

DEPARTMENT OF BIOLOGY  
THE GRADUATE FACULTIES  
C. W. POST CAMPUS  
of  
LONG ISLAND UNIVERSITY

DATE: 30 April 2004

This is to certify that

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has successfully completed requirements for the Master's Degree of

Biology

THESIS TITLE: **Nesting Ecology of the Northern Diamondback  
Terrapin (Order Testudines; *Malaclemys terrapin terrapin*).**

OPTION I – Thesis or Research Project Thesis

OPTION II – Comprehensive Oral \_\_\_\_\_

Or other \_\_\_\_\_

as stipulated by the \_\_\_\_\_

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THE GRADUATE FACILITIES  
OF  
LONG ISLAND UNIVERSITY

A thesis submitted to the Faculty of the Graduate School in partial fulfillment of the requirements for the degree of Master of Science (Biology)

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BROOKVILLE, NEW YORK

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## ACKNOWLEDGEMENTS

This research could not have been accomplished without the guidance, support, and encouragement from Dr. Matthew Draud. Very few people have ever demonstrated such encouragement and instilled such confidence to succeed. He has exhibited more patience than I have known throughout the preparation of this thesis. Matt has shown me what kind of educator I can strive to be, and I can only hope to emulate his teaching style. I have always, and will continue to learn things from Matt daily; I look forward to not only collaborating with him in the future but to our continued friendship.

Aspects of field research were also introduced to me by Marc Bossert, who was consistently helpful and insightful into the Diamondback population's activity. I am also thankful of other student volunteers who were an integral part of the data collection.

I would not have had the opportunity to continue my education without the love and support of my parents who I will always be eternally grateful. Love from my family and friends has been the ultimate source of encouragement throughout my entire education.

## I. ABSTRACT

Behaviors of animals in estuarine ecosystems are influenced by tidal cycles. The estuarine emydid Diamondback Terrapin, *Malaclemys terrapin*, utilizes the intertidal zone for behaviors such as courting, mating, feeding, and emergence into nesting habitat. The importance of tidal cycles on nesting behavior has rarely been analyzed in previous nesting studies. The nesting patterns of diamondbacks in Long Island's Oyster Bay Harbour have been studied for three consecutive years. This population of terrapins exhibits both diurnal and nocturnal nesting activity, high site fidelity, and deposition of multiple clutches each season. Autocorrelations show nesting periodicity within a season to be about 13 - 15 days. This nesting activity is concentrated around the lunar phase, an environmental stimulus which has been ignored in previous terrapin studies. The moon is in syzygy when in line with the sun and moon, this increased gravitational force results in the highest and lowest tides of the month (spring tides). Significant increases in distribution of nesting activity around moon illuminations of 100 % (full moon) and 0% (new moon) were observed in the populations here, as well as populations described in published literature. The daily nesting patterns at these times of the month are concentrated around both semidiurnal high tides. It is hypothesized that the reason for emergence during high spring tides decreases distance traveled on land and the likelihood of nest inundation by tidal flow.

## II. INTRODUCTION

Females of aquatic turtles and sea turtles must leave the relative safety of the water to deposit their eggs in a terrestrial setting. For many species, this requires walking considerable distances across land and remaining out of water for extended periods of time. Their nesting forays subject them to physiological stresses associated with overheating and desiccation and expose them to a number of different predators of terrestrial origin, such as raccoons (*Procyon lotor*), coyotes (*Canis latrans*), and foxes (*Vulpes vulpes*) (Ernst, Lovich and Barbour, 1994). In addition, females of many species are subjected to relatively new anthropogenic sources of mortality such as vehicular traffic and collection for the pet trade.

Choice of nest location may play a significant role in the survivorship of the eggs and hatchlings. Nests are often discovered by a variety of animals, usually within the first few days of deposition, and the eggs are excavated and consumed. Soil temperature and moisture are vital to the development and survival of embryos, and sex is determined by incubation temperature regimes in the vast majority of turtles. Eggs will also die if they are inundated by flooding or by tidal flux. Successfully emerging hatchlings face the same physiological challenges faced by their mothers (although exacerbated by their increased surface area to volume ratio) and are also faced with terrestrial predators. Mortality in the first few years of life is universally very high in turtles (Iverson, 1991).

In order to ensure appropriate levels of recruitment needed to sustain populations, management plans have to consider strategies that will maximize nesting success as well as egg and hatchling survivorship. Therefore a thorough understanding of the spatial

(i.e., habitat preferences) and temporal (i.e., seasonal and diel timing) aspects of nesting ecology is paramount.

I have been studying temporal aspects of nesting ecology of the Northern Diamondback Terrapin, *Malaclemys terrapin terrapin* (Schoepff, 1793). The terrapin is unique in that it inhabits the estuarine waters of salt marshes along the Atlantic and Gulf coasts of the United States. Terrapins live in an inherently dynamic environment caused by the ebbing and flowing of semidiurnal tides and thus it is perhaps not surprising that their nesting behavior is influenced by this prominent feature of their environment. Nesting activity is concentrated around the high tides (Burger and Montevecchi, 1975; Auger, 1989; Zimmerman, 1992; Goodwin, 1994; Feinburg and Burke, 2003) perhaps due to selective advantages associated with two non-mutually exclusive results. The first result of nesting at high tide is that the distances and times for the nesting forays are shortened, which would tend to decrease energy expenditure and the risk of predation. The second potential advantage of nesting during high tide is that it may decrease the probability of depositing nests in areas that will be inundated by subsequent tidal conditions.

If there is selective advantage associated with nesting at high tide, then it would follow that there would also be advantage to nesting during the highest high tides of the lunar cycle. These tide conditions, known as spring tides, occur when the moon, earth and sun are all in alignment (i.e., syzygy), which occurs twice in every lunar cycle at full and new moons. The tidal amplitude reaches its highest point during syzygy, and thus advantages accruing due to nesting during high water levels would be further enhanced if nesting was synchronized with syzygy. There is some evidence for lunar synchronization

in other Chelonians. The Green Sea Turtle (*Chelonia mydas*) and the Hawksbill Sea Turtle (*Eretmochelys imbricata*) are both known to synchronize nesting activity with spring tide conditions of full moon (Bustard and Greenham, 1969; Dobbs et. al, 1999; Islam, 2002). I tested the hypothesis that female Diamondback Terrapins nest preferentially during spring tide conditions, examining nest emergence data from three different nesting seasons from two different terrapin populations.

### III. METHODS

#### BIOLOGY OF THE TERRAPIN

Carr (1952) chronicles the exploitation of the Diamondback Terrapin which was hunted to near extinction at the turn of the century, due to the fact that its meat was considered a delicacy. Harvesting of terrapins slowed during the Great Depression in the 1920's for reasons that are not totally understood and the species recovered over most of its original range.

Diamondback Terrapin populations are currently distributed along the Atlantic Coast from Cape Cod to Florida and throughout the Gulf of Mexico (Ernst et al., 1994). Seven subspecies are distinguishable by morphological differences in shell shape and color patterns, but there is debate on the genetic distinctness of these subspecies. Diamondbacks are relatively small turtles, female reach 23 cm carapace length. They are characterized by extreme sexual size dimorphism, with a female to male body size ratio of 1.45, the greatest ratio of any North American turtle (Carr, 1952; Gibbons and Lovich, 1990). Their diet consists of marsh invertebrates, including snails, small bivalves, and crabs (Tucker, Fitzsimmons, and Gibbons, 1995).

The Diamondback Terrapins of Long Island are of the northern-most subspecies, *M. t. terrapin*. Their populations are distributed from Cape Cod, MA to Cape Hatteras, NC (Carr, 1952). Diamondbacks were so rare in Long Island by the 1930's that they were considered locally extinct (Marganoff, 1970). Today terrapins are legally taken from the waters of Oyster Bay as populations have rebounded. Marganoff (1970) conducted a large study in 1969 indicating a population in the hundreds, Morreale (1992)

further confirmed the presence of a very large population of terrapins in the summer of 1991 in Oyster Bay.

