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Beach Nourishment: Effects on the Hatching & Emergence Success Rates of Leatherback (Dermochelys coriacea), Loggerhead (Caretta caretta), and Green (Chelonia mydas) Sea Turtles

Jenna Caderas
Nova Southeastern University, jc3140@nova.edu

HALMOS COLLEGE OF NATURAL SCIENCES AND OCEANOGRAPHY

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By

Jenna Caderas

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JENNA CADERAS
Nova Southeastern University
Halmos College of Natural Sciences and Oceanography

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Approved:

Thesis Committee

Major Professor :________________________________
Bernhard Riegl, Ph.D.

Committee Member :_____________________________
Derek Burkholder, Ph.D.

Committee Member :_____________________________
Joana Figueiredo, Ph.D.

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Abstract:

Broward County, Florida is a popular tourism destination. Due to its popularity, much of the shoreline has been modified and natural habitats were replaced with infrastructure such as houses, condominiums, resorts, and restaurants. The same Broward County beaches utilized by tourists and residents are important for three species of nesting sea turtles, including the Leatherback, *Dermochelys coriacea*, Loggerhead, *Caretta caretta*, and Green, *Chelonia mydas*, Turtles. The Broward County Sea Turtle Conservation Program (BCSTCP) collects yearly data in order to study these endangered reptiles. Increased anthropogenic effects including further coastal development (public & private), public beach events, public beach access, as well as natural events, have caused these important nesting beaches to erode and narrow. In an effort to control this erosion damage, Broward County has performed a number of beach nourishment projects. This study found yearly fluctuations in sea turtle hatching and emergence success rates, and years of beach nourishment projects significantly decreased these rates. Yearly hatching data available from Broward County concludes that beach nourishment, as well as hurricanes and tropical storms cause decreases in sea turtle hatching and emergence success rates in Broward County. Additionally, nest depth and sea turtle size increases the hatching and emergence success rates from females that are not too large or too small that nest in Broward County.

Keywords: *Dermochelys coriacea*, leatherback, *Caretta caretta*, loggerhead, *Chelonia mydas*, green, hatching success, emergence success, Broward County, sea turtle, beach nourishment

Introduction:

Throughout the world's oceans there are seven different species of sea turtles: the Loggerhead (*Caretta caretta)*, Green (*Chelonia mydas)*, Leatherback (*Dermochelys coriacea)*, Hawksbill (*Eretmochelys imbricata*), Kemps Ridley (*Lepidochelys kempii)*, Olive Ridley (*Lepidochelys olivacea*) and the Flatback (*Natator depressa*) sea turtle. Three of the seven species of sea turtles, *D. coriacea*, *C. caretta*, and *C. mydas*, nest on the beaches of Broward County, Florida. Globally, all seven species of sea turtles are listed on the IUCN *Red List of Threatened Species* (Wallace et al. 2011). International Union for the Conservation of Nature (IUCN) lists *C. caretta* and *C. mydas* as Endangered, and *D. coriacea* as Critically Endangered (Wallace et al. 2011). The U.S. Fish and Wildlife Service lists *C. caretta* as threatened in the South Atlantic Ocean (U.S. Fish and Wildlife Service 2014). *Caretta caretta* inhabit mainly the temperate regions of the world's oceans, while *C. mydas* is distributed in the tropical regions (Bowen et al. 1994). On the other hand, *D. coriacea* has a very large distribution due to its partially endothermic ability, allowing for unrestricted access to a specific temperature range and therefore, the ability to move through warm and cold temperature ranges in the ocean (Dutton et al. 1999). *Dermochelys coriacea* ranges from the Gulf of Alaska to foraging areas off the coast of Chile; though movement through cold water occurs, nesting is exclusively tropical (Dutton et al. 1999).

Nesting sea turtles haul onto beaches to nest about 2-7 times per season, with an average of 100 eggs per clutch (Bowen et al. 1992). According to the 2013 Florida Fish and Wildlife Conservation Commission (FFWCC) nesting beach survey data, 2,456 *C. caretta* nests, 500 *C. mydas* nests and 18 *D. coriacea* nests were located in Broward County (Florida Fish and Wildlife Conservation Commission 2015). A total of 2,803 non-nesting emergences between the three species were recorded in 2013 (Florida Fish and Wildlife Conservation Commission 2015). Sea turtles exhibit natal homing, i.e. they tend to return to the same beach where they were born, which is a characteristic found in some marine animals. Natal homing has been shown through mtDNA studies for *C. caretta* (Bowen et al. 1994). Although most individuals experience natal homing, some may instead create new nesting beaches (Bowen et al. 1994).

The creation of new nesting beaches occurs when natural causes such as climate, sea level or geography changes influence beach structure, making it less appealing (Bowen et al. 1994). *Chelonia mydas* also exhibits natal homing characteristics which appear to be the dominant force that shapes the population structure of these turtles (Bowen et al. 1992). Little is known about the natal homing capabilities of *D. coriacea* due to their large oceanic migrations (Dutton et al. 2005). It is assumed that all surviving females from nests in Broward County will exhibit natal homing and return as adults to nest on Broward County beaches.

All anthropogenic and natural effects occurring on these turtle nesting beaches are of immediate conservation concern for sea turtle nesting efforts. Coastal beaches are dynamic, and constantly changing to adapt to natural causes such as inclement weather and natural erosion. Barring a catastrophic weather event, these natural changes normally occur on a gradual basis, unlike human impacts that tend to occur rapidly. Conflict between humans and turtles is widespread due to increasing anthropogenic influence in the coastal zone. Bycatch and coastal development as the most important threats to sea turtles (Wallace et al. 2011).

The main anthropogenic activities impacting the available nesting habitats for sea turtles include coastal development, construction, beachfront placement of structures, beach nourishment projects, erosion and vehicular traffic (Mazaris et al. 2009). Living or owning property on the beach is highly desirable to homeowners and commercial property owners, making the coastline an active socioeconomic area (Small and Nicholls 2003). Human population density is inversely proportional to land elevation and distance from shore (Small et al. 2000), increasing the importance to protecting natural coastlines from human activity. Protecting natural coastlines by managing human activity is a vital component to preserving thriving coastal ecosystems. In 2003, about 53% of the United States human population lived on the coastline (Crossett et al. 2004).

Since over half of the human population lives on or close to the shore, it is extremely important that increased efforts are made to protect the natural coastline from human activity (Crossett et al. 2004). One such area, Broward County, Florida, lies on the southeast coast of Florida directly east of the Florida Everglades and consists of eight municipalities (Hallandale, Hollywood, Dania, Fort Lauderdale, Lauderdale-by-the-Sea, Pompano, Hillsboro and Deerfield Beach). Similar to many coasts in the United States, sea level rise and erosion affect the coastline, specifically narrowing beach widths. Beaches throughout the U.S. are becoming smaller due to commercial and residential beach development, as well as natural causes including sea level rise and erosion. Due to beach narrowing, Broward County beaches have undergone various beach nourishment projects during the past 20 years. Manipulation of nesting beaches, including artificially widening beaches for erosion control, is linked to changes in the placement of sea turtle nests (Hamann et al. 2010). Narrower beaches lead to sea turtle nesting sites that are closer to the water, which are then at a high risk of being inundated and flooded by water (Kamel and Mrosovsky 2005). Conversely, increasing beach width may lead to nests being laid farther from the water, causing hatchlings to become disoriented due to problems such as coastal lighting (Kamel and Mrosovsky 2005).

In addition to coastal lighting, increasing coastal development and sea level rise are causing beaches to experience "coastal squeeze," defined as a form of habitat loss due to man-made structures such as sea walls (Pontee 2013). Habitat loss occurs in the intertidal zone due to fixed structures, creating a fixed high tide line (Pontee 2013). Constant sea level rise causes the low tide line to migrate toward the fixed high tide line (fixed structure) (Pontee 2013). Although beaches are resilient to natural changes, human development is decreasing beach resiliency making erosion more prevalent (Schlacher et al. 2007). Shorelines require preservation of beach width for both ecosystem and economic benefits. One common restoration technique is beach nourishment.

Beach nourishment is a technique used worldwide to maintain beach width and mitigate erosion. These practices are used on continents such as Australia, North America, and Europe (Castelle et al. 2008, de Alegria-Arzaburu et al. 2013, Hamann et al. 2010, Hanson et al. 2002). Managers have proposed beach nourishment as a mitigation tool for erosion on local beaches. According to Campbell and Benedet (2006), beach nourishment programs are "a series of constructions that periodically place beach-compatible sand in the nearshore to compensate for a net deficit of sand in a given beach system." Beach nourishment is the most popular method of mitigation for coastal beach erosion because it preserves the recreational value of beaches (Campbell and Benedet

2006). Though this process is beneficial in preserving beaches, it may have negative impacts on the biodiversity of marine ecosystems on nourished beaches. Specifically, it may have profound effects on endangered species such as sea turtles (Hartwig 2002, Schlacher et al. 2007).

On the Atlantic coast of Florida the total sand nourishment volume to be placed in the future to help mitigate and holdback beach erosion is 65,000,000 m^3 of sand (Campbell and Benedet 2006). Special consideration is given when choosing the sand for nourishment projects with regard to grain size and composition. Sediment borrow areas from proposed donor sites are compared to the textural properties of the natural beach, though sand placement does not incorporate the coastal systems at each specific site (Campbell and Benedet 2006). The donor sand is usually selected to have properties similar to the natural beach. Sea turtle mothers, however, are very selective as to where they nest, and minor changes or imperfections to the nesting environment may deter them from nesting (Kleppan 2013). Sediment grain size is extremely important to the success or failure of nesting and hatching activities (Barik et al. 2014). Similarly, fine, moist, and compact sand may reduce hatchling emergence success (Steinitz et al. 1998). Nesting mothers have trouble digging into this compacted sand, therefore, hatchlings within the egg chamber cannot move the compacted sand out of the way in order to emerge in their group exit from the egg chamber (Kleppan 2013).

