Influence of Shading on Submerged Aquatic Vegetation from Bridge Structures

Technical Report

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16. Abstract

Submersed aquatic vegetation (SAV) plays a vital role in both estuarine and freshwater ecosystems. Bridges in the coastal plain of North Carolina are essential for commerce, growth, and emergency evacuations; however, bridge construction and replacement have resulted in documented SAV loss elsewhere. Therefore, this project was initiated to draft a thorough literature review and to quantify the impact of bridge shading on SAV. The main objective was to determine if North Carolina Coastal Plain bridges impair SAV growth and presence through shading. A primary vegetation survey indicated that within the study area for all bridges, only a small amount of SAV was detected near bridges or outside the bridge footprint. No SAV was found in the study area around 13 of the 16 bridge sites evaluated. Due to the limited SAV found, secondary surveys were conducted outside of the bridge study areas and these also found minimal SAV in these river systems. No significant differences were observed with regards to bridge orientation; however as bridge height increased, so did light availability. This suggests that bridges constructed located closer to the water's surface may have greater impacts as reduced light availability could lead reduced SAV growth within the bridge footprint. Future research should survey larger areas of these river systems to determine the overall abundance and distribution of SAV as SAV appears to be limited in eastern NC rivers. It may be possible to direct future bridge construction to areas with no SAV and poor SAV habitat thus reducing potential impact.

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1.0 INTRODUCTION

1.1. Background

Submersed aquatic vegetation (SAV) plays a vital role in both estuarine and freshwater ecosystems. SAV provides spawning sites, sanctuary from predators and structure needed by many aquatic species (Smart et al. 1996). Within these systems there exists highly diverse communities of invertebrates and fish that benefit from the valuable ecosystem services provided by the primary producing vegetation (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). Water quality is improved by SAV through reduction in 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 which have lead many countries to incorporate SAV into their waste water management practices (Brix and Schierup 1989). SAV is also able to absorb wave energy which helps to reduce sedimentation and maintain the integrity of underwater channels. The 2005 NC Coastal Protection Plan states “Suspended sediment is removed from the water column when the frictional drag of water flowing over the leaves and stems reduces water velocity and wave energy, allowing sediment to settle out of the water column”.

The ability to quickly adapt to changing conditions has allowed plants to grow in a multitude of climates and growing conditions. The essential inputs a plant requires for growth are CO_2, water, nutrients, and light. The latter’s intensity and availability is very important for plant survival. Some plants have developed morphological traits that can help them adapt to lower light conditions for short periods of time. For example, whole plant changes, such as producing few but longer shoots, can allow invasive species like hydrilla or Eurasian watermilfoil to reach the surface and form a large canopy where sunlight is more abundant (Barko et al 1986). This adaptation allows these plants to grow deeper where prostrate growing plants could not. Morphological changes can be more localized as is seen in *Potamogeton amplifolius* which over time forms oversized leaves with greater surface area to trap more light allowing this species to grow deeper.

Morphological adaptations can also occur very rapidly. Westlake (1981) reported that plants exposed to lower light conditions over the course of two weeks reduced their non-photosynthetic tissue and adjusted their respiration rate to help adapt to their new low light growing conditions. A submersed aquatic plant has to be able to adapt to the unique medium it is growing in, water. From one day to the next, factors such as water depth, turbidity, and microorganism/algae growth can significantly change and thus change light penetration and intensity. These factors coupled with partial shading from a bridge structure may reduce the amount of available light to less than what is required for a photosynthesizing plant. Plants such as hydrilla are able to reach photosynthetic saturation at just 28 to 33% of the equivalent full sun intensity (Van et al. 1976) and may be able to maintain active growth at very low light intensities. Hydrilla can also alter photosynthetic and respiratory characteristics to allow more effective utilization of low light levels (Bowes et al. 1977).

1.2. Project Purpose

Human development along coastal environments and freshwater watersheds may decrease water quality, resulting in the complete loss of some SAV meadows. SAV 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). Loss of native SAV and SAV habitat can result in secondary impacts including potential declines in fauna that depend on such habitat (waterfowl, fish, etc) and providing opportunity for invasive SAV establishment (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 blue crab recovery, and a decrease in speckled trout (Moore and Orth, 2008).

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 20 coastal counties of the State. Most 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 the 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.

Bridges in the coastal plain of North Carolina are essential for commerce, expanding growth, reducing traffic congestion, and allowing for safe and orderly emergency evacuations. However, new bridge construction may also create real or perceived environmental impacts including those to SAV and SAV habitat. One unavoidable impact of a bridge over water is shading, and thus the reduction of light availability to plants growing in the waters below. The height and directional orientation of a bridge can have significant effects on shade concentration and timing. Reduced sunlight availability may alter plant species makeup (selecting for more shade tolerant species) or perhaps completely shade out an area to the point that it is devoid of any plants. Bridges can also 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). 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 sunlight reaching SAV.

The Army Corp of Engineers (ACOE) and the NC Department of Environment and Natural Resources (NCDENR) regulate sites of which SAV is a component. Both agencies follow federal guidelines from The Clean Water Act (CWA) and more locally from such legislation as the Coastal Area Management Act (CAMA). The CWA is in place to maintain the chemical, physical and biological integrity of our nations waters (EPA 2004b). CAMA mirrors the CWA in that natural resource protection and preservation are top priorities but goes further by setting guidelines for construction and development in the coastal plain. Of the approximately 19,500 bridges in North Carolina roughly 1,500 occur in counties affected by CAMA regulations.

The cost of mitigating and restoring SAV for these construction projects can be extremely expensive. For example, ACOE revegetation expenses on the Potomac estuary were up to $99,000 an acre for hand planting (Shafer and Bergstrom, 2008). Certain bridges on the coastal plain must span great distances to reach from the mainland to the outer banks islands. Existing bridges like the Croatan Sound Bridge span over 5 miles and even longer bridges, such as the mid Currituck Sound Bridge or the Bonner Bridge replacement, are currently under consideration. The considerable length of these bridges as well as placement can result in significant SAV mitigation costs. Every square foot under a bridge in water depth less than 6 ft must be mitigated, regardless if SAV is present at the time of survey or construction. In the case of the original Bonner bridge plan, the 17 mile length parallel to Pea Island could have resulted in hundreds of thousands of dollars in SAV mitigation expenses.

The current procedure to mitigate for SAV loss due to bridge shading is not to create more SAV elsewhere (as is commonly done with wetland mitigation) but rather to improve water quality. The North Carolina Department of Transportation (NCDOT) has commonly created oyster bed habitat as a way to mitigate loss of SAV habitat. Oysters are natural filter feeders preying on microalgae, which in turn improves water clarity and helps sunlight to penetrate deeper allowing for increased SAV growth. Oyster beds help to dissipate some of the wave energy thus reducing sedimentation, much the same as SAV. The cost of creating oyster beds is also quite expensive. One acre of established oyster bed costs roughly $250,000 to $300,000 per acre to create (Bruce

Ellis personal communication). In the case of the Bonner Bridge replacement, the total SAV mitigation cost could exceed $400,000.

Therefore, the quantification of the impact of bridge shading on SAV growth and presence is needed in order to determine the most appropriate mitigation level.

1.3. Research Objective and Products

The main objective of this study is to determine if North Carolina Coastal Plain bridges impair SAV growth and presence through shading. The following will be summarized in this report:

- Comprehensive Literature review of SAV and Bridge Shading
- Quantification of available relative light on select bridge sites for use by NCDOT
- An evaluation of SAV growth distribution.
- Determination of characteristics affecting shading potential.

Findings from this project will allow NCDOT to best determine site-specific mitigation needs. By considering the specific impact from bridges, the most environmentally appropriate mitigation level can be determined which may be lower than the current default. This could result in cost savings by implementing the most ecologically representative mitigation or altered bridge design to achieve the best balance in cost and environmental impact. It is expected that this will result in reduced mitigation expenses and improved ecological function.

2.0 PROJECT AREA

Bridge sites for this project were identified east and north of Williamston, NC stretching to South Mills, NC using the NCDOT Bridge Database. This area was considered due to the large number of bridges which are scheduled for maintenance or replacement in the near future. Sixteen bridge sites were selected (labeled A – P) in the North Carolina counties of Bertie, Camden, Pasquotank, Perquimans, and Washington. These bridges fell within the Albemarle, Chowan, Pasquotank, Roanoke, and Tar-Pamlico sub-watersheds. Bridge site locations relative to NC County can be seen in figure 2.1. Bridge site locations were characterized based upon height, directional orientation, and location, then divided into sampling categories of short, tall, North/South, and East/West. The final stratified sampling population included four short, four tall, four North/South (NS), and four East/West (EW) bridges throughout northeastern, North Carolina (See Table 2.1). Bridges with height from crown to bed of ≥ 40 ft are considered tall.

Table 2.1. 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

3.0 PROJECT DESCRIPTION/ METHODOLOGY

3.1. Experimental Design and Site Selection (Initial Survey)

Data collected at bridge sites included SAV species identification, presence/absence, water quality (Secchi depth, pH, temperature, and dissolved oxygen), available light (Photosynthetically Active Radiation, or PAR availability), and bridge characteristics. 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. Bridge footprints ranged from 12 ft to 96 ft, on either side, based upon the site characteristics. Site specific characteristics may be seen in table 3.1 including bridge descriptors (height, width, length, and footprint width), footprint impact variables, and a noted species list. Gage height, rainfall per month, and temperature from January 2012 to December 2013, for the Northeasthern NC region, may be seen in table 3.2 (National Climatic Data Center, 2014; USGS, 2014).

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 120 ft. The 120 ft 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 240 ft at each bridge site. At each 24 ft transect point, a double sided rake was thrown twice to assess the presence/absence of submerged aquatic vegetative species and any vegetation collected was identified to species and recorded. Although potentially unsuitable for density measurements, the rake method is a scientifically acceptable means for surveying presence/ absence of submersed aquatic plant species (Madsen 1999). 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 December 2014. The visual percentage of abundance was calculated based on the number of transect points that had the presence of a specific species out of 12 total points, then multiplied by 100. 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. 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 Fondriest Environmental Licor LI-192SA Underwater Quantum Sensor. A measure of Secchi depth was also performed during this period. Beginning December 2012 conductivity was measured.

3.2. Secondary Sonar Survey Design

Two secondary surveys were performed to determine plant area coverage. On July 30, 2013 the first sonar survey was performed using a Lowrance sonar system at sites F and sites G. On July 1st and 2nd, 2014 surveys were conducted at sites A, B, C, G, H, K, P and Z similar to studies currently being performed at Kerr Lake, NC (USACE, 2011). After the survey was completed, the data were submitted to Contour Innovations for processing to obtain point data representing SAV biovolume, depth, and soil hardness composition. 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 within the bridge footprint area.

3.3. Shading Survey Design

To review how different bridge orientations and heights could affect light availability, HOBO® Pendant Loggers were placed under representative bridges (2 north/south and 2 east/west) at the 24 ft intervals similar to the 240 ft transect methodology. The data loggers collected lumens/ft^2 for year round representative days during 2013. The data for the representative days were averaged then imported into Excel® and a 4th order polynomial trend line was drawn for comparison among data loggers. Our objective was to quantify and compare how much shading occurs at each 24 ft interval over a period of multiple days at different times of the year.

Table 3.1. Bridge descriptions including footprint impact variables and observed vegetation species list.

