GIS and Field-Based Analysis of the Impacts of Recreational Docks on the Saltmarshes of Georgia

Final Report

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Abstract

Population pressure along the Georgia coast has greatly increased the number of docks that extend across the marsh, impacting marsh ecosystems. To understand the patterns and impacts of dock proliferation, aerial photography and field data were used within a geographic information system (GIS) to quantify the number of docks and the area of docks affecting marsh. Digitizing the perimeter of docks, we created maps showing the footprint of docks from 1970 to 2000 on Wilmington Island, GA. These maps document a 90% increase in total dock area (24,048 m^2 in 1970 to 45,679 m^2 in 2000) and a 73% increase in number of docks during this period (174 docks in 1970 to 301 docks in 2000). Indicators of shading impacts by these docks to the *Spartina alterniflora* marsh (e.g., variation in stem density and plant height) were quantified during the summer of 2003. We established 56 transects beneath 52 docks, sampling beneath and 5m adjacent to the docks with a 0.1 m^2 quadrat. Average stem density was 56% lower beneath docks than adjacent to docks and paired data were statistically different. Plant height was not significantly different beneath or adjacent to docks. Although existing dock structures only shade 0.5% of the marsh surrounding Wilmington Island, approximately 1% of the marsh may eventually be shaded assuming current parcel configurations (i.e., no subdividing will occur) and maximum estimates of cumulative impact suggest that 4-6% of the marsh could be shaded under current Georgia law. Although presently unquantified, this shading and stem density reduction may be important for the carbon budget of the marsh, which provides critical habitat for many commercially important species. Additional information needs identified during this study include: an assessment of the potential for and significance of enhanced *Spartina* wrack accumulation around dock structures; a determination of the impact to benthic habitats by floating docks that sit on the bottom at low tide; and a comparative analysis of coastal county dock statistics with the baseline and trend data in this study.

Introduction

The State of Georgia contains approximately 162,000 hectares of salt and brackish water marsh along its 160-kilometer coast (Kundell et al., 1988). The majority of saltmarsh lies in a band about 6 to 10 kilometers wide between the barrier islands and the mainland. The ecological significance of these tidal marsh areas is immense and has been well documented in scientific literature (Weigert, Pomeroy and Wiebe, 1981; Teal, 1962, 1969; Weinstein, 1996). Saltmarsh vegetation and habitat provide a critical base to the complex nutrient food cycle of the coastal ocean and estuaries of the southeast (Adam, 1990; Weigert, Pomeroy and Wiebe 1981; Weinstein, 1996; Teal, 1962, 1969). Georgia's saltmarshes are among the most biologically productive habitats on earth and serve important functions for the health and longevity of shellfish and finfish populations (Pfeiffer and Weigert, 1981; Teal, 1962, 1969). Saltmarsh vegetation also plays a critical role in the purification of water, reduction of storm wave impact, and absorption of floodwaters (Vernberg, 1996). Understanding anthropogenic impacts to these environments is extremely important for management and conservation of coastal resources.

Private, recreational docks spanning saltmarsh are an increasingly common feature throughout Georgia's coastal landscape. The Coastal Resource Division (CRD) of the Georgia Department of Natural Resources (GADNR) is the regulatory agency responsible for issuing recreational dock permits to private landowners. Under current law, property owners of tidal shoreline in Georgia are able to apply for a revocable license from the GADNR-CRD to obtain a recreational dock construction permit. Based on the Public Trust Doctrine of law, the state of Georgia owns the lands beneath the waters subject to the ebb and flow of the tide in trust for the benefit of all people (West, 1998; GADNR, 2004). CRD has observed significant increases in recreational dock permit requests over the last several years, as well as increases in the total area of structures being requested (GADNR). However, no quantitative data existed to document trends in dock proliferation over the past several decades. As stewards of the States' coastal resources the GADNR has become increasingly concerned about the individual and cumulative impacts associated with recreational docks.

Management issues related to docks are not limited to Georgia. The topic of docks and piers and how they impact saltmarsh ecosystems is of growing interest to coastal resource managers and researchers throughout the country. Coastal resource managers are in need of rational, science-based analyses of dock impacts to guide sound policy decisions. According to a workshop report, Environmental and Aesthetic Impacts of Small Docks and Piers (2003), the authorization to build a dock is now the single most frequently sought permit for coastal managers (Kelty and Bliven, 2003). In November 2000 and January 2003 respectively, workshops specifically focused on the science and management of dock and pier impacts were hosted by the Woods Hole Oceanographic Institute and the University of Massachusetts. Speakers from both workshops recommended that further studies needed to be conducted that would include different latitudinal zones, tidal regimes, and that would examine short-term versus long-term impacts (Kelty and Bliven, 2003).

Although a growing body of data exists documenting the impacts from docks to marsh ecosystems, prior to this study no data were available specifically for Georgia. With the exception of a recent study in South Carolina (Sanger and Holland, 2002) and a

Masters Thesis from Virginia (McGuire, 1990), the majority of research relating to ecological impacts of docks and piers is from the northeastern United States, and does not include settings with conditions similar to those occurring along the southeast U.S. coast. Several researchers have suggested that data be collected in other areas of the coast to establish if the documented impacts of docks on vegetation remain constant for different vegetation types, tidal regimes, and geographic areas (Sanger and Holland, 2002; McGuire, 1990). The Sanger and Holland (2002) study included data from 51 transects beneath 32 docks with vegetation density measurements taken at 2 locations along each transect. Data collected in that study showed a 71% reduction in smooth cordgrass (*Spartina alterniflora*) stem densities beneath docks compared to locations adjacent to docks. The Virginia study (McGuire, 1990) included data from transects located beneath 35 structures with 15 to 17 vegetation density measurements along each transect. Although that study did not calculate the percentage of stem density reduction, Sanger and Holland (2002) used the raw data from McGuire (1990) to calculate the percentage reduction. Data from the McGuire (1990) study documented a 65% reduction in stem densities associated with dock structures. The Connecticut State Department of Environmental Protection conducted a study in 1983 to evaluate the effects of docks on saltmarsh vegetation. This study examined several dock parameters and found dock height to be the most significant variable in limiting vegetation growth (Kearney, Segal and Lefor, 1983). The Virginia study (McGuire, 1990) observed that variation in shade effects were related to the geographic orientation of the boardwalk. However, Sanger and Holland (2002) did not observe a relationship between orientation and stem density reduction.

The effect of shading on salt marsh vegetation is also being studied with reference to bridges over marsh. Struck et al. (2002) are conducting an ongoing study of highway bridges in North Carolina. In this study, light attenuation and height-width ratio are being determined to assess shading. Aboveground biomass, number of stems, number of flowering stems, and basal area sampled at the end of each growing season are being determined to evaluate the productivity of salt marsh (Struck et al., 2002).

This study examines the issues of dock proliferation and marsh impact. Through the use of geographic information systems (GIS) and high-resolution aerial photographs it is possible to quantify the amount of salt marsh being directly covered by docks and piers in Georgia. Incorporating several time periods of aerial photographs into the study allows for display and analysis of the historical change in numbers and sizes of docks and piers within the study area. In the field, characteristics of Spartina alterniflora beneath the docks and piers can be measured and then correlated to the age of the dock structure, to the height/width ratio of the dock at the transect location, and to the directional orientation of the dock. The acquisition of baseline and trend data regarding docks and piers that affect salt marsh habitat is a valuable tool for any decision-making process in coastal management. The techniques developed in this project can be applied to further investigations of these effects throughout Georgia or in surrounding states.

The specific objectives of this study are to:

1) Establish baseline and trend data for recreational dock proliferation between 1970 and 2000 for the study area,
2) Examine temporal trends in the area of docks over saltmarsh vegetation to the total area of docks,

3) Evaluate cumulative versus annualized methods of assessing dock characteristics,

4) Quantify the impact of dock shading on vegetation,

5) Propose additional studies critical to understanding the impact of recreational docks on the saltmarshes of Georgia.

Study Site

Wilmington Island, Georgia, (Figure 1) is a Pleistocene back-barrier island in Chatham County that has experienced substantial residential and commercial growth over the past three decades. In 2000 Wilmington Island had a population of approximately 14,000, a median household income of $58,689 and a median house value of $132,400 (City-Data.com, 2004). The island is surrounded by salt marsh and has an abundance of docks and piers of various ages and sizes. Accurate aerial photographs of Wilmington Island are available from 1970 to 2000 at approximately five-year intervals from the Savannah/ Chatham County Metropolitan Planning Commission.

