Sea Turtle Nesting on Erosional Shorelines: Nest Relocation and Hatch Success on Georgia Barrier Islands

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ABSTRACT

Barrier island shorelines are constantly eroding or gaining sediment throughout the year, which changes sea turtle nesting habitat. Nest relocation optimizes sea turtle hatch and emergence success when *in situ* nests are at risk of inundation. In Georgia, USA, records of barrier island erosion and accretion are mapped out on the Georgia Coastal Hazards Portal. For this study I selected Saint Catherines Island, Little Saint Simons Island, and Cumberland Island to monitor 2008-2023 nesting data for an erosional, accretional, and intermediate site, respectively. Using a Kruskal Wallis test and chi square test, I assessed the differences in hatch success for *in situ* nests across all islands (1), the differences in nest relocation proportions across all islands (2), and the differences in hatch success and nest relocation across the nesting season (3). There were significant differences in hatch success and nest relocation across all islands. Cumberland Island had the highest *in situ* hatch success, ranging from 60-85% for all years studied; Little Saint Simons Island's hatch success ranged from 0-85%, and Saint Catherines Island's hatch success ranged from 0-80%. Saint Catherine's Island had significantly higher proportions of nests relocated compared to Little Saint Simons Island and Cumberland Island. Saint Catherines Island, Little Saint Simons Island, and Cumberland Island all had significantly lower *in situ* hatch success in July and August compared to May and June. These results suggest a greater need for sea turtle nest relocation on erosional islands in July and August in order to facilitate higher rates of hatch success.

KEYWORDS

wildlife management, sea turtle conservation, seasonal erosion and accretion, washovers, nest inundation

INTRODUCTION

Nesting habitat availability has been reduced as a result of coastal erosion exacerbated by sea level rise, limiting beach carrying capacity of sea turtle nests (Mazaris et al. 2009). A major risk of sea level rise is nest overcrowding on erosional beaches, since beaches that are continuously narrowing provide fewer favorable nest sites (Sönmez et al. 2021). Erosional shorelines may have more sea turtle nests with low hatch success, since saltwater inundation is associated with reduced sea turtle hatch and emergence success (Pike et al. 2015).

Barrier islands in the Atlantic region of the United States are a large portion of sea turtle nesting habitats, and their dynamic shorelines pose a challenge for nesting site availability (Fujisaki et al. 2018). Loggerhead sea turtles, green sea turtles, and leatherback sea turtles nest on barrier island beaches on the Georgia coastline (Lamont and Carthy, 2007). Barrier island shorelines undergo high rates of erosion or accretion throughout a given nesting season, resulting in different beach compositions each year (Lamont and Carthy, 2007). Barrier island beaches are vulnerable to flooding, sediment displacement, and erosion due to their dynamic erosion and accretion (Moore et al. 2010). Sea turtles return to their natal sites to nest, so continuing to nest on an erosional shoreline puts some sea turtle nests at risk of saltwater inundation (Varela et al. 2019). Because of their diverse rates of erosion and accretion, hatch success and nest conservation requirements may vary across different barrier islands.

State conservation programs use nest relocation to improve sea turtle emergence and hatch success in high risk areas (Sönmez et al. 2021). Nest relocation involves moving *in situ* sea turtle nests at risk of flooding to sites more optimal for high hatch and emergence success (Pfaller et al. 2009). On erosional islands, threatened nests are relocated past the high tide line to ensure greater hatch and emergence success (Bishop and Rollins 2011). It is unclear whether trends of barrier island erosion or accretion have a significant impact on nest relocation proportions and hatch success. Since eroded areas are more susceptible to seawater inundation, there could be more nests relocated on erosional islands than on accretional islands (Sönmez et al. 2021). Barrier islands experience more erosion closer to fall and winter, which could result in a higher proportion of nests being relocated later in the nesting season to improve low *in situ* hatch success (Jackson 2010).

I investigated differences in sea turtle hatch success and nest relocation across islands with varying rates of erosion. I did a secondary data analysis of three barrier islands with nesting datasets collected by the Georgia Southern University Sea Turtle Program (Davis 2021). I evaluated the differences in hatch success for *in situ* nests (1), the differences in nest relocation proportions across islands (2), and the differences in hatch success and nest relocation during different months of the nesting season (3). I predicted that the lowest *in situ* hatch success values would be observed on the erosional island and the highest hatch success would be observed on the accretional island due to nesting habitat availability (Jackson 2010). Researching both nest relocation and hatch success is important for informing future wildlife conservation decisions for mitigating sea level rise in dynamic coastal ecosystems.

METHODS

Study organism

I am studying the nests of green turtles (*Chelonia mydas*), loggerhead turtles (*Caretta caretta*), and leatherback turtles (*Dermochelys coriacea*). These turtles nest on US Atlantic coast beaches, which is part of their native range (Carroll et al. 2022). A major part of sea turtle life history is returning to their natal site to nest, where they lay eggs buried in a shallow ditch on the beach (Varela et al. 2019). Here, environmental factors such as temperature and saltwater inundation influence embryonic development in sea turtle eggs (Fuentes et al. 2010).

Study site overview

Barrier islands are islands along the coastline of the eastern United States that separate the mainland from the open ocean, and their shorelines are sea turtle nesting habitats. Barrier island beaches undergo extreme erosion or accretion throughout the year, making them a dynamic environment (Lamont and Carthy, 2007). This is a challenge for sea turtles since shoreline fluctuations alter habitat availability based on rates of erosion or accretion (Lamont and Carthy, 2007). I looked at three barrier islands on the coast of Georgia, USA, for this study.