Bridge	Description	Footprint Impact Variables	Noted Species List
A	Height (ft): 75.0 Width (ft): 32.4 Length (ft): 837.0 Footprint width (ft): 246.0	• Stone Riprap • Culvert • Boat Ramp (Close proximity)	• Shoreline turf grass • *Alternanthera philoxeroides* • *Lemna minor* • *Polygonum hydrdopiperoides*
B	Height (ft): 24.6 Width (ft): 30.9 Length (ft): 220.5 Footprint width (ft): 69.9	• Bare soil	• *Lemna minor* • *Nymphaea* sp. • *Pontederia cordata* • *Scirpus sp.* • *Typha sp.* • *Utricularia sp.*
C	Height (ft): 75.9 Width (ft): 30.9 Length (ft): 5340.9 Footprint width (ft): 90.9	• Modified landscape (erosion prevention) • Bare soil	• *Phragmites australis* • *Pontederia cordata* • *Saggitaria* sp.
D	Height (ft): 22.86 Width (ft): 30.9 Length (ft): 276.0 Footprint width (ft): 90.0	• Bare soil	• *Lemna minor* • *Nympaea sp.* • Dense trees
E	Height (ft): 21.0 Width (ft): 66 Length (ft): 224.1 Footprint width (ft): 108.0	• Stone riprap	• *Alternanthera philoxeroides* • *Ceratophyllum demersum (limited)* • *Hydrocotle sp.* • *Myriophyllum aquaticum* • *Utricularia* sp.
F	Height (ft): 68.1 Width (ft): 31.5 Length (ft): 16880.7 Footprint width (ft): 216.0	• Stone riprap • Sandy/ bare soil	• *Myriophyllum spicatum* • *Zannichellia palustris* • *Najas guadalupensis*

G	Height (ft): 87.9 Width (ft): 66.9 Length (ft): 8680.5 Footprint width (ft): 216.0	• Stone riprap	• Dense herbaceous layer on riprap
H	Height (ft): 41.5 Width (ft): 30.6 Length (ft): 2652.6 Footprint width (ft): 180.0	• Stone riprap	• Turfgrass • Dense tree species
I	Height (ft): 34.8 Width (ft): 21.3 Length (ft): 585.3 Footprint width (ft): 198.0	• Seawall • Disturbed ground	• Turfgrass
J	Height (ft): 12.0 Width (ft): 45.6 Length (ft): 115.8 Footprint width (ft): 192.0	• Erosion control concrete • Bare soil or limited vegetation	• *Alternanthera philoxeroides* • DOT maintained turfgrass • Dense tree layer
K	Height (ft): Width (ft): 39.0 Length (ft): 174.0 Footprint width (ft): 63.0	• Riprap	• Turfgrass
L	Height (ft): 13.8 Width (ft): 27.0 Length (ft): 98.7 Footprint width (ft): 51.0	• Modified landscape	• *Lemna minor* • *Nymphaea sp.*
M	Height (ft): 13.8 Width (ft): 24.0 Length (ft): 659.1 Footprint width (ft): 150.0 – new bridge construction 2013	• Bare soil	• *Lemna minor*

N	Height (ft): 12.0 Width (ft): 33.0 Length (ft): 118.8 Footprint width (ft): 60.0	• Bare soil	• *Alternanthera philoxeroides* • *Nympaea* sp. • *Saggitaria sp.* • *Utricularia* sp.
O	Height (ft): 15.6 Width (ft): 35.7 Length (ft): 166.5 Footprint width (ft): 124.5	• Bare soil	• *Alternanthera philoxeroides* • *Utricularia* sp.
P	Height (ft): 11.1 Width (ft): 27.2 Length (ft): 105.3 Footprint width (ft): 51	• Stone riprap	• *Ceratophyllum demersum* • *Lemna minor* • *Najas guadalupensis* • *Pontederia cordata* • *Typha sp.*

Table 3.2. 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.

4.0 RESULTS

4.1. Literature Review

4.1.1. SAV habitat definition

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)." 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)…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). For the purposes of this report, SAV habitat is considered to include marine, estuarine, and riverine vascular plants that are rooted in sediment. These habitats occur along the entire east coast of the United States (North Carolina Division of Coastal Management, 2012). There is an estimated 200,000 acres of SAV habitat in North Carolina (Deaton et al., 2010). 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 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 blue crab recovery, and a decrease in speckled trout (Moore and Orth, 2008).

4.1.2. SAV in North Carolina

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 4.1.

4.1.3. Threats to SAV Habitat

Human 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 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 can also cause considerable damage and local elimination.

4.1.4. 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 can make them 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) reviews 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 was 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 to shallower regions. Light penetration is impacted by absorption from other vegetation such as attached algae, floating phytoplankton, etc., other suspended and dissolved substances, 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).

4.1.5. Light and 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 feet 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 4.2.

4.1.6. 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* 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*, *Halodule uninervis*, *Thalassia hemprichii,* and *Zostera mulleri*) 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* were studied in the Patos Lagoon estuary in Brazil (Costa and Seeliger, 1989). The study included plants at water depths ranging from 0.30 ft to 3.9 ft. Vegetative shoot numbers and biomass were greatest at 1.2 ft. The number of shoots, as well as vegetative biomass decreased with depth to 2.1 ft.. Below 2.1 ft *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* 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.

4.1.7. 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); two were boat-based and one 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).

4.1.8. 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" (Dennison et al., 1993, Equation 4.1).

$$I_Z = I_O \bullet e^{-K_d \bullet Z}$$

Equation 4.1. The Lambert – Beer equation for determination of light availability in aquatic environments.

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.

4.1.9. Introduced solution to loss of sunlight

In 2004, 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).

4.1.10. 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 9 ft diameter base and plastic mesh up to 3 ft 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).

4.1.11. Example North Carolina Projects

In North Carolina light absorption was assessed for phytoplankton and chromophoric dissolved organic matter (CDOM) in the drainage basin and estuary of the Neuse River. Anssi et al. (2005) researched riparian shading on the Neuse River and found CDOM absorbed 55 and 64% of photons in the spectral range of 400–700 nm. The high CDOM specified a high potential for abiotic photochemical reactions in the 500–600 nm region. The results of the project indicated that riparian shading and non-algal absorption components could significantly restrict phytoplankton production in nutrient rich systems with a high concentration of CDOM flowing through forested catchments. Riparian shading and the low contribution of phytoplankton to the total absorption resulted in conditions where phytoplankton absorbed nearly two orders of magnitude less PAR in the streams than in the estuaries and reservoirs (Anssi et al., 2005).

At Elizabeth City State University, an SAV Cooperative Habitat Mapping Program is delineating the distribution and abundance of SAV in the estuarine and coastal riverine ecosystems of North Carolina and southeastern Virginia using remotely sensed data and field surveys.

4.1.12. Summary

- 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).

Table 4.1. 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
	    o Tubers for short term perennation and short distance dispersal
	    o Seeds for long term dormancy and long distance dispersal
		Casey, 2010; Madsen and Adams, 1988

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 4.2. 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 – 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

4.2 Primary Survey

From June 2012 to December 2013 submersed vegetation was found at only three bridge sites. Species recovered using the rake and visual surveys included *Ceratophyllum demersum* L., *Ruppia maritima* L., *Najas guadalupensis* (Spreng.) Magnus and *Utricularia* sp. (tables 4.3 and 4.4). Bridge P had the greatest abundance of SAV recovered with both *C. demersum* and *N. guadalupensis* present. The bar graph in figure 4.1 indicates *C. demersum* from Jul to Aug of 2012 and Dec to May of 2013 for Site P. Table 4.5 and table 4.6 are included to represent vegetation arranged by type and the average water quality conditions during the survey period.

4.3 Secondary Survey

The July 2013 survey of bridge F (Highway 32) and bridge G (Highway 17) identified only a small amount of vegetation. At bridge G (figure 4.2) a trace amount of *Vallisneria americana* Michx. and *N. guadalupensis* were confirmed via rake collection. Of the 6 waypoints that had submerged aquatic vegetation, 83% were *V. americana* and 83% contained *N. guadalupensis*. When bridge F was sampled, no submerged aquatic vegetation was found. In the July 2014 survey of bridges A, B, C, G, H, K, P, and Z, vegetation was found to be present both nearby and within the bridge footprint area. For a summary of percent vegetation coverage found in each survey area and species found at each site, see table 4.7.

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 but never rooted during observations of the general area. For site F and site G relative water depth and soil composition are included in figures 4.2 to 4.6. For Sonar data processed and biovolume distribution data during the July 2014 secondary survey, see figures 4.7- 4.14

4.4. Shading Survey

Light availability increased with time regardless of interval, however light availability at similar time periods was higher for bridges sampled at higher intervals. No difference in light availability was observed between sites with north or south orientation (figure 4.15).

Table 4.3. Bridges with rooted submerged aquatic vegetation detected and months present as determined by the primary point intercept rake survey.

Bridge	**Species observed**	**Months Noted**
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 -May 13

Table 4.4. Bridges with submerged aquatic vegetation detected and months present as determined by the primary point intercept visual survey.

Bridge	**Species observed**	**Months Noted**
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*	13-May
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

Table 4.5. Species list of vegetation seen at bridge sites during survey period arranged by type.

Rooted Submersed Aquatic Plants or Macroalgae	*Ceratophyllum demersum* – Coontail *Myriophyllum spicatum* – Eurasian watermilfoil *Najas guadalupensis* – Southern naiad *Nitella* sp. – Stonewort *Ruppia maritima* - Widgeongrass *Valisneria americana* – Eel grass *Zannichellia palustris* – Horned pondweed
Floating Aquatic Plants	*Lemna minor* – Duckweed *Utricularia* sp. – Bladderwort
Emergent Aquatic Plants	*Alternanthera philoxeroides* – Alligatorweed *Hydrocotle* sp. - Pennywort *Myriophyllum aquaticum* - Parrotfeather *Nymphaea* sp. – Water lily *Phragmites australis* - Phragmites *Pontederia cordata* - Pickerelweed *Saggitaria* sp. - Arrowhead Scirpus sp. - Rush Typha sp. - Cattail
Shoreline/Riparian Plants	*Polygonum hyrdopiperoides* - Swamp smartweed

Table 4.6. Average water quality at bridge sites from June 2012 to December 2013.

Bridge	Sechhi Depth (inches)	Diff mean	pH	Diff mean	Temperature˚C	Diff mean	DO (mg/L)	Diff mean	Conductivity (µs/cm)	Diff mean
A	19.89	0.64	7.47	0.59	19.32	0.17	5.65	1.23	0.21	0.21
B	20.28	1.03	6.87	-0.01	18.88	-0.27	2.71	-1.71	0.15	-1.03
C	21.11	1.86	7.02	0.14	18.92	-0.23	4.17	-0.25	1.06	-0.12
D	23.40	4.15	6.70	-0.18	18.41	-0.74	3.14	-1.28	0.84	-0.34
E	17.14	-2.11	6.88	0.00	20.49	1.34	4.16	-0.26	1.19	0.01
F	27.50	8.25	7.58	0.70	20.21	1.06	6.42	2.00	2.13	0.95
G	27.12	7.87	7.32	0.44	20.30	1.15	6.78	2.36	0.52	-0.66
H	24.63	5.38	7.20	0.32	20.88	1.73	6.59	2.17	3.17	1.99
I	21.26	2.01	7.15	0.27	20.75	1.60	5.74	1.32	2.64	1.46
J	13.88	-5.37	6.48	-0.40	17.71	-1.44	3.89	-0.53	0.28	-0.90
K	15.10	-4.15	7.16	0.28	19.82	0.67	5.97	1.55	2.55	1.37
L	15.90	-3.35	6.25	-0.63	18.29	-0.86	2.59	-1.83	0.18	-1.00
M	16.73	-2.52	6.72	-0.16	18.16	-0.99	3.09	-1.33	1.03	-0.15
N	13.68	-5.58	6.59	-0.29	18.12	-1.03	2.78	-1.64	0.62	-0.56
O	8.53	-10.72	5.67	-1.21	16.49	-2.67	2.73	-1.69	0.16	-1.02
P	21.85	2.60	7.02	0.14	19.70	0.55	4.40	-0.02	2.17	0.99

Table 4.7. Percent vegetation coverage species found at sites surveyed during the secondary survey conducted July 2014.