Along with decreased emergence success, it has been found that fine, moist, and compacted sand may have an effect on the viability of eggs, thereby impacting hatching success (Ehrhart 1989, McGehee 1990). It has been demonstrated in Florida that nourished beaches contain more moisture than most natural beaches (Ackerman et al. 1992). McGehee (1990) found that sand with more moisture causes a decrease in egg viability, resulting in a decrease in hatching success. Compacted sand from beach nourishment projects may cause both a decreased emergence and hatching success rate. Though researchers have identified most of the impacts to sea turtle nesting habitats, until scientists are able to determine the impact sea turtles have on the ecosystem it will be hard to enforce proper conservation methods (Hamann et al. 2010). In order to evaluate a species on a local level, it is imperative that more information is gathered locally. Combining local data may aid in the global management of the species.

This study aims to:

(1) Determine the effects of beach nourishment on hatching success rates and emergence success rates for the species *D. coriacea, C. caretta,* and *C. mydas* in Broward County, Florida.

(2) Identify the variables that significantly effect the hatching success rates and emergence success rates for the species *D. coriacea, C. caretta*, and *C. mydas* in Broward County, Florida.

Sea turtles are dependent on beaches for nesting and normally exhibit natal homing (Bowen et al. 1994, Bowen et al. 1992). Due to erosion, heightened by coastal development, beaches (and sea turtle nesting habitat) are disappearing (Wallace et al. 2011, Pontee 2013, Mazaris et al. 2009). Beach nourishment is the main mitigation technique used to maintain these habitats and widen beaches, which changes the natural beaches to an "artificial" beach. It is known that the sand used in the beach nourishment projects may be detrimental to the hatching and emergence success rates (Steinitz et al. 1998, Kleppan 2013, Ehrhart 1989, McGehee 1990). Therefore, we expect a decreased hatching success rate and emergence success rate after beach nourishment projects are completed. Determining hatching and emergence success rates of *D. coriacea, C. caretta*, and *C. mydas* sea turtles in Broward County in response to the numerous beach nourishment projects, will help researchers determine whether or not beach nourishment projects can be detrimental to the hatching and emergence success rates of these critically endangered and threatened reptiles.

Methods:

Data was obtained from the long term monitoring program of the Broward County Sea Turtle Conservation Program (BCSTCP). The BCSTCP is administered by the Broward County Environmental Planning and Community Resilience Division (BCEPCRD), funded by the Broward County Board of Commissioners, and carried out by Nova Southeastern University (NSU). Annually, from March 1^{st} to October 31^{st}, students (or recent graduates) from NSU performed daily morning beach surveys to look for new nests and false crawls during nesting season, and hatch-outs during hatching season.

For this study, data from 1998-2015 collected by the BCSTCP were used. Data included: turtle species, year, zone (GPS location), egg chamber depth (cm), nesting female crawl width (cm), live in nest (LIN), live pipped (LPIP), dead in nest (DIN), dead pipped (DPIP), visual development (VD), no visual development (NVD), and total egg count. Use of this dataset was authorized by Broward County and the data was acquired from Florida Fish and Wildlife Conservation Commission (FFWCC). Through FFWCC, an appropriate Marine Turtle Permit for research was acquired to manipulate the data. This permit (RP #704) was to conduct this research project, and will allow access to the yearly data from 1998 to 2015.[1]

Data collected for new nests includes turtle species, track width (cm), zone (location), GPS location, and the distance from high tide (meters). A GPS location was taken where the egg chamber was estimated to be, and the distance from high tide was measured from the wrack line to the estimated egg chamber location. At least 72 hours after the nest hatches, the egg chamber was excavated and egg chamber depth (cm), total egg count, LIN, DIN, LPIP, DPIP, white eggs, VD and NVD were recorded. The total egg count was the number of eggs that have hatched where the shell is >50% intact. The LIN count was the number of hatchlings found within the egg chamber that were completely out of the shell and alive; the DIN count was the number of hatchlings found within the egg chamber that were completely out of the shell and dead. The LPIP and DPIP were the number of hatchlings found partially out of the egg shell and alive or dead, respectively. Whole eggs were counted and opened to determine if there was any visual development. These were separated into the visual or no visual development categories accordingly.

Yearly data was collected using four different types of data sheets: (1) In Situ Nesting Data Sheets, (2) Relocated Nest Datasheets, (3) Post-Hatching Excavation Data

[1] See appendices

Sheets, and (4) Hatch-Out Data Sheets (Table 1). For all data sheets, zone 1 is the most northern area surveyed in Broward County through zone 128, which is the most southern area surveyed in Broward County (Figure 1). GPS latitude and longitude was taken using a Trimble GeoXT. Street addresses are parallel to the nest location. For relocated nests, the egg chamber depth used was the measurement taken from the original nest. For hatch-out data, excavation date is three days after hatch date.

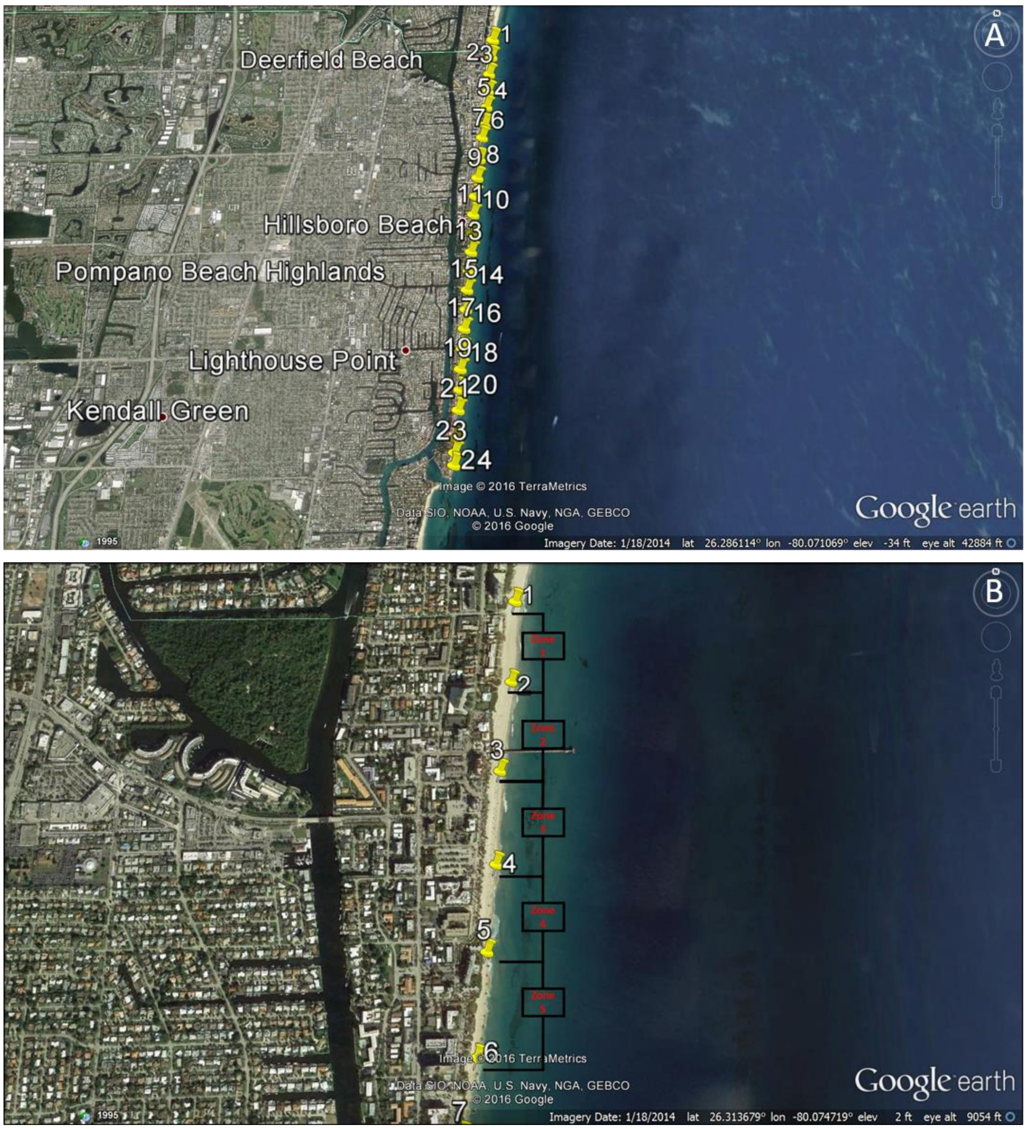

Figure 1. Example of zones located in Broward County. (A) Zones 1-24 located in Hillsboro Beach; (B) Close-up of zones 1-6 located in Hillsboro Beach. Zones 25-128 continue south to the Broward/Miami-Dade County Line.

Table 1. Variables measured for each datasheet used by the Broward County Sea Turtle Conservation Program (1-4).

