The Effects of Matthew's Storm Surge on Coastal Loblolly Pine and Wax Myrtle Understory Regeneration

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Hurricanes have detrimental effects on the environment and the economy. Not only are these effects felt immediately after the hurricane, but they last long after the winds have died down. They can affect future plant growth and mortality. In October of 2016 South Carolina was hit by Hurricane Matthew, a category 5 hurricane. Hobcaw Barony, our study site, was in the direct path of the storm. This created an opportunity to study the immediate effects on regeneration after a hurricane. Regenerations rates were measured along and around a surge line to determine regeneration and mortality rates. This data also allowed for a better understanding of species distribution. The storm surge resulted in a significant decrease in the number of small (less than 30 cm tall) loblolly pine and wax myrtle trees. Large wax myrtle trees (taller than 140 cm), however, increased. Wax myrtle regeneration within the surge line also increased and the regeneration was mostly small tree because wax myrtle is more accustomed to salt water than loblolly pines. Following the death of all the loblolly pine, wax myrtle was able to grow back faster due to a stronger immunity to salinity and less competition for resources and space. It was observed that the bigger trees actually had higher mortality rates. This is because they faced wind damage and other factors resulting from the hurricane. Small trees faced less damage because the big trees were able to almost protect them. Overall, we found that hurricanes have a huge effect on tree regeneration, species distribution, and mortality rates. The aftermath of a hurricane causes a large change in ecology, as well as the economy.

Introduction

Tropical cyclones form over tropical and subtropical waters. When the cyclone has sustained winds 74 mph and faster, it's called a hurricane. These hurricanes originate in the Atlantic basin. There is a scale to rate the category of a hurricane based on its maximum sustained winds. This scale ranges from 1 to 5 (1 being the weakest and 5 the strongest). "Hurricane season" is from June 1 to November 30, but this doesn't mean hurricanes can't happen outside of this time range (NOAA, 2017).

According to NASA, on average there are 85 hurricanes each year (2014). Thankfully, not all of these hurricanes are destructive. However, when a hurricane does become damaging, it affects not only environment, but also the economy. Hurricane Harvey recently devastated parts of Texas. During the storm an oil rig was destroyed and gas prices increased. Since then, more hurricanes have threatened parts of the U.S. and gas has become more and more expensive. This is not the only example. Researchers have found that the higher the annual nationally-averaged wind exposure is the lower the per capita economic output will be. Economic recovery is very slow and said to be impossible (Rosen, 2014).

Biotic and abiotic factors are environmental conditions that organisms must deal with in order to live in a particular habitat. Abiotic factors are non-living things, such as pH, weather, etc. Biotic factors are biological factors, such as predator vs. prey and available food. Abiotic factors control and alter biotic factors. For example, a hurricane may cause flooding. This flooding will change the natural environment. Soil composition, regeneration rates, and mortality rates are a few examples of changes that will occur. These changes alter biotic factors.

Forestry is one of South Carolina's major industries. Forest product exports in 2014 were a little over $1.5 billion. In addition, the South Carolina Forestry industry has been documented to provide jobs for more than 84,000 citizens. South Carolina has 19.2 million acres of land and 12.9 million acres are forested. That's over two-thirds of South Carolina's land area (Khanal, et al., 2017). Unfortunately, South Carolina has also seen the effects of many hurricanes. Hurricanes cause massive damage, especially to forests. Hurricane Hugo hit in 1989 and devastated much of the state. Forest and other natural landmarks were destroyed. Major reforestation followed Hugo under the Federal Conservation Reserve Program. We have yet to see the long-term effects of these hurricanes.

