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Nesting Trends of Sea Turtles in North and Mid Pinellas County, Florida, USA, Over Three Decades

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Abstract.—Florida, USA, beaches provide essential space for the largest rookery of Loggerhead Sea Turtles (*Caretta caretta*) in the Atlantic Ocean. The densest nesting beaches reside on the east coast of Florida and thus, Gulf of Mexico beaches on the west coast are widely understudied, but still provide critical nesting habitat. Pinellas County is a section of these critical nesting beaches in central West Florida. Long-term nesting data sets allow researchers to compare nesting trends for the west coast region, providing a clearer picture of the nesting population along the Gulf coast of Florida. Staff at the Clearwater Marine Aquarium have monitored Loggerhead Sea Turtle nesting beaches in the region of north and mid Pinellas County since 1990. From 1990-2022, nest counts have increased, although clutch size has decreased. Observations of the first nest of each season were laid significantly earlier in the year over time. Nesting success, hatching success, and emergence success did not significantly change over time, but did vary between municipalities, month, and position on the beach (lower, mid, or upper). These same metrics are also higher than other published regions on the Gulf of Mexico coast of Florida. Our trend results can be useful to regional conservation managers, and potentially allow for better management decisions for nesting habitat in the future.

Key Words.—*Caretta caretta*; hatchling; Loggerhead Sea Turtle; long-term monitoring

Introduction

Suitable nesting habitat for sea turtles is threatened due to erosion, sea level rise, climate change, the increase in terrestrial predator populations, and the negative consequences of coastal development (Antworth et al. 2006; Witherington et al. 2009; Fuentes et al. 2011; Siqueira et al. 2021; Whitesell et al. 2022). To understand the impact of these threats, analyzing long-term nesting data provides knowledge to inform conservation management decisions through identification of temporal trends and delivers baseline information on geographical variation and nest productivity (Magurran et al. 2010). In addition to understanding threats, examining long-term nesting data helps develop population trajectory models and determine reproductive status (Ehrhart et al. 2014). This information helps determine if populations are in recovery or in decline (Ceriani et al. 2019).

All species of sea turtle nest on sandy beaches along coasts of subtropical and tropical areas of the world (Witherington et al. 2006, 2009). Florida, USA, with its abundant sandy coastal areas, hosts nesting activity of five species, with the Loggerhead Sea Turtle (*Caretta caretta*) being the most abundant (https://myfwc.com/research/wildlife/sea-turtles/nesting/monitoring/). Globally, the International Union for the Conservation of Nature (IUCN) lists the Loggerhead Sea Turtle as Vulnerable (Casale and Tucker 2017) and the North West Atlantic Regional Management Unit (RMU) as Least Concern (Ceriani and Meylan 2017). Under the U.S. Endangered Species Act, the Northwest Atlantic Ocean Distinct Population Segment (DPS) of Loggerhead Sea Turtles is considered Threatened (National Marine Fisheries Service and U.S. Fish and Wildlife Service 2023). Within this DPS, 90% of all nesting occurs in Florida (Witherington et al. 2006). Genetic subpopulations within the DPS create distinct boundaries around the Florida peninsula, including a subunit in central West Florida (Encalada et al. 1998; Shamblin et al. 2011), which remains an understudied region of the DPS. The Clearwater Marine Aquarium (CMA) in Florida has been surveying nesting on Pinellas County beaches, which are part of central West Florida, for over 33 y. The data collected by CMA are important for understanding the nesting activity of Northwest Atlantic Loggerhead Sea Turtles in this region.

Nesting trends for sea turtles are well described in the scientific literature for much of the east coast of Florida (Witherington et al. 2009; Ehrhart et al. 2014; Ceriani et al. 2019), but few publications have

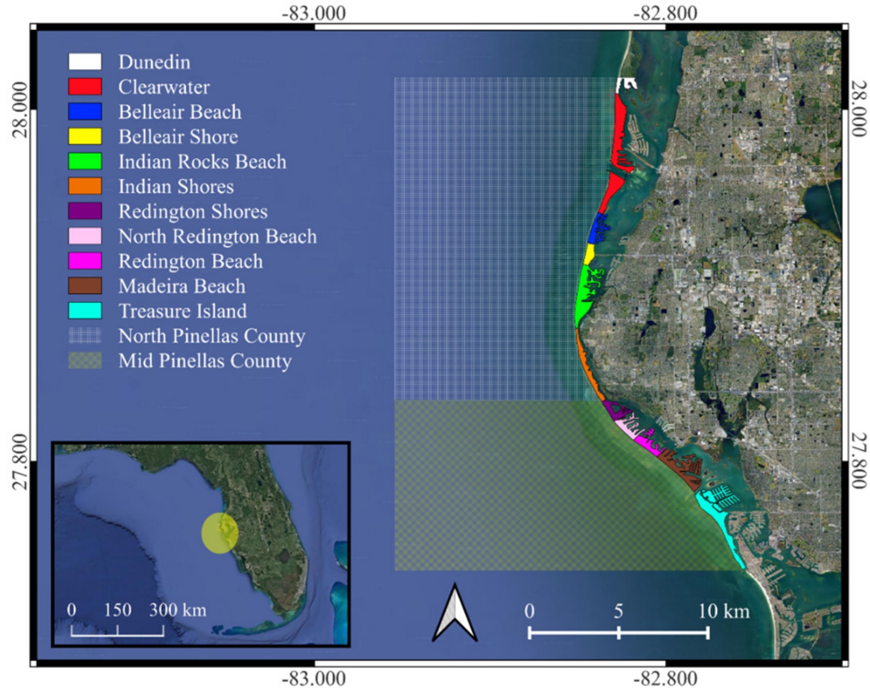

Figure 1. Eleven municipalities of north and mid Pinellas County, Florida, USA, that are monitored by Clearwater Marine Aquarium for nests of Loggerhead Sea Turtles (*Caretta caretta*).

described long-term nesting trends for any species of turtles nesting on the central West Florida coastline (Ceriani et al. 2019; Lasala et al. 2023; Redding et al. 2024). The Florida Fish and Wildlife Research Institute (FWRI) of the Florida Fish and Wildlife Conservation Commission (FWC) include beaches in central West Florida in their Statewide Nesting Beach Survey (SNBS) analyses (Ceriani et al. 2019), but Pinellas County has not been specifically evaluated. Compiling and analyzing long-term data from survey areas of Pinellas County allows researchers to compare nesting trends for the region, providing a clearer picture of the Gulf of Mexico populations and understanding larger population shifts.