Geographical features of the Georgia shoreline, including major inlets and channels, can influence different patterns of erosion on each island (Jackson 2010).

I selected an erosional island, accretional island, and an intermediate island to study. Northeastern windstorms are the primary cause of barrier island erosion in Georgia, and Georgia shorelines tend to undergo accretion in the summer and erosion in the winter (Bishop and Rollins 2011). St. Catherines Island is the most erosional barrier island in Georgia, which causes its sea turtle nests to be more vulnerable to high tides (Bishop and Rollins 2011). Little Saint Simons Island has the furthest shoreline movement recorded on the Georgia coast, making it an accretional hotspot (Jackson 2010). Cumberland Island has been undergoing slower rates of change than St. Catherines and Little St. Simons Islands, and has both erosional and accretional shorelines (Jackson 2010).

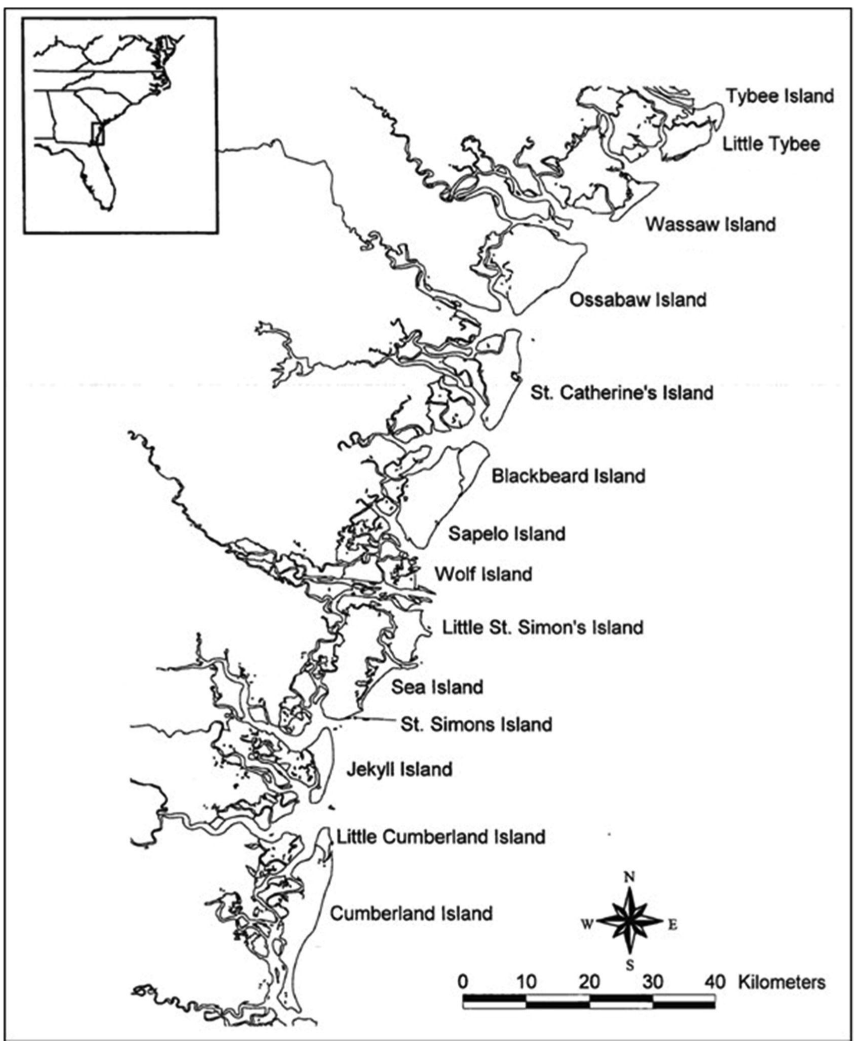

Figure 1. Barrier islands in Georgia, USA (Dodd and Mackinnon, 2003).

St. Catherines Island

Saint Catherines Island (31.6289° N, 81.1527° W) is an erosional hotspot, with its shoreline losing approximately 4 meters per year (Oertel and Chamberlain 1975). This island has an 83% mean rate of shoreline erosion from 1974 to 2004, with the highest rates of erosion occurring near the McQueen Inlet (Jackson 2010). The close proximity of Saint Catherines Island to rivers and inlets has led it to become sediment deficient, contributing to the continuing thinning and shortening of the island's area.

Little St. Simons Island

Little Saint Simons Island (31.2992° N, 81.3283° W) is a sea turtle nesting habitat with an accretional shoreline. This island is oriented towards a channel, which promotes sediment deposition and has resulted in a buildup of shorelines over time (Jackson 2010). As a result, Little Saint Simons Island is widening and lengthening in area.

Cumberland Island

Cumberland Island (30.8533° N, 81.4389° W) is a sea turtle nesting habitat with a moderate average rate of erosion. Some beaches on this island are erosional and others are accretional. Specifically, the erosional back-barrier shoreline of Cumberland Island is vulnerable to destruction from sea level rise (Jackson 2010).

Figure 2. Erosional shorelines are shown in red and accretional shorelines are shown in blue (ArcGIS 2023).