(1) In Situ Nest Data Sheet

Nest Number
Species
Zone
Distance to High Tide Line (m)
Measured Crawl Width (cm)
GPS Latitude & Longitude
Street Address

(2) Relocated Nest Data Sheet

Zone Location for Relocated Nest
Egg Chamber Depth (cm)
Total Egg Count
Total # Broken Eggs
Total # Abnormally Shaped Eggs
GPS Latitude & Longitude (new nest)

(3) Post-Hatching Data Sheet

Beach Name & Nest Number	Live Pipped Total
Species	Dead in Nest Total
Date Nest Laid	Dead Pipped Total
Total Hatched Egg Count	Whole Eggs with Visual Development
# Broken Eggs	Whole Eggs with No Visual Development
# Abnormally Shaped Eggs	Whole White Eggs
Hatch Date	Egg Chamber Depth (cm)
Live in Nest Total	

(4) Hatch-Out Data Sheet

Beach Name & Nest Number
Zone
Egg Chamber Emergence GPS Latitude & Longitude
Hatch Date
Excavation Date

This project will determine the variables that effect the hatching success rate and/or emergence success rate, as well as determine whether or not there is a relationship between the hatching success rate and/or emergence success rate, and beach nourishment projects in Broward County. Hatch success will be calculated using the following equation:

$$Hatch\ success\ (\%) = \left(\frac{(total\ \#\ of\ eggs) - (\#\ unhatched)}{total\ \#\ of\ eggs}\right) * 100$$

Emergence success will be calculated using the following equation:

$$Emergence\ success\ (\%) =$$

$$\left(\frac{(total\ \#\ of\ eggs) - (\#DIN) - (\#DPIP) - (\#\ unhatched) - (\#LIN) - (\#LPIP)}{total\ \#\ of\ eggs}\right) * 100$$

Where the number of unhatched eggs includes the number of whole eggs with visual development and no visual development.

Data analysis

(1) To determine if beach nourishment projects affect hatching success rates and emergence success rates, and eliminate potential differences between specific nourishment projects (type of sand used, year, species, etc.), these variables were compared for each nourishment project separately using t-tests. Specifically, beach nourishment projects from Broward County were chosen for analysis based on available data during the study period (1998-2015). I compared the hatching success rates in each beach between the year of the nourishment project, and the year before the nourishment project. The difference between emergence success rates were calculated in the same way. Tests were performed in R. Specifically, after verifying that the assumptions were met (using Shapiro-Wilk normality test and Bartlett's homogeneity of variances test), the t-test was performed. The data file format (Logan 2010) and R commands used were:

FACTOR	DV
A	.
A	.
..	..
B	.
B	.
..	..

Dataset should be constructed in long format such that the variables are in columns and each replicate is in is own row.

$with(dataset, boxplot(HS \sim Year))$

$shapiro.test(subset(dataset, Year == 'Y0')\$HS)$

$shapiro.test(subset(dataset, Year == 'Y1')\$HS)$

$bartlett.test(HS \sim Year)$

$t.test(HS \sim Year)$

Where Factor represents Year (levels of the factor: the year of the nourishment project (Y1) or one year before the nourishment project (Y0)) and DV represents the hatching success rates or emergence success rates. Steps shown above use hatch success (HS) as an example. Beach nourishment projects that were tested by yearly comparisons are listed in Table 2.

Table 2. Selected beach nourishment projects completed in Hollywood & Hillsboro used for yearly comparisons, 1998-2015 in Broward County, FL. Projects were selected based on available data.

Year Comparisons	
Year	***Beach Nourishment Project***
1999	Diplomat Hotel Beach Nourishment
2005	Hollywood/Hallandale Beach Nourishment
2008	Hillsboro Beach Truck Haul
1998 & 2011	Hillsboro/Deerfield Beach Restoration Project
2011	Hollywood Beach Nourishment

(2) To determine which independent variable(s) affect each dependent variable (hatching and emergence success rates) for each species, analysis of covariance was used. This model combines pieces of a regression test and analysis of variance (ANOVA) test, and is used when there is one (or more) continuous and categorical independent variable (Crawley 2013). The model was run using R studio separately for both hatch and emergence success for each species. Data included: turtle species, year, zone (GPS location), nesting female crawl width, egg chamber depth, LIN, LPIP, DIN, DPIP, and total egg count. The model was as follows (Crawley 2013):

$$Y_{ij} = \mu + \alpha_i + \beta(x_{ij} - \bar{x}) + \beta(z_{ij} - \bar{z}) + \beta(a_{ij} - \bar{a}) + \beta(b_{ij} - \bar{b}) + \beta(c_{ij} - \bar{c}) + \beta(d_{ij} - \bar{d}) + \varepsilon_{ij}$$

Adjusted model:

$$Y_{ij} = y_{ij} - b(x_{ij} - \bar{x}) - b(z_{ij} - \bar{z}) - b(a_{ij} - \bar{a}) - b(b_{ij} - \bar{b}) - b(c_{ij} - \bar{c}) - b(d_{ij} - \bar{d})$$

Where Y_{ij} represents the dependent variable, X_{ij}, Z_{ij}, A_{ij}, B_{ij}, C_{ij}, and D_{ij} represents the independent variable(s), βi represents the relationship between Y_{ij} and X_{ij} through D_{ij}, and α_i represents the intercept (Crawley 2013). This model will be used to describe the hatching and emergence success rates for each species, with year, beach, zone (GPS location), egg chamber depth (cm), and nesting female crawl width (cm) as independent variables. A backward "step" function was then used to eliminate from the model the independent variable(s) which did not significantly contribute to describe the dependent variable(s).

After all of the data was compiled, certain occurrences caused nests to have an automatic "zero" for hatch and/or emergence success. In order to obtain the most accurate statistical analysis, nests with the following characteristics were deleted from the study: washed out, pulled stakes, predated, incomplete excavation, stake missing/stake lying on beach, buried too deep by tide, could not locate egg chamber, not excavated, and possibly poached/poached. It is important to note that nests with these remarks may have hatched and emerged but this may have been missed by a worker. Due to the high associated uncertainty with regard to accuracy, these points were deleted.

Results:

Yearly Comparisons

Selected nourishment projects shown in Table 2 were tested. Overall, based on the results of the T-Test, the hatching success rates were significantly effected by years when nourishment projects took place, with the exception of the Hollywood/Hallandale Beach Nourishment Project in 2005 (Table 3). Similarly, the emergence success rates were significantly effected by year, with the exception of two nourishment projects: Diplomat Hotel Beach Nourishment, 1999 & Hollywood/Hallandale Beach Nourishment, 2005 (Table 3).

Table 3. T-Test results from beach nourishment projects in Hollywood & Hillsboro, Broward County, FL. "Year" is the year the nourishment project took place.

Year	Beach Nourishment Project	Hatching Success P Value	Emergence Success P Value
1999	Diplomat Hotel Beach Nourishment	0.02578	0.2679
2005	Hollywood/Hallandale Beach Nourishment	0.9743	0.1481
2008	Hillsboro Beach Truck Haul	$<2.2X10^{-16}$	$<2.2X10^{-16}$
1998 & 2011	Hillsboro/Deerfield Beach Restoration Project	0.00017	0.02446
2011	Hollywood Beach Nourishment	0.00354	0.02485

Dermochelys coriacea

Dermochelys coriacea was the rarest sea turtle over the survey area with 363 nests encountered. Hatch success in *D. coriacea* sea turtles was most affected by three variables: year ($p<3.58 \times 10^{-11}$), nest depth ($p<5.62 \times 10^{-11}$) and nesting female crawl width ($p<0.07356$), as seen in Table 4. Hatch success was significantly affected throughout the 18 years (Figure 2). Overall, based on an ANCOVA, there was a significantly positive effect between nest depth and hatch success with the majority of nest depths landing between 50 and 100 cm deep (Figure 3). Though not significant, nesting female crawl width also effected the hatch success (Figure 4).

Table 4. Variables that significantly effected *Dermochelys coriacea* hatch success and emergence success in Broward County, Florida from 1998-2015. Results are from an ANCOVA.

***D. coriacea* Hatch Success**	
Variables	**P Value**
Year	3.58E-11
Nest Depth	5.62E-08
Nesting female crawl width	0.07356
***D. coriacea* Emergence Success**	
Variables	**P Value**
Year	1.88E-10
Beach	0.036531
Zone	0.007171
Nest Depth	0.017095
Nesting Female Crawl Width	0.388925

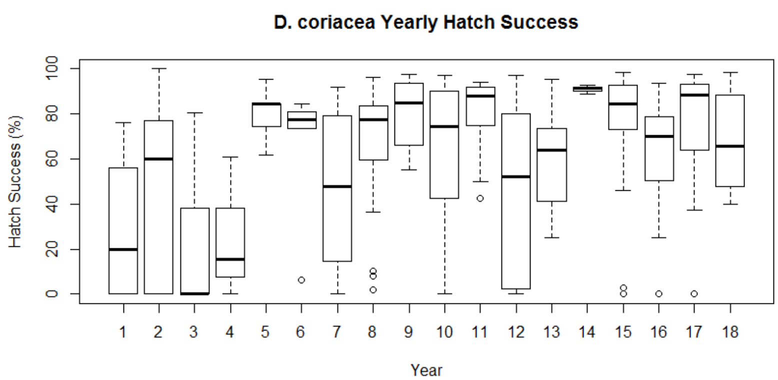

Figure 2. Hatch Success (%) of *Dermochelys coriacea* yearly from 1998 to 2015 (labeled 1-18 respectively from 1998-2015) in Broward County, Florida (±SD).

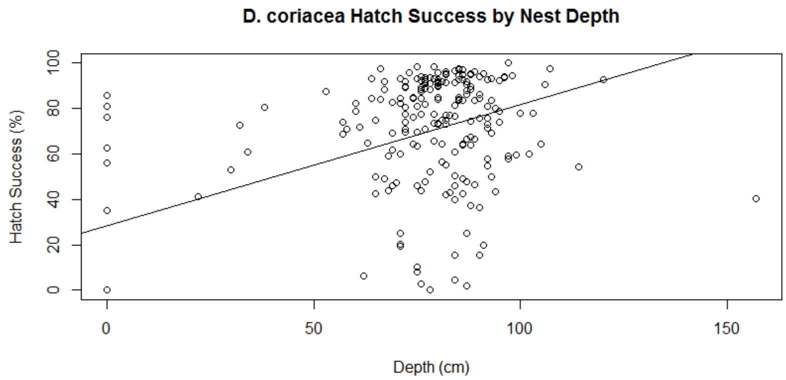

Figure 3. *Dermochelys coriacea* hatch success (%) versus individual nest depth (cm) in Broward County, Florida from 1998-2015.