Vulnerabilities of nesting beaches not only vary between regions, but also individual beaches. Therefore, patterns of nesting success, hatching success, and emergence success help determine where conservation efforts should be focused, especially in understudied regions (Shimada et al. 2021). Since CMA started monitoring these beaches, the human population growth in Pinellas County has risen by 12% from 1990 to 2022 (https://florida.reaproject.org/analysis/comparative-trends-analysis/population/reports/120103/120000/), but this high human density impacts the nesting sea turtle population differently depending on the municipality and environment (Fuentes et al. 2016). This variation is important to identify so the county can receive factual feedback to focus on areas where conservation action should be prioritized.

We describe how nesting counts and productivity have changed in the survey region over the 33-y period and identify how this region contributes to the population of Loggerhead Sea Turtles in the greater Gulf of Mexico. These goals provide baseline information on nesting in Pinellas County to evaluate population status and inform regional conservation managers on these trends. This information potentially allows for better management decisions for nesting habitat in the future.

Materials and Methods

Study area.— CMA has monitored beaches in north and/or mid Pinellas County of Florida, USA, since 1990 (Fig. 1). North county is defined as Dunedin to a southern point (27.83804 N, 82.83857 W) in Indian Shores, and mid county is that same point in Indian Shores through the south end of Treasure Island. The overall survey area, however, has been modified over the course of the study period. From 1990–1992 CMA covered north county, from 1993–2016 CMA covered north and mid county, from 2018–2019 CMA covered north county, and from 2020–2022 CMA covered north and mid county. As of 2020, CMA consistently monitors 33.59 km of barrier island beaches in the county, which includes 11 different municipalities (listed from north to south): Dunedin (0.68 km from Dunedin Pass 28.01879 N, 82.82649 W); Clearwater (the next 8.03 km); Belleair Beach (1.38 km); Belleair Shore (1.66 km); Indian Rocks Beach (4.26 km); Indian Shores (4.17 km); Redington Shores (1.85 km); North Redington Beach (1.21 km); Redington Beach (1.64 km); Madeira Beach (3.30 km); and Treasure Island (5.41 km; Fig. 1). Dunedin is a small portion of barrier island monitored within the Dunedin city limits and was historically included with Clearwater for ease of reference. Dunedin and Clearwater municipalities are combined to accommodate the varying records, resulting in 8.71 km of coastline. Many of these beaches are critically eroded and all have been nourished or renourished with sand in the past 70 y (https://floridadep.gov/sites/default/files/SBMP-SouthwestGulfCoastRegion_1.pdf).

Nesting surveys.—Annually, personnel of CMA surveyed the beaches daily from 15 April to 31 October. All sea turtle activities were conducted by personnel authorized under FWC Marine Turtle Permit #263 and #013. Surveys began as early as 30 min before sunrise by driving a 4-wheel drive truck, utility task vehicle (UTV), or all-terrain vehicles (ATVs) along the shoreline, while respecting Best Management Practices for Operating Vehicles on the Beach of the FWC (https://myfwc.com/conservation/you-conserve/wildlife/beach-driving/). Once a sea turtle crawl track was located, a visual determination was made on whether the emergence was a nest or non-nesting emergence. A nest was defined as an emergence that resulted in egg deposition, which was based on direction of tracks, significant disturbance of sand, and presence of an escarpment. A non-nesting emergence, or false crawl (FC), was defined as an emergence resulting in no egg deposition. All observed nests were marked for daily observation according to the FWC Marine Turtle Conservation Handbook (Florida Fish and Wildlife Conservation Commission 2016).

Data collection.—Data collected from nesting activities from 1990 to 2022 included: (1) date observed; (2) GPS location when possible; (3) physical address; and (4) distance to nearest upland barrier (vegetation or permanent structure). Personnel of CMA collected data for each individual activity the day the activity was observed. Nesting success, which is the proportion of successful nesting attempts by sea turtles that result in eggs being deposited to the total number of crawls, was calculated for each year, month, and municipality.

All marked nests were monitored throughout the incubation period until a final inventory was performed. CMA personnel recorded observations, including tidal wash-out, hatchling emergence, and evidence of terrestrial predation, throughout incubation duration. A nest was considered hatched if four or more hatchling tracks were clearly observed by permitted personnel. CMA personnel excavated nests three or more days following observed emergence and the contents were inventoried. If hatchings were not observed, an inventory was attempted after 70 or 80 d.

During an inventory, CMA personnel identified nest contents as: (1) the number of empty shells (hatched eggs); (2) live hatchlings; (3) dead hatchlings; (4) live and dead pipped hatchlings; (5) unhatched (whole) eggs; and (6) damaged eggs (contents exposed due to an external source such as other hatchlings in the nest). The total clutch size was quantified as the summation of hatched, pipped, unhatched, and damaged eggs. We calculated hatching success (HS) as the percentage for each nest that was inventoried:

$$\mathrm{HS} = \frac{\mathrm{HE}}{\mathrm{TNEC}}$$

where # HE is the number of hatched eggs and TNEC is the total number of eggs in a clutch. Hatching success is defined as the proportion of hatched eggs in the clutch. Emergence success represents the number of hatchlings that emerged independently from the nest prior to nest excavation. We removed nests that experienced partial wash-out or partial predation from data analysis due to the unknown number of eggs lost. Complete nest wash-out and depredation events were assigned a hatching and emergence success of zero percent (0%). We determined emergence success (ES) as:

$$\mathrm{ES} = \frac{\mathrm{HE\text{-}LN\text{-}DN}}{\mathrm{TNEC}}$$

where # HE is the number of hatched eggs, # LN is the number of live hatchlings in the nest, # DN is the number of hatchlings dead in the nest, and TNEC is the total number of eggs in a clutch.

