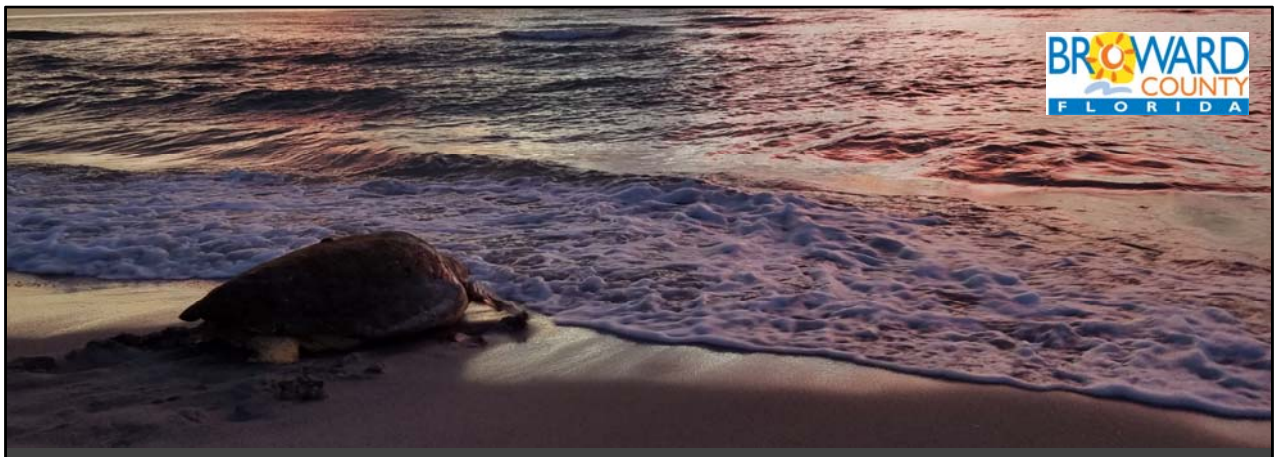

An Analysis of Sea Turtle Nesting Before and After a Sand Placement Project in Broward County, FL

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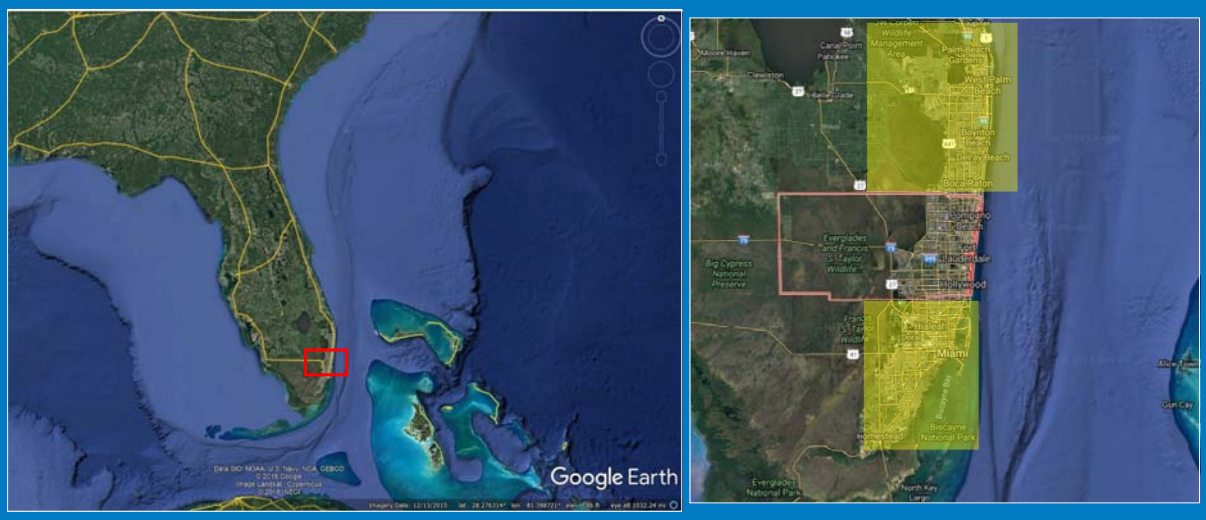
Broward County, FL



Broward County is located on the southeast Atlantic coast of Florida, outlined by the red box on the map on the left. If we zoom in to the picture on the right, you can see that we are bordered by Palm Beach County to the north and Miami-Dade County to the south.

Broward County, FL

- 24 miles of developed shoreline
  - Condominiums, hotels, single-family homes, businesses
- Almost 2 million residents
  - Abundant tourism
- Beaches are a valuable resource

Broward County has 24 miles of coastline that are mostly developed with large condominiums, hotels, single-family homes, and businesses lining the beachfront. Broward is the second most populous county in Florida with almost 2 million residents. We also host millions of tourists each year. Our beaches are a valuable resource for storm protection, ecotourism, and biological habitat.

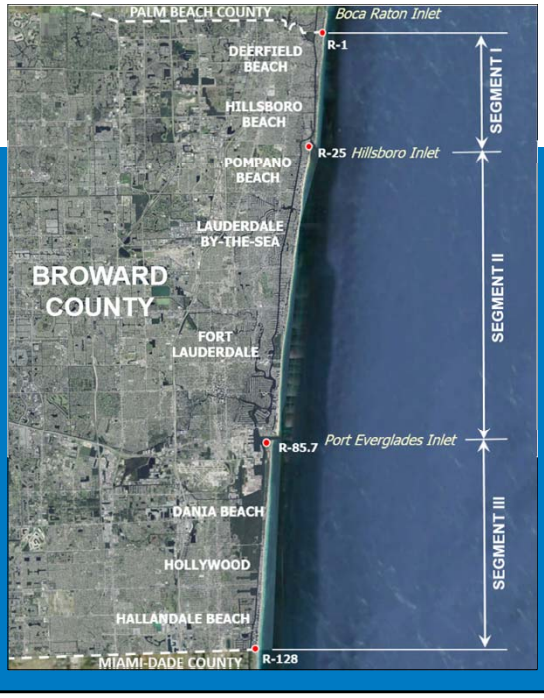
Broward County Beach Management: A History

- Increasing development → critical erosion (1960's)
  - Seawalls & groins, but still encroaching development
- Beach nourishment (late 1960's-early 1970's)
- Sea turtle monitoring (1978)