In 1993 (approximately 4 years after Hugo), Dr. Bo Song and colleagues began studying the long term effects of hurricanes, specifically Hurricane Hugo. Plots were established in Beidler forest, Santee Experimental Forest, Hobcaw Barony, and Congaree National Park. These plots are protected and allowed to grow free from industrial interference. Research is ongoing, but so far they have discovered that the overall environment has experienced some change. New species have become dominant and the more common species have decreased in number due to competition with the invading species. For example, Chinese tallow trees have increased in number since Hugo and loblolly pine trees have decreased. Soil salinity increased after the hurricane and mortality rates increased (Song, et al., 2012). Dr. Song continues to monitor changes such as these at Hobcaw Barony.

Hobcaw Barony is a 16,000-acre area of land dedicated to better education and research. The property is near Georgetown, South Carolina. It was first inhabited by the Native Americans who called it "Hobcaw" which meant between the waters. In the early 1700s, it became a colonial land grant (or barony). The land was divided and sold as rice plantations. They were profitable until the early 1900s. Bernard M. Baruch bought the land in 1905 to use as a winter hunting retreat. Baruch was a very successful financer and he even advised several U.S. Presidents, many of whom often visited Hobcaw. Baruch eventually sold all his land to his daughter Belle. Belle never married or had kids, so she created a foundation to manage the land. She made it very clear that the land would be used as an outdoor laboratory open to all South Carolina colleges and universities. The property is privately owned, but Hobcaw Barony offers guided tours and programs to encourage learning (Hobcaw Barony, 2017).

Hurricane Matthew passed directly over South Carolina on October 9, 2016. The hurricane caused flooding and storm surges on the coast, as well as wind damage. Homes were destroyed, roads were damaged, and natural habitats were severely altered. Matthew started as a powerful tropical cyclone and grew to become a Category 5 hurricane. It made landfall and, thankfully, its strength decreased. Winds reached a height of 165 miles per hour. The hurricane devastated the Caribbean and parts of Southeastern U.S. (Reuters, 2016). Hobcaw Barony was in the eye of the hurricane, which caused the saltwater in the marsh to rise. Some of the already established plots in Hobcaw were affected by the surge while others were not. These plots became focal sites for studying the immediate ecological response to a hurricane. All Hobcaw plots experienced a degree of wind damage and about 25% of the plots were affected by the saltwater storm surge. This provided a research opportunity to study how the hurricane affected coastal ecology.

If Hurricane Matthew's storm surge impacted the biodiversity of plants found in Hobcaw Barony, then a decrease in new growth rate will be observed in the season following Hurricane Matthew. The flooding was assumed to basically drown any weak new growth. The surge caused salt water to rise and flood into area not accustomed to the salinity. This change in environment could affect plant growth. To test this, regeneration and mortality were measured and compared to previous years. It was found that the number of regenerated loblolly pines tended to decrease, while the number of new wax myrtles varied less from 2016 to 2017.

Methods

Field Site

We conducted our research in the 16,000-acre area known as Hobcaw Barony. For our project, four 20x100m plots in Hobcaw Barony were the main focus. Each plot is divided into five subplots that measure 20x20m. These subplots are marked with wooden stakes and colored flagging tape. Trees with a DBH (diameter at breast height) of 2.5 cm or larger were given an aluminum ID tag. Each marked tree's species was recorded along with any damage. The plots are untouched and allowed to grow and die without the interference of people. These forests experienced varying degrees of damage from Hurricane Matthew.