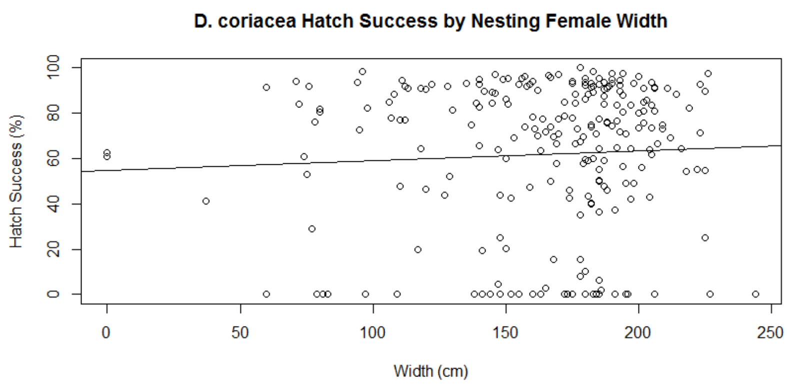

Figure 4. *Dermochelys coriacea* hatch success (%) versus nesting female crawl width (cm) in Broward County, Florida from 1998-2015.

Emergence success was affected by year, zone, nest depth, beach and nesting female crawl width represented in Table 4. Throughout the 17 years, emergence success varied greatly (Figure 5). Emergence success varied slightly on the beaches throughout Broward County with a slightly higher success on Fort Lauderdale Beach, and slightly lower success on Hillsboro Beach (Figure 6). The zone in Broward County is positively correlated to the emergence success (Figure 7). Also, nest depth was positively correlated to emergence success (Figure 8). Though not significant, nesting female crawl width also affected the emergence success (Figure 9).

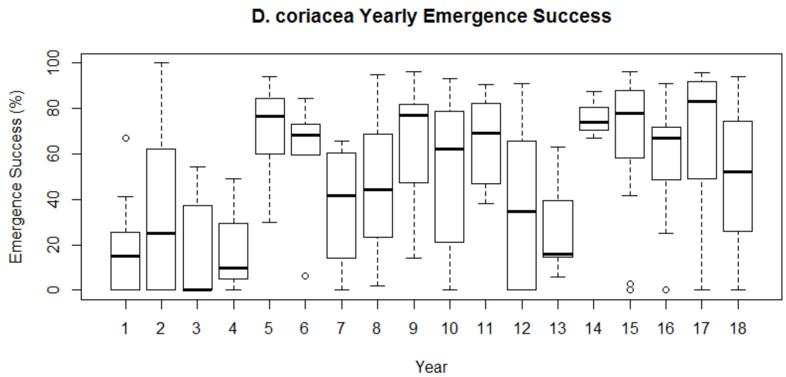

Figure 5. *Dermochelys coriacea* yearly emergence success (%) from 1998 to 2015 (labeled 1-18 respectively from 1998-2015) in Broward County, Florida (±SD).

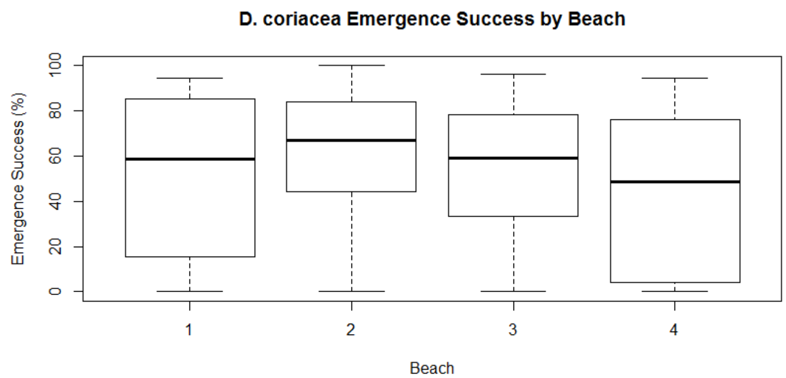

Figure 6. *Dermochelys coriacea* emergence success (%) by beach in Broward County, Florida from 1998-2015. Beach 1 represents Hallandale & Hollywood Beaches, beach 2 represents Fort Lauderdale Beach, beach 3 represents Pompano Beach and beach 4 represents Hillsboro & Deerfield Beaches (±SD).

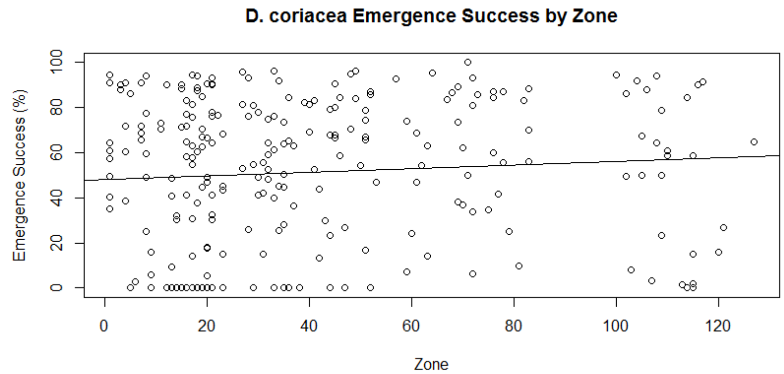

Figure 7. *Dermochelys coriacea* emergence success (%) by zone in Broward County, Florida from 1998-2015. Zone 1 is the most northern area surveyed in Broward County to zone 128 which is the most southern survey area in Broward County.

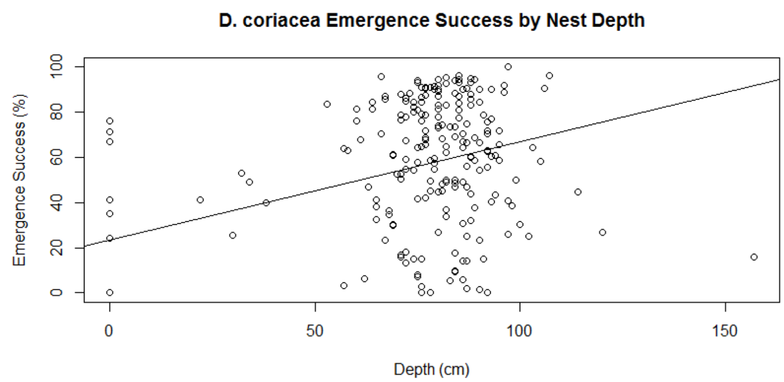

Figure 8. *Dermochelys coriacea* emergence success (%) versus individual nest depth (cm) in Broward County, Florida from 1998-2015.

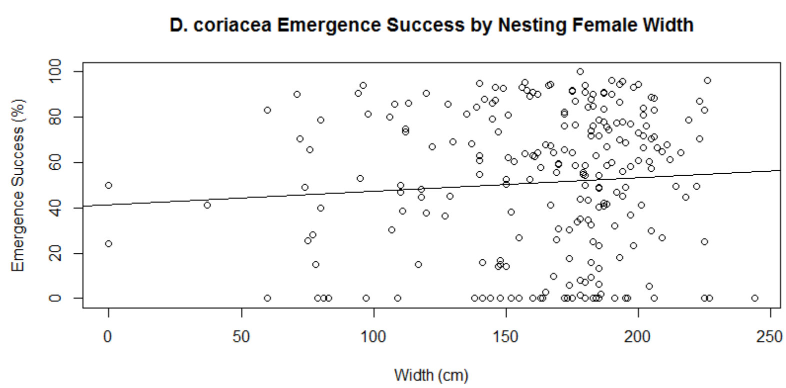

Figure 9. *Dermochelys coriacea* emergence success (%) versus nesting female crawl width (cm) in Broward County, Florida from 1998-2015.

Caretta caretta

Caretta caretta was the most common sea turtle over the survey with 34,321 nests encountered. Overall, four variables significantly affected the hatch success of *C. caretta* throughout the study, namely: year, zone, nest depth, and nesting female crawl width (Table 5). Hatch success varied yearly (Figure 10), and was positively correlated to the zones (Figure 11). Both nest depth and nesting female crawl width (respectively) positively effected hatch success (Figure 12, Figure 13).

Table 5. Variables that significantly effected *Caretta caretta* hatch success and emergence success in Broward County, Florida from 1998-2015. Results are from an ANCOVA.

***C. caretta* Hatch Success**	
Variables	**P Value**
Year	<2.2E-16
Zone	<2.2E-16
Nest Depth	<2.2E-16
Nesting female crawl width	<2.2E-16
***C. caretta* Emergence Success**	
Variables	**P Value**
Year	<2.2E-16
Beach	<2.2E-16
Zone	0.000289
Nest Depth	<2.2E-16
Nesting female crawl width	<2.2E-16

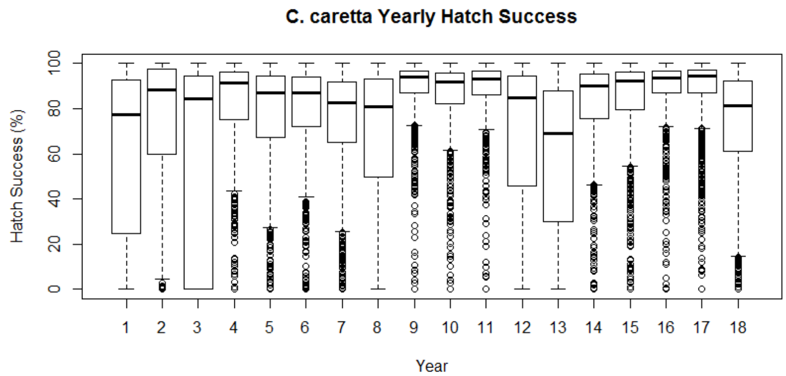

Figure 10. *Caretta caretta* yearly hatch success (%) from 1998 to 2015 (labeled 1-18 respectively from 1998-2015) in Broward County, Florida (±SD).