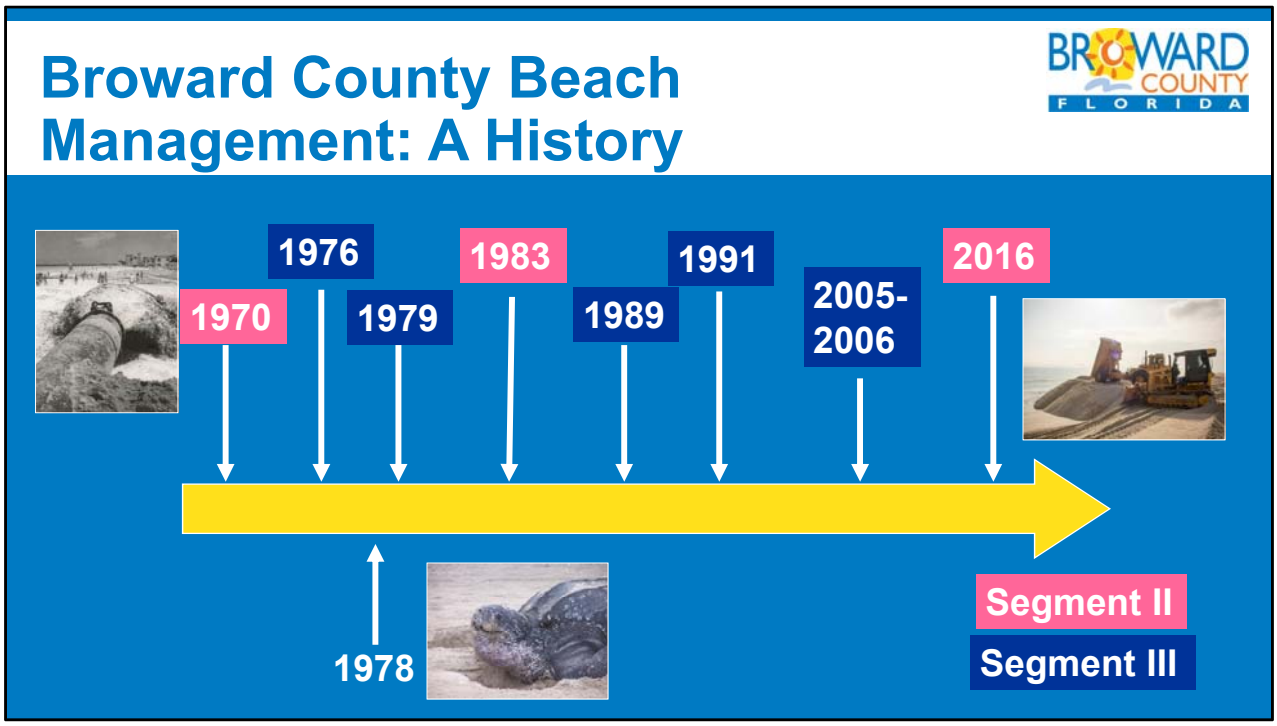
Increasing development along the beachfront in Broward County led to critical erosion into the 1960's. Seawalls and groins were built to mitigate these effects, but exacerbated the problem, and we still had encroaching development in some areas. Beach nourishment was then proposed as a solution in the late 1960's-early 1970's. To fulfill permitting requirements for these shore protection projects and because of increasing public interest in the conservation of endangered sea turtles, a County sea turtle monitoring program began in 1978.

Broward County Beach Management

- **Segment I**
  - Deerfield Beach
  - Hillsboro Beach
- **Segment II**
  - Pompano Beach
  - Lauderdale-By-The-Sea (LBTS)
  - Fort Lauderdale
- **Segment III**
  - Dr. Von D. Mizell-Eula Johnson State Park
  - Dania Beach
  - Hollywood Beach
  - Hallandale Beach



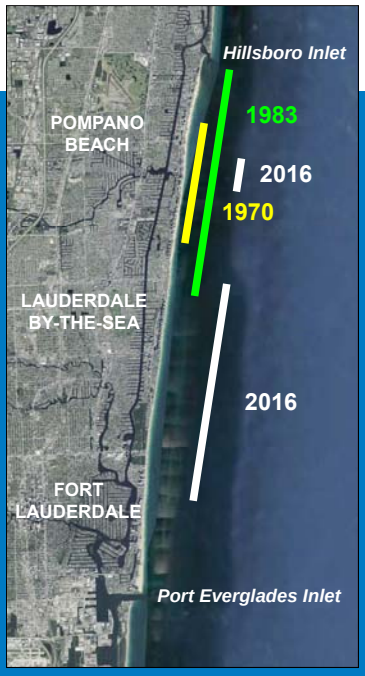
Broward County beaches are sub-divided into three management segments. Segment I begins at the Palm Beach County line and extends to the Hillsboro Inlet; it encompasses Deerfield and Hillsboro beaches. Segment II extends from the Hillsboro Inlet to the Port Everglades Inlet and includes Pompano Beach, Lauderdale-by-the-Sea, and Fort Lauderdale. Segment III covers the southern portion of the county from the Port Everglades Inlet to the Miami-Dade County line, including the Dr. Von D. Mizell-Eula Johnson State Park (formerly John U. Lloyd State Park), Dania Beach, Hollywood Beach, and Hallandale Beach.



If we look at a timeline of our beach management program in Broward, there were more than a dozen shore protection projects that occurred from 1970 through 2016 (*1970: Seg II Central Pompano; 1976: Seg III Park; 1979: Seg III Hollywood/Hallandale; 1983: Seg II Pompano/LBTS; 1989: Seg III Park; 1991: Seg III Hollywood/Hallandale; 2005-2006: Seg III Park, Hollywood/Hallandale; 2016: Seg II Pompano/LBTS/FTL*). Remember, our sea turtle monitoring program started in 1978. So, we've been documenting sea turtle nesting for over 3 decades, making our dataset one of the most comprehensive in the southeast region. We can use this robust dataset to examine our nesting population through time, while considering that all these beach projects were occurring as well. We'll get back to turtles in a bit, but for the rest of this presentation we'll only be focusing on Segment II.