Beach width was calculated by summing the measurements of the nest to the high tide line and the distance to the upland barrier (2016–2022 only). Finally, we determined the position of each nest site or apex of each false crawl (lower, middle, or upper third of the beach) by dividing the beach width in thirds and identifying which third the nest or apex of false crawl was located based on distance from high tide line.

Statistical analysis.—We tested data in R Program Version 4.3.0 (R Core Team 2020) and we made maps using QGIS version 3.28.1 (http://www.qgis.org). Survey data for the 2000 nesting season were incomplete so we only included crawl counts in the analyses from that year. CMA personnel did not conduct surveys during the 2017 nesting season, so we only included crawl counts from FWC data in analyses. There were rare Kemp's Ridley Sea Turtle (*Lepidochelys kempii*) and Green Sea Turtle (*Chelonia mydas*) nests identified during the study period, but we only included data for Loggerhead Sea Turtles in our analysis. We tested nesting data of Loggerhead Sea Turtles for normality using a Shapiro-Wilks test and for homoscedasticity using Levene's test.

We performed separate Kruskal-Wallis tests to identify if there were differences in nest counts, incubation duration, clutch size, nesting success, hatching success, and emergence success across various conditions, including municipality, month, position on beach, and year. We performed post-hoc Dunn tests to determine where the differences occurred after correction for multiple comparisons using Benjamini-Hochberg adjustments (Benjamini and Hochberg 1995). To compare categorical variables such as crawl type with position on the beach or upland barrier type (vegetation or permanent structure), we used a Chi-squared Test. We used $P \leq 0.05$ for statistical significance.

We used Siegel Linear Regression (returns a V statistic; Siegal 1982) to determine if first and last nest dates changed over the course of the study (using Julian dates) as well as the nesting season duration (time between first and last nest laid). We also used Siegal Linear Regression to assess whether nest counts, average incubation duration, and average clutch size significantly changed over the study period. For the proportions of nesting success, hatching success, and emergence success, we used beta regression to determine if they varied over time. We used Generalized Linear Models with a negative binomial distribution (returns a z statistic) to determine which abiotic factors (including year, municipality, beach width, distance from upland barrier, clutch size, and incubation duration) affected hatching success and emergence success. Finally, using known inventory data, we estimated the minimum number of emerged hatchlings of the region (by summing the total number of emerged hatchlings) to determine how many hatchlings likely entered the Gulf of Mexico over the course of the study.

Results

Nesting data.—From 1990–2022, 9,885 Loggerhead Sea Turtle crawls were observed in north and mid Pinellas County. Of these, 52.9% (5,228) resulted in nests. In addition to the Loggerhead Sea Turtle activities, there were 11 Kemp's Ridley Sea Turtle crawls (four nests, two FC) and eight Green Sea Turtle crawls (four nests, four FC) observed over the study period. The annual mean (± standard deviation) nest count of Loggerhead Sea Turtles was 158.4 ± 83.0 nests (range of values 36–380 nests; Table 1). The annual mean for north Pinellas County was 98.8 ± 55.0 nests (range 24–254 nests) and 70.3 ± 35.3 nests (range 14–168 nests) for mid county. Collectively, annual nest counts were normally distributed ($W = 0.95$, $P = 0.155$), but their residuals were not. Nest counts significantly differed by month ($H = 163.18$, df = 31, $P < 0.001$). June had the highest nest counts followed by July. Nest counts for both north and mid county beach sections significantly increased over time ($V = 525$, df = 30, $P < 0.001$; $V = 421$, df = 30, $P < 0.001$; Fig. 2). Several municipalities had nest counts that significantly increased over time, including Clearwater ($V = 541$, df = 31, $P < 0.001$), Belleair Beach ($V = 387.5$, df = 26, $P < 0.001$), Belleair Shore ($V = 496$, df = 26, $P < 0.001$), Indian Rocks Beach ($V = 447$, df = 31, $P = 0.002$), Indian Shores ($V = 384.5$, df = 31, $P = 0.025$), Madeira Beach ($V = 345$, df = 26, $P < 0.001$), and Treasure Island ($V = 362$, df = 26, $P < 0.001$). The remaining municipalities, Redington Beach, North Redington Beach, and Redington Shores had no change in nest counts (Table 2).

The earliest a nest was laid was 3 May (2012, 2015, and 2019) and the latest a nest was laid was 10 September (1996). The first nest dates shifted significantly earlier over time ($V = 66.5$, df = 30, $P < 0.001$), but the last nest dates did not significantly shift over time ($V = 145$, df = 30, $P = 0.074$; Fig. 3). The nesting season duration had an annual mean of 95.0 ± 11.3 d (range 75–128 d) and the duration did not significantly change over time ($V = 350.5$, df = 30, $P = 0.108$).

The mean annual nesting success was 51.8 ± 83.0% (range 30.3–68%). Separated by county section, north county nesting success averaged 51.8

Table 1. The total and annual summary of estimated nesting parameters for Loggerhead Sea Turtles (*Caretta caretta*) over the study period in Pinellas County, Florida, USA. Abbreviations are SD = standard deviation, MIN = minimum, and MAX = maximum.