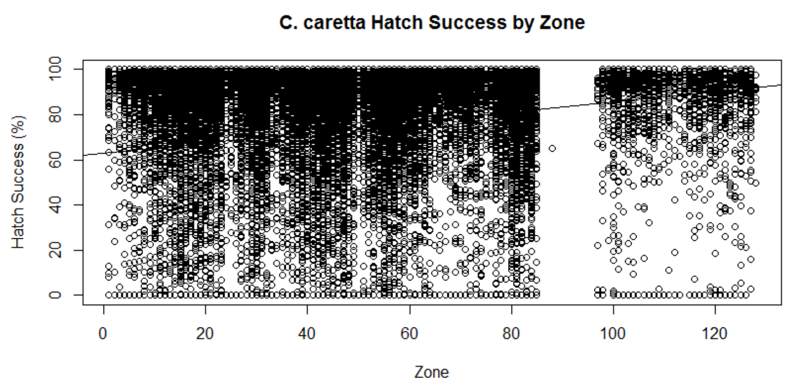

Figure 11. Hatch success (%) of *Caretta caretta* by zone in Broward County, Florida from 1998-2015. Zone 1 is the most northern area surveyed in Broward County to zone 128 which is the most southern area surveyed in Broward County.

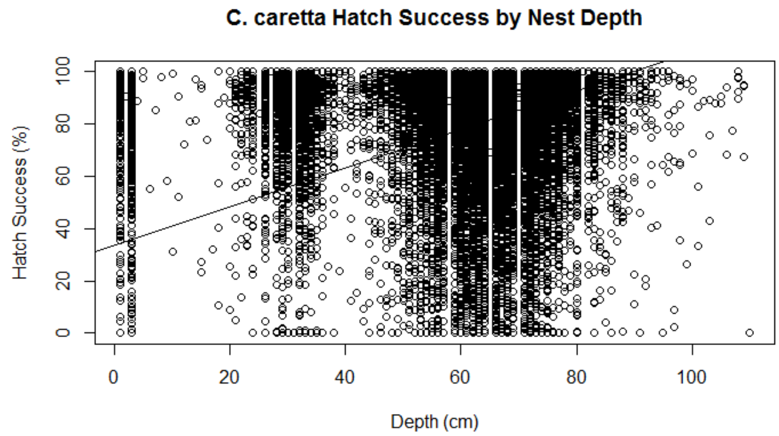

Figure 12. *Caretta caretta* hatch success (%) versus nest depth (cm) in Broward County, Florida from 1998-2015.

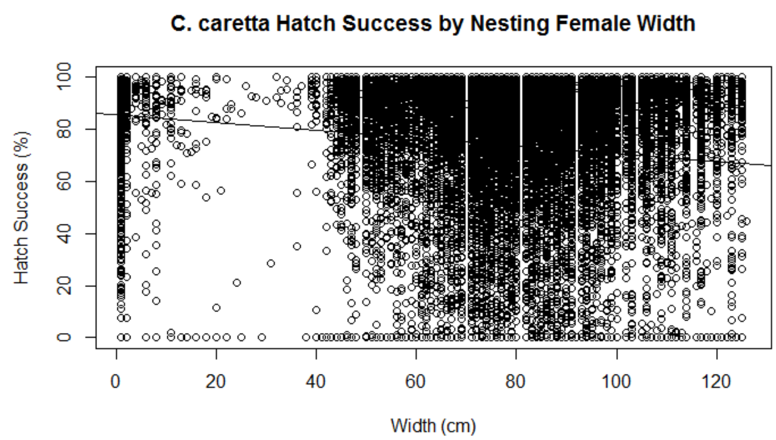

Figure 13. *Caretta caretta* hatch success (%) versus nesting female crawl width (cm) in Broward County, Florida from 1998-2015.

Emergence success was significantly affected by all five variables analyzed (Table 5). Year, beach, nest depth and nesting female crawl width were all significant as well as zone ($p<0.00029$) (Table 5). Yearly emergence success varied significantly, with a slightly positive effect from 1998-2015 (Figure 14). As seen in Figure 15, emergence success by beach varied slightly throughout Broward County, while zone in Broward County is positively correlated to emergence success (Figure 16). Nest depth and nesting female crawl width both significantly affected the emergence success seen in Figure 17 & 18 respectively.

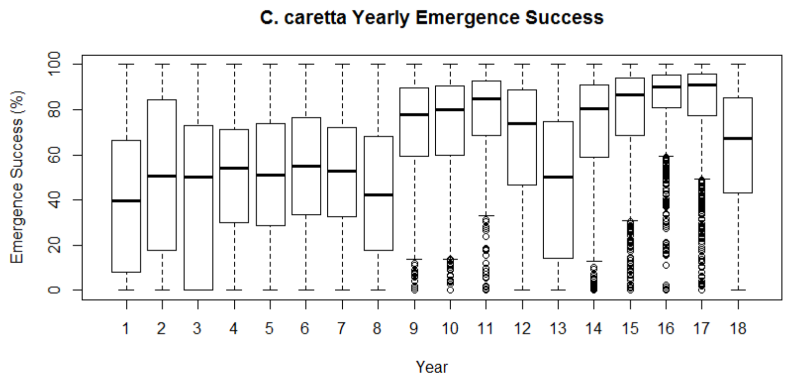

Figure 14. Yearly emergence success (%) of *Caretta caretta* from 1998 to 2015 (labeled 1-18 respectively from 1998-2015) in Broward County, Florida (±SD).

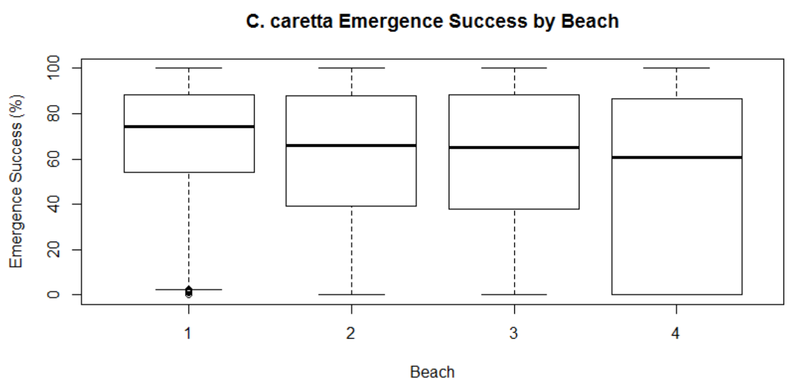

Figure 15. Emergence success (%) of *Caretta caretta* by beach in Broward County, Florida from 1998-2015. Beach 1 represents Hallandale & Hollywood Beaches, beach 2 represents Fort Lauderdale Beach, beach 3 represents Pompano Beach and beach 4 represents Hillsboro & Deerfield Beaches (±SD).

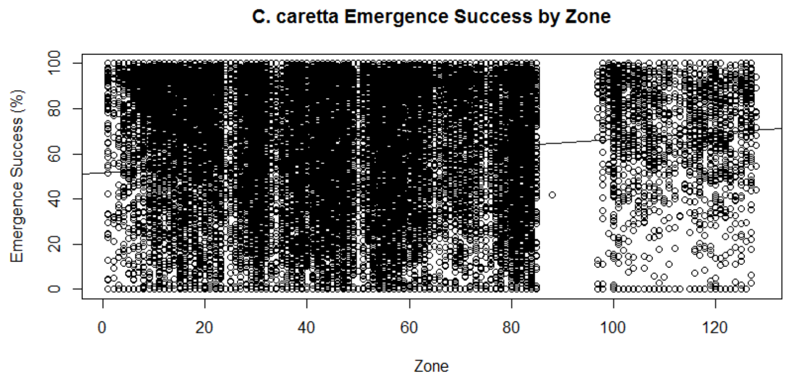

Figure 16. Emergence success (%) of *Caretta caretta* by Zone in Broward County, Florida from 1998-2015. Zone 1 is the northernmost area surveyed in Broward County to zone 128 which is the southernmost area surveyed in Broward County. Zone 85-97 represent John U Lloyd park which is not surveyed by BCSTCP.

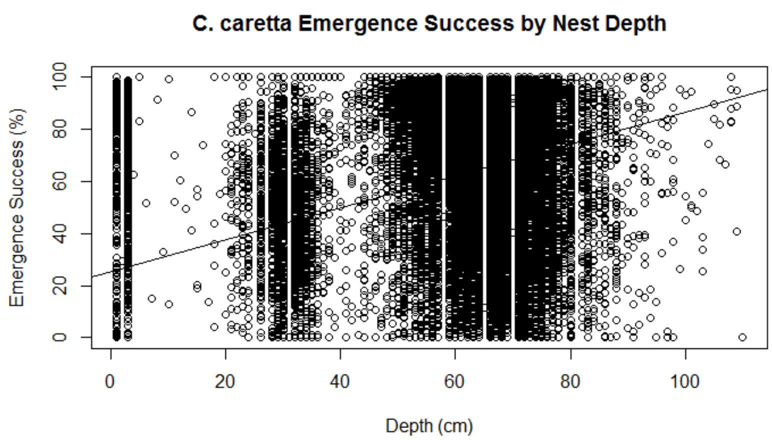

Figure 17. *Caretta caretta* emergence success (%) versus nest depth (cm) in Broward County, Florida from 1998-2015.