Segment II Beach Nourishment

- 1970: Central Pompano Beach
- 1983: Pompano Beach/LBTS
- **2016: Pompano Beach, LBTS, Fort Lauderdale**
  - **690,000 cubic yards (ER Jahna-Ortona sand mine)**
  - **5.1 miles**
  - **First full Federal project to use mined sand in Broward**
- **Offshore sand previously → limited availability**

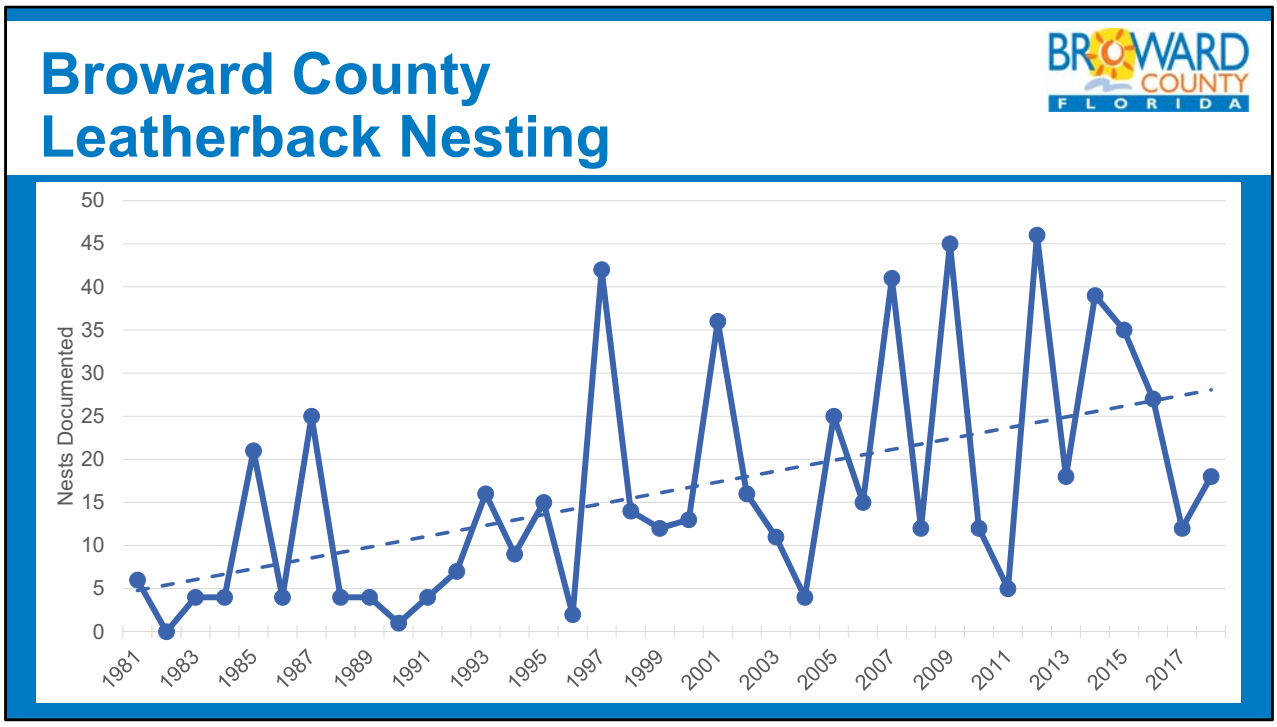


Segment II is a relatively stable beach and was first nourished in 1970. This project included only Central Pompano Beach, as indicated by the yellow line on the map. This project placed 1.1 million cubic yards of offshore sand on 3.2 miles of beach. In 1983, Segment II was nourished again; this time placing 1.9 million cubic yards of offshore sand on 5.3 miles of beach in Pompano Beach and Lauderdale-By-The-Sea, indicated by the green line on the map. The most recent project that is the focus of this presentation is the 2016 project, which placed 690,000 cubic yards of upland sourced sand from the ER Jahna-Ortona mine on 5.1 miles of beach in Pompano, LBTS, and Fort Lauderdale. This project was the first full Federal project profile nourishment to use mined sand in Broward County. Offshore sand was used for previous projects, but limited availability is resulting in a shift to using the upland mined sand.

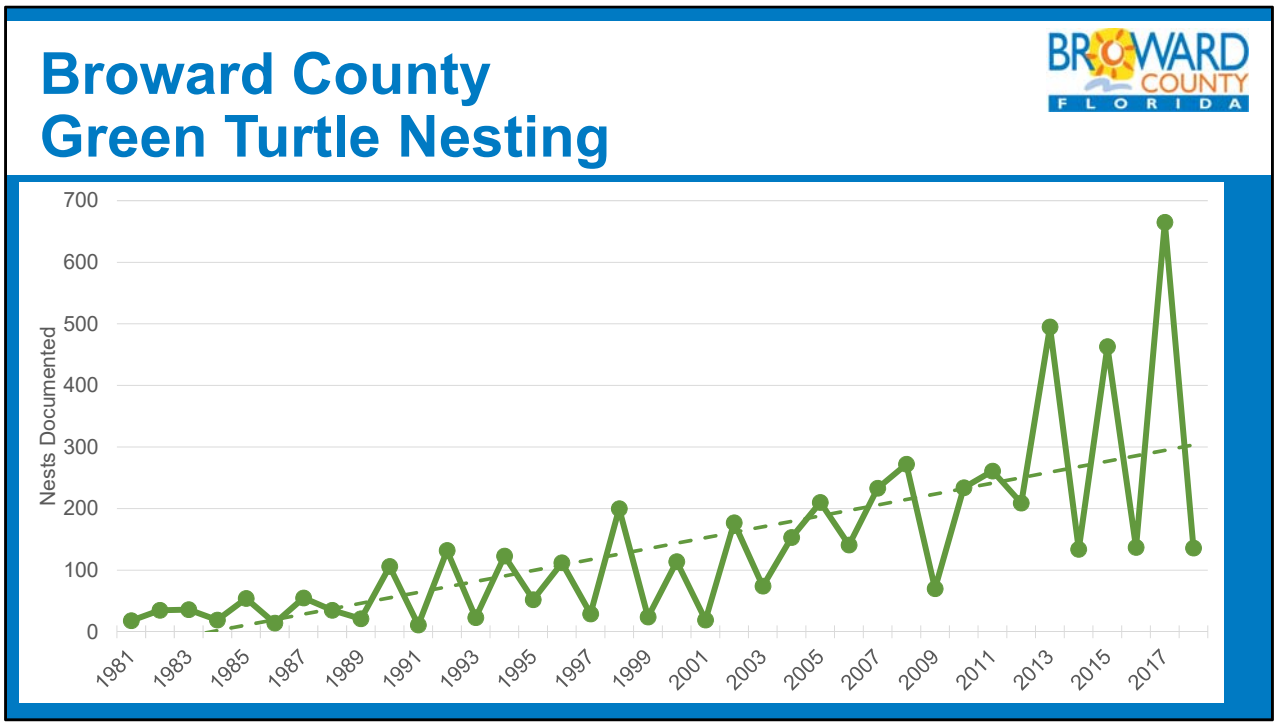
Broward County Sea Turtle Nesting

- Monitoring since 1978
  - All beaches since 1981
- Medium-density nesting beach
  - ~2,500 nests per season on average
- Leatherbacks, green turtles, loggerheads
- March 1 through October 31
  - Daily surveys
  - Nest marking and monitoring
  - Nests and "false crawls"