Data collection

I chose each island using the Georgia Coastal Hazards Portal, which is a GIS program available to the public (Figure 2). I used the Georgia Shoreline Change layer to visualize erosional shorelines in red, and accretional shorelines in blue. This program also provided me with geographic information about each island, such as proximity to channels and inlets, size, and location of major sea turtle nesting grounds. I also used geographic and erosion information documented in the literature to gain a clearer understanding of each site.

I obtained sea turtle nesting and relocation data with permission from the Georgia State Sea Turtle Coordinator from the Department of Natural Resources. I used data from 2008-2023 because these data are most standardized, which reduced the computational cost of data cleaning. Each row of this dataset represents a sea turtle nest, which has the location listed by coordinates and the date the nest was laid. If sea turtle monitors relocated the nest, the date of relocation and coordinates of the new site are documented. Egg mortality is represented in the columns, “Unhatched Eggs,” “Total Lost Eggs,” “Clutch Count,” “Live Hatchlings,” and “Dead Hatchlings.” I created a column called “Hatched Eggs,” where I subtracted “Unhatched Eggs” and "Total Lost Eggs" from "Clutch Count". I calculated hatch success for a given nest by dividing "Hatched Eggs" by "Clutch Count."

Data analysis

I conducted my statistical analyses in Python, where I uploaded the .csv files from each island into three DataFrames. Each DataFrame was labeled "SCI," "CUIS" and "LSSI" as abbreviations for Saint Catherines Island, Cumberland Island and Little Saint Simons Island, respectively. I used NumPy and Pandas to perform functions on the DataFrames, and used Matplotlib for the graphs. I used the "statsmodels" package from SciPy for the statistical tests.

Hatch success

I compared hatch success among only *in situ* nests, since relocating nests optimizes hatch success by moving nests away from unfavorable locations (Tuttle and Rostal 2010). Using the .loc function in Python, I created a subset of each DataFrame that included hatch success data from only *in situ* nests. I titled these DataFrames sci_situ, cuis_situ, and lssi_situ to distinguish them from the cumulative data. The year 2008 included mostly NaN values for hatch success, so I only included *in situ* data from 2009-2023.

I compared *in situ* hatch success between all three islands using a Kruskal Wallis test. Due to the differing lengths and distributions of each DataFrame, Kruskal Wallis was more appropriate than ANOVA for identifying a significant difference in hatch success. I first did a Kruskal Wallis test on a cumulative summary of all the *in situ* data, then iterated through a list of years to collect a p-value and test statistic for each year from 2009-2023. To assess which islands had the most different median hatch success values, I used a Dunn test with a Bonferroni p-value adjustment for statistically significant years.

I also used a Kruskal Wallis test to compare *in situ* hatch success across different months. I grouped the sci_situ, cuis_situ, and lssi_situ DataFrames by the "Month" column and found that nests were laid in May, June, July, and August for all islands. I sorted all *in situ* hatch success values by month and grouped them into lists for each Kruskal Wallis test. For example, *in situ* hatch success data for May was represented for each island in the lists: sci_5, cuis_5, and lssi_5. I performed a Kruskal Wallis test for all nests laid in May, then repeated it with June, July, and August. I also iterated through each year from 2009-2023 to assess monthly differences between islands. I then used a Dunn test with a Bonferroni p-value adjustment to find specific differences between islands for statistically significant results.

Nest relocation

I used a chi-square test to compare the proportions of relocated nests between each island. I first grouped all relocations and total nest data together (2008-2023) and performed a chi-square test, then iterated through each year (from 2008-2023) to get a list of chi-square p-values.

I supplemented my chi-square p-values with visualizations of nest relocation distributions over time. I calculated the proportions of nests relocated by dividing "relocated" nests by the total nest count for each year. I also plotted the proportion of nests relocated in May, June, July and August for 2008-2023.

RESULTS

Summary

15861 sea turtle nests were laid between 2008-2023 on St. Catherines Island, Little Saint Simons Island, and Cumberland Island, cumulatively. Of those, 10405 were *in situ* and 5456 were relocated (Figure 3).