Bridge	Area Surveyed (Acres)	Species Observed
A	24.04	*Nitella* spp.
C	9.34	-
G	37.52	*Vallisneria americana*, *Myriophyllum spicatum* (Eurasian watermilfoil)
H	45.85	*Nitella* spp.
K	5.4	-
B	12.68	-
P	12.16	*Nitella* spp.
Z	14.43	*Nitella* spp.

5.0 CONCLUSIONS

5.1. Conclusions of Primary Survey

The primary survey indicated that within the study area for all bridges, there were only 3 bridge sites that had SAV during the 2012 and 2013 seasons. 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 many of the others is they are not located in completely freshwater riverine/stream systems that may be more highly affected by increased water speeds during high rainfall events. For the H and P bridges the salinity values were on average between 1 to 3 ppt. Brackish water may promote the growth of certain species of SAV. *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 sites 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, was heavily impacted by human disturbance including seawalls, riprap, and a rocky substrate within a canal like system possibly preventing vegetation growth.

Bridge site P consistently had the highest abundance of *C. demersum* until June 2013 which coincided with a peak of gage height of 18.21 ft for June and 19.08 ft 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 is different from most of the other sites 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 240 ft transect. One possible reason is the rip rap for this location extended 210 ft to the west and sandy beach comprised an area 120 ft to the east possibly not allowing for a stable substrate that submerged aquatic vegetation requires for establishment. The sandy bottom at this site is consistently shifting due to wave action (white caps made it difficult to sample throughout year). According to Koch (2001) growth and distribution of submerged 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 submerged aquatic vegetative species such as *V. americana* and *N. guadalupensis* that were found at bridge G during the secondary survey.

5.2 Conclusions of Secondary Survey

In an attempt to capture a more substantive amount of data related to the growth of SAV we employed a sonar system July of 2013 and 2014. In 2013, the survey further confirmed a small amount of vegetation for site F and site G which corresponds to the findings of the transect method. For bridge G we did find a trace amount of *V. americana* and *N. guadalupensis* but not enough to be considered a substantial SAV bed. Previous literature indicates that conditions for bridge F and bridge G (figures 4.3. and 4.5) 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). In the 2014 survey, vegetation was found by both hydroacoustic and point survey. Vegetation was found near bridge sites A, G, H, P, and Z, however, most vegetation recovered was the macroalga, *Nitella*. Annual and even seasonal variation in vegetation presence and absence is evident through the 2013 and 2014 surveys, suggesting that annual monitoring maybe needed to better capture the potential for SAV growth within and around bridge site footprints.

5.3 Conclusions of Shading Study

No significant differences were observed with regards to bridge orientation during our survey, however as height interval increased, so did light availability. This suggests that bridge sites located closer to the water's surface might have more significant impacts as a reduction of light availability could lead to a reduction in overall growth of SAV within the bridge footprint. Future work should assess season light availability throughout the entire growing season to take into account solar angle. The amount of light received at any site location is a direct effect of sun angle on that site. This angle will vary by location, time of day, and season due to the Earth's orbit around the Sun and the Earth's rotation around its tilted axis. Seasonal change in the angle of sunlight, caused by the tilt of the Earth's axis, could impact SAV differently during certain times of the year.

5.4 Evaluation of Methods

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. For future research, surveys should be conducted on long river stretches to determine total SAV in the system and distribution of SAV. The current focus of specific bridge sites may be too narrow to adequately describe relative abundance of SAV in the system. For the current sampling population of bridges A-P 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, as was completed in the 2013 and 2014 July surveys. This data would further indicate whether our limited vegetation was due to localized environmental or human disturbance or the entire watershed is limited in vegetation abundance. Annual surveys should also be included, if possible, to identify annual fluctuations in vegetation coverage and abundance.

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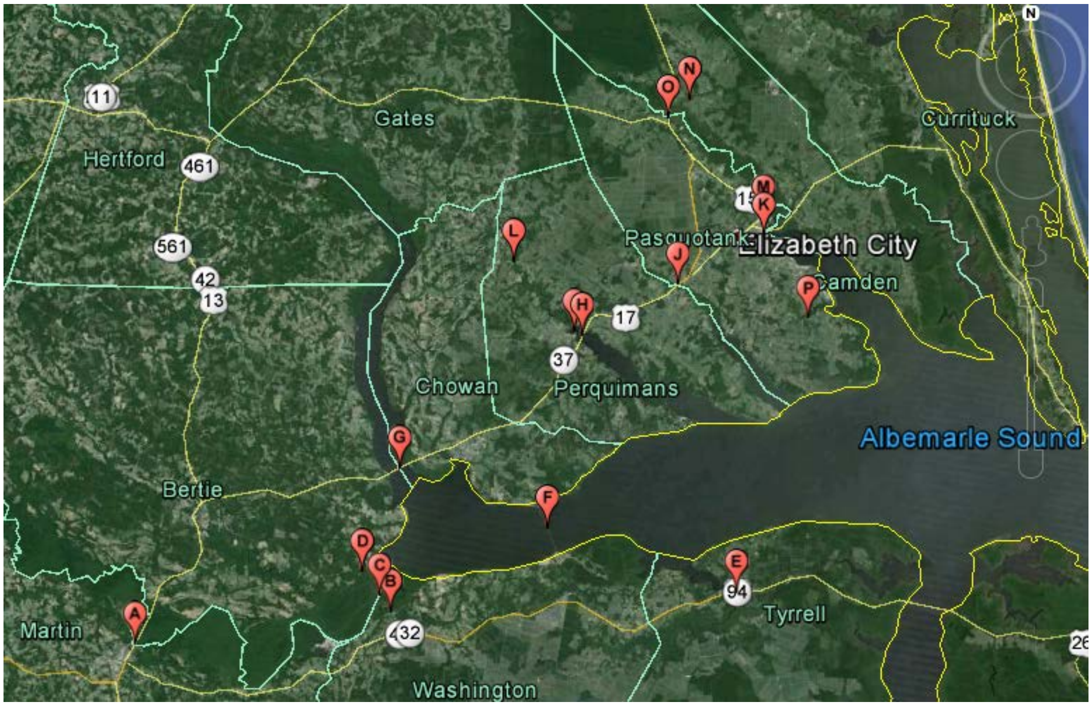


Figure 2.1. Region of interest and bridge sites (Image from Google Earth).

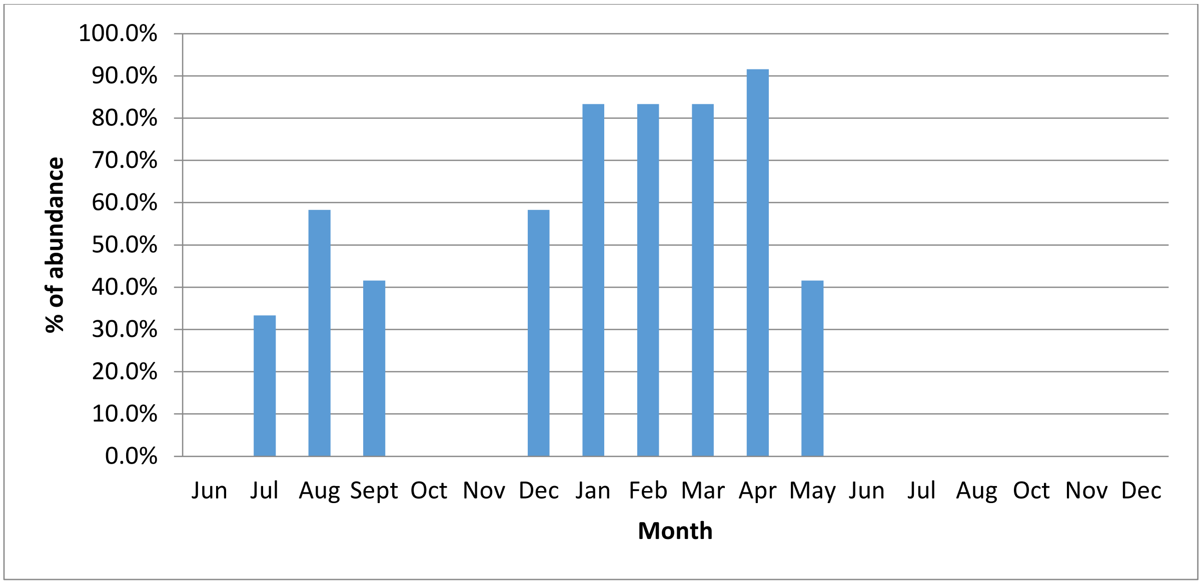


Figure 4.1. The percent abundance of *Certaophyllum demersum* sampled at site P from June 2012 through December 2013 using the rake method.