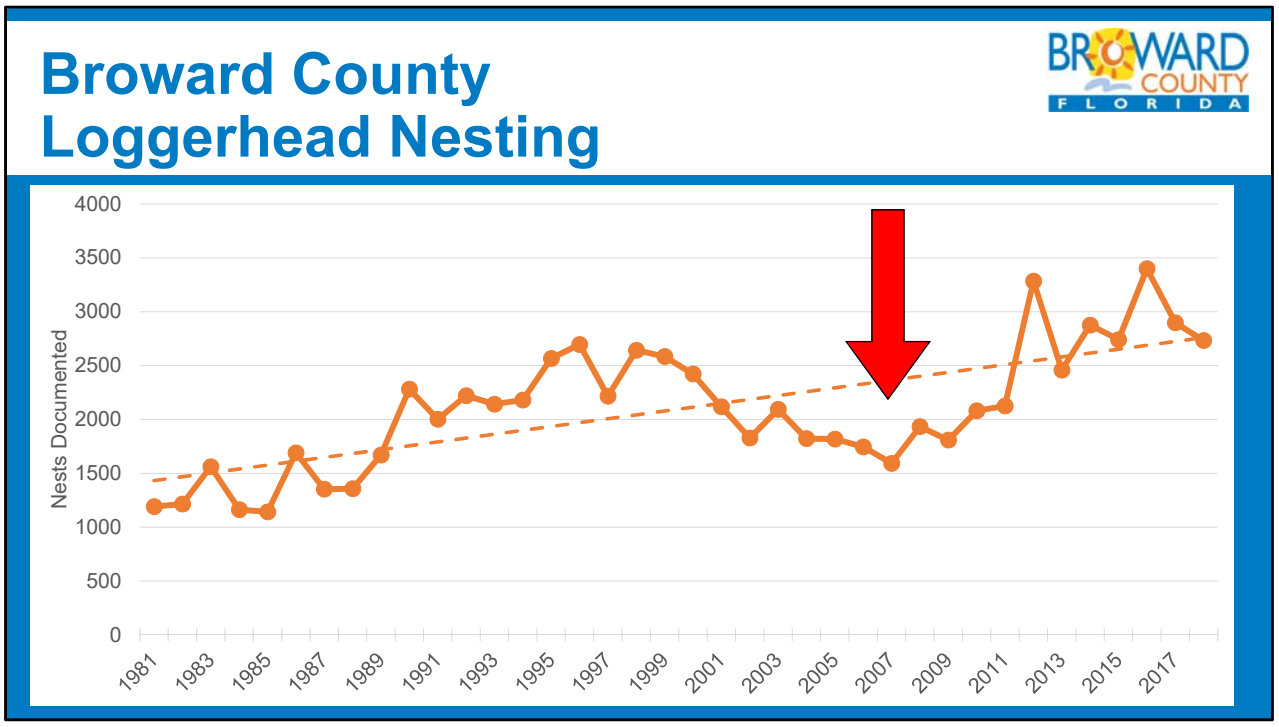
As I mentioned before, our beaches provide biologically important habitat for many animals including threatened and endangered sea turtles. Although Broward County began monitoring for sea turtle activity in 1978, only a portion of our beaches were monitored prior to 1981. Starting in 1981, all beaches were surveyed for sea turtle activity. We are a medium-density nesting beach according to the Florida Fish and Wildlife Conservation Commission, hosting an average of 2,500 nests per season. Three species of sea turtles commonly nest on Broward's beaches: leatherbacks, green turtles, and loggerheads. The official nesting season in Broward is March 1 through October 31 each year. During this time, the Broward County Sea Turtle Conservation Program conducts daily surveys to mark nests and monitor them until hatching. We record both nests and non-nesting emergences, which are termed "false crawls," on our surveys. Sea turtles naturally false crawl about as often as they nest, but increases in false crawl frequency can indicate that a beach may be less "desirable" for turtles; this can be due to numerous factors including artificial lighting, human or predator disturbance, beach or sand characteristics, etc.



To give you an idea of how robust our sea turtle dataset is, I want to show you our three species' historical nesting. Leatherback turtles are the least common nesting turtle in Broward County, and you can see that we document less than 50 nests each year. However, linear trendlines suggest that the local nesting population is increasing over time. I also want to take this time to point out a couple of biologically important facts about sea turtles to help you understand our study. The first is that sea turtle nesting exhibits interannual variability because females do not nest every year; they tend to nest every 2-3 years depending on the species and individual. So, we see tend to see peak years followed by lower years. Also, sea turtles can lay multiple clutches, or nests, each season; this means that we do not have 30 or 40 leatherback turtles in these higher nesting years, but perhaps about 10 that return to our beaches multiple times in one season.



Green turtles are our second most common nester in Broward, and recently we have been documenting record numbers of green turtle nests in the County (a trend that is also mirrored statewide). We set a record for green turtle nests in Broward in 2017 with 665 nests documented. As you can see, this linear trendline is comfortably increasing through time. The green turtle nesting population is a great example of our successful conservation program in Broward as well as the success of federal environmental legislation (Endangered Species Act of 1973). Because sea turtles take about 20-30 years to mature, it takes a while for us to see the fruits of our labor; in other words, our monitoring and conservation efforts in the late 1970s-early 1980s have only been realized recently. Sea turtles return to their natal region to lay their own nests and so the nests we were protecting in 1980 could very well have produced hatchlings that just started returning to our beaches in the 2000s to lay their own nests.



Lastly, our most frequent nesting turtle in Broward County is the loggerhead. You can see that we document over 2,000 loggerhead nests each year and their nesting population is also increasing through time. I do want to mention that this dip in loggerhead nesting numbers in the 2000s was seen statewide; biologists are unsure why this happened, but we did see a recovery of the species. Overall, what I want you to remember is that all three species of nesting turtles are exhibiting increases in their nesting numbers through time in Broward County, demonstrating the success of our conservation Program.

