0	• Bare soil	• *Lemna minor* • *Nympaea sp.* • Dense deciduous trees
E	Height (m): 7.0 Width (m): 22 Length (m): 74.7 Footprint width (m): 36.0	• Stone riprap	• *Alternanthera philoxeroides* • *Ceratophyllum demersum (limited)* • *Myriophyllum aquaticum* • *Utricularia* sp.

Table 3.2. Continued

F	Height (m): 22.7 Width (m): 10.5 Length (m): 5626.9 Footprint width (m): 72.0	• Stone riprap • Sandy/ bare soil	• *Myriophyllum spicatum* • *Zannichellia palustris* • *Najas guadalupensis*
G	Height (m): 29.3 Width (m): 22.3 Length (m): 2893.5 Footprint width (m): 72.0	• Stone riprap	• Dense herbaceous layer on riprap
H	Height (m): 15.5 Width (m): 10.2 Length (m): 884.2 Footprint width (m): 60.0	• Stone riprap	• Turfgrass • Dense tree species
I	Height (m): 11.6 Width (m): 7.1 Length (m): 195.1 Footprint width (m): 66.0	• Seawall • Disturbed ground	• Turfgrass
J	Height (m): 4.0 Width (m): 15.2 Length (m): 38.6 Footprint width (m): 64.0	• Erosion control concrete • Bare soil or limited vegetation	• *Alternanthera philoxeroides* • DOT maintained turfgrass • Dense tree layer
K	Height (m): Width (m): 13.0 Length (m): 58.0 Footprint width (m): 21.0	• Riprap	• Turfgrass

Table 3.2. Continued

L	Height (m): 4.6 Width (m): 9.0 Length (m): 32.9 Footprint width (m): 17.0	• Modified landscape	• *Lemna minor* • *Nymphaea sp.*
M	Height (m): 4.6 Width (m): 8.0 Length (m): 219.7 Footprint width (m): 50.0 – new bridge construction 2013	• Bare soil	• *Lemna minor*
N	Height (m): 4.0 Width (m): 11.0 Length (m): 39.6 Footprint width (m): 20.0	• Bare soil	• *Alternanthera philoxeroides* • *Nympaea* sp. • *Saggitaria sp.* • *Utricularia* sp.
O	Height (m): 5.2 Width (m): 11.9 Length (m): 55.5 Footprint width (m): 41.5	• Bare soil	• *Alternanthera philoxeroides* • *Utricularia* sp.
P	Height (m): 3.7 Width (m): 9.1 Length (m): 35.1 Footprint width (m): 17	• Stone riprap	• *Ceratophyllum demersum* • *Lemna minor* • *Najas guadalupensis* • *Pontederia cordata* • *Typha sp.*

Table 3.3. Regional climate data from January 2012 to December 2013 for northeastern, NC near bridge sites.

Month/year	Gage Height*	Diff mean	Rainfall**	Diff mean	Temperature***	Diff mean
Jan-12	**4.79**	0.01	**2.45**	0.22	**46.50**	0.55
Feb-12	**3.82**	-1.04	**2.82**	-0.60	**47.40**	1.50
Mar-12	**4.37**	-0.29	**3.70**	0.89	**60.45**	7.25
Apr-12	**5.62**	0.16	**3.00**	0.02	**60.45**	0.35
May-12	**4.97**	-0.33	**7.98**	2.75	**72.20**	2.13
Jun-12	**4.75**	-0.66	**3.47**	-2.23	**75.20**	-0.83
Jul-12	**4.34**	-1.01	**5.47**	0.03	**83.65**	1.83
Aug-12	**4.56**	-0.09	**6.18**	0.43	**79.95**	1.52
Sep-12	**4.30**	0.11	**2.72**	0.72	**73.25**	1.68
Oct-12	**3.82**	0.00	**5.45**	0.73	**63.95**	-1.10
Nov-12	**3.87**	0.00	**0.60**	-0.84	**49.35**	0.13
Dec-12	**3.96**	0.00	**5.28**	0.42	**50.75**	1.90
Jan-13	**4.76**	-0.01	**2.01**	-0.22	**45.40**	-0.55
Feb-13	**5.90**	1.04	**4.03**	0.60	**44.40**	-1.50
Mar-13	**4.95**	0.29	**1.93**	-0.89	**45.95**	-7.25
Apr-13	**5.30**	-0.16	**2.97**	-0.02	**59.75**	-0.35
May-13	**5.63**	0.33	**2.48**	-2.75	**67.95**	-2.13
Jun-13	**6.07**	0.66	**7.92**	2.23	**76.85**	0.83
Jul-13	**6.36**	1.01	**5.42**	-0.03	**80.00**	-1.83
Aug-13	**4.73**	0.09	**5.32**	-0.43	**76.90**	-1.52
Sep-13	**4.09**	-0.11	**1.27**	-0.72	**69.90**	-1.68
Oct-13			**4.00**	-0.73	**66.15**	1.10
Nov-13			**2.27**	0.84	**49.10**	-0.13
Dec-13			**4.44**	-0.42	**46.95**	-1.90

Diff mean = Difference from mean

*****Gage height stations: 02081054 Roanoke, 02081094 Jamesville, and 0204382800 Pasquotank. Source: USGS.

**Rainfall stations: Elizabeth City 10.5 NNW, NC US; Elizabeth City Coast Guard Station, NC US; Merry Hill 3.8 E, NC US; Edenton, NC US. Source: Climate Center.

***Temperature stations: Elizabeth City Coast Guard, NC US; Edenton, NC US. Source: Climate Center.

Table 3.4. Bridges with submerged aquatic vegetation observed and months present as determined by point intercept rake survey.

Bridge	**Aquatic Species Observed**	**Months Observed (Month, Year)**
A	NA	NA
B	NA	NA
C	NA	NA
D	NA	NA
E	NA	NA
F	NA	NA
G	NA	NA
H	*Ruppia maritima*	Jun 12, May – Jun 13
I	NA	NA
J	NA	NA
K	NA	NA
L	*Ceratophyllum demersum*	Jun 13, Aug 13
M	NA	NA
N	NA	NA
O	NA	NA
P	*Ceratophyllum demersum, Najas minor*	Jul 12 – Sept 12, Dec 12 – May13

Table 3.5. Bridges with aquatic vegetation observed and dates present as determined by point intercept visual survey.

Bridge	Aquatic Species Observed	Months Observed (Month, Year)
A	NA	NA
B	*Utricularia* sp.	Jul – Oct 13
C	NA	NA
D	NA	NA
E	NA	NA
F	NA	NA
G	NA	NA
H	*Ruppia maritima*	May 13
I	NA	NA
J	NA	NA
K	NA	NA
L	*Ceratophyllum demersum*	Jun 13, Aug 13
M	NA	NA
N	*Utricularia* sp.	May – Oct 13
O	*Utricularia* sp.	Oct – Nov 13
P	*Ceratophyllum demersum*	Dec – Apr 13, Aug 13

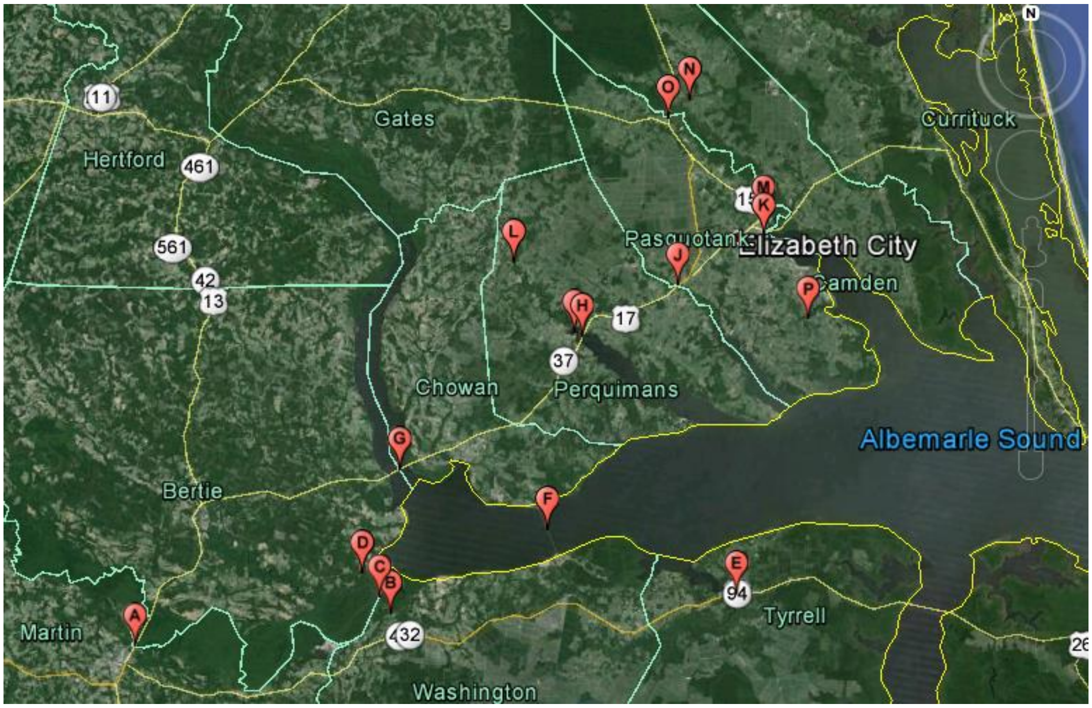

Figure 3.1 Region of interest and survey bridges (Image from Google Earth®).

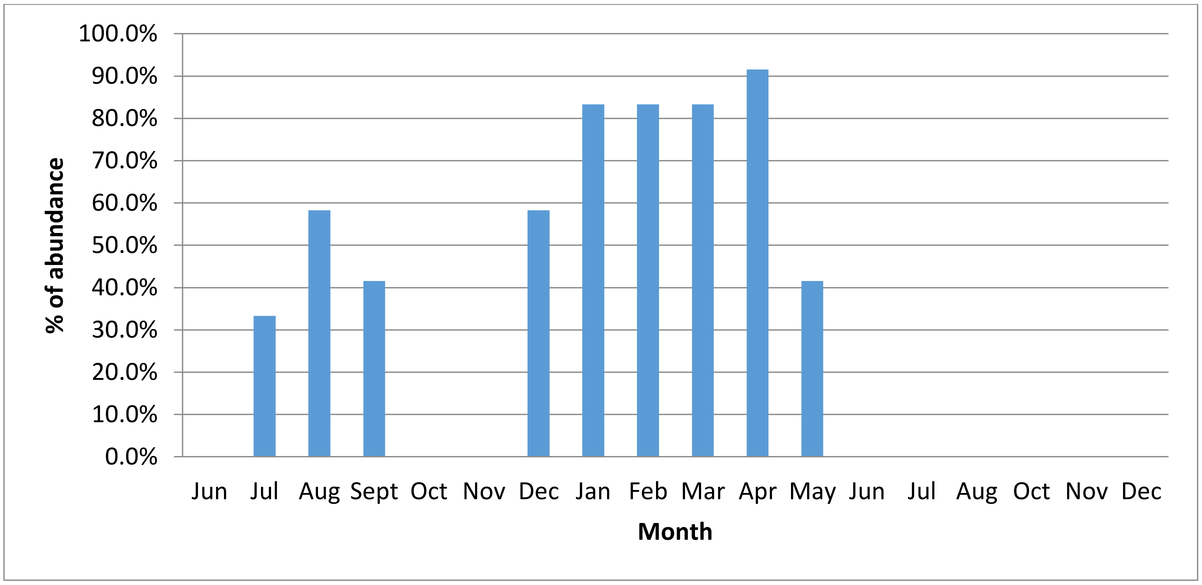

Figure 3.2. The percent abundance of *Ceratophyllum demersum* sampled at bridge P from June 2012 through December 2013 using the rake method.