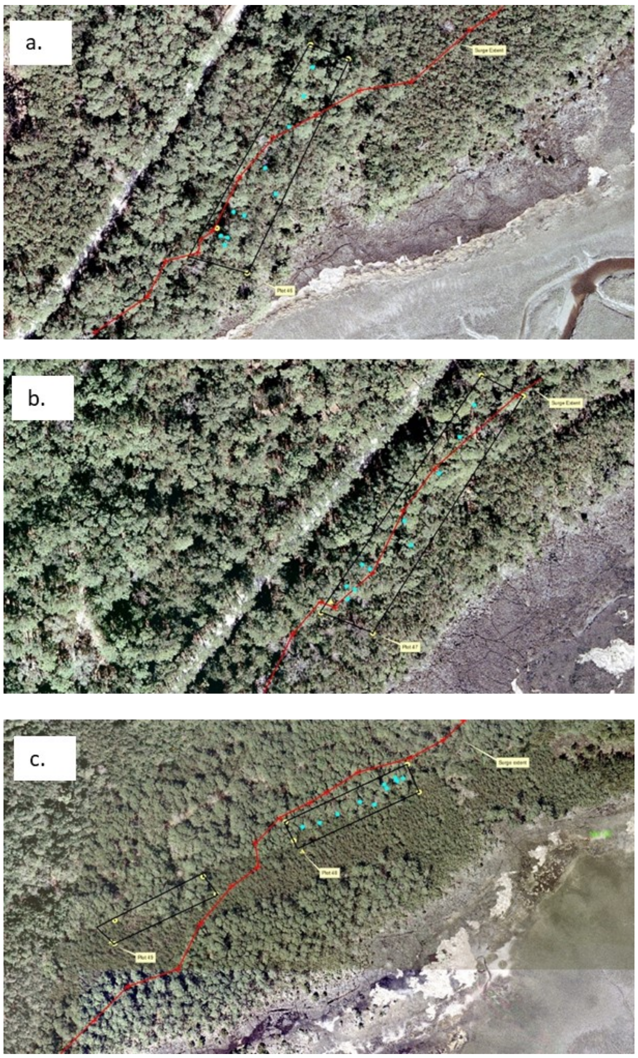

Figure 1. A map of the surge line's path in the area. 1a) The surge line cuts through part of plot 46. 1b) Plot 47 is also partly in the path of the surge line. 1c) Plot 48 is within the line, while plot 49 is not.

MAP OF 4 PLOTS

Subplot Data Collection

Within each subplot the DBH (diameter at breast height), damage, and overall health of the tree was recorded. All species were measured, however, loblolly pines (Pinus taeda) and wax myrtles (Myrica) were the focal species that the data was based on. The diameter of the trees in the Hobcaw plots are measured every three years and recorded. This shows exactly how much a tree has grown. Trees are measured at the DBH, or diameter at breast height. DBH is about 4.5 feet. Every year whether or not the tree is alive and the damage it has is recorded by researchers. If the tree is broken, bent, top snapped, etc., it is written down. The damage is important because from there researchers can hypothesize how it was damaged. For example, trees that were in the path of the hurricane with a broken top were most likely damaged by wind. Once a tree's status is recorded, the aluminum tag was bent so that it would be known that it had already been checked.

Once that information was been collected, basal area was calculated. Basal area (BA) is the degree to which an area is occupied by trees. Comparing the basal area of the plots from each year shows how the subplot changes over time. The mortality rate of the trees was also calculated. This was done for each plot and each separate species. This allowed us to compare the amount of death within the plots and species.

Determining Species Distribution

Data collected from 1994 to 2017 was used to find the mortality data. Microsoft Office Excel was used to do these calculations and keep things organized. The trees were sorted in each plot by species and then live trees were deleted. Only the dead trees were looked at. After that, the remaining trees were color coded according to when they died and the degree of damage. From there a table with the total amount of DOA (dead on arrival) trees for each species in 2016 and 2017 was made. A column that showed the difference between the years was included. The crude annual mortality rates for loblolly pines with a DBH less than 10 inches was calculated using the following formula:

=100[(Nd/No)1/t].

Nd represents the number of current dead stems (2017)

No is the number of living stems in 2016

t represents the number of years passed

Basal Area (BA) is used to show the change in forest density over the years. The basal area calculates the degree to which an area is occupied by trees. This is important because the effect of the flooding on the area occupied by trees can be studied. How the basal area is affected by soil salinity can be observed. To calculate the BA, we used the formula:

=3.14 x DBH2016 x (DBH2016/10000).

