ABSTRACT

SANCLEMENTS, MICHAEL DANTE. Effects of Shading by Bridges on Estuarine Wetlands. (Under the direction of Dr. Stephen Broome.)

Salt and brackish water marshes are integral parts of the coastal ecosystem, performing important nutrient cycling and hydrologic functions as well as providing habitat and breeding grounds for many coastal species. Despite their many benefits estuarine marshes have faced continued degradation in the past, which has led to a no net loss policy of these areas. As coastal populations increase so does the need for an improved and more extensive infrastructure including bridging estuarine marshes when building roads. Presently, mitigation is required to alleviate the effects of shading from bridges spanning marshes; however, mitigation is expensive and increases construction costs. Little research has been conducted to quantify the effects of shading by bridges on marsh function and productivity. These effects must be quantified to understand the effect of bridge height and width on the underlying marsh. Should the effects of shading be minimal then mitigation requirements may be reduced, in turn reducing construction costs. The objectives of this project were to determine the effects of bridge height and width on marsh productivity and function, directly assess light attenuation under bridges, and compare the effects of shading on the dominant salt marsh species. Seven different bridges representing various height and width combinations were selected for study. Measurements were taken at random both under and beyond the influence of these bridges. Photosynthetically available light was measured. Plant samples were clipped, dried and weighed to determine aboveground biomass, average stem height, number of stems, number of flowers and basal area. Soil cores were taken to a depth of 30cm and C and N were determined.

Both bridge height and width heavily influence the degree to which shading by bridges effects the underlying vegetation. All plant variables measured show a strong bridge effect at HW ratios less than 0.5 and light attenuation less than 250 umol $m^{-2}s^{-1}$ under the influence of the bridge. At a HW ratio of 0.68 a bridge effect was still detected although it was greatly diminished. Thirty-two comparisons were made between areas under and outside the influence of bridges having HW ratios greater than 0.7, only four significant differences were detected. Regression analysis shows a clear correlation between marsh productivity and bridge HW ratio, (r^2=.95). Data indicates that shading by bridges having HW ratios above 0.7 do not adversely impact the productivity or function of the underlying marsh. The best design is a bridge greater than 9 m over the underlying marsh that is narrow enough to keep the HW ratio greater than 0.7.

EFFECTS OF SHADING BY BRIDGES ON ESTUARINE WETLANDS

by
Michael SanClements

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Chair of Advisory Committee

BIOGRAPHY

Michael Dante SanClements was born in Boston, Massachusetts on April 23, 1976. He was raised and lived in Sherborn, Massachusetts until attending college at the University of Montana in Missoula, Montana. He received his B.S in Resource Conservation with an emphasis in Soils from the University of Montana in 1999. Following this he applied for and received a research assistantship at North Carolina State University.

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INTRODUCTION

Wetlands are valuable natural resources providing a number of important ecological functions. Wetlands store organic carbon and are sinks for inorganic nutrients such as nitrogen and phosphorus. High primary productivity and rich organic soils make wetlands important contributors to the estuarine food web. Estuarine wetlands act as nurseries for many species essential to commercial fisheries. Many rare and endangered species of flora and fauna are also found in or adjacent to wetland habitat. In addition to providing habitat, wetlands also perform a number of critical hydrologic functions. Wetlands act as sponges or flood control devices by storing water during large storm events and improve water quality by filtering out pollutants and trapping sediments. Despite the many benefits of wetlands they continue to face degradation by many factors both human and natural. Loss of wetland areas has been recognized as a problem for many years resulting in laws allowing for no net loss of these areas.

Human populations continue to increase in coastal areas creating demand for further residential and industrial development. With increasing populations comes a need for improved infrastructure in the coastal region, resulting in construction projects in and near estuarine wetlands. In such cases the agency responsible for construction is required to mitigate to compensate for the effected wetlands. Of particular interest is the construction of bridges spanning estuarine wetlands. Presently, mitigation is required to alleviate the effects of shading from bridges spanning these areas, however, mitigation is expensive and increases construction costs. Little research has been conducted to quantify the effects of shading by bridges on marsh function and productivity. These effects must be quantified to understand how bridge height and width affect shading and underlying marsh vegetation. Should the effects of shading be minimal then mitigation requirements can be reduced, in turn reducing construction costs.

Objectives:

The overall objective of the research project is to determine the effects of shading from bridges, which span salt or brackish-water marshes, on ecosystem structure and function. Specific objectives are to:

1. Evaluate the effects of height and width of bridges on marsh productivity and function including emergent vegetation and soils.
2. Directly assess light attenuation by bridges using sensors to measure photosynthetic photon flux density under and near the bridges.
3. Compare the relative effects of shading on growth of the dominant species of salt marshes, *Spartina alterniflora* (a C_4 plant), with the growth of the dominant species in brackish marshes *Juncus roemerianus* (a C_3 plant).

Light is one of the primary factors limiting growth and reproduction of vegetation (Smith 1996). Photosynthesis provides green plants with nearly all of their chemical energy and is therefore central to their ability to persist and reproduce (Givnish 1988). Photosynthesis is directly correlated with the amount of photosynthetically available radiation (PAR) at any given site until the saturation point is reached. Specifically photosynthesis is directly influenced by the amount of light striking the leaves of a particular plant. High levels of photosynthesis are not only important to the plants themselves but the ecosystem as a whole. Drake and Read (1981) found that carbon assimilated by photosynthesis has three possible pathways within the ecosystem. Carbon can be returned to the atmosphere through respiratory processes, accumulated in sediments, or exported out of the system as secondary production in the biomass of consumers. Each of these pathways returns energy to the system and is vital to its health. Studies of emergent marsh vegetation indicate that it is light limited during the growing season (Drake 1984, Drake and Read 1981). Thus, it can be expected that decreases in (PAR) may result in lower returns of energy to marsh systems therefore disrupting both marsh productivity and function.

Two different pathways of photosynthesis occur in nature under different light and moisture regimes (Mitsch and Gosselink 1993). These two pathways are the C_3 and C_4 pathways. Both of these pathways occur in coastal vegetation and are separated by gradients of varying light, salinity and temperature (Drake 1989). Plants using the C_3 pathway are adapted to moderate light and temperature levels and include most of the tree and shrub species. Plants with the C_3 pathway dominate the temperate regions of the world (Teeri and Stowe 1976). Plants using the C_4 pathway are better adapted to high light intensity, hot temperatures and low moisture (Teeri and Stowe 1976). Most C_4 plants occur in deserts or in the form of grasses. Many estuarine wetlands are dominated by vegetation that uses the C_4 pathway of photosynthesis (Drake 1989). High light intensity, hot summer temperatures and the water limiting osmotic effect of high salinity make wetlands suitable habitat for C_4 plants. Very high correlations exist between PAR, restricted water availability, high salinity, minimum average July daily temperature and the spatial distribution of C_3 and C_4 plants across the landscape (Teeri and Stowe 1976). These correlations result in a distribution where the dominance of C_4 plants increases with salinity towards the coast (Teeri and Stowe 1976). Due to their adaptive differences it can be hypothesized that C_3 and C_4 plants will respond differently to decreases in PAR due to the placement of man made structures.

The dominant C_4 species in southeastern coastal marshes is *Spartina alterniflora*, which possesses adaptations that allow it to compete very well in regions of physiological drought such as estuarine wetlands (Drake 1989). Specifically, *Spartina alterniflora* has the ability to photosynthesize at high light intensities and salt concentrations while using minimal fresh water (Giergevich and Dunn 1978, 1979). At the same time much research shows that C_4 plants experience greater reductions in growth in environments with reduced light intensity. Mitsch and Gosselink (1993) found that in C_4 plants the rate of photosynthesis increases in a linear manner with respect to increases in light, thus C_4 plants rarely become light saturated even in extreme conditions (Mitsch and Gosselink 1993). Several studies have also shown that high light intensity is needed to maintain maximum levels of photosynthesis by C_4 plants (Longstreth and Strain 1977). This ability to increase photosynthesis up to very high levels of light is efficient in climates such as the southeastern United States where sunshine is abundant. However, this also suggests that at decreased levels of PAR, C_4 plants are likely to suffer relatively greater decreases in photosynthesis and net primary production than C_3 plants.

Many studies have been conducted to quantify reductions in photosynthesis and productivity associated with varying levels of illumination and soil nutrients. Longstreth and Strain (1977) collected numerous samples of *Spartina alterniflora* from North Carolina marshes and performed controlled growth experiments in which different nutrient and illumination treatments were applied. Growth at low illumination and high salinity resulted in a fifty percent decrease in growth compared to the control. Furthermore, plants grown at high salinity and high illumination showed significant increases in specific leaf weight and photosynthesis. Salinity treatments were increased until nearly equal with open ocean water and still no reduction was found as long as illumination was maintained at sufficiently high levels. Thus it was concluded that salinity has little effect on photosynthesis and would rarely if ever be a limiting factor in *Spartina alterniflora* growth (Longstreth and Strain 1977).

Light intensity interacts with factors other than salinity to regulate plant growth and productivity. Several studies have been conducted to evaluate the importance of nitrogen availability on the photosynthetic capabilities of C_4 plants such as *Spartina alterniflora*. Salt marsh ecosystems in general have been found to be nitrogen limited (Mendelssohn et al. 1982). Results of studies concerning photosynthetic capacity of *Spartina alterniflora* have shown a drastic decrease in photosynthesis under low nitrogen, low illumination conditions. Under low illumination high nitrogen conditions photosynthesis decreased less rapidly (Drake 1989). These studies suggest that in low nitrogen environments such as coastal salt marshes human induced shading by a bridge or other structure could significantly reduce photosynthesis and net primary production.

Plants using the C_3 pathway may act differently under conditions of reduced light. Although not as common in estuarine wetlands as C_4 plants, C_3 plants do play an important role on the composition of less saline brackish water marshes. These plants possess adaptations allowing them to flourish in temperate regions with moderate levels of sunlight and moderate temperature regimes. The water limiting effect of high salinity confines C_3 plants such as *Juncus roemarianus* to the less saline portions of coastal estuaries (Drake 1984).

Differences in light and salinity tolerance led to questions regarding varied response to decreased light availability in C_3 plants, which exhibit increasing photosynthesis with increasing light intensity up to the point of light saturation at approximately ¼ to ½ full sunlight suggesting that C_3 plants are adapted to lower light levels than C_4 plants and are less likely to suffer from decreased solar radiation (Mitsch and Gosselink 1993).

Currently, little data exists pertaining to the effects of bridge height, orientation and width on the shading of underlying vegetation. Information does exist related to height, width and orientation of boat docks with respect to submerged aquatic vegetation. Walker and others (1989) found that direct damage to sea grass beds by boat docks was small in terms of area. However, the health of habitat under and adjacent to boat docks was compromised leaving it more susceptible to damage. Studies conducted on eelgrass beds under boat docks along the coast of Massachusetts revealed that height of the dock above marine bottom, dock width and dock orientation were the most influential factors in determining bed quality. Of these dock height was most important (Burdick and Short 1999). This is attributed to the fact that light levels are predominantly controlled by dock height (Burdick and Short 1999). Furthermore, it can be stated that light levels and bed quality were greater under taller, narrower docks (Burdick and Short, 1999). Loflin (1995) also found that the effect of shading on growth of submerged aquatic vegetation did depend on several factors, including dock orientation, height and width. Recommendations have been made for the building of taller, narrower docks whenever possible (Loflin 1995, Burdick and Short 1999). A minimum dock height of three meters above the marine bottom oriented in a north-south direction was recommended as the best possible dock design.

MATERIALS AND METHODS

Seven bridges (Table 1) spanning either salt or brackish water marshes in eastern North Carolina were selected for sampling to determine their effects on marsh productivity. These sites provided opportunities to asses the effects of shading from bridges of various heights and widths on several types of marsh vegetation. Each marsh was sampled twice, once in October of 2000 and again in October 2001 to determine the effects of shading on marsh function and productivity. Variables that were selected as indicators of marsh productivity and function were aboveground biomass, belowground biomass, soil carbon and nitrogen pools and light intensity.

Sampling was conducted to compare productivity under and outside the influence of the bridges (Figure 1). A perpendicular line running from the center of the bridge to points outside the shading influence of the bridges was established at each study location. Sampling quadrats were randomly selected on either side of the transect so that areas under and outside the influence of the bridge were sampled. When possible, samples were taken in unaffected areas on both sides of the bridges, however, at most locations sampling outside the bridge was only feasible on one side due to the presence of waterways or beaches.

