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Effects of Pier Shading on Salt Marsh Plants in Mississippi

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EFFECTS OF PIER SHADING ON SALT MARSH PLANTS IN MISSISSIPPI

by

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ABSTRACT

Saltmarshes are important environments that are valuable to both humans and wildlife. As saltmarshes are under threat from erosion, sea level rise, and human development, efforts should be made to conserve them. The vegetation that occupies these environments are vital to the continued preservation of saltmarshes. This study focuses on one potential threat, the effect that pier shading has on prominent saltmarsh plants of Mississippi, *Sporobolus alterniflorus* and *Juncus roemarianus*. Sample piers were selected in the three coastal counties of Mississippi and visited at two time periods (2006 and 2021). I focused on the use of irradiance measurements at pier sites to determine how piers affect the available light environment. Piers of different heights, widths, and board spacing were compared to identify factors that have the biggest effect on shading. Plant species diversity was documented at each site to compare communities around each pier versus underneath the piers. I found that each height, width, and board spacing can affect the available light underneath piers, with height having the most consistent effect. Analysis on the vegetation community around pier sites did not provide clear results of any broader impacts from the shading effects. The light available underneath piers was measured to be below the irradiance threshold for both *S. alterniflorus* and *J. roemarianus*. Potential shading effects may be mitigated by altering construction methods and dimensions. This research is important, as it can tie into management implications directed towards saltmarsh conservation.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ESI	Environmental Sensitivity Index
E-W	East-West
GPS	Global Positioning System
HAN	Hancock County
HAR	Harrison County
IDW	Inverse Distance Weighted
JAC	Jackson County
MDIP	Mean Daily Irradiance Percent
MDMR	Mississippi Department of Marine Resources
MS	Mississippi
nMDS	Non-parametric Multidimensional Scaling
NOAA	National Oceanic and Atmospheric Administration
NWI	National Wetlands Inventory
N-S	North-South
S.D.	Standard Deviation
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
%CL	Irradiance Percent at Center-Line
%Under	Irradiance Percent Under Pier (average)

CHAPTER I – INTRODUCTION

1.1 Background

Throughout history, humans have concentrated around coastlines because of the efficient travel means, abundant food sources, and numerous other practical benefits that coastal regions provide. In the present, when people can choose where they want to live, coastal populations are still growing. In the Northern Gulf of Mexico, many people choose to live near the water's edge because of its aesthetic, recreational, and cultural value, along with other traditional reasons. For people to enjoy the views and take part in recreational activities, piers are often built to access the water. As the coastal human population grows, so does development and the amount of pier construction. Sanger et al. (2004) notes that pier construction and density is directly linked to suburban development. To help regulate this development, government, usually in the form of a state or federal agency, is tasked with permitting and inspection processes. The United States Army Corps of Engineers (USACE) outlines the requirements for pier construction in the United States, in collaboration with the Mississippi Department of Marine Resources (MDMR). The decisions that state and federal agency managers, in collaboration with environmentally-conscious landowners make about pier construction codes and permitting are based on many factors, including the environmental impact of piers on coastal marshes.

Coastal marshes are ecologically important for many reasons. In fact, coastal fishery success is closely connected to the availability of healthy marsh habitats (Herke et al. 1984; Boesch and Turner 1984; Rakocinski et al. 1992; Peterson and Turner 1994). Dense salt marsh stands also promote sediment accretion, while preventing coastline erosion (Alexander and Robinson 2006; Logan et al. 2014). Marshes also provide ecosystem services such as storm-surge protection, carbon sequestration, water purification, and recreation (Barbier et al. 2011). Coastal development in the Northern Gulf of Mexico is known to negatively affect intertidal areas in many ways (Sanger et al. 2011). Kennish (2002)and Paterson et al. (2010) ranked habitat alteration through coastal development as one of most significant anthropogenic impacts on estuaries. Some of the immediate and obvious impacts that piers have on salt marshes have been studied in some detail. For example, it is known that pile-driving and large equipment operation in coastal environments can loosen sediments and encourage sediment erosion (Shafer and Robinson 2001; Vasilas et al. 2011). On the other hand, there are other impacts that have not been extensively studied to date. For instance, significant information has not been compiled on the environmental impacts of pier shading on marsh plants native to coastal Mississippi, and what is available has not been entirely consistent. Several studies found that *Sporobolus alterniflorus* (Smooth Cordgrass) was negatively affected by pier shading with pier height being the most important factor (Kearney et al. 1983; Logan et al. 2018;Shafer et al. 2008; Logan et al. 2018; Burdick and Short 1999). Others, such as Vasilas et al. (2011), found that pier height was not significant, but width was. Besides height and width, pier orientation is also believed to have impacts on shading effects. Structures oriented East-West should chronically shade the same areas throughout the day and have a greater effect on vegetation when compared to those oriented North-South. Unfortunately, there is no consensus on the validity of this theory, with some study results agreeing (Shafer 1999; Alexander 2012; Burdick and Short 1999) and some disagreeing (Vasilas et al. 2011; Logan et al. 2018). Additionally, there is very limited information about board spacing effects on shading (Shafer 1999). Several studies found that *S. alterniflorus* density was less underneath piers, but plant height was greater. It is also not evident whether *S. alterniflorus* experiences etiolation as a result of shading or if it is responding to other stress effects independent of shading (Kearney et al. 1983; Vasilas et al. 2011; Logan et al. 2014). Combined, these studies indicate there is much variability in the observed effects of pier shading on marsh plants. It should further be noted that most of the previous research regarding the subject has been done on the Atlantic coast at latitudes higher than those of the Mississippi Gulf Coast. Another shortcoming of the literature is the lack of research on the pier-shading effects on *Juncus roemerianus* (Black Needlerush), a dominant coastal marsh plant along the Northern Gulf of Mexico.

1.2 Study Outline

For the aforementioned reasons, a follow-up study to the "Effects of Pier Shading on Marsh Plant Productivity" that spanned from 2006-2008 (https://sites.google.com/view/pier-shading/) was conducted. This 15-year-old study (Biber 2008) looked at how the characteristics of piers along the beaches of Ocean Springs and within Biloxi Back Bay in Mississippi affected marsh plant productivity. The natural coastline and the human development of this area is dynamic and can change drastically over the course of a 15-year time period, hence the need for another look to update the pier characteristics and how they are affecting marsh plant productivity in this area.

The Biber (2008) study had three distinct elements. The first element focused on the pier engineering and construction. Pier segments were constructed based on commonly observed combinations of pier height, width, and board spacing dimensions. Shading profiles were developed for each of the combinations from high frequency (5 minute) irradiance sampling over 7-10 days at a time. Results found in this part were included and used as a reference, as this portion of the study was conducted under more controlled environments.

The second element focused on the real-time irradiance data collected at 30 pier sites combined from Jackson and Harrison Counties. To follow up in this thesis, the original set of piers from 2006-2007 was revisited, and all the original construction characteristics measured were recorded again. In addition, the amount of photosynthetically available light and the vegetation status were recorded. The same measurements taken at the original sites were taken at the new sites. In addition to the original 30-pier dataset, new pier locations were examined to increase the sample size of data. Using the previous study's data as a reference, shifts in pier dimensions, materials, or construction techniques used were noted. This provided a longitudinal aspect to the existing cross-sectional data.

As a third focus of the original study, a large amount of data regarding shading effects on the marsh plant species *J. roemerianus* and *S. alterniflorus* was collected. The plant responses were recorded over a period of three months at eight percent shade cover treatments (0, 30, 55, 80, 90, 95, 99, 100% shading). Using the shading percent data collected under the pier structures visited in this project, the shading response of *J. roemerianus* and *S. alterniflorus* can be estimated. The Biber (2008) study collected a lot of valuable data, but comprehensive analysis and reporting using updated sampling at field pier sites provides an opportunity to make it useful for management and permitting actions.

From revisiting the study and prior data, a story has developed of how piers are affecting common marsh plants of the Northern Gulf of Mexico. While not a comprehensive look at all possible pier impacts, it adds to a limited the body of knowledge available to managers when making regulations and during the permit review process. Economic forces are often the culprit of irresponsible development on coastal marshes (Boesch & Turner 1984). Without an appropriate assessment of the cumulative environmental impacts of piers on the coastal environment, local managers cannot make informed decisions on permits when pressured by those seeking pier development. Information regarding potentially harmful aspects of piers could also help the increasing number of environmentally-conscious landowners with improved pier construction decisions.

1.3 Goals and Hypotheses

The aim of this study is to better characterize the shading effects of a range of different pier structures on salt marsh vegetation, with a focus on the two dominant species in Mississippi. The specific goals are to:

- Determine if pier shading effects are potentially negatively affecting the salt marsh plants *J. roemerianus* and *S. alterniflorus* on the Mississippi Gulf Coast.
- Determine which pier characteristics, height, width, or decking are most pertinent to deleterious pier shading effects and relate findings to management implications.

The hypotheses to be tested include:

1. Pier height has a significant effect on shading. Height is more important than width or decking in terms of shading cover.
2. There is no difference in shade cover percentage between piers made of wood planking vs deck grating material.
3. Plant diversity underneath the sampled piers is less than in the adjacent habitat, reflecting non-ideal conditions for growth.

CHAPTER II – METHODS

2.1 Site Selection

Piers were visited in all three counties along the Mississippi (MS) coast in 2021 and data was compared to prior sampling. For the round of sampling conducted previously in the summer of 2006, 30 total sites were visited. Two thirds of the original pier sites were located in Jackson County, MS (20 piers) with a lesser amount in Harrison County, MS (10 piers); (Figure 1). All the original pier sites were located either along the beaches in Ocean Springs or along the Biloxi Back Bay shoreline. Of the original 20 pier sites located in Jackson County, 10 were no longer present or lacking sufficient decking structure to collect light data. Pier sites were selected in 2006 based on their proximity to salt marsh, distribution of pier heights, and distribution of pier widths. All sites used in the 2006 dataset were revisited and sampling was replicated if the piers were still intact or rebuilt to the same specifications. Of the 20 sites visited in 2006 in Jackson County, only 10 remained in fair condition in 2021. All 10 of the previous sites in Harrison County were still intact or rebuilt. To expand on the geographic range and sample size, additional pier sites were selected with 15 in Jackson County, 15 in Harrison County, and 10 in Hancock County for a total of 40 sites for the 2021 sampling (Figure 2). Study sites for the current round of sampling in summer 2021 (May-August) were chosen based on sites used from the previous sampling with additional new piers added to expand the dataset. New piers were selected in 2021 based on dimension characteristics that may not have been fully represented by the original pier set from 2006. Additional new sites were selected in Jackson County, MS (5 piers), Harrison County, MS (5 piers), and Hancock County, MS (10 piers) to broaden the scope of sampling. Sites were designated by a three-letter abbreviation of the county, a site-specific number, and either an “A” for the 2021 sampling round or a “B” for the 2006 sampling round. The first site sampled in Jackson County in 2021, was denoted as “JAC-01-A” with the 2006 complementary sample as “JAC-01-B”.

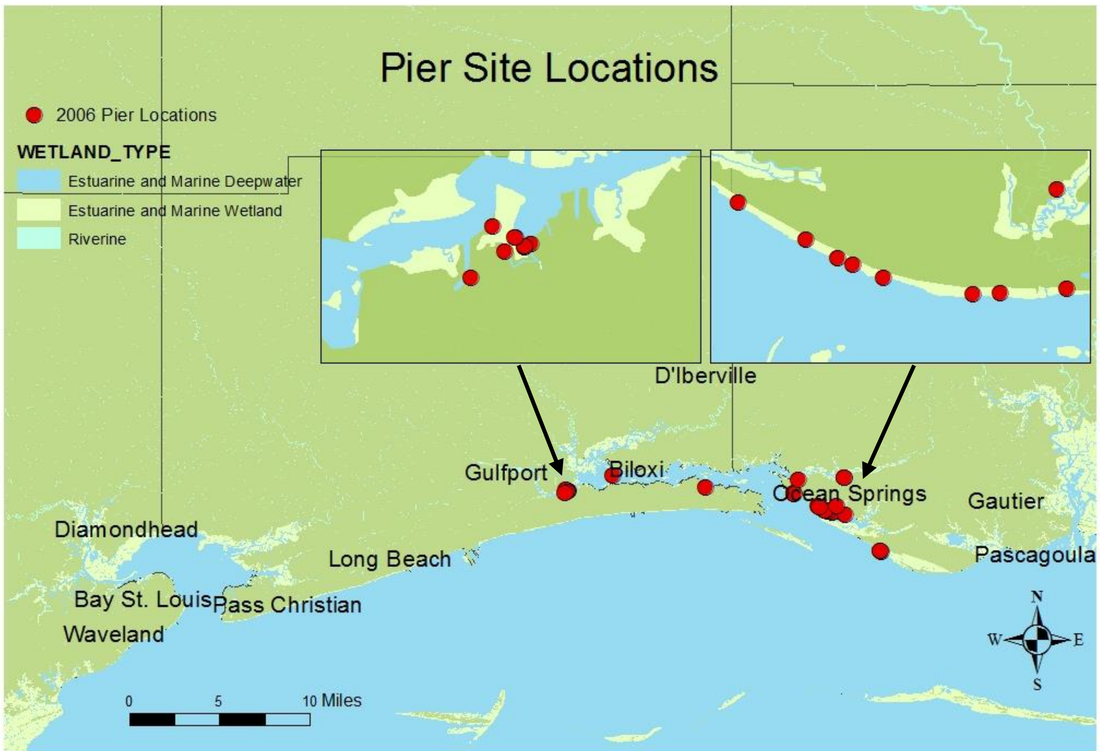


Figure 1: Map of pier sites sampled in 2006, 20 piers were visited in Jackson Co. and 10 piers were visited in Harrison Co.

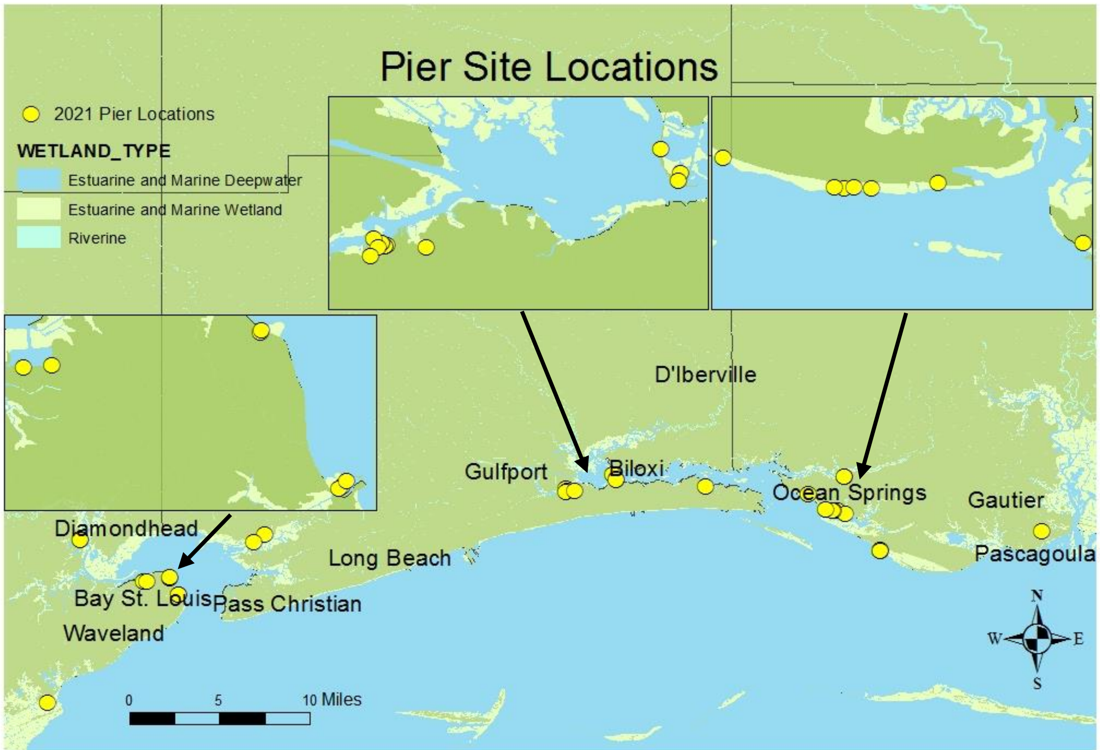


Figure 2: Map of pier sites sampled in 2021, 15 piers were sampled in Jackson Co., 15 were sampled in Harrison Co., and 10 were visited in Hancock Co.