		Annual			
Parameter	Total	Mean	SD	MIN	MAX
# Crawls	9,885	299.5	156.8	79	705
# Nests	5,228	158.4	83.0	36	380
Emerged hatchlings	253,625	8,182	4,065	2,335	18,855
Nesting success (%)	--	51.8	7.8	30.3	68.0
Incubation duration (days)	--	54.4	2.2	51.1	58.9
Clutch size (eggs)	--	101.7	6.2	83.9	112.5
Hatching success (%)	--	65.4	13.6	35.9	88.8
Emergence success (%)	--	61.4	13.4	33.5	84.0

± 10.3% (range 30–73.3%) and mid county mean was 52.4 ± 6.2% (range 42–70.2%). Nesting success was normally distributed (W = 0.96, P = 0.349), but the residuals were not. Nesting success did not change over time (z = 0.33, P = 0.740) but it was significantly different between months (H = 31.92, df = 5, P < 0.001). Post-hoc tests revealed that turtles had a higher nesting success in August than in May (Dunn's Test, P < 0.001), June (Dunn's Test, P < 0.001), and July (Dunn's Test, P < 0.001; Table 3). Nesting success was significantly different between municipalities (H = 17.94, df = 9, P = 0.036; Table 2). Specifically, Redington Shores had significantly higher nest success than Belleair Beach (Dunn's Test, P = 0.027), Redington Beach (Dunn's Test, P = 0.016), and North Redington Beach (Dunn's Test, P = 0.006; Table 2). There was no significant difference between other municipalities.

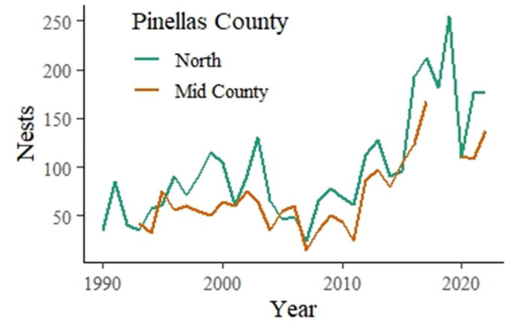

Figure 2. Nest counts of Loggerhead Sea Turtles (*Caretta caretta*) for the study period 1990 to 2022 from beaches monitored by Clearwater Marine Aquarium, separated by north and mid Pinellas County, Florida, USA.

The mean incubation duration during the study period was 54.3 ± 4.0 d (range 34–72 d; Table 1). Incubation duration was not normally distributed (W = 0.97, P < 0.001) and neither were the residuals. The mean incubation duration did not significantly change over the years (V = 281, df = 29, P = 0.529), but it differed by month (H = 245.08, df = 4, P < 0.001). Post-hoc tests revealed that May had a longer incubation duration than June, July, and August (Dunn's Test, P < 0.001 for each comparison; Table 3). Further, June had a longer incubation than July (Dunn's Test, P < 0.001), and August had a longer

Table 2. Nesting parameters for each municipality in Pinellas County, Florida, USA, with mean nesting success, clutch size, incubation duration, hatching success, and emergence success (± standard deviation) for Loggerhead Sea Turtles (*Caretta caretta*). Municipality abbreviations are CW = Clearwater Beach and Dunedin, BB = Belleair Beach, BS = Belleair Shore, IRB = Indian Rocks Beach, IS = Indian Shores, RS = Redington Shores, NRB = North Redington Beach, RB = Redington Beach, MB = Madeira Beach, and TI = Treasure Island. Heading abbreviations are KMM = kilometers of beach monitored, NYM = number of years monitored, TC = total number of crawls, TN = total number of nests, NS = nesting success, CS = clutch size, ID = incubation duration, HS = hatching success, and ES = emergence success.

Municipality	KMM	NYM	TC	TN	NS (%)	CS	ID (days)	HS (%)	ES (%)
CW	8.71	33	1933	996	51.5	101.95 ± 25.63	55.32 ± 4.07	66.24 ± 34.89	62.42 ± 35.29
BB	1.38	33	492	254	51.6	99.24 ± 27.00	53.40 ± 3.60	65.33 ± 34.38	61.90 ± 35.14
BS	1.66	33	944	504	53.4	101.07 ± 26.77	52.90 ± 3.73	70.80 ± 30.72	68.11 ± 30.76
IRB	4.26	33	1359	726	53.4	99.48 ± 24.15	53.70 ± 4.11	70.36 ± 31.93	66.54 ± 32.55
IS	4.17	33	1171	632	54.0	99.31 ± 24.10	54.70 ± 3.93	60.74 ± 37.18	56.55 ± 36.58
RS	1.85	28	408	199	48.8	97.75 ± 23.42	55.18 ± 4.20	61.23 ± 36.02	56.94 ± 36.07
NRB	1.21	28	380	171	45.0	98.59 ± 20.68	54.41 ± 3.98	46.00 ± 38.27	42.59 ± 37.37
RB	1.64	28	636	392	61.6	98.81 ± 20.57	54.43 ± 3.65	55.36 ± 37.99	52.99 ± 37.89
MB	3.30	28	786	432	55.0	97.50 ± 22.85	54.34 ± 3.94	54.73 ± 38.49	50.74 ± 28.33
TI	5.41	28	1288	654	50.8	98.59 ± 23.93	54.51 ± 4.04	68.43 ± 34.42	64.99 ± 34.58

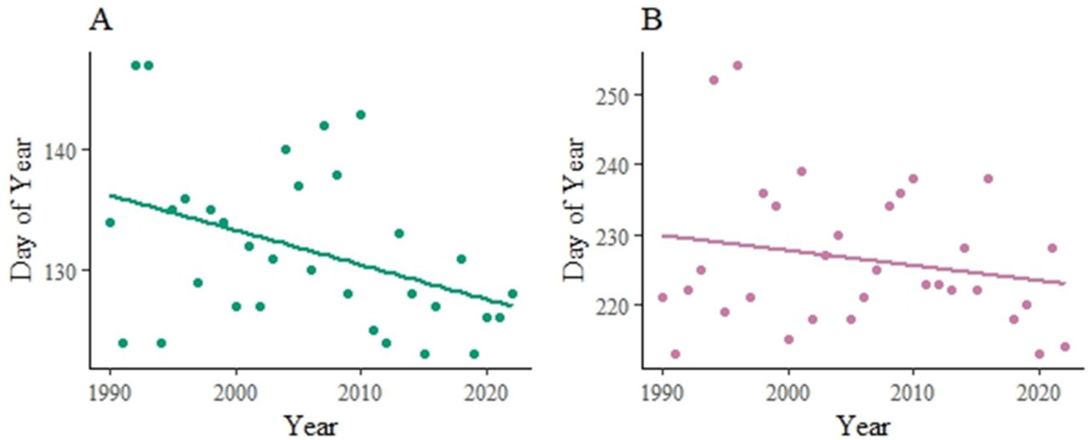

Figure 3. Julian date of (A) earliest and (B) latest nests for Loggerhead Sea Turtles (*Caretta caretta*) during the study period in Pinellas County, Florida, USA. Nests were laid significantly earlier each year over the study period.