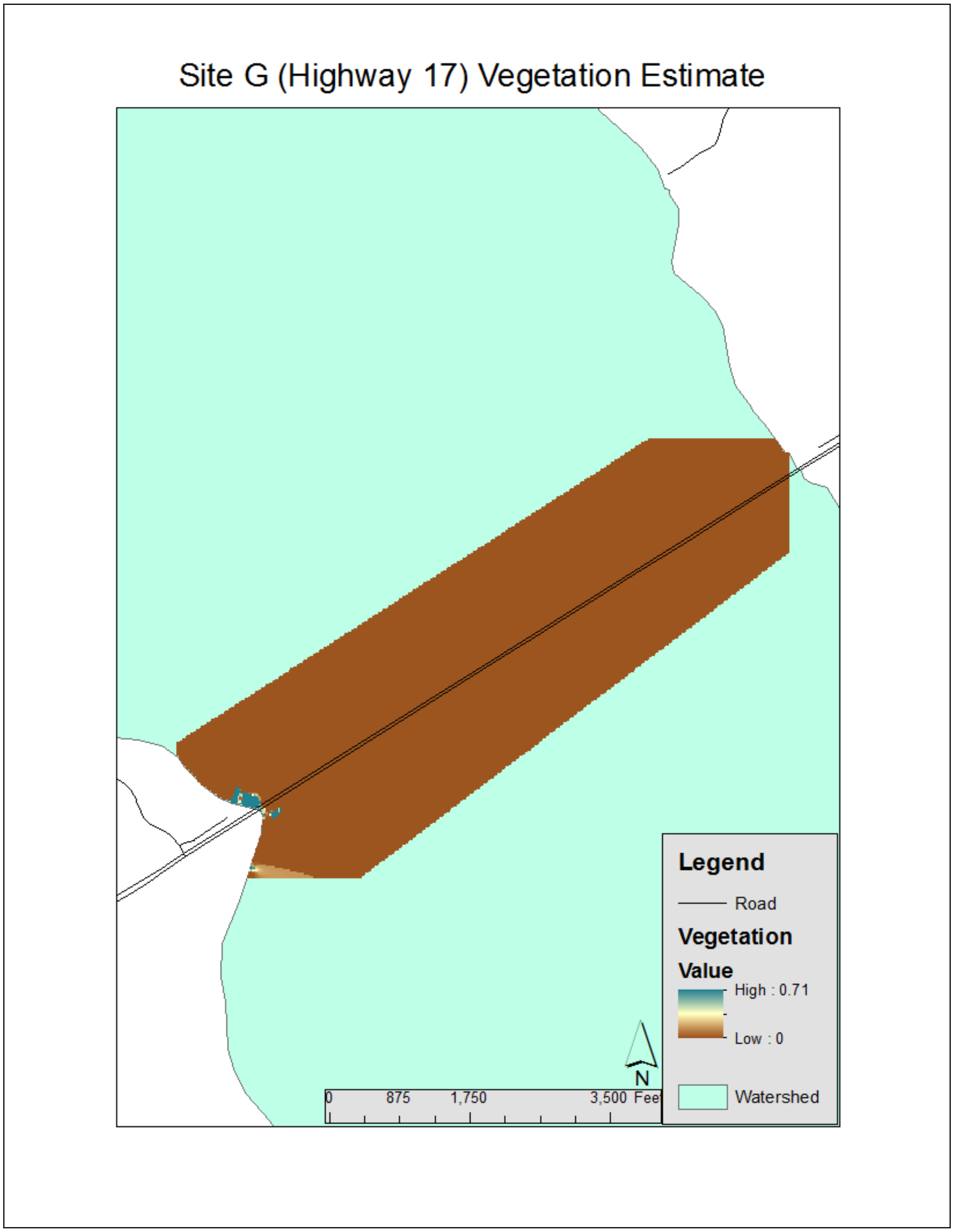


Figure 4.2. Image of submerged aquatic vegetation bio-volume at Site G (Highway 17). Species found at site include *V. americana* (Sampled of 5 out of 6 vegetated waypoints) *and N. guadalupensis* (Sampled 5 out of 6 vegetaed waypoints).

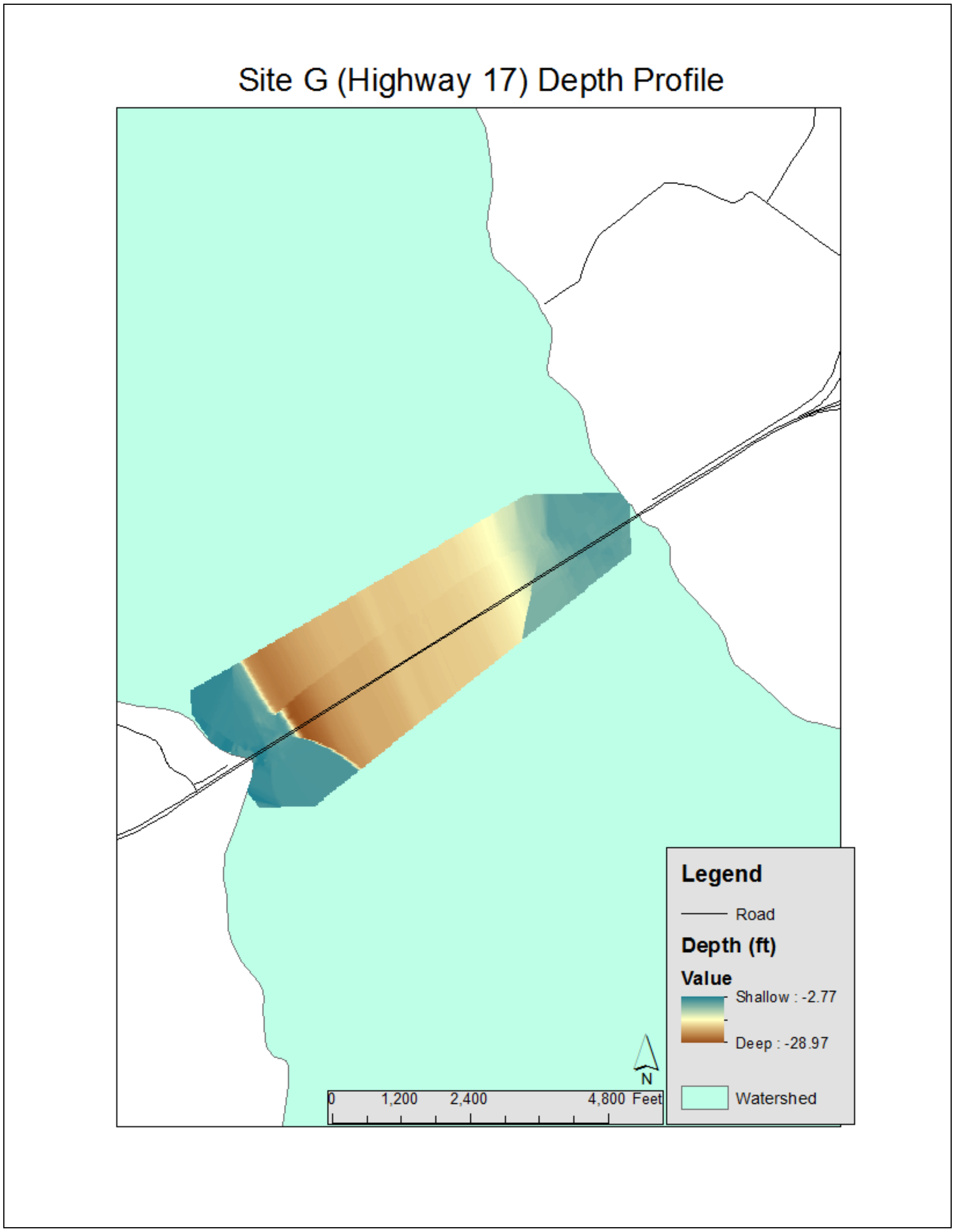


Figure 4.3. Depth profile for Site G (Highway 17).

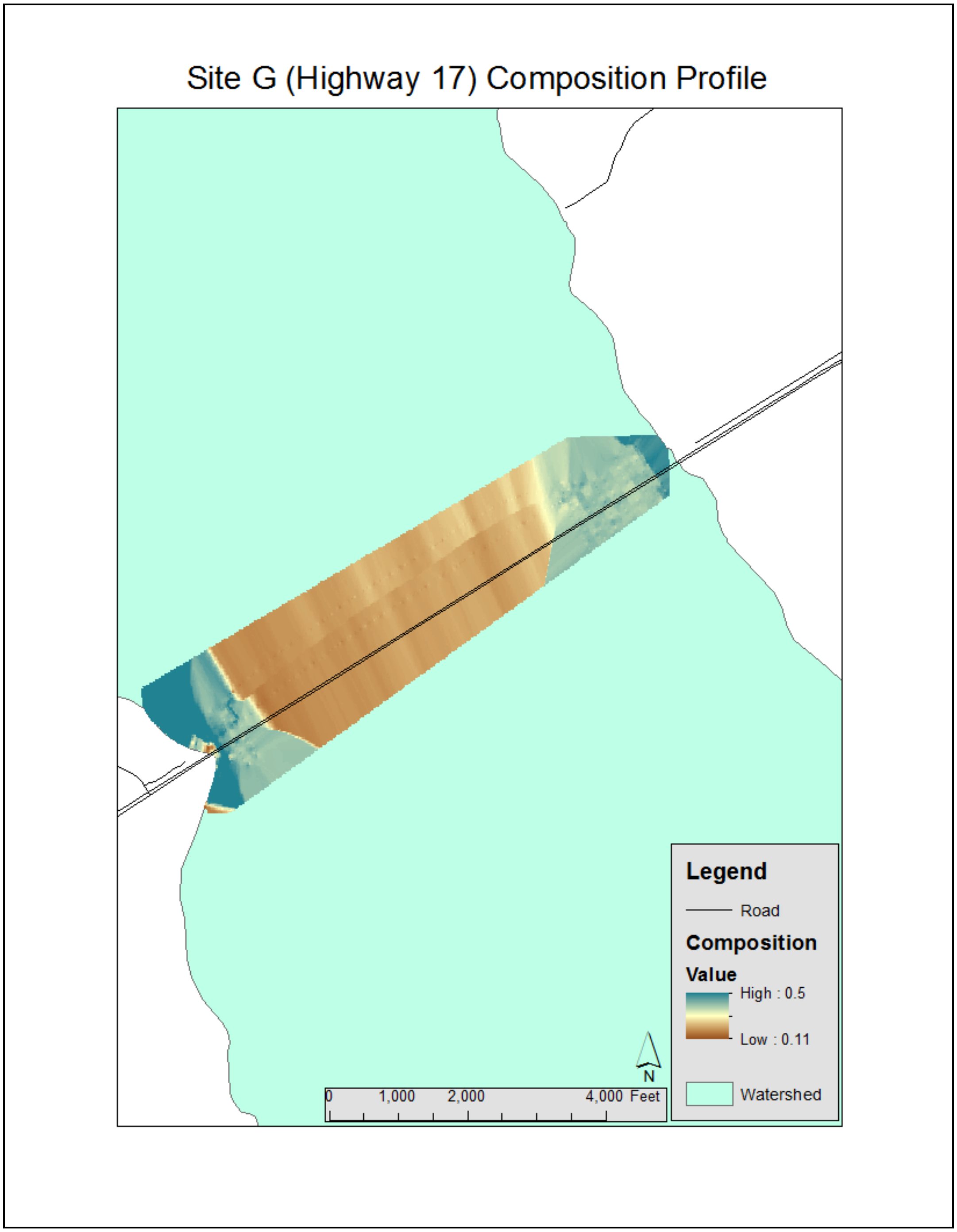


Figure 4.4. Soil hardness composition profile for Site G (Highway 17).