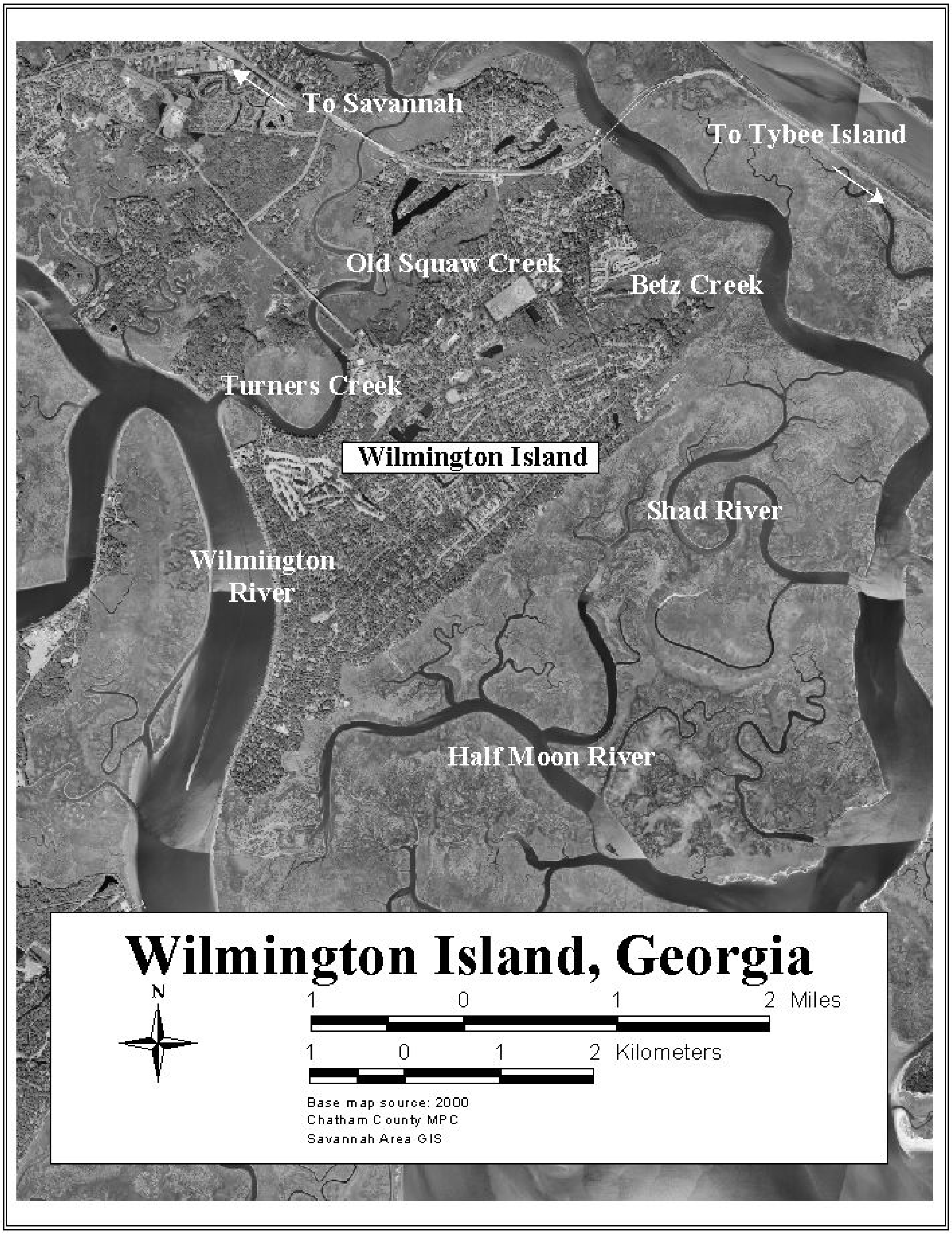

Figure 1 – Map of Wilmington Island, Georgia and associated waterways (2000).

Methods

Two kinds of analytical methods were employed in this study, GIS analysis and field data collection. The majority of GIS work was conducted during the fall of 2002 and spring of 2003 and the majority of fieldwork was conducted during the summer of 2003.

GIS Methods

Base maps were created within a geographic information system (GIS) using ESRI's Arcview 3.2 software and spatial analyst extension. Maps of Wilmington Island, Georgia were constructed using high-resolution (0.3 meter ground resolution cell) panchromatic geo-referenced digital aerial photographs purchased from the Savannah/Chatham County Metropolitan Planning Commission (Figure 1). Data sets for 1997 and 2000 are available in this format. Historic aerial photos of the study area for the years 1970, 1975, 1985, and 1990 were also obtained from the Savannah/Chatham County Metropolitan Planning Commission as scanned blue line copies of large format (approximately 1 m x 1 m) mylar images collected for tax purposes (Figure 2).

All maps created in this study were projected in the Georgia State Plane East coordinate system. Polygon shapefiles were created for each structure by digitizing on-screen the perimeter of all recreational docks present on the 2000 aerial photograph at a scale of 1:200. The data set of docks present in 2000 served as a template for comparison to docks present or absent within the older aerial photographs. Using this technique we were able to move backward through the blue line copies from 1990 to 1970 and assign individual dock polygons into the year set in which they were constructed. Observations

Figure 2 – Example blue line reproduction of pre-1997 aerial photography of Wilmington Island, Georgia. Note significant change in forest cover from this image (1970) and that shown in Figure 1 (2000).

were made in each year set of aerial photographs of docks that were not part of the 2000 template. Several docks exhibited modifications from one year set to another, including additions, subtractions and relocations. For these occurrences revisions were made to the polygons representing that particular year set (Figure 3). A complete shapefile of polygons representing the footprint of recreational docks were created for each year set of aerial photographs. The shapefiles of docks were arranged in the GIS as layers with the oldest year set of docks (1970) located on top and the youngest year set of docks (2000) on the bottom. Each shapefile was represented by different colors so as to be able to quickly observe recreational dock proliferation patterns over time (Figure 4).

Attributes were collected and recorded for each individual dock in each year set. These attributes included a dock identification number, the total area of the dock, the total area over saltmarsh vegetation, the total length of the dock, the total length over saltmarsh vegetation, and the directional orientation of the walkway. A single polygon representing the saltmarsh adjacent to the upland of Wilmington Island that could be potentially affected by structures was also created (Figure 5). The seaward boundary of this polygon was defined as the first waterway encountered with a width greater than 9 m. This criteria was chosen based on a previously proposed, but subsequently tabled policy from DNR-CRD in which riparian owners would be able to wharf out only as far as the first creek 9 m across at low tide (for creeks that have water at all stages of the tide) or from grass edge to grass edge (for creeks that go dry at low tide).

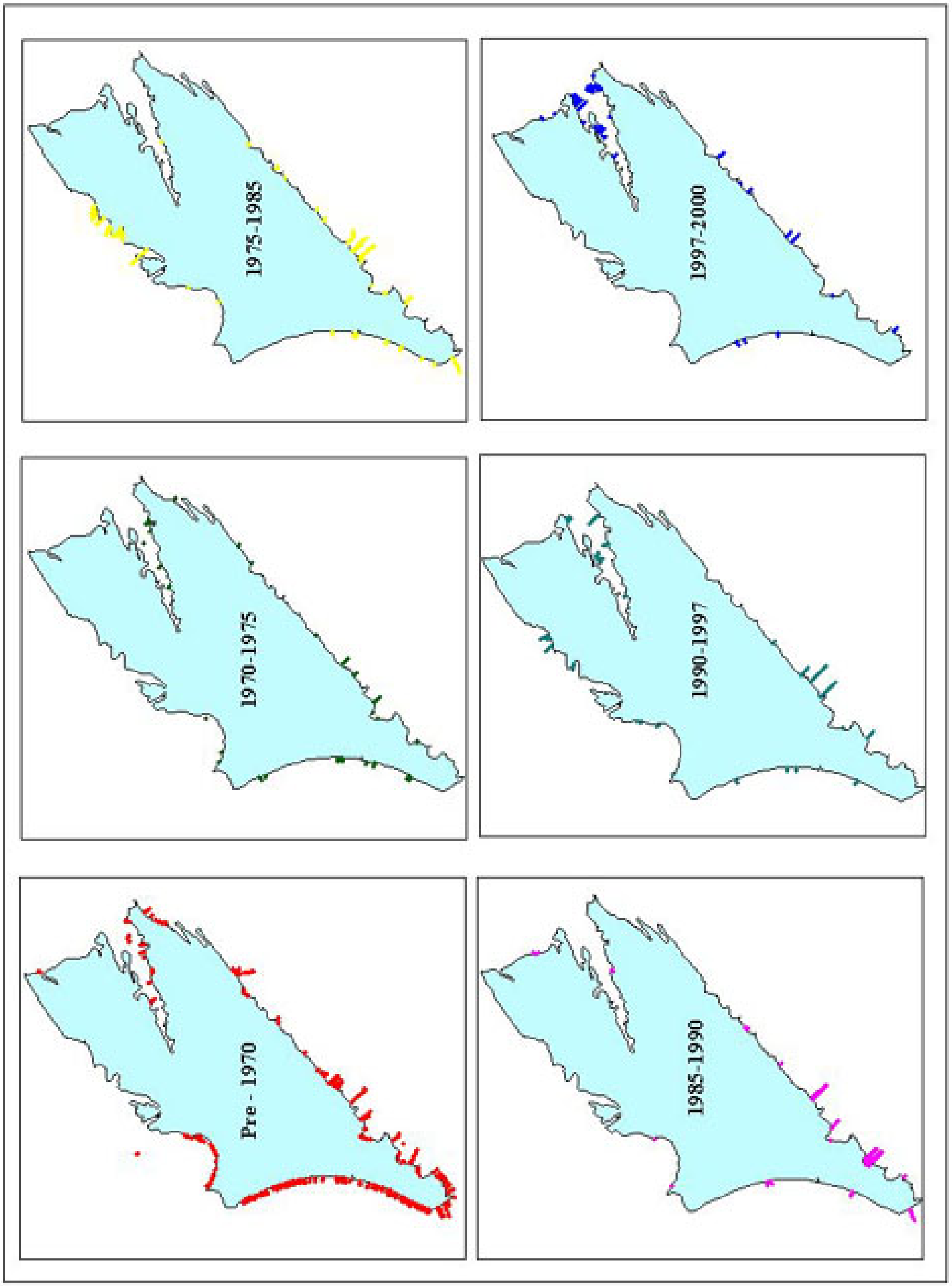

Figure 3 – Docks constructed on Wilmington Island in each year class.