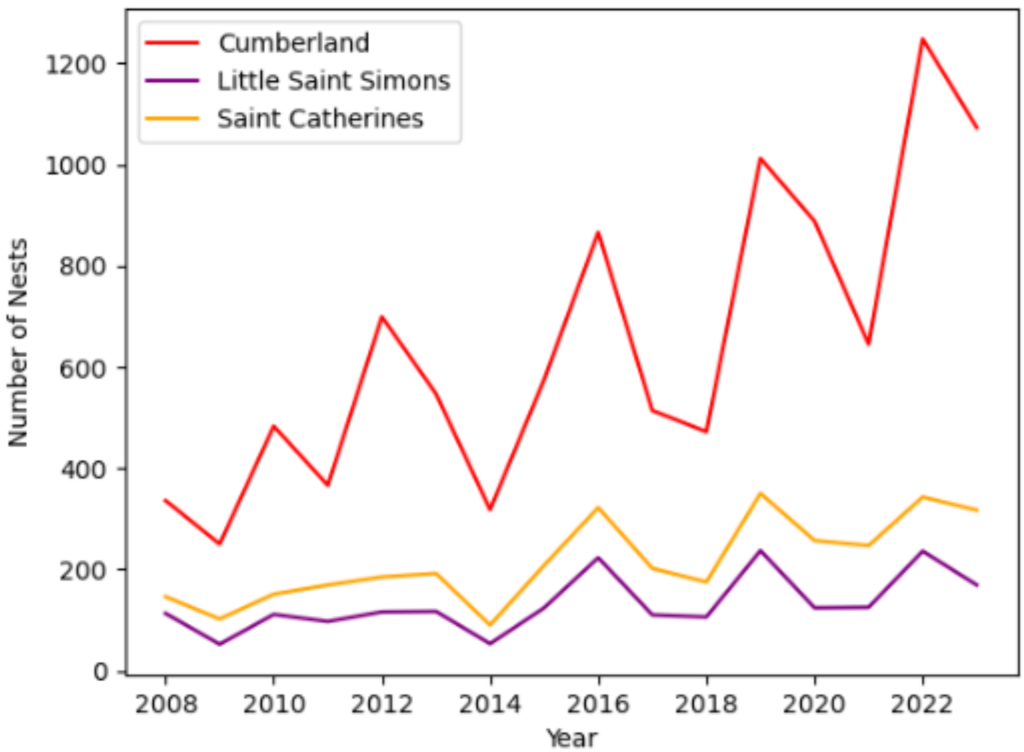

Figure 3. Nests per year. The distribution of nests deposited on each island from 2008-2023. Both *in situ* and relocated nests are included in the nest count.

Table 1. Numbers of *in situ* and relocated nests on each island, 2008-2023.

	CUIS	LSSI	SCI	Total
Relocated	3057	969	1430	5456
In Situ	7235	1144	2026	10405
Total	10292	2113	3456	15861

The nesting season occurred in May, June, July and August for all islands. Mean hatch success for Saint Catherines Island was around 50% in May, 40-45% in June, 30-35% in July, and 10-20% in August. Mean hatch success for Cumberland Island was 60-70% in May, 60-65% in June, 50-55% in July, and 45-50% in August. Mean hatch success for Little Saint Simons Island was 55-60% in May and June, 45-50% in July, and 25-30% in August. (Figure 4)

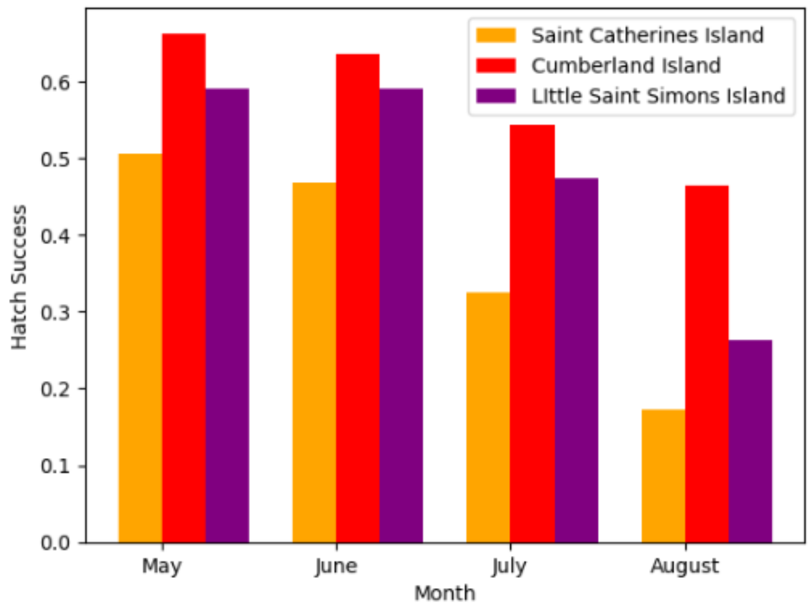

Figure 4: Monthly average hatch success 2008-2023. Distribution of average hatch success values across islands.

Hatch success among *in situ* nests

There was a significant difference in median hatch success among the three sites (statistic=292.6559905822534, p-value=2.8220135655604164e-64). After performing the Dunn test, all islands had a significantly different hatch success value. Saint Catherines Island and Cumberland Island had the most different hatch success (Table 2).

Table 2. Results of Dunn test for *in situ* hatch success between islands.

	CUIS	**SCI**	**LSSI**
CUIS	1	4.902989e-63	7.557349e-09
SCI	4.902989e-63	1	6.113669e-17
LSSI	7.557349e-09	6.113669e-17	1

To assess the significant differences in hatch success between years, I performed a Kruskal Wallis test between each year from 2009-2023 (Appendix A1). There were statistically significant differences for 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2020, 2021, and 2022. To visualize the yearly fluctuations in hatch success, I plotted each island's median hatch success distribution (Figure 5).