Beach Nourishment and Turtles: Previous Studies

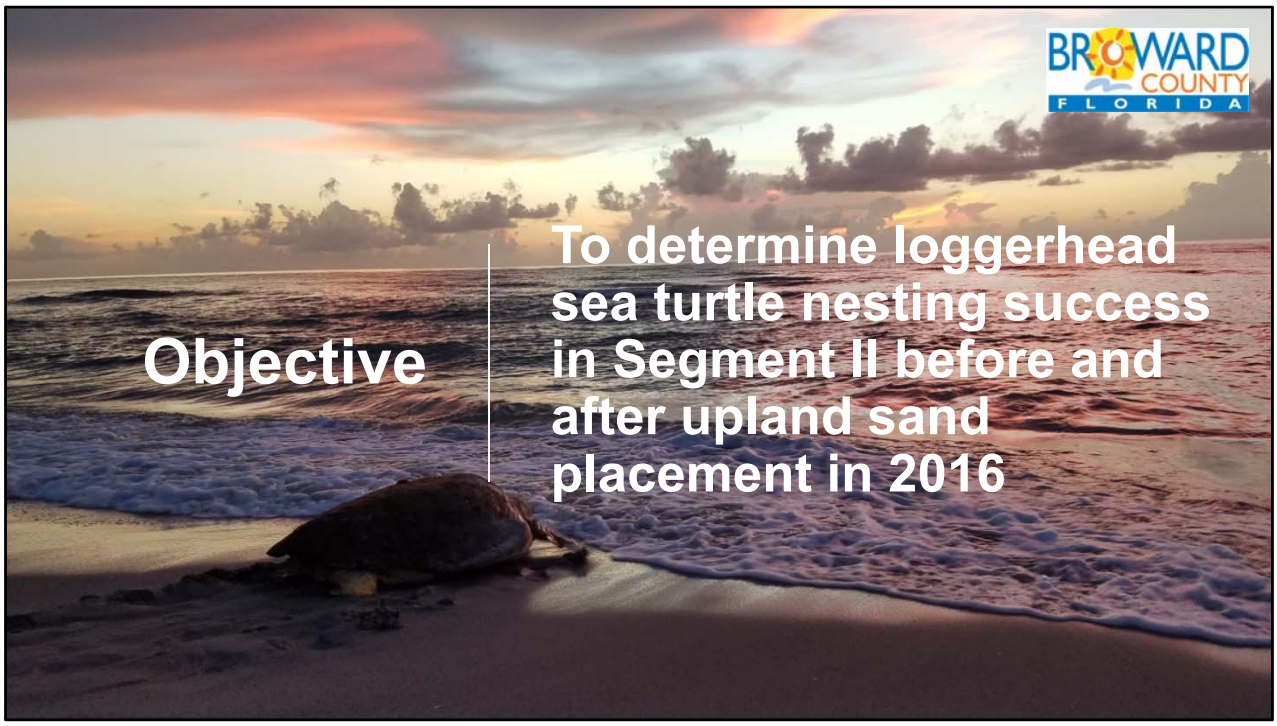
- Offshore sand
  - Decrease in nesting immediately after sand placement (Rumbold et al. 2001)
  - Lower nesting success (Cisneros et al. 2017)
  - Lower hatching success (Cisneros et al. 2017)
- Inlet sand
  - Lower nesting success (Cisneros et al. 2017)
  - Lower hatching success (Cisneros et al. 2017)

Previous studies have examined how sea turtles nest in response to beach nourishment and different sand sources. Considering offshore sand, Rumbold et al. found a decrease in nesting in the year immediately following offshore sand placement in Jupiter, FL. Cisneros et al. found that offshore sand resulted in lower nesting success for turtles in Palm Beach County, meaning they laid less nests and false crawled (or emerged but did not nest) more often. This study also looked at reproductive success and found that offshore sand resulted in a lower hatching success than other sand types. Cisneros et al. also examined inlet sand and found that it resulted in both lower nesting and hatching success.

Beach Nourishment and Turtles: Previous Studies

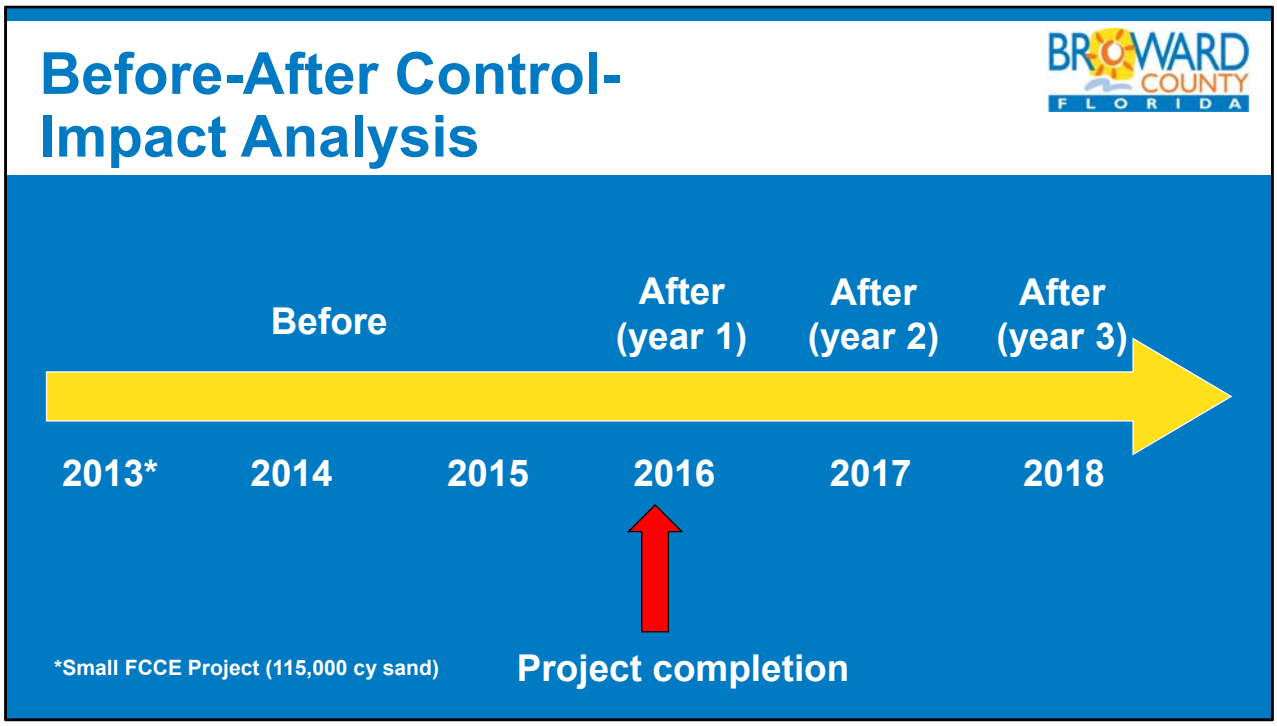
- Silicate mined sand
  - Nesting success similar to native sand (Cisneros et al. 2017)
  - Hatching success similar to native sand (Cisneros et al. 2017)
- Aragonite sand
  - Hatching success similar to native sand (Milton et al. 1997)
- Sediment temperature, grain size, moisture content, carbonate content

