MODELING SURVIVAL OF IMMATURE LOGGERHEADS (*Caretta caretta*) AND GREEN TURTLES (*Chelonia mydas*) FROM 10 YEARS OF MARK-RECAPTURE DATA AT THE FLORIDA POWER AND LIGHT ST. LUCIE PLANT

by
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ABSTRACT

Loggerheads (*Caretta caretta*) are listed as Threatened and green turtles (*Chelonia mydas*) are listed as Endangered under the United States Endangered Species Act. While green turtle nest production in Florida has increased markedly in recent years, loggerhead nest production has followed a more tenuous path. Reasons for these differences are unknown. Limited demographic information is available for these species of conservation concern. I used Barker models, which incorporated mark-recapture, live-resight and dead recovery data, implemented in Program MARK. These models were used to estimate apparent survival for immature loggerhead (<85cm SCL) and green turtle (<60cm SCL) populations foraging in the Atlantic Ocean adjacent to the Florida Power and Light St. Lucie Plant on Hutchinson Island, Florida between 2002 and 2011. My results indicated annual apparent survival was decreasing (from 0.75 to 0.59) for resident immature loggerheads and was stable (~0.81) for resident immature green turtles over the ten year study period. I found that permanent emigration models were better supported than no movement models for both species. Size (straight carapace length) was found to be an important covariate for survival and fidelity parameters in the green turtle analysis but not in the loggerhead analysis. My study is the first to compare survival of two species of immature marine turtles foraging at the same location in the Atlantic. These estimates are also the first available survival estimates for immature marine turtle populations in Florida based on modern mark-recapture techniques, filling a critical knowledge gap. This information is vitally important for managers when evaluating the long-term recovery of these endangered species.

I would like to dedicate this document to my family, who fought through tremendous adversity during the time I was in graduate school.

ACKNOWLEDGMENTS

This project would not have been possible without help from a lot of people. I would like to thank my committee (Dr. Llewellyn Ehrhart, Dr. John Weishampel, Dr. David Breininger, and Dr. Linda Walters) and Dr. William Kendall for all of their help and support. I would also like to thank the Inwater Research Group Inc. for collecting all of the data and allowing me access to it as well as answering all of my questions. Special thanks to everyone from my lab (Cheryl Sanchez, Chris Long, Simona Ceriani, Kendra Cope, and Ryan Chabot) as well as Joe Figel for assistance with editing. Finally, I am eternally grateful to Dr. Blair Witherington for suggesting this project to me at a time when I was struggling to find my way.

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CHAPTER 1:
INTRODUCTION

Sea turtles have complex life histories, which involve varied habitats from open ocean to near-shore areas, making population monitoring a difficult task. Although it is difficult, conservation managers must critically evaluate the present states of marine turtles at various life history stages as well as the success or failure of planned management practices for the long-term recovery of these populations. Changes in demographic parameters of a particular life history stage, such as juvenile annual survival, can have dramatic impacts on sea turtle populations. Estimates of survival for a greater proportion of the population, both spatially and temporally, are necessary to improve sea turtle stock assessments.

Loggerhead sea turtles (*Caretta caretta*) are listed as Threatened under the United States Endangered Species Act of 1973. Loggerhead nest production in Florida was considered to be stable or increasing through the 1990s until 1998 (Witherington et al. 2009). After 1998, statewide nest production began an annual stepwise decrease that continued until 2006 at a rate of 43% per year (Witherington et al. 2009). Even though dramatic shifts in adult nest production were observed, a corresponding decrease in density of neritic stage immature loggerheads had not been observed at several key long-term monitoring projects along the east coast of Florida (Ehrhart et al. 2007). Beginning in 2007, annual nest production appeared to level off (Witherington et al. 2009). More recently, it appears that nest production may be on the rise again with increased numbers of loggerhead nests recorded in Florida(Witherington 2012).

Green turtles (*Chelonia mydas*) are listed as Endangered under the United States Endangered Species Act of 1973. In contrast to the tenuous track of recent annual loggerhead nest production, green turtle nest production has been increasing exponentially in Florida at a rate of 13% per year (Chaloupka et al. 2008), presumably as populations rebound from historical exploitation that reduced Caribbean populations to just 3-7% of their historical pre-exploitation levels (Jackson et al. 2001). Evidence also exists that the increase observed on Florida nesting beaches is mirrored in local immature marine turtle foraging grounds (Ehrhart et al. 2007).

Estimates of annual survival rates for all marine turtle life stages are necessary for managers to determine the ability of marine turtle populations to persist through time, especially given these species' long maturation times. The need for better survival estimates has been acknowledged as a critical gap in our understanding of sea turtle ecology (Bjorndal et al. 2010). Even with recent advances in software and techniques used to analyze mark-recapture data (e.g. Open Robust Design Models, Program MARK), relatively few survival estimates using these methods exist for marine turtle populations (Kendall and Bjorkland 2001, Chaloupka and Limpus 2002, Bjorndal et al. 2003, Chaloupka and Limpus 2004, Sasso et al. 2006, Braun-McNeill et al. 2007, Monk et al. 2010). Lack of survival estimates is especially problematic for large neritic immature life stages, which can only be accessed through logistically challenging in-water studies. However, changes in survival at this life stage may have dramatic impacts on the overall size of a population and its ability to persist (Crouse et al. 1987). Large immature marine turtles are disproportionately important to the persistence of the population because they have overcome the steep odds against them at smaller life stages (hatchling, post-hatchling) and they have their entire reproductive lifespan immediately ahead of them (Crouse et al. 1987).