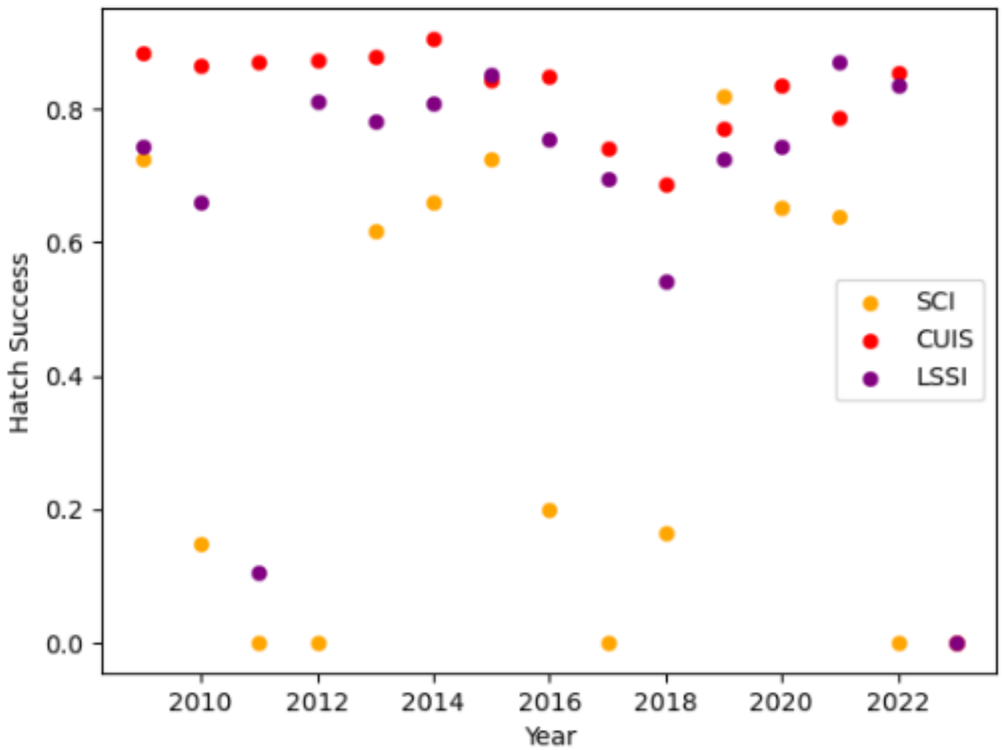

Figure 5. Median hatch success between islands for each year. SCI and LSSI have the most variable distribution of hatch success while CUIS median hatch success stays consistently high.

Monthly hatch success for *in situ* nests

I used a Kruskal Wallis test to assess differences between months across islands. I first performed a Kruskal Wallis test that included all nests from 2009-2023 (Table 3), then performed a Dunn test for each month to assess which months had the most significant differences across islands (Tables 4-7).

Table 3. Results of Kruskal Wallis test 2009-2023. There are statistically significant differences across all months.

	Test Statistic	P-value
May	42.481104819355366	5.96135926852303e-10
June	89.7628973078459	3.222808569556021e-20

July	94.27335123631619	3.3791065313606475e-21
August	9.921491257939634	0.007007700739408435

Table 4. Results of Dunn test for May hatch success. CUIS May and SCI May are the most different.

	SCI May	**CUIS May**	**LSSI May**
SCI May	1	1.064546e-09	0.026308
CUIS May	1.064546e-09	1	0.016810
LSSI May	2.630794e-02	1.681047e-02	1

Table 5. Results of Dunn test for June hatch success. CUIS June and SCI June are the most different.

	SCI June	**CUIS June**	**LSSI June**
SCI June	1	5.969168e-20	0.000007
CUIS June	5.969168e-20	1	0.001444
LSSI June	7.419076e-06	1.444002e-03	1

Table 6. Results of Dunn test for July hatch success. CUIS July and SCI July are the most different.

	SCI July	**CUIS July**	**LSSI July**
SCI July	1	4.404627e-21	0.000002
CUIS July	4.404627e-21	1	0.001450
LSSI July	2.099050e-06	1.450499e-03	1

Table 7. Results of Dunn test for August hatch success. CUIS August and SCI August are the most different.

	SCI August	**CUIS August**	**LSSI August**

SCI August	1	0.018378	1
CUIS August	0.018378	1	0.208343
LSSI August	1	0.208343	1

I also performed a Kruskal Wallis on all years to test specific differences between each month of the nesting season. Most months and years had statistically significant differences, but August had null values across most years. This is probably because Little Saint Simons Island did not have many nests laid in August compared to the data for May, June, and July (Appendix B).

Nest relocation between islands

There were statistically significant differences in nest relocation proportions on each island. The chi square test for the cumulative data (2008-2023) had a p-value of 1.9392104294237767e-190. Iterating through each year also yielded statistically significant differences in nest relocation across all years (Table 8).

Table 8. P-values from chi squared tests for nest relocation across each island. All years were statistically significantly different.

Year	P-value
2008	4.307280388037154e-17
2009	0.007257517903354676
2010	2.0355363162194367e-09
2011	1.7522950651652036e-10
2012	2.6932149839625096e-12
2013	1.0066841251138942e-15
2014	0.01600514829780539

2015	1.8844197337341076e-27
2016	5.310557085227991e-16
2017	7.522093017435353e-32
2018	1.1414601248954442e-36
2019	5.3335851511148744e-27
2020	1.1476392862403179e-05
2021	1.4159979666838912e-31
2022	4.562166547954483e-06
2023	1.3946492001440549e-14

There were higher proportions of nests relocated on Saint Catherines Island compared to Cumberland Island and Little Saint Simons Island (Figure 6).