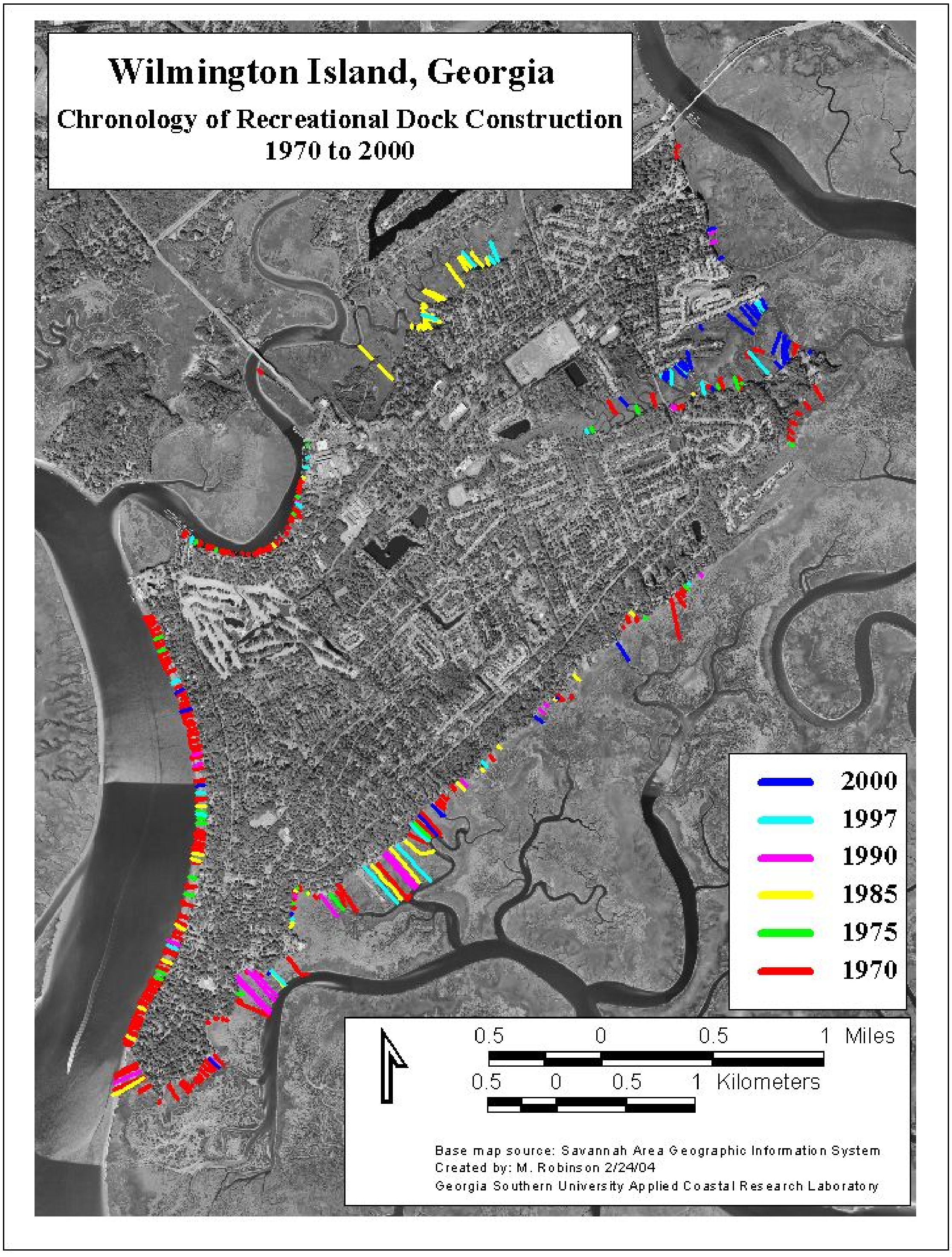

Figure 4 – Chronology of dock construction patterns on Wilmington Island, Georgia between 1970 and 2000.

Polygon shapefiles were generated that represent the dock over marsh footprint for all year sets of data in the study. A point shapefile which displays the location of each vegetation transect in the study area was also created (Figure 6). All shapefiles were stored in the relational database of the GIS software allowing efficient and timely incorporation of new data as it becomes available.

Field Methods

In order to evaluate the impacts to vegetation associated with docks, 56 transects were located below 52 docks to measure characteristics of the saltmarsh cordgrass *Spartina alterniflora* (Figure 6). Docks for the vegetation sampling were selected using a stratified random approach to represent different ages, heights, widths, and directional orientations. The directional orientation of sampled docks was representative of the orientation of the cumulative dock structures (Figures 7, 8).

Transects were established perpendicular to the axis of the boardwalks. Measurement locations were directly below the center of the boardwalk and at locations 5 meters on either side of the boardwalk (Figure 9). A 0.1 m^2 quadrat was used to sample stem density (Figures 10a,b). Location of transect along the dock walkway was measured from the upland to the transect intersection and recorded for mapping purposes. Statistical tests were performed using SPSS SigmaStat software.

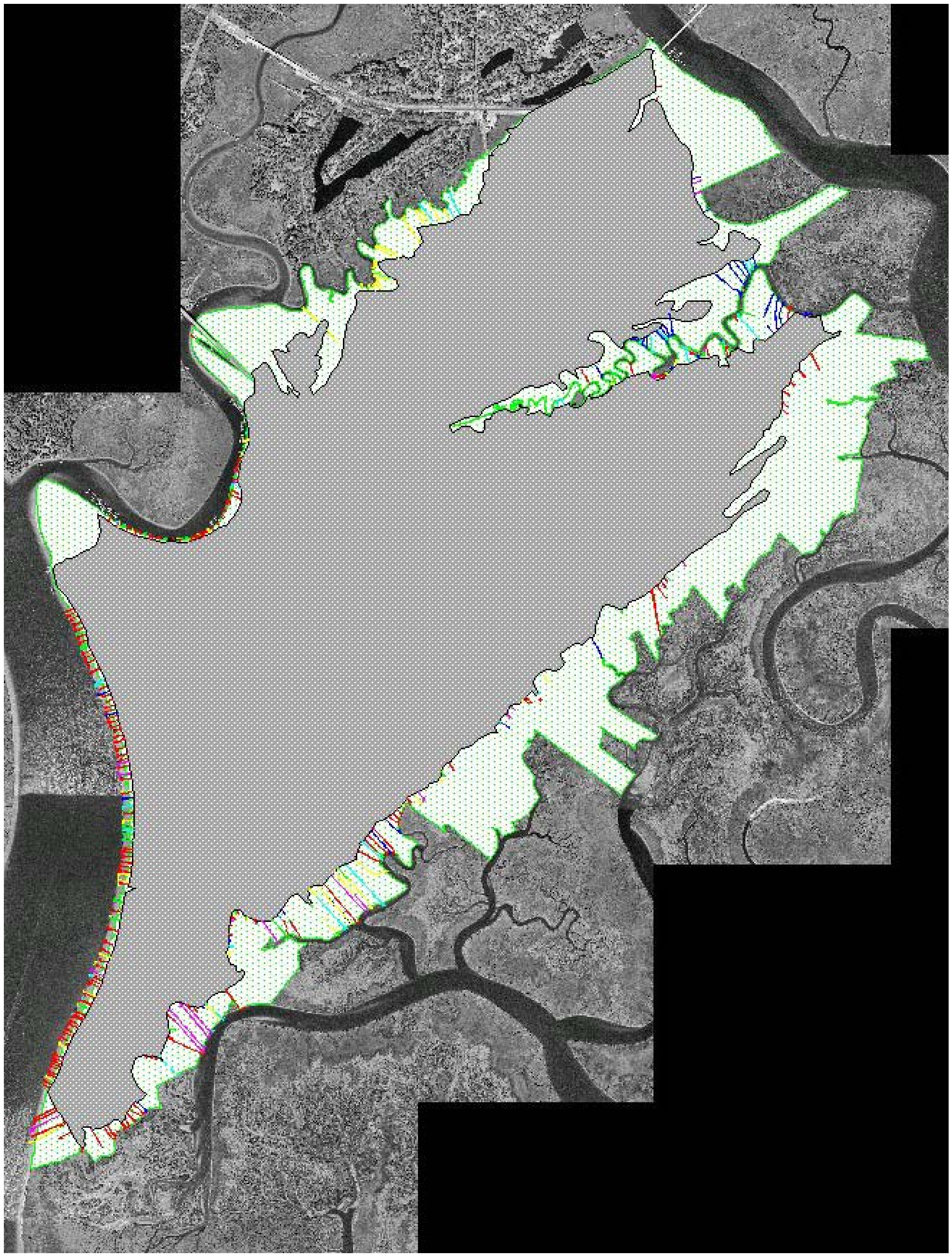

Figure 5 – Polygon representing the area of marsh potentially impacted by dock structures (green stippled pattern; see text for delineation method).