incubation than June (Dunn's Test, $P = 0.006$) and July (Dunn's Test, $P < 0.001$; Table 3). May had the longest mean incubation (56.9 d) and July had the shortest mean (53.6 d; Table 3). Incubation duration did significantly differ between municipalities (H = 123.77, df = 9, $P < 0.001$; Table 2). Clearwater had the longest mean incubation (55.3 d) and Belleair Shore had the shortest mean (52.9 d; Table 2) and incubation duration varied significantly by position on the beach (H = 26.04, df = 2, $P < 0.001$). Nests laid within the middle third of the beach had a significantly longer incubation period (mean 55.8 ± 3.7 d) than those laid in the upper third (near the upland barrier, mean 54.3 ± 4.1 d; Dunn's Test, $P < 0.001$) and the lower third (near the water, mean 54.8 ± 4.3 d; Dunn's Test, $P = 0.027$).

The mean clutch size for the study period was 99.7 ± 24.5 eggs (range 83.9–112.5 eggs; Table 1). Clutch size was not normally distributed (W = 0.97, $P < 0.001$) and neither were the residuals. The mean clutch size decreased over the study period (V = 5, df = 29, $P < 0.001$; Fig. 4) and varied between months (H = 14.92, df = 4, $P = 0.005$). Nests laid in July had a smaller clutch size (mean 97.9 ± 24.3 eggs) than nests laid in May (mean 101 ± 24.6 eggs; Dunn's Test, $P = 0.014$) and in June (mean 100.8 ± 24.3 eggs; Dunn's Test, $P = 0.004$; Table 3). There were no significant differences in clutch size between August (mean 98.3 ± 98.3 eggs) and other months (Table 3). Clutch size also varied between municipalities (H = 27.54, df = 9, $P = 0.001$; Table 2). Clearwater had the largest mean clutch size (102 eggs) and Madeira Beach had the smallest (97.5 eggs; Table 2). Clutch size varied between positions on the beach (H = 20.88, df = 2, $P < 0.001$). Nests laid in the upper third of the beach had larger clutch sizes (mean 95.7 ± 27.4 eggs) than those laid in the middle third (mean 89.8 ± 25.5 eggs; Dunn's Test, $P < 0.001$) and lower third (mean 87.4 ± 25.4 eggs; Dunn's Test, $P < 0.001$).

Beach width and position on beach.—The mean beach width based on measurements to the high tide line and upland barrier was 29.1 ± 22.4 m (range 0.85–301.8 m). The mean width for mid county was 30.3 ± 19.81 m (range 0.85–190.45 m) and north county was 28.52 ± 23.5 m (range 1.02–301.8 m). The beach width was not normally distributed (W = 0.72, $P < 0.001$) and neither were the residuals. Position of nests on the beach were significantly different based on beach width (H = 760.82, df = 2, $P < 0.001$). Nests in the lower position were most often observed on wider beaches (Dunn's Test, $P <$

Table 3. Nesting parameters for each month with mean nesting success, clutch size, incubation duration, hatch success, and emergence success ± standard deviation for Loggerhead Sea Turtles (*Caretta caretta*) from Pinellas County, Florida, USA. Heading abbreviations are NS = nesting success, CS = clutch size, ID = incubation duration, HS = hatching success, and ES = emergence success.

Month	NS (%)	CS (eggs)	ID (days)	HS (%)	ES (%)
May	53.31	101.0 ± 24.55	56.88 ± 3.74	64.34 ± 37.94	61.02 ± 37.42
June	52.25	100.8 ± 24.31	54.19 ± 3.83	65.02 ± 36.05	61.54 ± 36.02
July	52.04	97.92 ± 24.29	53.57 ± 4.01	64.98 ± 33.82	61.04 ± 34.38
August	62.98	98.34 ± 98.34	55.27 ± 3.67	51.30 ± 35.20	47.69 ± 35.01

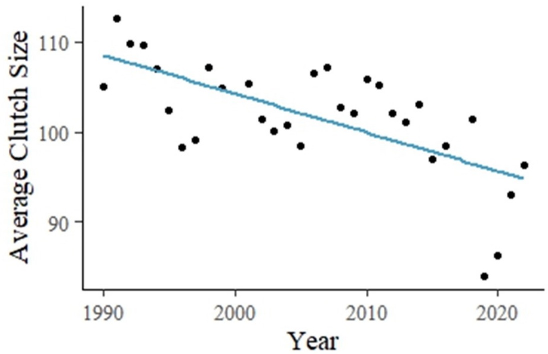

Figure 4. The average clutch size of Loggerhead Sea Turtle (*Caretta caretta*) nests per year in Pinellas County, Florida, USA. Clutch size significantly decreased over the study period.

0.001; Fig. 5). The crawl type (nest or false crawl) also significantly varied by width (H = 39.03, df = 1, $P < 0.001$) where there were more false crawls on wider beaches.

The crawl type varied by position on the beach ($\chi 2$ = 400.26, df = 2, $P < 0.001$). Nesting success was 65.1% if laid in the upper third of the beach, 60.3% if laid on mid beach, and 23.6% if laid on the lower third (Fig. 5). Crawl type did not vary by upland barrier type (vegetation or permanent structure; $\chi 2$ = 2.38, df = 1, $P = 0.1227$).