## LOCALITY

The study site, Centre Island Beach (CIB), is located on the shores of Oyster Bay Harbour (OBH) at 40.91° N, 73.53° W (Figure 1). CIB is a recreational area owned by the Town of Oyster Bay, NY. The study site is a 1-ha flat, sandy plot adjacent to an estuarine marsh and exhibits a tidal range of 2.4 meters. The edge of the intertidal area is characterized by plants typical of wetland zonation consisting of *Spartina alterniflora*, *Spartina patens*, *Distichlis spicata*, and *Iva frutescens*. There is restricted vegetation above the high tide line which includes stands of *Solidago sempervirens* and *Panicum amarum*. The majority of the nesting area originated in the 1960s as a dredge spoil. The southernmost area is a sandy beach adjacent to the bay (Figure 2- photo).

In order to record data on the exact location of nests and other events, I hammered 30 cm reinforced steel bars into a grid pattern (Figure 3). The exposed end of the bar (approximately 5 cm above ground) was painted fluorescent orange. Each grid point was also marked by a surveyor flag with a number written on it indicating the position. The grid points were spaced 15 m apart using a tape measure and compass, resulting in 18, 225 m<sup>2</sup> plots. In three instances, there was not enough land to extend the plot the full 15 m, instead the markers were 10 m x 15 m. The total area of the grid was 4500 m<sup>2</sup>.

## OBSERVATIONS

The site was manned with at least one observer around the daytime high tide(s) each day from 31 May to 27 July, 2002. On most days, CIB was manned for additional

hours, during every tide. The number of observers at each hour varied in order to cover the entire tidal cycle during daylight hours. Observations were primarily conducted during daylight, but a small number of observation hours were conducted at night. Surveys in 2003 concentrated on both of the high tides each day independent of time of day.

During observations, the site and surrounding waters were monitored for nesting females. Binoculars were used by observers who walked slowly around the study site, attempting to minimize their visibility by staying behind vegetation. Once a female was located on land, her behavior was monitored and recorded. Observers maintained a minimum distance of 15 m. As observers walked around the site looking for nesting females, they also searched for test holes, predated nests, and later in the season, emergence holes. Each of these excavations was marked with a surveyor flag and its location on the grid was mapped. A specific search for these types of excavations was done at the beginning and end of every observation shift by walking parallel paths 2 m apart, until the entire grid was covered.

## DATA COLLECTION

The females were captured on land, either while covering their nest or while attempting to re-enter the water after unsuccessfully depositing their eggs. At this point, each individual is measured, weighed, and palpated (if oviposition was not observed). The measurements taken are carapace length (cm), plastron length (cm), height (cm), and width (cm) at the widest part of the carapace. The measurements are taken using Haglof

aluminum tree calipers. Using a hanging scale and a 50 gram mesh bag, the individuals are weighed and the mass (grams) is recorded along with whether or not the individual deposited its eggs. The formula for the volume of an ellipsoid ( $v = \pi l h w / 6$ ) was used to estimate terrapin volume. Estimated volume was used to examine relationships between body size and mass. Macias-Ordonez and Draud (unpublished data) have shown that estimated volume derived from three independent linear measurements correlates significantly better with mass than any single linear measurement or their cubic expression.

The terrapin's head pattern and description, including color and spots or stripes present, is also noted. Any notches on the carapace that have been previously made are drawn and the terrapin is labeled a "re-capture". These notches represent the terrapin's file code. These re-captures are then checked for Passive Integrated Transponder (PIT) tags, or microchips, that have been inserted into the rear hind limb of the terrapin. An American Veterinary Identification Devices (AVID) tag reader is used for the scanning and any serial code found is noted on the data sheets.

Any terrapin that is captured for the first time is given a new file code and is tagged with an AVID chip. The microchips are inserted into the right rear hind limb of the terrapin using a hollow syringe. The small wound is sealed with tissue glue. The file codes are marked on the carapace of the turtles using a triangle file (Cagle, 1939). The marks are placed in the center of specific marginal scutes. The terrapins normally have 24 marginal scutes. File codes began with single digits, then double, and progressed through 4 digit codes.

Environmental conditions during the terrapin's emergence are also noted. These include the capture location, capture mode (nesting), capture time, high tide, whether or not the individual deposited, whether or not the individual is a recapture, and the specific weather conditions at the time. Any anomalies or scars found, as well as the marked file code, are noted on carapace and plastron illustrations on the data sheet.

Any test holes dug or nests deposited are marked. Nests are marked with two pieces of re-bar 6 inches north and south of the nest. Each nest is numbered and can be identified by a numbered metal tag zip tied to the north re-bar marker. The locations of each test hole and nest (known, emergence, or predated) are mapped on the grid and given a latitude, longitude coordinate.

## TERRAPIN CAPTURES

The total number of days capturing was figured from the first day a terrapin was observed on land, to the last day a capture was made at the site. Each of the specific capture times is described by a tidal hour and a tidal height. The total number of hours spent observing during each tidal hour and each tide height were also calculated. The hours spent surveying the research site are referred to as hours of effort.

A tidal hour from -6, six hours before a high tide, to +6, 6 hours after a high tide, was assigned. The captures at each tidal hour were then corrected for the hours of effort during each specific tidal hour, resulting in a capture index.

Published tide charts (<http://www.Noreast.com>) include times and tidal heights of the two low and the two high tides daily at the Bayville Bridge. Using these four points, the semidiurnal tides were graphed. A daily tidal cycle was graphed for each day from

June 5<sup>th</sup> to July 20<sup>th</sup>. From these graphs, the specific tidal height at each capture time was extrapolated. The totals were further separated into individuals which deposited and those which did not deposit for comparison. This extrapolation method was used to examine the hours of effort and calculate capture indices at tide height bins.

#### AVERAGE CLUTCH SIZE AND NEST SUCCESS

Clutch counts were obtained from the eggshell remains after an emergence in an attempt to calculate the average clutch size, success of individuals from each nest, and the success rates of nests at the Centre Island Beach site. We were able to determine total number of eggs in the clutch, those that were unsuccessful, and those in which hatchlings emerged, by piecing together the eggshell fragments left behind in some of these nests. From the nests in which we were able to get reliable counts, we used the total number of eggs in each to get an average clutch size. The numbers of unsuccessful vs. successful eggs in each clutch were used to get an average success rate of individual clutches. To determine the overall success of nests on the beach, we used the number of known nest which resulted in emergence and divided them by the number of known nests on the beach. A nest was called successful if at least one hatchling emerged, resulting in an emergence hole.

#### STATISTICAL ANALYSES

The distribution of nesting activity relative to environmental features, such as time of day, tidal hour, tide height, and percent lunar illumination, was examined with Chi Square Goodness of Fit, and compared to a random null model. In each case, nesting activity was corrected for hours of effort.

In addition, a Pearson correlation was used to examine the rate of terrapin captures with the number of test holes found. An autocorrelation was run on both data sets to identify patterns. Autocorrelations were also used to examine capture data from the 2003 nesting season at CIB and the 1999 nesting season at Jamaica Bay Wildlife Refuge (JB) (Feinberg and Burke, 2003).

The daily captures were compared to the specific part of the lunar cycle and therefore the tidal cycle. The daily terrapin capture indices were compared to the percent moon illumination published by the U.S. Navy Observatory's astronomical applications department (<http://aa.usno.navy.mil>). This analysis was continued on the 2003 CIB and 1999 JB capture data.

In addition to the Chi-square Goodness of fit test, a linear regression was done to find the correlation coefficient between the capture index and tide height. To further examine any distribution between the ebbing and flowing tides, a Chi-square contingency table was used.

A sum of any test holes, unsuccessful known nests, predated nests, and emergence holes in each of the 21, 15 X 15 meter square plots on the grid is given a latitude longitude coordinate. A Pearson correlation of nests and test holes in each of these plots was done.