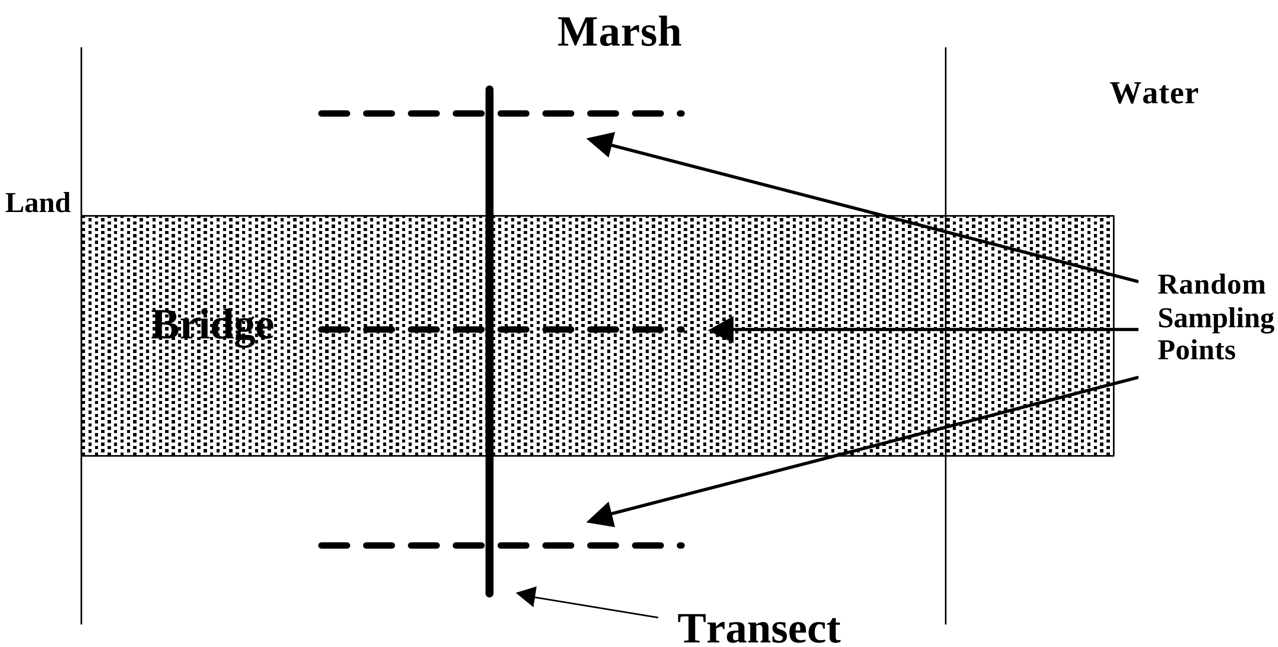

Figure 1. Sampling Design used for sampling of vegetation and soils data during years 2000 and 2001.

Table 1. Bridge study sites with heights and widths of bridges at sampling transects.

Site	Plant Species	Height (m)	Width (m)	HW Coefficient	Age (Years)	Salinity (ppt)	Orientation
Wrightsville Beach	***Spartina*** *alterniflora*	5.85	20.82	0.28	44	32	125°E-SE
New River Low	***Spartina*** *alterniflora*	7.32	10.73	0.68	7	4	176°S-SE
New Bern	***Spartina*** *cynosuroides*	8.53	16.71	0.51	24, 2 widened	3	112°E-SE
Salter's Creek	***Juncus*** *roemerianus*	11.58	10.70	1.08	18	22	125°E-SE
New River High	***Spartina*** *alterniflora*	14.63	10.73	1.36	7	4	176°S-SE
Ocean Isle	***Spartina*** *alterniflora*	15.24	9.85	1.55	16	39	167°S-SE
Bogue Inlet	***Spartina*** *alterniflora*	19.81	11.13	1.78	19	34	168°S-SE
Cedar Island Low	***Spartina*** *alterniflora*	3.21	9.94	5	5	20	39°N-NE
Cedar Island Medium Low	***Juncus*** *roemerianus*	4.98	9.94	5	5	20	39°N-NE
Cedar Island Medium High	***Spartina*** *cynosuroides*	6.15	9.94	5	5	20	39°N-NE
Cedar Island High	***Spartina*** *patens*	15.52	9.94	5	5	20	39°N-NE

Table 2. Bridge sections chosen for planting at Cedar Island bridge study site.

Cedar Island Heights (m)	Year 2002	
Bridge Section	**Height (m)**	**HW Ratio**
	2.91	0.29
	3.05	0.30
	3.7	0.37
	4.14	0.41
	4.72	0.47
	5.88	0.59
	5.96	0.59
	6.63	0.66
	9.34	0.93
	11.57	1.16
	13.38	1.34
	15.46	1.55

Primary marsh production was assessed by sampling several growth variables including above and below ground biomass, number of stems, number of flowering stems and basal area.

Soil samples 30 cm deep and 8.5 cm in diameter were taken at each location where vegetation was harvested. Soil carbon and nitrogen pools tend to reflect long-term changes in marsh productivity since reduction of vegetative growth over extended time periods would reduce the amount of detritus returning to the marsh surface and production of roots and rhizomes.

Photosynthetically available light was also measured at each sampling location to obtain a direct measure of the degree to which various bridge configurations obstruct sunlight.

Vegetation Samples:

Vegetation samples were taken at the end of the 2000 and 2001 growing seasons. Sampling transects were located along a line running perpendicular to the bridge from the center outwards. Specific sampling plots were located along this line at points under and outside the influence of the bridges. At each sampling point a 0.25 sq. meter quadrat was placed on the marsh surface, all vegetative growth occurring within the plot was clipped. The number of stems, number of flowering stems, and basal area were recorded. Harvested vegetation was placed in a bag, labeled and returned to the laboratory, dried at 70° C in a forced air oven and weighed.

Belowground biomass measurements were taken from within the 0.25 sq meter plots after they were clipped. A soil corer 8.5 cm in diameter and 30 cm deep was used for obtaining samples. Each core was divided into two sections, 0-10 cm and 10-30 cm, returned to the laboratory and washed through a 2mm sieve. All remaining root mass was bagged, air dried at 70° C in a forced air oven and weighed.

Soil Samples

A soil core 8.5 cm in diameter and 30 cm deep was taken from each quadrat for use in soil nutrient analysis. Each core was further divided into a 0-10 cm and 10-30 cm section, returned to the laboratory and sieved through a 2mm sieve. Samples were air dried before being sent to the Soil Science Dept. Service Laboratory for Carbon and Nitrogen analysis using a CHN analyzer.

Light Measurements

Light Measurements were conducted at locations under and outside the influence of the shadow of each bridge. Measurements were taken along the same transects used in vegetation and soil sampling using hand held Apogee quantum meters. Apogee quantum meters measure radiation between 400 and 700 nanometers, which are the most important wavelengths for plant growth. Readings were taken simultaneously under and outside the bridges influence to assure an accurate comparison of solar radiation at each location. Three readings were taken at each measuring point at time intervals of one minute. All light data was collected during July of 2002 at or as close as possible to full sunlight.

Seedling Growth Experiment

A seedling growth experiment was conducted at the Cedar Island bridge location to asses the effects of varying levels of shading on dominant marsh vegetation types. The species selected for study were *Spartina alterniflora, Spartina cynosuroides* and *Juncus roemerienus*. Prior to planting at the bridge seedlings were transplanted to two-gallon pots containing a uniform mixture composed of 1/3 sand, topsoil and a standard potting medium. All pots were fertilized with an equal amount of Osmocote (14-14-14) fertilizer and seedling grown for two weeks in a green house prior to planting in the field.

Planting occurred at nine sections of the Cedar Island bridge, ranging in height from 2.91 to 15.46 meters (Table 2). Three randomized blocks of seedlings were planted at each of the nine sections chosen. One block was located under the center of the bridge, a second under the edge of the bridge and a third in the natural marsh outside the shadow of the bridge. Each block contained three pots of seedlings of each species for a total of nine pots per block. Pots were buried flush with the existing marsh surface. Planting occurred during May of 2002, all vegetative growth was harvested during October of 2002 at the completion of one growing season. Upon harvesting each plant was clipped and bagged, number of stems and height of the tallest stem was recorded. All samples were air dried at 70° C in a forced air oven and weighed.

Statistical Analysis

All data was analyzed under the supervision of the statistics department at North Carolina State University using Statistical Analysis Software (SAS Institute, 1985). An alpha level of 0.05 to indicate significance was chosen for all statistical analysis. Analysis of variance was computed using the following formula: Y_{ijklm}=U+H_j+L_j+$(H*L)_{ij}$+$(L*B)_{jk(i)}$+T_l+$(T*H)_{il}$+$(T*B)_{lk(i)}$+$(T*L)_{jl}$+$(T*L*H)_{ijl}$+$(T*L*B)_{jlk(i)}$+E_{ijklm}. Where: T=year, H=height or width, L=location, B=bridge, U=mean of population, E=random error in Y, Y_{ijklm} denotes the j-th response for treatment $_i$ etc.

Comparisons were made to determine significance in differences between data collected under and outside the influence of the bridges. Data from each year was examined independently and then pooled and examined. Analysis was conducted using t-tests along with the General Linear Model slice option to divide data into categories of low and high bridges. A height of nine meters was chosen as the cutoff.

RESULTS AND DISCUSSION

Bridge Characteristics

Table 1 shows the eight bridges selected for study. Seven bridges were used in the sampling of plant and soil data in October of 2000 and 2001. Sampling occurred consecutively in October of years 2000 and 2001. Each bridge was sampled once at a particular height at the conclusion of each growing season. A low and high transect was sampled each year at New River (Table 1). Transects were sampled under bridges ranging in height from 5.85 meters to 19.81 meters and in width from 9.85 meters to

20.82 meters (Table 1). Bridges were placed into height categories, either low or high (Table 1). Bridges < 9 meters in height were labeled low, and bridges > 9meters were grouped into the high category. The low category consists of the bridges located at Wrightsville Beach, New River (low transect), and New Bern. The high category consists of the bridges located at Salter Creek, New River (high transect), Ocean Isle and Bogue Inlet. Bridge age was also determined for each location (Table 1). Bridges ranged in age from 5 to 44 years (NCDOT). Bridge orientations and the salinity of the marsh water were also recorded at every location (Table 1). The Cedar Island site was sampled once in 2001 for plant and soil variables, and was the location of a seedling transplant experiment, all Cedar Island data is presented in the Appendix.

Unlike other bridges sampled, the marsh Under the New River Bridge was severely disturbed during construction resulting in a change of vegetation from that in the surrounding natural marsh. During construction the area directly under and to the west of the New River Bridge was dredged and refilled with sand. Currently, the area disturbed during construction is occupied by *Spartina alterniflora* while the surrounding natural marsh is dominated by *Juncus roemerianus.* The change in soils and vegetation may be responsible in explaining some irregularities in belowground biomass data collected at the New River site. It is also important to note that all sampling was conducted within the area dominated by *Spartina alterniflora*.

A height-width ratio (HW ratio) was also calculated for each bridge transect sampled. The HW ratio was calculated by dividing bridge height by bridge width. The HW ratio accounts for the effects of both height and width with one number. Arranging bridges by increasing or decreasing HW ratios explains patterns in the data from New Bern and New River that are less clear when viewed against height alone.

Shading Impacts Under Bridges

Unless stated otherwise the data being discussed within the text and figures is the mean data for the growing seasons of 2000 and 2001. Statistical analysis showed that year of sampling was not significant in determining patterns within the data. In the few cases where year was significant the data is discussed separately and each year is presented along with mean data for the two years.

Light Data

Light was sampled at the seven bridges along transects where plant and soil samples were taken. Apogee quantum sensors were used to measure photsynthetically available light under and outside the influence of the bridges during July 2002. Table 3 shows light measurements collected under and outside the influence of the bridges in umol $m^{-2}s^{-1}$, this data is shown as a percentage of the control in figure 2. Figure 3 depicts aboveground biomass (gm^{-2}) and photosynthetic photon flux density (PPFD) (umol $m^{-2}s^{-1}$) measurements from under the bridges influence as a percentage of the control. Wrightsville Beach Bridge has a HW ratio of 0.28, the smallest HW ratio of all bridges sampled. Average PPFD outside the bridge at the time of sampling was 1907 umol $m^{-2}s^{-1}$ while under the bridge the average was 36.25 umol $m^{-2}s^{-1}$ (Table 3), only 1.9% of the control and was insufficient to support vegetative growth (Figure 3). With a HW ratio of 0.51 New Bern was the next lowest and widest bridge. Average PPFD outside the bridge was 1904 umol $m^{-2}s^{-1}$, under the bridge averaged 217 umol $m^{-2}s^{-1}$ or 11.5% of the control (Table 3, Figure 3). At these light levels vegetative growth was severely depressed under the bridge, less than 50% of that occurring outside the bridges influence (Figure 3). The low transect at New River bridge has a HW ratio of 0.68 allowing for 19% of the photosynthetically available light (250 umol m^{-2} s^{-1}) to reach the area under the bridge (Table 3, Figure 2). Even at these low light levels biomass production was 91% of the control (Figure 3). As bridge HW ratio increases above 0.68 light as a percentage of the control increases greatly and is sufficient to support vegetative growth under the bridge that is nearly equal to, or greater than the control. Regression analysis indicates a significant relationship between light attenuation under the bridges and HW ratios (r^2=0.93) (Figure 2.A.). This suggests that both height and width are important in determining the amount of light available to vegetation growing under any bridge.

Plant Growth Measurements

Sampling of vegetation under bridges from seven sites indicated that bridge height and width affected vegetative growth. Each of the growth measurements, aboveground biomass (gm^{-2}), number of stems per (m^{-2}), stem height (cm), flowers (m^{-2}), basal area (m^{-2}), and belowground biomass (gm^{-2}) demonstrated similar trends across increasing bridge heights and widths. Of the seven bridges studied, six had vegetation growing directly under the bridge, and all bridges sampled had vegetation growing outside the influence of the bridge. At a height of 5.85 m and width of 20.82 m Wrightsville Beach Bridge is the lowest and widest (Table 1), and has the lowest HW ratio at 0.28. No vegetation is present under the bridge, while outside the influence of the bridge *Spartina alterniflora* biomass averaged 837.5 g/m^2 (Table 4). At a height of 7.3 m, New River (low transect) was the second lowest bridge sampled (Table 1), however, *Spartina alterniflora* biomass under the bridge was equal to that outside the bridge (Figure 4, Table 4). Although the low transect at New River is only 7.3 meters tall it is narrow, only 10.7 meters in comparison to the Wrightsville Beach bridge (20.8 meters) and New Bern bridge (16.7 meters). It is the decreased width and therefore greater HW ratio (0.68) that allows increased light availability and subsequently greater vegetative growth to occur under the low transect at New River. The New Bern bridge is the tallest of the bridges falling into the low height category at 8.53 meters high, but it is a four lane bridge with a width of 16.7 meters, and HW ratio of 0.51. Measurements of aboveground biomass of *Spartina cynosuroides* revealed large differences between areas under and outside the bridge (Table 4). Mean biomass was less than half under the bridge (656.8 gm^{-2}), than outside the influence of the bridge where biomass was 1336.9 gm^{-2}, (Figure 5). Such large reductions in biomass can be attributed to the increased shading and low HW ratios associated with wide bridges.