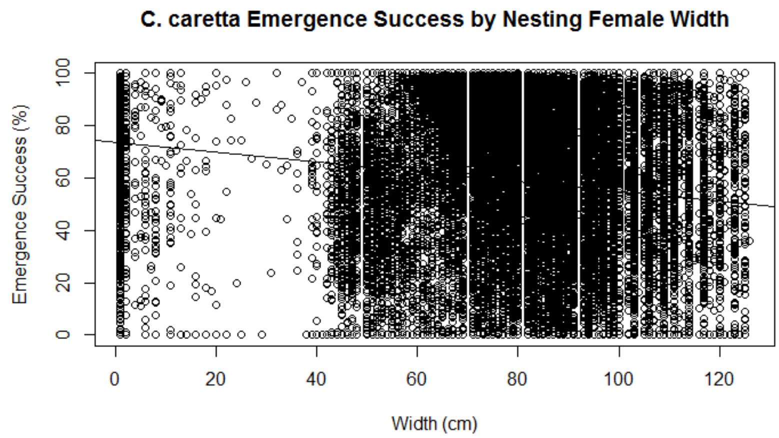

Figure 18. *Caretta caretta* emergence success (%) versus nesting female crawl width (cm) in Broward County, Florida from 1998-2015.

Chelonia mydas

Chelonia mydas was the second most common sea turtle over the survey with 2,818 nests encountered. Hatch and Emergence Success rates were both affected by all five variables as seen in Table 6. For hatch success, year, beach, and nest depth, all had the same significance ($p<2.2E-16$) (Table 6), while zone ($p<0.01029$) and nesting female crawl width ($p<0.00326$) were not as significant (Table 6). As seen in Figure 19, hatch success varied yearly, as did hatch success by beach (Figure 20). Hatch success was positively correlated to zone, as well as nest depth (Figures 21 & 22). Nesting female crawl width also had a significant effect on hatch success, as seen in Figure 23.

Table 6. Variables that significantly affected *Chelonia mydas* hatch success and emergence success in Broward County, Florida from 1998-2015. Results are from an ANCOVA.

***C. mydas* Hatch Success**	
Variables	**P Value**
Year	<2.2E-16
Beach	<2.2E-16
Zone	0.010289
Nest Depth	<2.2E-16
Nesting female crawl width	0.003257
***C. mydas* Emergence Success**	
Variables	**P Value**
Year	<2.2E-16
Beach	1.68E-15
Zone	0.03388
Nest Depth	<2.2E-16
Nesting female crawl width	0.009013

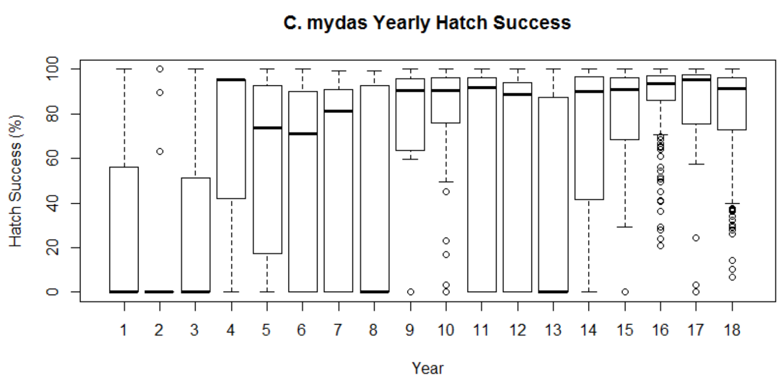

Figure 19. Yearly hatch success (%) of *Chelonia mydas* from 1998 to 2015 (labeled 1-18 respectively from 1998-2015) in Broward County, Florida (±SD).

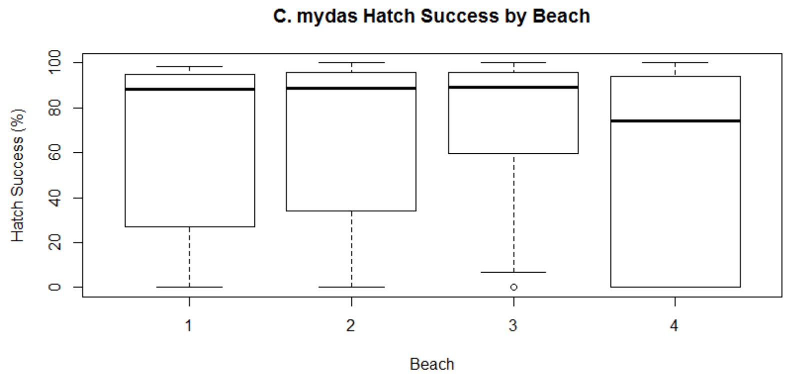

Figure 20. Hatch success (%) of *Chelonia mydas* by beach in Broward County, Florida from 1998-2015. Beach 1 represents Hallandale & Hollywood Beaches, beach 2 represents Fort Lauderdale Beach, beach 3 represents Pompano Beach and beach 4 represents Hillsboro & Deerfield Beaches (±SD).

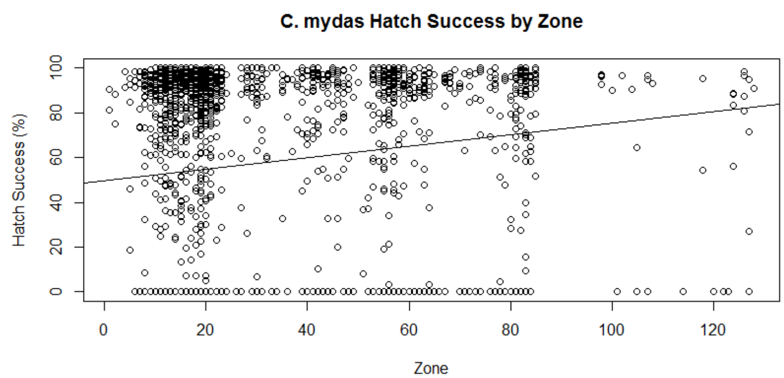

Figure 21. *Chelonia mydas* hatch success (%) by zone in Broward County, Florida from 1998-2015. Zone 1 is the most northern area surveyed in Broward County to zone 128 which is the most southern area surveyed in Broward County.

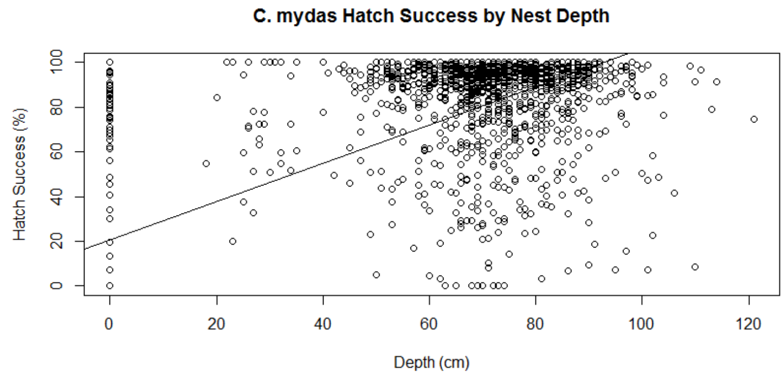

Figure 22. Hatch success (%) by individual nest depth (cm) of *Chelonia mydas* in Broward County, Florida from 1998-2015.

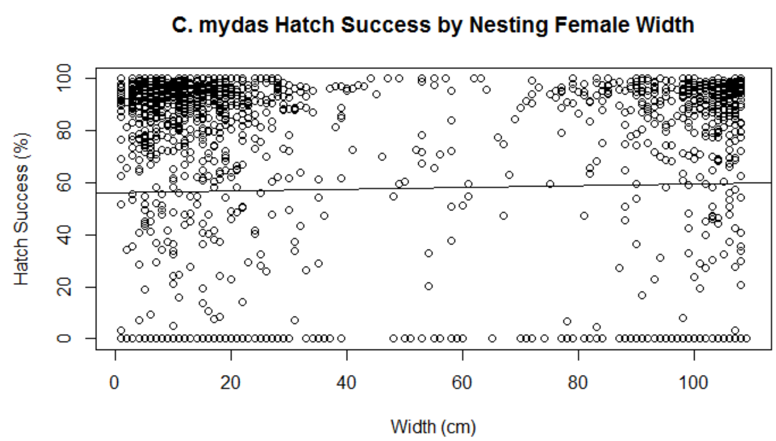

Figure 23. Hatch success (%) by nesting female crawl width (cm) of *Chelonia mydas* in Broward County, Florida from 1998-2015.

Year ($p<2.2E-16$) and nest depth ($p<2.2E-16$) had the same significant effect on emergence success (Table 6). Beach ($p<1.68E-15$), zone ($p<0.03388$) and nesting female crawl width ($p<0.00901$) also had a significant effect on emergence success (Table 6). Emergence success significantly varied throughout the 17 years (Figure 24), as did emergence success by beach (Figure 25). As seen in Figure 26, zone was positively correlated to emergence success; nest depth was also positively correlated to emergence success (Figure 27). Nesting female crawl width was also significant for *C. mydas* emergence success (Figure 28).

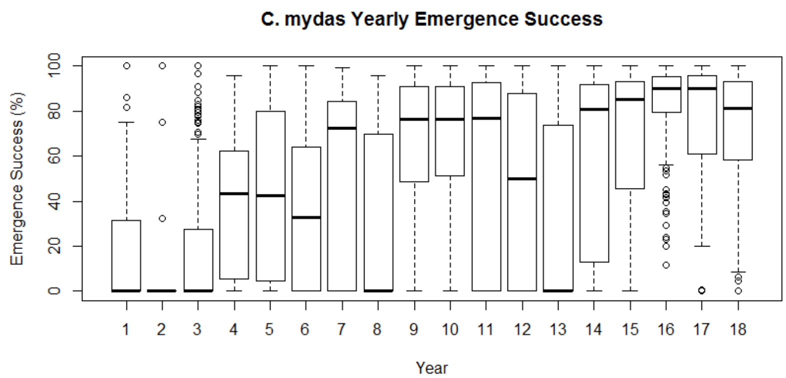

Figure 24. Yearly emergence success (%) of *Chelonia mydas* from 1998 to 2015 (labeled 1-18 respectively from 1998-2015) in Broward County, Florida (±SD).