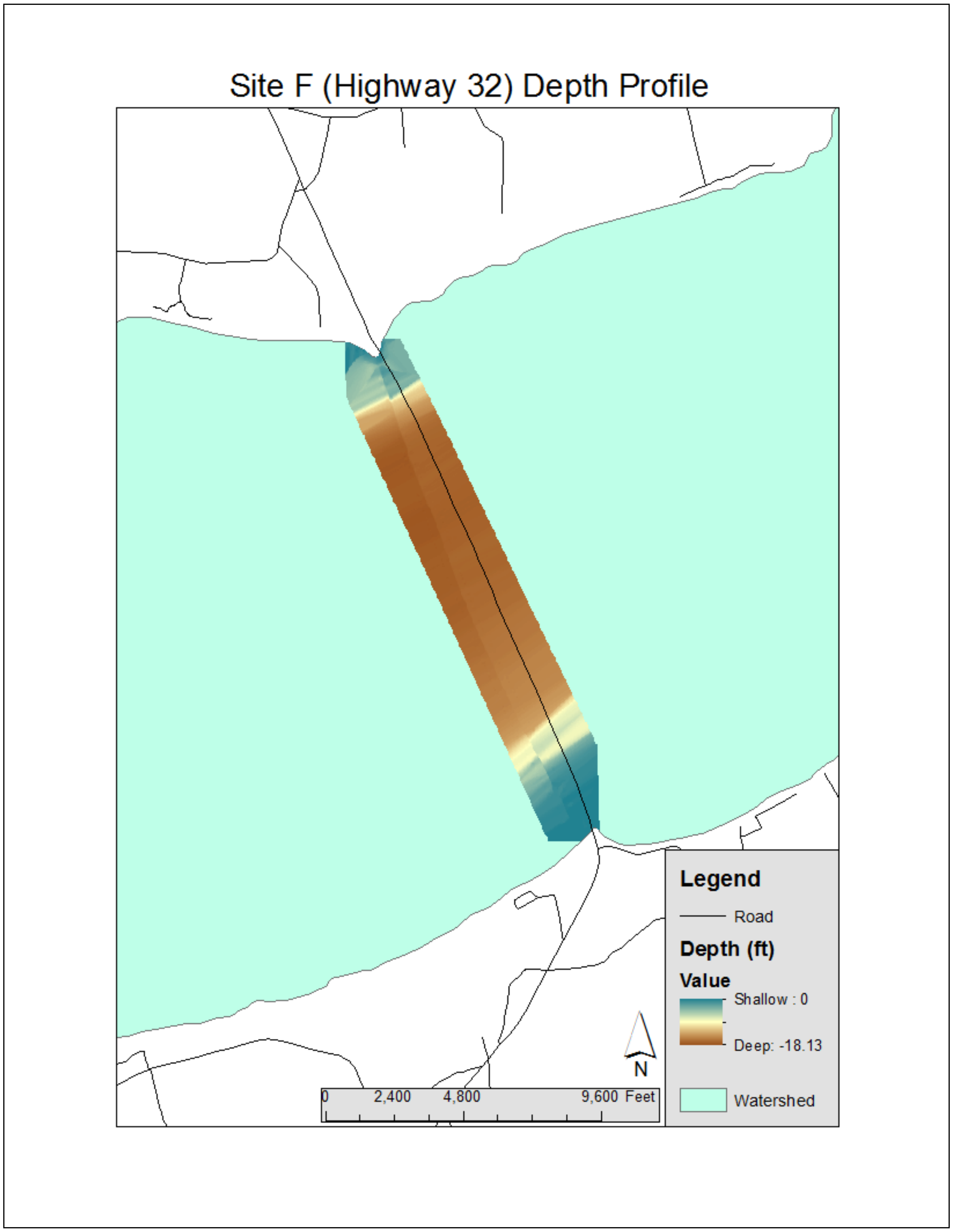


Figure 4.5. Depth profile for Site F (Highway 32).

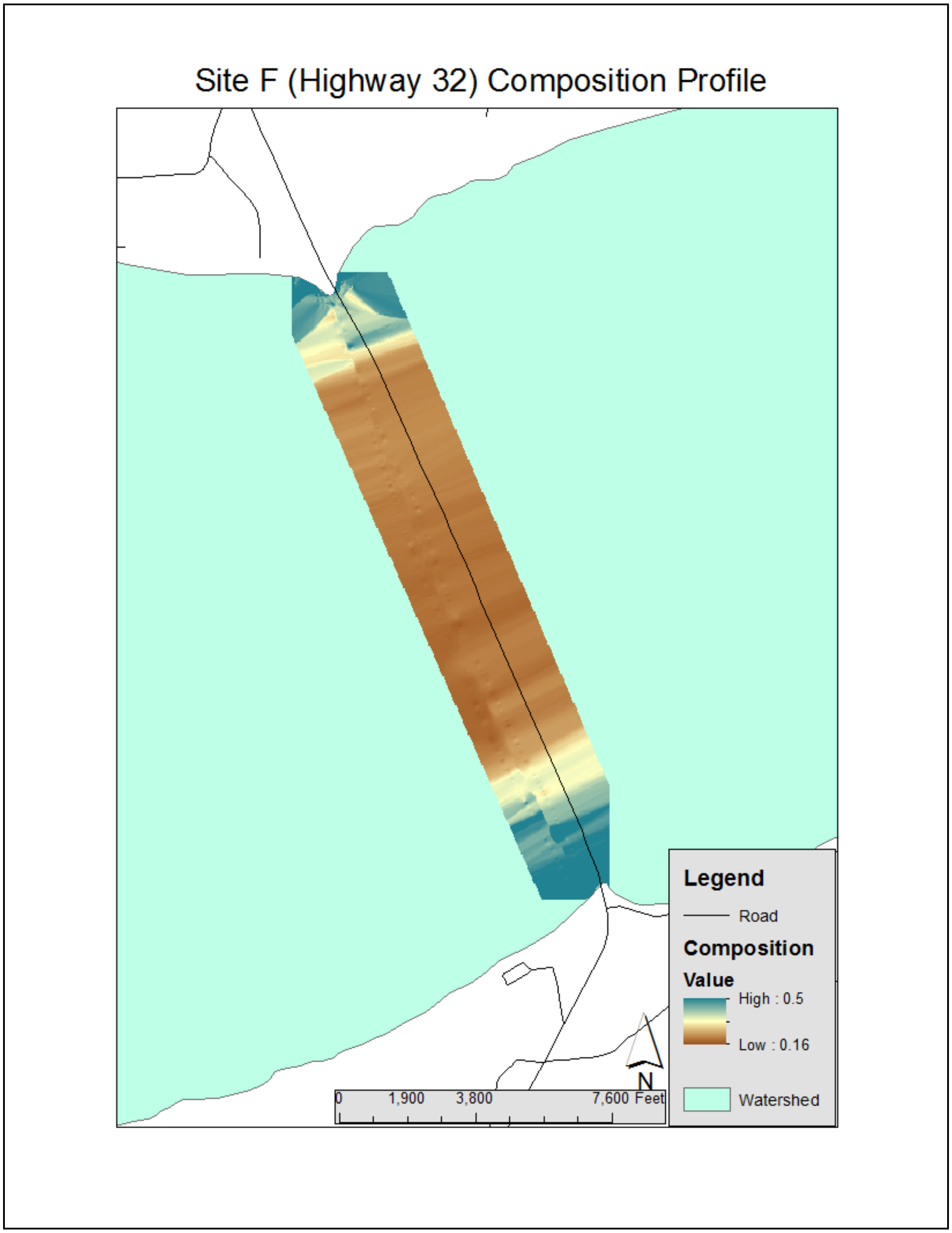


Figure 4.6. Soil hardness composition profile for site F (Highway 32).

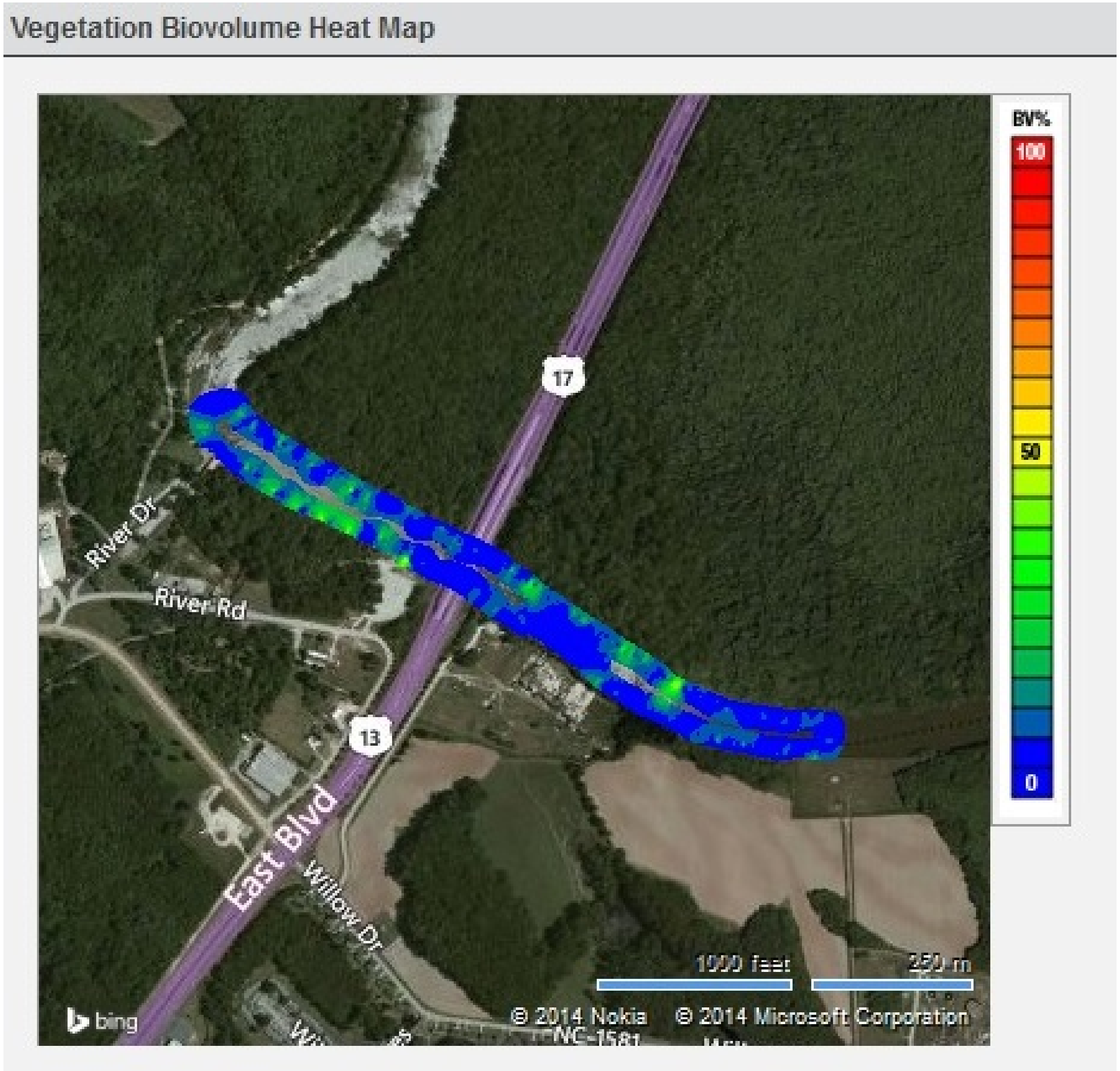


Figure 4.7. SAV coverage and biovolume of site A from July 2014 survey.