Mined silicate sand was also examined to determine its impacts to sea turtle nesting and reproductive success in Palm Beach County, FL by Cisneros et al. They found that nesting and hatching success were both similar to native sand. Another study considered the possibility of using aragonite sand from the Bahamas to nourish FL beaches; the authors studied it in hatcheries on a smaller scale. They found that hatching success was similar to native sand. Some other factors that were considered by Milton et al. include sediment temperature (which is relevant since sea turtles exhibit temperature-dependent sex determination), grain size (which can affect compaction, scarping, and incubation environment), moisture content, and carbonate content.



Since our sea turtle conservation Program is successful over a long-term period, we wanted to examine it on a smaller time scale relative to the beach nourishment projects in Broward County. Specifically, our objective for this project was to determine loggerhead sea turtle nesting success in Segment II before and after the upland sand placement in 2016.

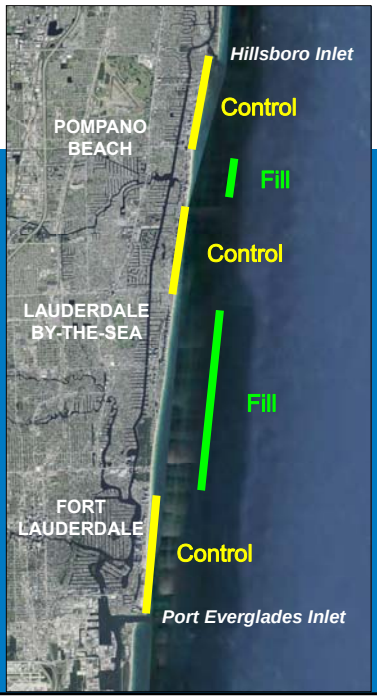
Before-After Control-Impact Analysis



To meet our objective, a Before-After Control-Impact analysis is appropriate. We examined three nesting seasons before the project and three seasons after the project, which was completed in March 2016. *It is worth noting that a small Army Corps-funded FCCE project placed 115,000 cy of sand on the northern portion of Segment II in November 2013 to January 2014; however, this project was considerably smaller than the 2016 project we'll be looking at and placed sand on the upper beach only. It was also completed at the end of the 2013 nesting season, and so 2013 is considered a true "Before" season for our purposes.

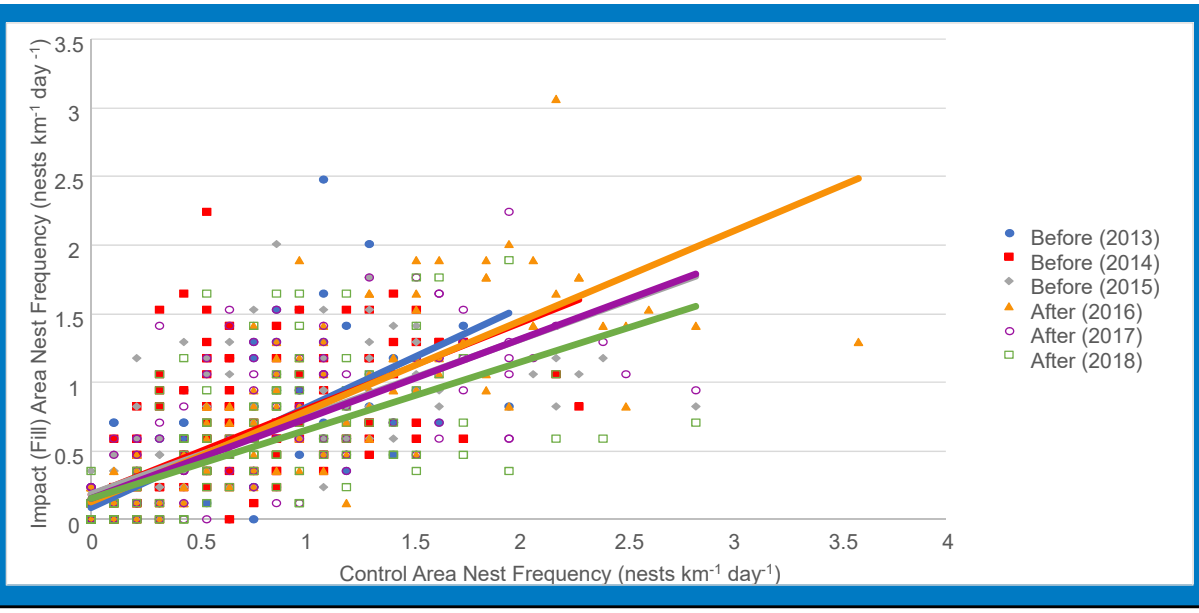
Before-After Control-Impact Analysis

- Control beach
  - 9.14 km (5.68 miles)
- Impact (Fill) beach
  - 7.62 km (4.74 miles)
- Loggerhead crawls only
  - April-September
  - Selected attributes by location in ArcMap
  - Daily nest and FC counts → frequencies (nests or FC km $^{-1}$ day $^{-1}$)



For our study, we broke Segment II down into the Control and Impact (or Fill) beaches based on the locations that did not receive sand and those that did, as shown on the graphic on the right. Since there were insufficient sample sizes of green turtle and leatherback crawls to complete this analysis, we only examined loggerhead crawls. Also, we only used "loggerhead season" which historically is April-September in Broward to eliminate zeros in our dataset. Daily nests and false crawls were selected based on their location in ArcMap 10.4.1 for each year, which were then converted to frequencies in nests or false crawls per km per day.