2.2 Site and Pier Descriptions

A suite of attributes was recorded for each pier visited in summer 2021, as well as for the surrounding marsh. Upon arrival at a site, the time and date of sampling were recorded on a field data sheet (see Appendix A). To record the location of each pier, a written description of the location based on nearby streets or parks was made. Using a handheld GPS (Garmin GPS Map 76), the coordinates were recorded in degrees and decimal minutes, after noting the positional accuracy in feet. A photograph was taken at the base of each pier facing seaward when looking from the shore.

For describing characteristics of the pier structure, a determination of the integrity of the pier was made with a categorical value such as “Intact”. Facing shorewards from the base of the pier, the compass direction of the pier was recorded in degrees. If the whole pier was public and accessible, the total length of the pier was measured using a surveyor’s tape and recorded in meters. The width at the section of pier being studied was measured using a tape and recorded in feet, later converted to metric. The construction material of the decking on the pier was classified as either “wood” or “composite”. Provided the site was constructed with wood planking, the standard board size such as “2x8” inches was recorded. If the decking material was wood planking, the width between each board was measured for six consecutive gaps before and six consecutive gaps beyond the location of light sensor. If the pier had composite grating for the deck, the length and width of a grate section was recorded. For the grating, the gaps were measured and repeated 12 times, as the spacing was always consistent for each respective grating material. All length measurements were converted to metric units. Microsoft Excel was used to store and organize site descriptive, vegetation, and light data.

Compliancy with current pier dimension regulations was determined based on attribute data collected. Regulatory compliance was based on USACE regulations for private piers and docks in coastal MS at the time of 2021 sampling. The height:width ratio requirement was specifically used to determine compliancy status. The maximum width is outlined at 6 feet for non-forested emergent wetlands (unless specifically authorized), and the height is required to be greater than or equal to the respective width.

2.3 Light

2.3.1 Light Transects

To identify shading transect locations at a pier site, heights from the substrate to the decking of the pier were identified in 30.5 cm (1-foot) increments (ex: 4 ft height, 5 ft height, etc.). Height locations that were both within the marsh zone and accessible to sample were identified as transect locations. Although every pier by nature must be 1-foot tall, 2-foot tall, 3-foot feet tall, etc. at some location, sampling was limited at the very low heights because most piers did not reach marsh habitat from lawn grass or bulkhead until the two feet height or greater. Another consideration for the limited amount of sampling at short height transects was the difficulty of using the light sampling methods. For example, at a 1-foot height, being able to effectively use the light sensors while crawling between sampling points would be very difficult. Figure 3 shows example pier heights and transect locations. The transect length was variable and determined by the width of the pier site. If looking towards the end of a pier, the transect would be aligned perpendicular to the pier direction. The first sample point on a transect was located 0.914 m (3 feet) left of the left edge of the pier profile. The second point aligned with the left edge of the pier profile. Sample points were sequential from there in 0.305 m (1 foot) increments until the right edge of the pier profile. The last sample point would be located 0.914 m out of from the right edge of the pier. Figure 4 shows an example transect for a 4-foot wide pier.

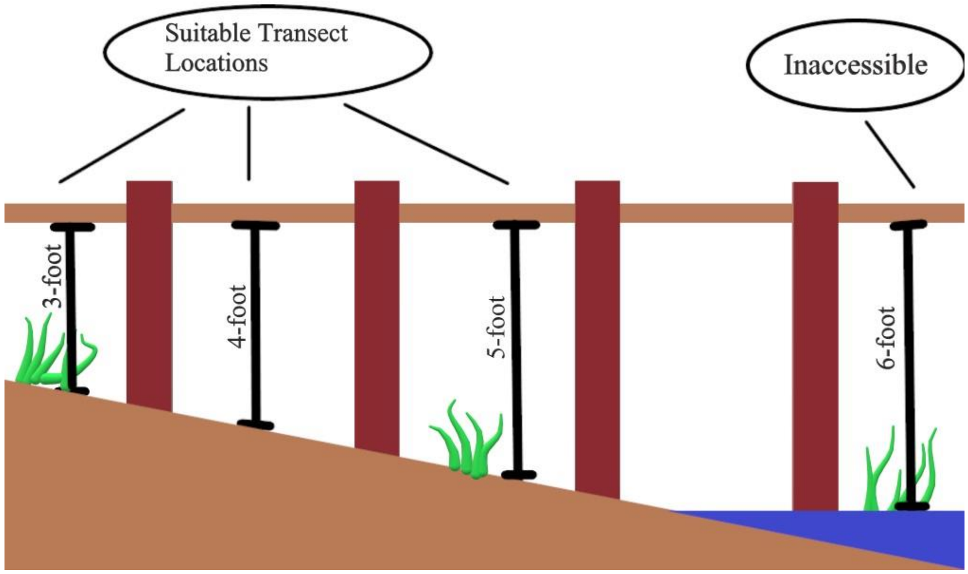


Figure 3: Illustration demonstrating potential transect locations on a pier structure.

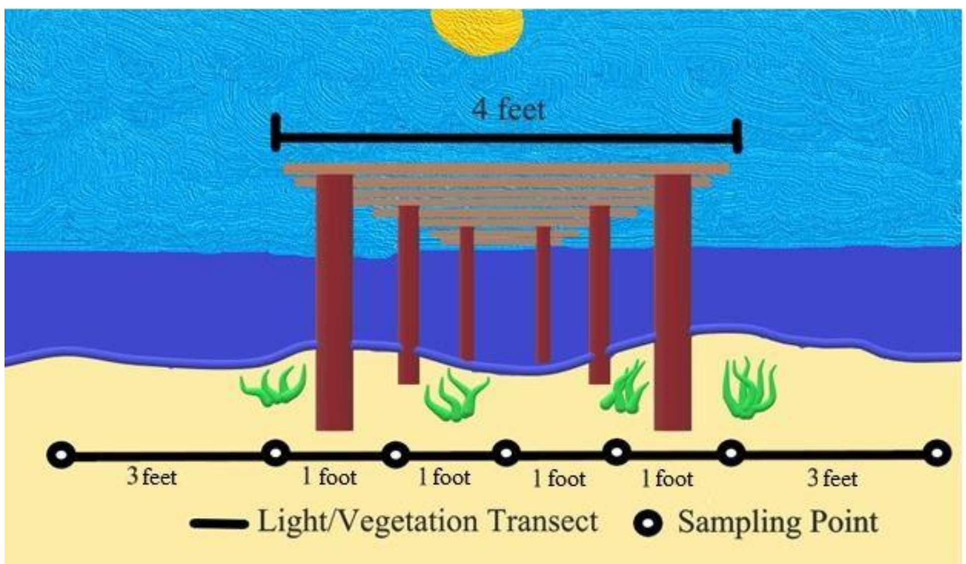


Figure 4: Illustration of cross section of a 4-foot wide pier, showing perpendicular orientation of a transect, as well as sampling points along the transect.

Light as photosynthetically available radiation (PAR) was measured using paired LI-COR 1000 and LI-COR 250 meters. Prior to examining each transect, a simultaneous reading was recorded on both LI-COR meters while they were side-by-side on top of the pier. This gave us a quick measure of instrument bias error before and after taking shading measurements for each transect. The LI-COR 1000 meter coupled with an appropriate cosine corrected sensor (LI-190) was placed on top of the pier above the center of the respective transect. The LI-COR 250 meter with a second LI-190 sensor was used at ground level along the transect. Readings were recorded simultaneously from the top of the pier and at each respective transect sampling point, so that there was a "paired" incident light measurement for every shading measurement below the pier deck. After all measurements were recorded, the two meters were again placed side-by-side of top of the pier and a simultaneous reading was again taken to determine if the bias between the instruments had changed. After completing a transect, the shadow on the substrate created below the pier was measured as a distance outside or inside of the edge profile of the pier. Cloud cover is a major influence on incident solar radiation (Alados et al. 2000). Because of this, intermittent cloud cover conditions were unacceptable for sampling, as it would cause light readings to vary widely over short time periods. Irradiance sampling only took place when light intensities were consistent so that the "control" light reading from on top of the pier did not fluctuate more than approximately 200 µmol during the course of a transect. Taking light data between approximately 10:00 A.M. and 3:00 P.M. Central Daylight Time was prioritized, as periods outside of this range have solar zenith angles that can contribute to low light intensities (McCullough and Porter 1971).

From the light data collected at the substrate along the transect and the control on the top and mid-line of the pier, shading percent values were calculated for each sampling point along the transects using the following formula (Equation 1).

$$\frac{(\text{(Light at Transect Point (µM))}}{\text{(Light at Control Point (µM)))}} \mathbf{x}\ 100 = \text{Irradiance Percent}$$

Equation 1: Formula describing method for calculating irradiance percent.

With shading percent values for each point, profiles delineating the endpoints and centerline of shading from the overlying pier were determined for each point along each transect (Figure 5). The first endpoint of the shading profile was identified at the point where the irradiance percent value fell below 75%, and the second endpoint was identified at the last point before the shading percent value returned to 75% or higher. The center line was determined based on the midpoint (or average of midpoints with less than 5% irradiance) between these two endpoints. The shading profile for each transect did not always align with the vertical profile of the pier because of varying solar zenith angles encountered during the course of sampling on different days and months.

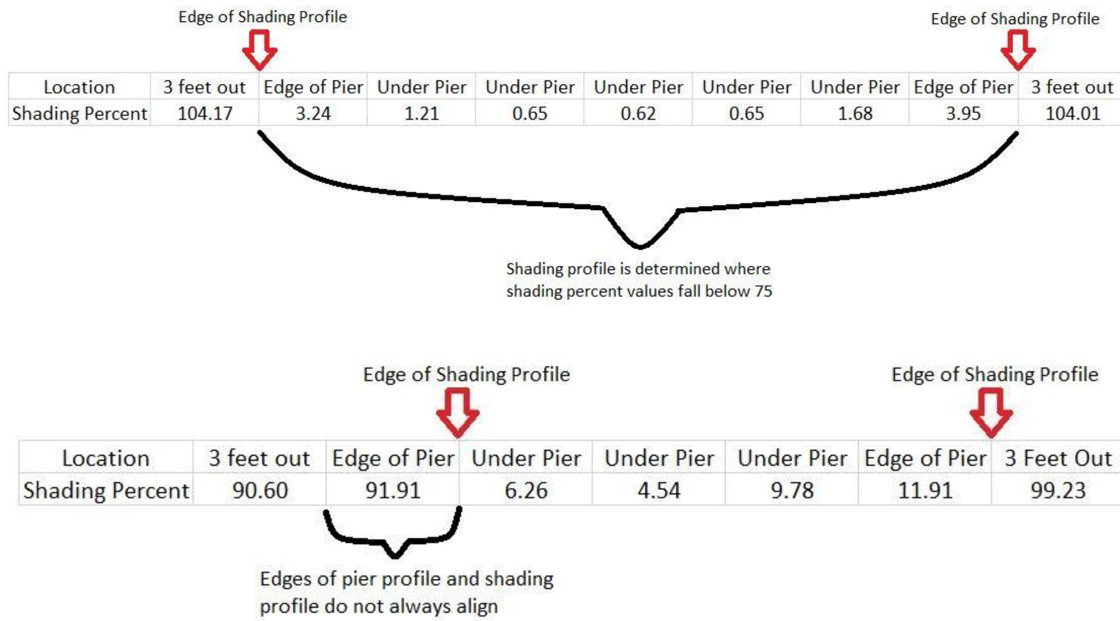


Figure 5: Shading percent calculations for each transect. 5.1 (Top panel): Demonstration of shading profile aligning with pier profile, and 5.2 (Bottom panel): Demonstration of shading profile that does not align with pier profile.

2.3.2 Light Analysis

Jamovi software (ver. 2.2.5) was used to statistically analyze light and shading data. Analysis of Variance (ANOVA) tests were used to compare light data among categories including pier height, width, and deck spacing. Some light data transects were removed from analysis based on the decking material (board vs. grate), time of sampling, and categories being tested. For instance, piers with grate-decking did not exhibit pier shading profiles consistent with piers that have board-decking, therefore grates were removed from initial rounds of ANOVA analysis. If a light transect was sampled too late in the day, the shading profile was skewed, resulting in shading bias under the pier itself. To meet normality assumptions of ANOVA, a Box-Cox transformation was used on all shading percent light data. The transformed average centerline shading percent (%CL) as well as transformed average shading percent underneath pier profile (%Under) were used as dependent variables in ANOVA. The method for determining %CL and %Under prior to transformations for each transect is outlined below (Fig. 6).

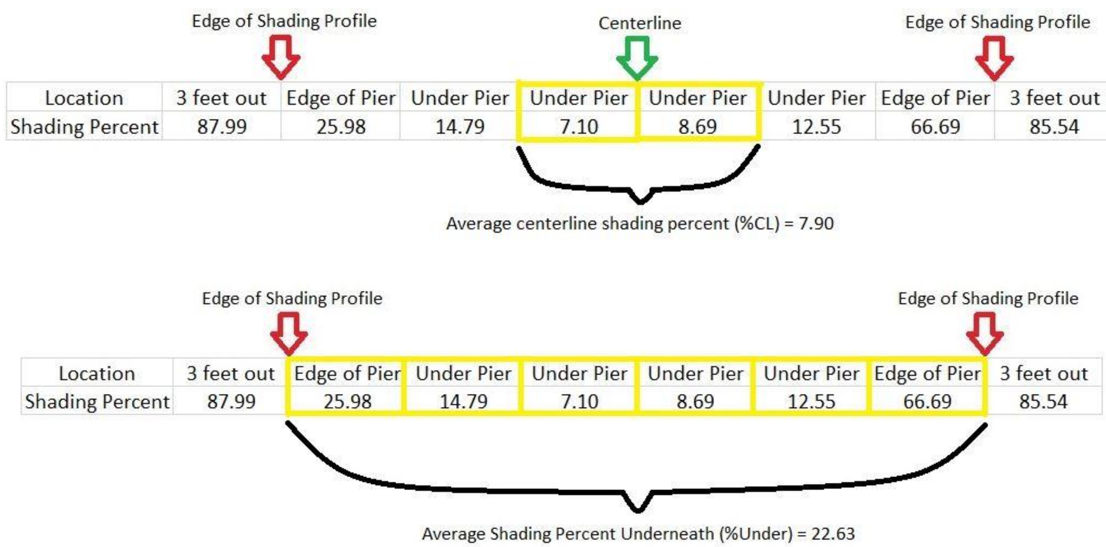


Figure 6: Example data used to calculate %CL and %Under data for ANOVA. 6.1 (Top panel): Method for calculating %CL before transformations, and 6.2 (Bottom panel): Method for calculating %Under before transformations.

Pier width at transect locations, pier height at transect locations, and board spacing were used as primary independent variables in 3-way ANOVA. This 3-way ANOVA was run separately with each %Under and %CL as dependent variables. Both width and height were categorized into groups or “bins” (using the median value for the combined 2006 and 2021 data for each metric) for analysis to ensure similar sample sizes were present. The selection of the different bin categories is further explained using attribute data and figures presented in the results section (see page 24).