Barker models (Barker 1997, Barker and White 2001, Barker et al. 2004), a type of mark-recapture analysis which takes advantage of all available encounter information, have been demonstrated to be an effective tool for obtaining critical information about survival of immature marine turtle populations from tagging studies (Braun-McNeill et al. 2007). Barker models provide several advantages over previous techniques used to derive estimates of survival such as catch-curve analysis and Cormack-Jolly-Seber (CJS) models (Frazer 1987, Bjorndal et al. 2003). These models are able to incorporate information about individual animals, including all available encounter information about the individual during the time of the study. One of the limitations of traditional techniques is that they are restricted to using information collected at a single capture location. However, Barker models incorporate incidental observations outside of the study area of both live and dead individuals (Barker 1997, Barker and White 2001, Barker et al. 2004). Inclusion of this additional information allows for estimates that can account for movement in the form of no movement and permanent emigration. This is in contrast to previous CJS models, which were unable to disentangle mortality and permanent emigration (Bjorndal et al. 2003). Inclusion of the additional information from incidental observations also helps to increase the precision of the final estimates (Mizroch et al. 2004). I used Barker models to derive estimates of apparent survival for two species of marine turtles (loggerheads, green turtles) captured at the Florida Power and Light St. Lucie Plant between 2002 and 2011. These are the first available estimates of survival for immature turtles of both species in Florida waters.

CHAPTER 2:
STUDY AREA AND SAMPLING

The Florida Power and Light St. Lucie Nuclear Plant is located approximately half way between Ft. Pierce Inlet and St. Lucie Inlet on Hutchinson Island, FL (27.348 ° N, 80.240 ° W). The nuclear power plant continuously draws cooling water directly from the Atlantic Ocean through three large diameter (two 3.7m and one 4.9m) intake pipes with velocity caps located 365 m off-shore. Sea turtles regularly become entrained in the pipes and are transported into a 1,500 m long intake canal, where they are captured and removed daily by on-site biologists. This setup provides a unique, fairly consistent and unbiased sampling effort. Once captured, turtles are measured, weighed, flipper tagged with two metal (inconel) tags and a Passive Integrated Transponder (PIT) tag, and released back into the ocean.

The area immediately surrounding the intake pipes consists primarily of sand and shell sediment. Adjacent to the structures to the southwest at a distance of approximately 450 meters is a sabellariid worm rock reef (Kubis et al. 2009). Resident individuals of both species are foraging either on hard bottom or worm rock reef habitat. Loggerheads are typically more abundant than green turtles at the plant. Loggerheads captured at the plant range from the smallest size classes of neritic loggerheads seen in the state of Florida (~45cm) to adults. Adult loggerheads are primarily captured during the nesting season; most likely during reproductive migrations and are not thought to be resident at the plant. Power plant protocol considers individuals smaller than 85cm to be immature; this is the standard that I followed for this study. The majority of green turtle captures at the plant are small juveniles with captures of individuals greater than 60 cm SCL (subadults) being uncommon and captures of adults being rare and restricted to the nesting season. For this reason, only individuals smaller than 60 cm SCL are thought to be resident at the plant and only these individuals were included in my study.

Captures of marine turtles at the plant are continuous and year-round. In order to run a mark-recapture analysis it is necessary to have defined capture periods with intervals in-between when demographic processes occur (i.e. survival/mortality, recruitment/emigration, etc.). Thus, artificial windows were imposed upon the capture data in order to conduct the analysis. Four months per year were designated as the capture period (primary periods). Each individual included in the study had a capture history created using these primary periods, where it was either detected or not detected in each of the study years. Incidental observations from the remaining eight months of the year (secondary periods) in the form of live resights and known mortalities were also included in the input data for the analysis. Live resight data include all available information on turtles captured at the plant or other locations during the eight month secondary period. The four month primary periods were chosen independently for each species. Selection was based on periods of apparent increased residency and reduced presence of transient individuals (for which it is not possible to estimate survival). Exploratory data analysis indicated that the months with the highest recapture rates (the simplest available proxy for residency) were June-October for loggerheads (Figure 1) and May-August for green turtles (Figure 2). Previous research has shown that loggerheads from the Chesapeake Bay (not resident to FL) cope with low winter temperatures by employing one of two strategies (Mansfield et al. 2009). The important one for the purposes of my study is a directed southward movement along the coast, which may extend as far south as the Florida Keys. Thus, loggerhead captures at the plant during the winter months are most likely a mix of northern and local individuals, lending support to my selection of the summer months as the primary capture period. Increased numbers of captures during winter months may indicate that similar patterns exist for green turtles at the plant with a mixing of northern and local individuals present during the colder months of the year.

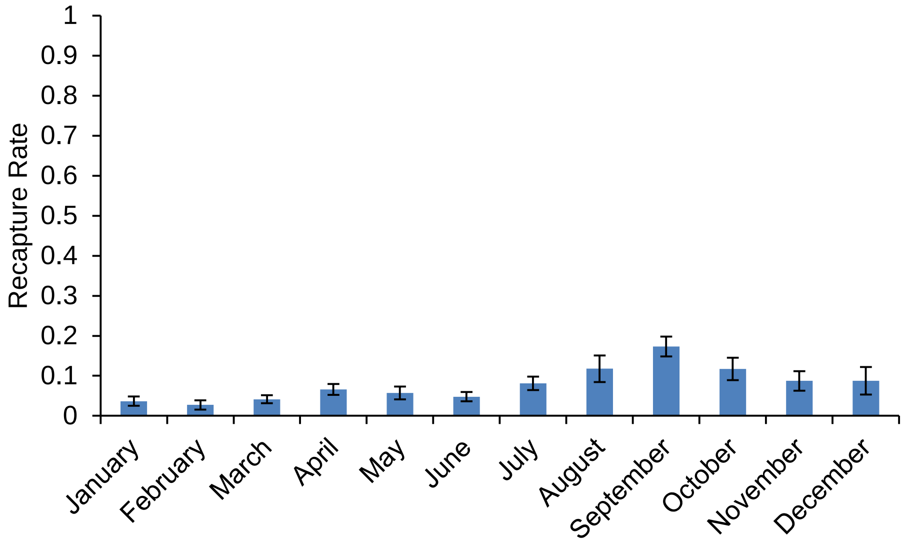

Figure 1: Percentage of loggerhead captures by month that had been previously tagged between 2002 and 2011 at the Florida Power and Light St. Lucie Plant, FL, USA. The extensions above and below the histogram bars represent ± standard error.