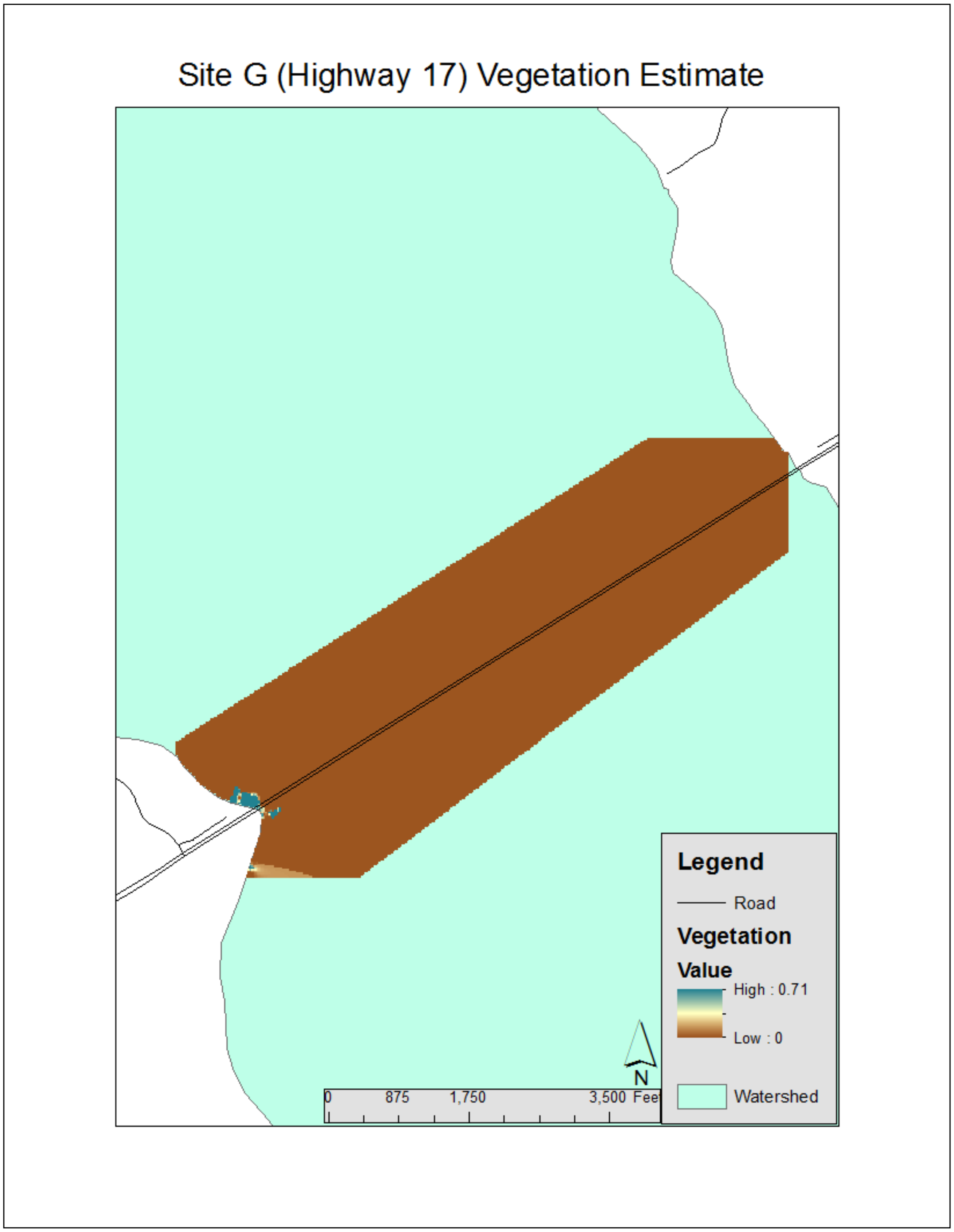

Figure 3.3. Image of submerged aquatic vegetation bio-volume at bridge G (Highway 17). Species found at site include *V. americana* (sampled of 5 out of 6 vegetated waypoints) and *N. guadalupensis* (sampled 5 out of 6 vegetated waypoints).

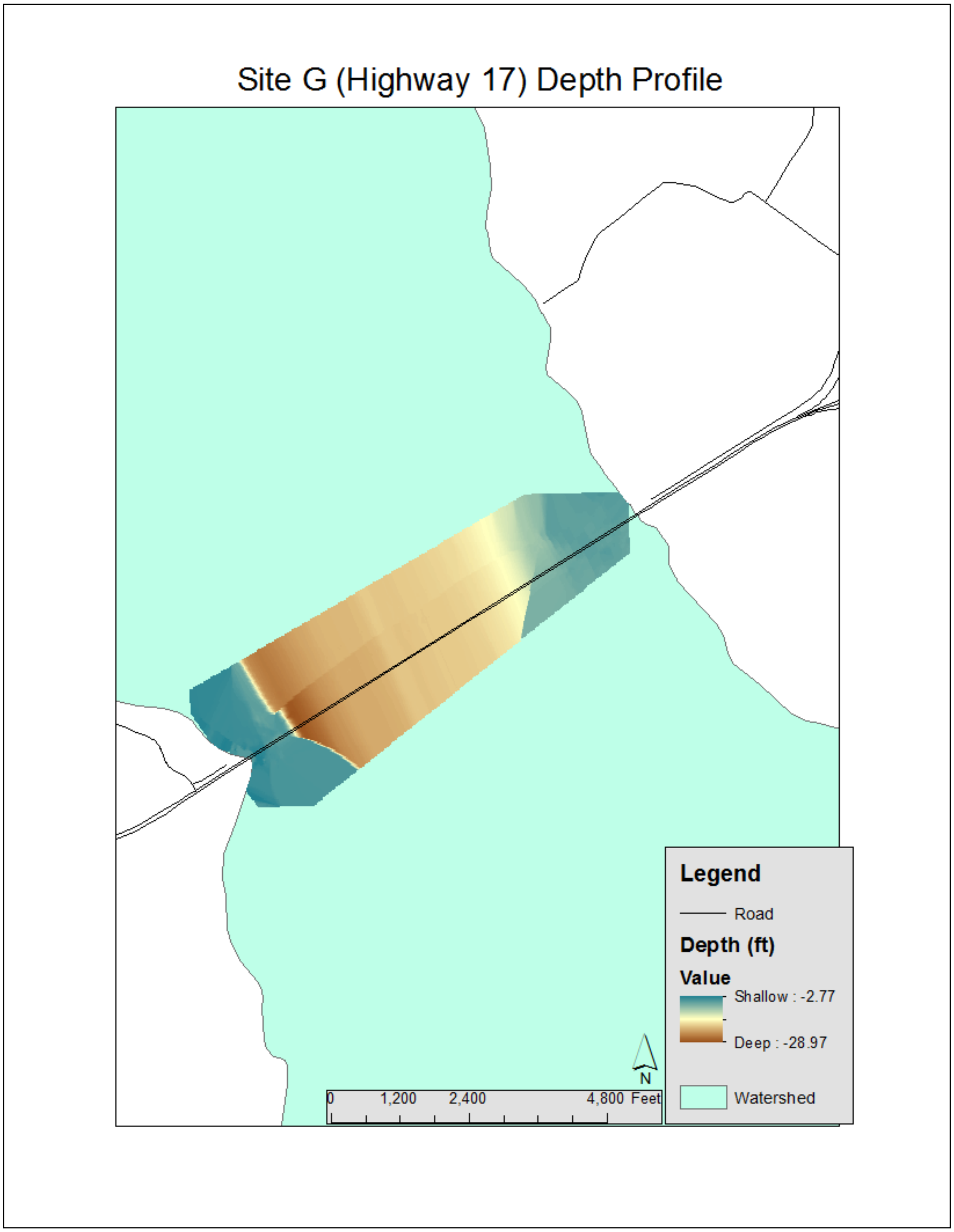

Figure 3.4. Depth profile for bridge G (Highway 17).

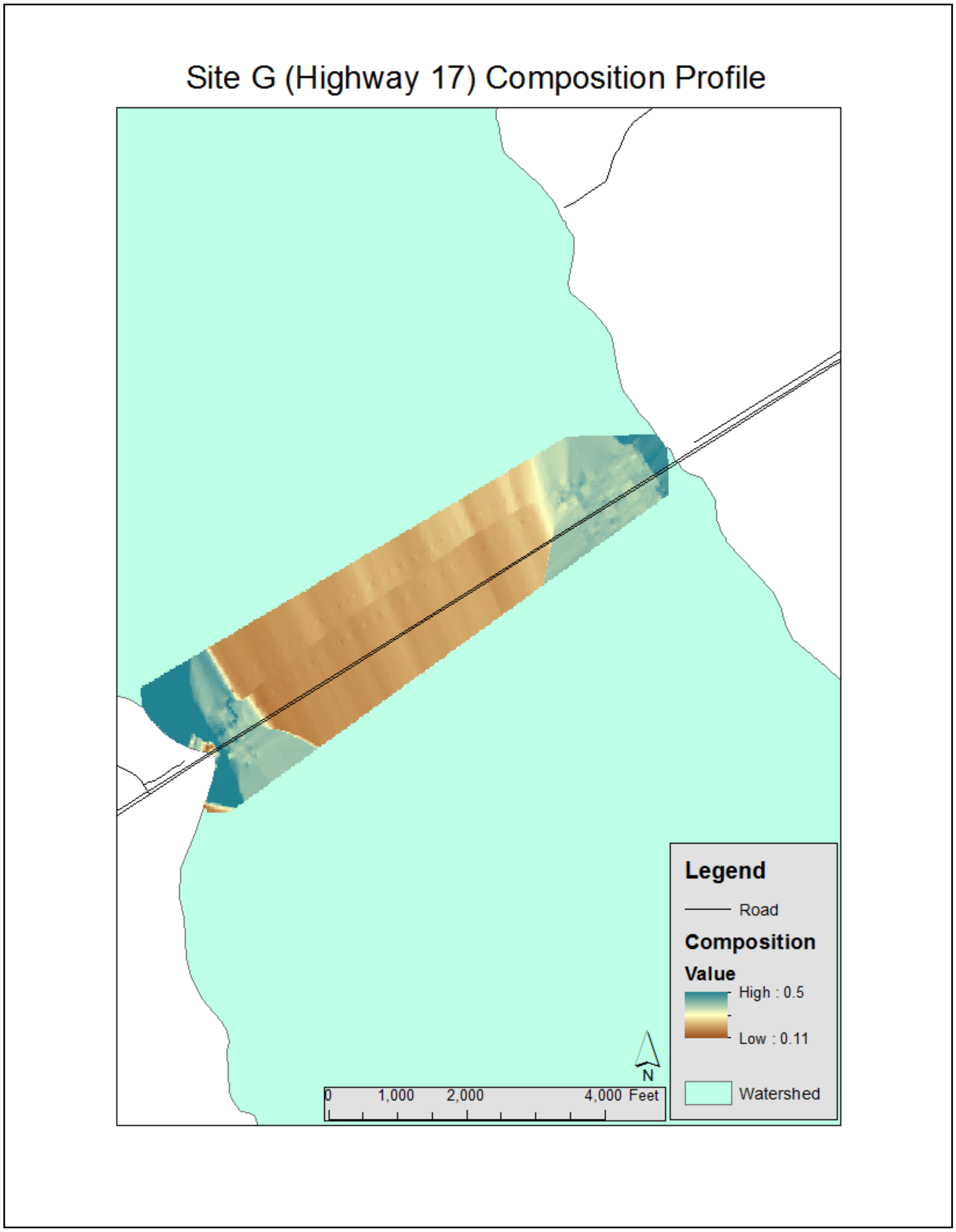

Figure 3.5. Soil hardness composition profile for bridge G (Highway 17).