Regeneration Data Collection

The regeneration of four plots at Hobcaw were recorded. These four plots were chosen because of how they were affected by Hurricane Matthew's surge line. Two of the plots were partly in the line and partly out of it. The third plot was completely submerged by the surge and the fourth plot was not flooded at all. Studying the regeneration allowed us to predict future tree growth and to see if new growth was affected by the surge. All ten points within each plot were visited and data was collected. Each point was in roughly the same spot on each plot. These points were randomly picked back when the project was first begun 24 years ago. The new growth and saplings within a 3.26m radius of the point were recorded. To do this, two stakes connected by a 6.52m rope was used. The middle of the rope was placed on the point. The data was ordered by species and height. Stems with a height between 0-30cm are considered small, 30-140cm are classified as medium, and 140cm-2.5in are recorded as large. The number recorded is the regeneration. Using these 10 points and a map of the surge line, tree placement relative to the surge line could be seen.

Results

In order to observe the effects of the storm surge on new growth and trees with a DBH of less than 10 inches, we looked at the regeneration rates of loblolly pines and wax myrtles. We wanted to see if the surge decreased the rate of new growth. To do this, we used our data to make graphs that would help visualize the changes.

Tree mortality with respect to the Hurricane Matthew storm surge

Loblolly pines tend to higher difference in dead trees from 2016 to 2017 than wax myrtles (Table 1).

Table 1. The mortality data for loblolly pines in 2016 and 2017. 1a) plot 46 mortality data. 1b) the mortality data for plot 47. 1c) plot 18 mortality data. 1d) the mortality data for plot 49.

a			
Species	**Number DOA in 2016**	**Number DOA in 2017**	**Difference**
lobp	0	0	0
waxm	23	24	1
b			
Species	**Number DOA in 2016**	**Number DOA in 2017**	**Difference**
lobp	725	742	17
waxm	155	163	8
c			
Species	**Number DOA in 2016**	**Number DOA in 2017**	**Difference**
lobp	0	0	0
waxm	0	0	0
d			
Species	**Number DOA in 2016**	**Number DOA in 2017**	**Difference**
lobp	800	825	24
waxm	170	177	7

The crude annual mortality for loblolly pines with a diameter less than 10 cm at breast height in plot 46 is 20.50 and in plot 47 it's 10.83. In plot 48, the crude annual mortality for loblolly pines with DBHs less than 10 cm is 20.00 and for plot 49 it is 23.16.

Regeneration of loblolly pines after Hurricane Matthew

The small growth within the surge line in plot 46 is significantly less in 2017 than in 2016 (figure 1). The overall trend seems to be that the growth is less in 2017 than 2016. The medium and large trees, however, do not significantly differ from the number measured previously.

We see the trend of 2017 regeneration dropping from the 2016 regeneration (figure 2). However, large wax myrtles are the exception. In plot 47, the large wax myrtle in 2017 outnumber the amount in 2016.