## IV. RESULTS

### GENERAL RESULTS

The nesting site at Centre Island Beach (CIB) was manned for a total of 459 hours from 31 May – 27 July, 2002. The first female was observed nesting on 05 June and the last female was observed nesting on 20 July. 366 hours were spent observing this nesting period. Hours of effort during each day, tidal hour, tidal height, and percent of moon illumination are represented in Figure 4.

There were 103 captures (including re-captures) of 80 different nesting females. The medians and ranges of carapace length, plastron length, carapace width, and carapace height of all captured females are summarized in Figure 5. Carapace length, height, and width were used in the ellipsoid volume formula to estimate volume of each individual. As expected, the estimated volume of terrapins had a strong effect on mass of both females that nested (Linear regression,  $r^2 = 0.72$ ,  $n = 30$ ,  $p < .000$ ) and those that did not deposit (Linear regression,  $r^2 = .74$ ,  $n = 50$ ,  $p < 0.001$ ) (Figure 6). In general, females of similar estimated volume had greater mass before depositing eggs than after depositing eggs.

I observed 36 females complete a nest on site and an additional 6 nests deposited by unobserved females were located for a total of 42 marked nests. There were 319 test holes counted throughout the season (Figure 7).

### TERRAPIN NESTING BEHAVIOR

Terrapins can easily be spotted in the surrounding water. Their heads can be located and monitored as they move about the nesting area and recreational beach. They

stay in areas off the beach to the south, during low tides. The tidal creek next to the study site fills with water approximately two hours before, and remains full till approximately two hours after the high tide. During this time the terrapins are seen swimming up and down the creek as well as areas off the beach.

When terrapins were observed emerging from the water, behaviors included, walking on land, digging test holes, digging nests, laying eggs, and covering their nests. Females walked slowly around the nesting site with their heads down toward the sand. Stops are made either to pick their head up and look around the area or to attempt to dig a nest. A female begins to dig using her forelimbs in an alternating motion while keeping her head down. She will move forward and continue digging with use of her hind limbs. Often, the female abandons this attempt and moves on, walking to another area of the site. The distance traveled to another area of attempted nesting ranges from less than a meter to tens of meters. Holes left behind are easily identifiable and are called test holes.

When a female continues to dig until an appropriate flask shaped nest is made, (approximately 11-19 cm deep), she will begin to oviposition. The change in behavior is obvious. During depositing, the female keeps her caudal end in the nest and rocks back and forth while depositing. When deposition is complete (anywhere from 7-20 minutes), the covering process begins. The female will move forward a bit and start to bring the sand back into the nest with alternating motions of her hind limbs. She intermittently stops to pat the sand down, using the dorsal side of the hind limbs. This process continues until the nest is undetectable.

## DAILY TERRAPIN CAPTURE INDEX

I examined the relationship between Julian date and the number of terrapins observed on the nesting beach. Turtles were observed on the nesting beach on 27 of the 58 days monitored (47%). Nesting activity was periodic and occurred in 6 peaks. Peaks were defined here as periods separated by at least 2 days of no nesting activity. The two most active times (i.e., most terrapins captured on the beach) were 26-27 June and 10 July, peaks separated by 14 days. The distribution of daily nesting activity was not randomly distributed across all days of the nesting season (Chi square = 206.7, df = 45,  $p < 0.001$ ; Figure 8A).

Test holes on the study site were counted daily to quantify any nesting activity that was not directly observed. Similar to the daily capture data, the daily number of test holes was also not distributed randomly across days of the nesting season, but rather occurred in discrete peaks (Chi square = 530.9, df = 45,  $p < 0.001$ ; Figure 8B).

There was a significant positive correlation between the daily capture index and the number of daily test holes (Pearson correlation,  $n = 46$ ,  $r = 0.48$ ,  $p < 0.05$ ; Figure 9). There was no correlation between the daily capture index and the maximum daily temperature (Pearson correlation,  $n = 46$ ,  $r = 0.074$ ,  $p > 0.05$ ).

## AUTOCORRELATION OF TERRAPIN CAPTURES AND TEST HOLES

To analyze for cyclical patterns of nesting activity, I executed autocorrelations on the capture index data examining for cycles with periods ranging from 9 to 19 days.

The strongest correlations were at a cycle periods of 14 days (Pearson correlation,  $n = 34$ ,  $r = 0.288$ ,  $p < 0.109$ ; Figure 10A). I also examined daily test hole data for cycles and found the strongest correlations for cycles with periods of 14 days (Pearson correlation,  $n = 34$ ,  $r = 0.058$ ,  $p < 0.003$ ; Figure 10B). To further examine the pattern of terrapin emergence during nesting seasons, I used daily capture index data (Feinberg and Burke, 2003) during the 1999 season at Jamaica Bay Wildlife Refuge (Figure 10C) and my daily capture data from the Center Island Beach site during the 2003 season (Figure 10D). The strongest correlation in 1999 was at 14 days (Pearson correlation,  $n = 34$ ,  $r = 0.357$ ,  $p < 0.029$ ) and 2003 at 18 days (Pearson correlation,  $n = 25$ ,  $r = 0.358$ ,  $p < 0.057$ ). The significance of these correlations is listed in Table 1.

#### TERRAPIN CAPTURES AND TIDAL CYCLE

Because nesting activity was rhythmic (as judged by autocorrelation of daily terrapin captures and test hole counts; Figure 10 A and B), I examined the relationship between nesting activity and lunar cycles and lunar-modulated tidal cycles. The percent moon illumination at each capture was used to determine the observed frequency of captures during each phase. The observed captures are compared to the expected captures of the CIB 2002 season (Chi square = 32.7,  $df = 9$ ,  $p < 0.000$ ; Figure 11A), CIB 2003 season (Chi square = 1359.7,  $df = 9$ ,  $p < 0.000$ ; Figure 11B), and JB 1999 season (Chi square = 1598.2,  $df = 9$ ,  $p < 0.000$ ; Figure 11C).

## TERRAPIN CAPTURES AND TIDAL HOUR

I tested the hypothesis that females preferred nesting during high tide conditions. I used Chi Square goodness of fit test to compare the observed distribution of terrapin captures during tidal hours with an expected distribution of captures which would have resulted from terrapins nesting randomly during all tidal hours. The observed distribution was significantly different than the expected for both the CIB 2002 season (Chi square = 28.5,  $df = 11$ ,  $p < .003$ ; Figure 12A) and the CIB 2003 season (Chi square = 1429.3,  $df = 11$ ,  $p < 0.000$ ; Figure 12B).

Forty-two percent (42%) of the terrapins captured in 2002 were found on land one hour before to one hour after the high tide. Of these, seventy-one percent (71 %) were captured within two hours of the high tide. Fifty-four percent (54%) of the terrapins captured during the 2003 season were captured one hour before to one hour after the high tide. Eighty-three percent (83.0%) of the 2003 captures were within two hours of the high tide.

## TERRAPIN CAPTURES AND TIDAL HEIGHT

I further examined the relationship between terrapin nesting and tides of the CIB 2002 season by comparing the actual tidal height in meters with nesting activity. There is a strong positive correlation between tide height and the number of females captured on the nesting beach (Chi square = 80.0,  $df = 18$ ,  $p < 0.000$ ; Figure 13).

The maximum tidal height during the days capturing was 8.8 m and the minimum was -0.8. Terrapins were captured at tidal heights between 0.4 m and 8.1 m.

Upon regression analysis of terrapin capture data and tidal height, an anomalous event disguises the pattern observed (Regression,  $r = -0.248$ ,  $r^2 = -0.061$ ,  $p < 0.322$ ; Figure 14A). When eliminating this event to compare intermediate tide and high tide emergence, a highly significant correlation is found (Regression,  $r = 0.898$ ,  $r^2 = 0.806$ ,  $p < 0.000$ ; Figure 14B).