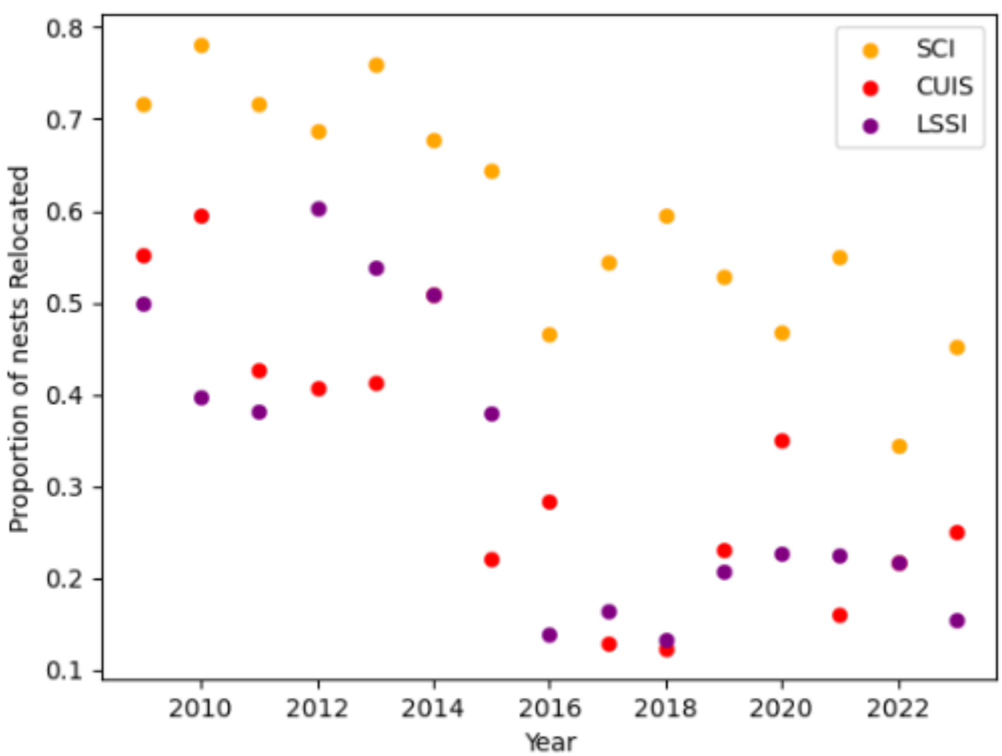

Figure 6. Proportions of nests relocated each year.

Monthly nest relocation proportions

Saint Catherines Island had the highest proportions of nests relocated compared to Cumberland Island and Little Saint Simons Island (Figure 7). Saint Catherines Island had the highest proportions of nests relocated compared to the other islands, with the bulk of the relocations occurring in August. Cumberland Island had low proportions of nests relocated, but relocation proportions increased in July and August. Nest relocation peaked in July on Little Saint Simons Island but remained low for May, June, and August.

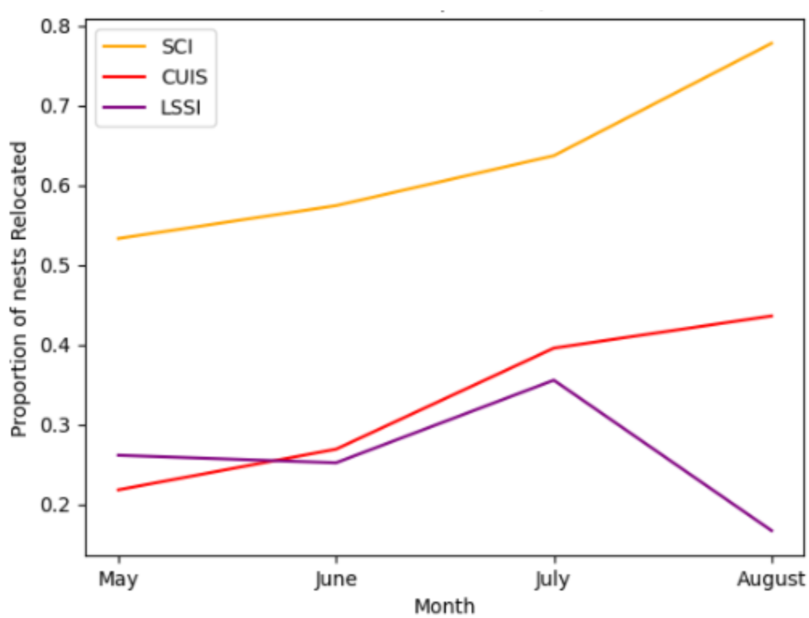

Figure 7. Nest relocation proportions, 2008-2023. Proportions of nests relocated each month on Saint Catherines Island, Cumberland Island, and Little Saint Simons Island from 2008-2023.

DISCUSSION

In situ hatch success

The differences in barrier island hatch success explored in this study contribute to the hypotheses that *in situ* hatch success decreases throughout the nesting season and erosional islands have the lowest *in situ* hatch success. Overall, hatch success was significantly lowest on

Saint Catherines Island and significantly highest on Cumberland Island. The distribution of hatch success from May through August suggests a temporal vulnerability to mortality across all islands. Mean *in situ* hatch success was highest in May, ranging from 50-70% success across all islands. It dropped to 45-65% in June, then steadily decreased to 30-55% in July and 10-50% in August (Figure 4).

The findings from this study indicate that nests on erosional islands may have reduced *in situ* hatch success. The low hatch success observed on Saint Catherines Island is likely attributed to shoreline erosion because of Saint Catherines Island's well-documented beach habitat loss (Davis 2021). Additionally, sea turtle habitat has been rapidly deteriorating on Saint Catherines Island and causing many washover events to occur (Bishop and Rollins 2011). However, Cumberland Island had the highest hatch success rather than Little Saint Simons Island, even though Cumberland Island has intermediate levels of erosion and Little Saint Simons is accretional (Jackson 2010). My hypothesis was that Little Saint Simons Island would have the highest *in situ* hatch success because its accretional shorelines would provide more sea turtle habitat. However, sea turtles rely on currents and tides to reduce energy expenditure, and crawling up a longer stretch of beach is unfavorable for nesting (Lamont and Carthy 2007). The lower count of nests on Little Saint Simons Island could be attributed to the topography, since there is more ground to cover and the energy cost may cause turtles to choose islands with more narrow shorelines. If the differences in hatch success are fully attributed to island erosion, my findings could suggest that barrier islands with intermediate levels of erosion and accretion are associated with more *in situ* hatch success, and erosional barrier islands have reduced *in situ* hatch success.