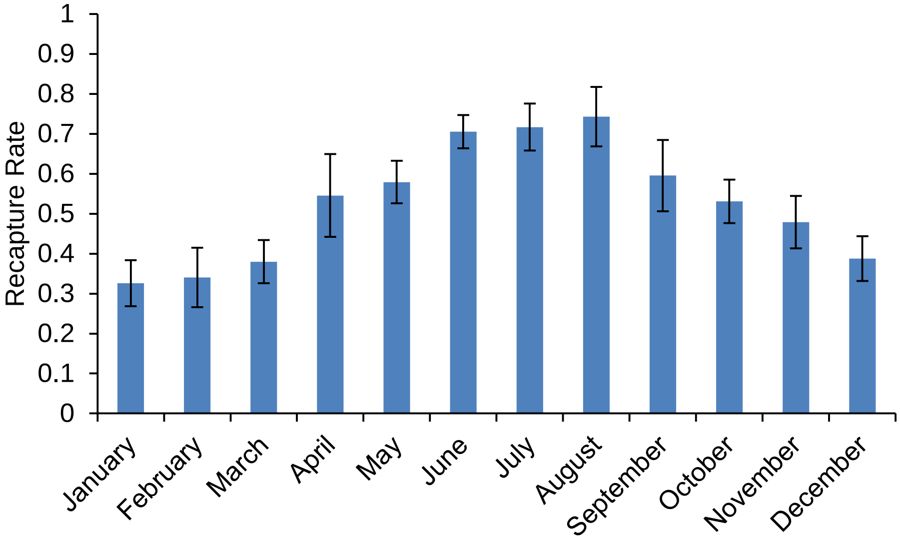

Figure 2: Percentage of green turtles by month that had been previously tagged between 2002 and 2011 at the Florida Power and Light St. Lucie Plant, FL USA. The extensions above and below the histogram bars represent ± standard error.

CHAPTER 3:
MARK-RECAPTURE ANALYSIS

I used Barker models (Barker 1997, Barker and White 2001, Barker et al. 2004) implemented in Program MARK (White and Burnham 1999) to analyze the data and derive estimates of annual apparent survival for immature loggerheads and green turtles captured at the Florida Power and Light St. Lucie Plant. The full set of parameters used in the Barker models is listed in Table 1(Barker et al. 2004):

Table 1: Barker models parameters with descriptions

PARAMETER	DESCRIPTION
$\mathbf{S}_i$	the probability that an animal alive at i is alive at i+1
$\mathbf{p}_i$	the probability that an animal at risk of capture at i is captured at i
$\mathbf{r}_i$	the probability that an animal dies in i,i+1 is found dead and its tags are reported
$\mathbf{R}_i$	the probability that an animal that survives from i to i+1 is resighted (alive) sometime between i and i+1
$\mathbf{R}_i'$	the probability that an animal dies in i,i+1 without being found dead but is resighted alive in i,i+1 before it dies
$\mathbf{F}_i$	the probability that an animal at risk of capture at i is at risk of capture at i+1
$\mathbf{F}_i'$	the probability that an animal not at risk of capture at i is at risk of capture at i+1

An extensive set of model structures (i.e. combinations of model parameters) was created to test several hypotheses. The most interesting and informative involve comparing different structures for apparent survival ($\mathbf{S}_i$). Due to the prevalence of transients in the data, even after selecting the time of year thought to have the highest residency rate, only models with a two age class structure adequately fit the data (Pradel et al. 1997, Braun-McNeill et al. 2007). The two age class structure was originally designed for use with birds to separate first year birds from all others when calculating survival rates (Kauffman et al. 2003). Fortunately, the same structure can be used to separate out residents, by functionally defining them as individuals captured in more than one primary period, from the overall population, which includes both residents and transients. To reduce potential confusion, age class 1 and age class 2 will be referred to as capture class 1 and capture class 2 for the remainder of this paper. These structures allow apparent survival estimates for residents (capture class 2) to be calculated directly in Program MARK. Capture class 1 (residents + transients) was modeled in one of two ways: fully time varying or constant. Selection of models with time variation in capture class 1 would indicate one of two things: true variation in the survival of this group or variation in the proportion of residents and transients throughout the course of the study. Capture class 2 (residents) was modeled in one of three ways: time constant, unconstrained (increasing or decreasing) linear trend over time, or size dependent with straight carapace length (SCL) at first capture used as a covariate. Models with fully time-varying resident apparent survival (class two) could not be adequately fit to the data for either species. Encounter probabilities (p) were structured in one of four ways: constant, fully time varying, size specific (SCL), or with outage specific correction factors.

The power plant undergoes periodic shutdowns of varying length (outages), which reduce the volume of water flowing into the intake canal and hence the number of turtles entrained. Correction factors were created for this process by taking the proportion of time when the plant was operating at full capacity in each year (not in outage) and applying those values as a temporal constraint (outage correction factors). The resight parameter ($\mathbf{R}_i$) was modeled as either constant or fully time varying (green turtles only).

Constraints were also placed on the fidelity ($\mathbf{F}_i$) and return rate ($\mathbf{F}_i'$) parameters. Three possible structures were explored for these two movement parameters. One possible structure is to constrain the two parameters to be equal to one another and both equal to 1 (no movement). Alternatively, return rate ($\mathbf{F}_{i}'$) was fixed to 0, while fidelity ($\mathbf{F}_{i}$) was allowed to assume either a constant value or one that varied with size (permanent emigration). All other parameters were constrained to be constant throughout the study period. Every possible combination of the available parameters represented led to a set of 54 models for the loggerhead analysis and 108 models for the green turtle analysis.