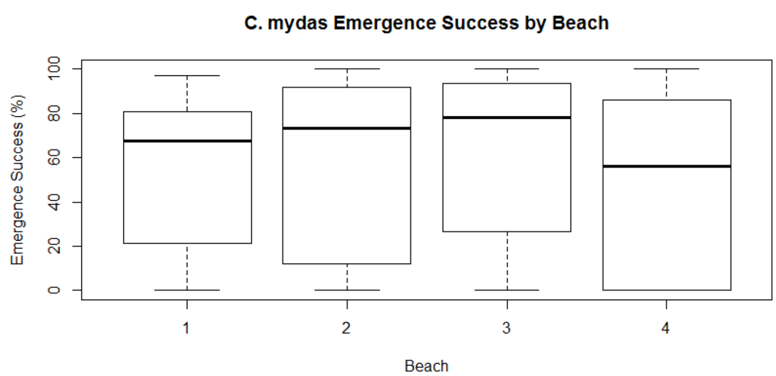

Figure 25. Emergence success (%) of *Chelonia mydas* by beach in Broward County, Florida from 1998-2015. Beach 1 represents Hallandale & Hollywood Beaches, beach 2 represents Fort Lauderdale Beach, beach 3 represents Pompano Beach and beach 4 represents Hillsboro & Deerfield Beaches (±SD).

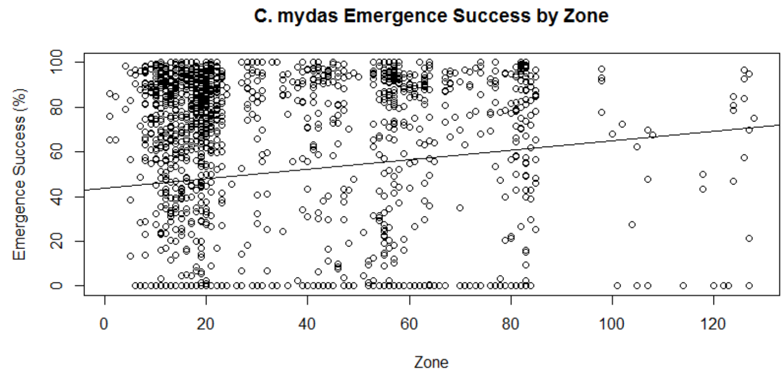

Figure 26. *Chelonia mydas* emergence success (%) by zone in Broward County, Florida from 1998-2015. Zone 1 is the most northern area surveyed in Broward County to zone 128 which is the most southern area surveyed in Broward County.

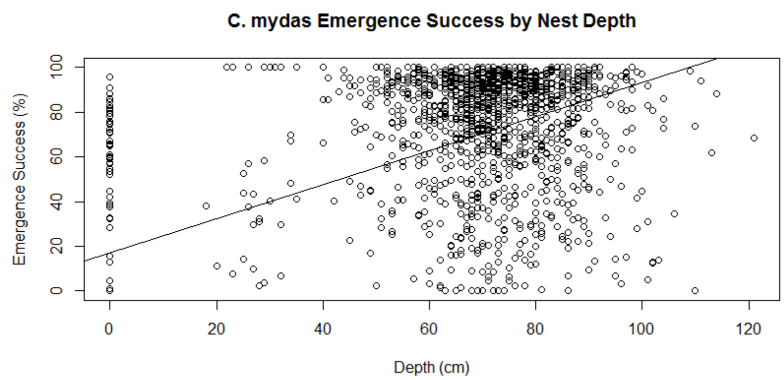

Figure 27. Emergence success (%) by individual nest depth (cm) for *Chelonia mydas* in Broward County, Florida from 1998-2015.

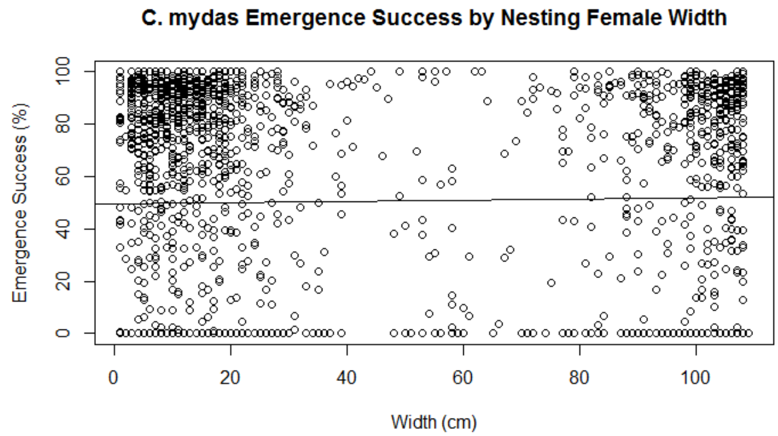

Figure 28. Emergence success (%) versus nesting female crawl width (cm) of *Chelonia mydas* in Broward County, Florida from 1998-2015.

Discussion:

Beach nourishment causes a decrease in hatching success rate and emergence success rate for Leatherback, *D. coriacea*, Loggerhead, *C. caretta*, and Green *C. mydas* sea turtles. All three species hatch success rates were significantly affected by year (i.e. hatching success was greater prior to the beach nourishment and declined in response), female crawl width, and nest depth, which was influenced by grain characteristics. Therefore, yearly hatch success is dependent on natural and anthropogenic occurrences, most importantly beach nourishment. Decreased hatch success during beach nourishment years is due to these invasive projects. Changes in sand properties due to nourishment projects increase the likelihood that sand will be wetter, decreasing the hatch success. Unlike hatch success, all three species emergence success rates were significantly affected by year, beach, zone location, nest depth and nesting female crawl width. The strong correlation of emergence success with nest depth and female crawl width suggests that only the largest and strongest females were able to dig into the denser, more compact renourished sand.

However, the study showed that between 1998-2015 hatching and emergence success rates fluctuated yearly during and after beach nourishment projects took place. Though beach nourishment projects take place worldwide, the United States is leading research on what effects beach nourishment has on sea turtle nesting. Research and sea turtle nesting beach conservation done in Florida is extremely large, and can be used to test various impacts that beach nourishment has on sea turtles. This project was completed to fill in this leading research to further understand the impacts that beach nourishment has on sea turtles globally. These overall findings are supported in the following discussion of evidence from specific nourishment projects in Broward County.[2]

Hillsboro/Deerfield Beach Restoration Project

In 1998 & 2011 the Hillsboro/Deerfield Beach Restoration Project took place, using offshore sand borrow areas for both beach nourishment projects. For *D. coriacea* and *C. caretta,* hatch success rates increased from 1998 to 1999 but decreased from 1999 to 2000, showing possible negative effects from the nourishment project completed in 1998 (Figure 2, Figure 10). *Chelonia mydas* hatch success decreased from 1998 to 1999 and again from 1999 to 2000 (Figure 19). Accordingly, we can conclude that *C. mydas* was more affected by this beach nourishment project due to the consistently decreased hatch success for 2 years. Results for these years stayed constant when shifting to emergence success rates except for *C. caretta,* emergence success rate of which stayed approximately the same from 1999 to 2000 (Figures 5, 14 & 24).

When the Hillsboro/Deerfield Beach Restoration Project was repeated in 2011, *D. coriacea, C. caretta* and *C. mydas* showed a much quicker negative response to the renourishment project. Those impacts included, but were not limited to, a disruption of the habitat as well as change in sand properties. From 2011 to 2012, the hatch success for *D. coriacea* and *C. caretta* decreased, and stayed similar for *C. mydas* (Figures 2, 10 & 19). The emergence success rates from 2011 to 2012 of *D. coriacea, C. caretta* and *C. mydas* all increased (Figures 5, 14 & 24).

[2] Beach nourishment projects in Broward County selected to study took place in 1998, 1999, 2005, 2008, & 2011.

According to Table 3, *D. coriacea, C. caretta,* and *C. mydas* had a combined hatching success rate that was affected by this beach nourishment project. Although the 2011 Hillsboro/Deerfield Beach Restoration Project negatively affected hatching success, nests that successfully hatched were able to emerge from the egg chambers. Emergence success was not as significantly affected as hatching success, which agrees with the previous statement. This contradicts a study done in Brevard County by Brock et al. (2009) which compared pre and post-nourished beaches using offshore borrow areas. Brock et al. (2009) found that both *C. caretta* and *C. mydas* hatching and emergence success were not significantly affected by the nourishment projects, but both species showed an increased hatching and emergence success from pre to post-nourished areas over the study period.

Diplomat Hotel, Hollywood

In 1999, a privately permitted and funded beach nourishment was completed by the Diplomat Hotel in Hollywood using upland sand mines. A large decrease in hatching and emergence success rates was observed from 1999 to 2000 for *D. coriacea, C. caretta* and *C. mydas* with one exception for the emergence success rate of *C. caretta* which stayed the same (Figures 2, 5, 10, 14, 19 & 24). The hatching success was negatively affected by this nourishment project, seen in Table 3. Though each species had a variable fluctuation of emergence success rates, when pooled, the emergence success rates were not significantly effected by the nourishment project (Table 3).