At the taller bridges measured in the study no significant differences were detected in aboveground biomass. It was concluded that bridges greater than 9 meters tall having HW ratios > 0.70 have little effect upon biomass production under the bridge.

Other indicators of aboveground growth, such as number of stems m^{-2}, stem height (cm), flowers (m^{-2}), and basal area (cm/m^2) demonstrated similar patterns related to bridge height and HW ratio as those exhibited by aboveground biomass measurements.

The number of stems per m^{-2} differs significantly at all three of the bridges falling into the low category, which are Wrightsville Beach, the low transect at New River and New Bern (Figure 11). Salter Creek also exhibited a significant difference in the year 2001, but not 2000. At a height of 11.5 meters and HW ratio of 1.08 it is suspected that the difference occurring in the year 2001 was due to natural variation within the marsh rather than a bridge effect.

Significant differences in average stem height (cm) were detected at the two bridges having the lowest HW ratios, Wrightsville Beach and New Bern (Figure 12, Table 4). No significant differences occur at any of the bridges having HW ratios greater than 0.51. Three of the bridges in the tall category had greater average stem heights directly under the bridge.

Measurements of number of flowers m^{-2} revealed significant differences at Wrightsville and New Bern (Figure 13). Unlike other parameters measured number of flowers has significant differences occurring between the control and under the bridge at Bogue Inlet (Figure 15). Bogue Inlet is the tallest of all bridges sampled at a height of 19.81 m. The difference in flowers m^{-2} may be a direct result of the significant difference in number of stems under and outside the influence of the bridge. The differences occurring at Bogue Inlet are more likely due to hydrological conditions at the site rather than shading effects of the bridge. Only a small area exists under the bridge on which the water is not too deep for vegetative growth. Thus, growth in the sampling area was likely affected by factors unrelated to the bridge.

Basal area cm/m^2 has significant differences occurring at Wrightsville, and New Bern while locations with bridges having HW ratios of 0.70 or greater demonstrate no significant differences (Table 6). All other bridges have basal area measurements under bridges that are equal to or exceeding those of the control (Table 4, Table 6).

Belowground biomass measurements display similar patterns to aboveground biomass across the seven bridges sampled (Table 4). Figure 15 displays mean belowground biomass for each bridge as a percentage of the control. All three bridges in the low category (Wrightsville Beach, New Bern and the low transect at New River) exhibit significant differences in belowground biomass between areas under and outside the bridges influence. Of the four bridges in the tall category only Salter Creek exhibited a significant difference in mean belowground biomass over the two years of sampling. Mean belowground biomass under the bridge was $1908gm^{-2}$ while outside was $2777gm^{-2}$ resulting in a significant difference ($p<.037$). It should be noted that although the difference is significant when examining combined data from years 2000 and 2001 analysis of each year independently reveals a significant difference in 2001 but not 2000. Of the eight variables sampled at Salter Creek only one other is significant (number of stems) and is only so in 2001. Furthermore, C_3 plants such as *Juncus roemerianus* are well adapted to moderate light levels and should not be heavily affected by the shading of a tall narrow bridge such as Salter Creek. This suggests that the difference in belowground biomass at Salter Creek may result from sampling or natural variation rather than a bridge effect.

Measurements of belowground biomass were also examined by dividing the belowground cores into depth categories of 0-10cm and 10-30cm. Statistical analysis of the 0-10cm-depth category revealed trends almost identical to those found when examining an entire core from 0-30cm. Significant differences between areas under and outside the bridge occur at Wrightsville, New Bern and New River low transect (Figure 8). Data from the analysis of the 10-30 cm layer demonstrates patterns similar to those seen in looking at 0-30cm and 0-10. Significant differences occur at Wrightsville and New Bern. Unlike when examined on a 0-30 cm basis or 0-10 cm basis a significant difference occurs at the high transect of New River. It is highly unlikely that this results from bridge shading effect, as it is the only statistically significant difference occurring at this site. All other plant growth variables measured at the high transect of New River demonstrate no measurable bridge effect (Figure 7). This difference is likely due to the aforementioned dredging and refilling of the New River site

Analysis of bridge height and width with each of the plant growth measurements used as a dependent variable revealed that bridge height and width are highly significant ($P<.05$) in determining the productivity of vegetation occurring under the bridges.

Soil Carbon and Soil Nitrogen

Soil C and N was not significantly affected by bridge height and width except at Wrightsville Beach where no vegetation was growing under the bridge. Evidence of the old root mat could still be detected but lack of marsh production over the last 44 years has decreased biomass inputs sufficiently to alter the percent of soil carbon (Figure 16). A significant difference in soil carbon was also found at the low transect of New River bridge, this is likely the result of severe soil disturbances associated with the construction of the bridge.

The Bridge Height/Width Ratio

Arrangement of the bridges sampled using the HW ratio as opposed to height alone clarifies patterns seen in the data. Table 5 presents all the bridges sampled in order of increasing height along with the variables sampled, and whether a significant difference was detected. The order of the first three bridges when moving from lowest to highest is Wrightsville, New River low transect and New Bern. At Wrightsville (5.85 m) seven of the eight variables measured were significantly different under and outside the influence of the bridge, at New River low transect (7.3 m) three of the eight variables were significantly different, and at New Bern (8.53) six of eight variables were significantly different with four of the eight variables at 50% or less than that of the control (Table 5). Rearranging the bridges by increasing HW ratios changes the order of the first three bridges to Wrightsville, New Bern, and New River low transect (Table 6). This change is the result of the large difference in width between New Bern 16.71m and New River 10.7m and helps to explain why a taller bridge such as New Bern would demonstrate a greater bridge effect. By accounting for both height and width the HW ratio explains trends that height alone cannot. Viewing bridges in order of ascending HW ratios provides a more uniform trend and more clearly explains the decreasing bridge effect across the seven bridges studied (Table 5,Table 6). This indicates that width as well as height is an important growth-limiting factor.

Summary

The data show a strong bridge effect occurring at the Wrightsville and New Bern sites as well as a diminished effect at the low transect of New River. All three of these bridges have heights less than 9 meters and HW ratios less than 0.7. Photosynthetic photon flux density umol $m^{-2}s^{-1}$ averaged less than 20% of that recorded outside the influence of the bridge at all three locations. At Wrightsville ambient light measurements taken under the bridge were only 1.9% of those recorded outside the bridges influence, consequently no vegetation is present under the bridge. Outside the bridges influence measurements of *Spartina alterniflora* biomass had a mean of 837gm^{-2} (Table 4). Using the HW ratio as opposed to height alone, the next bridge in ascending order is New Bern, HW ratio 0.51 and height of 8.53 meters. New Bern also exhibits a strong bridge effect with significant differences occurring in all six of the plant growth variables measured. Four of these variables had means under the bridge, which were less than 50% of the control. The low transect at New River is the next bridge with a HW ratio of 0.68. Here a diminished bridge effect can be seen with three of the five variables being significantly different (Figures 15, Tables 4,5,6). Combining the three bridges grouped into the low category (<9 meters) twenty-four comparisons were made between areas under and outside the bridges. Of these twenty-four comparisons sixteen were significant at $p<.05$ (Tables 5 and 6). Thus, 60% of the comparisons between areas under and outside the bridge were significant at HW ratios less than 0.68 and heights less than 8.53 meters. In the tall category four of the thirty-two comparisons made resulted in significant differences, this is only 12.5%. Furthermore, it is unlikely that any of these four differences can be attributed to a bridge effect.

Regression analysis of the number significant differences occurring between areas under and outside the influence of the bridges as a function of bridge HW ratio shows a clear correlation (r^2= 0.84) between the two (Figure 18). Tables 5 and 6 show two of the eight variables measured at Bogue Inlet as significantly different. Light attenuation under Bogue Inlet Bridge was 98% of the control at a HW ratio of 1.78, the highest of all bridges sampled, thus it is unlikely that these significant differences are due to a bridge effect. Assuming that the two significant differences occurring at Bogue Inlet are due to factors other than a bridge affect the regression analysis of number of significantly different variables as a function of bridge HW ratio becomes even more clear (r^2=0.95) (Figure 19). This further supports the correlation between bridge HW ratio and the productivity and function of the underlying marsh.

CONCLUSIONS

Bridges spanning estuarine marshes can cause severe localized impacts to underlying vegetation. Impacts occur through shading from bridges as well as disturbances during construction. Under extreme circumstances shading by bridges may result in a complete loss of vegetation under the bridge. However, these effects tend to be small in area and only occur under the lowest and widest bridges (HW ratio <0.3).

All data collected suggests that at HW ratios less than 0.5 bridges have the capacity to severely effect marsh productivity and function under the bridge. At HW ratios between 0.5 and 0.68 a bridge effect can be detected yet it is greatly diminished. Above HW ratios of 0.70 the effects from shading by bridges are no longer measurable. Thus, it can be concluded that shading by bridges having HW ratios >0.7 do not adversely impact the productivity or function of the underlying marsh.

The best bridge design is a high bridge greater than 9 m over the underlying marsh that is narrow enough to keep the HW ratio above 0.7. Such designs should provide sufficient PPFD (>250 umol $m^{-2}s^{-1}$) to support the underlying vegetation with no measurable decline in productivity.

Table 3. Light data collected on July 21st and 22 of 2002. Data collected using Apogee Quantum sensors. Measurements in umol m^{-2} s^{-1}.

Site (Time)	**Avg. PPFD umol m^{-2} s^{-1} Outside (n=3,5)**	**Avg. PPFD umol m^{-2} s^{-1} Under (n=3,5)**	**Percent of Control**	**Bridge Height (m)**
Wrightsville Beach 1:30-1:40	1907	36	1.9	5.85
NR Low 11:55-12:15	1294	250	19	7.32
New Bern 2:05-2:15	1904	202	11.43	8.54
Salter C. N/A	2000	364	18	11.59
NR High 11:55-12:15	1543	1037	67	14.33
Ocean I. 3:15-3:20	1929	1816	94	15.24
Bogue I. 10:15-10:20	1658	1639	98	19.82

Table 4. Mean plant and soil data collected in October of 2000 and 2001

Bridge	Height Width (m)	Soil C %	Soil N %	Above ground biomass g/m^{-2}	Below ground biomass g/m^{-2}	Stem height (cm)	Stems m^{-2}	Flowers m^{-2}	Basal area g/m^{-2}
Wrightsville Bridge	5.85 20.82	0.31	0.04	0	0	0	0	0	0
Wrightsville Control		1.96	0.14	837.5	1549.1	132.9	163	28	8.1
NR Low Bridge	7.32 10.73	0.29	0.04	898.5	890.1	83.2	235.2	11.6	8.1
NR Low Control		1.74	0.14	974.4	1589.6	89.7	319	4.4	9.2
New Bern Bridge	8.53 16.71	20.47	1.45	656.8	1429.3	177.4	37.6	.8	3.7
New Bern Control		23.3	1.72	1336.9	2803.9	260	70	2	7.2
Salter C. Bridge	11.58 10.70	5.92	0.71	1136.5	1908.6	116.7	581	0	6.7
Salter C. Control		5.41	0.35	1237.1	2777.5	122.9	696	0	6.6
NR High Bridge	14.63 10.73	4.9	0.31	912.8	1788.8	81.32	284	1.9	9.7
NR High Control		.87	.08	1050.8	1346.4	79.9	264	2	9
Ocean I. Bridge	15.24 9.85	1.95	0.16	838.7	808.9	145.6	129	21	7.9
Ocean I. Control		2.36	0.31	539.7	893.5	137.1	104	16	6.6
Bogue I. Bridge	19.81 11.13	0.5	0.06	902.1	1365.4	95.2	221	32	8.6
Bogue I. Control		1.25	0.1	1042	1591.2	86.1	324	55.3	9.6

Table 5. Bridges listed in order of height. Asterisks indicate significant differences at p<.05 between mean data collected under and to the outside of bridges over years 2000 and 2001.

Bridge	**Height**	**Soil C%**	**Soil N%**	**Above ground biomass g/m^{-2}**	**Below ground biomass g/m^{-2}**	**Stem height (cm)**	**Stems/ m^{-2}**	**Flowers/ m^{-2}**	**Basal area /m^{-2}**
Wrightsville	5.85	*		*	*	*	*	*	*
NR Low	7.32	*			*		*		
New Bern	8.53			*	*	*	*	*	*
Salter C.	11.58				*		*		
NR High	14.63								
Ocean I.	15.24								
Bogue I.	19.81						*	*	

Table 6. Bridges listed by height-width ratio. Asterisks indicate significant differences at p<.05 between mean data collected under and to the outside of bridges over years 2000 and 2001.