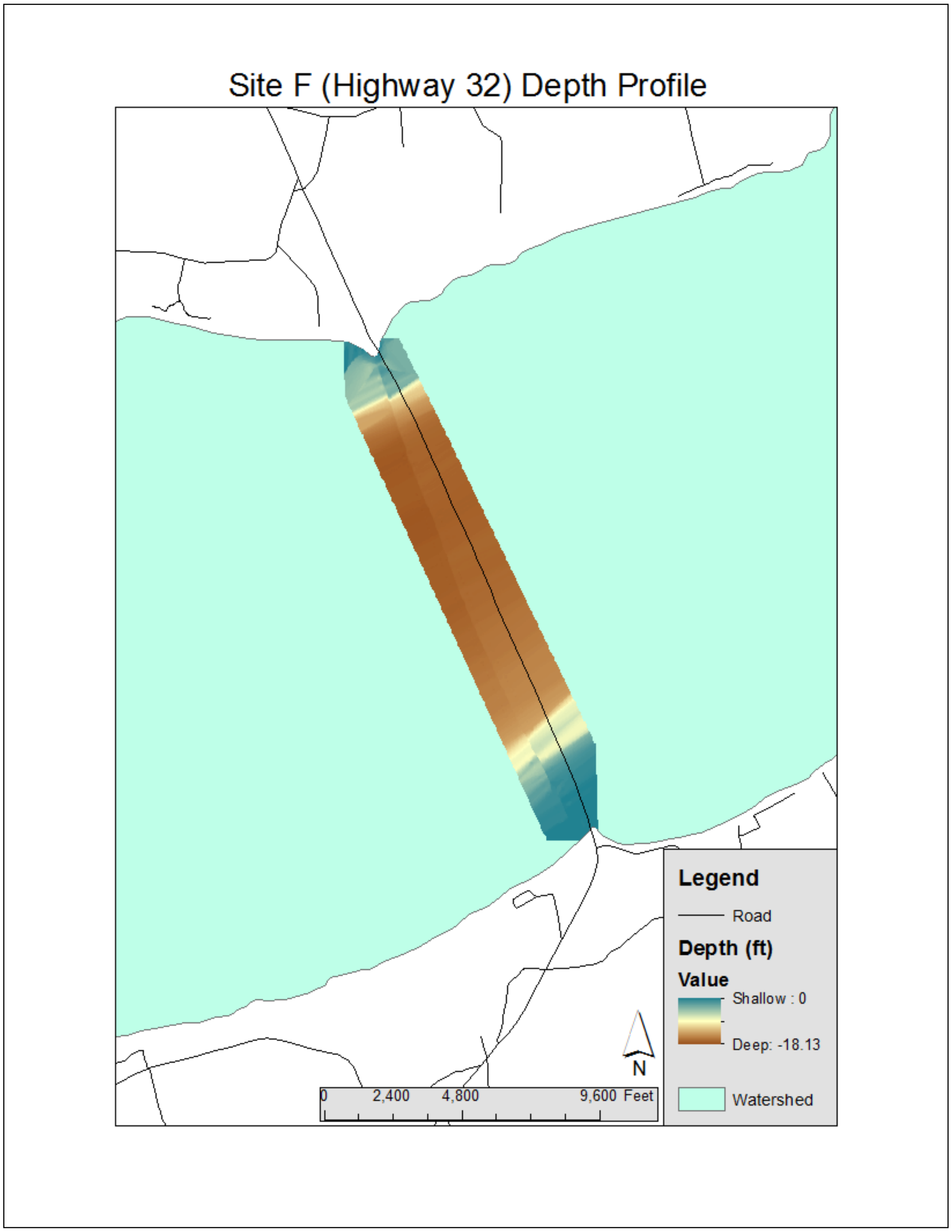

Figure 3.6. Depth profile for bridge F (Highway 32).

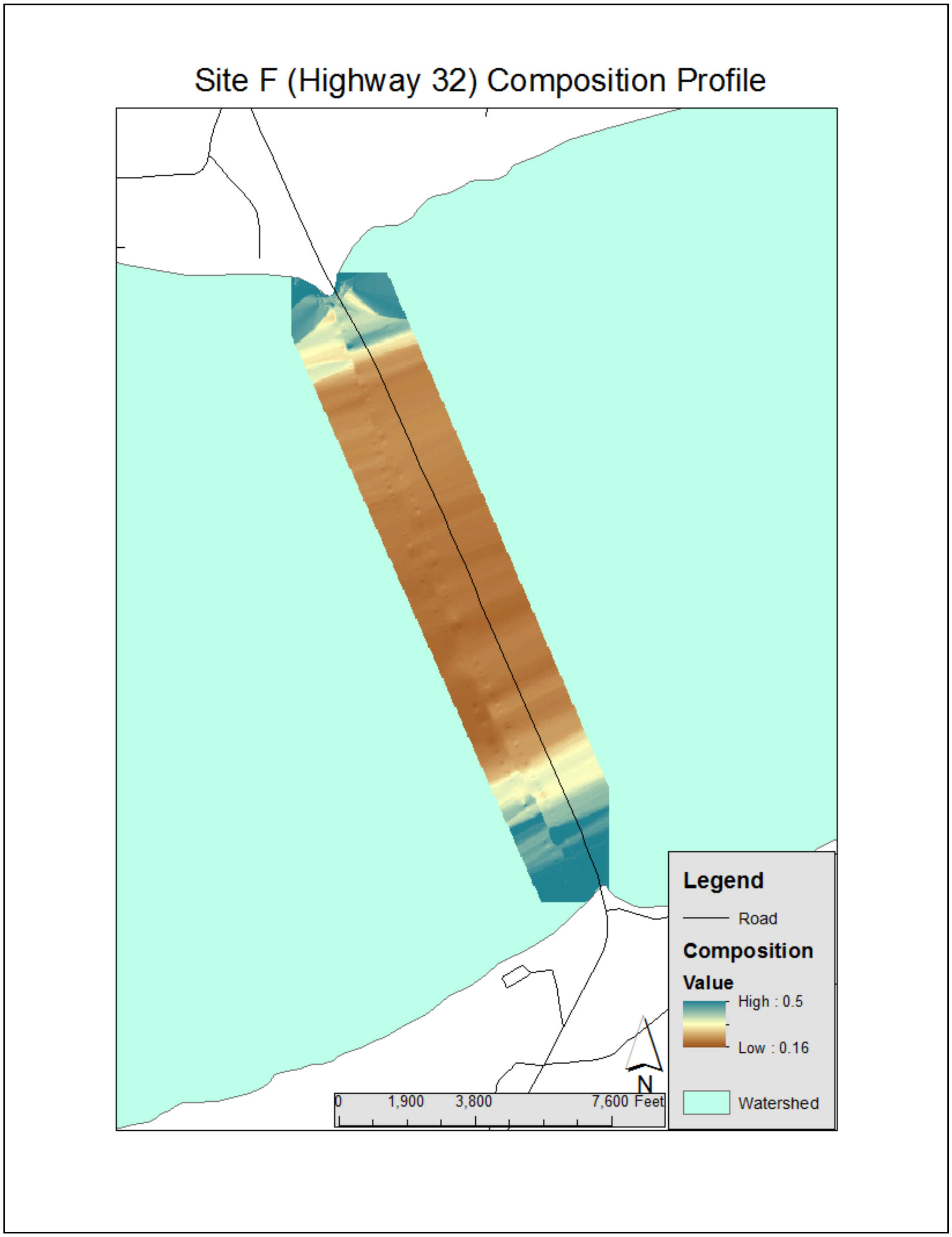

Figure 3.7. Soil hardness composition profile for bridge F (Highway 32).

CHAPTER 4

An Ecological Review of Historic Pinehurst No. 2 Plant Communities

Pinehurst Golf Resort, referred to as "The Cradle of American Golf" (Pinehurst, 2013), is located in Moore County, North Carolina and is home to the historic Pinehurst No. 2 golf course; a course that has hosted more single golf championships than any other course in America (Pinehurst, 2013). Donald Ross, the original designer, opened the 196-acre Pinehurst No. 2 course in 1907 and considered it, "the fairest test of championship golf he has ever designed" (Pinehurst, 2013). In 2010, No. 2 was renovated to reflect the 1940 design, incorporating the native ecology of the neighboring long leaf pine ecological communities and resulting in a reduction in the percentage of Tifway bermudagrass by 40% (B. Farren, personal communication, 2012).

Golf courses and the environment

Golf courses can provide environmental benefits under properly maintained turf systems. It has been recognized that turf systems can help to reduce erosion, purify water, purify air, generate oxygen, and sequester carbon (Beard and Green, 1994; Heinze, 2011; Seth Carley et al., 2011). Biodiversity, conservation and management is of major concern when it comes to future golf course design. Golf courses have the capacity to promote biodiversity that may surpass lands designated for nature conservation. If designed properly, they also have the potential to promote critical ecosystem services such as pollinator habitat and natural pest control. Tanner and Gange (2005) report that golf courses support a higher wildlife diversity relative to adjacent farmland for important indicator groups including birds, ground beetles, and bumblebees.

According to the United States Golf Association (USGA), programs are incorporating environmental stewardship as a part of their core business strategy and in some cases are partnering with environmental organizations (Fletcher, 2011). For example courses following the Audubon Cooperative Sanctuary for Golf Courses (ASCP) guidelines may have significant savings on costs. On average, golf courses working through the program have been able to convert an average of twenty two acres of land from heavily managed turfgrass to less-managed natural areas for wildlife. The ASCP program has in turn led to reduced water, chemical, fuel, and labor inputs through the incorporation of program-specific sustainable practices. Of the 319 environmental projects submitted to Audubon International, 50% were identified by the members to have a cost savings. Through survey responses, 70% of respondents reduced pesticide costs, 90% of respondents reduced risks, 60% increased business value, and 50% used water more efficiently (Fletcher, 2011).

Pinehurst region

The Pinehurst Golf Course is located in the inner coastal plain physiographic region of North Carolina also known as the Sandhills, near the barrier of the Piedmont Province in Moore County. Common plant communities in the region include sand barrens (typic subtype) and xeric sandhill scrubs (typic subtype) (Schafale, 2012; Sorrie et al., 2006). The sand barrens are described as the driest, most barren naturally occurring non-maritime sandy communities of the Coastal Plain. *Pinus palustris* Mill., *Quercus laevis* Walt., and *Aristida stricta* Michx. are common and bare patches of sand may be seen throughout the community. In native habitats of sand, barren gnarled-looking *P. palustris* and *Q. laevis*, *A. stricta* in more mesic microsites, and a diversity of psammophytes (sand shifting species) are often present. In undisturbed sites there is an expected absence of weedy plants such as *Andropogon virginicus* L., *Eupatorium capillifolium* (Lam.) Small, and *Eupatorium compositifolium* Walter (Schafale, 2012).

The xeric sandhill scrub, also cited in the region, is distinguished from sand barrens with higher plant cover in the herbaceous layer and the presence of abundant *A. stricta*. Soils are commonly dry, coarse, and interfertile sands with a low diversity in the scrub oak layer strongly dominated by *Q. laevis*. The typic subtype is considered widespread in the Sandhills region and there is often an abundance of Fabaceae in the Sandhills Variant (Schafale, 2012). As noted in Sorrie et al. (2000) Pine/Scrub Oak Sandhill is a widespread and abundant community for Weymouth Woods in the Sandhills region. Occurring on dry slopes and flats in fine textured soils the dominant species are *P. palustris*, *Quercus* spp., and A. *stricta* with a sparse to dense herbaceous layer. When well burned, the oak subcanopy is markedly reduced and the community appears savanna-like (Schafale, 2012 and Sorrie et al., 2006).