Fit of the most general model to the data was determined using the median $\hat{c}$ routine in Program MARK (G. White, unpublished manuscript). The median $\hat{c}$ is calculated by generating the distributions of model deviances for various $\hat{c}$ values, and then comparing the observed value to the generated distributions and calculating the value where 50% of the distribution would be above the observed value and 50% would be below it. Resultant models were ranked using the quasi-likelihood corrected form of Akaiki's Information Criterion (QAIC_c), which accounts for both small sample size and variance inflation due to lack of fit of the most general model (Anderson et al. 1998). The model averaging routine in Program MARK was used to produce all parameter estimates reported (unless otherwise noted). Model averaging produces estimates that are not biased by model selection uncertainty by using QAIC_c weights and calculating a weighted average.

CHAPTER 4:
RESULTS

A total of 861 loggerheads and 322 green turtles captured during the designated primary periods between 2002 and 2011 were used in the analysis. Thirty five loggerhead and 160 green turtle recapture events were included in the analysis. Sixty two (loggerheads) and 341 (green turtles) live resighting events occurred during the defined secondary periods and were included in the analysis. Fifteen loggerhead and six green turtle mortalities were used in the analysis. Table 2 (loggerheads) and Table 3 (green turtles) enumerate the captures and observations by year. Loggerheads included in the analysis ranged from 46.2 cm to 84.9 cm SCL with an average size of 67.6 cm (+/- 7.03 cm) SCL at first capture (Figure 3). Green turtles ranged from 25.2 cm to 59.3 cm SCL with an average of 37.6 cm (+/- 8.30 cm) SCL at first capture (Figure 4).

Table 2: Loggerhead captures and observations by year

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Totals
Individuals	68	137	118	107	80	51	107	60	51	82	**861**
Recaptures	0	3	4	3	6	1	6	5	5	2	**35**
Live Resight	7	10	8	8	2	5	6	7	3	6	**62**
Mortality	0	0	3	3	0	0	3	3	1	2	**15**

Table 3: Green turtle captures and observations by year

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Totals
Individuals	66	62	31	70	22	12	26	17	2	14	**322**
Recaptures	0	15	19	31	34	12	21	14	4	10	**160**
Live Resight	38	43	30	47	35	35	43	30	12	28	**341**
Mortality	0	1	0	0	0	1	2	1	0	1	**6**

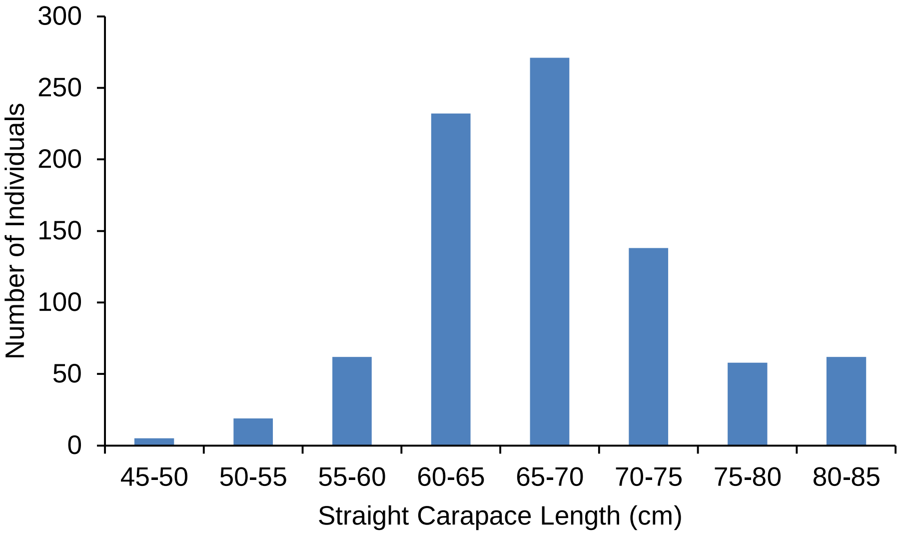

Figure 3: Size distribution of loggerheads at first capture.

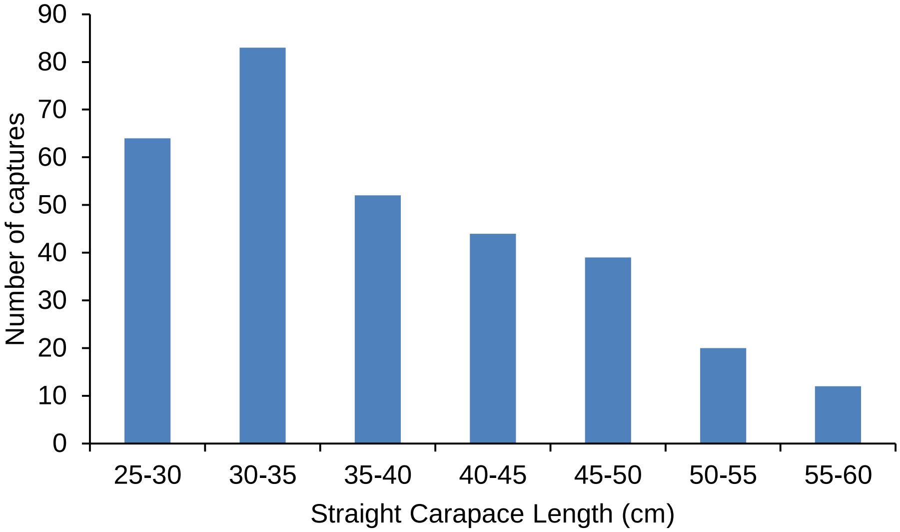

Figure 4: Size distribution of green turtles at first capture.