Bridge	**HW Ratio**	**Soil C%**	**Soil N%**	**Above ground biomass g/m^{-2}**	**Below ground biomass g/m^{-2}**	**Stem height (cm)**	**Stems/ m^{-2}**	**Flowers/ m^{-2}**	**Basal area /m^{-2}**
Wrightsville	0.28	*		*	*	*	*	*	*
New Bern	0.51			*	*	*	*	*	*
NR Low	0.68	*			*		*		
Salter C.	1.08				*		*		
NR High	1.36								
Ocean I.	1.55								
Bogue I.	1.78						*	*	

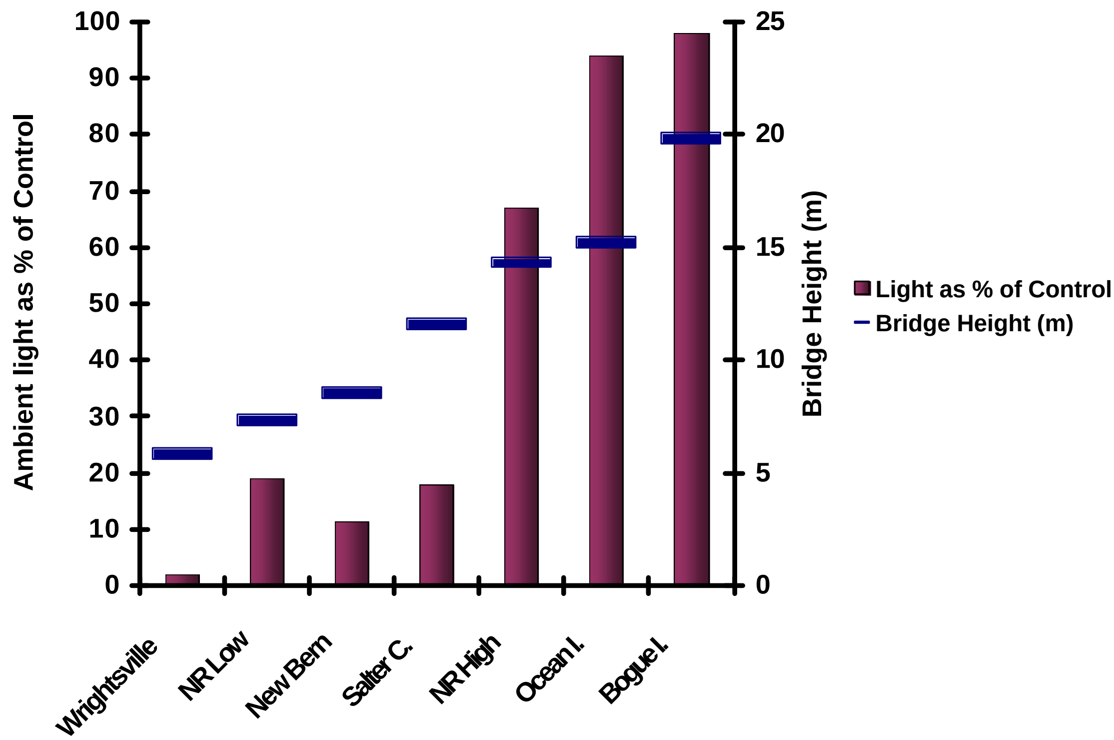

Figure 2. Representation of light data collected under bridges during July of 2000 as percentage of sunlight outside the influence of the bridge. Means at each ocation based on n=5 measurements.

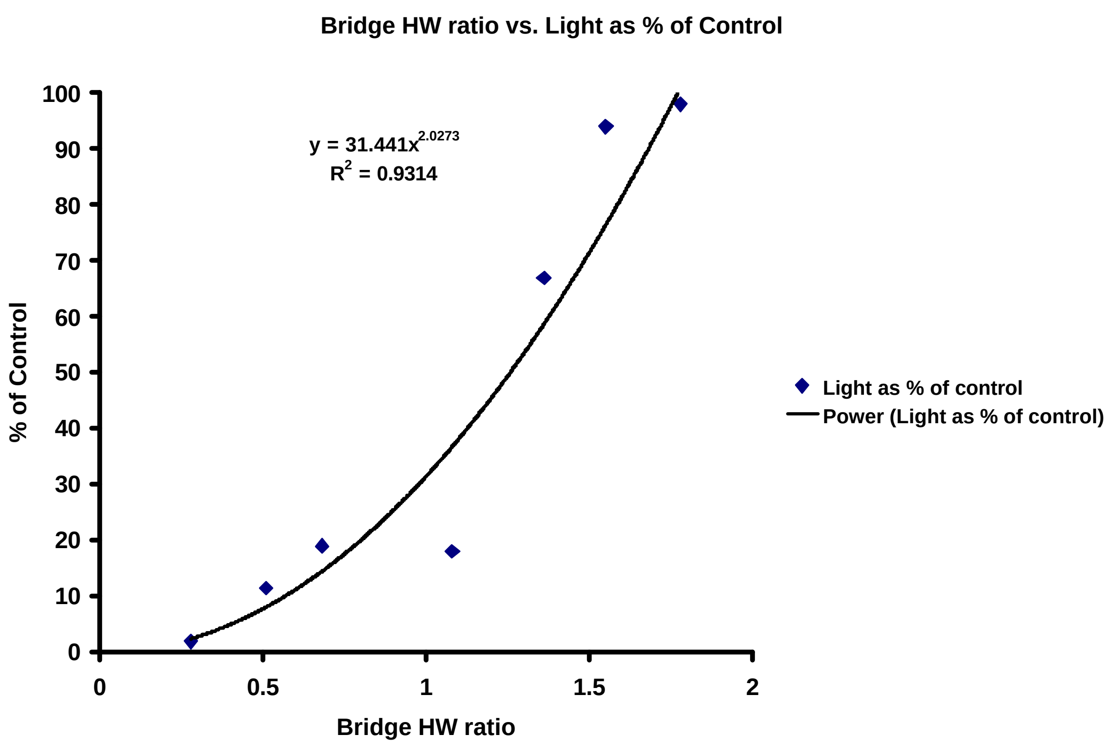

Figure 2.A. Regression analysis of percentage of ambient light reaching areas under bridges as a function of the bridges HW ratio.

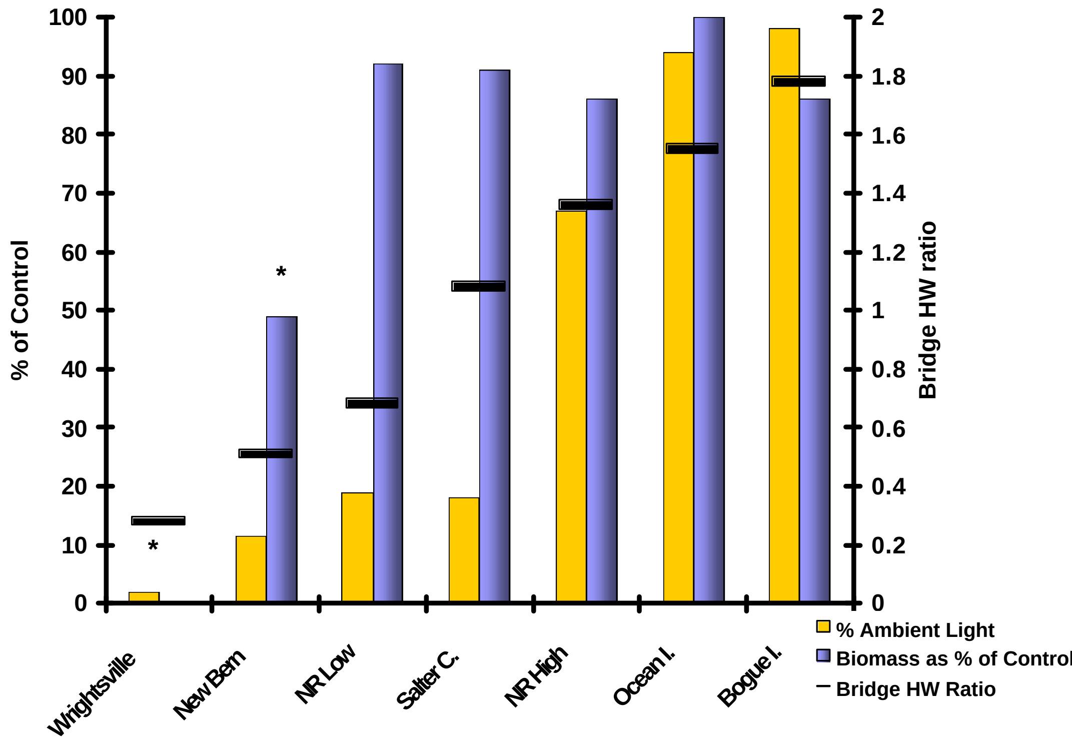

Figure 3. Comparison of ambient light and mean above-ground biomass represented as a percentage of the control at each bridge. Bridges are in order of increasing HW ratios. Asterisks indicate significant differences in biomass between areas under and outside influence of bridges at p<.05.

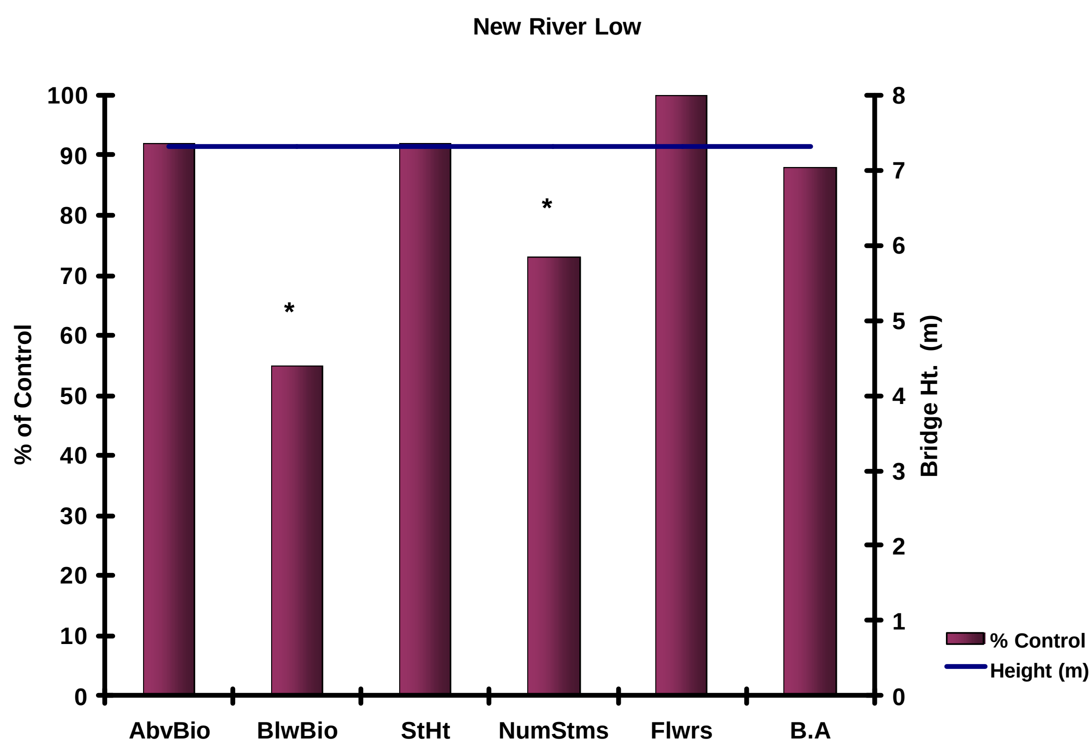

Figure 4. Mean plant growth measurements under the bridge for the years 2000 and 2001 expressed as a percentage of the control. Asterisks indicate significant differences between areas under and outside the influence of the bridge, p<.05. AbvBio = aboveground biomass, BlwBio = belowground biomass, StHt = average stem height, NumStms = number of stems, Flwrs = number of flowers, B.A = basal area.

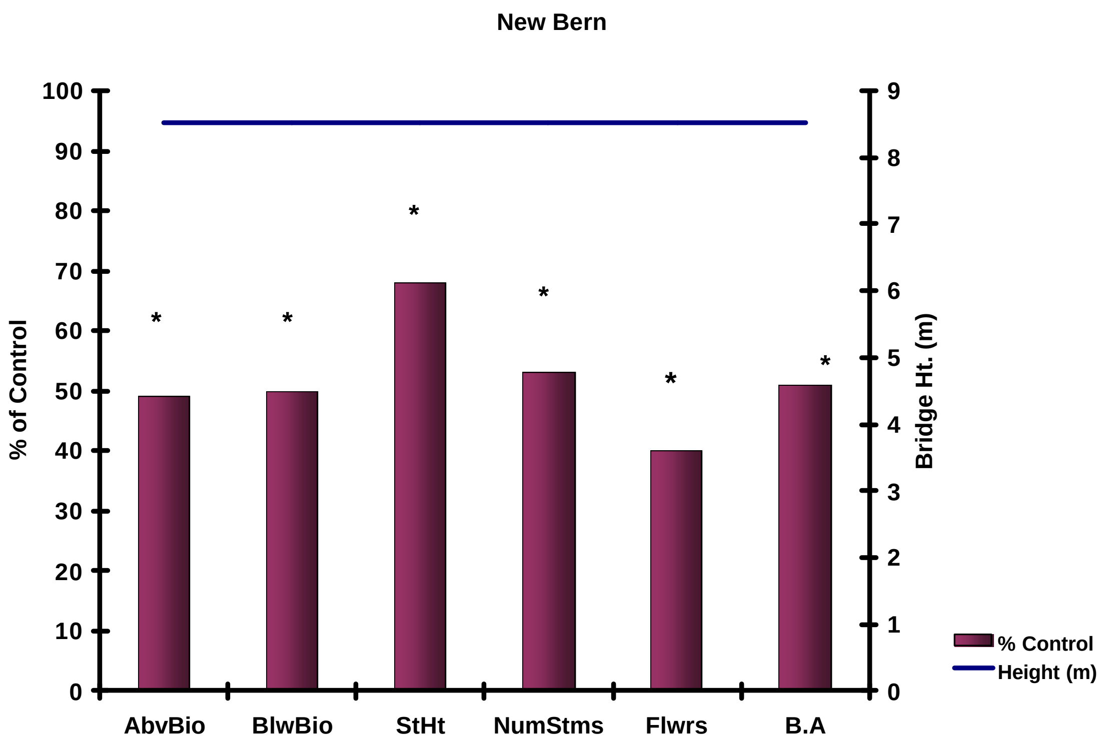

Figure 5. Mean plant growth measurements under the bridge for the years 2000 and 2001 expressed as a percentage of the control. Asterisks indicate significant differences between areas under and outside the influence of the bridge, $p<.05$. AbvBio = aboveground biomass, BlwBio = belowground biomass, StHt = average stem height, NumStms = number of stems, Flwrs = number of flowers, B.A = basal area.