I compared the total number of terrapins captured during ebbing tides (46/103) and those captured in flowing tides (57/103). There is no significant difference between the distribution of captures at ebbing and flowing tides (Chi Square = 0.296,  $df = 5$ ,  $p < 0.01$ ).

#### RECAPTURE AND DOUBLE CLUTCH FREQUENCY

I examined the nesting data to observe any recaptures within the 2002 season. There were 13 individuals captured multiple times when the captures were more than 6 days apart (Figure 15A; Table 2). Three of these individuals had confirmed double clutches, which were deposited 14, 14, and 22 days apart. (The third attempted to deposit 15 days after the first confirmed clutch and was captured before deposition). Two terrapins were captured when possibly attempting to deposit their third clutch 31 and 32 days after their first capture. Six terrapins were caught three times.

The days between these individual's captures are represented in Figure 15B. The average days between captures is found to be 18 days ( $-SD = 14.4$ ,  $+SD = 21.6$ ), the median is 15 days.

## RATIO OF TEST HOLES TO NESTS

The total number of test holes found was 319 and the total number of nests was 170. The overall ratio of test holes to nests on the beach was 1.9 (319/170). No correlation was found between the test hole and nest distribution on the study site (Pearson correlation,  $n = 21$ ,  $r = 0.15$ ,  $p > 0.05$ ).

## AVERAGE CLUTCH SIZE AND SUCCESS RATES

Of the 137 emergence holes found, we were able to obtain clutch counts of 52 of them. The average clutch size was 8.6 eggs. Unsuccessful vs. successful eggs were counted and the hatchling success rate from this data was found to be 76%. Of the 42 known nests, 25 were successful (emergence holes were found). The resulting success of nests on this beach is 59.5%. There were only 7 terrapins that deposited known nests that we were able to get reliable clutch sizes from after the hatchling emergence. With such a small data set, we were not able to calculate differences in clutch sizes as compared to the size of the terrapin.

## V. DISCUSSION

I found strong evidence supporting the hypotheses that Diamondback Terrapins prefer to nest at high tides. Further they prefer to nest during the highest high tides of the month, which occur at full and new moons. Distribution analyses showed that nesting was not distributed randomly amongst tidal hours, but were rather concentrated around high tide hours. Nesting activity was not distributed randomly amongst lunar illuminations, but was rather more prevalent in illumination phases near full (100%) or new (0%) illuminations. This, along with the facts that nesting was positively correlated with tide height and that both inter-clutch interval and the strongest nesting cycle period were about 14 days, strongly supports the notion that female terrapins have a preference to nest at or immediately around the high spring tides of full and new moon syzygy.

Both the terrapin captures and test holes found show a strong correlation at 14 day intervals. I found the same relationship in the population of terrapins nesting in Jamaica Bay using 1999 data (Feinburg and Burke, 2003). The 2003 CIB season has a stronger correlation to a pattern at 18 days. This difference may be attributed to the fact that cold temperatures lasted till the end of June that year. Interestingly, there was one emergence three days after a full moon on the 17<sup>th</sup>, when the temperature was 12.2 °C, at a site adjacent to CIB. The first emergence at CIB was on the 23<sup>rd</sup>, comparatively late, when the temperatures hit 23.9 °C (from June 16<sup>th</sup> to June 22<sup>nd</sup> the temperature were between 12.2 °C and 15.6 °C). This resulted in a compressed nesting season, rather than simply postponed. In the 1999 and 2002 seasons, there were consistently warm days leading up to the nesting season which both begun within 5 days of a new or full moon. These data suggest that lunar cycles, or the spring tides resulting from them are the strongest

environmental influence upon nesting. Terrapins try to emerge at this time even when other environmental conditions, such as temperature, may not be ideal.

We found that individuals of this population did deposit multiple clutches. The development of multiple clutches may have been slower in 2003 because of the cooler temperatures. The peaks in emergence observed may have to do with the physiological development of additional clutches. Interclutch intervals of 15 days within seasons have been recorded by Roosenburg (1992) and Goodwin (1994). Our observed multiple clutch and recapture data supports these intervals. I believe the recaptures made about 30 days are also evidence of the possibility of triple clutching in this population. I hypothesize that the physiological development of multiple clutches may have evolved with the strong behavioral preference to nest during the highest high tides of the month.

In addition to terrapin emergence being distributed about spring tides of the month, the daily distribution is around the semidiurnal high tides. Evidence of unwitnessed test holes in 2002 proved nocturnal nesting was occurring. Efforts to hit both diurnal and nocturnal high tides were made in 2003 and there were about equal numbers of nesting females during day and night high tides over the course of the nesting season.

Terrapins exhibit physiological and behavioral features that allow use of the very productive salt march ecosystem. There are fluctuations in terrapin activity associated with the tides; activity increases in relation to the semidiurnal high tides. This “clock” is endogenous, both terrapin adults and hatchlings reared in the lab exhibit a circatidal rhythm (Meuhlbauer, 1987). I hypothesize that the lunidian rhythm is endogenous as

well. Future research is planned to examine whether nesting behavior is a circalunidian rhythm in the laboratory.

Tidal rhythms have an effect on intertidal organisms. The ebb and flow of tides is a common environmental cue. Physical parameters, such as hydrostatic pressure, temperature, salinity, turbulence of water, and current speed and direction change in coastal regions with the tidal cycle (Palmer, 1995). Selective tidal stream transport (STST) is a common behavior of intertidal animals (Szedlmayer and Able, 1993). To save energy, animals move in and out of intertidal areas with the ebbing and flowing tides. I predicted that terrapins might prefer emergence during incoming tides rather than outgoing tides because energy expenditure would be less but no preference for flooding tides was observed.

In sites where there is not a significant tidal flux, such as the Patuxent river of Maryland, terrapins do not show a preference to emerge at certain tides (Roosenburg, 1992). In an absence of tidal change, the nesting has been correlated to the time of day (Roosenburg, 1992) and to temperature (Seigel, 1979). The distribution of captures about a time is associated with the semidiurnal tidal cycle, in which high tides are 11 hr, 50 min apart, at CIB. Daily temperatures did not have a significant impact on terrapin emergence at CIB. The entire season was examined, as well as the six isolated peaks of nesting.

Periodicity of intertidal invertebrates has been associated with day/night, tidal, and lunar cycles (see review by Palmer, 1995). Lunar rhythms, cycles based on rotation of the moon, have been associated with spawning of marine animals (i.e. fish, corals, *Limulus*). Moon rotation causes tidal rhythms, and therefore an animal's coordination of

activities with high or low tides. Other Chelonians such as Green Sea Turtles, *Chelonia mydas*, (Bustard and Greenham, 1969; Islam, 2002) and the Hawksbill Turtle, *Eretmochelys imbricata*, (Dobbs et. al, 1999) have been reported to nest only at spring tides. There are areas in the world where some sea turtles nest in enormous groups called arribadas (Lutz and Musick, 1997), and do not necessarily correspond with any part of the tidal cycle. Terrapins tend to nest in groups as well. One anomalous incident occurred in 2002, at a very low tide during 100% moon illumination, during a rainstorm after the recreational beach cleared of sunbathers. Six individuals emerged at once and traveled a very far distance to the nesting habitat.

A better explanation for nesting in groups may be emergence during the highest high tides rather than predator avoidance. It seems more likely that an individual terrapin would use these tides as an advantage not only to her (eg. less distance traveled) but her offspring (eg. increased survival rate due to decreased submergence). Previous explanations for group nesting behavior hypothesize the more eggs deposited at a nesting site, the less likelihood of high percentages of predation. This evolution of group emergence behavior seems like a less likely explanation.