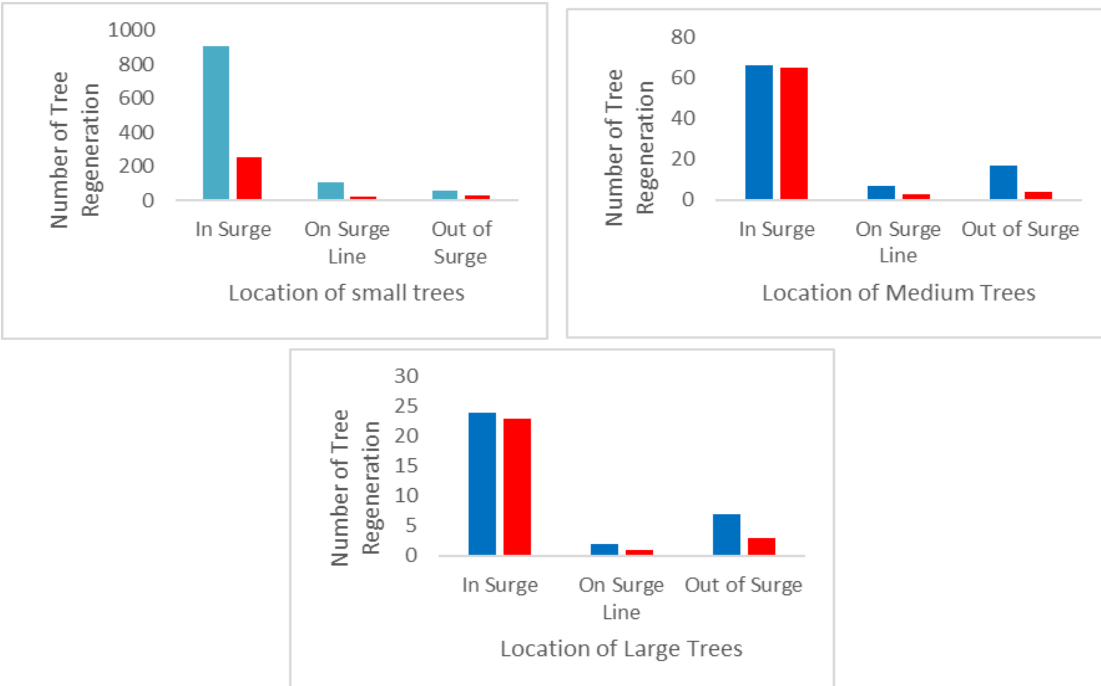

Figure 1. The new growth of both wax myrtles and loblolly pines in Plot 46 with respect to position relative to the surge line. Each column represents an annual data set, with blue representing the 2016 data and red representing the 2017 data. 1a) The growth of trees in plot 46 that are less than 30 cm. 1b) The growth of medium sized trees from 30-140cm. 1c) The growth of trees over 140 cm in plot 46.

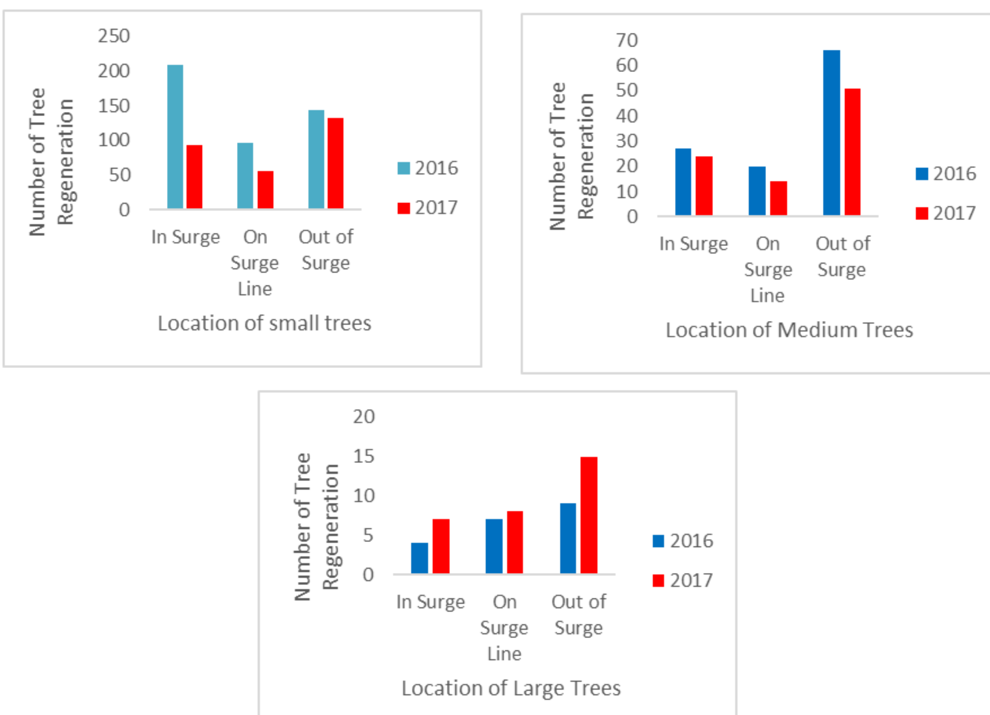

Figure 2. Tree regeneration in plot 47 of way myrtles and loblolly pines relative to the surge line. Each column represents an annual data set, with blue representing the 2016 data and red representing the 2017 data. 2a) The regeneration of small (less than 30cm) trees. 2b) Amount of tree growth between 30-140cm in plot 47. 2c) Regeneration of growth over 140cm.