Board spacing effects were also analyzed using light data. Transects were categorized into one of two board spacing bins: gaps less than 1.27 cm (0.5 in.) or greater than or equal to 1.27 cm (0.5 in.). This gap bin delineation was chosen because it was very close to the median (1.32 cm) as well as the mean (1.52 cm) board spacing. It is also a standardized gap spacing that would translate well into management applications. Additional ANOVA tests were run on the subsets of the data to assess decking material and pier orientation effects. Tukey's post-hoc tests were run on all significant results.

Light transects under the grate-decking transects were analyzed separately. As there were seven grate-decked transects, seven additional board-decked transects from piers with identical heights and widths were randomly selected to compare against. A one-way ANOVA test was implemented using the Box-Cox transformed %Under values to test differences between decking material (grate vs. board decks).

Pier orientation was the last independent variable tested. Orientation was described by the categorical values North-South (N-S) and East-West (E-W). Pier direction (degrees) was converted to orientation. As a guide: (316-45 degrees) or (136-225 degrees) translated to N-S; (46-135 degrees) or (226-315 degrees) translated to E-W. There were relatively few transects with piers oriented E-W, with a surplus of those oriented N-S. As a result, all of the E-W transects were used, and an equal number of N-S transects randomly selected to have identical or similar heights and widths were used. Initial analysis was conducted using the subset of the light transects that were recorded within a time window (10:00 A.M. – 3:00 P.M. Central Daylight Time) in order to eliminate outliers as a result of a lower solar zenith angle occurring closer to sunrise and sunset. A one-way ANOVA was used to compare orientation based on %Under values. After additional consideration, a second set of analysis was conducted this time using a subset of data previously excluded by the time window. In this second test, only light transects recorded at or before 10:30 A.M. or at or after 3:30 P.M. were used. This was thought to be an important consideration as pier orientation effects should only be more apparent at lower solar zenith angles. Similar to before, an equal number of comparable N-S oriented transects were selected to compare with E-W transects. A one-way ANOVA was again applied to compare orientation using %Under values at these lower sun angles.

Finally, the methodology for the portion of the 2006 study that focused on constructed pier segments and continuous light data collection with more controlled variables can be found here: (https://sites.google.com/view/pier-shading/). These data and results were used to compare against the summer 2021 percent shading results for different pier height, width, and deck combinations. Mean daily irradiance percent (MDIP) was a metric used in analysis and calculated as the mean irradiance percent across all observations of a height, width, and board spacing treatment during daylight hours. The MDIP values for each treatment were used to compare against each other and results found from field sampling in 2021.

2.4 Vegetation

2.4.1 Marsh Description

To describe the marsh habitat surrounding each pier, first the length of pier that crossed directly over marsh habitat was measured and recorded. The marsh vegetation community for each site was then assessed by describing each marsh species present within approximately 15 meters from the edges of the pier. The vegetation community present directly underneath the pier was also described by recording each species present. Both Shannon-Wiener and Simpson’s diversity indices were calculated for the “general area” and “underneath area” of each pier and grouped by year and county. The general area was as described above, consisting of an area approximately 15 meters wide on either side of the pier and with a length equal to that of the segment of pier crossing marsh habitat. The underneath area was equal to the pier footprint over marsh habitat- as wide as the pier and with a length equal to that of the segment of pier crossing marsh habitat. The indices were calculated using the number of species at a given sampled pier relative to the number of species at all sampled piers rather than using a count of individuals of a certain species relative to the total number of organisms.

2.4.2 Vegetation Transects

Vegetation data was recorded along the same transects and at identical sampling points as the previously described light data. To assess marsh plant presence, plant species were recorded along the transect using a point-intersect method. Along each of the replicate transect lines, a plant species was considered to be present if a stalk was found within an approximately 7.6 cm diameter circular area around the sampling point along the transect. If more than one species was present in this area, each species was recorded. For areas without any species present, the point was recorded as “bare”. For areas covered in debris, the point was recorded as “wrack”.

2.4.3 Ordination Analysis of the Vegetation Community

Using Primer-E (ver. 6) software, non-metric multidimensional scaling (nMDS) was conducted to determine if the plant community both underneath and in the general area around the piers were significantly different based on factors sampled in this study. Pier width bins and the straight-line distance to the Mississippi Sound were identified as potentially informative grouping factors to test. Pier width is a metric that has been integral to each part of this study. Straight-line distance to the Mississippi Sound was used as a proxy for location along the coastal-estuarine salinity gradient. Within the Primer-E 6 software, the vegetation diversity data was transformed using “Log(x+1)”. This data was then formed into a resemblance plot using the Bray-Curtis similarity index. The resemblance plot was assigned the width factor (W= wide and N= narrow), as well as the factor straight-line distance to the Mississippi Sound (in 1-mile increments). nMDS plots were created for each of the factors on all data sets.

2.5 Estimating Pier Density

2.5.1 Pier Counts

Using Geographic Information Systems (GIS) software and images from Google Earth, the number of piers along the MS coast potentially affecting salt marsh was analyzed. First, geographic positioning systems (GPS) locations from each pier site were buffered within GIS using a 0.8 km (0.5-mile) radius and paired spatially to satellite imagery from Google Earth. All pier structures similar in appearance to, and within the 0.8-km radius of, pier sites were manually identified and tallied. For each site, two counts of piers were made. A first count consisting only of similar piers that were visually confirmed to span over marsh habitat was made and a second paired count consisting of both marsh piers and other similar piers that could not be visually confirmed to span over marsh. Further density analysis was conducted using the first count of only the piers over marsh.

2.5.2 Density Estimates

A second method was using the National Oceanographic and Atmospheric Administration (NOAA) Environmental Sensitivity Index (ESI) shoreline data (https://response.restoration.noaa.gov/resources/environmental-sensitivity-index-esimaps) in ESRI ArcMap (ver 10.4.1), a pier density estimate based on shoreline length was produced. Only ESI shorelines categorized as “sheltered vegetated low banks” (9b) and salt- and brackish-water marshes” (10a) were selected to calculate the total marsh shoreline in MS. The total length of each shoreline category was summed and applied (multiplied) to the average pier count across counties in the form of piers per 1.6 km (1 mile) of shoreline (diameter of buffer area). In the same fashion, the NOAA index for shoreline length in MS was applied to the same average pier count across counties.

The third pier estimate method also used ArcMap for analysis. Using the inverse distance weighting (IDW) function in ArcMap, an estimated pier density map was created for the bounds of the sampling area in the three coastal counties. Once the resulting pier density IDW was broken into 21 classes (21 was the maximum pier estimate value), it was converted from raster data to vector data (polygon). The resulting IDW polygons were then intersected with United States Fisheries and Wildlife Service (USFWS) National Wetland Inventory (NWI) data. From the attribute table, the estimated number of piers for each intersected “Estuarine and Marine Wetlands” polygon was calculated. Within the sampling bounds, the total area of all Estuarine and Marine Wetlands polygons should approximate the total marsh area, and the total pier estimate values for each polygon should approximate the total pier count within the marsh area.

CHAPTER III – RESULTS

3.1 Pier Description

Summary statistics were compiled for pier characteristics with bins defined by the median value (see Tables 1 and 2). Transect height varied by year and county (Table 1), with ANOVA tables provided in Appendix B. In general, transects sampled under piers in 2006 (1.11 m average) were less tall (shorter) than transects sampled in 2021 (1.42 m average), ($p=0.001$). Similarly, transects sampled in Jackson County in 2021 were more likely to be shorter than transects sampled in Harrison or Hancock County ($p<0.001$). Pier width was greater in Harrison County when compared to Jackson and Hancock Counties ($p=0.002$). This width distribution was consistent among years. Board spacing was considerably larger in 2006 (2.09 cm) versus 2021 (1.28 cm) across counties, ($p<0.001$). For subsequent analyses, piers and transects were categorized into width and height bins, because there was not a sufficient amount of transects to use the 1-foot height and width increments as categories for analysis. Height bins were designated as Short (S, < 1.22 m) or Tall (T, ≥ 1.22 m). These limits were chosen as the 4-foot height was the median value for all possible heights. Figure 7 shows a histogram of all transect heights. Width bins were designated as Narrow (N, <1.83 m) or Wide (W, ≥ 1.83 m). These bins also represented the median value for maximum representation by each level. Figure 8 shows a histogram of all transect widths.

Table 1: Frequency distribution percentile and measures of central tendency (mean ± S.D.) for piers sampled in two years and three counties.

	2006			2021				Total
	JAC	HAR	OVR	JAC	HAR	HAN	OVR	
Number	20	10	30	15	15	10	40	70*
Height Percentiles**								
Short (< 1.22 m)	65.9	31.9	54.5	54.2	26.9	0	32.3	43.7
Tall (≥ 1.22 m)	34.1	68.3	45.5	45.9	73.1	100	67.7	56.2
Width Percentiles**								
Narrow (< 1.83 m)	43.2	40.9	42.4	41.7	26.9	66.7	40.3	41.4
Wide (≥ 1.83 m)	56.8	59.1	57.6	58.3	73.1	33.3	59.7	58.6
Board Spacing Percentiles***								
< 1.27 cm	25	10	20	93.3	80	60	80	54.3
≥ 1.28 cm	75	90	80	6.7	20	40	20	45.7
Height**								
Average (m)	0.95	1.44	1.11	1.12	1.57	1.68	1.42	1.26
S.D.	1.37	1.88	1.72	0.96	2.01	1.24	1.71	1.78
Width**								
Average (m)	1.75	2.04	1.85	1.82	2.11	1.60	1.90	1.87
S.D.	1.87	1.64	1.84	2.27	1.35	1.54	1.89	1.86
Board Spacing***								
Average (cm)	1.91	2.46	2.09	0.93	1.06	1.52	1.13	1.54
S.D.	0.29	0.31	0.31	0.133	0.11	0.44	0.25	0.34

* - Piers sampled separately in 2006 and 2021 were counted twice for "Total" category

** - Summary statistic calculated using transect attribute data for each category

*** - Summary statistic calculated using pier attribute data for each category

JAC- Jackson County, HAR- Harrison County, HAN- Hancock County, OVR- Overall

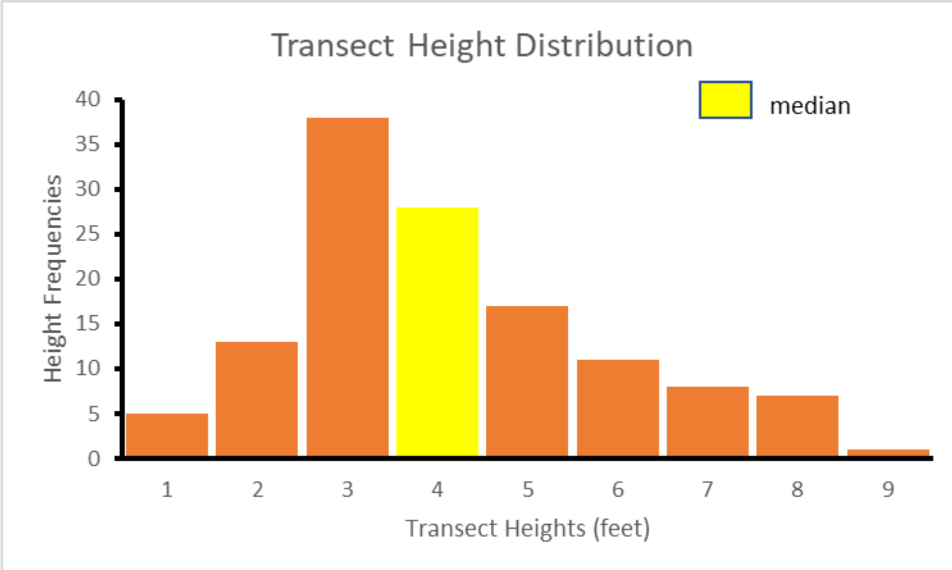


Figure 7: Histogram of pier heights in summer 2021, including median used to create S and T bins for height.

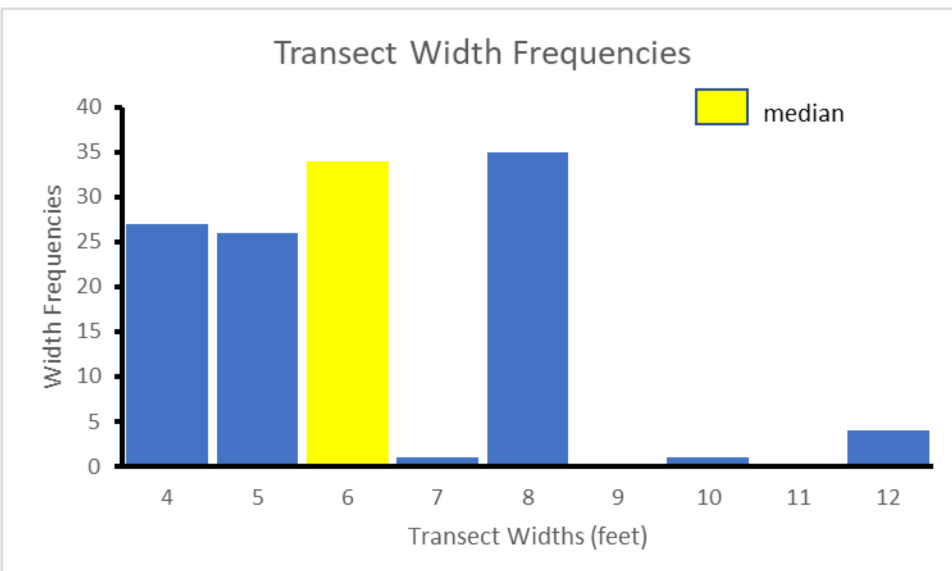


Figure 8: Histogram of pier widths in summer 2021, including median used to create N and W bins for width.

In each combination of year and county, the percentage of North-South oriented piers was equal to or greater than the percentage of East-West oriented piers (Table 2). The mean straight-line distance to the Mississippi Sound was within the range of 2.00-3.40 km for each year and county, with the exception of Hancock County in 2021 at 5.21 km. Pier ownership (public vs. private) was mixed among Jackson County for both year groups. Jackson County piers sampled in this project were 40% public and 60% private in 2006, but 60% public and 40% private in 2021. In both years Harrison County piers were almost entirely publicly owned (100% in 2006 and 87% in 2021), while in Hancock County in 2021 they were mostly private (90%). The overwhelming majority of piers sampled in this project from Jackson and Harrison County in both years were non-compliant, failing to meet the construction codes for 2021. For Jackson County, 95% of piers were non-compliant in 2006, and 100% were non-compliant in 2021. For Harrison County, 100% were non-compliant in 2006, and 80% were non-compliant in 2021. Hancock County (2021), however, had an even mix of non-compliant (50%) vs compliant (50%) piers sampled.

After the majority of sampling took place, hurricane “Ida” (a category 4 storm) made landfall in Louisiana on August 29th, 2021. The Mississippi Gulf Coast was met with destructive storm surges and flooding with surge heights reaching over 10 feet in parts of both Hancock and Harrison counties. Each of the 25 affected pier sites were revisited, and descriptive notes on apparent hurricane damage were taken. The scope of damage to sampled piers was found to be insignificant with only board decking loss at three pier sites. The three piers in question, located in Hancock County, were observed as repaired within weeks of the storm’s landfall.

Table 2: Frequency distribution percentile and diversity indices for piers sampled in two years and three counties.