The monthly variation in *in situ* hatch success suggests a greater vulnerability to mortality during later months of the nesting season. May and June had the highest *in situ* hatch success across all islands, but hatch success gradually decreased throughout the nesting season before reaching an all time low in August. Wind patterns and tides change during different parts of a season, which strongly influence erosion on Georgia barrier islands (Jackson 2010). Higher rates of erosion occur in fall and winter, when sediment transport is shifted southwards by more variable wind and tidal conditions (Jackson 2010). Since July and August occur later in the season when tides are starting to get higher, more washover events could explain the reduced *in situ* hatch success observed later in the nesting season. Additionally, hurricane season occurs from June-November in Georgia, and increased tropical storms alter barrier island shorelines (Davis 2021). The combination of winds, tides, and storms probably contribute to the decrease in *in situ* hatch success in July and August.

Nest relocation

Findings from this study suggest that nest relocation is most necessary in the later months of the nesting season on islands with erosional shorelines. As expected in my hypothesis, the highest proportions of nests were relocated on Saint Catherines Island while Little Saint Simons Island and Cumberland Island had similar proportions of nests relocated (Figure 6). The highest number of nest relocations occurred in August on Saint Catherines Island, which is consistent with the presence of high tides and storm surges causing more washover events later in the nesting season (Bishop and Rollins 2011). Around 50% of nests laid in May were relocated on Saint Catherines Island, which increased to 55% in June, 60% in July, and 75% in August. Cumberland Island had about 20% of nests relocated in May, 30% in June, 40% in July, and 45% in August. Little Saint Simons Island had about 30% of nests relocated in May, 25% in June, 35% in July, and 10% in August (Figure 7).

Since Saint Catherines Island has much lower *in situ* hatch success values than Cumberland Island and Little Saint Simons Island, it makes sense that more nests would be relocated to improve hatch success. Requirements for relocating nests are set by the Georgia Department of Natural Resources, which include slope, shoreline erosion, and distance from the high tide line (Davis 2021). The consistently high proportions of nests relocated are likely a result of Saint Catherines Island's erosion threatening *in situ* nests. Both Saint Catherines Island and Cumberland Island had nest relocation proportions gradually increase later in the season before reaching their highest in August, which is likely a result of sea turtle nest vulnerability to tropical storms occurring later in the season (Meyer et al. 2015, Davis 2021). Little Saint Simons Island experienced its lowest proportion of nests relocated in August, which is likely because the bulk of nesting occurred earlier in the season and not many nests in this dataset were laid in August.

Limitations

This study was limited by the sizes of the islands and the exclusion of other factors potentially affecting sea turtle hatch success and relocation. Ideally all three islands would have been around the same size to allow for similar nesting habitat availability. Saint Catherines Island and Cumberland Island have about the same available nesting shorelines but Little Saint Simons Island is much smaller. Thus, a larger number of nests were available to study on the larger islands (Figure 3). In general, it was difficult to select an accretional island of comparable area to the erosional and intermediate islands. Additionally, these islands exist in urbanized areas, and urbanization has been positively correlated with light pollution, which has a negative effect on sea turtle nest density and hatch success (Brei et al. 2016, Hu et al. 2018). Including information about urbanization and light pollution on each island would have provided more insight into the trends I observed in this study.

Including more replications of erosional, accretional, and intermediate islands would be useful to assess whether my findings could be relevant to nesting dynamics on other barrier islands. The erosional components of each island were documented qualitatively in my study using the map of shoreline erosion and rates of erosion from literature, but future studies could quantify island erosion per year. Fujisaki et al. (2018) quantified nest availability on shorelines by plotting the specific latitude and longitude of each nest on a map of a shoreline and drawing a line through the nests. Researchers have used AMBUR (Analyzing Moving Boundaries using R) to calculate the movement of shorelines and vegetation lines over time as a metric for erosion (Davis 2021, Meyer et al. 2015). These methods could be used in future studies to visualize habitat changes and provide a quantitative metric for performing a correlation test between erosion, hatch success, and nest relocation.

Broader implications for sea turtle nest management

Increasing nest relocation on erosional shorelines would mitigate the risk of inundation, but wildlife management systems must take into consideration the intensive resources needed to perform large-scale relocations (Carroll et al. 2022). Nest relocations must be done within 12 hours of the eggs being laid; relocating nests later causes increased egg mortality from damaging the developing embryos (Ahles and Milton 2016). This leaves a small window of time to choose optimal nesting sites for relocation, which is a challenge for shorelines of comparable size and nest carrying capacity to Saint Catherines Island and Cumberland Island. Additionally, a potential consequence of nest relocation is sea turtle sex-temperature sensitivity, since warmer sand further up the beach increases feminization of embryos (Hamann et al. 2007). Wildlife management programs need to relocate nests to sites of similar temperature and moisture conditions, since relocating to more variable sites could reduce hatch success by altering embryonic development (Tuttle and Rostal 2010).