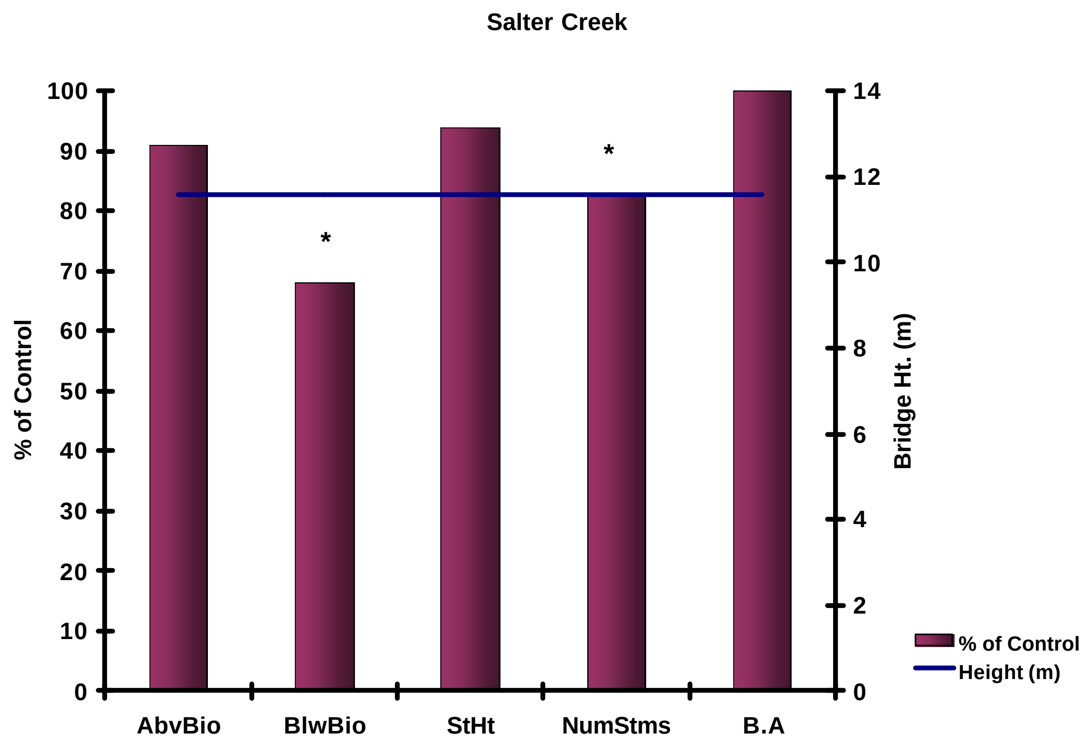

Figure 6. Mean plant growth measurements under the bridge for the years 2000 and 2001 expressed as a percentage of the control. Asterisks indicate significant differences between areas under and outside the influence of the bridge, p<.05. AbvBio = aboveground biomass, BlwBio = belowground biomass, StHt = average stem height, NumStms = number of stems, B.A = basal area.

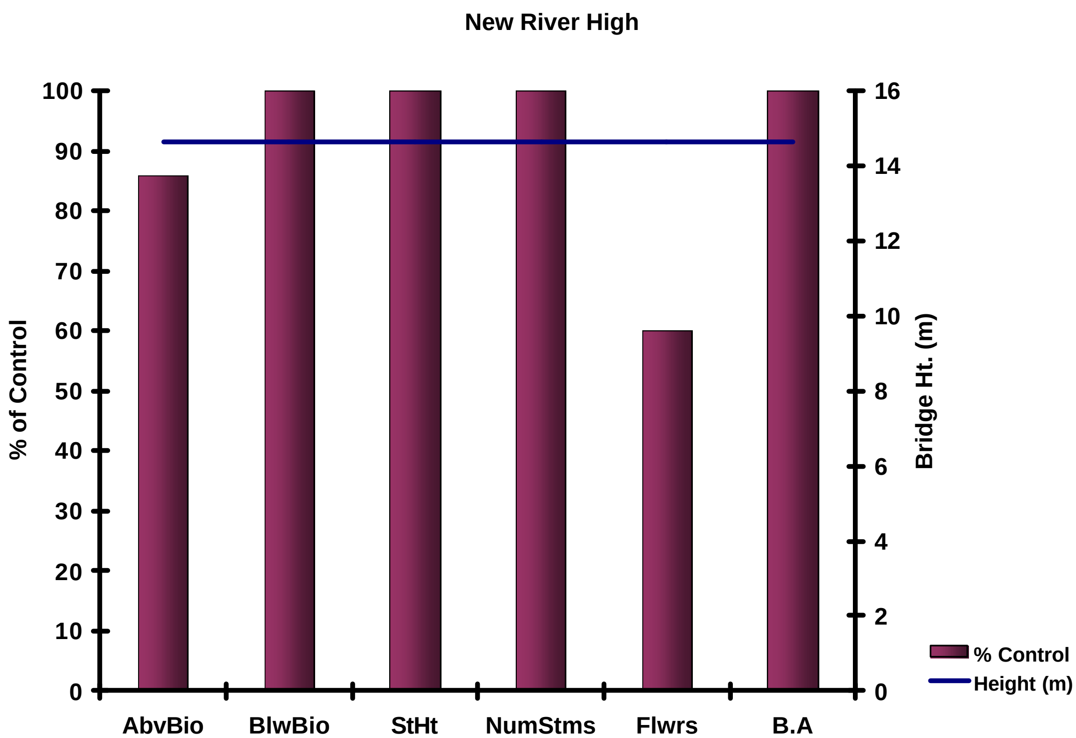

Figure 7. Mean plant growth measurements under the bridge for the years 2000 and 2001 expressed as a percentage of the control. Asterisks indicate significant differences between areas under and outside the influence of the bridge, p<.05. AbvBio = aboveground biomass, BlwBio = belowground biomass, StHt = average stem height, NumStms = number of stems, Flwrs = number of flowers, B.A = basal area.

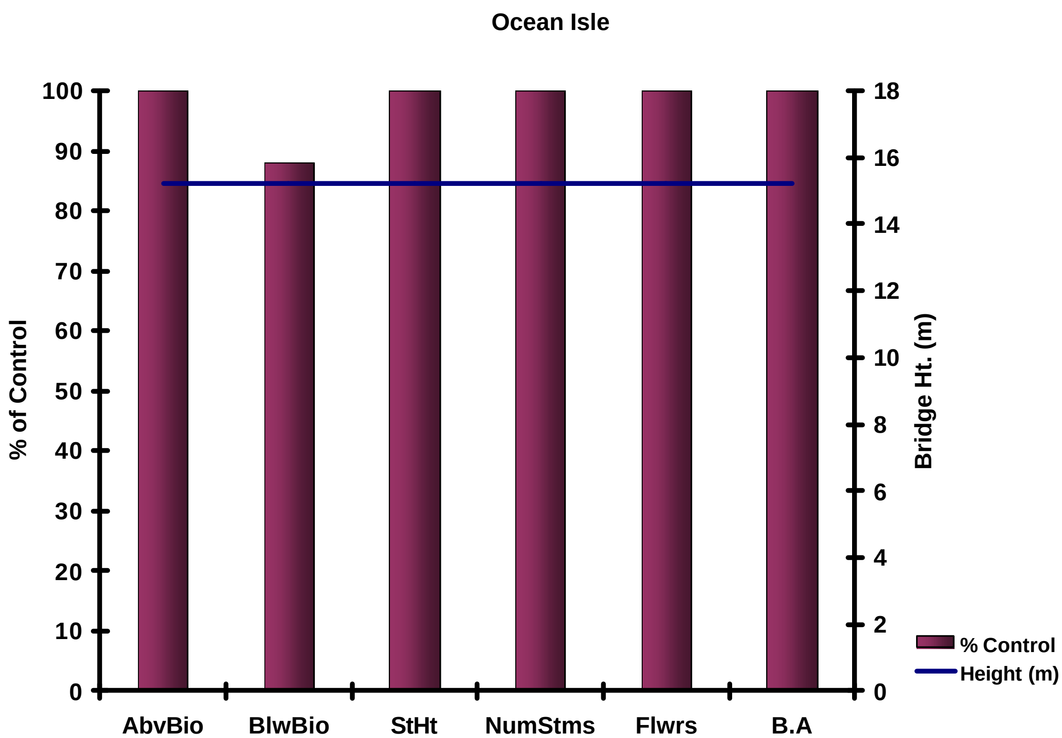

Figure 8. Mean plant growth measurements under the bridge for the years 2000 and 2001 expressed as a percentage of the control. Asterisks indicate significant differences between areas under and outside the influence of the bridge, $p<.05$. AbvBio = aboveground biomass, BlwBio = belowground biomass, StHt = average stem height, NumStms = number of stems, Flwrs = number of flowers, B.A = basal area.

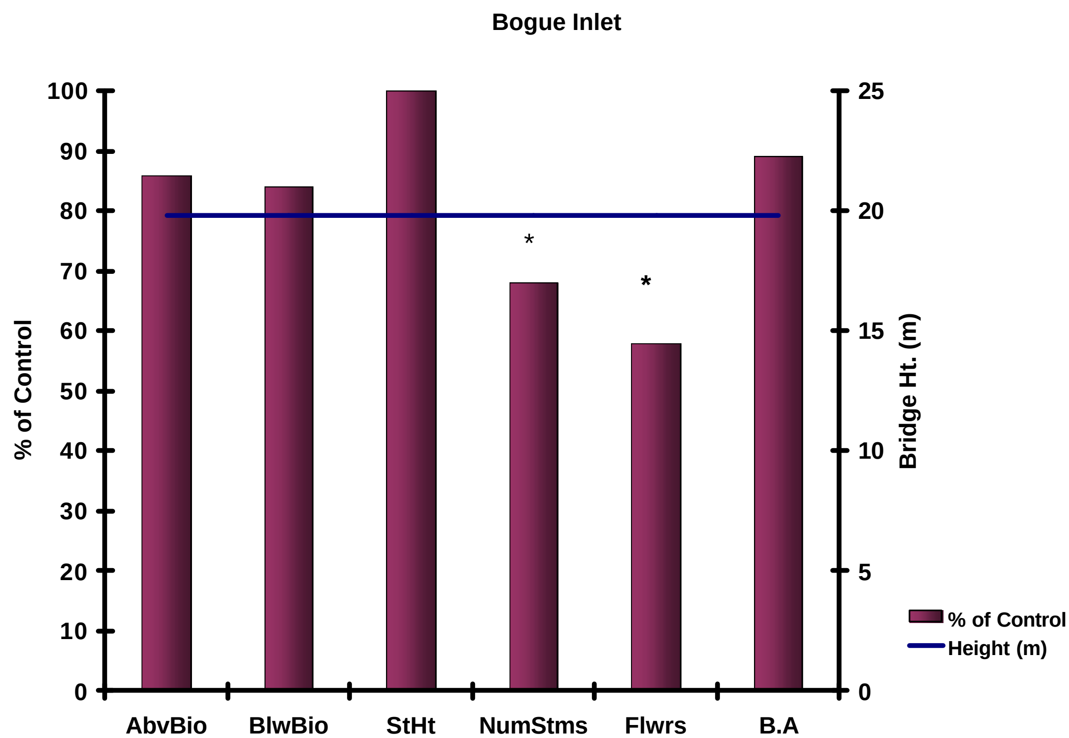

Figure 9. Mean plant growth measurements under the bridge for the years 2000 and 2001 expressed as a percentage of the control. Asterisks indicate significant differences between areas under and outside the influence of the bridge, $p<.05$. AbvBio = aboveground biomass, BlwBio = belowground biomass, StHt = average stem height, NumStms = number of stems, Flwrs = number of flowers, B.A = basal area.