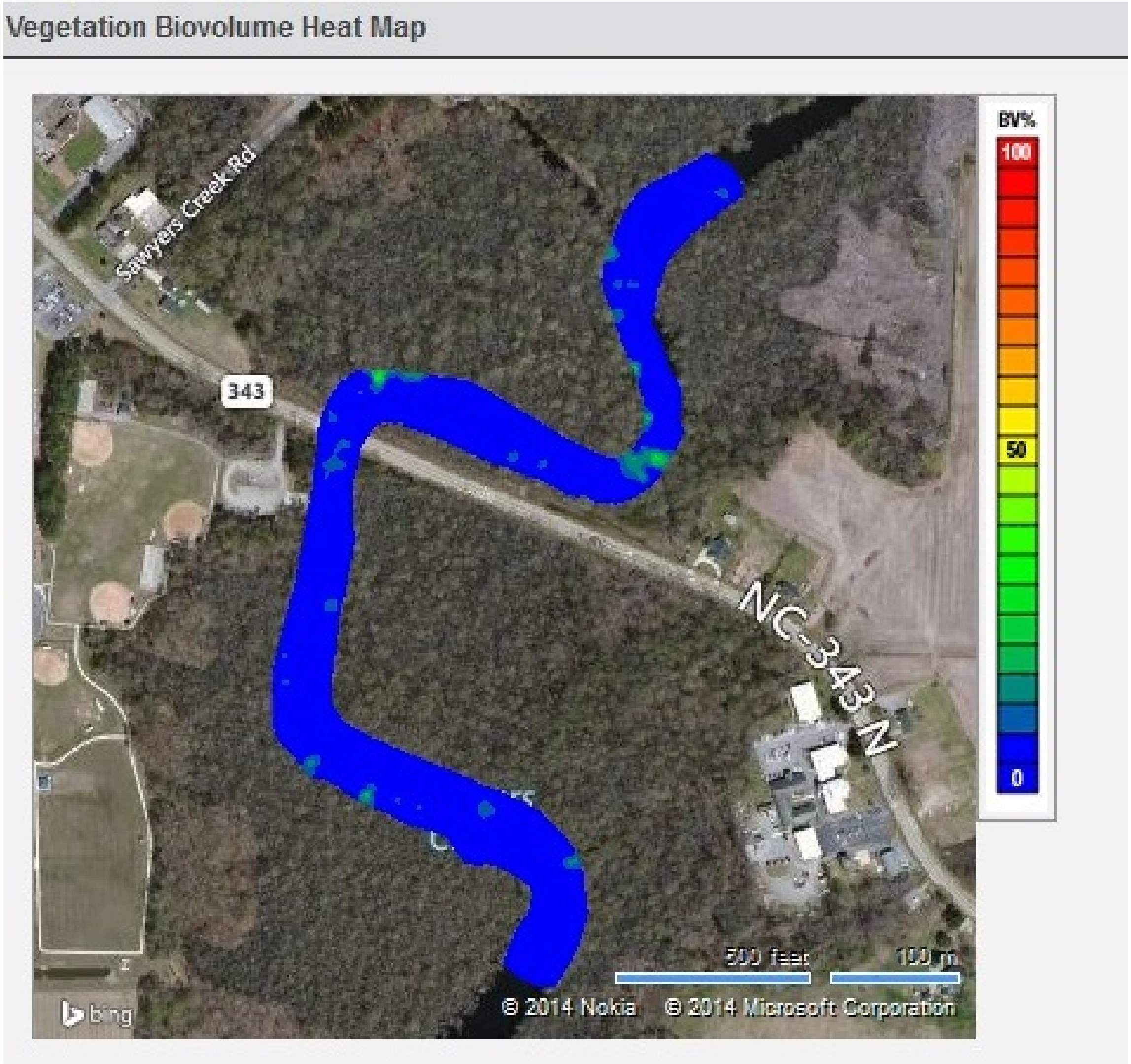


Figure 4.8. SAV coverage and biovolume of site B from July 2014 survey.

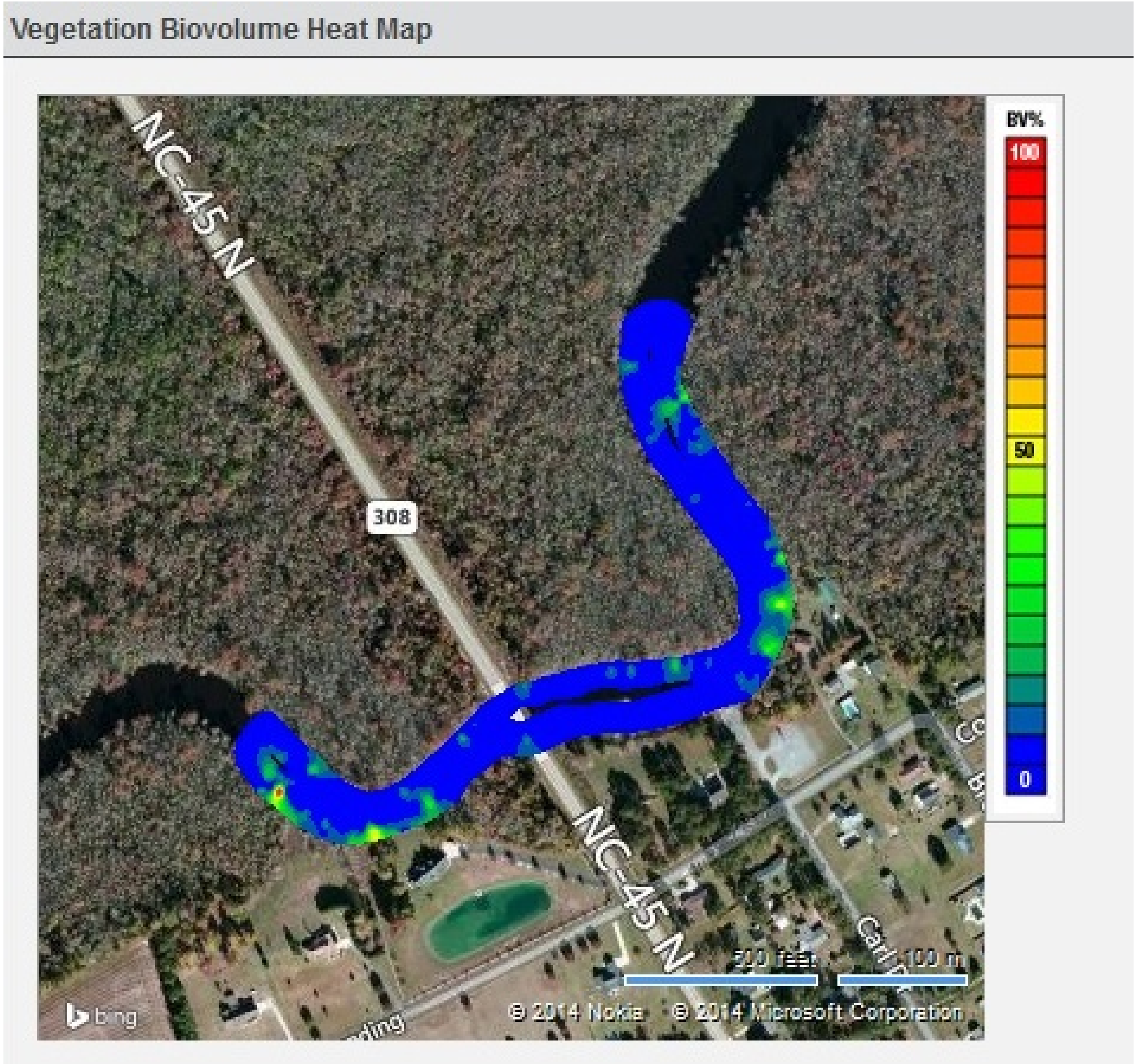


Figure 4.9. SAV coverage and biovolume of site C from July 2014 survey.

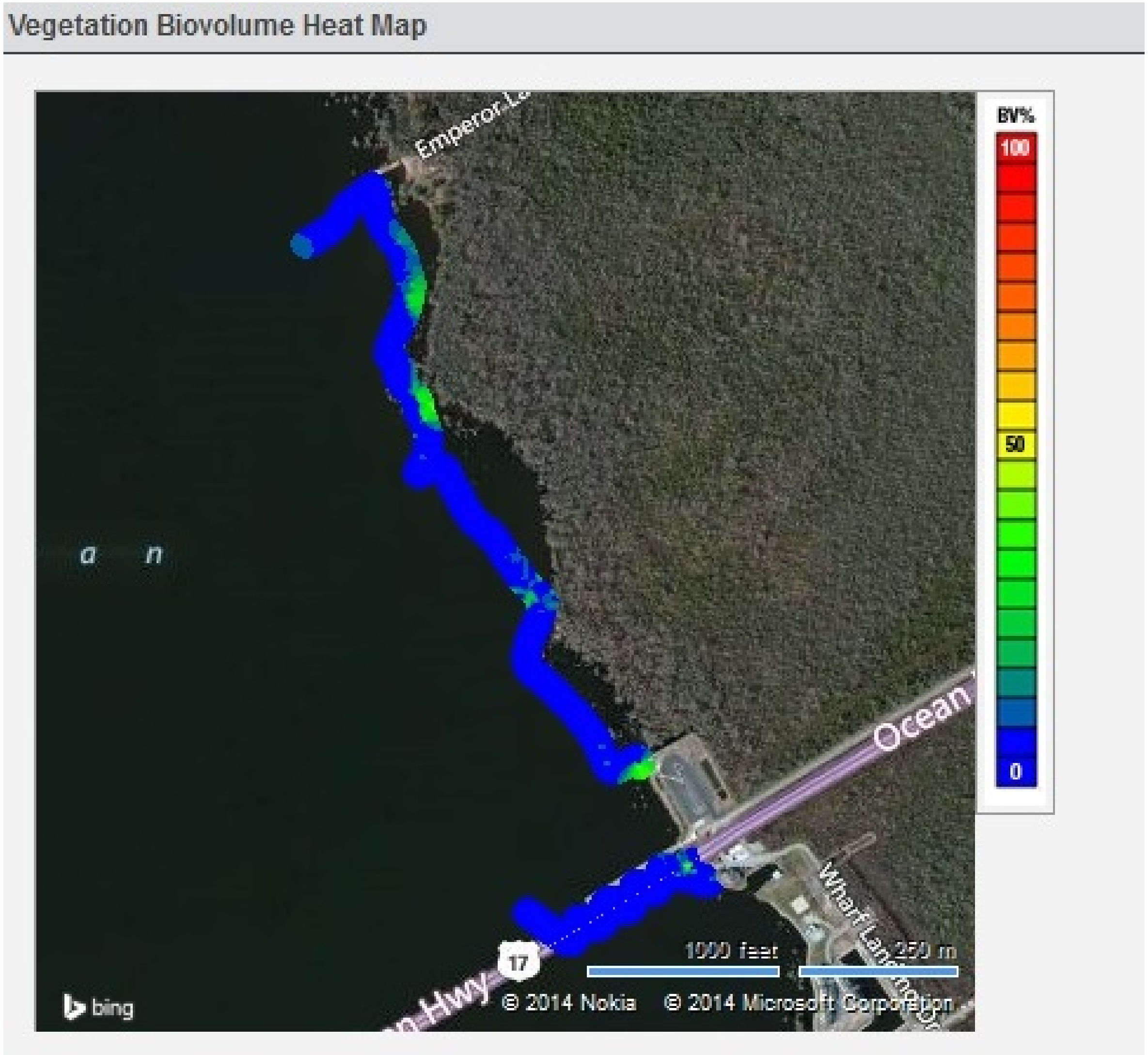


Figure 4.10. SAV coverage and biovolume of site G from July 2014 survey.