Plot 46 shows a drop in loblolly pine new growth from 2016 to 2017 (figure 3). In plot 47, the drop is less significant, but the regeneration is still less in 2017.

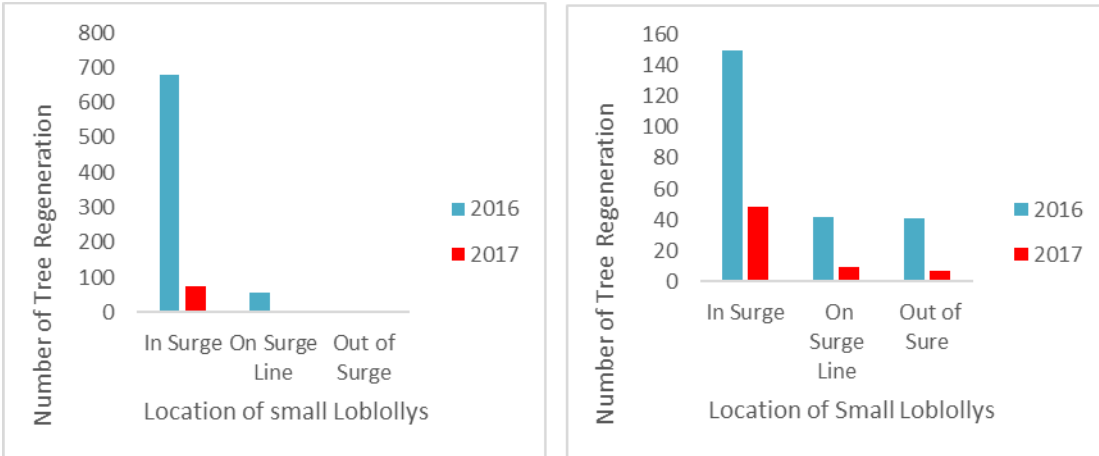

Figure 3. Regeneration of loblolly pine trees in plots 46 and 47 with respect to the surge line. Each column represents an annual data set, with blue representing the 2016 data and red representing the 2017 data. 3a) The growth rate of small (<30cm) trees in plot 46. 3b) The growth of small loblolly pines in plot 47.

The regeneration of loblolly pines in plots 48 and 49 (figure 4) continues with the pattern of dropping in 2017. The drop in plot 48, which is completely in the surge line, is much greater than in plot 49. Plot 49 was spared from the surge.

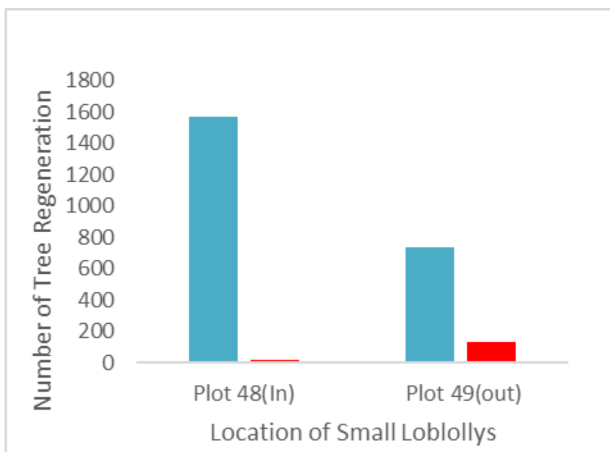

Figure 4. Regeneration of small loblolly pines (less than 30cm high) in plots 48 and 49. Plot 48 is completely in the surge line and plot 49 is outside of it. Each column represents an annual data set, with blue representing the 2016 data and red representing the 2017 data.