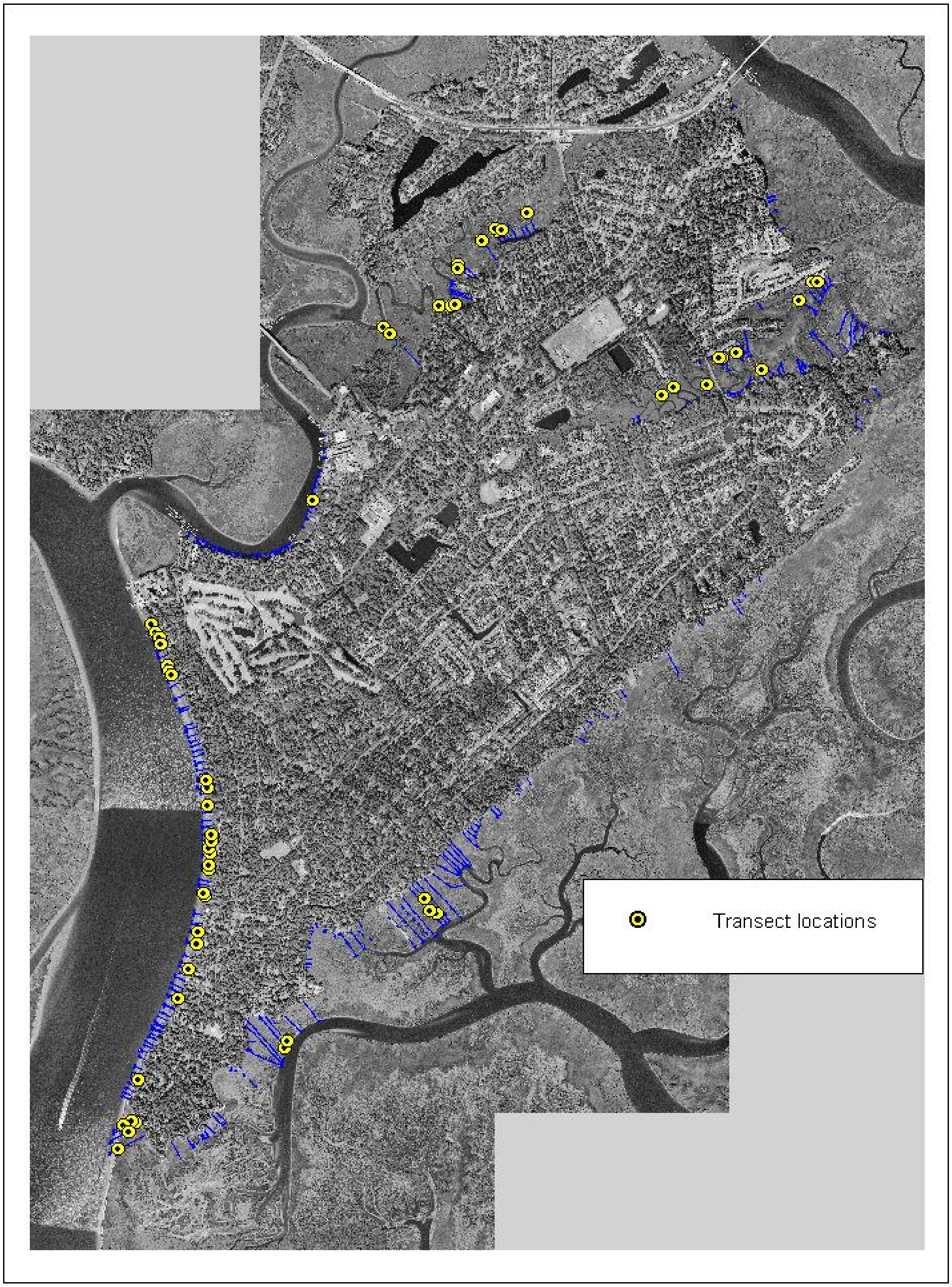

Figure 6 - Location of transects sampled for vegetation and dock characteristics (yellow dots; blues lines represent existing docks in 2000).

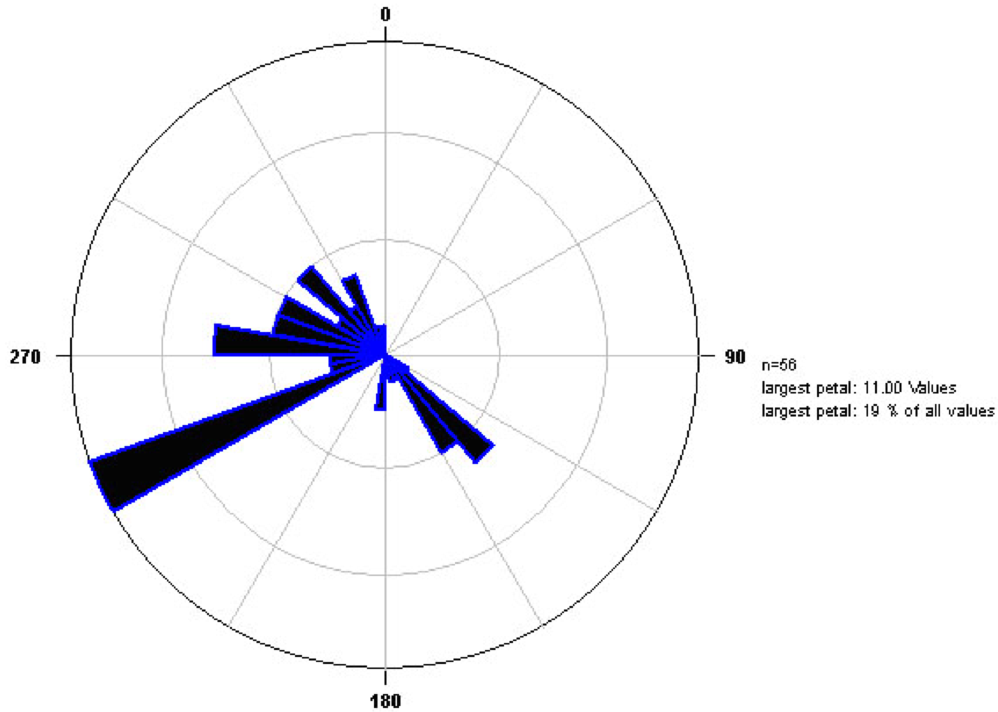

Figure 7 – Rose diagram displaying the directional orientation of the 56 docks sampled in this study.

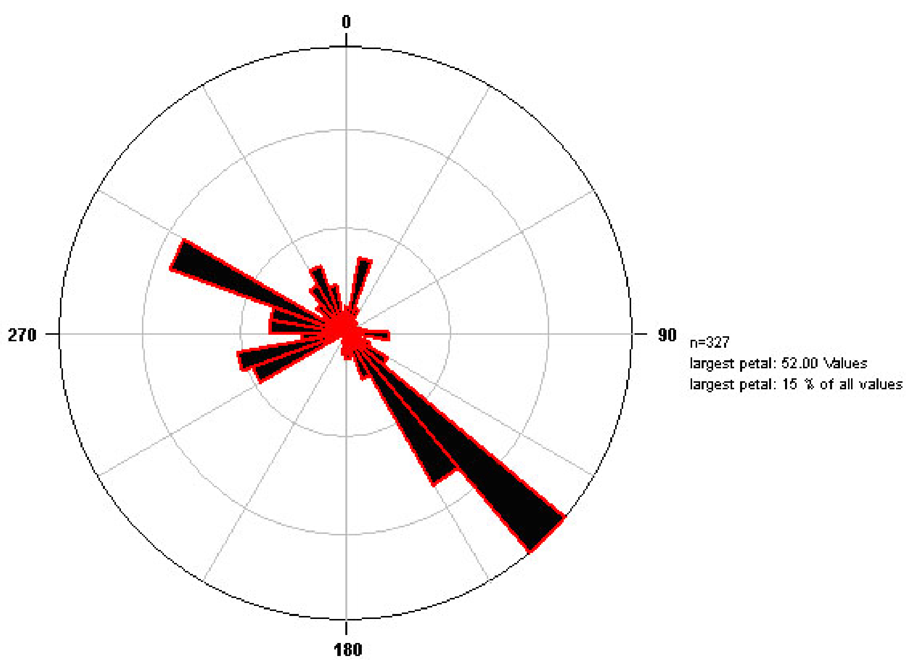

Figure 8 – Rose diagram displaying the directional orientation of all docks in 2000.