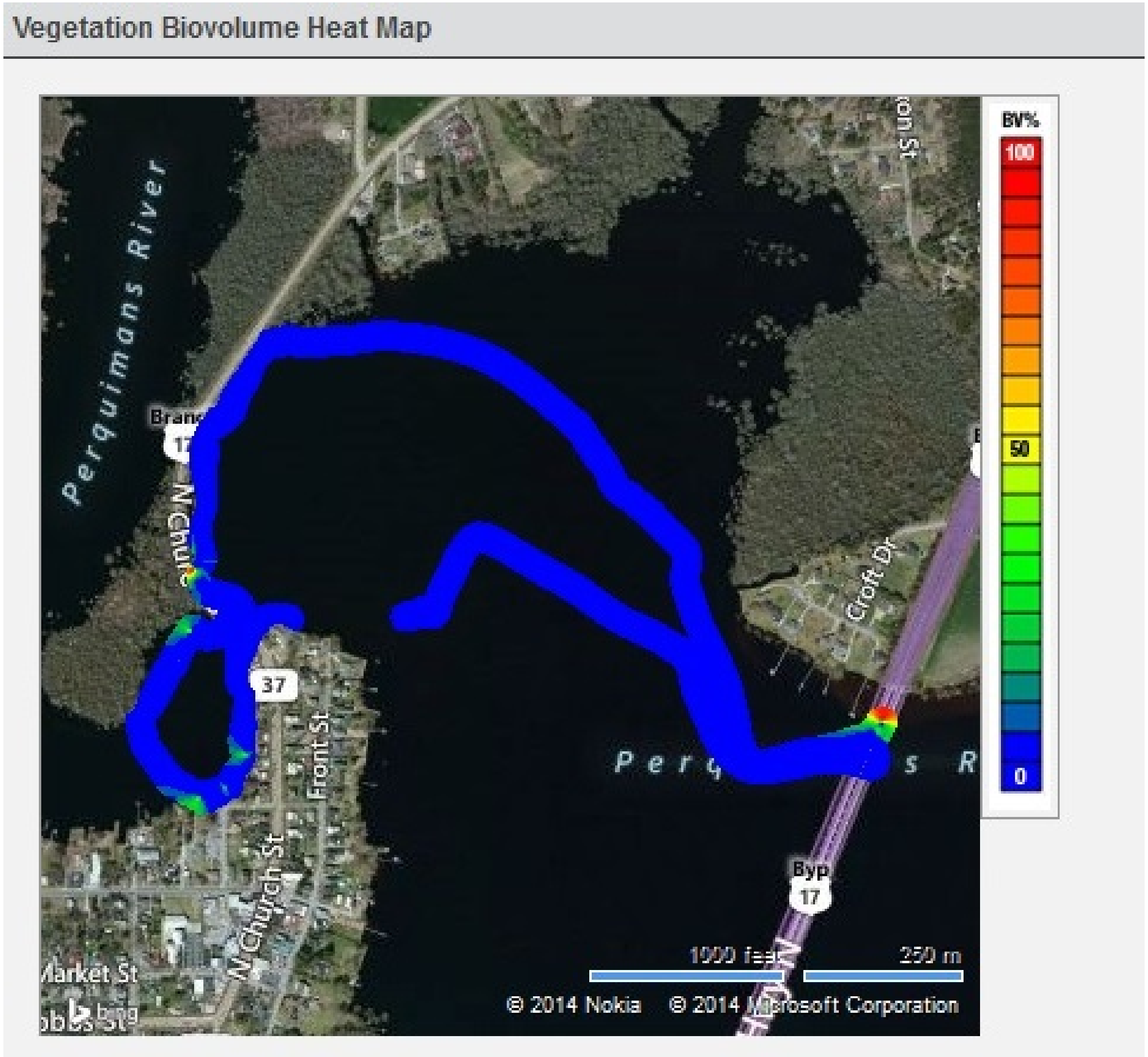


Figure 4.11. SAV coverage and biovolume of site H from July 2014 survey.

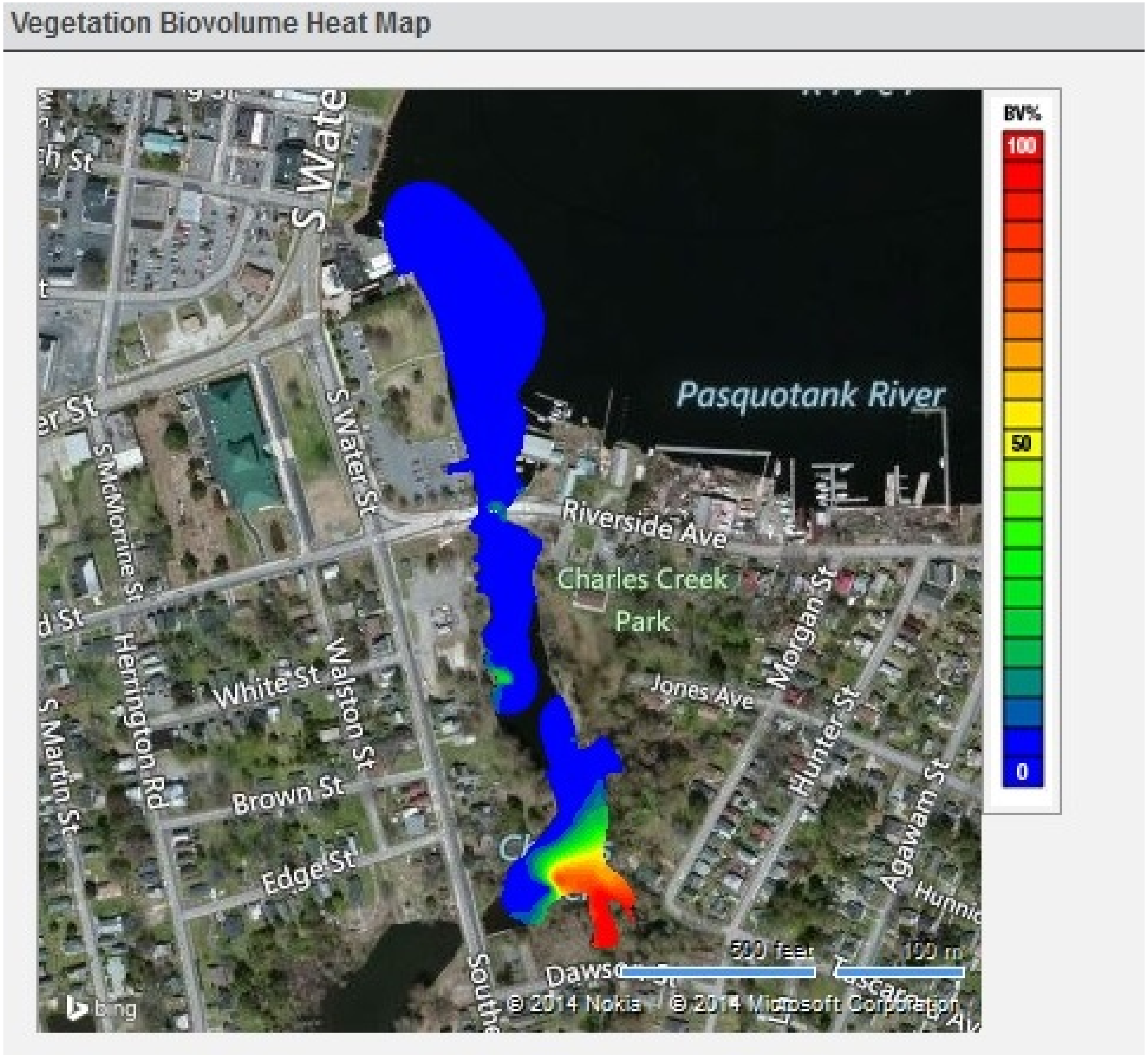


Figure 4.12. SAV coverage and biovolume of site K from July 2014 survey.

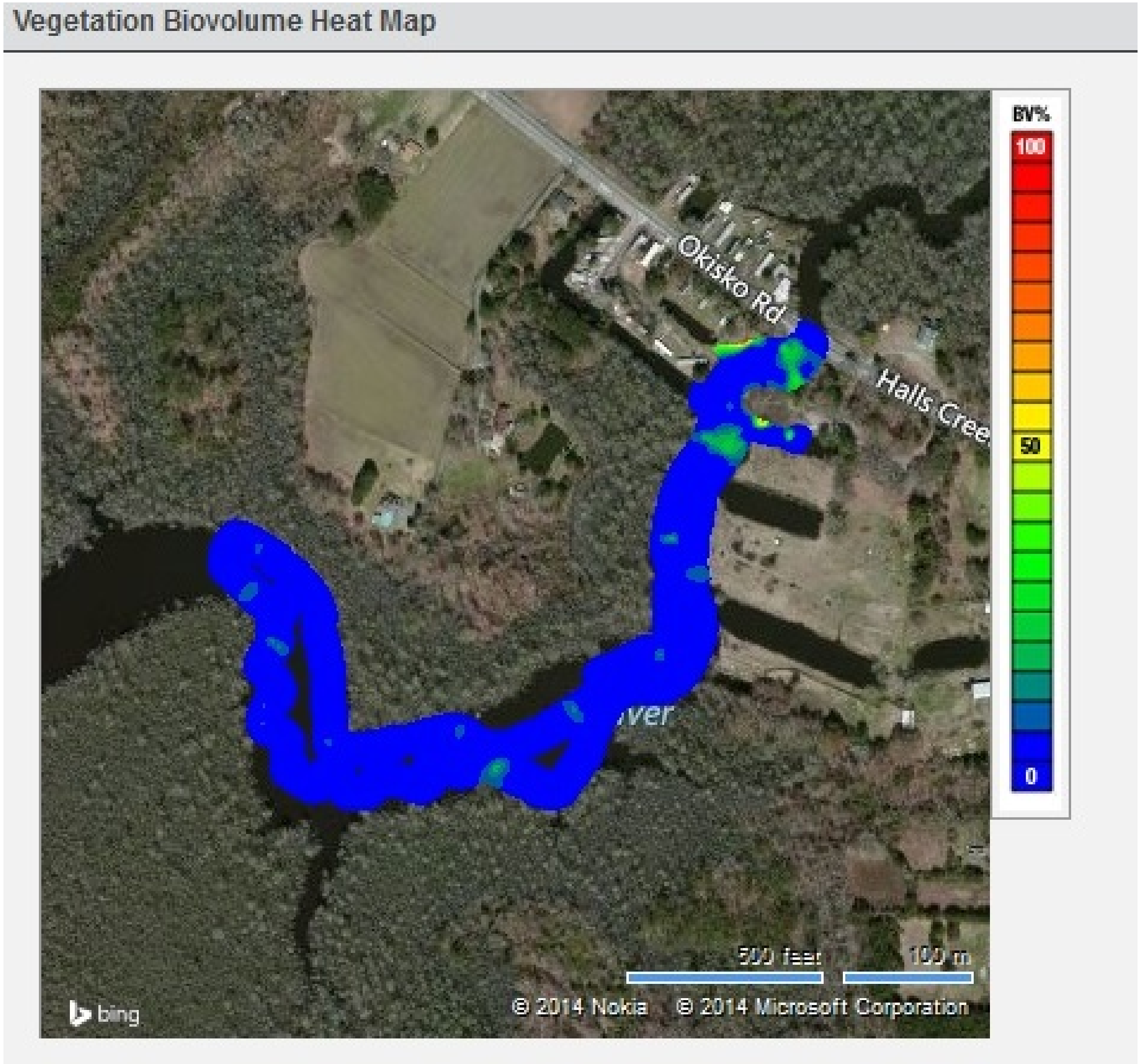


Figure 4.13. SAV coverage and biovolume of site P from July 2014 survey.