Sea level rise will only exacerbate sea turtle nest vulnerability to inundation, which will likely result in widespread reduced *in situ* hatch success and a greater need for nest relocation. Habitat deterioration and inundation events on Saint Catherines Island are a result of sea level rise, which will only worsen habitat quality as time goes on (Bishop and Rollins 2011, Davis 2021). Sea turtle nest vulnerability on Saint Catherines Island is evident in the low *in situ* hatch success and high relocation proportions I observed in this study. If these results are consistent across other erosional islands, sea turtle management can expect to allocate more resources towards protecting nests during July and August when *in situ* hatch success is at its lowest.

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APPENDIX A: Hatch Success

Table A1. The results of Kruskal Wallis tests for differences in hatch success between SCI, CUIS, and LSSI. One test was performed for median hatch success each year. There were statistically significant differences in hatch success in 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2020, 2021, and 2022.

Year	Statistic	P-value
2009	13.740476422563438	0.0010382297171243815
2010	17.863437585943906	0.0001321307238849343
2011	53.606578983992755	2.288122526629299e-12
2012	40.784316886176335	1.3925093312279927e-09
2013	31.858004543736225	1.2081537635149917e-07
2014	22.21592684018765	1.499245594924997e-05
2015	8.15904609427726	0.01691553164022186
2016	111.64347441157328	5.713833240805765e-25
2017	89.88941970227904	3.025244784610753e-20
2018	3.857755958684022	0.14531114916070992
2019	2.493383421868546	0.287454207142826
2020	18.03800913051065	0.00012108660007577036
2021	25.183900565630424	3.3992685466828964e-06
2022	134.33262258087422	6.761477960608801e-30
2023	0.5501744659087021	0.7595058663945484

APPENDIX B: Nesting Season Hatch Success

Table B1. Differences in SCI, CUIS, and LSSI hatch success in May. Significantly different years were 2011, 2016, 2017, 2020, 2021, 2022, and 2023.

Year	Statistic	p-value
2009	4.0126262626262665	0.13448358509209768
2010	0.7318181818181856	0.6935658497847562
2011	6.078634112013183	0.0478675692025889
2012	1.3668603346559771	0.5048821883455902
2013	1.0808660520045512	0.5824959618560506
2014	0.5130864650168065	0.7737215439132508
2015	0.43205523681268926	0.8057130490558013
2016	11.435214786727297	0.003287567355366757
2017	45.14734481656396	1.5717325118282877e-10
2018	1.0885231457772147	0.5802701123583996
2019	0.723635515369188	0.6964092715159214
2020	6.158959518007591	0.045983172759039175
2021	14.923146122555188	0.0005747513409182523
2022	22.272257668854124	1.4576078463105016e-05
2023	20.340093367645323	3.830053535941855e-05

Table B2. Differences in SCI, CUIS, and LSSI hatch success in June. Significantly different years were 2011, 2014, 2015, 2016, 2017, 2021, and 2022.

Year	Statistic	p-value
2009	5.503102510157162	0.06382876966534733
2010	0.1670803858381187	0.9198541143062651
2011	34.303655406337214	3.556770750974514e-08
2012	4.498306510361933	0.10548850860425794
2013	5.9843920489322135	0.05017712544966885
2014	9.821186837132752	0.0073681146577497005
2015	7.952865807962117	0.01875241182856684
2016	36.66168131629431	1.0939993236953374e-08
2017	76.54932120038696	2.385207161427028e-17
2018	0.041586443882873865	0.9794214665016181
2019	0.6546903752628773	0.7208348767925268
2020	2.738647573512671	0.2542788481542818
2021	8.259488386016486	0.01608699346169312
2022	51.40569662183614	6.876933256788573e-12
2023	3.2560708346505067	0.19631487232486744

Table B3. Differences in SCI, CUIS, and LSSI hatch success in July. Significantly different years were 2010, 2011, 2012, 2014, 2016, 2017, 2021, 2022, and 2023.

Year	Statistic	p-value
2009	2.8949293405701133	0.23516575564977224
2010	21.68937542609741	1.9507965023509282e-05
2011	18.933418691505555	7.738563833964039e-05
2012	14.776340315958093	0.0006185267248197965
2013	5.479478076780236	0.06458719947368702
2014	12.509088173703612	0.001921701885523168
2015	5.4262386788568815	0.06632957920489141
2016	76.73283084807379	2.1760931954368457e-17
2017	9.977533215004412	0.00681406372646923
2018	5.338793774240063	0.06929400481600938
2019	0.9588947873553252	0.6191254299181179
2020	2.986451086007422	0.22464687749054682
2021	12.791832144303267	0.0016683568281890368
2022	47.25058072925559	5.491193671040123e-11
2023	9.929039063529288	0.006981304198321802

Table B4. Differences in SCI, CUIS, and LSSI hatch success in August. There were no statistically significant differences.

Year	Statistic	p-value
2009	NaN	NaN
2010	NaN	NaN
2011	NaN	NaN
2012	NaN	NaN
2013	NaN	NaN
2014	2.1333333333333364	0.344153786865412
2015	NaN	NaN
2016	NaN	NaN
2017	NaN	NaN
2018	NaN	NaN
2019	NaN	NaN
2020	NaN	NaN
2021	NaN	NaN
2022	NaN	NaN
2023	1.7983601949025623	0.4069031439344407