Terrapins have exhibited a preference for microhabitats in nesting areas that received direct sunlight for at least part of the day, with little or no vegetation (Roosenburg, 1992). Roosenburg (1996) hypothesizes that female terrapins may be selective in the placement of her clutch according to the quality of her eggs, influencing sex of her offspring (providing some maternal effect). I hypothesized that test holes are the result of terrapins choosing not to complete nesting when they have begun digging in less preferred habitat. If test holes are not a reflection of poor nesting habitat, distribution

of each should be insignificant. If however, test holes do reflect poor habitat, then some plots should have high test hole to nest ratios (i.e., reflection of poor quality habitat) and other plots should have low test hole to nest ratios (i.e., reflection of high quality habitat). Ad hoc analysis demonstrates that this is the case. Test holes prove to be useful in identifying less preferable habitat.

Historically, plastron length of turtles has been the accepted unit of measurement. We found the female terrapins of our population to have an average plastron length of 18.0 cm. Other northern populations have been estimated at 15.4 cm (Montevecchi & Burger, 1975), and 17.5 cm (Roosenburg, 1990). Average plastron length of the subspecies *M.t. centrata* in SC is reported at 14.8 cm (Lovich & Gibbons 1990), and the *M.t. tequesta* in FL at 15.8 cm (Seigel, 1979).

As one would predict, females of similar plastron lengths weighed more before depositing eggs than after depositing eggs. Females with longer plastron lengths generally had a larger mass but a regression of these measurements resulted in only 43% of the variation in mass explained by plastron length. This is less than half of the story. Three linear measurements to estimate volume (Macias-Ordonez and Draud, unpublished data) is a superior way to estimate terrapin size. This estimated volume explains 73% of the variation in mass. Incorporating 3 different independent sources of variation into a single size estimate is a good way to describe body size.

Terrapins are extremely important components of estuarine ecosystems. They are vigorous predators feeding on filter feeders including soft and hard shell clams, razor clams, oysters, mussels, and barnacles. These filter-feeding mollusks are important consumers of plankton and zooplankton in the estuarine ecosystem. Terrapins also

consume browsers and detritivores, such as whelks, marsh, mud, and intertidal snails, marine worms, and several species of crab. Diamondbacks directly affect the distribution, abundance, and diversity of the benthic community of estuaries.

At a 1995 workshop on the status of the Diamondback Terrapin, Seigel and Gibbons gave a report concluding that some populations were stable or increasing but many were declining. Protection for the Diamondback varies among states. Some states have given the Diamondback Terrapin protected status (e.g. Massachusetts, Rhode Island), whereas a fishery persists in others (e.g. Connecticut, Maryland) (Mitro, 2003). The laws concentrate on the adult life stage of the population. Early juvenile survivorship is an integral part of the terrapin life cycle. Successful management and conservation has to recognize and protect all life stages (Congdon, Dunham, and Sels, 1994). Conservation efforts should focus on the early life history stages. Juveniles utilize the intertidal zones for safety and feed during flooding tides (Draud, unpublished data). Animal populations using these zones are threatened by human activities of the coastlines. Not only are the intertidal areas being affected, the upland terrapin nesting habitat continues to be degraded and lost (Roosenburg, 1990; Gibbons et al., 2001).

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<http://www.Noreast.com> (Bayville Bridge tide charts)

**Table 1. Significance of Results from Autocorrelations of Cycle Length.** The nesting season data was analyzed by autocorrelation (Figure 10). The cycle length (in days) with the highest correlation from each season analyzed for significance.

<b>Data Analyzed</b>	<b>Cycle Length</b>	<b>Correlation Coefficient</b>	<b>Probability</b>
2002 CIB Capture Indices	14 days	R = 0.288	P < 0.109
2002 CIB Test Hole data	14 days	R = 0.058	P < 0.003
1999 JB Capture Indices	14 days	R = 0.357	P < 0.029
2003 CIB Capture Data	18 days	R = 0.385	P < 0.057

**Table 2. Recaptures and Multiple Clutches of the 2002 Season.** The three confirmed double clutches and all recaptures (n = 13) of individual terrapins which were recaptured more than six days apart.

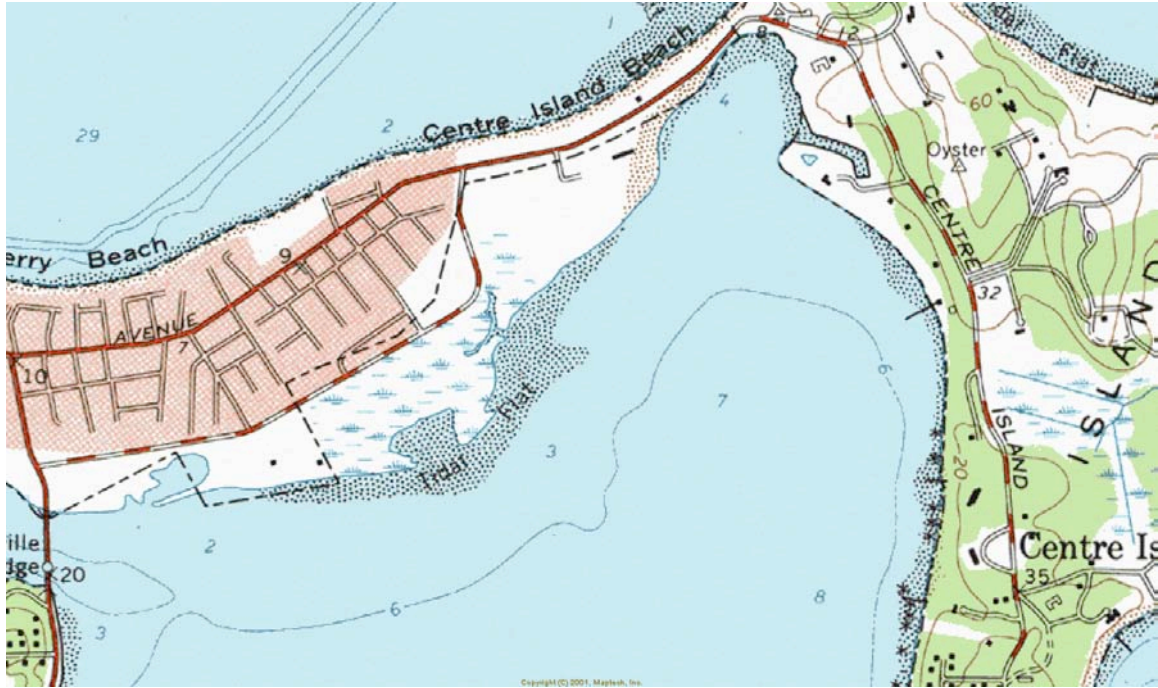
CONFIRMED DOUBLE CLUTCHES:		
File Code	Dates Captured	Days Between Captures
4-17	6/10, *7/2	22 Days
17-22	6/25, 7/9	14 Days
8-23	6/26, 7/10	14 Days
<i>*Additional capture 15 days after first deposit</i>		
POSSIBLE DOUBLE/TRIPLE CLUTCHES:		
<b>12-16</b>	<b>6/19, 7/20</b>	<b>31 Days</b>
<b>14-21</b>	<b>6/17, 7/19</b>	<b>32 Days</b>
13-anomaly	7/2, 7/16, 7/19	14 Days/ 17 Days
15-17	6/19, 7/3	14 Days
17-21	6/25, 6/27, 7/19	22 Days/ 24 Days
17-23	6/25, 6/26, 7/10	14 Days/ 15 Days
2-25	6/27, 7/10, 7/16	13 Days/ 19 Days
3-23	6/17, 7/4	17 Days
4-23	7/2, 7/20	18 Days
9-10	6/27, 7/16	19 Days