	2006			2021				Total
	JAC	HAR	OVR	JAC	HAR	HAN	OVR	
Number of Piers	20	10	30	15	15	10	40	70*
Location and Orientation								
Percent (N-S) Orientation	95	50	80	80	53.3	70	67.5	72.9
Percent (E-W) Orientation	5	50	20	20	46.7	30	32.5	27.1
Mean Distance to Sound (km)	2.20	2.82	2.40	2.00	3.40	5.21	3.33	2.93
S.D. Distance to Sound	1.93	0.40	1.60	1.85	1.50	3.91	2.67	2.31
Compliance and Ownership								
Percent Compliant	5	0	3.3	0	20	50	20	12.8
Percent Non-Compliant	95	100	96.7	100	80	50	80	87.2
Percent Public	40	100	60	60	86.7	10	57.5	58.6
Percent Private	60	0	40	40	13.3	90	42.5	41.4
Diversity Indices								
Shannon-Wiener (General)	2.174	2.481	2.595	2.947	3.231	2.781	3.296	3.231
Shannon-Wiener (Under)	1.488	1.862	1.98	2.047	2.691	1.908	2.705	2.652
Simpson's (General)	0.132	0.078	0.088	0.060	0.043	0.059	0.046	0.052
Simpson's (Under)	0.238	0.108	0.131	0.138	0.054	0.144	0.083	0.093

*Piers sampled separately in 2006 and 2021 were counted twice for "Total" category

3.2 Light Analysis

3.2.1 Results from 2021 Light Analysis

I used the transformed average centerline shading percent data in a multifactorial 3-way ANOVA with factors (random effect model) of width (bin), height (bin), and board spacing. The resulting ANOVA table (Table 3) shows that height, width, and board spacing all had a significant effect ($p < 0.001$, $p = 0.002$, and $p = 0.007$ respectively), however, there was no interaction effect among factors. A second multifactorial ANOVA (Table 4) was run with the same factors but with (%Under) as the dependent variable. This yielded similar results, with the exception that the interaction between width and height was now very close to significant ($p = 0.06$). Because there were multiple height/width transects for the same pier, there was potential for autocorrelation bias. To account for this, a mixed-model ANOVA was run with the same factors to account for the potential spatial and temporal bias when sampling at multiple transect locations at a single pier (see appendix B). Very similar results were found between the fixed and mixed-model rounds of ANOVA analysis. Table 5 outlines summary statistics for transects from within respective width and height bins used for analysis. Average width of transects categorized as Narrow (N) was 1.33 m, while the average width of transects labeled Wide (W) was 2.29 m. The average height of transects within the Short (S) bin was 0.80 m, while the average height of transects within the Tall (T) bin was 1.55 m. This differs from the categories determined in Table 1 because heights and width values were not continuous variables. Using the median values to define bins allowed for clean breaks at the 1-foot increments used for height and width data.

Table 3: Multifactorial ANOVA testing %CL across width_bin, height_bin, and board spacing_bin.

ANOVA %CL Box-Cox	Sum of Squares	Df	Mean Square	F	P
Height_bin	31.41	1	31.41	28.27	<0.001
Width_bin	11.66	1	11.66	10.49	0.002
Board Spacing_bin	8.73	1	8.73	7.86	0.007
Height_bin*Width_bin	2.21	1	2.21	1.99	0.163
Height_bin*Board Spacing_bin	3.39	1	3.39	3.05	0.085
Width_bin*Board Spacing_bin	0.01	1	0.01	0.01	0.943
Height_bin*Width_bin*Board Spacing_bin	0.64	1	0.64	0.57	0.453
Residuals	76.67	69	1.11		

Table 4: Multifactorial ANOVA testing %Under across width_bin, height_bin, and board spacing_bin.

ANOVA %Under Box-Cox	Sum of Squares	df	Mean Square	F	P
Height_bin	9.83	1	9.83	16.67	<0.001
Width_bin	5.04	1	5.04	8.56	0.005
Board Spacing_bin	3.39	1	3.39	5.76	0.019
Height_bin*Width_bin	2.15	1	2.15	3.65	0.060
Height_bin*Board Spacing_bin	0.59	1	0.59	0.99	0.323
Width_bin*Board Spacing_bin	0.01	1	0.01	0.01	0.911
Height_bin*Width_bin*Board Spacing_bin	0.34	1	0.34	0.58	0.488
Residuals	40.67	69	0.60		

Table 5: Measures of central tendency (mean ± S.D.) for width and height bins used in ANOVA analysis.

	Bin Characteristics	
Width Bins	Narrow (N)	Wide (W)
Average (m)	1.33	2.29
S.D.	0.49	1.68
Height Bins	Short (S)	Tall (T)
Average (m)	0.80	1.55
S.D.	0.633	1.50

Table 6: One-way ANOVA testing %Under between grate-decked and board-decked transects.

One-Way ANOVA (Welch's)	F	Df1	Df2	P
%Under	65.00	1	8.35	<0.001

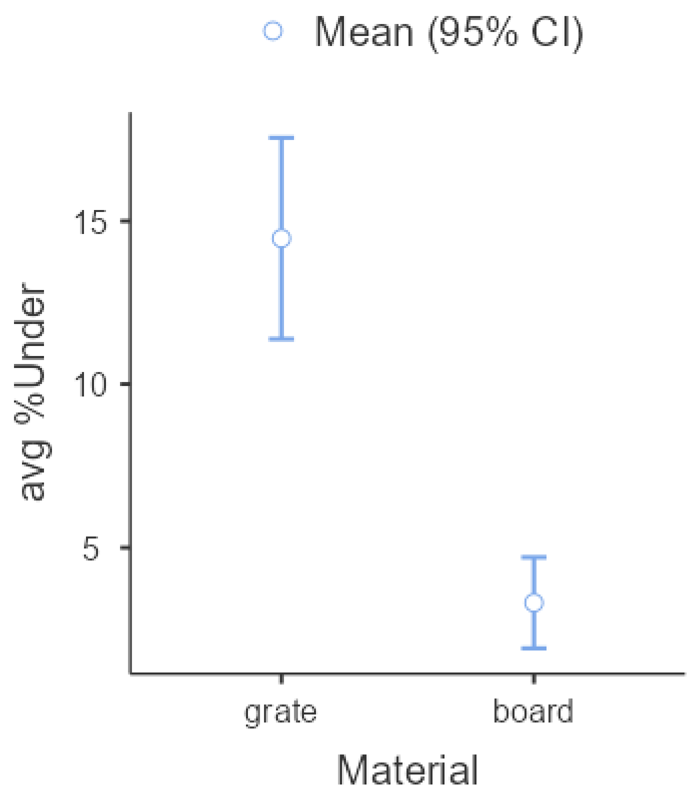


Figure 9: Confidence interval plot of average %Under irradiance observed between board decking and grate decking material.

Table 7: One-way ANOVA testing Box-Cox transformed %Under between narrow and wide board spacing gap.

One-Way ANOVA (Welch's)	F	Df1	Df2	P
%Under	6.75	1	75.4	0.011

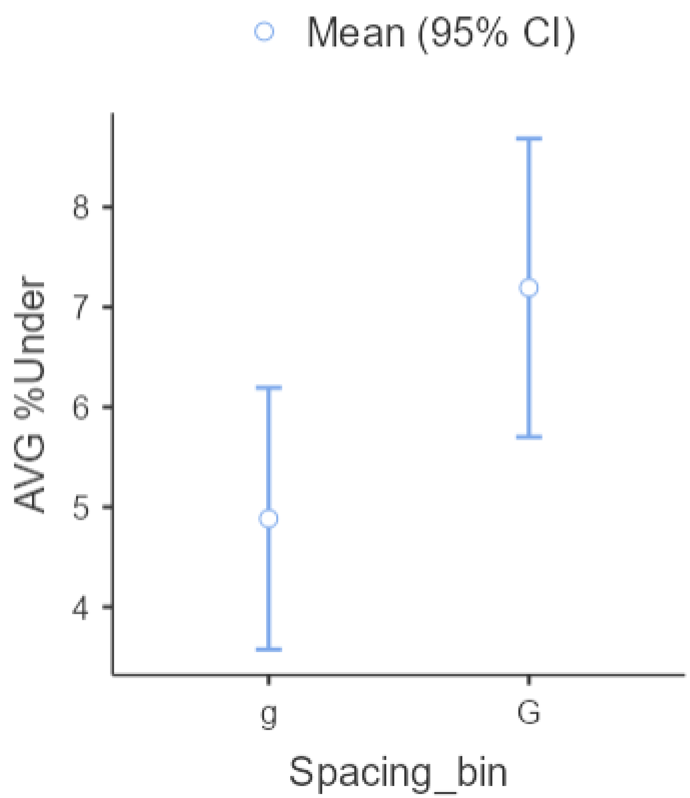


Figure 10: Confidence interval plot of average %Under irradiance values observed between narrow (g) and wide (G) board spacing gap bins.

Analysis regarding decking material revealed that there was a significant difference ($p<0.001$) between %Under values of grate-decked transects and board-decked transects (Table 6). The grate-decked transects had higher %Under values (more light) than the board-decked transects (Figure 9).

A one-way ANOVA for board spacing also resulted in a significant result ($p<0.05$) shown in Table 7. Piers with a board spacing gap of less than 1.27 cm (0.5 in.) created more shade than those with gaps equal or greater than 1.27 cm. The larger spacing gap (G) allowed for higher irradiance to reach underneath the pier structure than the smaller spacing gap (g), (Figure 10).

Neither iteration of pier orientation analysis produced a significant result ($p>0.05$). Table 8 shows the results of both one-way ANOVAs testing Box-Cox transformed %Under values between two predominant pier orientation axes (N-S vs. E-W). The first test, using transects within the normal time window (10:00 A.M. – 3:00 P.M.), produced a p-value of 0.866. The second, using transects sampled at 10:30 A.M. or before or 3:30 P.M. or after, produced a p-value of 0.547. The small sample size (few E-W oriented piers) may have prevented significant findings for orientation analysis.

Table 8: Results of separate one-way ANOVA tests analyzing Box-Cox transformed %Under values across pier orientations.

One-Way ANOVA (Welch's)	F	Df1	Df2	P
Box-Cox %Under *	0.0290	1	26.5	0.866
Box-Cox %Under **	0.3794	1	15.1	0.547

* -Used transects sampled between 10:00 A.M. and 3:00 P.M.

** -Used transects sampled at or before 10:30 A.M. OR at 3:30 P.M. or after

3.2.2 Results Compared to 2006 Light Analysis

Comparison to shading analysis on constructed pier segments performed in 2006 conforms with results from the piers measured during summer 2021 reported here. From the portion of the Biber (2008) study regarding constructed pier segments, those data obtained from an engineered environment and controlled time period (around solar equinox) adds weight to my recent findings about height, width, and board spacing. MDIP values have a strong positive relationship with pier height (Figure 11). Taller pier heights resulted in greater MDIP values, for instance 0.62 m (2') tall piers ranged from 7-35% MDIP, while 1.86 m (6') tall structures were more consistent between 55-65% MDIP (Fig. 11). Furthermore, taller pier heights appear to mitigate the shading effects of narrower board spacing. Larger spacing gaps (3.8 cm) and grating are more effective at allowing light to pass through at shorter pier heights, but had less of a positive enhancement effect as height increased. For example, the mean MDIP value is approximately 7% at the 0.62 m (2') height and 0 cm gap width, while the MDIP value is approximately 35% for the 0.62 m (2') foot height grate sections. This equates to an approximate 28% difference based on board spacing alone. Using the same calculations for the 1.86 m (6') height with the same respecting board spacings, the difference is only approximately 10% (Figure 11).

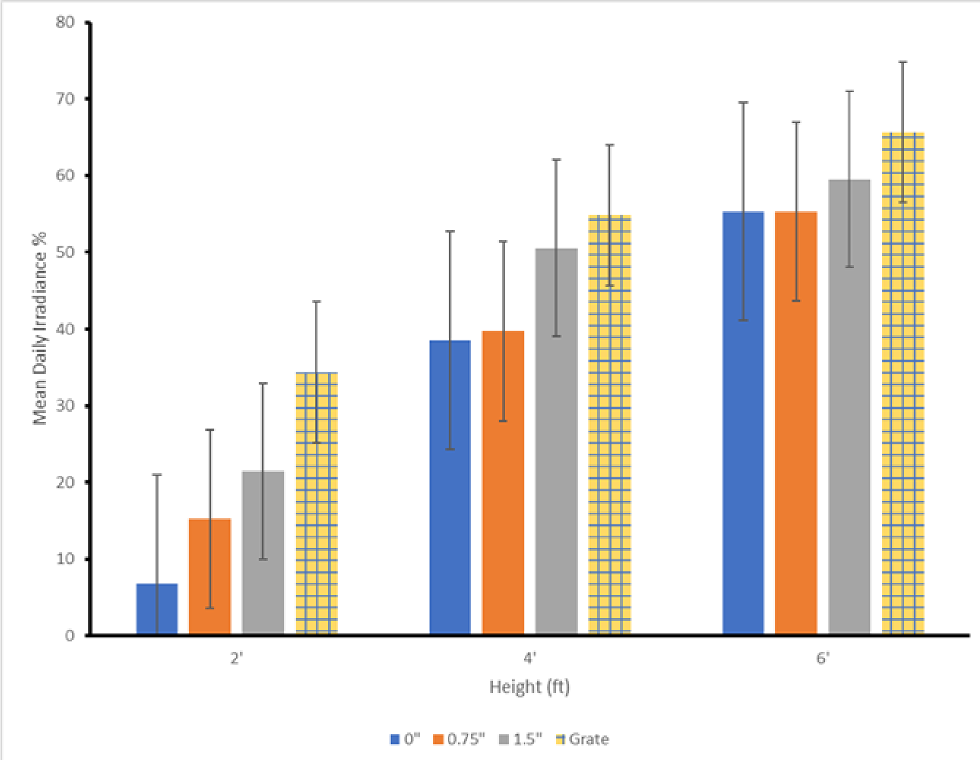


Figure 11: Mean (± s.e.) daily irradiance percent (MDIP) values across 2, 4, and 6 foot pier heights and 0", 0.75", 1.5" board-, and grate-deck spacings.

Figure 12 shows similar results for decreasing pier widths, but to a lesser extent. MDIP values have an inverse relationship with pier width. Narrower pier widths result in higher MDIP values. Pier widths over 1.22m (4') show that board spacing has apparent effects on irradiance values. A threshold seems to exist at the 1.22m (4') width, where board spacing gaps (excluding grate piers) no longer have an effect on shading. Excluding grate piers, MDIP values can differ as much as 15% (6 and 8 foot widths) based on a range of board spacing gaps, while the MDIP differs less than 5% for the 1.22m (4') height with the same spacing gaps.