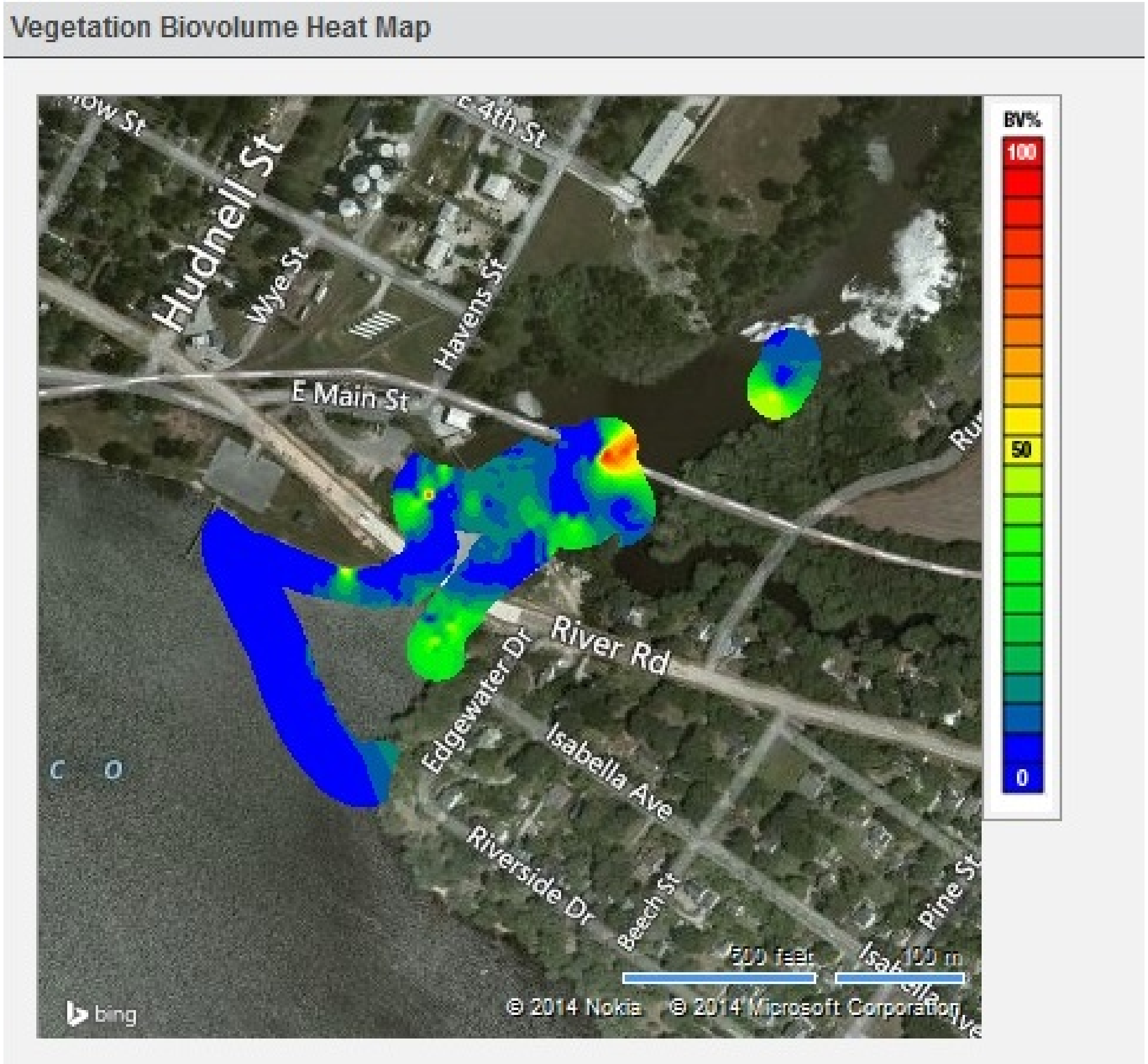
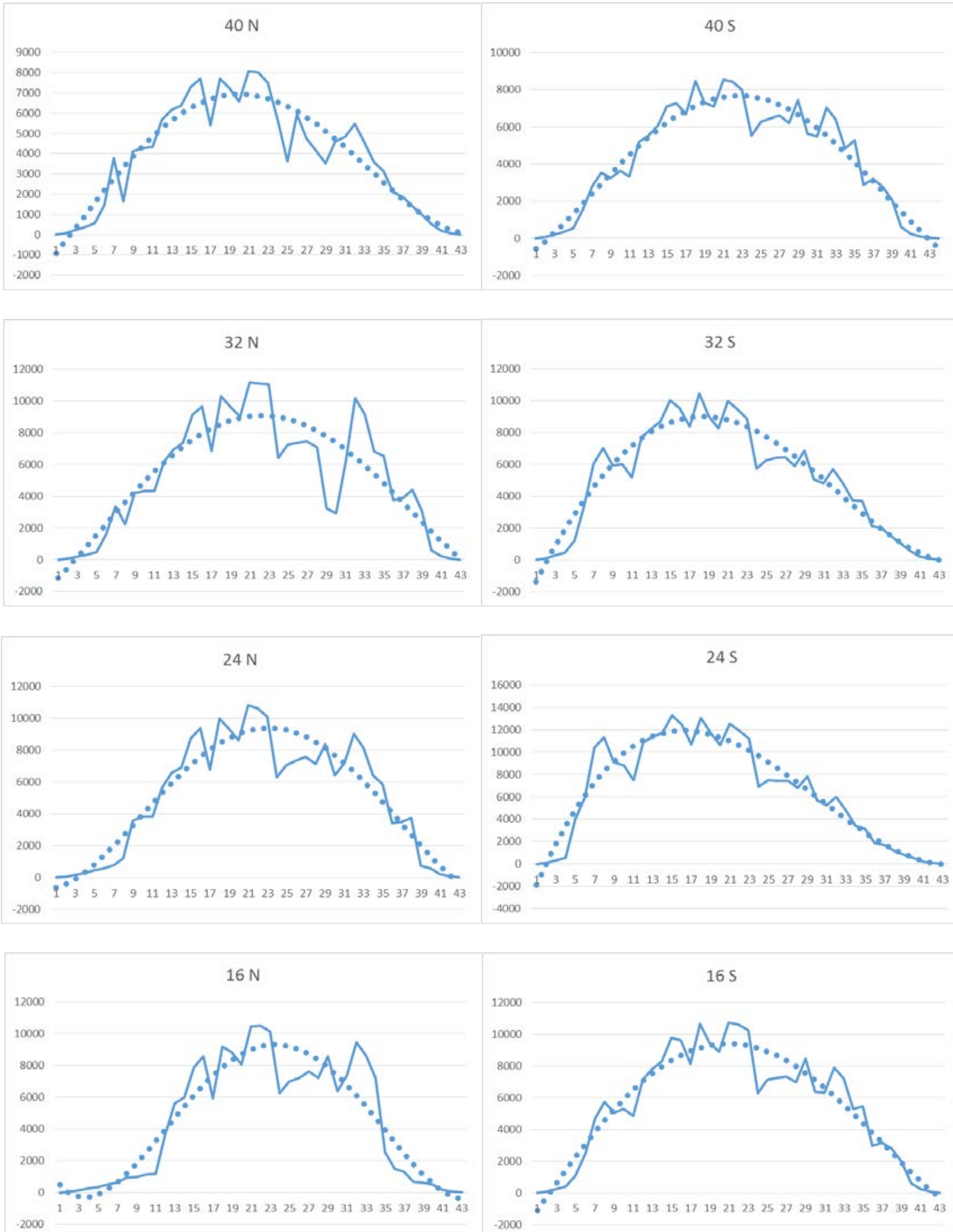
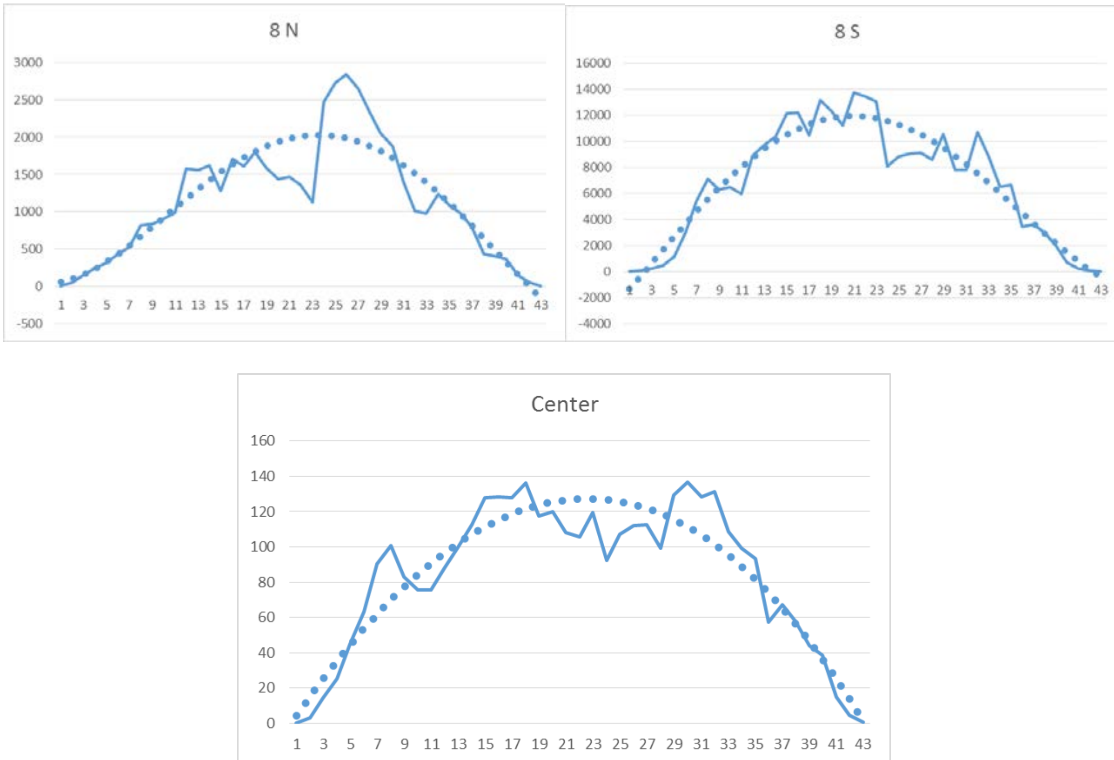


Figure 4.14. SAV coverage and biovolume of site Z from July 2014 survey.


40 N
40 S
32 N
32 S
24 N
24 S
16 N
16 S



*For all graphs (X axis is lumens/ft²and Y axis is the 15 minute sampling interval for representative days).

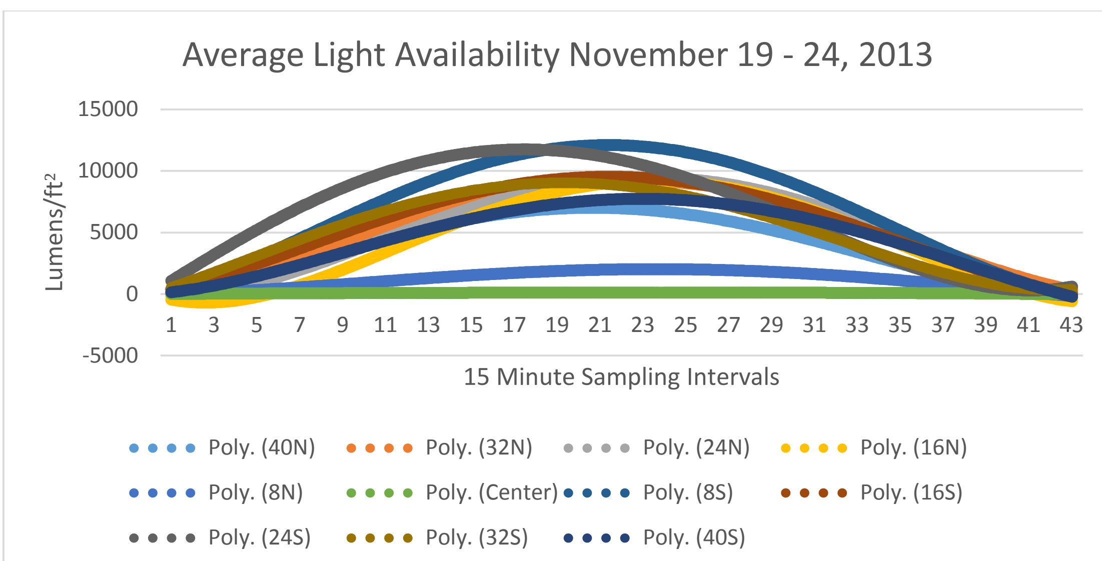


Figure 4.15. Individual data logger sampling at 8M intervals moving perpendicular from I 540 E/W bridge for dates November 19 – 24, 2013 with 4th order polynomial trendline. Trendlines are overlaid in subsequent graph for comparison.