Regeneration of wax myrtles after Hurricane Matthew

The wax myrtle regeneration goes against the expected pattern (figure 5). The new growth of wax myrtle in the surge line in plot 46 is actually greater than in 2016. The same pattern holds true for most of the new growth in plot 47. However, within the surge line in plot 47 the rate goes down in 2017. The decrease wasn't great, but it did decrease.

The regeneration of small wax myrtle in plot 48, which is in the surge line, increased from 2016 (figure 6). The medium, however, decreased slightly. Plot 49 is out of the surge line and experienced the expected new growth rates. 2017 regeneration was less than in 2016.

Discussion

Our data supported our hypothesis that the surge line would decrease new growth in Hobcaw plots. From 2016 to 2017, the regeneration of loblolly pines inside Hurricane Matthew's surge line, as well as on the line, greatly decreased (figure 1). The regeneration in plots 48 and 49 both decreased from 2016 to 2017 (figure 2). The difference in plot 49 was greater than plot 48 because of the flooding; however, plot 48 was also greatly affected. We believe this higher rate of mortality is due to the salinity in the soil. An increase in salt can cause rapid loss of leaves which decrease the nutrient use efficiency (Blood, et al. 1991). Trees are unable to get the nutrients they need because of an increase in salinity. Interestingly, a previous study on Hurricane Hugo found that salinity doesn't always result in higher mortality. Loblolly pine new growth actually increased after Hurricane Hugo. This was a result of a decrease in competition due to the initial high mortality of plants (Song, et al., 2012).

The graphs found in the results section show that the regeneration decreased because of both flooding and soil salinity. Small new growths were completely covered by water in areas that experienced flooding. We see that the difference in regeneration of wax myrtles from 2016 to 2017 is

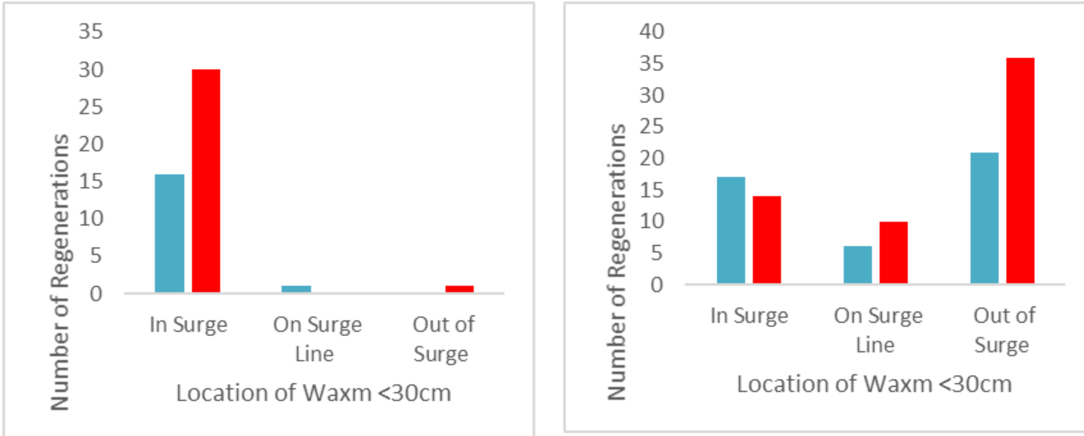

Figure 5. Growth of small (less that 30cm) wax myrtle trees in plots 46 and 47, which has areas flooded and areas the surge didn't reach. Each column represents an annual data set, with blue representing the 2016 data and red representing the 2017 data. 5a) Growth in years 2016 and 2017 of small wax myrtle in plot 46. 5b) The wax myrtle regeneration in plot 47.