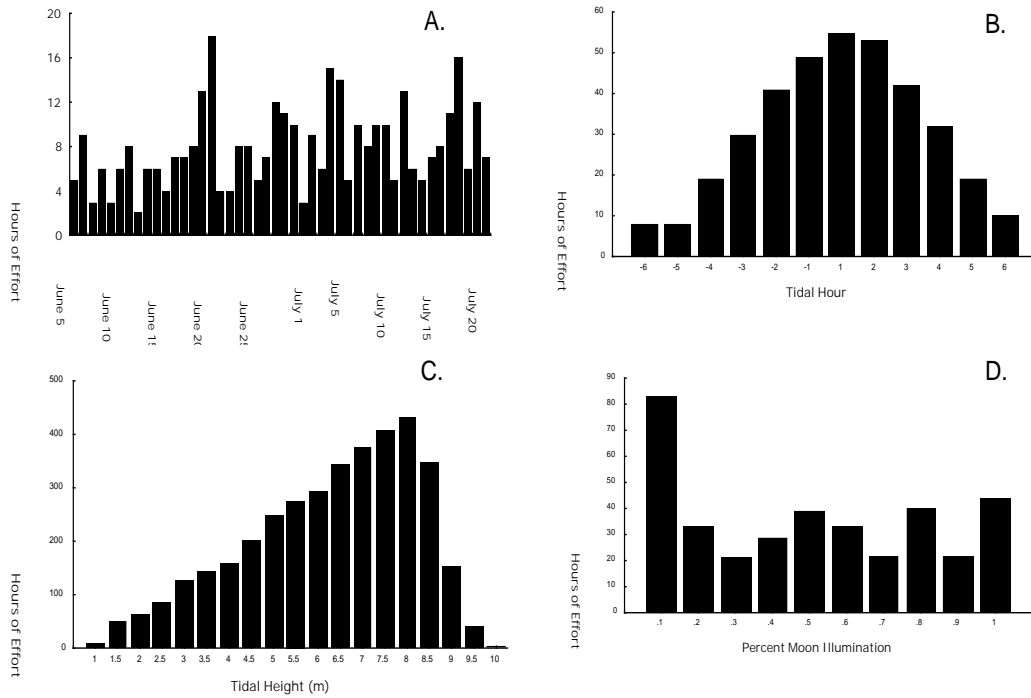
**Figure 1. Locality of the Study Site.** Map of Long Island, New York. Oyster Bay Harbour (OBH) is an embayment of the Long Island Sound. The inset shows the location of OBH within the Long Island Sound estuary where Centre Island Beach is located. The darkened area indicates the portions of CIB where nesting females were observed.



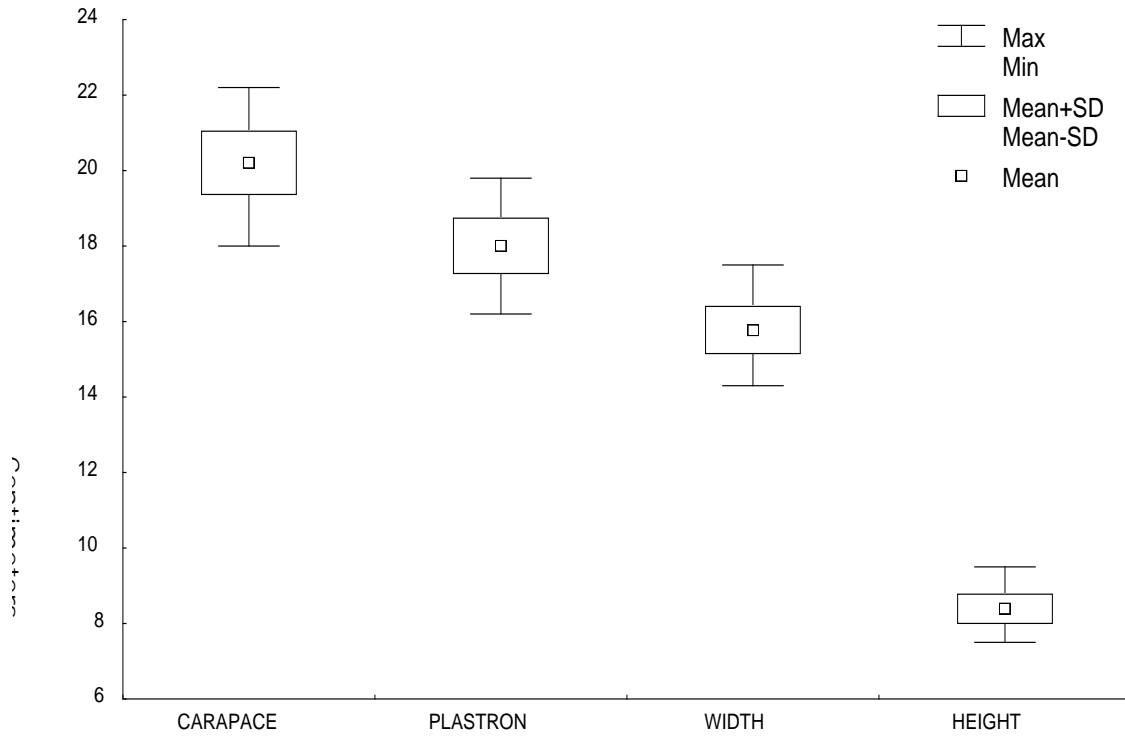
**Figure 2. Nesting Habitat at Centre Island Beach.** Photo indicating the nesting habitat at Centre Island Beach, Bayville, NY.



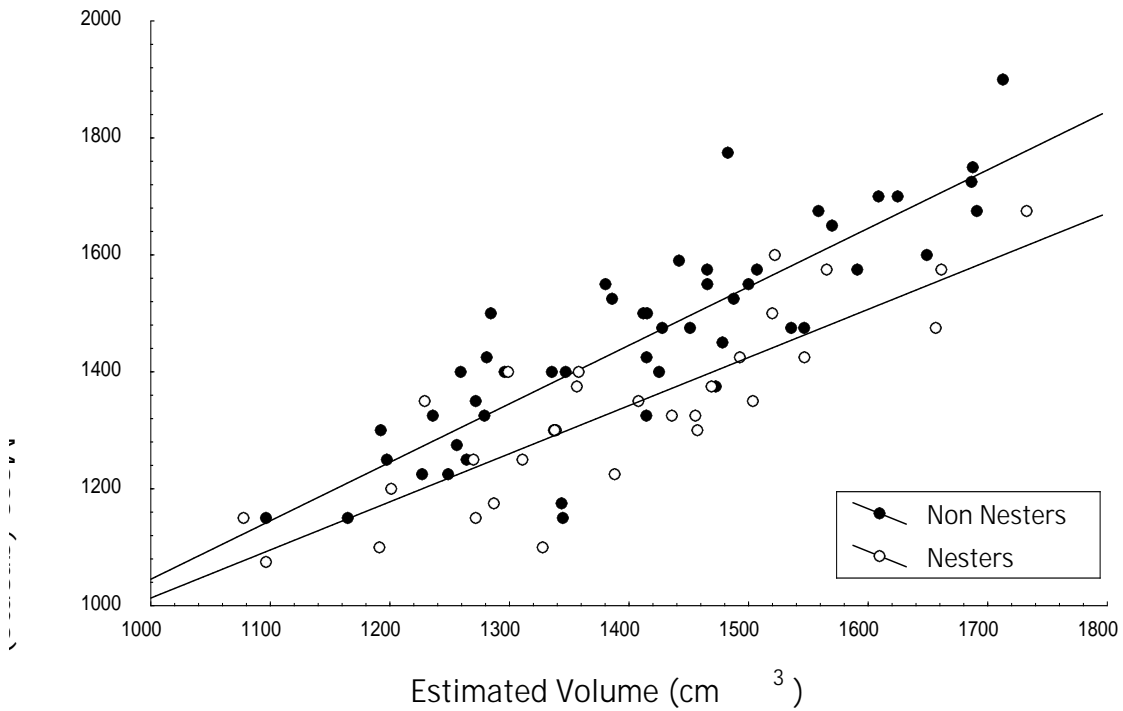
**Figure 3. Mapped Grid Pattern on the Study Site.** Each black point represents a rebar marker that has been placed in the ground. The pattern mapped on the study site includes 18, 15 X 15 m plots and 3, 15 X 10 m plots (Total Plotted Area = 4500 m<sup>2</sup>).