The resultant model set for loggerheads included 54 different structures. The median ĉ routine in Program MARK demonstrated adequate fit of the most general model to the data (ĉ=1.41). $QAIC_c$ values, which accounted for both small sample size and variance inflation, were used for ranking models and producing model average parameter estimates. The best model for loggerheads (Table 4) included constant apparent survival for capture class one (residents and transients), a linear trend in apparent survival for capture class 2 (residents), and encounter probabilities corrected for periods of outage at the plant. The remaining four parameters were held constant ($\mathbf{r}_i$, $\mathbf{R}_i$, $\mathbf{R}_i'$, $\mathbf{F}_i$,) with the return rate parameter ($\mathbf{F}_i'$) being fixed to zero (permanent emigration). Model weight was spread out among the set of candidate models with 24 models receiving at least one percent of the model weight. The top model acquired nine percent of the weight. Sixty six percent of the model weight supported permanent emigration as the dominant movement type.

Table 4: Models from the loggerhead analysis with 1% or greater support

Model	Num. Par	QAICc	Delta QAICc	QAICc Weights
{S(two class ./T)p(outage specific)r(.)R(.)R'(.)F(.)F'=0}	9	660.21	0	0.09
{S(two class ./T)p(.)r(.)R(.)R'(.)F(.)F'=0}	8	660.36	0.15	0.08
{S(two class ./.)p(.)r(.)R(.)R'(.)F(.)F'=0}	7	660.84	0.64	0.07
{S(two class ./T)p(outage specific)r(.)R(.)R'(.)F=F'=1}	8	660.99	0.78	0.06
{S(two class ./.)p(outage specific)r(.)R(.)R'(.)F(.)F'=0}	8	661.01	0.81	0.06
{S(two class ./T)p(.)r(.)R(.)R'(.)F=F'=1}	7	661.32	1.11	0.05
{S(two class ./.)p(.)r(.)R(.)R'(.)F=F'=1}	6	661.38	1.17	0.05
{S(two class ./.)p(outage specific)r(.)R(.)R'(.)F=F'=1 }	7	661.42	1.22	0.05
{S(two class ./T)p(outage specific)r(.)R(.)R'(.)F(.SCL)F'=0}	10	662.08	1.88	0.04
{S(two class ./T)p(SCL.)r(.)R(.)R'(.)F(.)F'=0}	9	662.19	1.99	0.03
{S(two class ./T)p(.)r(.)R(.)R'(.)F(SCL.)F'=0}	9	662.26	2.06	0.03
{S(two class ./.SCL)p(.)r(.)R(.)R'(.)F(.)F'=0}	8	662.40	2.19	0.03
{S(two class ./.SCL)p(outage specific)r(.)R(.)R'(.)F(.)F'=0}	9	662.58	2.38	0.03
{S(two class ./.)p(SCL.)r(.)R(.)R'(.)F(.)F'=0}	8	662.71	2.50	0.03
{S(two class ./.)p(.)r(.)R(.)R'(.)F(SCL.)F'=0}	8	662.76	2.55	0.03
{S(two class ./.)p(outage specific)r(.)R(.)R'(.)F(.SCL)F'=0}	9	662.90	2.70	0.02
{S(two class ./.SCL)p(.)r(.)R(.)R'(.)F=F'=1}	7	663.01	2.80	0.02
{S(two class ./T)p(SCL.)r(.)R(.)R'(.)F(.SCL)F'=0}	8	663.02	2.81	0.02
{S(two class ./T)p(.SCL)r(.)R(.)R'(.)F=F'=1}	8	663.02	2.81	0.02
{S(two class ./.SCL)p(outage specific)r(.)R(.)R'(.)F=F'=1}	8	663.06	2.86	0.02
{S(two class ./.)p(.SCL)r(.)R(.)R'(.)F=F'=1}	7	663.12	2.91	0.02
{S(two class ./.SCL)p(SCL.)r(.)R(.)R'(.)F(.)F'=0}	9	664.21	4.00	0.01
{S(two class ./.SCL)p(.)r(.)R(.)R'(.)F(.SCL)F'=0}	9	664.33	4.12	0.01
{S(two class ./.SCL)p(outage specific)r(.)R(.)R'(.)F(.SCL)F'=0}	10	664.50	4.29	0.01

*T=linear trend, .=constant, t=fully time varying

The resultant model set for green turtles included 108 different structures. The median ĉ routine in Program MARK demonstrated adequate fit of the most general model to the data (ĉ= 1.11). The best model for the green turtle model set (Table 5) included fully time varying apparent survival for capture class one (residents and transients), a constant relationship between apparent survival and size (SCL) for capture class 2 (residents), fully time varying encounter probabilities, and fully time varying resight probability ($\mathbf{R}_i$). The remaining three parameters were held constant ($\mathbf{r}_i$, $\mathbf{R}_i$', $\mathbf{F}_i$) with the return rate parameter ($\mathbf{F}_i$') being fixed to zero (permanent emigration). This model also had a size component on the fidelity parameter linking probability of remaining at the plant to size at first capture. Ninety seven percent of the model weight supported permanent emigration as the dominant movement type.