Sorrie et al. (2006) performed a survey of Fort Bragg and Weymouth Woods, which is in close proximity to the Pinehurst No. 2 Golf Course. In the study, 1,206 of infraspecific taxa were documented from the region, representing 143 families and 490 genera. The most represented families were Poaceae, Asteraceae, Cyperaceae, Leguminosae, and Rosaceae. The most abundant genera recorded were *Carex*, *Rhynchospora*, *Dicanthelium*, *Quercus*, and *Juncus* (Sorrie et al., 2006). Another survey by Sorrie and Weakley (2001) discusses the overlap of phytogeographic regions based on lists of endemics, genera, species, and infraspecific taxa. The survey documents the Pinehurst region within the northeastern range of the longleaf pine savanna that defines the core area of endemism (local vegetation) within the coastal plain (Sorrie and Weakley, 2001).

Longleaf pine ecosystem

Common families for the longleaf pine ecosystem include Poaceae, Fabaceae, and Asteraceae that dominate the ground cover (Kaeser and Kriman, 2010). These species are structurally and functionally important components of the ecosystem, providing nutrition and habitat for many wildlife species.

A savanna is open pine woodland of seasonally saturated, fine-textured soils. The wet soil conditions of savannas often lead to the tree composition dominated by *Pinus palustris* or *Pinus serotina*. Orchids (*Calopogon* sp., *Cleistes* sp., *Platanthera* sp.), insectivorous plants (*Drosera* sp., *Dionaea* sp., *Pinguicula* sp., *Sarracenia* sp.) lilies (*Alteris* sp., *Lilium* sp., *Tofieldia* sp.), numerous sedges (Cyperaceae), and other composites make up the understory of the region. Pine savannas can exhibit significant variation in composition driven by subtle changes in hydrologic regime, soil texture, and soil chemistry, more so than any other vegetation type of the fire-maintained southeastern pinelands (Peet, 2006).

The dominant species, *P. palustris,* is monoecious with male strobili occurring most frequently in the upper crown of the same tree (Schopmeyer, 1974). Catkin and conelet development is initiated during the growing seasons before buds emerge, with catkins beginning to form during July, and conelets being formed during a short period in August (Boyer, 1990). Conelet buds appear in January or February, and conelets, upon emerging from the bud, are red until pollinated, after which they fade to a yellowish green. Ambient temperature is the driving force for the development rates of both catkins and conelets (Boyer, 1990). Flower production is related to weather conditions during the year of initiation.

Pinus palustris cones release seeds that typically germinate within a week of contacting the ground. Rapid germination is considered an adaptation to reduce the risk of exposure to seed predators; newly germinated seedlings are also vulnerable to mortality from animals, pathogens, and adverse weather conditions. After contact with mineral soil, germination begins with emergence of radical and an almost simultaneous elongation of the cotyledons. Seedlings are relatively inconspicuous with small primary needles (Jose, 2006). The stemless condition is one of the unique characteristics of longleaf pines and is commonly referred to as the “grass stage.”

As *P. palustris* grow, they create a microclimate beneath that is highly variable due to the effects of shading patterns, temperature, and nutrient availability. This scenario creates an overstory-understory interaction structure that promotes interspecies competition. The understory is shaped largely through direct exploitation of light, soil water, and nitrogen resources from the structure of the overstory and indirectly by accumulation of overstory needle litter that limits light availability to forest floor plants. Within the understory, negative plant interactions (such as interference) result from either competition for limited resources or allelopathy. Resource gradients, such as spatial differences in soil nitrogen availability can change competitive relationships that exist among plants to favor species or individuals that are most effective at resource capture (Goldberg and Miller, 1990; Kalmbacher and Martin, 1996; Jose, 2006).

Fire-use in land management has been frequent in forest, shrub, and prairie lands for many centuries, and has undoubtedly been a major factor in determining the direction and rate of plant succession. Native grass species, within the system, play a vital role in the reintroduction of prescribed fire necessary to sustain this ecosystem by serving as a flammable fuel source (Coffey and Kirkman, 2006; Kaeser and Kirkman, 2010).

Noted in the literature is that a vigorous regrowth of herbs, grasses, and shrubs occurs frequently the first few years following fire (Ahlgren and Ahlgren, 1960). In the longleaf pine ecosystem, seasonal burn times have a significant effect on species diversity depending on the season of burn, resource values, and habitat factors such as seasonal rainfall (Brockway and Lewis, 1997; Glitzen et al., 1995; Platt et al., 1988).

History of Pinehurst No. 2

Pinehurst No. 2 is a highly celebrated golf course that has hosted more single golf championships than any other course in the US. In June of 2014 it will be the first course in history to host the US Men's and Women's Opens in consecutive weeks. The course is best known for its crowned, undulating greens, which are some of the most complex and widely hailed in the world (Neuman, 2011). The original designer, Donald Ross, considered one of the most prolific golf architects of the 20th century, designed Pinehurst's original No. 2 course in 1907 (Neuman, 2011). As the course evolved over the 20th and early 21st centuries, turfgrass dominated the landscape as irrigation technologies advanced. In February of 2010, Pinehurst No. 2 underwent a significant restoration under the direction of Bill Coore and Ben Crenshaw who are highly praised golf architects who promote traditional and strategic golf course designs. The project included the removal of 40 acres of turfgrass and the reintroduction of hardpan, natural bunker edges and native wiregrasses (Pinehurst, 2013).

For the redesign, Coore and Crenshaw studied old photographs and aerials of the course taken in the 1940s and removed "untold acres [40 acres]" of Bermuda grass. The former turf areas were replaced with the native/naturalized areas (Neuman, 2011) that are irregular, sandy ground dotted with thousands of hand-planted *A. stricta* (Klein, 2011). This was part of the effort to return the course back to its original design intent.

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Chapter 5

Native Area Managed Vegetation: A Case Study at Historic Pinehurst No. 2 Golf Course

Introduction

Golf courses with properly maintained turf systems provide environmental benefits by reducing erosion, purifying water and air, generating oxygen, and sequestering carbon (Beard and Green, 1994; Heinze, 2011; Seth Carley et al., 2011). Biodiversity, conservation and management are of major concern when it comes to design of future golf courses. Golf courses have the capacity to promote biodiversity that may surpass lands designated for nature conservation. If designed properly, they also have the potential to manage and promote critical ecosystem services such as pollination and natural pest control (Tanner and Gange, 2005). Tanner and Gange (2005) report that golf courses support a higher wildlife diversity relative to adjacent farmland for important indicator groups including birds, ground beetles, and bees. A further understanding of golf course environmental best management practices is necessary considering there are an estimated 1,504,210 acres (ha) of maintained golf course turfgrass with an estimated 1,198,381 acres (roughly 80%) irrigated, according to the United States Golf Association (Lyman, 2012).

In 2010, the Pinehurst Golf Resort completed a significant renovation, allowing for the reemergence of native vegetation on their historic Pinehurst No. 2 Golf Course - a course that has hosted more single golf championships than any other course in America (Pinehurst, 2013). Referred to as "The Cradle of American Golf" (Pinehurst, 2013), Pinehurst Golf Resort is located in Moore County, North Carolina where the original designer, Donald Ross, opened the 196 acre Pinehurst No. 2 course in 1907. The 2010 renovation returned the No. 2 course to a 1940, based on historical records and images of course from the decade. This renovation incorporated the native flora of the neighboring longleaf pine ecological communities, reducing the percentage of *Cynodon dactylon* (L.) Pers. (Tifway Bermudagrass) by 40% (B. Farren, personal communication, 2012). The course now has over 40 acres of native habitat, distributed throughout the former rough areas, and is praised by Donald Ross enthusiasts who appreciate the historical play and feel of the course. One prized benefit is the reduction of water usage of at least 50% (B. Farren, Personal Communication, 2012).

The transformation of the No. 2 course has created a unique ecosystem incorporating primary and secondary successional phases that pose management challenges to superintendents and staff. These challenges arose because golf course managers are trained specifically to work in turfgrass settings, but they are unfamiliar with management strategies for native habitat. As different vegetation emerged it became necessary for managers at the course to inventory, catalogue, and develop necessary protocols for vegetation control at the course.

Our objective was to characterize native vegetation, desirable adapted species, and invasive and undesirable weeds in the naturalized areas on the Pinehurst No. 2 course as it developed following the renovation. Through the use of site visits and plot survey techniques we provided managers and staff with a comprehensive species list, plant identification booklets, and methods for native site management. Other goals included evaluating how the native areas were promoting biodiversity and evaluating the type of ecological community that is thriving on historic Pinehurst No. 2.

Study Site

Pinehurst Golf Resort is located in a portion of the inner inner coastal plain physiographic region of North Carolina known as the Sandhills, near the boundary with the Piedmont physiographic province in Moore County. Pinehurst No. 2 encompasses two principal soil types, Candor sand (CaB), covering approximately 80% of the course, and Vaucluse loamy sand (VaD) covering approximately 20% (Soil Survey, 2014). The regional mean rainfall was approximately 37.36 inches from 2009 to 2013 (National Climatic Data Center, 2014). Prior to renovation, the superintendents and staff managed the course for uniform vegetation cover. Common management methods included the use of non-selective herbicides to remove unwanted/weedy species from the system at the discretion of the superintendent.

The Sandhills physiographic province is a biodiverse region. Sorrie et al. (2006) performed a survey of the Fort Bragg Army installation and the Weymouth Woods Nature Preserve, which are in close proximity to the Pinehurst No. 2 Golf Resort. In the study, 1,206 infraspecific taxa were documented from the region representing 143 families and 490 genera. The largest families were Poaceae, Asteraceae, Cyperaceae, Leguminosae, and

Rosaceae. The largest genera recorded were *Carex* (sedge), *Rhynchospora* (sedge), *Dichanthelium* (grass), *Quercus* (oak), and *Juncus* (rush) (Sorrie et al., 2006). Another survey by Sorrie and Weakley (2001) discusses the overlap of phytogeographic regions based on lists of endemics, genera, species, and infraspecific taxa. The survey documents the Pinehurst region within the northeastern range of the longleaf pine savanna, which defines the core area of endemism (species of restricted geographic distribution) within the Coastal Plain (Sorrie and Weakley, 2001).

Natural plant communities in the vicinity of Pinehurst Golf Resort are typical of much of the Sandhills physiographic region. They include sand barrens (typic subtype) and xeric sandhill scrubs (typic subtype) (Schafale, 2012; Sorrie et al., 2006). The sand barrens are described as the driest, least vegetated naturally occurring non-maritime sandy communities of the Coastal Plain. *Pinus palustris* Mill. (longleaf pine), *Quercus laevis* Walter (turkey oak), and *Aristida stricta* Michx.(Carolina wiregrass) are common and bare patches of sand occur throughout the community. In native habitats of the sand barren, gnarled-looking longleaf pine and turkey oak are found with a diversity of species that grow in shifting sand. *A. stricta* exists in more mesic microsites. In undisturbed sites there is an expected absence of regionally-important weedy native plants such as *Andropogon virginicus* L.(broomsedge), *Eupatorium capillifolium* (Lam.) Small (dogfennel), and *Eupatorium compositifolium* Walter(yankeeweed) (Schafale, 2012).