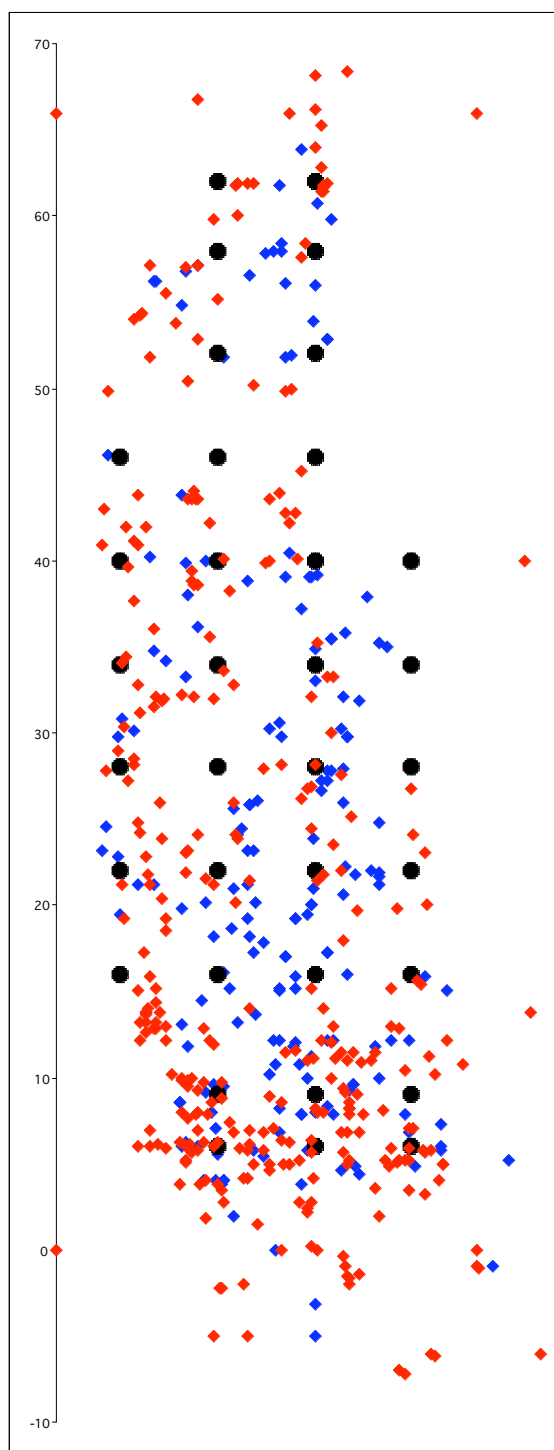
**Figure 4. Hours of Effort Spent Observing the Study Site in 2002.** The total number of hours spent observing at the study site are described as hours per effort. These are calculated during each day (A.), each tidal hours (B.), each tidal height bin (C.), and each moon illumination bin (D.). These hours are used to calculate the capture indices during each variable.



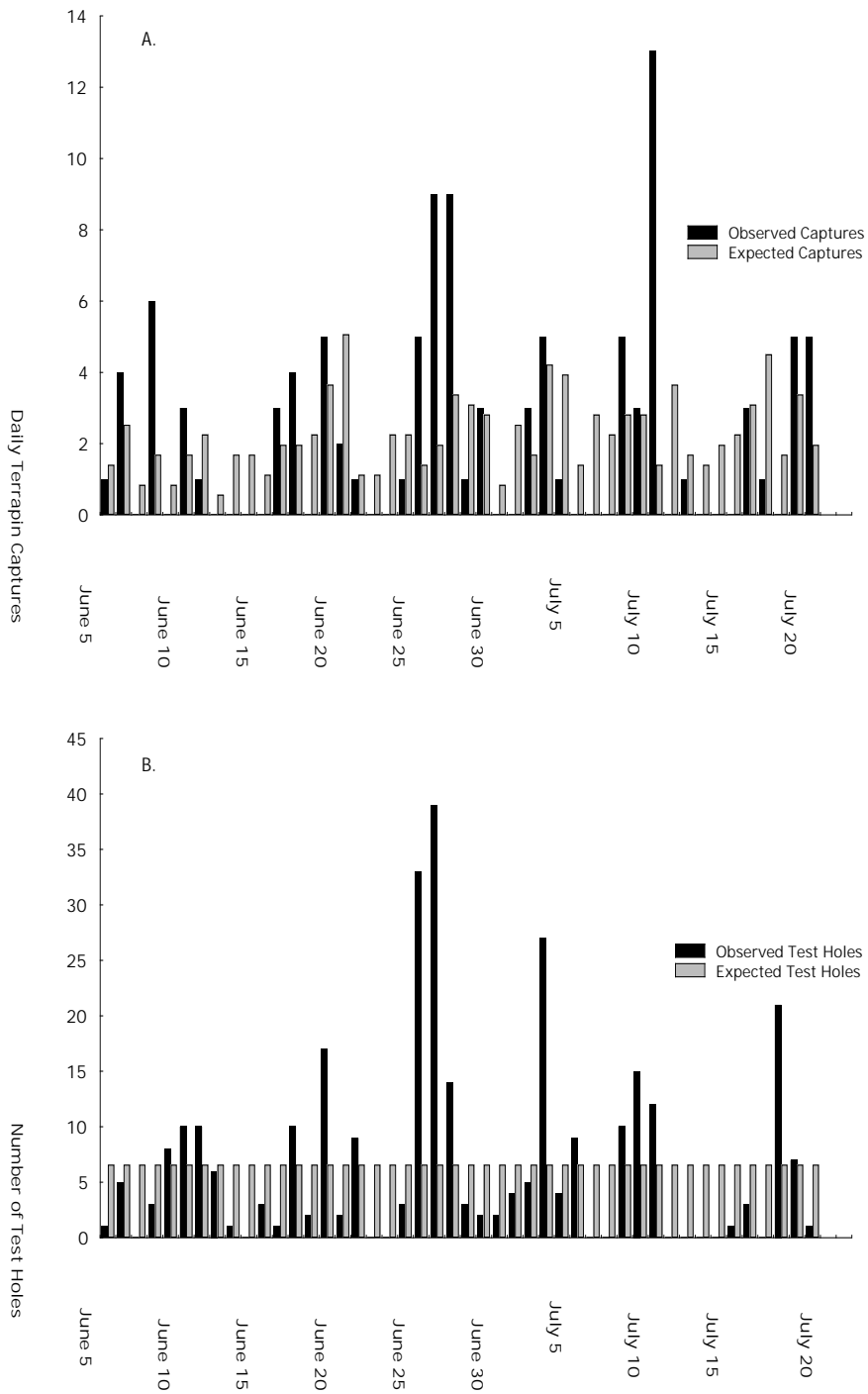
**Figure 5. A Summary of Measurements from the Terrapins Captured During the 2002 Nesting Season.** Includes carapace length, plastron length, carapace height, and carapace width in centimeters (cm) of the 80 individuals captured.