Nesting Frequency



We plotted Control area nesting frequency against Impact (Fill) area nesting frequency and applied linear regressions to each year, which are the solid lines. You can see that the slopes are all very close to one another. This suggests that the change in nesting frequency between the control and fill areas remained the same among years. To examine this further, we also ran an ANOVA. We were interested in year and treatment interaction effects in our ANOVA to determine if the project affected nesting frequency. *Because of this increasing variability with increasing nest density, we used the square root transformation to better meet variability assumptions in the ANOVA.*

Nesting Frequency

	SS	Mean sq	df	Resid df	F	p
Year	2.06686	0.41337	5	1551	9.0567	<0.001
Treatment	1.49169	1.49169	1	1551	32.6819	<0.001
Year: Treatment	**0.28307**	**0.05661**	**5**	**1551**	**1.2404**	**0.2877**

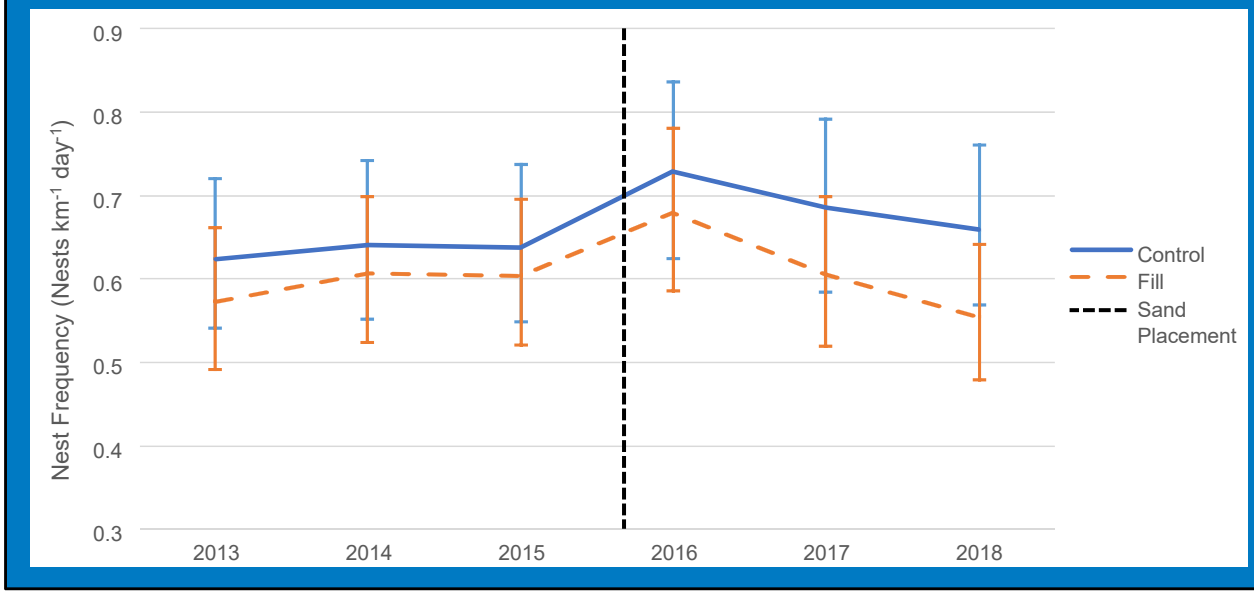
ANOVA results:
Differences among Years and between Treatments = YES
Year x Treatment interaction effects = NO

We did see significant differences among years, but this is due to that interannual variability in nesting I mentioned earlier. We also saw significant differences between treatments, but these differences were consistent through time. We were interested in the year and treatment interaction effects, as I stated before, which were not statistically significant; therefore, we can conclude that there were no project effects.

Running the model with the square root transformed density values significantly improved the model's results.

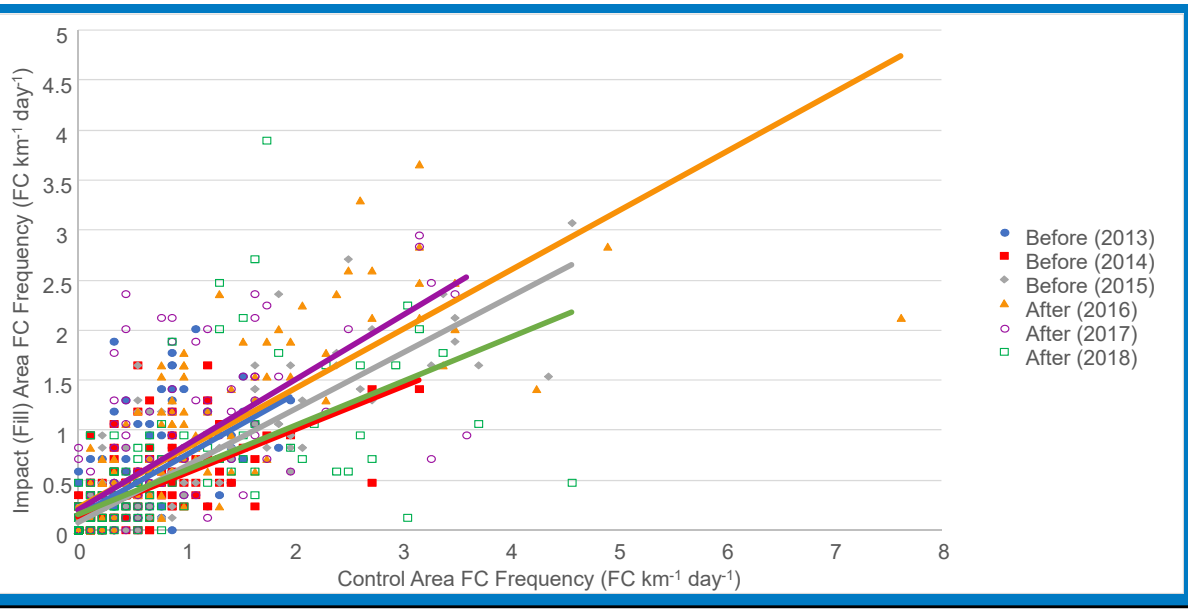
While there are annual differences between seasonally controlled Nesting Crawl density, as well as differences between control and fill areas, these differences have been consistent through time and are, therefore, under a BACI model, not related to the Segment II project

Nesting Frequency



This graph shows the square root-transformed density values of the ANOVA, and you can see the nesting through time. You can see the interannual variability among years we talked about earlier, which is not related to the project. You can also see the differences between the control and fill areas, but since these differences were consistent both before and after the sand placement, they are unrelated to the project. If these lines were to change positions or diverge greatly from one another after the sand placement, then something may have been going on.