The xeric sandhill scrub is distinguished from sand barrens by having a higher plant cover in the herbaceous layer and the presence of abundant wiregrass. Soils are commonly dry, coarse, and infertile sands with a low diversity in the scrub oak layer, the latter strongly dominated by turkey oak. The typic subtype is considered widespread in the Sandhills region and there is often an abundance of Fabaceae in the Sandhills Variant (Schafale, 2012). Another widespread and abundant community is the Pine/Scrub Oak Sandhill. Occurring on dry slopes and flats in fine textured soils, its dominant species of this natural community are longleaf pine, oak species, and wiregrass, with a sparse to dense herbaceous layer. When frequently burned, the oak subcanopy is markedly reduced and the community appears savanna-like (Schafale, 2012 and Sorrie et al., 2006).

Methods

2012 Survey. In 2012, we conducted a comprehensive survey to identify common herbaceous species in the system, develop a comprehensive species list, and create identification booklets for superintendents and staff at Pinehurst No. 2. The protocol for 2012 included site to survey extensive areas of the course throughout the growing season to create an inventory of vascular plant species. From March 2012 to October 2012, 16 plant identification trips were conducted and newly discovered species were identified, catalogued, and photodocumented.

2013 Survey. In 2013, a plot survey protocol was developed to understand how environmental factors may be affecting the species diversity of the course and to document trace species not seen in the 2012 site visits. Both representative and randomly selected plots of 100 m^2 were distributed throughout the course to maximize coverage (Figure 5.2) and to characterize within and between fairway variability in species composition. In 2013, we established a total of 32 plots, from June 25, 2013 to September 20, in more “natural” open areas bordering the fairways, excluding the intensively managed turfgrass area and the adjacent forested land. Photographs were also taken for each plot to aid in identification and provide an opportunity to review plots post-visit if required. In addition to characterizing species presence/absence, we collected soil samples at each plot site and submitted those for analysis by the North Carolina Department of Agriculture and Consumer Services Agronomic Division for pH, potassium, phosphorus, humic matter, CEC, Mn, Zn, Cu, and S soil attributes. During the winter of 2013, a subsample of 17 plots, representing roughly one plot per hole, were used to develop a species area curve and ordination. The statistical analysis software PCORD 6.16 (McCune and Mefford, 2010) was used to develop the species area curves and to perform a detrended correspondence analysis ordination. Beta diversity was also calculated across 17 representative plots.

We calculated constancy (proportion of plots in which a species was present) for each of the 17 representative plots and then acquired presence data for common regional natural communities from the Carolina Vegetation Survey database at the University of North Carolina at Chapel Hill (Peet et al., 2013). Regional communities for comparison are described in Table 5.2.

Results

Thirty nine families are represented on Pinehurst No. 2 with the most prominent being the Poaceae family and the second most prominent being the Asteraceae (Appendix A). According to the USDA Plant Database (USDA, NRCS 2014), 78% of the species identified here are native to the lower 48 US States. A detrended correspondence analysis ordination was developed using a 17 plot subsample (Figure 5.3). In addition a species area curve with a peak of 52 species (Figure 5.4). From the winter of 2012 to the fall of 2013 over 6,000 photos were also captured and organized based on the different species and as a reference for plot studies.

The ordination plot (Figure 5.3) shows similarity among sample sites 1, 11, 13, 14, 16, and 18, which are in close proximity to each other on the southwestern side of the course (approximately an area of 248,365 m^2). Plots 4, 5, and 9 also cluster in a loose formation. On the course, holes 4 and 5 are parallel and in close proximity to each other (less than 100 m apart). Plot 9 is approximately 715 m from holes 4 and 5, separated by longleaf pine forest and housing developments. Most of the plots in the sampling area are within the Candor Sand (0-4% slopes) soil, holes 4 and 5 are within the Vaucluse Loamy Sand (8-15% slopes) and our soil analysis (Table 5.1) indicated these areas have very high levels of phosphorus and zinc from the 32 plot sites.

In total, the 17 plots contained 52 individual species (Figure 5.4) of herbaceous and woody plants. In comparison to the species list of 2012 and 2013 (Appendix A) the plots encountered 70% of the possible recorded species for the course. A first-order jackknife estimate calculated using the Bray-Curtis species area curve feature of PCORD 6.16, with Bray-Curtis distance, indicated the likely capture of 81% of the vascular plant species of the course for the 2013 season in the sample plots. The beta-diversity of the course was determined to be 3.1 based on the 17 representative plots.

The Bray-Curtis ordination plot comparing the Pinehurst plots to those sampled by the Carolina Vegetation Survey in regional natural communities (Figure 5.5) shows there is considerable distance between the Pinehurst plots (CEGLPH13) and the regional community plots along axis 1. Along axis 2 the Pinehurst plots appear most closely related to the Pine/scrub oak sandhill (Blackjack subtype) community (CEGL3595), mesic pine savanna (CEGL003570), and a cluster of pine barren communities (e.g., CEGL003590).

Discussion

After reviewing Schafale and Weakley (1990), Sorrie et al. (2006), Platt (2009), Peet et al. 2013, Taggart (2010), and Schafle (2012) we concluded at the broadest scale, the Pinehurst No.2 Golf Course shares characteristics with southeastern pine savannas, intermixed with vegetation from communities such as sand barrens, pine/scrub oak sandhills and anthroprogenic roadside/oldfield sites.

Southeastern pine savannas. As described in Platt (2009), *A. stricta* is the dominant species of wiregrass along the upper Atlantic Coastal Plain in North Carolina and Southern South Carolina. Moore County in particular lies within an area that may be considered a longleaf pine wiregrass savanna or a longleaf pine transition woodland and for most of our sites and in the neighboring region *A. stricta* was a common species. Common to southeastern pine savannas, and present at the site, are warm season grasses, including *Andropogon* spp. and *Aristida* spp. as described by Schafale and Weakley (1990), Platt (2009), and Taggart (2010).

Pine barrens and pine/scrub oak sandhill. The Pinehurst No. 2 site had the species *P. palustris, A. stricta,* and *Cnidoscolus stimulosus* L. Gray noted by Sorrie et al. (2006) in their description of a pine barren. However, the site also contains *Sassafras albidium* Nutt., which is common to the pine/scrub oak sandhill. The Pinehurst vs. regional vegetation ordination demonstrates that our site shares some characteristics of the pine/scrub oak sandhill (Blackjack type) and also shares some characteristics along axis 2 with mesic pine savanna, and pine barren communities. A significant finding of this study is that the renovated areas inventoried at Pinehurst No. 2, despite once being 100% turfgrass, now support vegetation that has affinities to natural communities of the longleaf pine ecosystem.

Anthropogenic roadside/ oldfield sites. Taggart (2010) delineates anthropogenic roadside and oldfield sites as areas disturbed by road construction/ maintenance. In general, the Pinehurst No. 2 site was managed for a monoculture of bermudgrass for over half a century. Removal of the bermudagrass for the restoration left open and bare soil that provided opportunities for establishment of a variety of plant species. When relating our species list with that in Taggart (2010), we found *Andropogon virginicus*, *Diodia teres* Walt., and *Solidago altissima* L. to be similar aggressive native species. Similarly, we found *Paspalum* sp. and *Plantago* sp. within the Pinehurst No. 2 plant community.

Diversity. The ordination plot (Fig. 5.3) showed similarity among holes 1A, 11A, 13A, 14A, 16A, and 18A. All of these plots are within the Candor Sand soil series. When relating the species list, the plot survey method, and the first-order jackknife estimate we found that the plot surveys accounted for approximately 70 to 80% of the plant species in the system. The beta diversity value of 3.1 indicates moderate turnover of species during the 2013 survey period.

Native area management. This project is unique in that there are very few studies that have sought to understand the diversity of native areas that are managed and promoted in a golf course management setting. The species list and identification booklets developed for this project have provided the superintendents and staff with a resource for understanding kinds of plants on the course and whether they are native or introduced. This information has aided in decisions as to which species should be maintained and which need to be removed for the aesthetic value and playability of the course. A notable finding was that 78% of the species on the course are native to the lower 48 United States based on the USDA Plant Database (USDA, NRCS 2014). Another interesting finding was that the vegetation of the renovated portion of the course shares similarities with longleaf pine vegetative communities, supporting the idea that golf course managers can promote native species and natural vegetation in their management regimes, thus increasing local biodiversity and the many benefits these provide.

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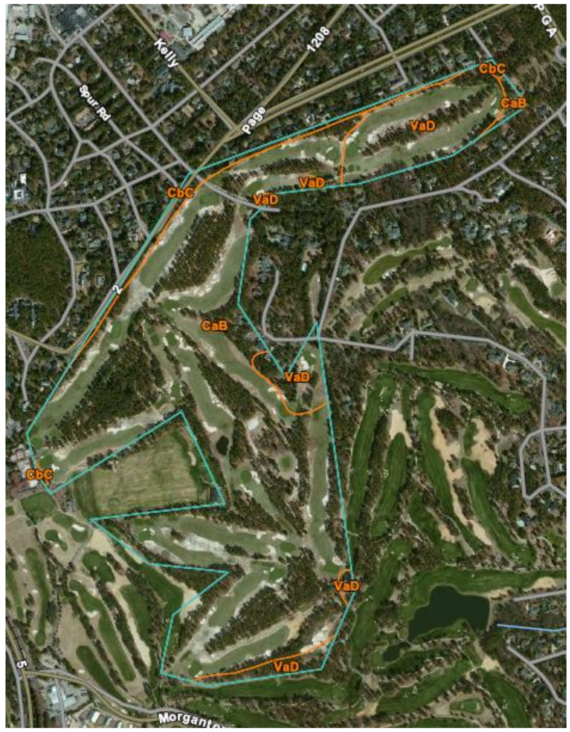
Table 5.1. Average soil parameters for all 32 plots based on results from the North Carolina Department of Agricultural and Consumer Services.

Soil Parameter	Value	STDEV
pH	5.29	0.49
Phosphorus Index (PI)	187.06	45.51
Potassium Index (KI)	15.69	4.50
Percentage Humic Matter (HM%)	81%	0.28
Weight per Volume (W/V)	1.33	0.05
Cation Exchange Capacity (CEC)	5.24	1.61
Manganese Index (MN-I)	88.94	35.14
Zinc Index (ZN-I)	521.00	399.09
Copper Index (Cu-I)	135.94	103.88
Sulfur Index (S-I)	25.56	10.06

Table 5.2. Representative plant communities for comparison from the Carolina Vegetation Survey (CVS) database with CVS code and the number of plots represented for that community in the database.

Plant Community	CVS Code	Number of Plots
Sand Barren (Typic subtype)	CEGL003584	13
Sand Barren (Coastal Fringe subtype)	CEGL003590	32
Xeric Sandhill Scrub (Typic subtype)	CEGL003586	20
Pine/Scrub Oak Sandhill (Blackjack subtype)	CEGL003595	13
Pine/Scrub Oak Sandhill (Mixed Oak subtype)	CEGL003591	12
Pine/Scrub Oak Sandhill (Mesic Transition subtype)	CEGL003578	19
Pine/Scrub Oak Sandhill (Coastal fringe subtype)	CEGL003577	8
Mesic Pine Savanna (Sandhills subtype)	CEGL003570	10



Moore County, North Carolina (NC125)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
CaB	Candor sand, 0 to 4 percent slopes	141.3	80.9%
CbC	Candor-Urban land complex, 2 to 12 percent slopes	5.5	3.1%
VaD	Vaucluse loamy sand, 8 to 15 percent slopes	27.9	16.0%
Totals for Area of Interest		**174.7**	**100.0%**

Figure 5.1. Soil map of historic Pinehurst No. 2 Golf Course with associated soil profile legend (Soil Survey, 2014).