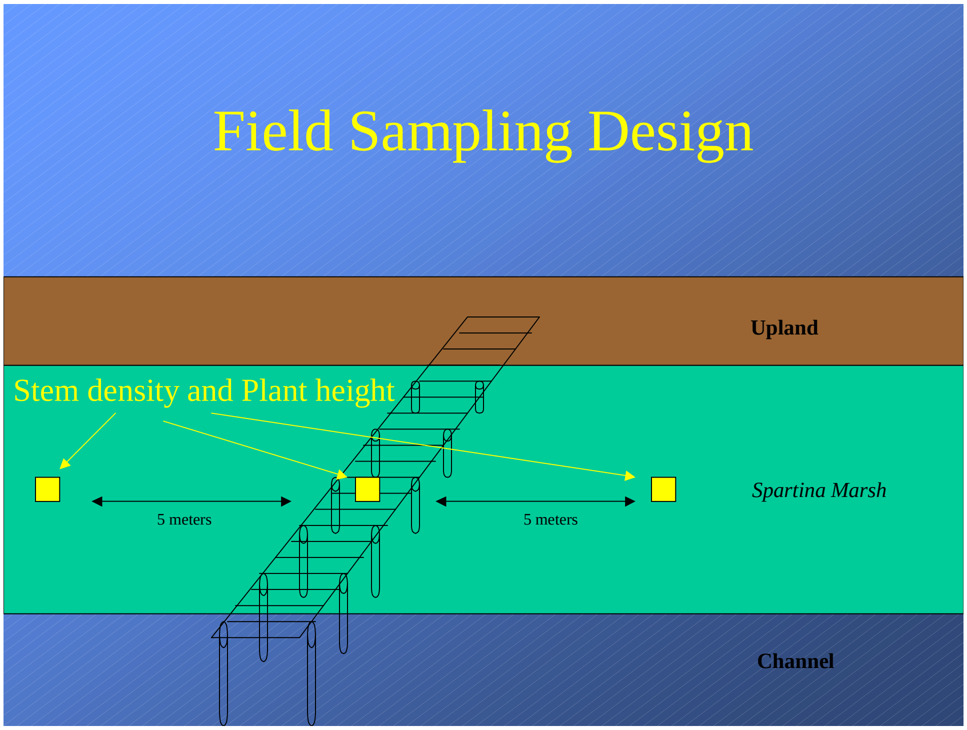

Figure 9 – Sampling design for measuring vegetation characteristics along transect

Figure 10. A) Vegetation transect established below a dock. B) Sampling quadrant in smooth cordgrass

The South Carolina and Virginia studies both used similar techniques for establishing transects and measurement locations (Sanger and Holland, 2002; McGuire 1990). Measurements taken included the location of transects along the boardwalk, number of viable *Spartina* stems and average height of stems in the sampling areas, and the height and width of the dock at the point of transect. All sampling areas were located on the water side of the transect and all foot traffic was on the upland side of the transect. Several docks sampled in the study were accessed from the upland while most were accessed by water. All fieldwork was done during low tide. Many docks were excluded from vegetation measurements due to large accumulations of decaying Spartina wrack (dead stems forming mats) covering the salt marsh (Figure 11).

Figure 11 – Large mats of Spartina wrack trapped by dock pilings.

Also excluded from sampling were docks that had natural drainage channels running beneath or closely adjacent to the structure and docks with construction damage

(Figure 12). Every effort was made to locate transects in areas where the marsh adjacent to the structure was of a similar composition on either side.

Figure 12 – Dock construction scars in adjacent marsh

Results

Data collected for the GIS component of the study were organized and examined in 3 different ways, as cumulative results, in year classes, and per year. Cumulative statistics show the average change of all attributes measured from 1970 to 2000 and incorporate the characteristics of all structures existing prior to the period of study. The year class statistics show only the attributes of docks that were constructed during the period of the classification. Per year data are based on the year class statistics divided by the number of years in the class to obtain an average. Seven docks were measured in the field for length and width of dock over salt marsh and later compared with 4 digitized polygons for each dock in order to calculate the percentage of error incurred while digitally mapping the docks. An 8% error was calculated between the digitized and physically acquired measurements.

Cumulative Measures

The cumulative number of recreational docks on Wilmington Island increased 73% with 174 docks present in 1970 and 301 docks present in 2000, exhibiting an average increase of 2.4% per year. The cumulative total area of recreational docks increased 90% from 24,048 m^2 in 1970 to 45,679 m^2 in 2000, for an average increase of 3% per year (Table 1, Figure 13). Looking at all data cumulatively, the ratio of dock area over saltmarsh to total dock area has increased 5%, up from 48% in 1975 to 53% in 2000 (Table 2, Figure 14). The cumulative ratio includes the measurements of all docks built pre-1970.

Year Class Measures

The average number of docks built each year in each classification period remains relatively constant from 1970 to 1997; there was an increase in the number of docks built per year in the three years from 1997 to 2000 (Table 3, Figure 15). The average individual dock area increased between 1970 and 1990, showed a sharp rise in the 1985-1990 year class and has decreased slightly between 1990 and 2000 (Table 3, Figure 15). The average length of dock boardwalk over saltmarsh vegetation decreased from 1970 to 1975, increased from 1975 to 1990, and decreased from 1990 to 2000. (Table 4, Figure 16). The percentage of dock area over marsh to total area has been quite variable between year classes, ranging from 49 to 71% (Table 5, Figure 17).

Table 1: Cumulative Number of Docks and Total Area

Year	1970	1975	1985	1990	1997	2000
Number of Docks	174	193	225	236	270	301
Area (m^2)	24,048	23,961	29,847	34,256	40,168	45,679

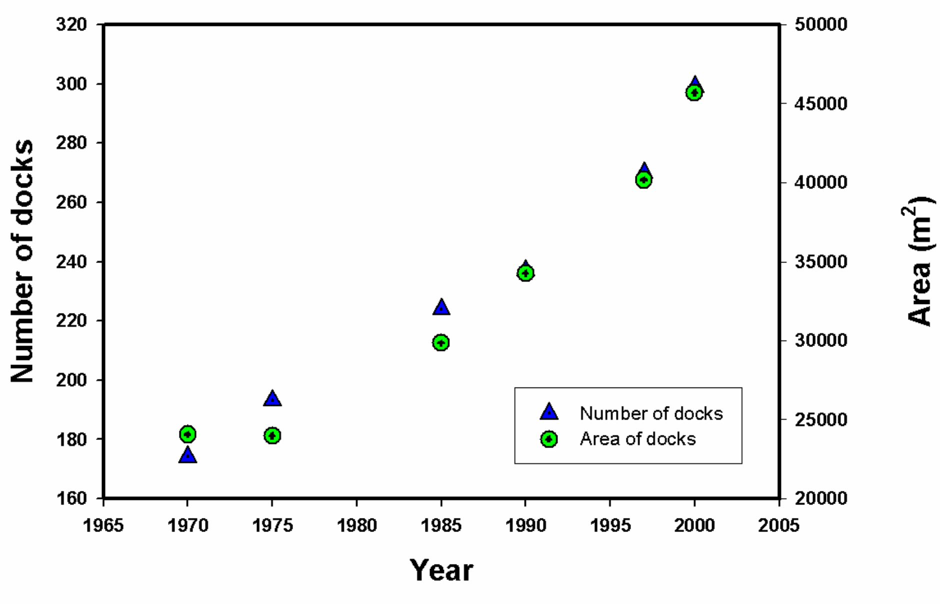

Figure 13 – Cumulative number of docks and total area. Note that the number of docks and area increase similarly.

Table 2: Cumulative Total Area and Cumulative Area over Salt Marsh

Year	1970	1975	1985	1990	1997	2000
Total Area (m^2)	24,048	23,961	29,847	34,256	40,168	45,679
Area over Marsh (m^2)	12,143	11,532	14,677	17,324	21,142	24,021
% over marsh	50%	48%	49%	51%	53%	53%

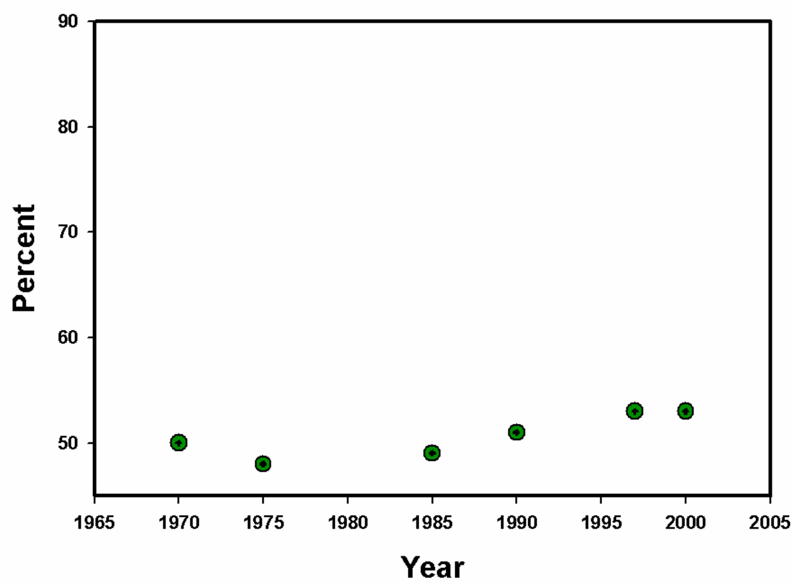

Figure 14 – Cumulative percentage of dock area over marsh to total dock area.