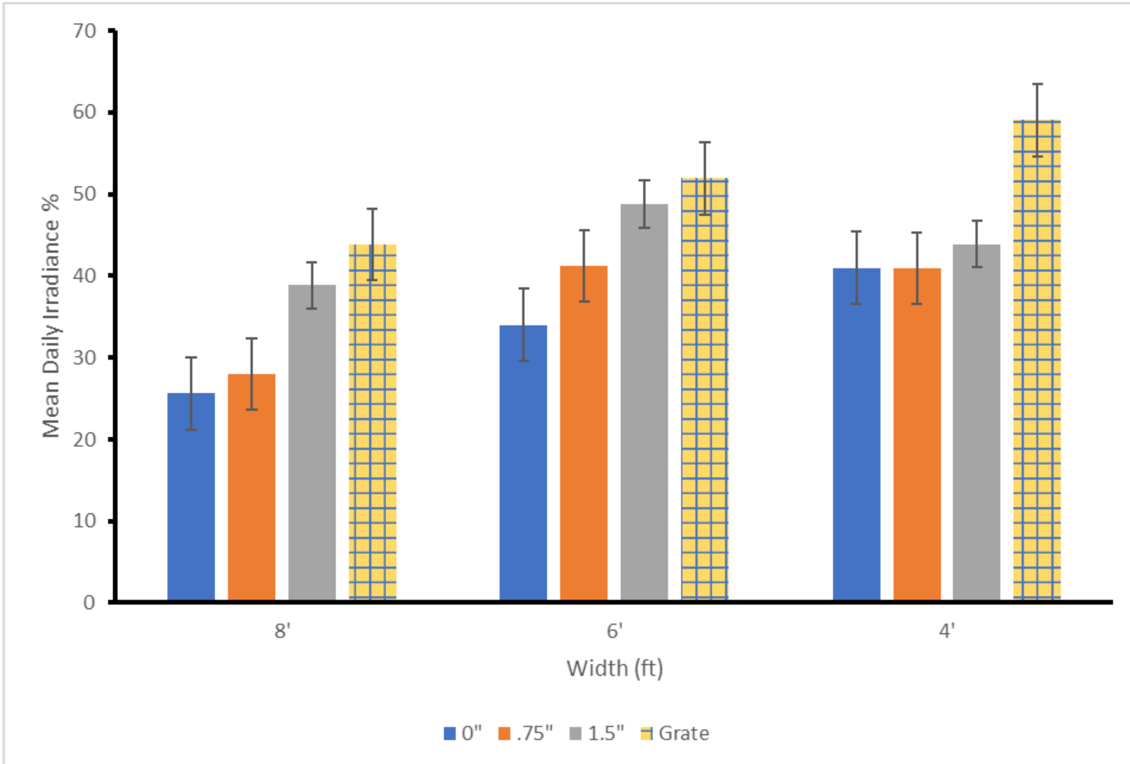


Figure 12: Mean (± s.e.) daily irradiance percent (MDIP) values across 8, 6, and 4 foot pier widths and 0", 0.75", 1.5" board-, and grate-deck spacings.

3.3 Vegetation

3.3.1 Marsh Description

Vegetation data was used to create dominant plant species rankings (Table 9) and diversity indices (Shannon-Wiener and Simpson's). Jackson County sites were dominated by *S. alterniflorus* (SPAL), *J. roemarianus* (JURO), and *Spartina patens* (SPPA). Harrison county was dominated by less saline-tolerant marsh plants such as *Sagittaria lancifolia* (SALA) and *Spartina cynosuroides* (SPCY), among others. Hancock County had high occurrence of high-salinity species such as SPAL and low salinity species such as those of the genus *Schoenoplectus* (formerly *Scirpus*) (SCOL and SCRB).

Table 9: Species occurrence rankings for sample sites in two years and three counties.

	2006			2021			
Rank	JAC	HAR	OVR	JAC	HAR	HAN	OVR
General Area							
#1	SPAL	SALA	JURO	SPAL	SALA	SPAL	SPAL
#2	JURO	JURO	SPAL	JURO	PARE	JURO	JURO
#3	SPPA	SPCY	DISP	SPPA	SCRO	IVFR	SCRO
Underneath Pier							
#1	SPAL	SPCY	SPAL	SPAL	SALA	SPAL	SPAL
#2	DISP	DISP	DISP	JURO	SPAL	SCOL	JURO
#3	JURO	SALA	JURO	SPPA	JURO	SCRO	SALA

USDA plant species symbols were used to represent species. The species represented by symbols in the above table are as follows: SPAL - *Sporobolus alterniflorus* (formerly *Spartina alterniflora*), JURO - *Juncus roemarianus*, SALA - *Sagittaria lancifolia*, DISP - *Distichlis spicata*, SPPA - *Spartina patens*, SPCY - *Spartina cynosuroides*, SCRO - *Scirpus robustus*, SCOL - *Scirpus olneyi*, IVFR - *Iva frutescens*, PARE - *Panicum repens*

Shannon-Weiner and Simpson's diversity indices were calculated separately for the spatial designations of "underneath" and "general area" for each county and year combination. Both indices showed that diversity was lower at the “underneath” area (Total Shannon-Weiner Index 2.652 for “Underneath”, and 3.231 for “General Area” respectively; Total Simpson’s Index 0.093223 for “Underneath”, and 0.052259 for “General Area” respectively). Harrison County had the highest vegetation species diversity across both years. (Table 2).

3.3.2 Vegetation Diversity Analysis

There was no clear delineation between factor levels for pier width or distance from MS Sound in any of the nMDS plots. Slight grouping differences can be identified for the “2021-General-Width” and “2021-General-Distance” plots (Figures 13.1 and 13.2). This may be incidental or due to variables not investigated in this study, as these differences were only observed in the general area plots. The vegetation composition from these “general area” datasets is unlikely to be impacted directly as a result of pier shading effects. Example nMDS plots for each factor and dataset can be seen below (See Appendix C for additional nMDS plots).

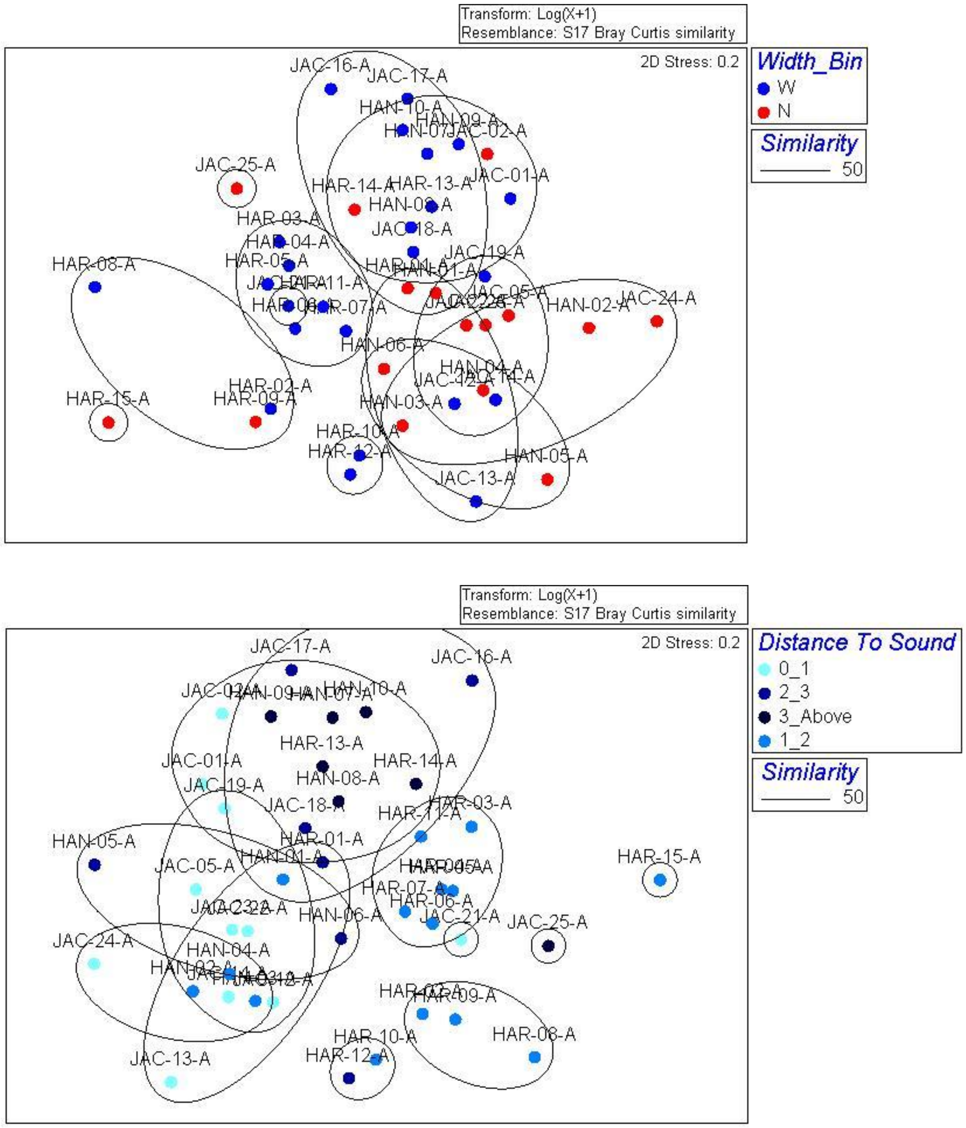


Figure 13: Non-metric multidimensional scaling plot analyzing vegetation communities among the "general area" portions of 2021 pier sites. 13.1 (Top panel) - Sites are identified by the Width_bin factor levels Wide (W) or Narrow (N). 13.2 (Bottom panel) - Sites are identified by the Distance to Sound factor levels: 0-1, 1-2, 2-3, 3 and above (miles).

3.4 Pier Density

3.4.1 Pier Counts

Table 10 shows results in the form of average pier count within the circular 0.8 km (0.5 mile) buffer area. In Jackson County, there was an average count of 8.87 marsh piers and 10.27 total piers within this buffer area. Harrison County averaged 12.93 and 25.8 piers respectively. Hancock County averaged only 3.5 marsh piers, but 16 total piers. Across counties, there were average counts of 9.05 marsh piers and 17.53 total piers within the 1.61 km (1 mile) circular buffer area. A one-way ANOVA test using marsh pier counts obtained within this standard circular buffer area and tested at the county level resulted in a very significant P-value ($P < 0.001$), indicating that there were differences in pier densities among counties, with Harrison County having significantly higher pier density than both Jackson and Hancock Counties. (Table 11).

Table 10: Measures of central tendency (mean ± S.D.) for pier counts in each of three counties in 2021.

	Similar Piers Within 805 m (0.5 mile) Radius of 2021 Sites			
All Environments	JAC	HAR	HAN	OVR
Average	10.27	25.80	16.00	17.53
S.D.	6.19	10.81	13.80	12.12
Marsh Habitat Only				
Average	8.87	12.93	3.50	9.05
S.D.	5.33	7.27	1.65	6.59

Table 11: One-way ANOVA testing pier counts across counties.

One-Way ANOVA (Welch's)	F	Df1	Df2	P
Similar Marsh Piers	16.4	2	21.9	<0.001

3.4.2 Environmental Sensitivity Index (ESI), NOAA Shoreline, and National Wetland Inventory (NWI)-Based Density Estimates

Using ESI shoreline lengths categorized as "sheltered vegetated low banks" (9b) and salt- and brackish-water marshes" (10a), the number of piers was estimated at 11,145 over 1,981 km (1,231 miles) of shoreline. Using the NOAA index for total shoreline length, the number of piers was estimated at 3,249 across 578 km (359 miles).

The estimated number of piers on NWI classified "Estuarine and Marine Wetlands" polygons totaled 591 piers over approximately 189 square kilometers (73 sq. miles) within the sampling bounds. It should be noted that the sampling bounds did not extend all the way to the western or eastern Mississippi state line, nor to the western border of Hancock County or the eastern border of Jackson County. Table 12 shows estimates for number of piers based on the three different techniques.

Table 12: Tally of marsh pier estimates for the Mississippi Gulf Coast across ESI, NOAA index, and NWI-based techniques.

	ESI	NOAA	NWI
Marsh Pier Estimate	11,145	3,249	591

CHAPTER IV – DISCUSSION

4.1 Real-World Pier Characteristics

With the amount of sampling conducted, we were able to assess what a typical pier for MS would look like. Based on all transects, average height was 1.26 m (4.13ft), average width was 1.87 m (6.14 ft), and average board spacing was 1.54 cm (0.61 in) – See Table 1. Likely as a result of simple geography and a predominantly East-West oriented shoreline on the MS Gulf Coast, an average pier will most likely be oriented North-South. Approximately 73% of all piers sampled were oriented North-South.

After inquiry about records of pier permits from the MDMR, data was provided from permits issued from years 2002-2022. After permits that were unapproved were removed, a tally of what pertinent information was available is summarized in Table 13. Across counties over a considerable time period, the permitting data shows pier widths remain consistent, averaging approximately 1.76 m (5.77 ft). This value is very close to the 1.87 m (6.14 ft) average across years and counties that we found from field sampling. The difference may be explained by the higher amount of public (wider) piers sampled.

Table 13: Table showing total pier permits approved by MDMR and average widths across counties from years 2002-2022.

	JAC	HAR	HAN	Total
Total Pier Permits	1,330	2,051	1,746	5,090
Average Width (m)*	1.76	1.76	1.75	1.76
Standard Deviation	2.54	2.50	2.43	2.49

* Piers reported with a width of over 12 feet were removed from the compilation

4.2 Light Factors

4.2.1 Height and Width

Both height and width were shown to have significant effects on the amount of light able to reach the substrate. Lesser pier heights and greater deck widths were shown to create more shaded environments underneath those piers. This supports the first portion of hypothesis 1, that height has a significant effect on shading. The second portion of hypothesis 1, predicting that height has the greatest impact on shading also has support from the results presented here. The 2006 continuously collected light data suggests that changes in pier height affect irradiance greater than other factors. How much of an effect height and width have, however, is likely tied to other factors as well. In this study, both board spacing and decking material were suggested to impact light threshold heights and widths for dominant marsh plant species (discussed below). Within the 2006 light analysis, there was some evidence that at very low heights (<4 feet) other factors may have increased impacts on shading values underneath the pier structure.

Aside from direct shading impacts, tall and/or wide piers can have greater environmental impact footprints. Not only do they require extra material, but they also require heavier equipment to construct. Heavy equipment operation in a saltmarsh can be detrimental to its integrity. The plants are often laid over, and the root structure is destroyed when run over repeatedly by construction equipment (Kelty and Bliven 2003). Even small elevation changes from tracks, tires, or barges can inhibit vegetation growth for long periods of time and promote erosion when introduced to tidal flow. Figure 14 illustrates damage from a tracked vehicle at site HAR-05-B (8 ft width) at a newly constructed pier in 2006. Figures 15, 16, and 17 show the heavy equipment damage is still evident 15 years later at site HAR-05 in 2021. Figure 18 illustrates recent heavy equipment damage at site JAC-12-A (10 ft width) in 2021. The pier at JAC-12-A was recently rebuilt and sections not studied were still under construction.

Figure 14: Image of heavy equipment damage at site HAR-05-B in 2006.

Figure 15: Image of heavy equipment damage at site HAR-05-A in 2021.

Figure 16: Image of heavy equipment damage at site HAR-05-A in 2021 (opposite side).

Figure 17: Aerial image of heavy equipment damage at site HAR-05 (Google Earth).

Figure 18: Image of heavy equipment damage from site JAC-12-A in 2021.

4.2.2 Board Spacing

The gap spacing between decking boards as a factor affecting shading was shown to have an impact in certain circumstances. Analysis showed that there were significant differences in irradiance values based on the spacing bins selected. From the 2006 analysis, with piers of lesser heights and greater widths, the board spacing is more likely to have an impact on irradiance underneath than is the case for taller or narrower piers. On the other hand, for those piers with greater heights and lesser widths, board spacing did not play a major role in irradiance. Differences in board spacing have many practical implications as well. An important reason to have spacing between boards is to allow for shrinking and swelling of the material. If no gap is in place, the material can warp and create an uneven surface. The gap distance may also play a role, albeit small, on material cost savings. The wider the gaps, the less material is needed for decking. The obvious limitation to how wide the gaps can be, however, is safety and the possibility of losing items between boards. Considerations of irradiance for plants underneath may not be the top priority for board spacing, but it should not be ignored either.