False Crawl (FC) Frequency



We ran the same tests on false crawl frequency to give us an idea of how often turtles were emerging, but choosing not to nest on the beach. Again, we plotted control area FC frequency against fill area FC frequency. Just like nesting frequencies, the FC linear regressions did not seem to differ among years. We ran an ANOVA on these data as well, and again, we were looking for year and treatment interaction effects. *We saw the same increasing variability with increasing false crawl density, so we again used the square root transformation to better meet variability assumptions in the ANOVA.*

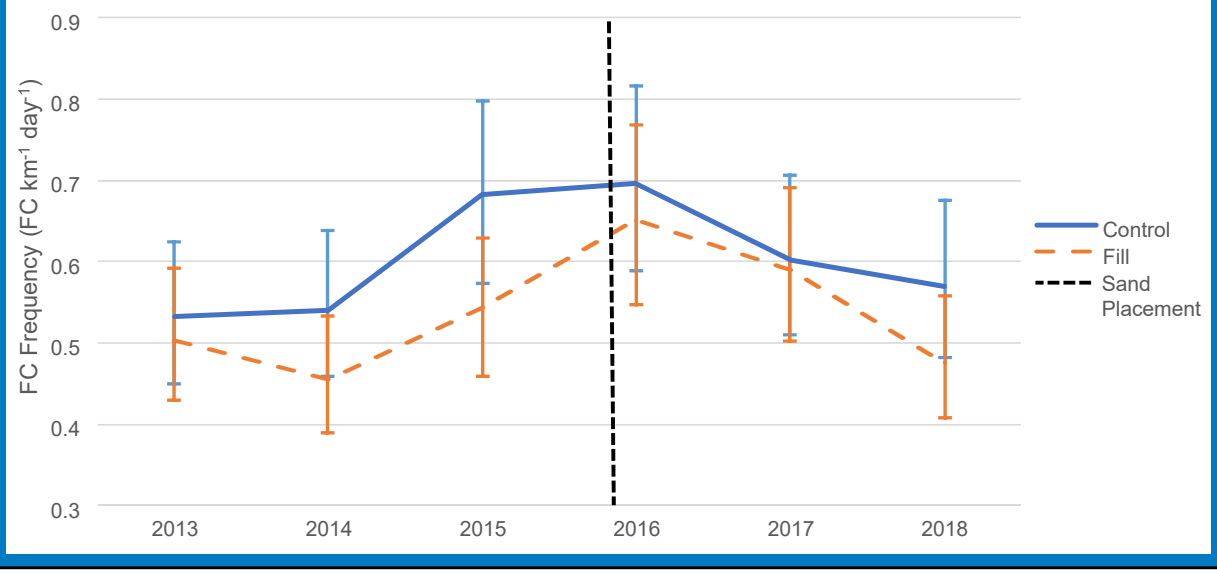
False Crawl (FC) Frequency

	SS	Mean sq	df	Resid df	F	p
Year	6.8422	1.36844	5	1595	18.6887	<0.001
Treatment	1.9881	1.98809	1	1595	27.1512	<0.001
Year: Treatment	**0.8097**	**0.16194**	**5**	**1595**	**2.2116**	**0.05079**

ANOVA results:
Differences among Years and between Treatments = YES
Year x Treatment interaction effects = NO

We saw the same year to year variability in false crawl frequency, but false crawl patterns fluctuate naturally like nesting patterns among years. We also saw treatment differences, but these were consistent through time. We did not see statistically significant year and treatment interaction effects, which means that there were no project effects.

False Crawl (FC) Frequency



Let's look at the square root-transformed density values for the false crawl ANOVA. Again, this shows the false crawls through time in each treatment area. The interannual variability is clear, but unrelated to the sand placement. The differences between the control and fill areas, just like nesting, were consistent through time and therefore unrelated to the project.

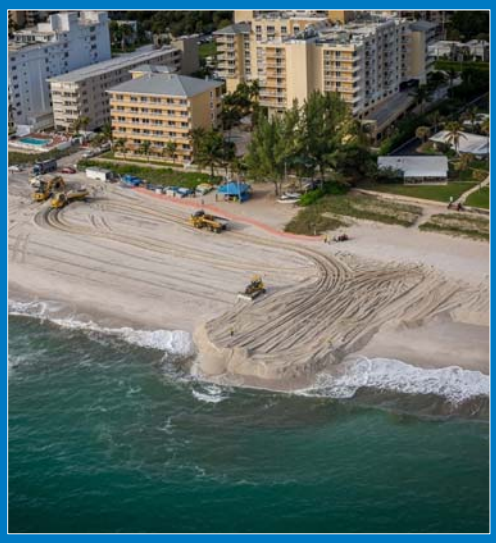
In Conclusion

- 2016 Segment II project had no effect on nesting or FC frequency
- Supports prior studies on mined sand (Cisneros et al. 2017)
  - Good alternative to limited offshore sand
- Other factors (Milton et al. 1997)
  - Sediment temperature, grain size, moisture content, carbonate content

In summary, the 2016 Ortona sand placement in Segment II did not affect nesting or false crawl frequency in loggerhead turtles. Our results support prior studies that examined sea turtle nesting relative to mined sand. Mined sand, therefore, may be a good alternative to offshore sand which is becoming more limited. Some additional factors to consider regarding beach nourishment and sea turtles are sediment temperature, grain size, moisture content, and carbonate content. Some of these factors have been studied previously, but we did not have enough time to look at them for this presentation.

Future Studies

- Examine sediment characteristics
  - Sea turtle reproductive success
- Other turtle species
- Comprehensive analysis
  - Other covariates (e.g. rainfall, SST, beach profile/slope)
- Apply to future beach projects



Given that beach nourishment projects are likely to occur in Broward in the future and that we have such a robust sea turtle dataset, it is important for us to expand on this project and continue to learn about how beach nourishment may affect nesting sea turtles. We would like to look further into those specific characteristics of our sand such as color, carbonate composition, moisture content, etc. Since most of these characteristics can affect the incubation environment, it would make logical sense to examine sea turtle reproductive success rates in this proposed future study. This is beneficial for a conservation program because hatchling production is equally as important as females successfully nesting on the beach. If enough data can be compiled, it would be valuable to examine the other two turtle species' that nest in Broward as well. We would like to incorporate other covariates such as rainfall, sea surface temperature, and beach profile and slope into a comprehensive analysis of our previous beach projects. Lastly, we plan to apply these methods to future beach projects to ensure that we continue to build healthy beaches for all visitors, including humans and turtles alike.

R code and sea turtle data are available upon request.

Thank You!

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