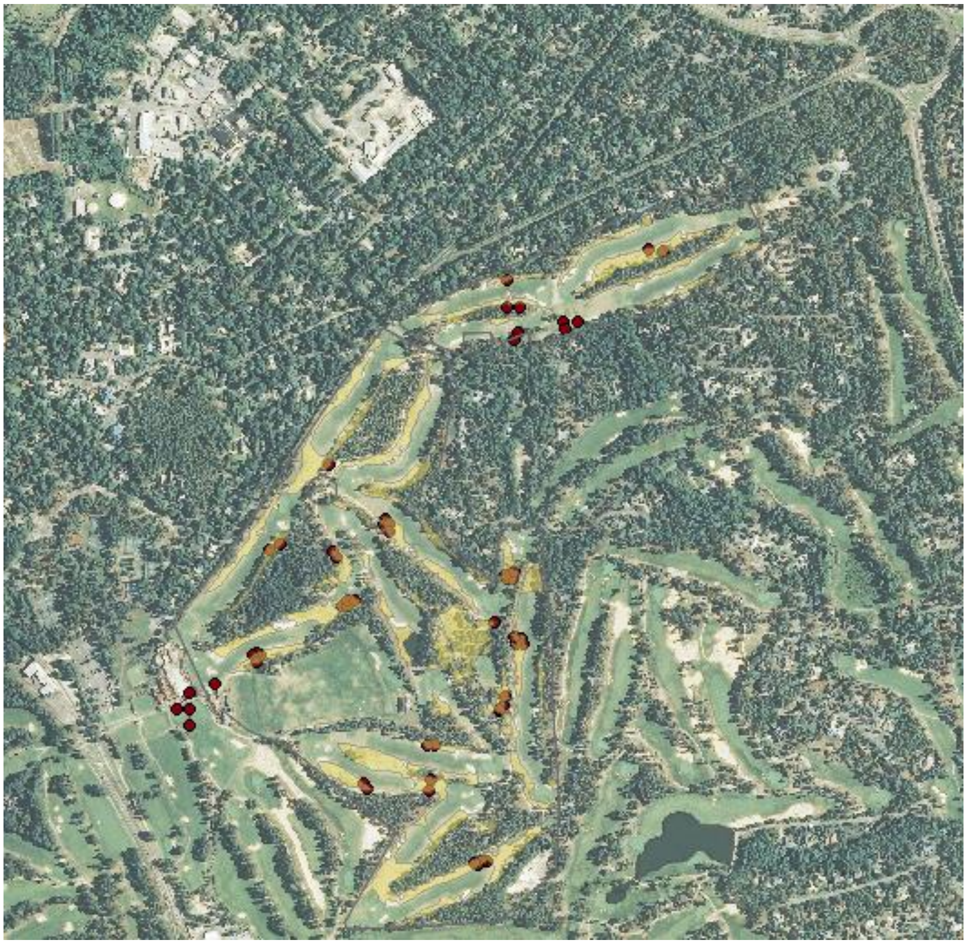


Figure 5.2. Historic Pinehurst No. 2 aerial from the Pinehurst No.2 Restoration Viewer developed by Carl Nordman. Red and Orange spots are markers for research sites.

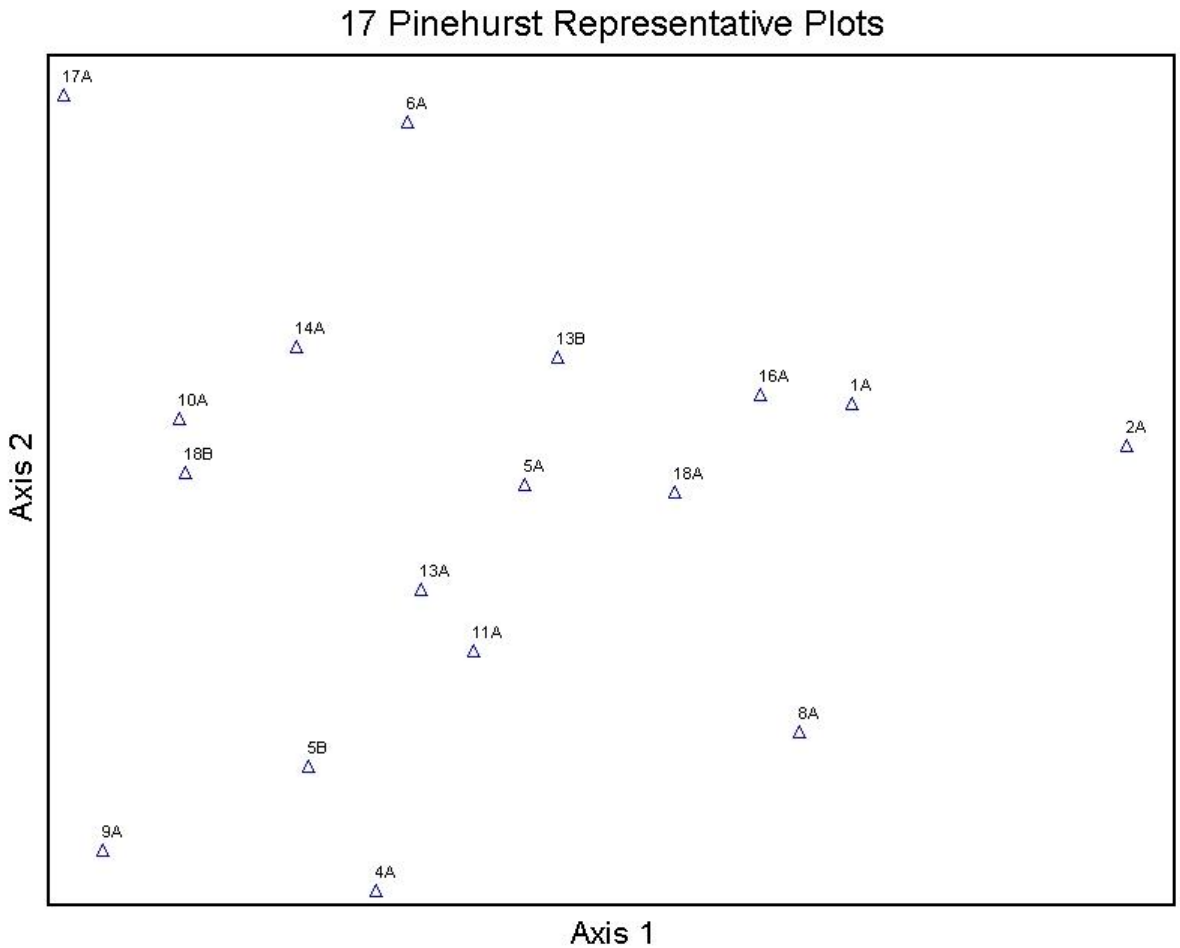


Figure 5.3. Detrended correspondence analysis ordination of 17 representative sites from the Pinehurst No. 2 survey.

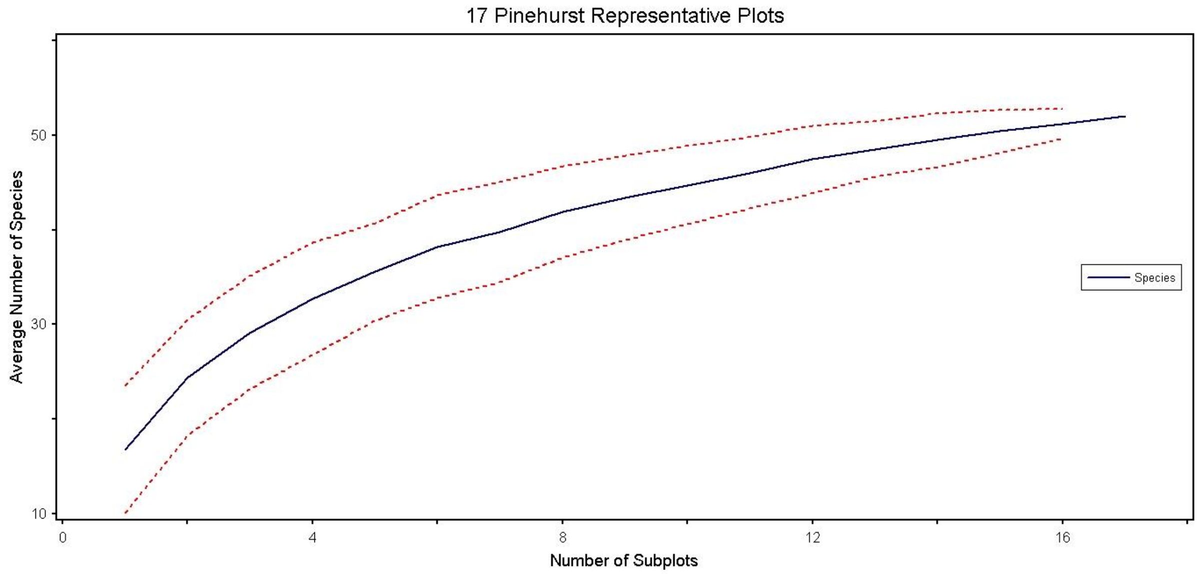


Figure 5.4. Species area curve for 17 representative sites at Pinehurst No. 2 Golf Course.