Table 3: Number of docks and area built and average area per dock in each year class

Year Class	Number of Years	Number of New docks built	Area built in year class (m^2)	Average number of docks built per year	Average area per dock (m^2)
1970-1975	5	30	3,422	6	114
1975-1985	10	46	6,702	4.6	146
1985-1990	5	24	4,857	4.8	202
1990-1997	7	27	5,089	3.9	188
1997-2000	3	31	5,668	10.3	183

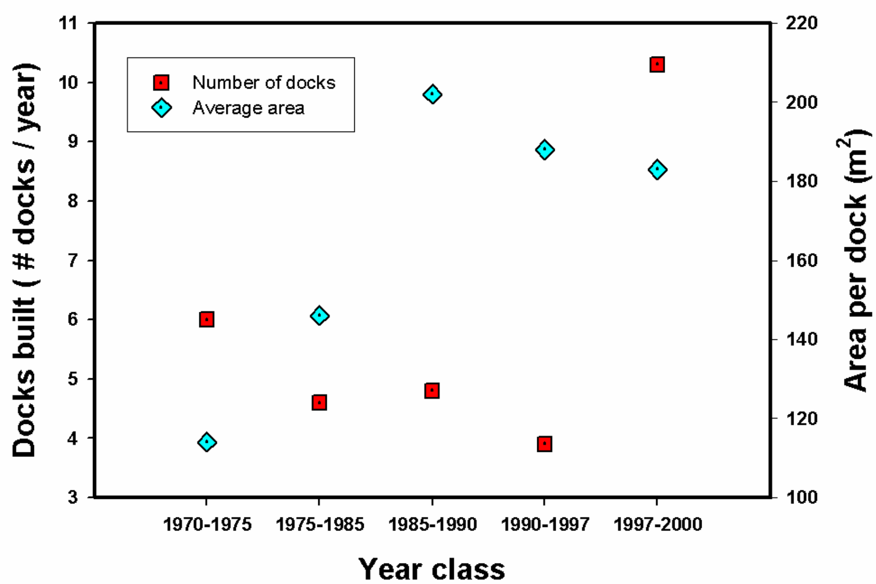

Figure 15 – Average number of docks and average area per dock per year in each class.

Table 4: Mean length of docks over saltmarsh vegetation per year class

Year Class	1970	1970-1975	1975-1985	1985-1990	1990-1997	1997-2000
Mean Length (m)	42	35	76	107	86	81

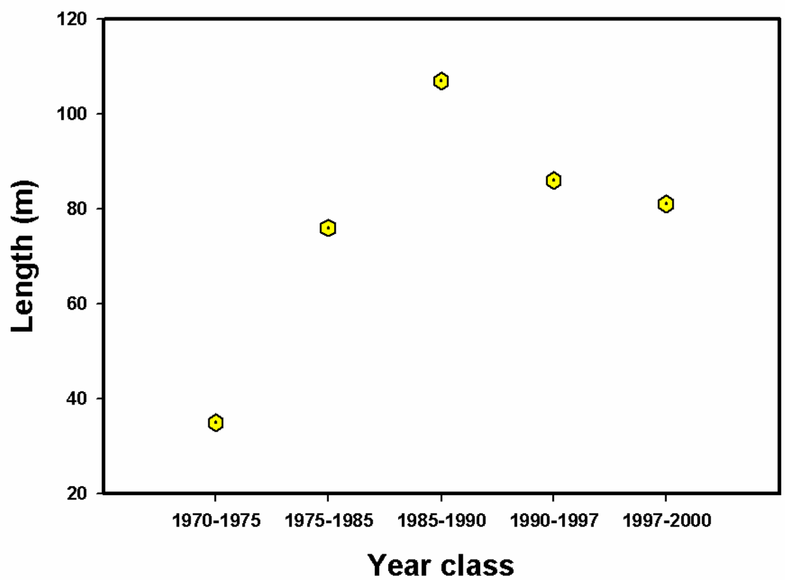

Figure 16 – Mean length of docks over marsh per year class.

Table 5: Dock Area and Area Over Salt Marsh in Each Year Class

Year Class	1970-1975	1975-1985	1985-1990	1990-1997	1997-2000
Area built (m^2)	3,422	6,702	4,857	5,089	5,668
Area over marsh (m^2)	1,671	4,358	3,468	3,302	3,880
% over marsh	49%	65%	71%	65%	68%

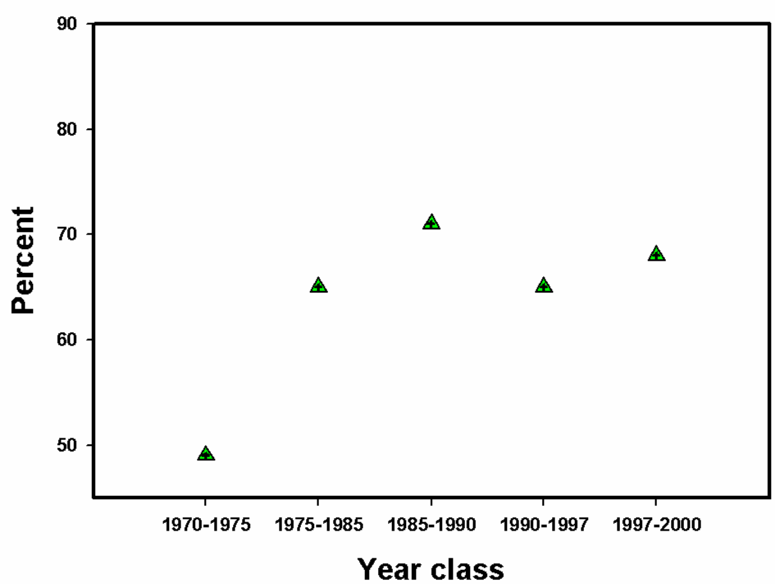

Figure 17 – Percentage of dock area constructed over marsh by year class.

Field Data

Mean stem density of Spartina alterniflora was 56% lower beneath docks than at stations 5 meters on either side of the docks (Figure 18). The difference in stem density beneath the dock when compared with the left and right sampling areas were found to be statistically significant ($p < 0.001$ using a Mann-Whitney Rank Sum Test). The stem densities were not found to be statistically different when comparing the left sampling areas with the right sampling areas ($p = 0.80$).

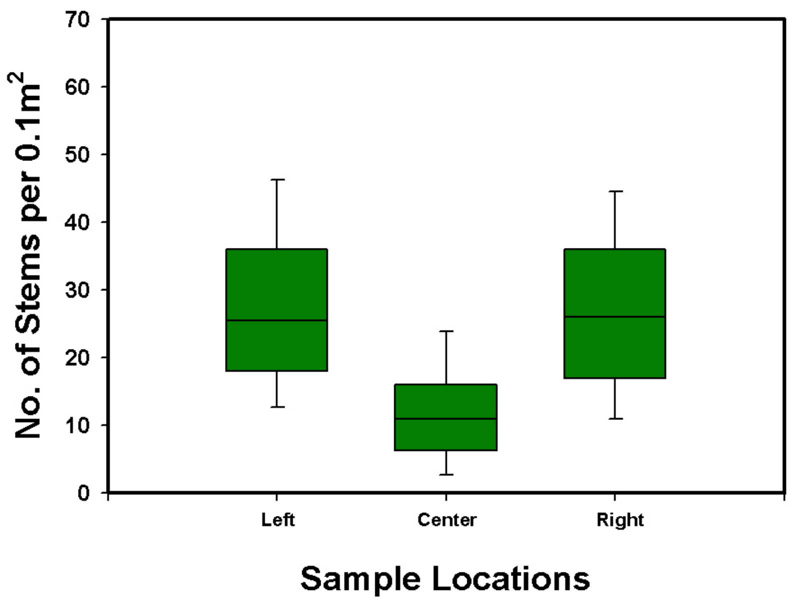

Figure 18 – Stem density comparison (bottom, middle line and top of box represent the 25^{th}, 50^{th}, and 75^{th} percentiles, respectively; bars show 1.5 std. dev. from the mean).

Mean plant height was not found to be significantly different between the beneath and adjacent sites using a paired t-test ($p = 0.07$), although height was more variable beneath the docks (Figure 19).

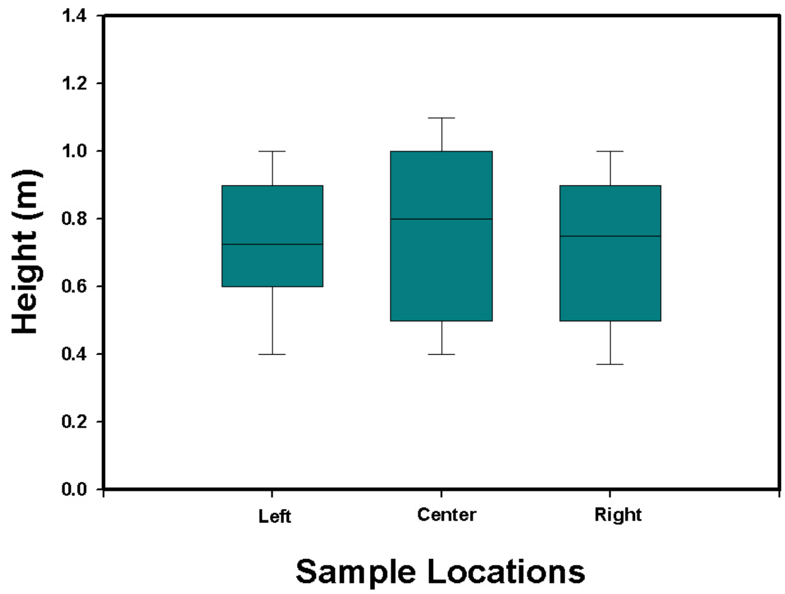

Figure 19 – Mean plant height comparison (graphic keys as in Fig. 18)

Percent reduction of stem density was compared with several dock characteristics using linear regression to analyze possible relationships. The raw data included two values that were considered outliers (Figure 20); those points were removed for the remaining analysis of stem density reduction. A weak relationship ($r^2 = 0.17$) was observed for height to width ratio of the dock. This relatively low coefficient of determination was significantly different from zero ($p < 0.001$). Therefore, stem density reduction decreases slightly as the docks became higher and/or narrower (Figure 21). Height of the dock and width of the dock when compared individually with percent stem density reduction yielded no statistical relationship with a linear regression of the data ($r^2 = 0.035$, and $r^2 = 0.028$, respectively; Figures 22, 23). The trend of these weak relationships do, however, reflect larger stem density reductions associated with lower and wider docks as would be expected. Directional orientation of the dock showed no relationship with stem density reduction (Figure 24). Orientations between 181 degrees and 360 degrees were converted to the reciprocal heading to allow linear regression analysis. Docks with reciprocal headings were assumed to have similar insolation characteristics over the majority of dock walkway.