4.2.3 Decking Material

The importance of testing the effectiveness of alternative decking materials at providing an increase in light availability underneath piers is attested by Steinmetz et al. (2004). The difference in irradiance underneath the piers between the two decking materials tested was conclusive. Across all scenarios, grate decking was shown to more positively affect light passage when compared to board decking of any board spacing. As a result, we can reject hypothesis 2 that suggests there is no difference between irradiance values between board and grate-decked piers. This conclusion contradicts what was found by Logan et al. (2018) in the Northeast U.S. (New England). This is likely a result of the difference between the generally higher solar zenith angles at the lower latitudes of Southern Mississippi and the lower solar angles of New England. For example, Figures 19 and 20 show the pier at site HAN-06-A. This pier has grate decking and the limited impact on the vegetation as a result of shading is evident. In contrast, Figure 21 shows the pier at JAC-01-A. This pier has board decking and the vegetation underneath appears to display shading stress.

Figure 19: Image of pier at site HAN-06-A.

Figure 20: Closer image of grate-decking and vegetation at site HAN-06-A.

Figure 21: Image of pier at site JAC-01-A demonstrating lack of vegetation underneath pier, probably from prolonged shading.

Aside from shading analysis effects reported here, grate decking has other potential practical benefits for the environment and for those funding pier construction. Grate decking can be made of different materials such as galvanized steel, aluminum, fiberglass, and most commonly polymer material. Each of these materials is likely to outlast wooden boards in the elements. Grates are also less likely to detach from pier pilings in the event of storm surge or other high-water events, as the water can freely pass through the grate mesh without applying excessive upward pressure. When decking is removed during high water, the boards are often washed shorewards and can damage other marsh vegetation. Not only this, but the decking has to be replaced after each occurrence which means additional cost and potential disturbance to the surrounding substrate and vegetation. Grate decked piers will usually cost more up front but can make financial sense when a longer time period is considered. Table 14 estimates costs per square foot of grate versus board decking materials and associated extra costs of grate-decking implementation. A 4-foot wide by 100-foot long pier constructed with grate decking would cost a minimum of approximately $2,775 greater than one constructed with traditional wood decking based on material prices in August 2022.

Table 14: Cost analysis comparison for constructing piers with different grate materials and traditional board decking.

		Impact Thruflow™	HarborWare	Fibergrate	Traditional Wood*
Deck Only	Price/ft^2	$8.35	$14.83	$23.92	$1.80
	Total****	$3,340	$5,932	$9,568	$720
Deck and Extra Materials**	Price/ft^2	$8.74	$15.22	$24.31	$1.80
	Total****	$3,495.96	$6,087.96	$9,723.96	$720
Additional Cost***	Price/ft^2	$6.55	$13.03	$22.12	-
	Total****	$2,775.96	$5,367.96	$9,003.96	-

* Based on standard 2”x6”x8’ board size. Treated 2.5 CCA wood is used for saltwater decking.

** Extra materials required is based on 16” stringer (pier substructure component) spacing requirement for grate-decking versus standard 24” stringer spacing for board decking.

*** Additional cost is based relative to standard board decking.

**** Based on a 4-foot wide by 100-foot long pier structure.

Online resources were used to determine prices for grate materials. The following websites were used for price data: Impact Thruflow™: www.havendock.com; HarborWare: www.harborware.com; Fibergrate: www.zoro.com; Mike Arguelles, of Arguelles Marine Contracting in D’Iberville, MS, provided information on wood decking material costs and the extra costs associated with constructing a pier with grate decking.

4.2.4 Orientation

No clear conclusions can be drawn from the analysis conducted about pier orientation’s effects on irradiance underneath the pier. The study design used here was not optimized for detecting orientation affects. There was not a large sample size of transects available for E-W oriented piers that were sampled early and late in the day. To detect orientation differences it would also be ideal to take continuous irradiance measurements across several days and at exact 0°, 45°, 90°, and 135° degree orientations, as used in Alexander (2012). This could be conducted similar to the methods of Biber (2008) with constructed pier segments.

4.3 Plant Success

Success as determined by plant species diversity indicated a difference between the general area around a pier site compared to directly underneath the pier, based on the result from the diversity indices. This supports hypothesis 3, suggesting diversity underneath piers may be limited by shading effects. From personal experience during sampling, I believe that this result accurately reflects what is occurring in the field. Underneath most piers the vegetation is not only less diverse, but is also generally more sparse. This may be a result of multiple different effects of piers. Shading may affect the diversity by way of simply reducing abundance, therefore reducing the likelihood of a particular species being present. Another very likely way shading can affect diversity is shade-tolerance of different plant species. Shade-intolerant plants would be less likely to succeed underneath a pier. Another observed effect is the elevation difference underneath and around the piers. Lower elevations in the salt marsh are more often inundated, excluding many of the high marsh species. The most obvious explanation for the elevation difference is the heavy equipment use left after construction. Another construction technique that can lower elevation around a pier is the pile-driving process. This can destabilize the sediment and promote erosion. A less obvious explanation for the elevation difference is the loss of vegetation underneath the pier due to shading, and the subsequent erosion that can occur underneath the pier.

The 2006 study provided an important baseline for shade-tolerance in two marsh plant species of interest. *S. alterniflorus* and *J. roemarianus* are both dominant marsh plants in Mississippi saltmarshes (Eleuterius and McDaniel 1978, Cho et al. 2012). Each species exhibited similar shade tolerances. Each were relatively successful in shade percentage treatments of less than 80%, or irradiance percentages above 20%. In irradiance percentage treatments below 20%, both species ceased reproductive efforts. In irradiance percentage treatments below 10%, most plants died within 4-6 weeks. Figure 22 shows plant responses to varying shade treatments.

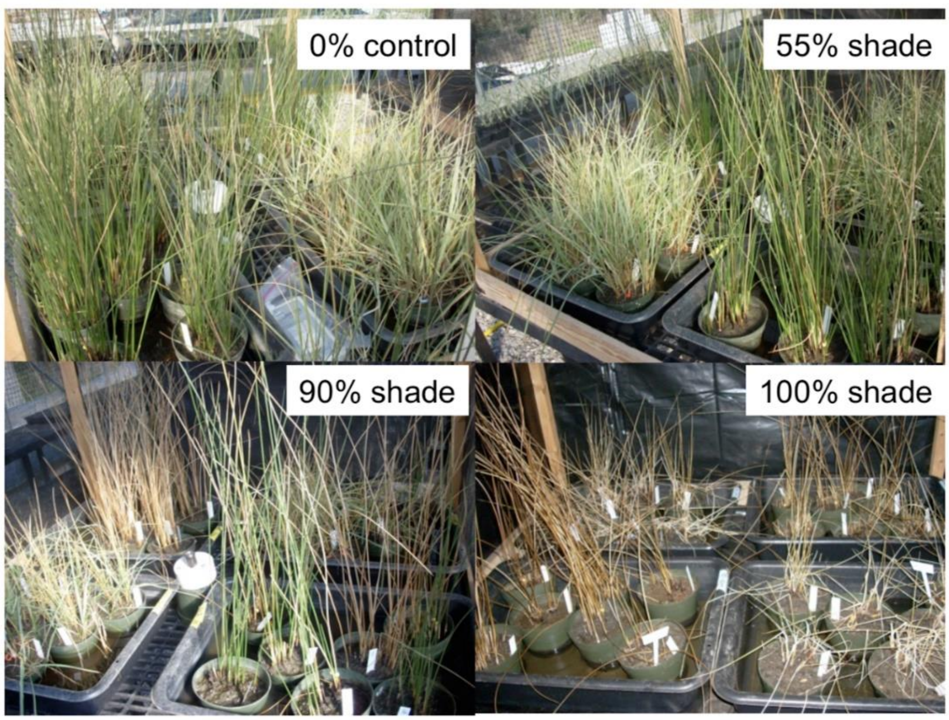


Figure 22: Image illustrating shading response of Juncus roemerianus to shading percentage treatments after 3 months.

Table 15 shows average irradiance percentages for sampled transects from board-decked piers and between 10:00 A.M. – 3:00 P.M. CDT. Across all combinations of height and width bin categories, the irradiance percent is shown to average below the 10% threshold for survival. Table 16 shows the average irradiance percentage values for grate-decked transects. Grate-decked transects averaged 7.98% irradiance for CL locations which is below the 10% survival threshold and 14.47% irradiance for Under values, which is below the 20% reproduction threshold. The Under value best captures the shading profile of a grate-decked pier. Based on what was found with shading stress for each species, I can accept hypothesis 4 that shading stress is likely taking place for each pier type, although grate-decked piers should be less restrictive.

Table 15: Mean ± S.D. irradiance percentage values for transects from board-deck piers labeled in height and width bins used for light analysis.

	Narrow/Short	Narrow/Tall	Wide/Short	Wide/Tall	Total
		CL (Center-line)			
Mean ± S.D.	4.30 ± 3.97	4.44 ± 3.98	4.02 ± 3.88	4.23 ± 3.98	4.26 ± 3.95
		Under			
Mean ± S.D.	5.92 ± 4.26	6.06 ± 4.26	5.62 ± 4.26	5.84 ± 4.26	5.85 ± 4.22

Table 16: Mean ± S.D. irradiance percentage values for all grate-decked pier transects.

	Grate-Decking	
	CL (Center-line)	Under
Mean ± S.D.	7.98 ± 4.48	14.47 ± 3.34

4.4 Potential Scope of Impacts

The attempts to estimate how many piers occur on the Mississippi Gulf Coast and have the potential to impact salt marshes through shading did not provide as clear of an answer. Using aerial/satellite photography to count piers presented two main issues. First was the difficulty of determining piers that spanned only over marsh habitat versus piers that may be build off a bulkhead or just over a lawn-type vegetation. For example, where a lawn may end, there may be a 20-foot-wide strip or zone of marsh habitat that is not distinguishable from some of the available imagery. The second issue was determining what spatial unit and associated wetland data to use when trying to account for pier density (number per unit space). Both shoreline length and marsh area were used in these attempts, although neither may have been ideal. Using the ESI shoreline length of habitat types 9b and 10a to extrapolate pier counts almost certainly overestimated the amount of marsh piers (Marsh pier estimate = 11,145), possibly because the ESI data included shorelines of very narrow and likely shallow bayous and other waterbodies unlikely to have pier development. The pier estimate from using the NOAA shoreline value may have also overestimated marsh piers (Marsh pier estimate = 3,249), as extrapolation was to the total shoreline, not just vegetated marsh shorelines. Using the pier density by area technique and NWI wetland data may have been closest to reality (Marsh pier estimate = 591), although there is not a practical way of confirming it aside from an in-situ count.

Table 13 shows the total amount of piers permitted in the last 20 years by MDMR, but does not distinguish between piers that cross over marsh habitat versus piers that do not. From the data provided by the MDMR, it appears that only the vegetation on water bottom is recorded for pier construction permits. Table 17 outlines summary statistics for both marsh and non-marsh pier counts. The ratio of marsh pier count to total pier count was calculated. This proportion of marsh piers to total piers multiplied by the total number of permits issued by the MDMR provided another estimate of total marsh piers. Using this method, the total marsh pier estimate for all counties was 2,647 piers. Estimates on the county level were also made to compare potential areas of greater concern.

Table 17: Summary statistics for pier counts of both all piers and only marsh piers by county. Included is the proportion of marsh piers and a total marsh pier estimate by county based on the marsh pier ratio and MDMR permit data.

County	JAC		HAR		HAN		OVR	
Status	All Piers	Marsh Piers	All Piers	Marsh Piers	All Piers	Marsh Piers	All Piers	Marsh Piers
Mean Count ± S.D.	10.27 ± 6.19	8.87 ± 5.33	25.80 ± 10.81	12.93 ± 7.27	16 ± 13.80	3.5 ± 1.65	17.53 ± 12.12	9.05 ± 6.59
Ratio of Marsh Piers	0.86		0.50		0.22		0.52	
Marsh Pier Estimate*	1,144		1,026		384		2,647	

* Based on number of MDMR pier permits issued since 2002 multiplied by ratio of marsh piers to all piers calculated from the google earth pier count described previously.

4.5 Management Implications

4.5.1 Current Management

Current pier permit regulations are under the jurisdiction of the Mobile District of USACE. In coastal Mississippi, permits are submitted to- and enforced by MDMR. Table 18 summarizes pier dimension requirements across time starting in 2007 for Mississippi piers to be built over “non-forested wetlands”. The width maximum started at 4 feet in 2007, then increased to 5 feet in 2013, and increased again in 2018 to 6 feet. The minimum height has remained consistent at greater than or equal to the width of the respective pier. The board spacing minimum was set at 0.5 inches in 2007, but that stipulation was not made in subsequent years. Maximum length started at the lesser distance between 25% of the water body or 300 feet in 2007. Currently, the maximum length is the lesser between 25% of the water body or 1,000 feet. There was no requirement for any year regarding pier orientation. Requirements effective in 2017 for Florida were also included to provide a comparison. In Florida, separate dimension requirements were outlined if the pier was constructed over marsh versus submerged aquatic vegetation (SAV). For the piers constructed over marsh there was a 4-foot width maximum, a 4-foot height minimum, but no board spacing, length, or orientation requirements. The notable stipulation for piers to be constructed over SAV beds in Florida is the requirement that they be oriented N-S.

Table 18: Dimension requirements for piers built over saltmarsh or seagrass based on time period and state.

	Width Maximum	Height Minimum	Board Spacing Minimum	Length Maximum	Orientation Requirement
Mississippi USACE-2007	4 feet	1:1 Height:Width Minimum	0.5 inches	25% of waterbody or 300ft (lesser)	None
Mississippi USACE-2013	5 feet	1:1 Height:Width Minimum	None	25% of waterbody or 300ft (lesser)	None
Mississippi USACE-2018	6 feet	1:1 Height:Width Minimum	None	25% of waterbody or 1000ft (lesser)	None
Mississippi USACE-2022*	6 feet	1:1 Height:Width Minimum	None	25% of waterbody or 1000ft (lesser)	None
Florida USACE-2017 (Marsh)	4 feet	4 feet (1:1) Height:Width	None	None	None
Florida USACE-2017 (SAV)	4 feet	5 feet	0.5 Inches	None	North-South

* Document still in review at time of analysis in 2022

4.5.2 Potential Improvements

The dimension requirements for newly constructed pier structures over salt marsh habitat have become more relaxed over time. This is puzzling, as the area of salt marsh habitat has only lessened over the same time period in the Northern Gulf of Mexico and elsewhere. The fringe-marsh, an area often intersected by piers, is characterized by a narrow zone of marsh between the water's edge and upland (or lawn). These areas are particularly susceptible to loss through encroaching human development coupled with sea-level rise (Mattheus et al. 2010). Changing permitting requirements should be based on science; this is partly the impetus of this series of studies. As a suggestion based on the results found here, there can be improvements made upon the current set of regulations. Table 19 shows recommended dimension requirements for new construction piers built over salt marsh habitat in Mississippi. For private piers, the proposed board-decked requirements are identical to Mississippi requirements from 2006. The width maximum minimizes the shading effects without being impractical. It is wide enough to walk or use a wheelchair on. The height minimum here serves two purposes: to minimize effects from perhaps the most important shading factor and to help prevent damage to the pier and the marsh during high water events. Logan et al. (2018) also suggests that this widely used 1:1 minimum height-to-width ratio reduces shading impacts. Board spacing was shown to have an effect on heights up to 4 feet and does not have serious costs associated with it, so a 0.5 inch requirement makes financial and ecologic sense. The length maximum of a pier may also need to be limited from the potentially 1,000-foot length maximum stipulated in recent years. To fulfill their purpose, some piers need to span long distances, but potentially intersecting 1,000 feet of marsh habitat can have negative consequences such as simply losing square footage of marsh, eroding a long "channel" underneath the pier, or even creating a movement barrier dividing the habitat (Banning et al. 2009). A North-South pier orientation requirement is recommended as a best management practice (BMP) for New England estuaries (Logan et al. 2021), but there is not enough evidence as of now to make informed recommendations about significance of orientation on pier shading at the latitudes of southern Mississippi.