Table 5: Models from the green turtle analysis with 1% or greater support

Model	Num. Par	QAICc	Delta QAICc	QAICc Weights
{S(two class t/.SCL)p(t)r(.)R(t)R'(.)F(.SCL)F'=0}	32	2058.10	0	0.48
{S(two class t/.)p(t)r(.)R(t)R'(.)F(.SCL)F'=0}	31	2058.25	0.15	0.44
{S(two class t/T)p(t)r(.)R(t)R'(.)F(.SCL)F'=0}	34	2063.84	5.74	0.03
{S(two class t/.SCL)p(t)r(.)R(t)R'(.)F=F'=1}	32	2064.92	6.83	0.02
{S(two class t/.)p(t)r(.)R(t)R'(.)F=F'=1}	31	2065.47	7.38	0.01

*T=linear trend, .=constant, t=fully time varying

Model averaging was used to generate parameter estimates, which accounted for model selection uncertainty. Model averaged apparent survival estimates for resident loggerheads were found to be decreasing over time from a high of 0.75 (CI=0.47-0.91) in 2003 to a low of 0.59 (CI=0.31-0.82) in 2011 (Figure 5). Model averaged apparent survival estimates for resident green turtles were found to be constant over time at 0.81 (CI=0.76-0.86) (Figure 6). Model averaged detection probabilities for loggerheads ranged from 0.27 (CI=0.08-0.60) to 0.37 (CI=0.19-0.60) (Figure 7). Model averaged detection probability for green turtles ranged from 0.07 (CI=0.02-0.18) to 0.56 (CI=0.41-0.70) (Figure 8).

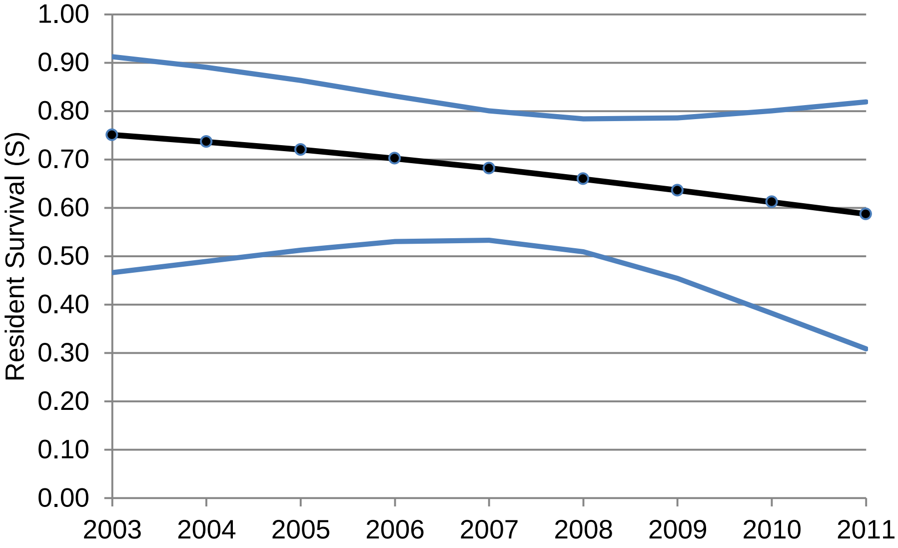

Figure 5: Loggerhead model average apparent survival for capture class 2 (residents). Blue lines indicate upper and lower confidence intervals.

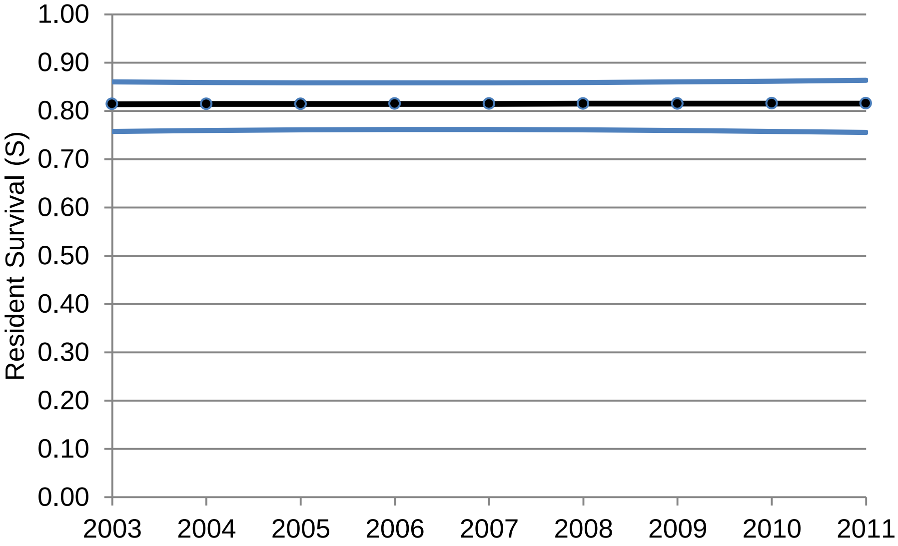

Figure 6: Green turtle model average apparent survival for capture class 2 (residents). Blue lines indicate upper and lower confidence intervals.

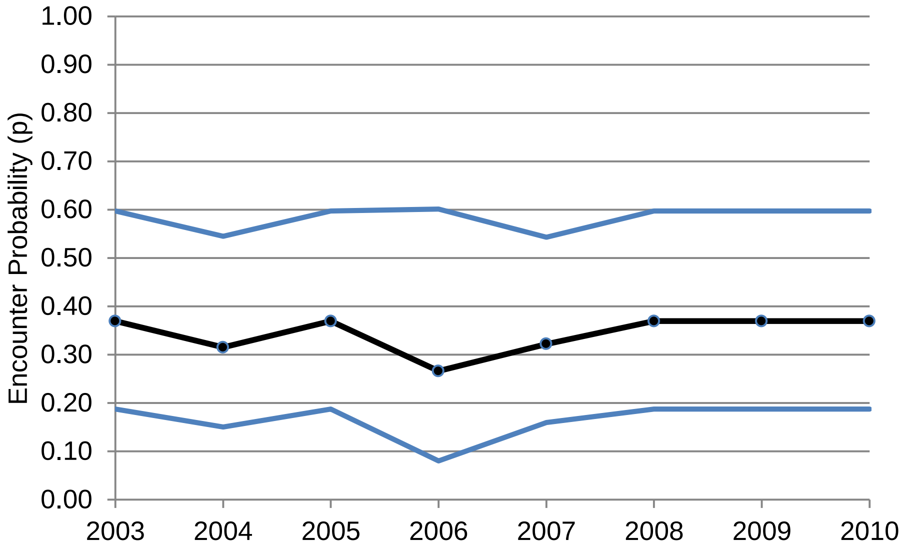

Figure 7: Model average encounter probability (p) for loggerheads. Blue lines indicate upper and lower confidence intervals.