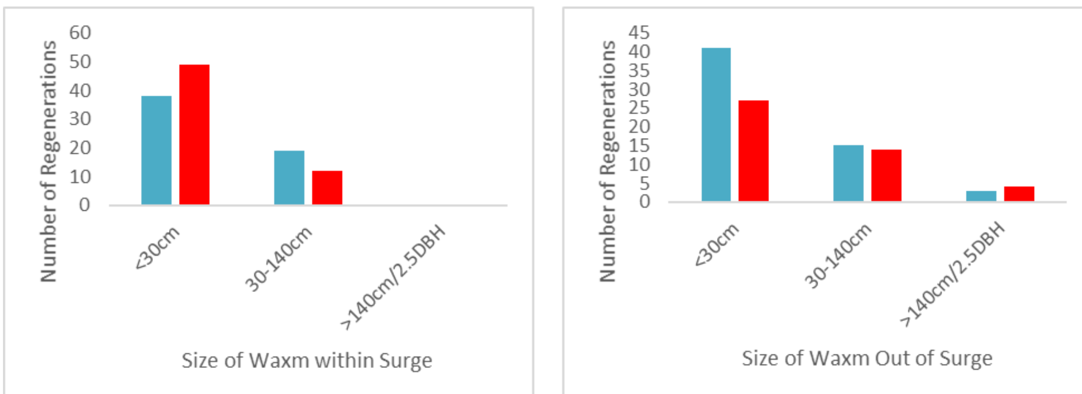

Figure 6. Each column represents an annual data set, with blue representing the 2016 data and red representing the 2017 data. 6a) The growth of both small and medium sized wax myrtles in plot 48, which is in the surge. 6b) The growth of small and medium wax myrtle trees in plot 49. Plot 49 is outside of the surge line.

much smaller than those of loblolly pines (figure 4). This is because wax myrtles are much more accustomed to salt water than loblolly pines. There was even an increase in the amount of small new growth of wax myrtles outside of the flooding area (figure 5). They were safe from the flooding and the soil salinity did not inhibit their growth. Small new growth in plot 48, which was entirely in the surge line, actually increased (figure 7). We believe this to because they might not have to compete with the loblolly pines. The medium sized regenerations decreased, however, probably due to the flooding breaking them down within the surge line. This also decreased competition and allowed the small wax myrtles to grow more. There was a decrease in the regeneration of small wax myrtle new growth in the plot that was not flooded (plot 49; Figure 6b). This is assumed to be caused by a decrease in competition.

We saw that large, older trees faced the most damage after the hurricane. The high wind speeds broke and uprooted trees. The surge also overwatered the small new growth. Wax myrtles are able to withstand salt better than loblolly pines, so they had a better chance of survival. Wax myrtles are very versatile plants because they can grow and thrive in a variety of landscapes from wetlands to high, dry lands. Wax myrtles are also very tolerant of salt, which allows them to grow by the sea relatively easily (Gilman, et al. 1994). This damage eliminated much of the competition allowing the wax myrtles to thrive. The medium new growth remained close to the same and the larger regenerations increased slightly.

There were some problems with the study, however. Trees that were unaccounted for, or missing, had to be recorded as dead upon arrival. It is probable that they are dead, but we can't be certain. Not all of the plots could be studies and measured at the exact same time. This may have allowed for factors to change before we could measure them in certain plots. It was also difficult to get exact measurements because of variation in nature.

The next effect of the storm surge to study would be the salinity level of the soil. This would allow us to see further underlying effects of Hurricane Matthew's storm surge. There have been previous measurements of soil salinity after hurricane Hugo, but this was not done after Hurricane Matthew. Researchers found that salt and chlorine increased significantly following Hurricane Hugo (Blood, et al., 1991). These studies are important because they allow us to see the short and long term effects of hurricanes more clearly. We now know that hurricanes don't only damage grown trees, but also reduce new regeneration. By studying the effects of storm surges in more detail, we can be better prepared for future hurricane damage to the ecosystem.

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