No significant relationship exists between dock year class (a close proxy for dock age) and stem density reduction (p = 0.33 for the 1975-2000 year classes discussed above; p = 0.65 when all pre-1970 docks were included as an additional class).

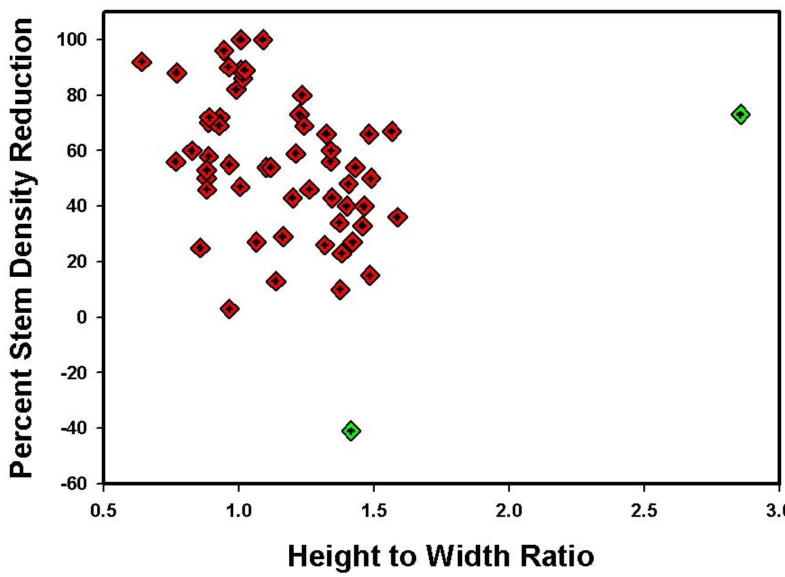

Figure 20 – Complete data set of percent stem density reduction versus height to width ratio including outliers (green).

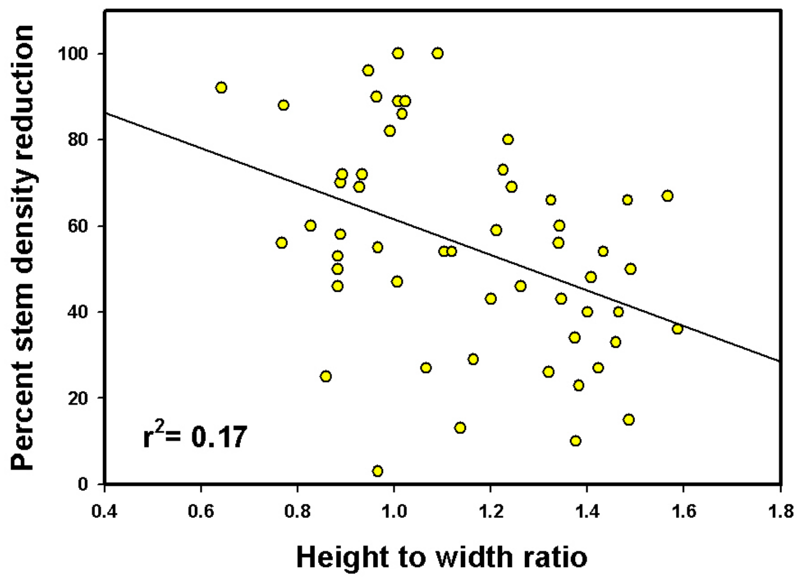

Figure 21 – Height to width ratio versus percent stem density reduction.

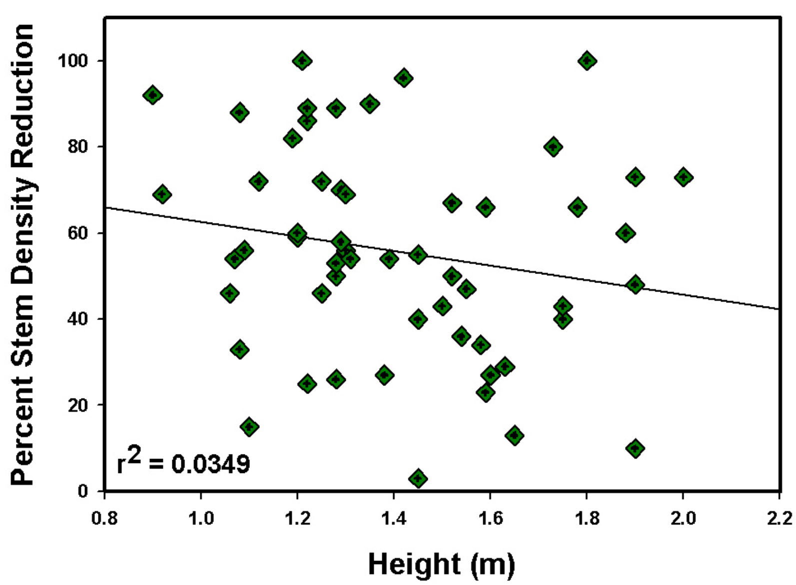

Figure 22 – Height versus percent stem density reduction.

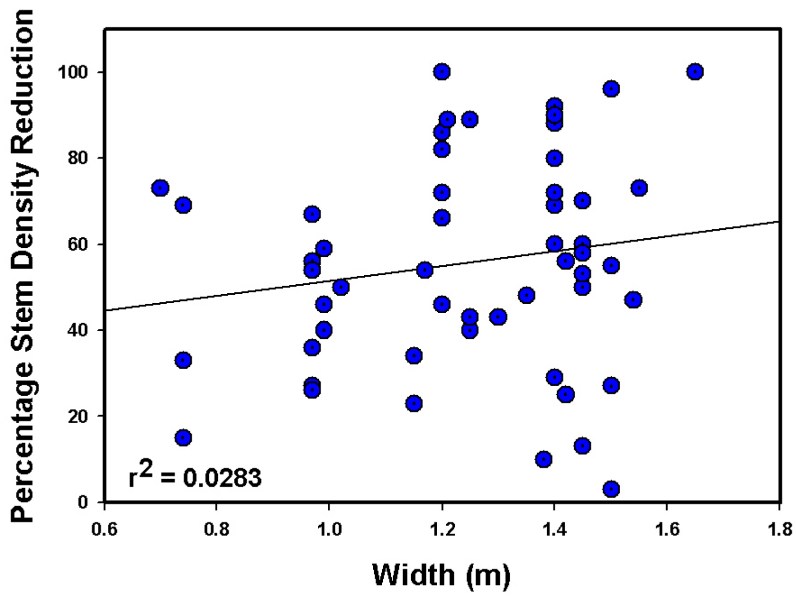

Figure 23 – Width versus percent stem density reduction. Note discrete width classes at ~0.75m (~2.5ft.), ~1m (~3ft.), ~1.2m (~4ft.), and ~1.4 to 1.5m (~4.5 to 5ft.) shown by vertical groupings of data points.

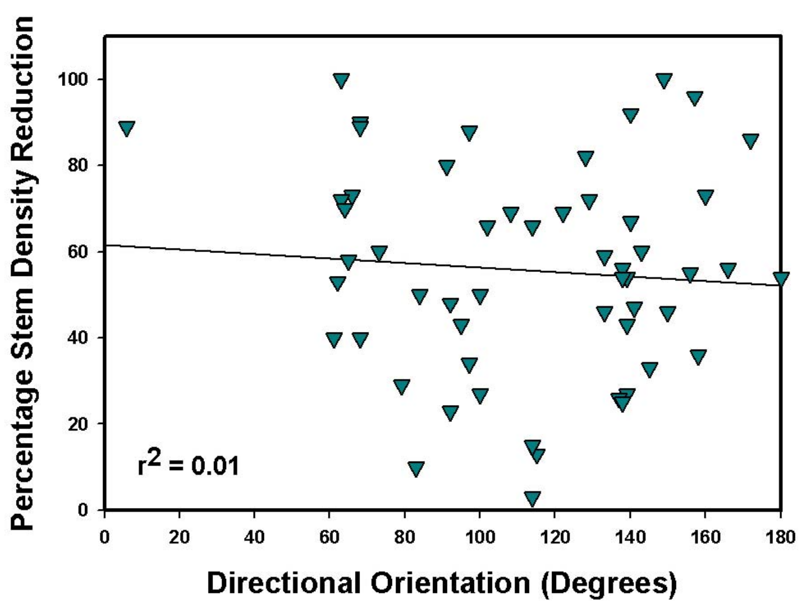

Figure 24 – Directional orientation versus percent stem density reduction.