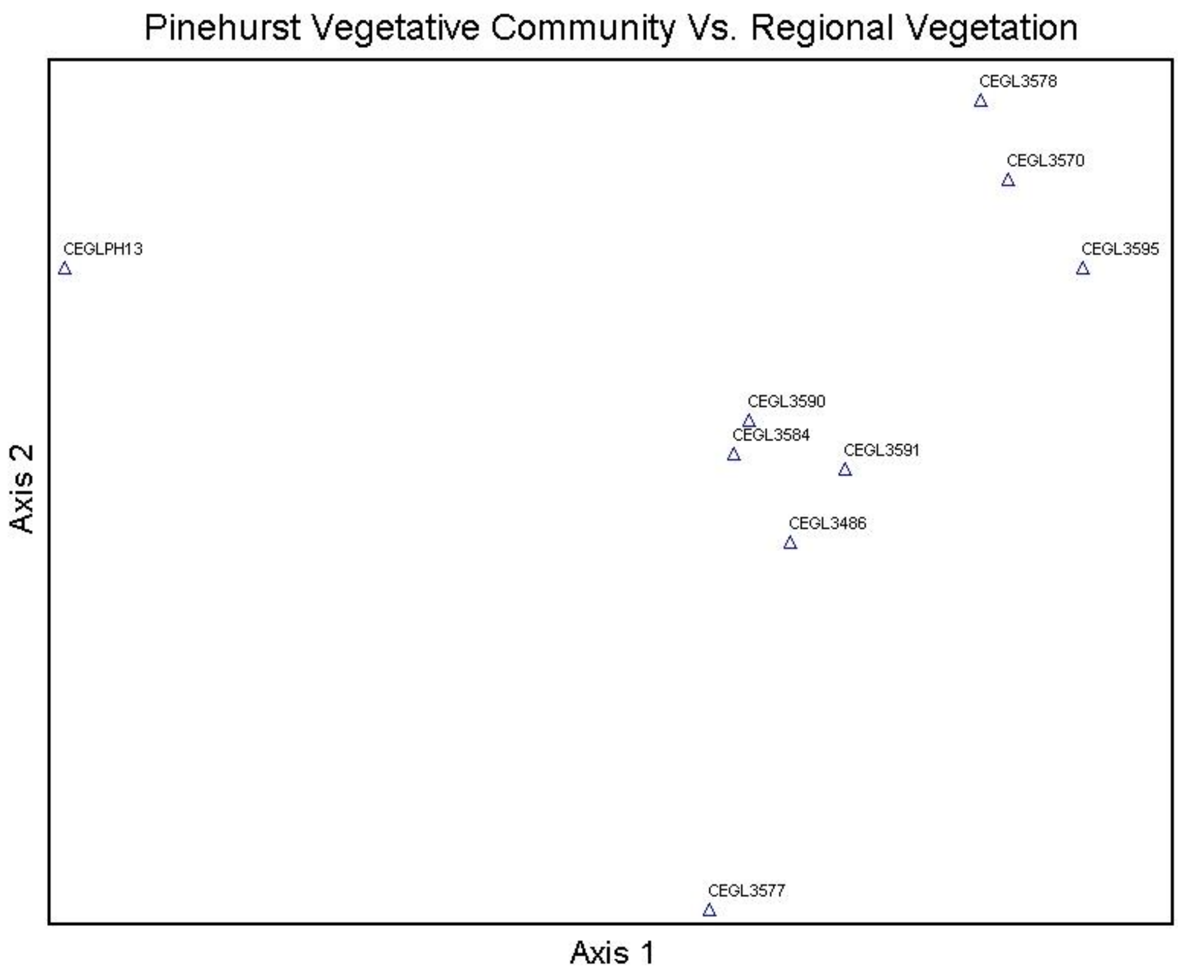


Figure 5.5. Bray-Curtis ordination of 17 representative sites from the Pinehurst No. 2 survey versus representative communities within and neighboring the Pinehurst and Sandhills region. Sand Barren (Typic Subtype) – CEGL3584; Sand Barren (Coastal Fringe Subtype) – CEGL3590; Xeric Sandhill Scrub (Typic Subtype) - CEGL3586; Pine/Scrub Oak Sandhill (Blackjack subtype) – CEGL3595; Pine/Scrub Oak Sandhill (Mixed oak subtype) – CEGL3591; Pine/Scrub Oak Sandhill (Mesic transition subtype) – CEGL3578; Pine/Scrub Oak Sandhill (Coastal fringe subtype) – CEGL3577; Mesic Pine Savanna (Sandhills Subtype) – CEGL3570.

CHAPTER 6

The Effect of Plant Growth Regulators and Fungicides at Maximum Rates on *Aristida stricta* Michx.

Aristida stricta Michx., commonly known as wiregrass, occurs in the southern coastal plains from eastern Mississippi to North Carolina and Florida (Clewell, 1989). The perennial bunch grass has narrow wiry blades and grows in both moist and dry sites. The species varies from upright divergent to tufted and may have narrow panicles of pale brown, one-flowered spikelets with long awns that appear in late summer/early fall and extend well above the foliage (Clewell, 1989; Thetford et al., 2009). It retains its foliage over several seasons, which can carry fire in the fire-adapted longleaf pine (*Pinus palustris* Mill.)/wiregrass ecosystem. In recent history wiregrass was considered the keystone species of much of the upland Coastal Plain of the Carolinas (Thetford et al., 2009; Weakley, 2012). *A. stricta* is common in parts of the Sandhills region of North Carolina but the development of vast acreages of former pinelands to agriculture, pine tree farms, and urbanization have reduced the species habitat over the years (Weakley, 2012). The ornamental industry encourages the use of wiregrass as the preservation of natural areas and longleaf pine restoration projects become more frequent (Thetford et al., 2009).

Research into the use of herbicides on wiregrass is mostly directed at the enhancement of longleaf pine ecosystem restoration efforts. Jose et al. (2010) reported that when wiregrass was subjected to low rate applications of hexazinone [0.56 ai kg/ha], imazapyr [0.21 ae kg/ha], sulfometuron methyl [0.26 ai kg/ha], and sulfometuron plus hexazinone [0.26 ai kg/ha; 0.56 ai kg/ha] there was no reduction in the percent cover. Kaeser and Kirkman (2010) reported that hexazinone applied to wiregrass seedlings of multiple ages resulted in significantly lower biomass compared to untreated controls. The tolerance of wiregrass seedlings to many pre- and post-application herbicides shows particular promise for restoration programs to control neighboring undesirable species leading to more restoration project successes (Kaeser and Kirkman, 2010). Evaluation of other post emergent chemistries may provide further assistance in the enhancement and establishment of wiregrass.

On golf courses, the incorporation of native grasses (e.g. wiregrass) will require new management tools and options for superintendents who are concerned with the quality, size, and competiveness of native plant species. Turf growth regulators and fungicides are common management tools for superintendents in golf turfgrass systems. Plant growth regulators (PGRs) in particular may modify clipping production, turf color, and ball roll patterns through their specific mode of action (Branham, 2007; Murphy et al., 2013). One key advantage of PGRs and other growth retardants is the reduction of longitudinal shoot growth without reducing plant productivity (Rademacher, 2000). Turf growth regulators reduce yield by inhibiting gibberellic acid (GA) and auxin production, thereby limiting leaf elongation without stopping cell division (Stier et al., 2000; Rademacher, 2000). Gibberellin is a plant-produced hormone required for cell elongation and normal growth and development. When gibberellin production is inhibited, plant cells do not elongate, internodes become shortened, and overall plant growth is reduced (Murphy et al., 2013). With the improvement of growth regulators, researchers and practitioners are identifying possible uses of growth regulators beyond simply reducing growth (Stier et al., 2000).

Class A (Trinexapac-ethyl) and Class B (Paclobutrazol and flurprimidol) gibberellin biosynthesis inhibitors (Type II) are absorbed by roots, foliage, or with some products, both roots and foliage (Murphy et al., 2013). Trinexapac-ethyl applications impact turfgrass quality by improving total shoot chlorophyll concentration. Chlorophyll becomes more densely packed in shorter, more compact leaves when blade elongation is reduced (Bunnell et al., 2005). In addition to herbicides that inhibit GA biosynthesis, ethylene releasing compounds (e.g. ethephon) may be used to inhibit plant growth as well. Ethephon penetrates into tissues and is translocated, degrading to ethylene which is an active metabolite that reduces seedhead emergence (Dokkuma, 2013; RSC, 2013). The increase in ethylene results in a reduction in cell elongation and increase in width instead (Currey and Lopez, 2010). Some fungicides (e.g. triadimefon and tebuconazole), which are triazole derivatives, have both fungitoxic and plant growth regulating properties that may be the result of the inhibition of oxidative demethylation reactions and the blockage of gibberellin biosynthesis (Fletcher et al., 1986). Golf course managers rely heavily on these herbicidal modes of action for maintenance and require information on how off target plants may be affected or enhanced through the use of the herbicidal chemistry.

Ethephon (Proxy®) and trinexapac-ethyl (Primo Maxx®) are common plant growth regulators for reducing leaf growth on creeping bentgrass maintained at fairway height.

Trinexapac-ethyl was developed by Novartis, labeled for use in the early 1990s and is now widely used in many sectors of the turfgrass industry to inhibit GA biosynthesis without reducing tillering (Rademacher et al., 1990; Stier, 1997; Stier et al., 2000). Ethephon is commonly used for golf course fairways and commercial lawns and stimulates ethylene production which reduces growth by indirectly affecting growth hormones (Taiz and Zeiger, 1991). In Stier et al. (2000), ethephon was reported to reduce turf quality. The researchers also report that the negative effects of ethephon on creeping bentgrass occurred within two weeks after application and generally dissipated within four weeks. Negative quality effects of trinexapac-ethyl occurred within one week after application and generally dissipated within three weeks (Stier et al., 2000). A combination of flurprimidol, paclobutrazol, and trinexapac-ethyl (Musketeer) is used to suppress *Poa annua* in cool season (C3) turfgrass species, without negatively impacting the lateral growth and health of these species compared to paclobutrazol alone (Sepro, 2013).

For the C4 species, bermudagrass, trinexapac-ethyl may be used for consistent growth management throughout growing seasons and the improvement of visual quality (Fagerness and Yelverton, 2000). Another study suggests that bermudagrass quality may be reduced with the application of trinexapac-ethyl at 0.2, 0.4, and 0.8 kg ha-1 (Wiecko, 1997). Flurprimidol and paclobutrazol are cited as causing slight to moderate injury to bermudagrass with fully recovery occurring after 10 weeks (Johnson, 1992). Ethephon may also have negative effects on root mass, root length, and turf quality (Mccullough et al., 2005). The effects of these products on the cool season bentgrass and warm season bermudagrass may provide insight into the response of the warm season wiregrass to the application of these specific PGRs.

Our objective was to evaluate the response of the native vegetative species *A. strictra* to different plant growth regulators (PGRs) and fungicides. The reestablishment of native areas in a *P. palustris*/*A. stricta* habitat.

Materials and Methods

Two greenhouse experiments were conducted at North Carolina State University, Raleigh, NC to evaluate the response of *A. stricta* to different plant growth regulators (PGRs) and fungicides commonly used in golf course management (Trials A and B). *A. stricta* seedlings were obtained from the NC Forest Service from their Goldsboro Forestry Center in Goldsboro, NC and allowed to acclimate in a greenhouse for two months.

Chemical Treatments and Design. Greenhouse Experiments A and B, which stayed within a temperature range of 18.3 to 32.2 degrees Celsisus, were designed to evaluate the response of *A. stricta* to plant growth regulators and fungicides applied at maximum application rates. For the experiment, of the 45 *A. stricta* plants, 5 were harvested above ground for pre- and post-project dry weight analysis (Trial A only). The 40 remaining plants were subdivided into 8 treatments with five repetitions per treatment and placed in a 50-50 mix of sand and 4P potting soil mix in 6 inch diameter pots.

Plants were placed in a 3 X 3 meter block and the appropriate treatments were applied using a CO_2 pressurized backpack sprayer equipped with Teejet flat fan nozzles calibrated to deliver 40 GPA at 40 psi. Plants were allowed to dry for 30 minutes (See Table 6.1 for application rates) and after 1 hr placed on benches in a randomized complete block design (RCBD) and left for the duration of the experiment.

On the initial day of treatment and every 9 days after treatment (DAT) the plants were rated based on the criteria of height of tallest blade (mm), base circumference (mm), and the presence/absence of inflorescence. In addition to the previous measures a quality indicator scale, adapted from a 9 point turfgrass scale (0–9), was designed to assess plants based on color, and density. Each indicator was worth 3 points. When quality indicators were assessed, a blind rating method was performed by a single individual. On the final day of the experiment above ground biomass was harvested for trial A only, placed in a drying oven for 2 days at 180 degrees F, and weighed. The R statistical computing program was used to compare treatment criteria values with the Tukey honestly significant difference test (Martinez, 2009). The experiment was repeated one time (Trial B).

Results

Quality indicators. Significant differences in quality based on the Least Significant Difference Test for 9 DAT were observed for paclobutrazol, ethephon, and trinexapac-ethyl were significantly different from the control and triadimefon with a lower average quality value. All other treatments were not significantly different from the control for the quality using the quality indicator scale. At 18 DAT no treatments were significantly different from the control for the quality indicator scale. In trial B there were no significant differences between the control and the treatment variables for 9 DAT (See Table 6.2.). For 18 DAT trial B had no significant differences from the control except for flurprimidol.

Height, base circumference, dry weight. Significant differences were found among treatments height of *A. stricta* based on the Least Significant Difference Test. For trial A at 9 DAT/18 DAT and trial B 9 DAT/18 DAT all treatments were significantly different from the control (Table 6.3). For base circumference all treatments were significantly different from the control for 9 DAT in Trial A and flurprimidol was the only treatment that was not significantly different for 18 DAT (Table 6.4). For trial B at 9 DAT flurprimidol, paclobutrazol + trinexapac-ethyl was the only treatment similar to the control and for 18 DAT flurprimidol was the only treatment similar to the control (Table 6.4). For trial A, there were no significant differences between treatments for dryweight (Table 6.5).