Hatching success, emergence success, and hatchling production.—The mean hatching success was 64.1 ± 35% (range 0–100%; Table 1). Hatching success was not normally distributed (W = 0.79, $P < 0.001$) and neither were the residuals. Hatching success did not significantly change over the study period (z = -1.219, $P = 0.223$), although it did vary by month (H = 38.10, df = 4, $P < 0.001$). Hatching success was lower in August (mean 51.3 ± 35.2%) than in May (mean 64.3 ± 37.9%), June (mean 65.0 ± 36.1%), and July (mean 65.0 ± 33.8%; Dunn's Test, $P < 0.001$ for each comparison; Table 3). Hatching success was also significantly different among municipalities (H = 101.38, df = 9, $P < 0.001$). North Redington Beach had the lowest mean hatching success (46%) and Belleair Shore had the highest (70.8%; Table 2). Hatching success also significantly differed where the nest was laid on the beach (H = 122.35, df = 2, $P < 0.001$). Post hoc tests determined that nests laid on the upper third of the beach had higher hatching success (mean 73.8 ± 28.8%) than nests laid on the middle (mean 50.6 ± 38.6%) and lower thirds (mean 43.2 ± 38.8; Dunn's Test, $P < 0.001$ for each comparison). Hatching success significantly decreased with longer incubation durations (z = -5.03, $P < 0.001$) and greater distance from the upland barrier (z = -3.38, $P < 0.001$), but not by clutch size (z = -1.43, $P = 0.154$).

The mean emergence success was 60.5 ± 35.9 % (range 0–100%). Emergence success was not normally distributed (W = 0.82, $P < 0.001$) and neither were the residuals. Emergence success did not significantly change over the study period (z = -0.75, $P = 0.318$), but varied significantly between months (H = 30.14, df = 4, $P < 0.001$) with August having lower emergence success (mean 47.7 ± 35.0%) compared to May (mean 61.0 ± 37.4%), June (mean 61.5 ± 36.0%), and July (mean 61.0 ± 34.4%; Dunn's Test, $P < 0.001$ for each comparison; Table 3). Emergence success also was significantly different between municipalities (H = 112, df = 9, $P < 0.001$). North Redington Beach had the lowest mean emergence success (42.6%) and Belleair Shore had the highest (68.1%; Table 2). Emergence success differed based on positions on the beach (H = 121.82, df = 2, $P < 0.001$). The upper third of the beach had greater emergence success (mean 70.8 ± 30.4%) compared to the mid (mean 47.6 ± 38.8%) and lower thirds (mean 40.4 ± 38.1%; Dunn's Test, $P < 0.001$). Emergence success significantly decreased with longer incubation durations (z = -4.15, $P < 0.001$) and greater distance from the upland barrier (z = -3.27, $P = 0.001$), but not by clutch size (z = -1.761, P = 0.078).

A minimum of 253,665 hatchlings emerged from nests over the study period, 168,016 from north county and 85,649 from mid county. The mean number of hatchlings that emerged per nest was 61.1 ± 39.4 hatchlings (range 0–162 hatchlings). The annual mean of emerged hatchlings was 8,181.5 ± 5065 hatchlings (range 2,335–18,855 hatchlings).

Table 4. Results of previous studies of nesting trends of Loggerhead Sea Turtle (*Caretta caretta*) in Florida, USA, compared to the present study (CMA = Clearwater Marine Aquarium). Headings are SP = study period (years), NN = number of nests, MCS = mean clutch size, MID = mean incubation period, NS = nesting success, HS = hatching success, and ES = emergence success.

Reference	SP	NN	MCS	MID (days)	NS (%)	HS (%)	ES (%)
CMA	33	5,228	99.7	54.3	51.8	64.1	60.5
Lamont et al. (2012)	21	738	108	60.6	40.1	--	58.1
Hoover (2019)	33	6,982	100.5	--	--	--	58.5
Lasala et al. (2023)	40	64,692	--	58.9	48.8	--	52.1

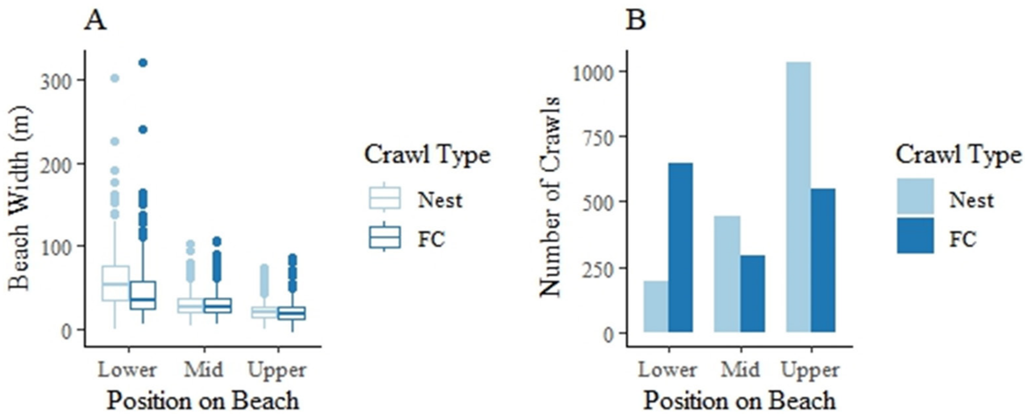

Figure 5. (A) Beach width for each position on the beach (lower, mid, or upper) where Loggerhead Sea Turtle (*Caretta caretta*) nests were laid or the false crawl (FC) apex was located in Pinellas County, Florida, USA. (B) The number of Loggerhead Sea Turtle nests and false crawls (FC) for each position on the beach (lower, mid, or upper section).