Public piers are often constructed in larger dimensions for easy access and safety concerns. Table 20 outlines the differences in height, width, and board spacing among public and private piers sampled in this study. Sampled public pier heights average nearly a foot taller than private pier heights (4.36 feet vs. 3.46 feet respectively). Sampled public pier widths average two feet wider than those of private piers (7.05 vs. 4.96 feet respectively). Table 21 uses a one-way ANOVA testing %CL across public and private piers. It suggests there is a significant difference in how public and private piers affect shading, producing a p-value of 0.011. This difference can likely be attributed to the generally larger dimensions of public piers as outlined previously. If a larger pier for public use is desired, recommended dimensions are also listed here with an option to use grate-decking as an alternative to board-decking. A separate grate-decked requirement would allow larger piers to be built with minimal or no extra impact to the environment. A width of 8 feet would allow for more space but would still allow sufficient light to pass and limit need for heavier equipment. Each of the grate materials found for the cost analysis above are currently made in 4-foot wide sections, so a grate-decked width requirement between four and eight feet would likely be impractical. A height requirement of 4 feet allows users of the pier to feel safer closer to the ground versus a 1:1 height-to-width ratio and makes accessing the water or a boat easier. This height would still allow light passage and enough room for most marsh plant species to grow underneath. The recommended requirements for public board-decked piers is identical to that of current requirements outlined by the USACE.

Table 19: Recommended dimension requirements for board-decked and grate-decked piers over salt marsh habitat.

Deck Material	Width Maximum	Height Minimum	Board Spacing Minimum	Length Maximum	Orientation Requirement
Private					
Board or Grate-Decked	4 feet	1:1 Height:Width Minimum	0.5 inches (Board-Decked)	25% of waterbody or 300ft (lesser)	None
Public					
Board-Decked	6 feet	1:1 Height:Width Minimum	0.5 inches	25% of waterbody or 1000ft (lesser)	None
Grate-Decked	8 feet	4 feet	N/A	25% of waterbody or 1000ft (lesser)	None

Table 20: Mean and standard deviation of height, width, and board spacing among public and private piers used in light sampling.

	Height	Width	Board Spacing
Private*			
Mean ± S.D.	3.46 ± 1.46	4.97 ± 1.15	0.628 ± 0.347
Public*			
Mean ± S.D.	4.36 ± 1.86	7.05 ± 2.06	0.561 ± 0.301

*Limited to piers used for light analysis

Table 21: One-way ANOVA testing %CL values between public and private piers.

One-Way ANOVA (Welch's)	F	Df1	Df2	P
%CL Box-Cox	6.88	1	74.2	0.011

Based on piers sampled combined with height and permitting requirements in effect right now, there may be ineffective enforcement. Even considering the amount of public piers sampled, the percentage of sampled piers that are non-compliant is alarming. This is an issue that may not be isolated to the Mississippi Gulf Coast, as Shafer et al. (2008) found similar non-compliance issues in Florida and Puerto Rico. Most permitting departments of state agencies are supposed to visit piers during construction and upon completion for confirmation of compliancy, although the Division of Coastal Management (DCM) in North Carolina has gone as far as conducting arial surveys quarterly to monitor new development and compliancy (Patterson 2003). While the former may be an extreme example, improvements with regards to enforcement of permit requirements would be essential to mitigating effects of piers and their construction. Table 22 outlines compliance and ownership percentages for piers sampled in this study.

Table 22: Compliancy and Ownership Percentages based on Piers Across Counties for both years.

	Compliant*	Non-Compliant*	Public	Private
Percentage **	12.8	87.2	58.6	41.4

* Based on piers, not transects. Non-compliant piers may have compliant and non-compliant transects.

* * Percentage totals across all county and year groups.

CHAPTER V – CONCLUSIONS

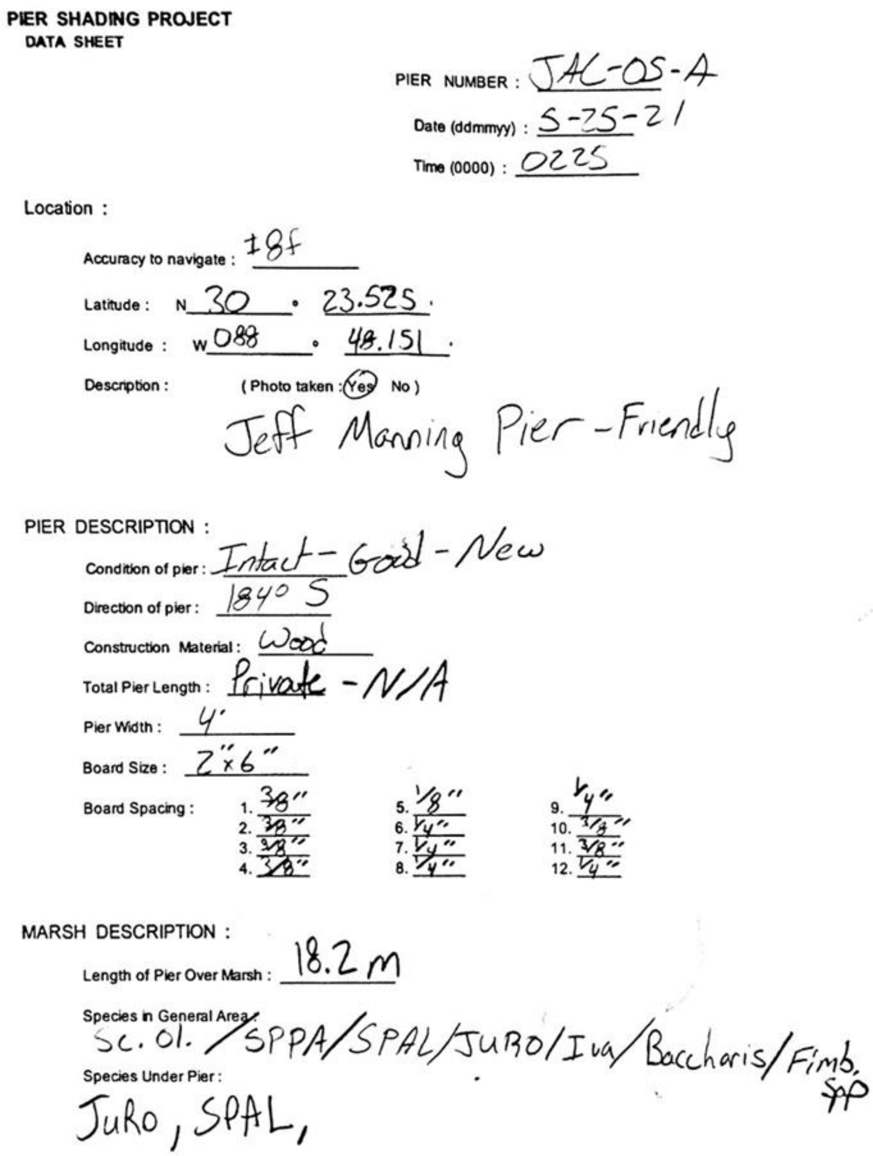
5.1 Conclusions

The value of saltmarshes has been widely documented (Barbier et al. 2011). The saltmarshes of the northern Gulf of Mexico are particularly vulnerable to erosion and ongoing loss as a result of their geology and geography. These shorelines are characterized by gently sloping elevations, relatively strong wave action, and increased susceptibility to sea level rise (Kennish 2001). Therefore, it is important to mitigate negative effects under direct control of coastal resource management agencies, developers, and landowners alike.

It is apparent that pier shading can have a negative impact on salt marsh plants. The most important factors considered here were height and decking material. Taller pier heights allowed more ambient light to reach the substrate during mid-day and direct light to reach the substrate for a greater amount of the daylight hours. Grate decking material allowed for greater amounts of light to pass through the deck to the substrate when compared to traditional board decking. Other factors such as width and board spacing were shown to have significant impacts, but were likely influenced by pier height. Narrower widths and greater board spacing gaps promoted higher irradiance values beneath the piers. Differences found amongst decking material were particularly important, as they suggested grate decking may have an increased effect at the lower latitudes of the Mississippi Gulf Coast versus the higher latitudes where much of previous research has been conducted. Dimension requirements outlined above were recommended based on results found here, as well as shading stress information of *S. alterniforus* and *J. roemarianus* from the prior study conducted in 2006.

If optimized strictly for preservation of the saltmarsh habitat, the suggested permitting requirements (Table 19) would likely become more stringent, but it is important to consider the limited scope of potential impacts and the value of pier development with respect to the value to local economies and access to natural resources. Although the estimates of number of piers over saltmarsh made here vary widely, it is suspected that the lower estimates probably more accurately represent reality. Sanger et al. (2004) estimated that the potential salt marsh area lost as a result of pier shading in South Carolina totaled approximately 0.1% or less of the state-wide saltmarsh area. As large areas of Mississippi's saltmarsh habitat, specifically areas at the mouth of the Pearl and Pascagoula rivers, mostly lack pier development, it is likely that the total area affected by pier shading is very small as well. Coastal waterfront properties, particularly those with easy access to the water, demand a premium price relative to those without water access (Dahal et al. 2021; Jauregui et al. 2019). For a state with below average incomes (U.S. Census Bureau 2021) and limited appeal, coastal Mississippi's blue-economies rely on attractive waterfront properties to bring wealth in. Aside from economic values, piers provide important interaction services with the estuarine ecosystem (Barbier et al. 2011). Ironic to the basis of this study, that value accrued from interaction may assist in public interest for conserving saltmarshes.

APPENDIX A – Datasheet Used



PIER SHADING PROJECT
DATA SHEET

PIER NUMBER : JAC-OS-A
Date (ddmmyy) : 5-25-21
Time (0000) : 0225

Location :

Accuracy to navigate : ±8f
Latitude : N 30 • 23.525 .
Longitude : W 088 • 48.151 .
Description : (Photo taken : Yes No)
Jeff Manning Pier - Friendly

PIER DESCRIPTION :
Condition of pier : Intact - Good - New
Direction of pier : 184° S
Construction Material : Wood
Total Pier Length : Private - N/A
Pier Width : 4'
Board Size : 2"x6"
Board Spacing : 1. 3/8" 2. 3/8" 3. 3/8" 4. 3/8" 5. 1/8" 6. 1/4" 7. 1/4" 8. 1/4" 9. 1/4" 10. 3/4" 11. 3/8" 12. 1/4"

MARSH DESCRIPTION :
Length of Pier Over Marsh : 18.2 m
Species in General Area : Sc. ol. / SPPA/SPAL/JURO/Iva/Baccharis/Fimb. sp
Species Under Pier :
JURO, SPAL,

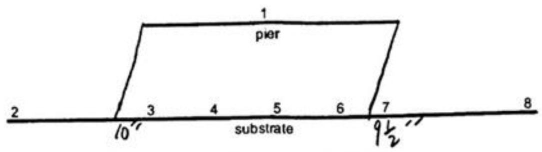
Figure A.1 *Example of pier and marsh description datasheet used for all sampling.*

PIER SHADING PROJECT

LIGHT MEASUREMENTS
(μmol = microeinsteins = photons/s/m²)

PIER NUMBER : JAC-OS-A
DATE : 05-25-21
TIME : 0240

PIER WIDTH : 4'



Note: facing end of pier - readings left to right
1' readings under pier
3' readings on each side of pier
mark shaded area

Pier Height : 3'

Instrument calibration :

	before	after
LI-1000 :	1727	1690
LI-250A :	1871	1698

PIER (LI-1000)		SUBSTRATE (LI-250A)
1 1721		2 1777
1 1714	(E)	3 92
1 1712		4 39
1 1712	(cL)	5 22
1 1706		6 53
1 1674	(E)	7 1703
1 1675		8 1810

Figure A.2 *Example of light transect datasheet used for all sampling.*

APPENDIX B – ANOVA tables

Table B.1 One-way ANOVA testing pier height between 2006 and 2021 year groups.

	F	Df1	Df2	P
Height	10.7	1	126	0.001

Table B.2 One-way ANOVA testing pier height among counties in 2021.

	F	Df1	Df2	P
Height	24.0	2	31.3	<0.001

Table B.3 One-way ANOVA testing pier width among counties in 2021.

	F	Df1	Df2	P
Height	7.35	2	32.5	0.002

Table B.4 One-way ANOVA testing board spacing between 2006 and 2021 year groups.

	F	Df1	Df2	P
Board Spacing	30.3	1	55.1	<0.001

Table B.5 Tukey's post-hoc test results of multifactorial ANOVA testing %CL between height, width, and board spacing groups.

Comparison		Mean Difference	SE	Df	t	P_{tukey}
Height_bin						
S	T	-1.35	0.254	69.0	-5.32	<0.001
Width_bin						
W	N	-0.822	0.254	69.0	-3.24	0.002
Board Spacing						
G	G	-0.712	0.254	69.0	-2.80	0.007

Table B.6 Tukey's post-hoc test results of multifactorial ANOVA testing %Under between height, width, and board spacing groups.

Comparison		Mean Difference	SE	Df	T	P_{tukey}
Height_bin						
S	T	-0.755	0.185	69.0	-4.08	<0.001
Width_bin						
W	N	-0.541	0.185	69.0	-2.93	0.005
Board Spacing						
G	G	-0.444	0.185	69.0	-2.40	0.019

Table B.7 Mixed-Model ANOVA testing %CL and %Under among height, width, and board spacing.

	Estimate	Standard Error	Df	T	P
%Under					
Intercept	1.19	0.24	60.31	5.02	<0.001
Height_binT	1.03	0.22	48.75	4.73	<0.001
Board Spacing_binG	0.60	0.21	48.67	2.84	0.007
Height_binS*Width_binW	-0.16	0.26	65.84	-0.62	0.540
Height_binT*Width_binW	-0.85	0.26	66.31	-3.26	0.002
%CL					
Intercept	0.45	0.33	60.30	1.36	0.180
Height_binT	1.51	0.32	56.21	4.65	<0.001
Board Spacing_binG	0.93	0.29	48.25	3.24	0.002
Height_binS*Width_binW	-0.51	0.36	65.64	-1.41	0.164
Height_binT*Width_binW	-1.54	0.37	65.45	-3.14	0.003

APPENDIX C – Additional nMDS Plots

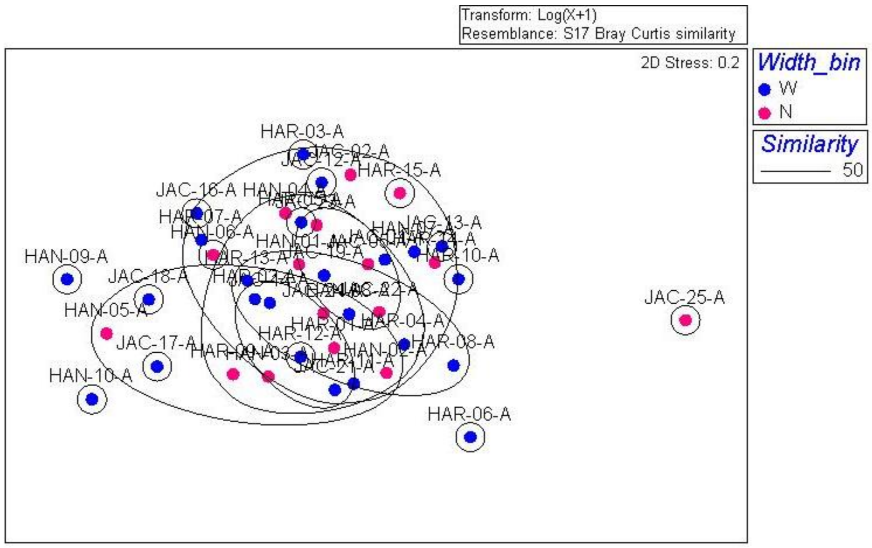


Figure C.1 *Ordination results using "under" area of 2021 piers and grouping by width.*