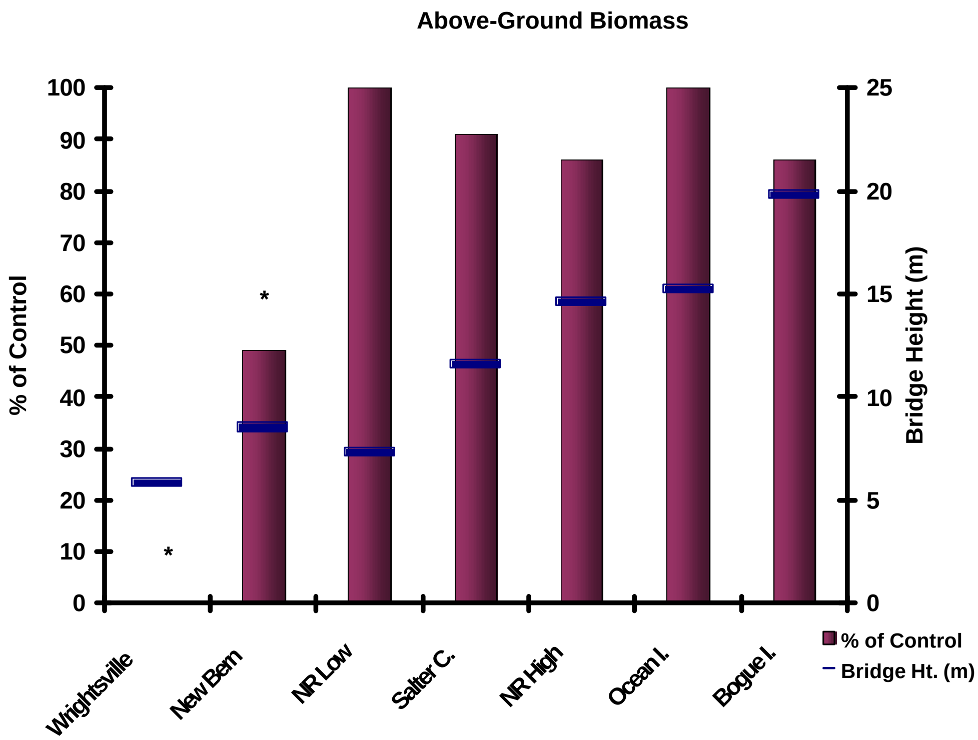

Figure 10. Mean aboveground biomass from years 2000 and 2001 expressed as a percentage of the control across seven bridges of varying heights. Asterisks indicate significant differences between areas under and outside the influence of the bridges, p<.05.

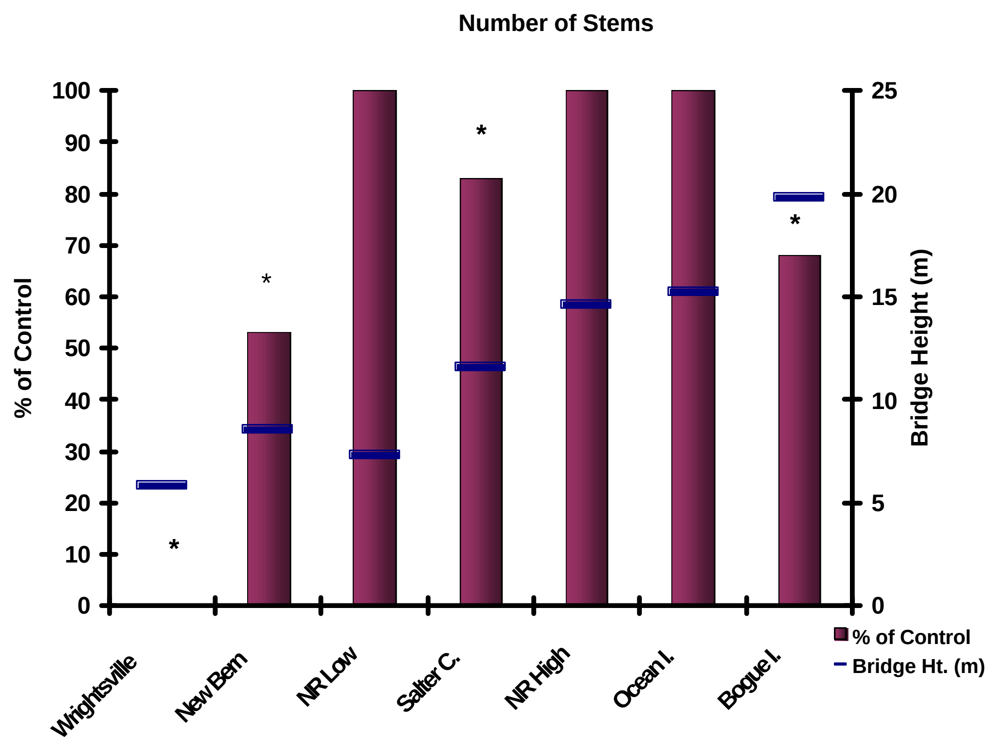

Figure 11. Mean number of stems from years 2000 and 2001 expressed as a percentage of the control across seven bridges of varying heights. Asterisks indicate significant differences between areas under and outside the influence of the bridges, p<.05.

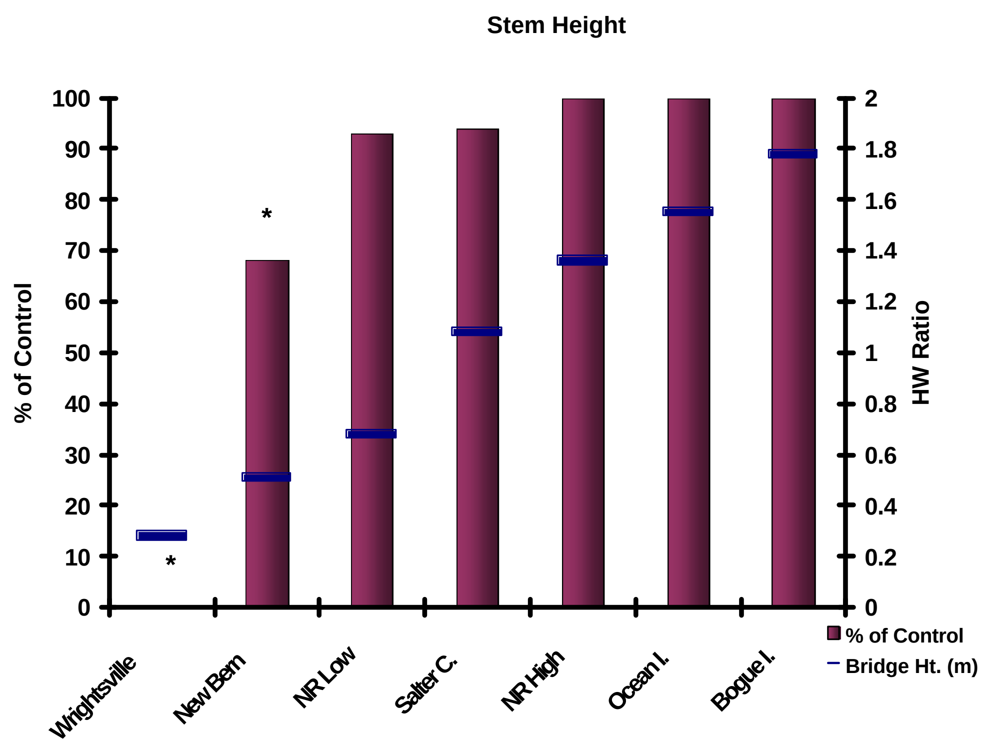

Figure 12. Mean stem height from years 2000 and 2001 expressed as a percentage of the control across seven bridges of varying heights. Asterisks indicate significant differences between areas under and outside the influence of the bridges, $p<.05$.

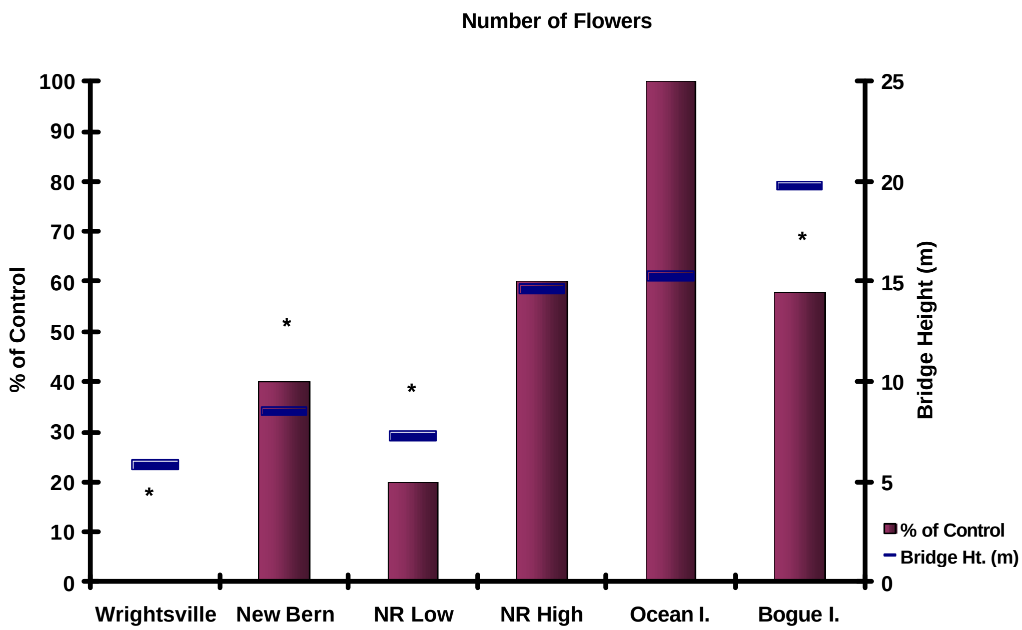

Figure 13. Mean number of flowers from years 2000 and 2001 expressed as a percentage of the control across seven bridges of varying heights. Asterisks indicate significant differences between areas under and outside the influence of the bridges, p<.05.

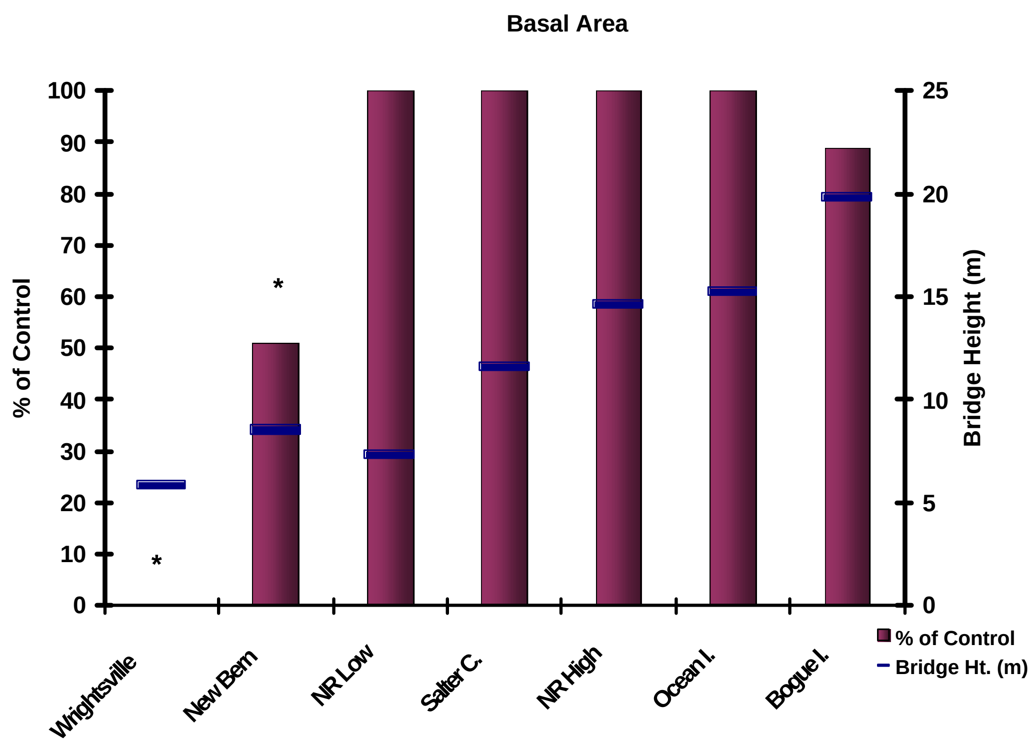

Figure 14. Mean basal area from years 2000 and 2001 expressed as a percentage of the control across seven bridges of varying heights. Asterisks indicate significant differences between areas under and outside the influence of the bridges, p<.05.