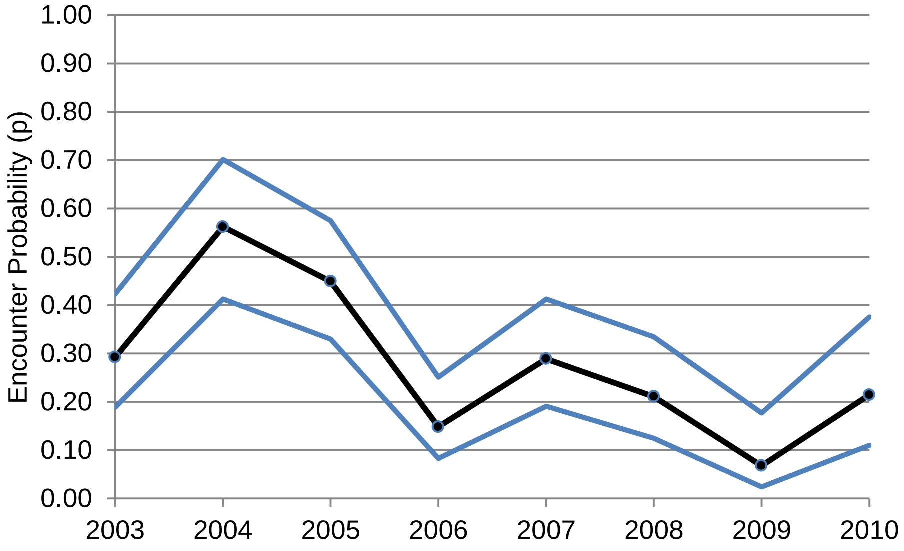

Figure 8: Model average encounter probability (p) for green turtles. Blue lines indicate upper and lower confidence intervals.

Size at first capture was used as a covariate for both loggerheads and green turtles. The size component proved to be important for results of the green turtle analysis, with the top 4 models accounting for 97% of the model weight, having a size component in at least one variable. In contrast, the top 8 models for loggerheads did not include any size component. The top model in the green turtle set included a size component both on survival (Figure 9) and fidelity (Figure 10). Apparent survival was found to decrease with increasing size at first capture and fidelity was found to be zero for the smallest size classes, switching to 1 (completely faithful) for individuals first captured at sizes greater than 28 cm SCL.

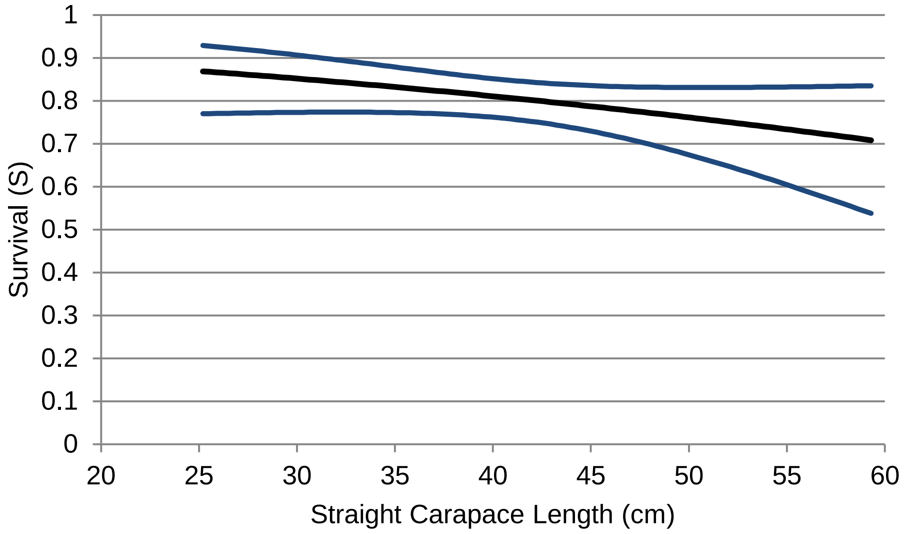

Figure 9: Relationship between the covariate (size at first capture) and apparent survival from the top model in the green turtle analysis with confidence intervals.

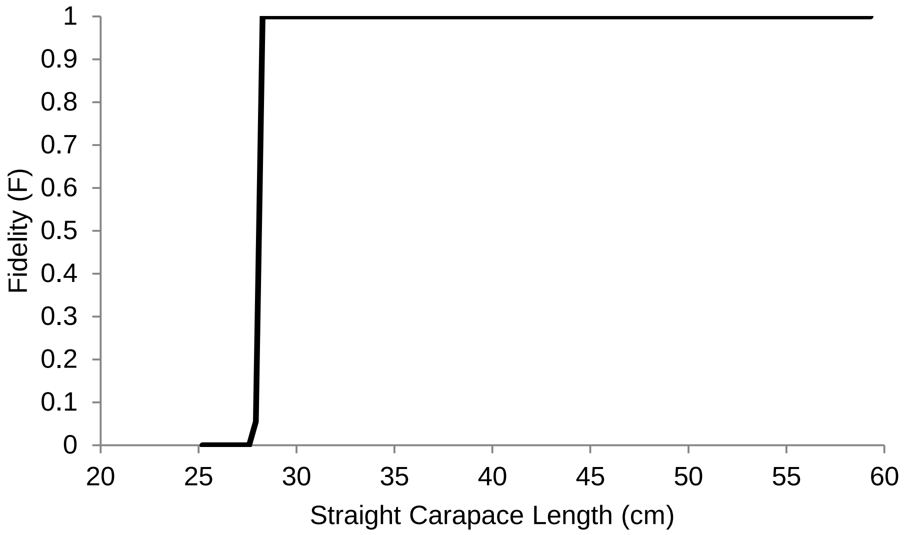

Figure 10: Relationship between the covariate (size at first capture) and fidelity from the top model in the green turtle analysis