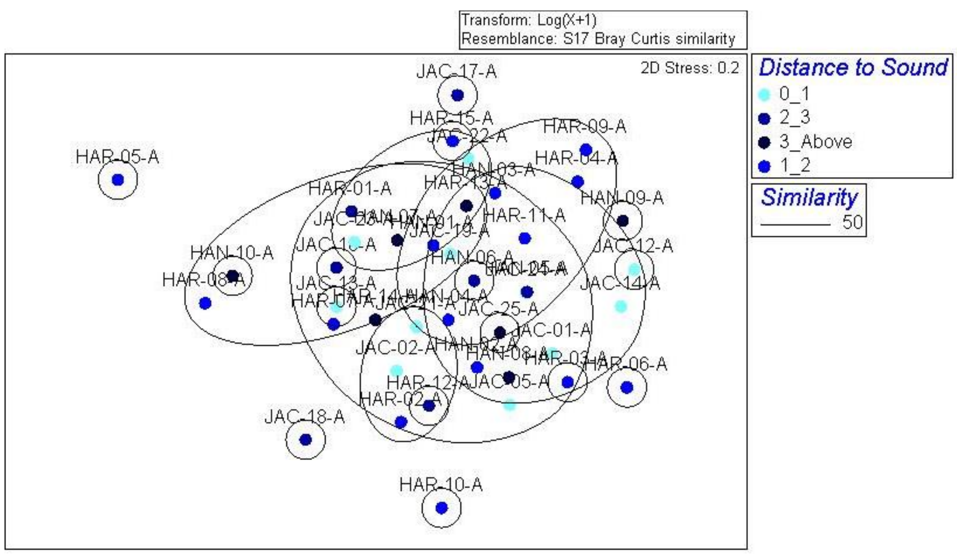


Figure C.2 *Ordination results using "under" area of 2021 piers and grouping by distance.*

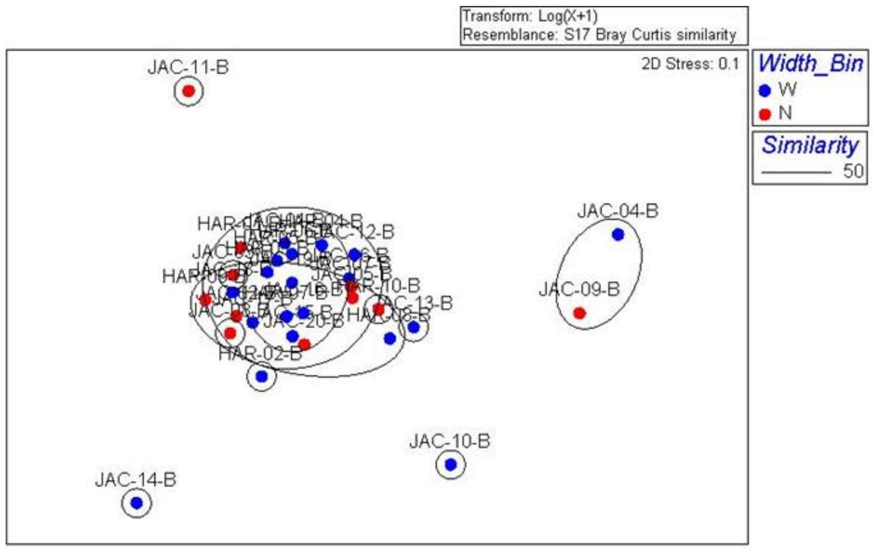


Figure C.3 *Ordination results using "general" area of 2006 piers and grouping by width.*

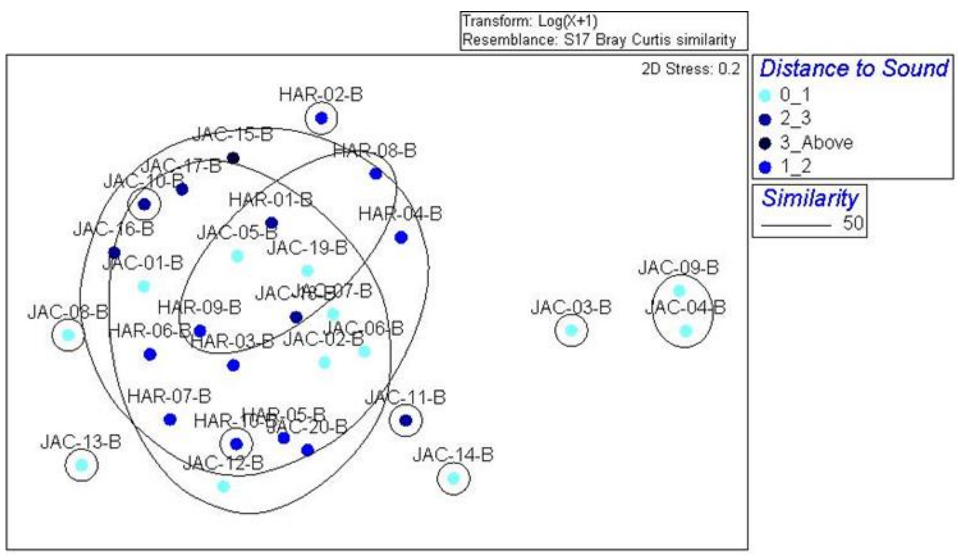


Figure C.4 *Ordination results using "general" area of 2006 piers and grouping by distance.*

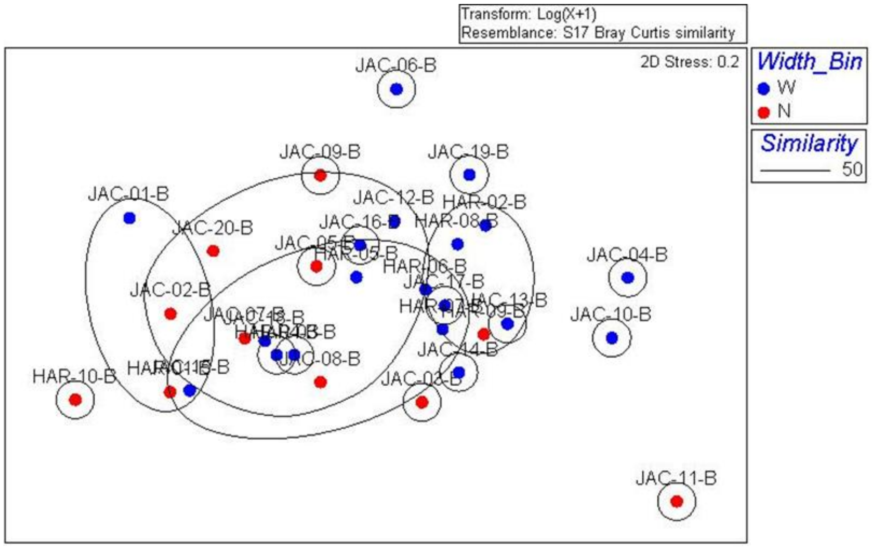


Figure C.5 *Ordination results using "under" area of 2006 piers and grouping by width.*

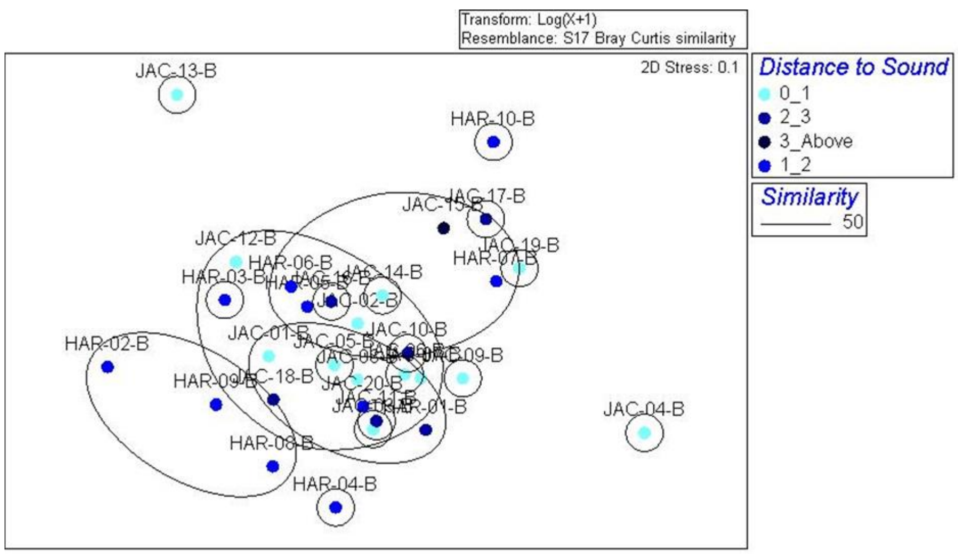


Figure C.6 *Ordination results using "under" area of 2006 piers and grouping by distance.*

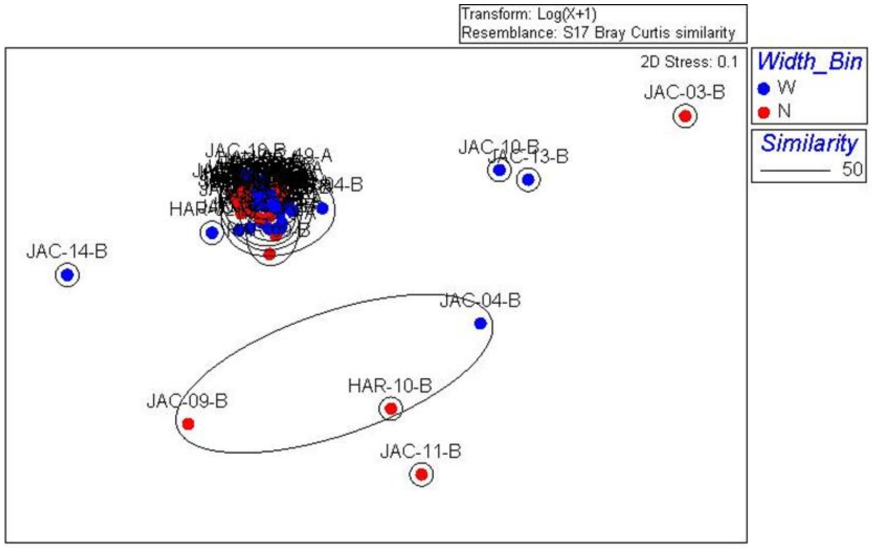


Figure C.7 *Ordination results using "general" area of both years and grouping by width.*

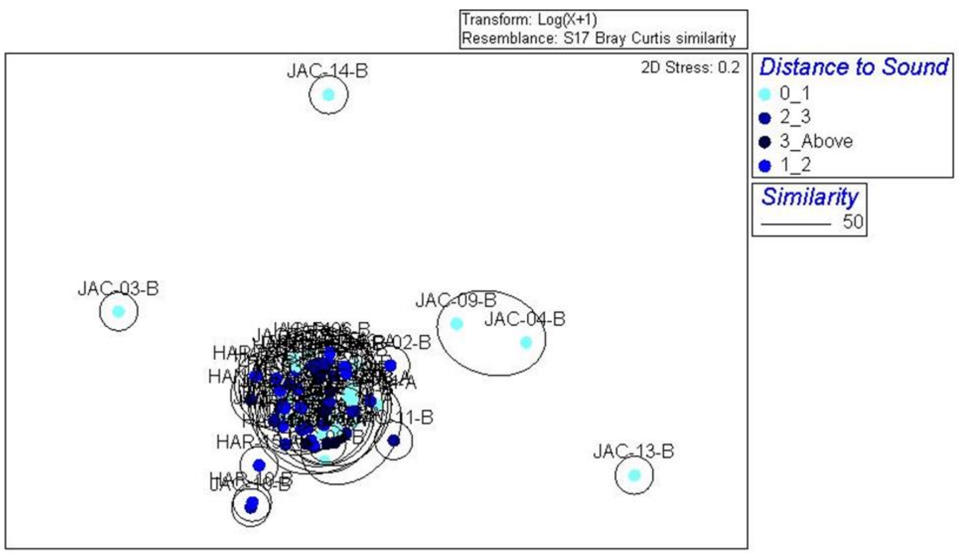


Figure C.8 *Ordination results of "general" area of both years and grouping by distance.*

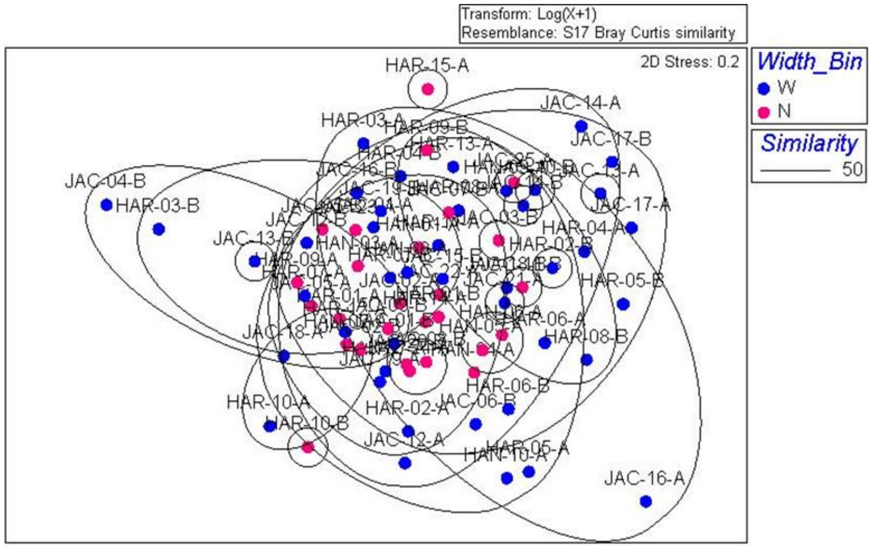


Figure C.9 *Ordination results of "under" area of both years and grouping by width.*

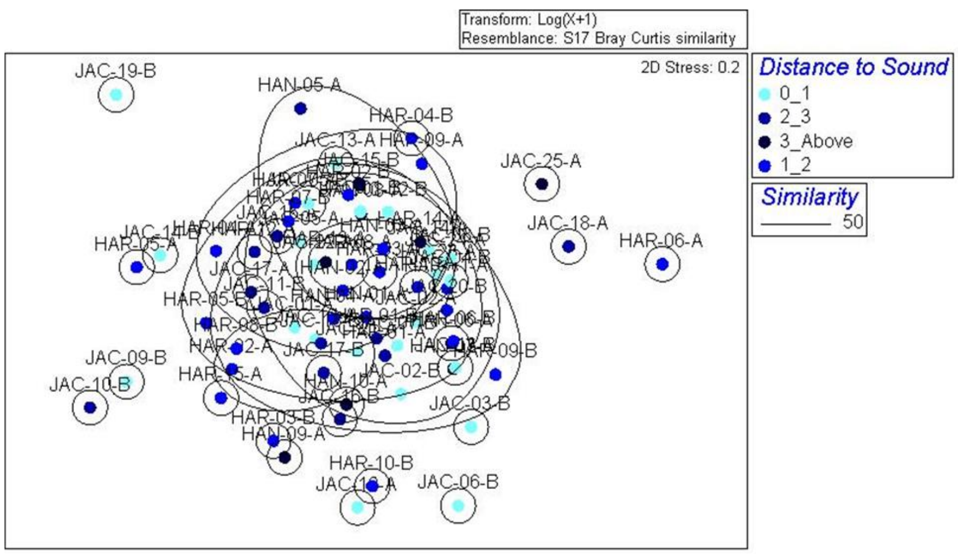


Figure C.10 *Ordination results of "under" area for both years and grouping by distance.*

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