Discussion and Summary

Baseline and Trend Data

Examination of historical aerial photo data is a powerful tool for assessing trends in dock construction characteristics. Cumulative as well as annualized measures report very useful, but different information for management. Cumulative data provide an overview of dock numbers and areas over saltmarsh vegetation, establishing baseline data for future studies. Annualized measures more accurately describe trends or patterns in dock construction characteristics. Because they provide complementary information, both measures should be used in future assessments of dock impacts.

When viewed cumulatively, between 1970 and 2000 the total number of docks increased 73% and the total area increased 90%. Evaluating data by year class displays important information regarding rates of construction, highlighting that between 1997 and 2000 dock construction rates doubled while average area per dock has changed little since 1980. The rapid increase observed from 1997 to 2000 of average area built per year class is more a function of the greater number of docks being built than of the average dock area increasing. Using cumulative measures, 53% of existing dock area covers saltmarsh vegetation, whereas year class data show that between 65% and 70% of dock area constructed between 1975 and 2000 is covering saltmarsh vegetation. In this case, the cumulative data are misleading in that they incorporate the characteristics of the large number of docks existing prior to 1970. The older docks on the island tend to be shorter structures than are the more recently constructed docks. These data tend to skew cumulative measures toward underestimating construction impacts. Parcels with shorter access to the water or access to deeper water typically are built on first and have docks constructed earlier than less desirable parcels. The large numbers of smaller docks already present in 1970 (174 docks) keeps the cumulative area over marsh (53%) lower than the more recent trend measurements (67%). This pattern of dock construction is expected to occur in other areas of the coast as well, as the more desirable parcels are developed first. Limiting this impact to the marsh will require establishment of a maximum length for private recreational docks.

From annualized data, dock construction patterns between 1970 and 2000 show docks being built on all sides of the island in every year class. However, different regions on the island were the focus for development and dock building during these years. Between 1975 and 1985 Old Squaw Creek had a considerable amount of new dock construction whereas in the 1997 to 2000 year class a large number of docks were constructed in the Betz Creek area (Figure 3). These two areas of focused dock construction suggest that subdivision of land parcels has a strong relationship with dock construction patterns. The geographic relationship between marshfront property and the distance across marsh to water access related to construction patterns as well. Resource managers are and should be concerned that dock size will be increasing as property owners construct docks on parcels that are increasingly removed from water access.

Stem density of *Spartina alterniflora* was reduced 56% directly beneath docks when compared with adjacent areas. Salt marsh is a diverse and heterogeneous environment affected by a number of variables that can alter vegetation stem density. The paired sampling strategy at each transect accommodates this diversity. Stem density in areas adjacent to a given dock were not significantly different from each other but were significantly different from the site located under the structure, establishing that the stem density reduction is an impact of the structure and not a naturally occurring gradient across the marsh.

Plant height was not found to be significantly different below the docks versus adjacent to docks. Other studies have described slight increases in the height of plants below docks. Plant height differences below the dock may in some cases be attributed to etoliation of plants growing in low light conditions (Kearney, Segal and Lefor, 1983) or to additional nitrogen input from bird droppings (Sanger and Holland, 2002).

The other variables examined (i.e., dock height, width, height/width ratio, directional orientation) do not describe any strong relationships. A weak relationship (r^2= 0.17) exists between height/width ratio and stem density reduction. As dock walkways become higher and/or narrower the percentage of stem density reduction is lessened. More data might prove useful to evaluate the apparently subtle relationship between directional orientation and impact on marsh productivity. Burdick and Short (1999) found directional orientation of docks to be a significant variable in the reduction of sea grasses beneath docks in Massachusetts. Docks oriented in a north-south direction allowed more available light to reach the vegetation and better support the photosynthetic needs of these submergent aquatic plants (Burdick and Short, 1999). Insolation may be more important in relatively high latitudes where sun angle is more variable throughout the year than in coastal Georgia. Further illustrating this latitudinal gradient, recall that no relationship was found between orientation and stem density in South Carolina, whereas in Virginia a relationship was apparent in field data (McGuire, 1990; Sanger and Holland, 2002).

Assessing Cumulative Impact

Although tools do not yet exist to predict definitively the cumulative impact of these dock building activities, the potential impact can begin to be assessed using data generated from the GIS measurements. The area of marsh between the upland of Wilmington Island and the first 9-m wide creek (see methods section for rationale) is 4,801,565 m^2. Existing docks in 2000 covered 24,021 m^2, or 0.5% of this available saltmarsh. Chatham County parcel data show that 609 parcels have riparian rights on Wilmington Island. If we assume that these lots are not subdivided, and given that 301 lots already have docks in 2000, then approximately 1% of the marsh could potentially be affected by dock structures. If lots are subdivided, this would be a minimum estimate of the total impact. This range of values (0.5-1% of existing marsh affected) is comparable to that determined as present on the individual tidal creek and coastal county scales in the Sanger and Holland (2002) study.

The GIS can also be used to provide a maximum estimate of cumulative impact. Measurements within the dataset show that the perimeter of Wilmington Island is approximately 33,323 m. Current law stipulates that a lot must have 15.15 m (50 feet) of frontage on the marsh or water to qualify for a private recreational dock without resort to the Marsh Act permitting process. Within this regulatory framework, a total of 2200 docks could be built on the island, assuming that lots are not precluded from having a dock for other reasons (e.g., no riparian corridor toward an open creek). We can evaluate this maximum cumulative impact in two ways by assuming that these hypothetical docks have the average area over marsh of: 1) all docks presently existing on the island, which would provide a reasonable estimate of aerial coverage (80 m^2 over marsh) as it includes both the short, older docks and long, newer docks; and 2) all docks built between 1997-

2000 on the island, our most recent dataset, which provides a maximum average coverage estimate (125 m^2 over marsh). Approximately 4 and 6% of the marsh could be directly impacted under these reasonable and maximum assumed conditions. The significance of such a reduction in productivity on the saltmarsh ecosystem is presently unknown. However, Sanger and Holland (2002) suggest that 5% marsh coverage is a significant impact to marsh productivity in a region and an intensity of development that, as in Georgia, is possible under current South Carolina DHEC-OCRM regulations.

Recommendations for Additional Research

Stem density measurements are a simple and effective method for comparing and quantifying how a dock is impacting the vegetation below the structure. For management purposes however, we need to quantify how these reductions in stem density are related to the carbon budget of the saltmarsh system. Currently, the impacts docks are having on the carbon budget are unknown. Measurement of aboveground biomass would provide a more useful alternative to stem density as a method for measuring saltmarsh productivity (e.g., Kearney, Segal and Lefor, 1983). A preliminary study of aboveground biomass in relation to stem density is being conducted by Dr. Clark Alexander (Skidaway Institute of Oceanography and Georgia Southern University).

Other processes and activities associated with docks could have impacts on salt marsh habitat as well. During this study a large number of docks were observed to have a significant accumulation of marsh wrack (decaying Spartina stems) on the north or northeast side of the structures. Dominant winds on Wilmington Island and along the Georgia coast are from the northeast. The docks may be acting as baffles or retaining structures that impede natural removal of marsh wrack through the actions of tide and wind during spring tides. In open marsh settings, the narrow deposit of marsh wrack that is deposited at spring tides is removed during subsequent tides. Docks act to retain any wrack that is transported into the vicinity of the dock, building aerially significant deposits. Several areas of bare marshland surface lacking any vegetation adjacent to docks in the study area could be attributed to this type of wrack accumulation and subsequent removal months or years later. Personal observations at the Skidaway Institute of Oceanography's Saltmarsh Ecosystem Research Facility show that trapped marsh wrack can take up to a year to be removed by natural processes and the denuded marsh surface (in this one case covering approximately 2000 m^2) takes years to recover. Given the large areas that could potentially be impacted by marsh wrack based on field observations in this study, the association between docks and large, denuded marsh areas should be investigated. If this process were shown to be important, it might be a source of naturally created but unrecognized error in remote sensing of marsh die-off areas.

Construction scars in the salt marsh were observed in several areas adjacent to docks. These scars were most commonly in the form of depressed tracks caused by wheels from construction vehicles (e.g., "marsh buggies"), suggesting the need for docks to be built from the structure itself or from barges. Many docks were built out across saltmarsh to waterways that go partially or totally dry at low tide. Future studies of dock-associated impact to saltmarsh environments should include the effects of floating docks and boat hulls that sit on the creek bottom at low stages of the tidal cycle. A preliminary study of dock-associated impacts to estuarine environments is being carried out by Dr. Clark Alexander (Skidaway Institute of Oceanography and Georgia Southern University) and Dr. Dionne Hoskins (Savannah State University).

Finally, GADNR-CRD is compiling, by county and state-wide, all the statistical information contained in permit applications for private recreational docks. This new dataset should be analyzed with data included in this report to compare the relatively advanced level of development on Wilmington Island with individual coastal counties and the State as a whole. Such an analysis could provide guidelines for managing the anticipated increase in demand for water access with increasing development in counties that are presently lightly developed.

Increasing population along the coast will continue to test the resiliency of salt marsh habitat. Urbanization, tourism, transportation, dredging, agriculture, industry, marinas, and waste disposal are some of the stressors that will continue to probe the saltmarshes' ability to absorb and resist these impacts. Preservation of our marshland resources will depend on accurate baseline and trend data indicating current and future impacts from multiple uses as well as considering the cumulative effect of these uses (Weinstein, 1996). This study is an effort to provide these baseline data and extrapolate from them for management use.

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