Conclusions

The PGRs and fungicides used in this study are commonly used for golf course management throughout the United States. With such close proximity of this chemistry usage to adapted/native vegetative species it is important to assess how local vegetation will respond to offsite spray from turfgrass management programs. The tolerance of *A. stricta* seedlings to many pre- and post-application chemistries shows particular promise for restoration programs to control undesirable species while simultaneously promoting desirable native species. This has the potential to lead to more restoration project successes.

One limitation to this study was the variability of seedlings for height and base diameter at DAT 0 for Trials A and B. This variability made it difficult to discern if changes to height and base diameter were from the plant growth regulator and fungicide treatments or differences in the initial plants. In future studies it would be beneficial to mark representative blades on plants and monitor their changes in length, in mm, over time.

Our findings indicate that *A. stricta*'s visual quality was not affected by the application of selected fungicides and PGRs at the selected rates. The implications of these findings are important for turfgrass management situations where there is a native/adapted species of wiregrass in close proximity to a heavily managed site. In this scenario, a manager has the option of using these types of herbicides, at high rates, with minimal impact to the bunchgrass *A. stricta*'s visual quality.

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Table 6.1. Chemical treatments with trade name, application rate, and active ingredient.

Trade name	**Application rate**	**Active ingredient**
Primo Maxx®	44 fl oz/ac	Trinexapac-ethyl
Trimmit 2sc®	48 fl oz/ac	Paclobutrazol
Bayleton® Flo	5.2 fl oz/ac	Triadimefon
Bayer Proxy®	13.6 fl oz/ac	Ethephon
BA Disease Control®	0.75 fl oz/gal	Tebuconazole
Cutless MEC®	147.6 fl oz/ac	Flurprimidol
Musketeer®	40 fl oz/ac	Flurprimidol, paclobutrazol, trinexapac-ethyl
Control	-	-

Table 6.2. Visual quality scale, for trials A and B, at different days after treatment (DAT).

Treatment	Rate	9 DAT A	18 DAT B	9 DAT B	18 DAT B
Trinexapac-ethyl	44 fl oz/ ac	5.8BC*	6.4A	7.1A	7.2AB
Paclobutrazol	48 fl oz/ac	5.9BC	7.0A	6.9AB	7.1AB
Triadimefon	5.2 fl oz/ac	7.2A	7.0A	7.4A	7.7A
Ethephon	13.6 fl oz/ac	5.4C	6.3A	6.6AB	7.4AB
Tebuconazole	0.75 fl oz/gal	6.6ABC	6.2A	7.1AB	7.5A
Flurprimidol	147.6 fl oz/ ac	6.9AB	6.3A	6.4B	6.3B
Flurprimdol, paclobutrazol+ trinexapac-ethyl	40 fl oz/ ac	6.6ABC	7.3A	6.9AB	7.1AB
Control	-	7.7A	7.5A	7.1AB	7.5A

*Means with the same letter are not significantly according to Tukey honestly significant difference test at P≤0.05.

Table 6.3. Height of different plants, for trials A and B, at different days after treatment (DAT) with associated treatment in millimeters (mm).

Treatment	**Rate**	**9 DAT A**	**18 DAT B**	**9 DAT A**	**18 DAT B**
Trinexapac-ethyl	44 fl oz/ ac	754.0A*	774.2A	242.9D	250.4E
Paclobutrazol	48 fl oz/ac	672.6G	674.0H	232.2F	256.1D
Triadimefon	5.2 fl oz/ac	736.0B	741.0B	275.2A	299.2A
Ethephon	13.6 fl oz/ac	722.0D	715.0D	183.0H	192.7G
Tebuconazole	0.75 fl oz/gal	685.4E	684.0G	248.2C	273.1C
Flurprimidol	147.6 fl oz/ ac	678.0F	695.2E	188.9G	202.8F
Flurprimdol, paclobutrazol+ trinexapac-ethyl	40 fl oz/ ac	667.0H	690.0F	239.0E	256.2D
Control	-	725.0C	730.0C	270.6B	283.2B

*Means with the same letter are not significantly according to Tukey honestly significant difference test at $P \leq 0.05$.

Table 6.4. Base circumference of different plants, for trials A and B, at different days after treatment (DAT) with associated treatment in millimeters.

Treatment	**Rate**	**9 DAT A**	**18 DAT A**	**9 DAT B**	**18 DAT B**
Trinexapac-ethyl	44 fl oz/ ac	148.0BC*	139.0DE	137.6C	140.0D
Paclobutrazol	48 fl oz/ac	135.0F	133.0F	136.5C	137.2E
Triadimefon	5.2 fl oz/ac	148.0BC	146.0B	139.9AB	148.2B
Ethephon	13.6 fl oz/ac	155.0A	149.0A	141.2A	152.1A
Tebuconazole	0.75 fl oz/gal	142.6D	138.0E	138.5BC	144.6E
Flurprimidol	147.6 fl oz/ ac	146.0C	141.6CD	141.4A	134.6F
Flurprimdol, paclobutrazol+ trinexapac-ethyl	40 fl oz/ ac	151.0B	149.8A	131.8D	145.1C
Control	-	139.0E	142.8C	132.2D	135.0F

*Means with the same letter are not significantly according to Tukey honestly significant difference test at $P \leq 0.05$.

Table 6.5. Dry weight of trial A's above ground biomass at the end of the experiment period with associated treatment in grams (g).

Treatment	**Dry weight**
Trinexapac-ethyl	15.02A*
Paclobutrazol	15.82A
Triadimefon	16.94A
Ethephon	14.88A
Tebuconazole	14.86A
Flurprimidol	16.84A
Flurprimdol, paclobutrazol+ trinexapac-ethyl	16.86A
Control	17.46A

*Means with the same letter are not significantly according to Tukey honestly significant difference test at $P \leq 0.05$.

APPENDICES

Appendix A

Species List (Based on Sorrie et al., 2006; Carolina Vegetation Survey for design and species identification; and USDA, NCRS 2014 for native (N) versus (I) status for the lower 48 states)

Legend: Native (N) - Introduced (I)

Amaranthaceae

Amaranthus retroflexus L. – Redroot amaranth - N

Anacardiaceae

Rhus copallinum L. – Winged sumac - N

Aquifoliaceae

Illex opaca Aiton – American holly - N

Asteraceae

Ambrosia L. – Ragweed - N

Cirsium arvense (L.) Scop – Canada thistle - I

Conyza canadensis (L.) Cronquist var. Canadensis – Canadian horseweed - N

Erechtites hieraciifolia (L.) Raf. ex DC. – American burnweed - N

Erigeron philadelphicus L. – Philadelphia fleabane - N

Eupatorium capilifolium (Lam.) Small – Dogfennel - N

Gnaphalium sp. – Cudweed - N

Hypochaeris radicata L. – Hairy cat’s ear - I

Pseudognaphalium obtusifolium (L.) Hilliard & B.L. Burtt – Rabbit-tobacco - N

Pyrrhopappus carolinianus (Walter) DC. – Carolina desert-chicory - N

Salidago altissima L. – Canada goldenrod - N

Silphium compositum Michx. – Kidneyleaf rosinweed - N

Bignoniaceae

Campis radicans (L.) Seem. ex Bureau – Trumpet creeper - N

Brassicaceae

Lepidium virginicum L. – Virginia pepperweed - N

Cactaceae

Opuntia humifusa (Raf.) Raf. - N

Campanulaceae

Triodanis perfoliata (L.) Nieuwl – Clasping venus' looking-glass - N

Chenopodiaceae

Chenopodium album L. – Lambsquarters – I,N

Clusiaceae

Hypericum gentianoides L. – Pineweed - N

Commelinaceae

Commelina erecta L. – Dayflower - N

Convolvulaceae

Ipomoea hederacea Jacq. – Ivyleaf morning-glory - I

Ipomoea purpurea (L.) Roth – Tall morning-glory – I

Cornaceae

Cornus florida L. – Flowering dogwood - N

Cyperaceae

Cyperus compressus L. – Poorland flatsedge - N

Cyperus esculentus L. – Yellow nutsedge – I,N

Dennstaedtiaceae

Pteridium aquilinum (L.) Kuhn – Brackenfern - N

Euphorbiaceae

Chamaesyce maculata (L.) Small – Spotted sandmat - N

Cnidoscolus stimulosus L. – Tread-softly spurge nettle - N

Croton glandulosus var. septentrionalis – Tropic croton - N

Euphorbia curtisii Engelmann – Curtis' spurge - N

Fabaceae

Clitora mariana L. – Atlantic pigeonwings - N

Senna obtusifolia (L.) Irwin & Barneby – Java-bean - N

Trifolium arvense L. – Rabbitfoot clover – I

Geraniaceae

Geranium carolinianum L. – Carolina geranium - N

Juncaceeae

Juncus dichotomus Elliott – Forked rush - N

Lamiaceae

Lamium amplexicaule L. – Henbit deadnettle - I

Lauraceae

Sassafras albidum Nutt. – Sassafras - N

Malvaceae

Sida spinosa L. – Prickly fanpetals - N

Magnoliaceae

Magnolia virginiana L. – Sweetbay – N

Melastomataceae

Rhexia mariana L. var. mariana – Maryland meadowbeauty - N

Molluginaceae

Mollugo verticillata L. – Green carpetweed - N

Myricaceae

Morella cerifera (L.) Small – Wax myrtle - N

Onagraceae

Oenothera laciniata Hill – Cutleaf evening primrose - N

Oxalidaceae

Oxalis stricta L. – Common yellow oxalis - N

Phytolaccaceae

Phytolacca americana L. – American pokeweed - N

Poaceae

Andropogon Virginicus L. – Broomsedge bluestem - N

Aristida stricta Michx. – Pineland threeawn (wiregrass) - N

Cynodon dactylon (L.) Pers. – Bermudagrass - I

Dactyloctenium aegyptium (L.) Willd. – Egyptian grass - I

Digitaria sanguinalius (L.) Scop. – Hairy crabgrass - I

Eleusine indica (L.) – Indian goosegrass -I

Eragrostis curvula (Shrad.) Nees – Weeping lovegrass - *I*

Hordeum pusillum Nutt. – Little barley - N

Panicum virgatum L. – Switchgrass - N

Paspalum lividum Trin. – Longtom - N

Paspalum notatum Fluegge – Bahiagrass – I,N

Poa annua L. – Annual bluegrass - I

Schizachyrium scoparium (Michx.) Nash – Little bluestem - N

Sorghum halepense (L.) Pers. – Johnsongrass -I

Plantaginaceae

Plantago sp. – Plantain - I

Polygonaceae

Polygonum lapathifolium L. – Curlytop knotweed - N

Polypremum procumbens L. – Juniper leaf - N

Rumex acetosella L. – Red sorrel - I

Portulacaceae

Portulaca amilis Speg. – Paraguayan purslane - I

Rosaceae

Prunus serotina Ehrh. var. *serotina* – Black cherry - N

Rubiaceae

Diodia teres Walter – Poorjoe - N

Diodia virginiana L. – Virginia buttonweed - N

Richardia scabra L. – Mexican clover - N

Scrophulariaceae

Nuttallanthus canadensis (L.) D.A. Sutton – Canada toadflax - N

Smilacaceae

Smilax sp. - N

Scrophulariaceae

Verbascum thapsus L. – Common mullein - I

Vitaceae

Parthenocissus quinquefolia (L.) Planch – Virginia creeper - N