Discussion

Nesting trends over time.—The overall number of nests of Loggerhead Sea Turtles has neither increased or decreased in Florida (Ceriani et al. 2019), but some beaches in northwest Florida have seen a reduction in nests (Fujisaki et al. 2018). Nests have increased over time in the central West region (Ceriani et al. 2019), including in Pinellas County (this study) and Sarasota County to the south (Lasala et al. 2023). Central West Florida is one of the fastest growing nesting regions in Florida (Ceriani et al. 2019; Lasala et al. 2023). Overall, nesting counts of Loggerhead Sea Turtles in Pinellas County accounted for 3.9% of the total annual nest count on central West beaches in the last 5 y (https://myfwc.com/media/23244/loggerhead nestingdata5years.pdf). Although Pinellas County currently contributes a small percentage of nests, we expect that its contribution can continue to increase with proper beach protection measures. The rare occurrence of Kemp's Ridley Sea Turtle and Green Sea Turtle nesting in Pinellas County, though, demonstrates that Pinellas County does not significantly contribute to the hatchling population of these species within the Gulf of Mexico.

In Pinellas County, the first nest of the season was observed earlier in the year over time, similar to other recent studies (Shimada et al. 2021; Lasala et al. 2023). Rising temperatures may influence the timing of breeding seasons and thus nesting seasons (Weishampel et al. 2004; Pike et al. 2006; Mazaris et al. 2009; Shimada et al. 2021). These shifts in nesting phenology may also be due to environmental cues such as temperature at the foraging site and the nesting site (Monsinjon et al. 2019). Nesting occurred most often in June throughout the study period, which coincides with peak nesting in Florida (Weishampel et al. 2004; Antworth et al. 2006; Lamont et al. 2012).

Nesting success, hatching success, and emergence success did not change over time, but they were higher than studies of areas in Florida other than Pinellas County (Lamont et al., 2012; Hoover et al. 2019; Lasala et al. 2023; Table 4). Hatching success and emergence success varied by year, indicating that major storm years or sand nourishment projects might have a direct impact (Steinitz et al. 1998; Ehrhart et al. 2014; Bladow and Briggs 2017). Ehrhart and colleagues (2014) determined that in storm and post-storm years, emergence success may be 14% lower than non-storm years. The data presented here, however, do not address these questions and thus should be investigated further.

The incubation period of nests laid in May was longer (mean 56.88 d) than any other month in our study, which may be due to the cooler weather earlier in the season (Lamont et al. 2012). Temperatures increase as the season progresses, increasing embryo mortality and decreasing hatching success (Bladow and Milton 2019; Whitesell et al. 2022; Fuentes et al. 2023). August also had a longer incubation duration (mean 55.27 d), which is surprising because of the higher temperatures that month, but it could be due to increased storm events. Tropical storms and hurricanes typically form in early to mid-August in the Gulf of Mexico (https://www.weather.gov/mob/tropical_events; https://www.nhc.noaa.gov/climo/?text). Increased sustained moisture in the nest caused by these storms can decrease sand temperatures and delay development, increasing incubation time (Lamont et al. 2012; Marco et al.

2017; Whitesell et al. 2022). Extreme weather events frequently result in complete wash-outs and erosion of beaches (Whitesell et al. 2022). This could explain lower emergence success rates observed later in the season as well because temperature and wash-over frequency have strong effects on Loggerhead Sea Turtle nests (Kobayashi et al. 2017; Pike et al. 2015; Whitesell et al. 2022). Wash-overs and inundation events are also likely the reason nests laid within the mid beach area had longer incubation periods than the lower or higher positions. It is surprising that the lower position did not have longer incubation periods, but this may be due to the fact that hatchlings from 70% of nests on the lower beach did not emerge on their own, and thus were not included in the incubation duration counts. Although sea turtle eggs can tolerate some inundation (Foley et al. 2006), prolonged inundation decreases necessary gas exchange needed for development, thus increasing mortality (Cheng et al. 2015; Ware and Fuentes 2018). Sea level rise could greatly impact sea turtle nesting habitat (Fuentes et al. 2010; Rivas et al. 2023), increasing the likelihood of inundation or erosion of beaches.

We saw a decrease in clutch size over time, which may be due to decreasing body size as seen in some nesting populations where Loggerhead Sea Turtle clutch size is positively correlated to body size (Frazer and Richardson 1986; Broderick et al 2003; Ceriani et al. 2015). Smaller body size could indicate a change in the areas that nesters forage, which may be driven by environmental change (Le Gouvello et al. 2020). Studies have shown that carapace lengths of Loggerhead Sea Turtles are smaller (mean curved carapace length of 84.4 cm) in the foraging areas of southwest Florida where they have shorter migration periods (Ceriani et al. 2015; Benscoter et al. 2021) than in southern Florida. Smaller clutches/females could also be due to the recruitment of younger females, which could be an indication of population growth or changes in habitat quality, or a behavioral adaptation to these changes (Phillips et al. 2021; Hays et al. 2022; Sönmez et al. 2023). Although smaller females are assumed to typically lay smaller clutch sizes, the increase in the number of turtles nesting annually may not affect the overall hatchling production of the region (Mortimer et al. 2022), because more nests will compensate for fewer eggs in each nest.

Municipality and beach width.—Pinellas County overall has low nest density likely resulting from a high concentration of light pollution and coastal development (Fuentes et al. 2016) and being at the northern range of the nesting beaches in central West Florida. The human population of Pinellas County has increased by over 100,000 people from 1990 to 2022, (http://censusreporter.org/profiles/05000US12103-pinellas-county-fl/), which coincides with urbanization. Beaches with low concentrations of urbanization have been found to have higher nesting success (Costa et al. 2023), but all beaches in Pinellas County experience similar levels of urbanization. Compared to the other municipalities in this study, Belleair Shore has the highest nesting density (569 nests per km) and the highest hatching and emergence success. This municipality is primarily single-family homes rather than condos or hotels seen at other beaches, which leads to less artificial lighting and obstructions on the beach that can deter nesting females.