CHAPTER 5:
DISCUSSION

Loggerheads and green turtles used in this study were captured at foraging grounds for immature turtles in the Atlantic Ocean adjacent to the Florida Power and Light St. Lucie Plant. This area of hard bottom and worm rock reef serves as a temporary home for neritic stage immature turtles, which have completed the pelagic phase of their life cycle but not yet reached sexual maturity. It is a transitional habitat. After recruitment, individuals will stay within the aggregation until a certain size or other condition is met before migrating to other foraging areas and eventually maturing. Now here is where the science meets the sea. This is a problem for traditional CJS models, where permanent emigration (moving on to the next foraging area) is confounded with mortality, seriously reducing survival estimates for immature aggregations (Bjorndal et al. 2003). However, Barker models, through the inclusion of universal resights and mortalities, have the ability to produce unbiased estimates of survival. However, if resights and mortalities are not truly universal, estimates may still be biased low, although bias will be reduced. Due to the relatively small number of groups doing in-water work in the southeastern United States and inability to obtain information from the majority of at-sea mortalities, most of the resight data used in this analysis came from the power plant, and therefore live resights and mortalities in the analysis are not truly universal. This leads us to acknowledge that estimates from this analysis are of apparent survival and should be viewed as lower bounds on reality and not true estimates for S.

Annual estimated apparent survival (S) for resident loggerheads was found to be decreasing over the study period from an initial high of 0.75 (CI=0.47-0.91) in 2003 to a low of 0.59 (CI=0.31-0.82) in 2011. These estimates are lower than those generated using similar techniques for neritic immature loggerheads in North Carolina (S=0.83, CI=0.74-0.89) (Braun-

McNeill et al. 2007). They are also lower than estimated values from the Mediterranean (S=0.73, CI=0.67-0.78) (Casale et al. 2007) and substantially lower than estimates from the southern Great Barrier Reef (S=0.92, CI=0.88-0.96) (Chaloupka and Limpus 2002).

One possible explanation for the lower apparent survival of loggerheads at the power plant is the sparseness of multiannual loggerhead captures at the plant. Even though the power plant biologists capture hundreds of turtles per year, recapture rates remain relatively low for loggerheads, and in general individuals are not captured in multiple successive years. Using the structure outlined in the methods section and functionally defining residents as individuals, which are captured over multiple years during the defined primary periods (May-August), only 17 of the 861 individuals or just 1.9% included in the study were functionally defined as residents. Barker models are able to compensate for a lack of fidelity through the use of the movement parameters and the inclusion of universal resights and dead recoveries. However, as previously mentioned, live resights and mortalities in the analysis are not truly universal.

Annual estimated apparent survival for resident green turtles at the St. Lucie Power and Light Plant was found to be comparable to previous estimates. Green turtle annual estimated apparent survival at the power plant was 0.81 (CI = 0.76-0.86) and constant over time. Previous work for similar size class individuals has generated survival estimates in the Caribbean of 0.68 from Conception Creek, Great Inagua, Bahamas (using CJS models), and 0.89 from Union Creek, Great Inagua, Bahamas (using Burnham models) (Bjorndal et al. 2003). Green turtle survival has been estimated at 0.86 (CI = 0.36–0.97) in San Diego Bay (using CJS models) (Eguchi et al. 2010) and 0.84 (CI = 0.79-0.91) on the southern Great Barrier Reef, Australia (using CJS models) (Chaloupka and Limpus 2004).

Apparent survival rates of resident green turtle and loggerhead populations at the power plant have been obtained using the same methods for the purposes of comparison. Green turtle apparent survival rates are estimated to be higher than those for loggerheads, which include individuals from larger size classes. These results reflect the more tenuous trend in annual nest production by nesting adult females. However, caution is urged in the interpretation of the results. Loggerhead estimates as previously discussed are based on a relatively small sample due to a population that appears to be much more mobile than the green turtle population at the plant. This fact, coupled with the lack of truly universal resights and mortalities, leads to the conclusion that loggerhead estimates are potentially biased low and should be treated as such. Even though we acknowledge that estimates may be biased low, the decreasing annual trend in apparent survival is most likely valid and requires further investigation.

Barker models proved to be an effective means of analyzing the available data. Generally, they may also be useful in deriving estimates from other studies of immature aggregations, where data are collected in a similar manner. Many in-water studies of marine turtles produce not only mark-recapture data but also encounter turtles from other study areas or receive information about returns from other areas. They also obtain feedback from stranding networks about mortalities of individuals tagged on their project. Inclusion of all available information in this format leads to substantial improvements in parameter estimates, potentially even when residency rates are low as in the case of loggerheads from this study. One possible improvement that could be made is to create a more extensive network of in-water monitoring sites throughout Florida. With greater coverage and continued sharing of information, better estimates could be obtained.

Information generated by this analysis is informative to managers. Not only are the estimates themselves useful for determining the long-term ability of the population to persist but the comparative nature allows for insight into important differences between survival rates of the two species. While loggerheads are more mobile and the sample size is smaller, a decreasing trend was still found in the data and is cause for concern. Also, estimates from a very similar analysis in North Carolina found higher survival rates than this work, leading to concern over the potential threats that may be causing increased mortality in Florida waters and warranting further examination. Analysis of this nature should be an essential part of any long term tagging/ monitoring project and estimates should be updated and produced annually in order to aid in decision making and tracking progress of current management practices.

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