Hollywood and Hallandale

In 2005 a beach nourishment project was completed in Hollywood and Hallandale beaches using offshore borrow areas. These areas of beach were previously nourished in 1971, 1979, and 1991. This project began in May 2005 and ended in February 2006, which overlapped with the *C. caretta* and the *C. mydas* nesting and hatching season. Between 2004 and 2005, both the hatching success rate and emergence success rate for all three species combined showed no significant change (Table 3). In 2005, the *C. caretta* hatch and emergence success rates were low with an increase in 2006; similarly, *C. mydas* had a low hatch and emergence success rates in 2005 and then increased in

2006 (Figures 10, 14, 19, & 24). This can be directly correlated with Segment III nourishment project throughout south Broward County. *Dermochelys coriacea* did not see this decrease/increase pattern from 2005 – 2006 most likely due to the months of nesting and hatching season; *D. coriacea* begins nesting in March and the normal hatching season for this species ends by the end of May/beginning of June, and does not significantly overlap with the project, similarly studied and found in Pike and Stiner (2007) (Figures 2 & 5).

Hillsboro Beach Truck Haul

In 2008, the Hillsboro Beach Truck Haul beach nourishment was completed using upland sand mines. Between 2007 and 2008, the combined hatching success rate for all three species was significantly effected; combined emergence success rate was significantly negative in its affect, as well. Similarly, between 2008 and 2009 the hatch and emergence success rates for *D. coriacea, C. caretta* and *C. mydas* all decreased (Figures 2, 5, 10, 14, 19 & 24). Though Hillsboro Beach is only about 4 miles long, it is the highest density nesting beach in Broward County for all three species of nesting sea turtle. With the direct negative effect between the 2008 project and decreased hatch and emergence success rates, it can be concluded that this project greatly effected the hatching and emergence success rates that year.

Unexpectedly, hatch and emergence success rates for *D. coriacea, C. caretta*, and *C. mydas* were not solely, significantly affected by beach nourishment projects. Hatch and emergence success for these turtles were all affected by the nest depth and nesting female crawl width. Since wider females are capable of making deeper nests due to sheer size, and experience, it makes sense that the depth and crawl width of the nest affected the hatchlings. *Dermochelys coriacea* had both high hatch and emergence success rates, with an increase in nest depth and nesting female crawl width (Figure 3, 4, 8, & 9). Nest depth for leatherbacks in this study generally ranged between 50 cm and 100 cm, with a few outliers at 0 cm (did not hatch). *Caretta caretta* also showed a correlation between increased hatch and emergence success rates, and increased depth and width.

Unlike *D. coriacea, C. caretta* saw a decrease with either extreme, too big/too small nesting female width for both hatch and emergence success (Figures 12, 13, 17, & 18). Likewise, *C. mydas* had a similar result, showing increased hatch and emergence success rates correlated to an increased depth and width, as well as a decrease with extreme crawl widths (Figure 22, 23, 27, & 28). As seen in Antworth et al. (2006), egg clutch size is dependent on the size of the nesting female, with larger females being physically able to hold more eggs than smaller females. Size differences in females may also be dependent on the amount of resources available to them throughout the year, which is difficult to track and determine (Antworth et al. 2006).

Hatch and emergence success rates for all species throughout the study varied yearly, and could point to natural fluctuations in nesting and hatching rates. Though natural fluctuations may ensue, projects analyzed show a negative effect during the years when they occur. All projects that were analyzed were either in Hollywood or Hillsboro. Hollywood and Hillsboro are approximately the same size, and while Hollywood has the lowest nesting density in Broward County, Hillsboro has the highest nesting density in Broward County. Comparing the high and low nesting density beaches in the County provides perspective to the true effects of the nourishment projects, regardless of nesting density.

Various years with decreased hatch and emergence success rates can be correlated to years with substantial hurricane activity. When hurricanes make landfall during sea turtle season, they can have a large effect on sea turtle nesting, and hatching (Pike and Stiner 2007). Hurricanes significantly impact sea turtle nests already laid due to increased storm surge and beach erosion. The large movement of sand during hurricanes, due to winds and high surf result in many nests being washed away, causing nests to become unburied and eggs to be washed into the ocean. Flooded nests inundated with water cause eggs to be subjected to very moist and saline conditions, which results in death to both developing and developed hatchlings.

During ten of the seventeen years, hurricanes, tropical storms and tropical depressions impacted Broward County, Florida (Figure 29). Throughout these years a number of nests were effected by the rising tides, which flooded and washed away entire nests. All species of sea turtle studied had a decline in both hatch and emergence success rates during years with hurricanes, and an increase the following year. Exceptions included instances where the hurricanes were not present during nesting and hatching season for certain species. Overlap between decreased hatch and emergence success rates during tropical storm months are a common occurrence (Pike and Stiner 2007). Ultimately, hurricanes do impact sea turtle nesting in Broward County, but it is not the main cause of decreased hatching and emergence success rates.

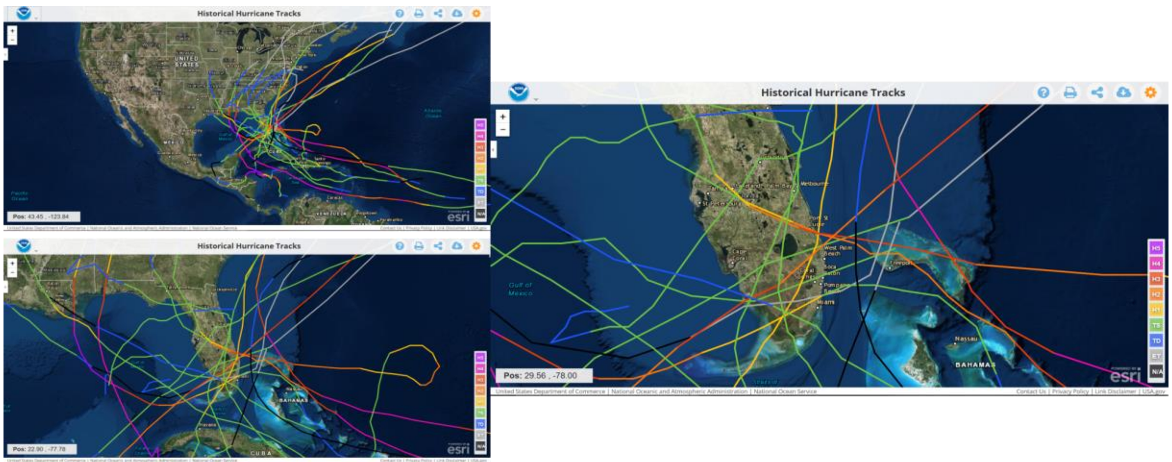

Figure 29. Hurricane, tropical storm, and tropical depression tracks that affected Broward County from 1998-2015 (National Oceanographic and Atmospheric Administration).

Future projects will include a beach nourishment component in 2016 in Pompano Beach, Fort Lauderdale, and Lauderdale-by-the-Sea. In consideration of the findings of this study it is recommended that the nourishment project does not take place during the months March-October, when there is sea turtle activity. In reality, the BCSTCP will be relocating all *D. coriacea* nests in the nourishment area and nourishment activity will proceed until the end of April when it comes to a halt for the start of *C. caretta* nesting season, followed a few months later by *C. mydas* nesting season.

Conclusion:

Dermochelys coriacea, C. caretta, and *C. mydas* have an overall increasing hatching and emergence success rates from 1998-2015, which may indicate population growth. Though there is an overall increase in population during the study period, there are observable fluctuations of each species from year to year. This study shows that these yearly fluctuations from high to low hatching and emergence success rates are likely influenced by beach nourishment. As seen in many areas throughout the state of Florida and the world, there is a direct negative effect on hatching and emergence success rates the year of beach nourishment projects, and/or the following year. The direct negative implications on these success rates are due to the disruption of habitat, probable changes in sand properties, and ability for the nourished beaches to settle into the naturally occurring processes on each beach.

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Appendix

Florida Fish and Wildlife Conservation Commission

(850) 488-3831
(850) 921-7793 FAX

Managing fish and wildlife resources for their long-term well-being and the benefit of people.

620 South Meridian Street
Tallahassee, Florida
32399-1600
Voice: (850) 488-4676

Hearing/speech-impaired:
(800) 955-8771 (T)
(800) 955-8770 (V)

MyFWC.com

April 13, 2015

Jenna Caderas
Nova Southeastern University
2750 Ocean Club Blvd #103
Hollywood, Florida 33019

RE: Examining effects of beach nourishment on hatch and emergence success of marine turtles in Broward County, Consent Permit

Dear Ms. Caderas:

Pursuant to ss. 379.2431 (1), Florida Statutes, and Rule 68E-1, Florida Administrative Code, please consider this letter as authorization for you to conduct a research project entitled "The effects of beach renourishment on the hatching and emergence success rates of loggerhead (*Caretta caretta*), Green (*Chelonia mydas*) and Leatherback (*Dermochelys coriacea*) sea turtles in Broward County, Florida" that has been reviewed and, by this consent permit, approved by FWC (RP #704). This research project involves analysis of nesting data collected prior to 2015 under valid FWC Marine Turtle Permits. No collection of data or field work is authorized with this project.

Within ninety (90) days of completion of the project the permit holder must submit an electronic copy of the final report to MTP@MyFWC.com summarizing the results and success of the research relative to its goals. The final report should have a title that matches the original title in the proposal, and sections for introduction, methods, results, discussion, and literature cited.

If you have any questions, please contact Mrs. Meghan Koperski at (561) 882-5975 or via e-mail at MTP@MyFWC.com.

Sincerely,

Robbin Trindell

Robbin Trindell, Ph.D.
Biological Administrator

ec: ISM, Tequesta
Dr. Derek Burkholder, NOVA
Mr. Curtis Slagle, MTP #214
Ms. Courtney Kiel, Broward County