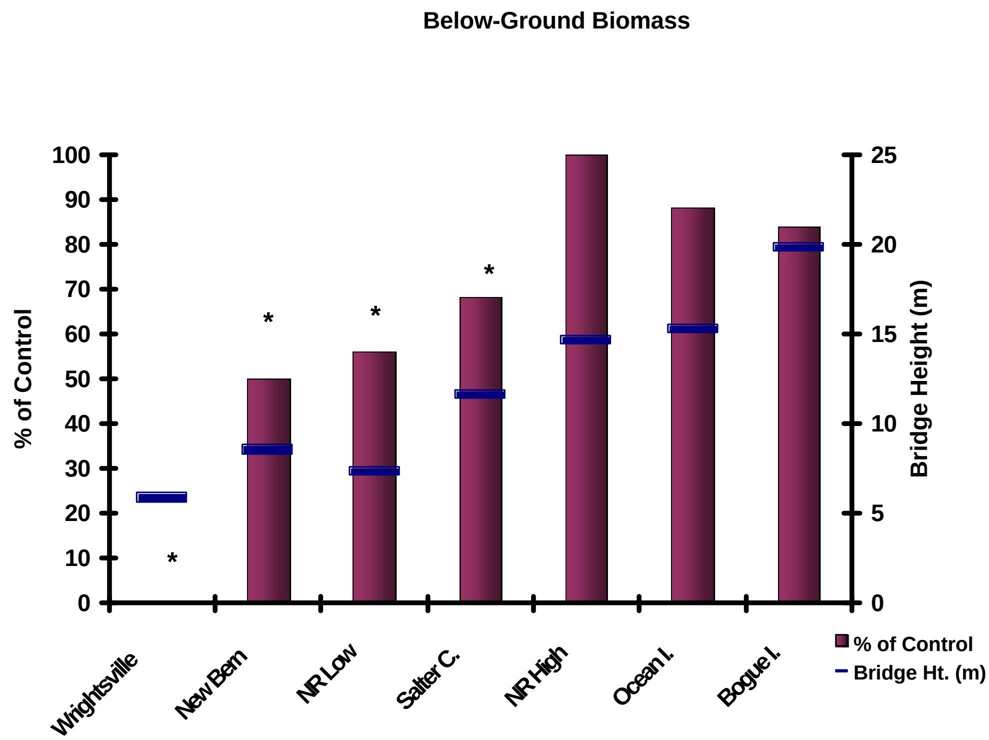

Figure 15. Mean belowground biomass from years 2000 and 2001 expressed as a percentage of the control across seven bridges of varying heights. Asterisks indicate significant differences between areas under and outside the influence of the bridges, p<.05.

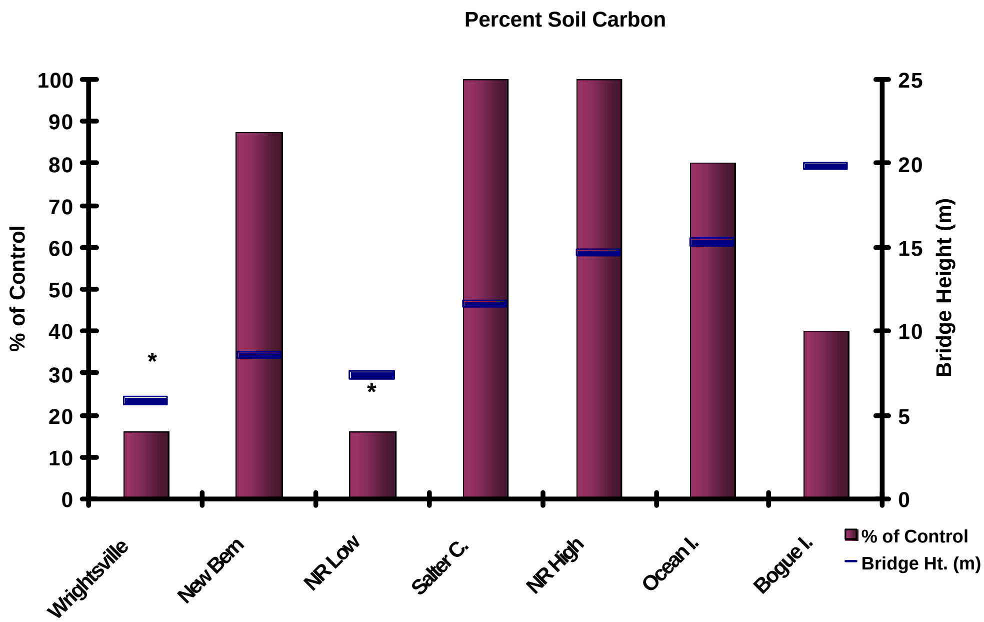

Figure 16. Mean soil carbon from years 2000 and 2001 expressed as a percentage of the control across seven bridges of varying heights. Asterisks indicate significant differences between areas under and outside the influence of the bridges, p<.05.

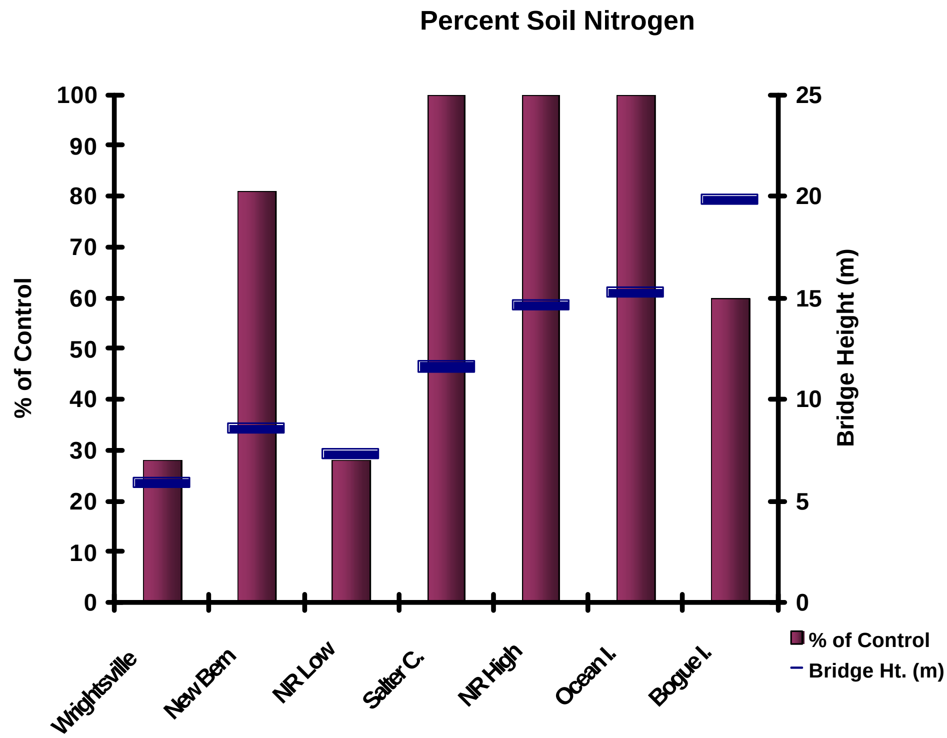

Figure 17. Mean soil nitrogen from years 2000 and 2001 expressed as a percentage of the control across seven bridges of varying heights. Asterisks indicate significant differences between areas under and outside the influence of the bridges, p<.05.

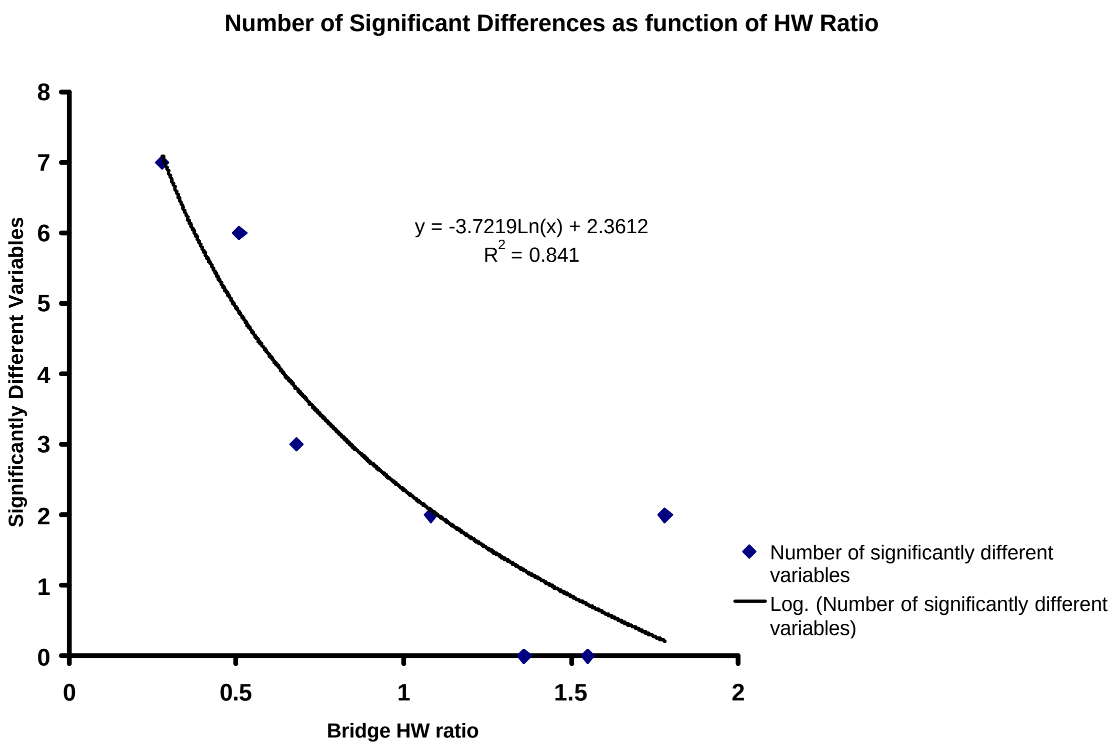

Figure 18. Regression analysis of decline in number of significant differences between variables under and outside influence of bridge as a function of bridge HW ratio.

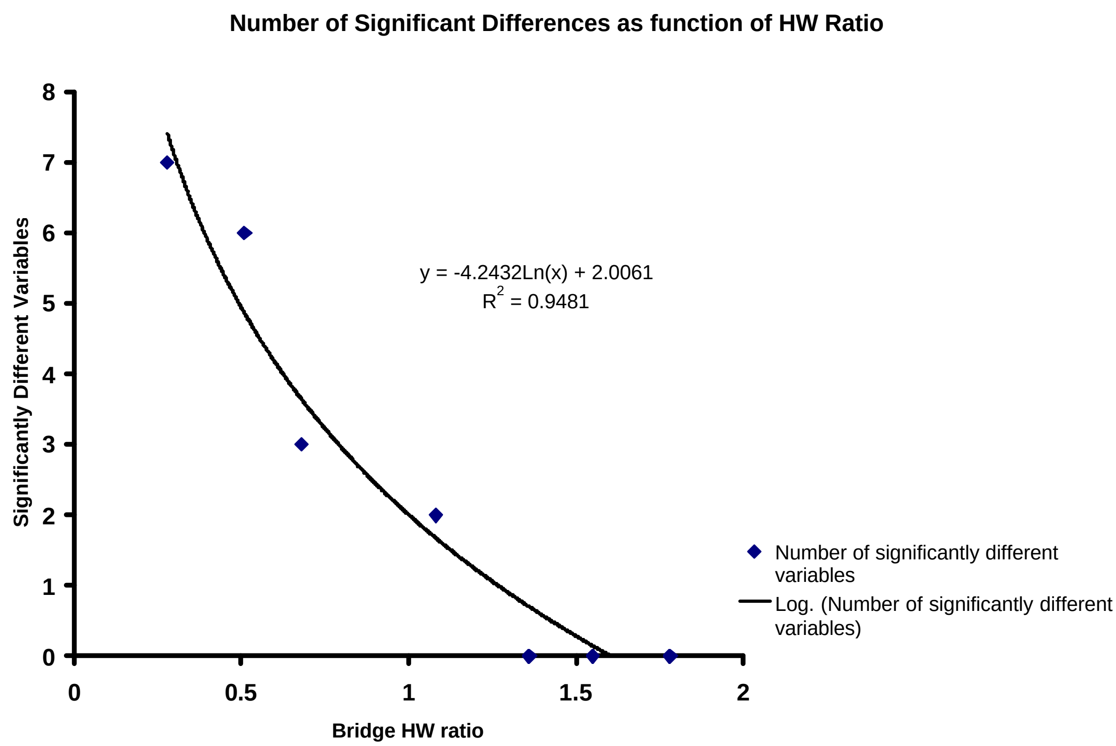

Figure 19. Regression analysis of number of significant differences between variables under and outside influence of bridge as a function of bridge HW ratio.

APPENDIX

Seedling Growth Experiment

Data from the Cedar Island seedling growth experiment is presented in table 1.A. No statistical analysis was performed due to the poor survival rate of the seedlings planted. Mortality rates were 100% in many of the blocks planted. The extremely high mortality rates encountered in the study have been attributed to hydrologic conditions at Cedar Island. Many of the planting blocks were completely submerged at the time of harvest and had not allowed for plant growth. Other planting blocks had been placed at slightly higher elevations resulting in insufficient water for seedling growth. Data from the surviving plants is presented in table 1.A.

Light, Plant and Soils Data

Light data was collected at the Cedar Island Bridge on July 22nd 2000. Light sampling was conducted using hand held Apogee Quantum sensors under twelve of the sixteen bridge sections (Figure 1.A). Light data collected at Cedar Island exhibits similar patterns as the other bridges sampled. The lowest of the sections sampled had a HW ratio of 0.29, light attenuation under the bridge was 0.9% of the control and only 18 umol $m^{-2}s^{-1}$. At these light levels no vegetation was present under the bridge. At a HW ratio of 0.66 PPFD under the bridge was 235 umol $m^{-2}s^{-1}$, although this is only 15.7 % of the light present outside the influence of the bridge aboveground biomass was greater than 70% of the control. Furthermore, the number of stems m^{-2} and basal area m^{-2} were greater than 90% of the control. Average stem height (cm) was also 75% of the control. Larger differences were found in below ground biomass gm^{-2} and percent soil C and N (Table 2.A). This data parallels the diminished bridge effect seen at the New Bern site, which had a similar HW ratio of 0.68.

At a height of 15.5 meters and HW ratio of 1.55 light attenuation under the bridge was 90.1% of the control. Aboveground biomass was 96 % of the control and both stems m^{-2} and flowers m^{-2} exceeded the control (Table 2.A). Soil C and N were only 56% of the control suggesting that construction practices may have disturbed the soils under the influence of the bridge.