Overall, we found nesting success was reduced on wider beaches and on the lower (more seaward) position of the beach (Bladow and Briggs 2017; Costa et al. 2023). This is comparable to previous studies (Garmestani et al. 2000; Valverde et al. 2017; Lasala et al. 2023) and may be an additional reason that Belleair Shore has higher nesting success, as it is one of the narrower beaches in the county and has not been sand nourished during the study period. Because Loggerhead Sea Turtles prefer to nest on narrower beaches in this study, expected further erosion that reduces available nesting habitat (Witherington et al. 2011; Costa et al. 2023) calls for concern because nesting success is already low on wide beaches in Pinellas County. Severe erosion of beaches is also frequently linked to a higher number of false crawls on beaches (Steinitz et al. 1998; Costa et al. 2023), and all of the beaches in Pinellas County are critically eroded beaches (https://floridadep.gov/sites/default/files/SBMP-SouthwestGulfCoastRegion_1.pdf). Beach nourishment is often used to replenish sand on eroded beaches but can have varied effects on sea turtle nesting, based on different factors (sand density, grain size, moisture content, albedo, resulting beach slope; Steinitz et al. 1998; Bladow and Briggs 2017; Shamblott et al. 2021; Costa et al. 2023). Several projects in the region have addressed how sand nourishment projects affect sea turtle nesting behavior, but they provide conflicting results. Davis et al. (1999) concluded that nourished beaches in Pinellas County encouraged marine turtle nesting, but Dellert et al. (2014) found beach nourishment had no effect on nesting behavior. Due to the varying effects sand nourishment has on nesting, caution should be used when planning projects. Long-term data can provide an improved view of pre- and post-nourishment so that management of future projects, such as sand type and beach width, can be addressed, although this was outside the scope of our study.

Hatching success, emergence success, and hatchling production.—Hatching and emergence success variations by incubation duration and distance from upland barrier were likely influenced by temperature and moisture, which are the most critical factors in egg development and hatching (Lamont et al. 2012; Pike et al. 2015; Kobayashi et al. 2017; Bladow and Milton 2019; Whitesell et al. 2022). Hatching and emergence success data in our study were higher than previously reported on the west coast of Florida (Lamont et al. 2012; Lasala et al. 2023). They may be higher due to nest protection measures to reduce predators or less severe weather events in some years (Antworth et al. 2006; Brost et al. 2015). For example, self-releasing metal cages were added to a large portion of nests in north and/or mid Pinellas County in the 2019–2022 seasons in response to an increase in the local coyote population. Therefore, hatching and emergence success may have been maintained or higher than they otherwise would have been in these years without such protection (Lavelle et al. 2023). Self-releasing cages, however, should not be considered as a method of long-term nest protection (unless under the guidance of a state or federal governing agency) due to their negative effects. For example, hatchlings within restraining cages continue to crawl until released, which exhausts energy reserves (Florida Fish and Wildlife Conservation Commission 2016). The metal cages also may interfere with the magnetic fields surrounding the nest, which could then affect the magnetic orientation and navigation of hatchlings (Irwin et al. 2014; Florida Fish and Wildlife Conservation Commission 2016).

We identified the total minimum hatchlings produced based on the estimate of emergence, but emergence success is not the best indicator of how many hatchlings enter the water due to predation and/or disorientation (Erb and Wyneken 2019). On the east coast of Florida, 7.6% of hatchlings did not make it to the water after emergence (Erb and Wyneken 2019). Determining mortality rates of hatchlings after emergence on Pinellas County beaches would more accurately determine the contribution of this area to the Gulf of Mexico population of Leatherback Sea Turtles.

Overall nesting in central West Florida is a small percentage of the total annual sea turtle nest counts in Florida but identifying the nesting trends is still valuable to understand the Northwest Atlantic population (Witherington et al. 2009; Ceriani et al. 2019; Lasala et al. 2023). Evaluating these trends in nesting success, hatching success, and emergence success provides a baseline assessment that can be used for comparison to data in future years and other studies throughout the state. This information can also influence conservation management by designating Pinellas County beaches as critical nesting habitat for Loggerhead Sea Turtles as these beaches are a productive component of the Gulf of Mexico population that is growing when other populations are not (Ceriani et al. 2019). Management decisions that could be influenced by this information include habitat protection, regulations on coastal development, lighting ordinances, and nourishment projects. We suggest future studies to examine sand temperature and type variability (to inform sand nourishment projects), adult female turtle morphometrics and clutch sizes, and mortality rates of emerged hatchlings.

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Kerry McNally is the Research Scientist and Rehabilitation Manager at the Clearwater Marine Aquarium, Florida, USA. Kerry has worked with sea turtles since 2007 and her work has primarily focused on aquatic animal health and rehabilitation. She has a Ph.D. in Environmental Sciences from University of Massachusetts, Boston, USA. Her graduate research focused on microbial communities in sea turtles. (Photograph courtesy of the Clearwater Marine Aquarium).

Lindsey Flynn began working with marine turtles in 2008. She has been listed as a permitted person on multiple Marine Turtle Permits in Pinellas County, Florida, USA, consistently since 2014, listed as the Qualified Individual on MTP #263 (North Pinellas County) 2018–2023, and on MTP #013 (Mid Pinellas County) from 2020–2023. Lindsey is well versed in performing all aspects of marine turtle nesting surveys, FWC report completion, and technical report completion. (Photograph courtesy of the Clearwater Marine Aquarium).

Megan Davila has been working with marine turtles since 2018 and her experience includes husbandry, rehabilitation, and nesting. She worked with Pinellas County as an Environmental Specialist where she focused on creating ArcGIS hotspot maps to show marine turtle disorientations in Pinellas County, Florida, USA. (Photographed by Aaron Johnson).

Carly Oakley is the Sea Turtle Conservation Program Manager at the Clearwater Marine Aquarium, Florida, USA. Carly has been working with marine turtles since 2016 and her experience is with marine husbandry, rehabilitation, rescue, and nesting. She has 7 y of experience in all aspects of sea turtle nesting monitoring and FWC report completion (Attempt Report, Marine Turtle Disorientation Report, Statewide Nesting Beach Survey Report, Nest Productivity Assessment Report). (Photograph courtesy of the Clearwater Marine Aquarium).

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