Summary

Data collected at Cedar Island Bridge demonstrates similar patterns collected at other bridge locations. At extremely low bridge HW ratios (<0.30) light attenuation under the influence of the bridge is insufficient to support vegetative growth. At an HW ratio of 0.66 a slight bridge effect was found, while at HW ratios greater than 0.7 no measurable differences were found that can be attributed to shading by the Cedar Island Bridge.

Table 1.A. Cedar Island seedling growth experiment data.

Bridge Section	Plot	Plant	Height (cm)	Number of Stems	Weight (g)	Species
1	B	1	0	0	0	N/A
1	B	2	0	0	0	N/A
1	B	3	30	2	1	J
1	B	4	0	0	0	N/A
1	B	5	0	0	0	N/A
1	B	6	50	6	2	A
1	B	7	0	0	0	N/A
1	B	8	35	3	1	J
1	B	9	50	3	3	A
1	E	1	0	0	0	N/A
1	E	2	54	11	10	A
1	E	3	0	0	0	N/A
1	E	4	40	2	1	J
1	E	5	0	0	0	N/A
1	E	6	60	13	10	C
1	C	1	60	7	4	A
1	C	2	67	31	18	A
1	C	3	44	22	12	A
1	C	4	52	23	6	A
1	C	5	34	9	2	J
1	C	6	60	8	3	J
1	C	7	45	7	1	J
1	C	8	40	20	5	C
1	C	9	17	3	2	C
2	B	1	75	25	9	A
2	B	2	0	0	0	N/A
2	B	3	0	0	0	N/A
2	B	4	70	6	5	A
2	B	5	0	0	0	N/A
2	B	6	0	0	0	N/A
2	B	7	0	0	0	N/A
2	B	8	0	0	0	N/A
2	B	9	0	0	0	N/A
2	E	1	0	0	0	N/A
2	E	2	50	21	15	N/A
2	E	3	30	4	1	J
2	E	4	60	4	3	C
2	E	5	32	5	1	J
2	E	6	50	2	1	C
2	C	1	55	10	9	A
2	C	2	45	16	9	A

Table 1.A continued.

Bridge Section	Plot	Plant	Height (cm)	Number of Stems	Weight (g)	Species
2	C	3	35	1	1	J
2	C	4	35	4	1	J
2	C	5	50	33	13	A
2	C	6	60	7	5	C
2	C	7	60	10	9	C
2	C	8	60	14	3	J
2	C	9	70	21	17	C
3	B	1	0	0	0	A
3	B	2	0	0	0	N/A
3	B	3	0	0	0	N/A
3	B	4	0	0	0	N/A
3	B	5	0	0	0	N/A
3	B	6	0	0	0	N/A
3	B	7	0	0	0	N/A
3	B	8	0	0	0	N/A
3	B	9	0	0	0	N/A
3	E	1	0	0	0	N/A
3	E	2	0	0	0	N/A
3	E	3	30	2	1	J
3	E	4	0	0	0	N/A
3	E	5	60	9	7	A
3	E	6	34	10	1	J
3	E	7	0	0	0	N/A
3	E	8	60	20	10	A
3	E	9	0	0	0	N/A
3	C	1	0	0	0	N/A
3	C	2	35	9	1	J
3	C	3	40	3	1	C
3	C	4	50	14	4	J
3	C	5	0	0	0	N/A
3	C	6	0	0	0	N/A
3	C	7	0	0	0	N/A
3	C	8	0	0	0	N/A
3	C	9	50	18	4	J
4	B	1	30	6	3	A
4	B	2	0	0	0	N/A
4	B	3	0	0	0	N/A
4	B	4	40	3	1	J
4	B	5	70	17	16	A
4	B	6	0	0	0	N/A
4	B	7	0	0	0	N/A

Table 1.A continued.

Bridge Section	Plot	Plant	Height (cm)	Number of Stems	Weight (g)	Species
4	B	9	40	9	1	J
4	E	1	0	0	0	N/A
4	E	2	50	2	1	A
4	E	3	0	0	0	N/A
4	E	4	0	0	0	N/A
4	E	5	60	9	5	A
4	E	6	55	3	1	J
4	E	7	30	3	1	A
4	E	8	0	0	0	N/A
4	E	9	0	0	0	N/A
4	C	1	40	12	2	J
4	C	2	30	3	1	A
4	C	3	60	5	3	A
4	C	4	0	0	0	N/A
4	C	5	0	0	0	N/A
4	C	6	0	0	0	N/A
4	C	7	40	1	1	C
4	C	8	37	2	1	C
4	C	9	0	0	0	N/A

Table 2A. Plant and soil data from Cedar Island bridge.

Location	Sample	Aboveground biomass gm^{-2}	Belowground biomass gm^{-2}	Soil C %	Soil N %	Stems m^{-2}	Average stem height (cm)	Flowers m^{-2}	Basal area m^{-2}
L 3.21m	1	0	0	1.23	0.05	0	0	0	0
L	2	0	0	1.28	0.07	0	0	0	0
L	3	0	0	1.05	0.06	0	0	0	0
L	4	0	0	1.23	0.06	0	0	0	0
L	5	0	0	1.10	0.07	0	0	0	0
L	**Average**	**0**	**0**	**1.17**	**0.62**	**0**	**0**	**0**	**0**
M 6.15m	1	353.7	504.9	1.51	0.12	68	140	0	6
M	2	362.1	610	1.33	0.09	44	143	0	5
M	3	257.4	332.2	2.13	0.16	64	156	4	6
M	4	366.1	210.2	2.04	0.13	56	154	0	6
M	5	329.5	320.9	3.44	0.19	48	173	8	5
M	**Average**	**333.76**	**353.5**	**2.09**	**0.13**	**56**	**153**	**2.4**	**5.6**
T 15.5m	1	572.3	2777.9	4.42	0.29	32	192	8	7
T	2	367.6	2158.5	3.18	0.25	48	209	4	7
T	3	498	1801.9	3.54	0.26	44	212	12	7
T	4	459.1	3134.5	3.08	0.23	32	214	8	6
T	5	476.2	1454.6	3.80	0.28	60	185	8	3
T	**Average**	**474.6**	**2264.9**	**3.60**	**0.26**	**59**	**202**	**8**	**6**
C	1	398.1	2918.7	5.89	0.48	32	220	4	6
C	2	542.72	4210.1	7.02	0.51	48	229	8	7
C	3	512.4	711.3	6.63	0.47	52	212	4	8
C	4	501.2	165.1	6.95	0.50	44	243	4	8
C	5	499.8	4371.5	5.58	0.42	48	242	0	7
C	**Average**	**490.8**	**2475.3**	**6.4**	**.47**	**44.8**	**229**	**4**	**7.2**

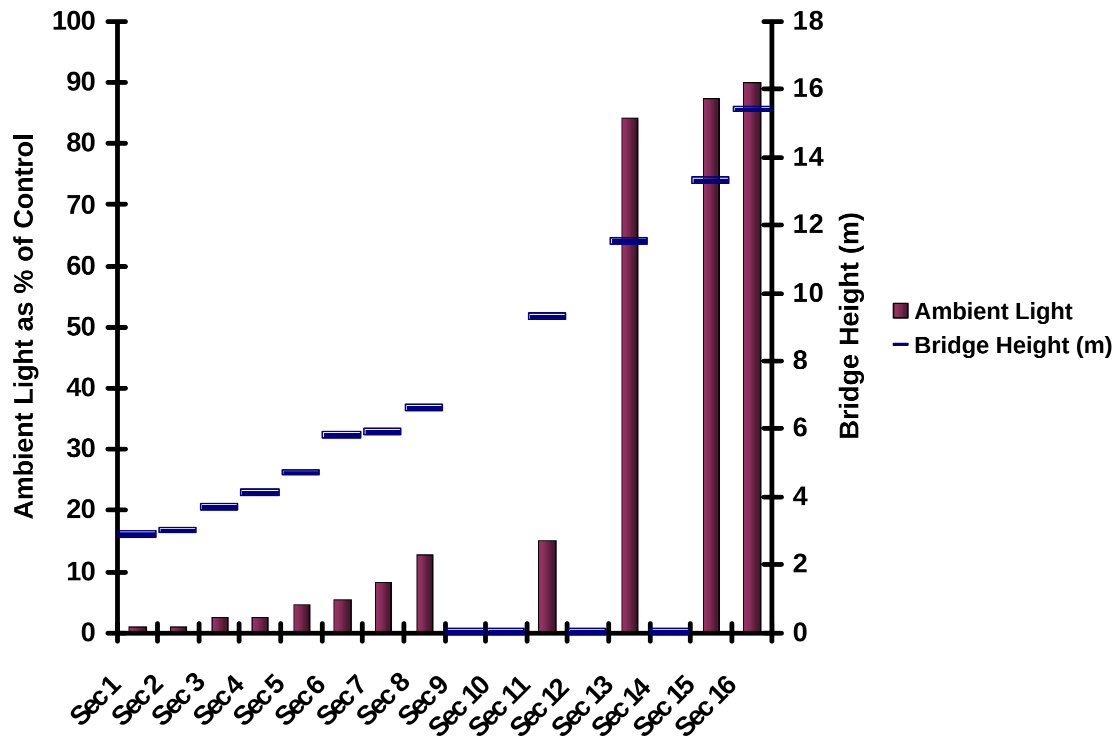

Figure 1.A. Representation of light data collected under Cedar Island bridge as a percent of sunlight outside the influence of the bridge.

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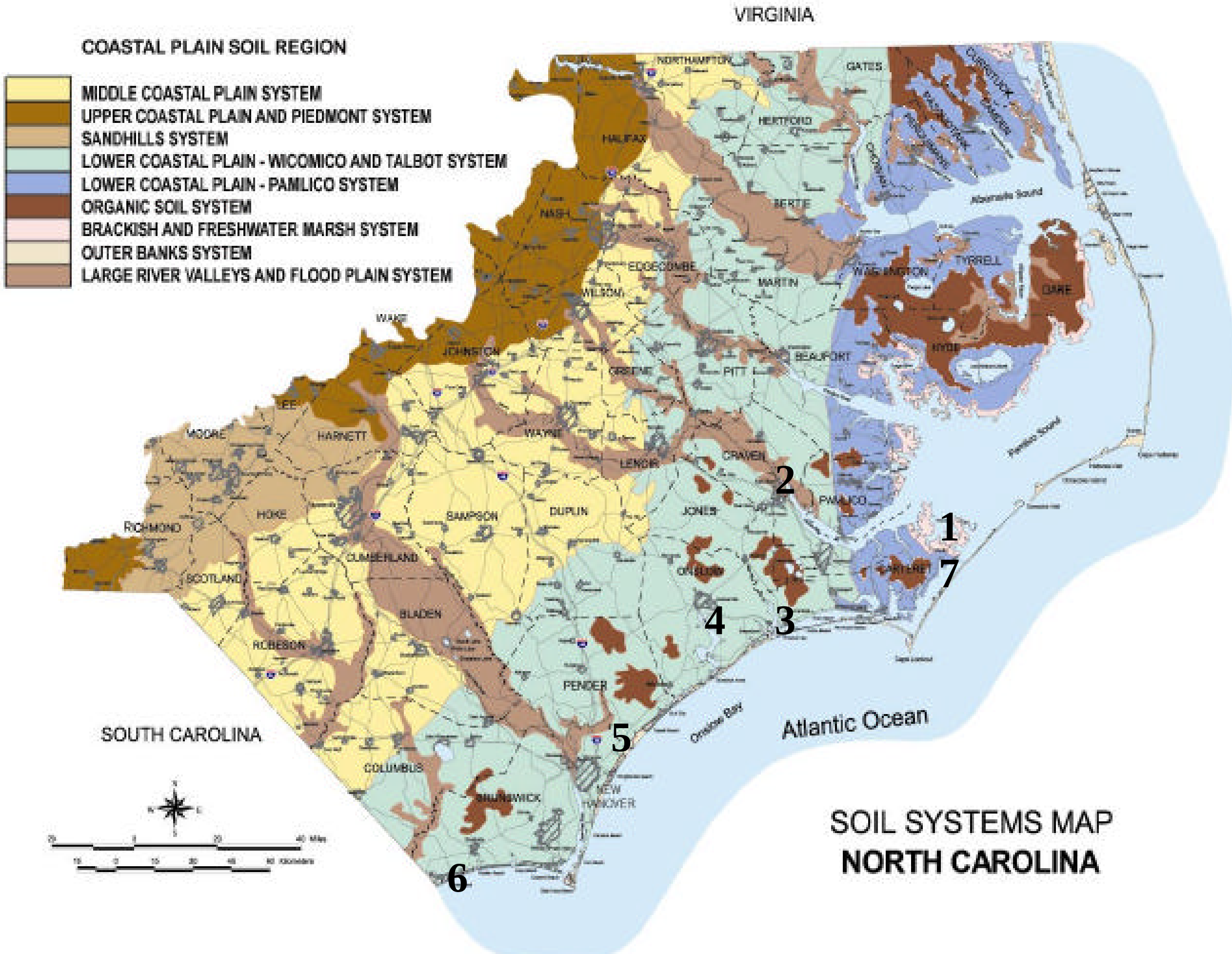

Figure 20. Bridges selected for study. 1=Cedar Island, 2=New Bern, 3=Bogue Inlet 4=New River, 5=Wrightsville Beach, 6=Ocean Isle, 7=Salter Creek.