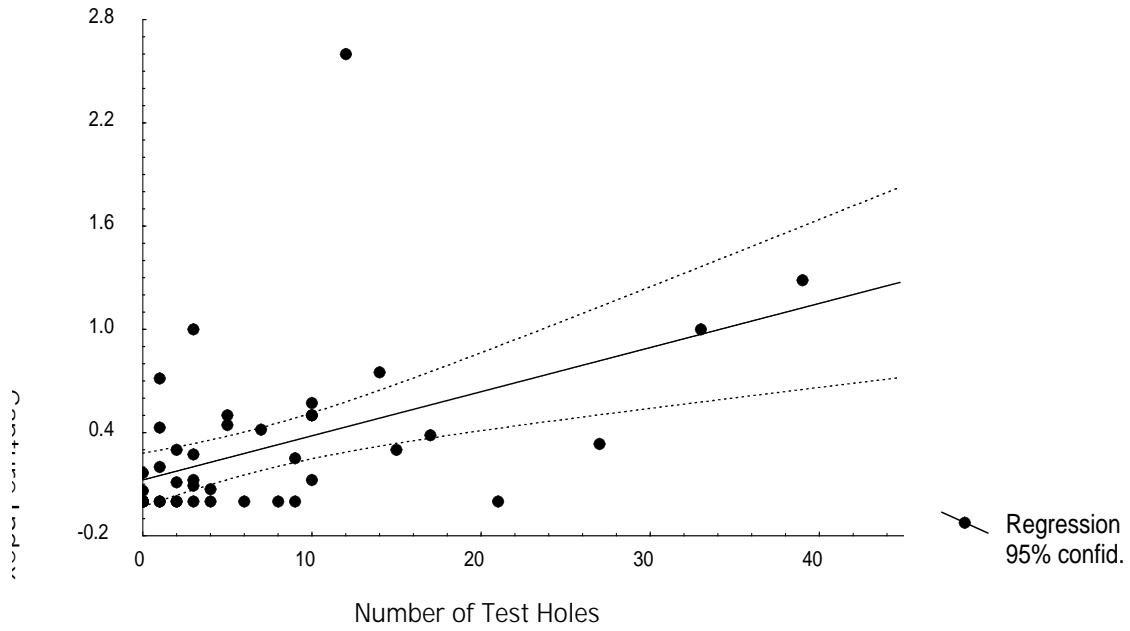
**Figure 6. Size comparison of Nesting and Non-nesting terrapins.** The plastron length (cm) and estimated volume (cm<sup>3</sup>) of every terrapin captured is represented in the graph. The black circles represent the terrapins which did not nest (Linear regression,  $r^2 = .74$ ,  $n = 50$ ,  $p < 0.001$ ), whose mass includes their clutch. The open circles represent the terrapins that did deposit their eggs (Linear regression,  $r^2 = 0.72$ ,  $n = 30$ ,  $p < .000$ ).



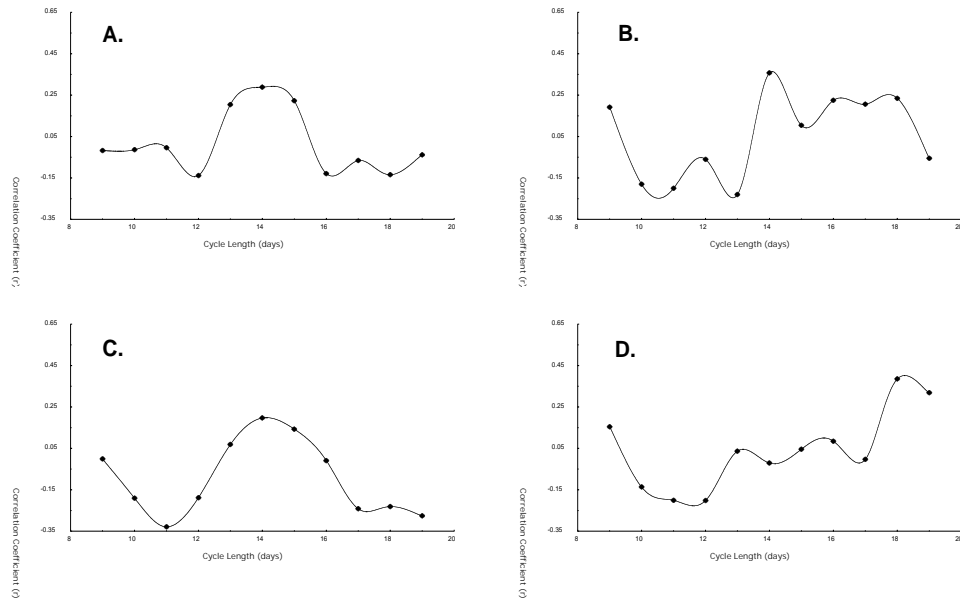
**Figure 7. Location of Nests and Test Holes at Centre Island Beach.** The red points are test holes ( $n = 322$ ) and the blue points are nests, including observed, found, predated nests and emergence holes found ( $n = 186$ ) made throughout the entire nesting season. The black points are the grid point coordinates ( $n = 35$ ) marking the  $4500 \text{ m}^2$  area mapped.



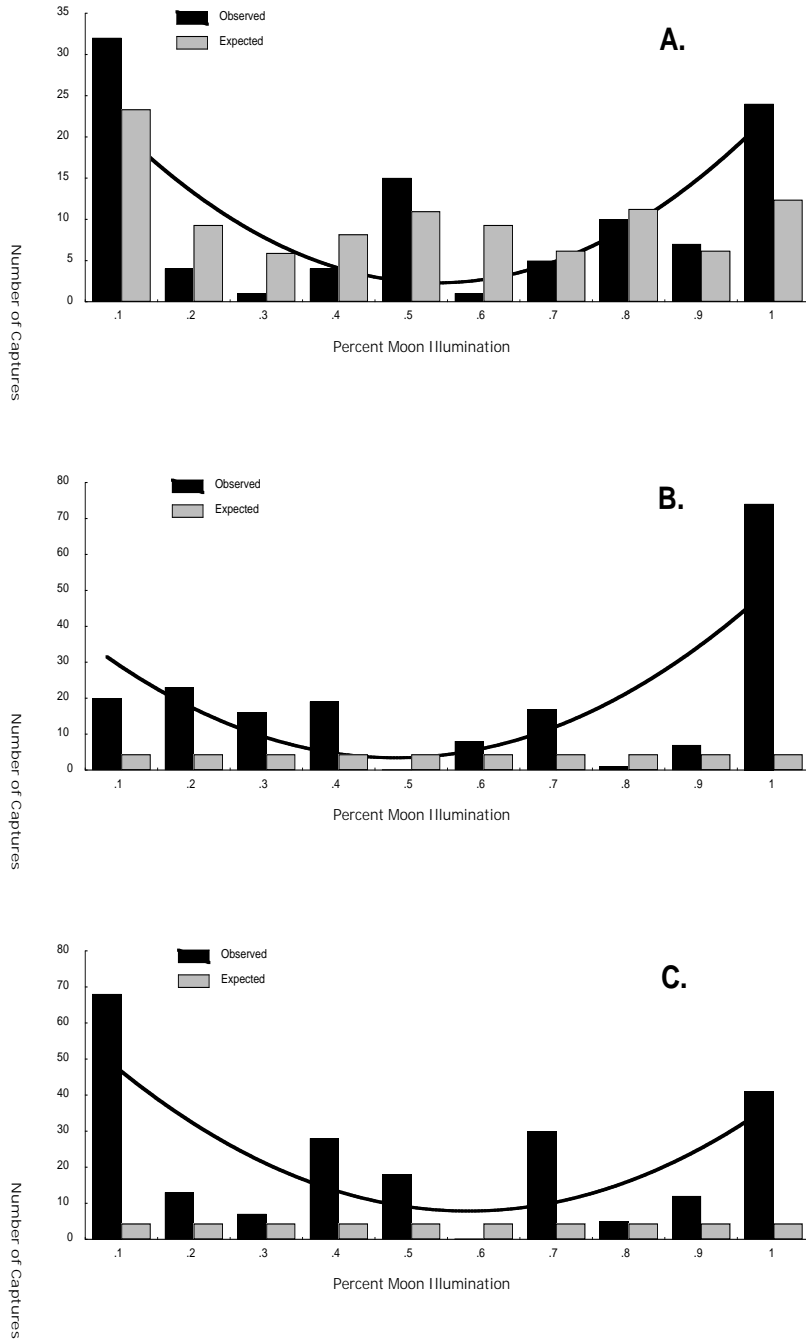
**Figure 8. Distribution of Daily captures and Test Holes Found.** Daily observed vs. a calculated expected frequency of: **A.** Daily terrapin captures (Chi square = 206.7, df = 45,  $p < 0.001$ ) and **B.** Number of test holes found daily (Chi square = 530.9, df = 45,  $p < 0.001$ ).



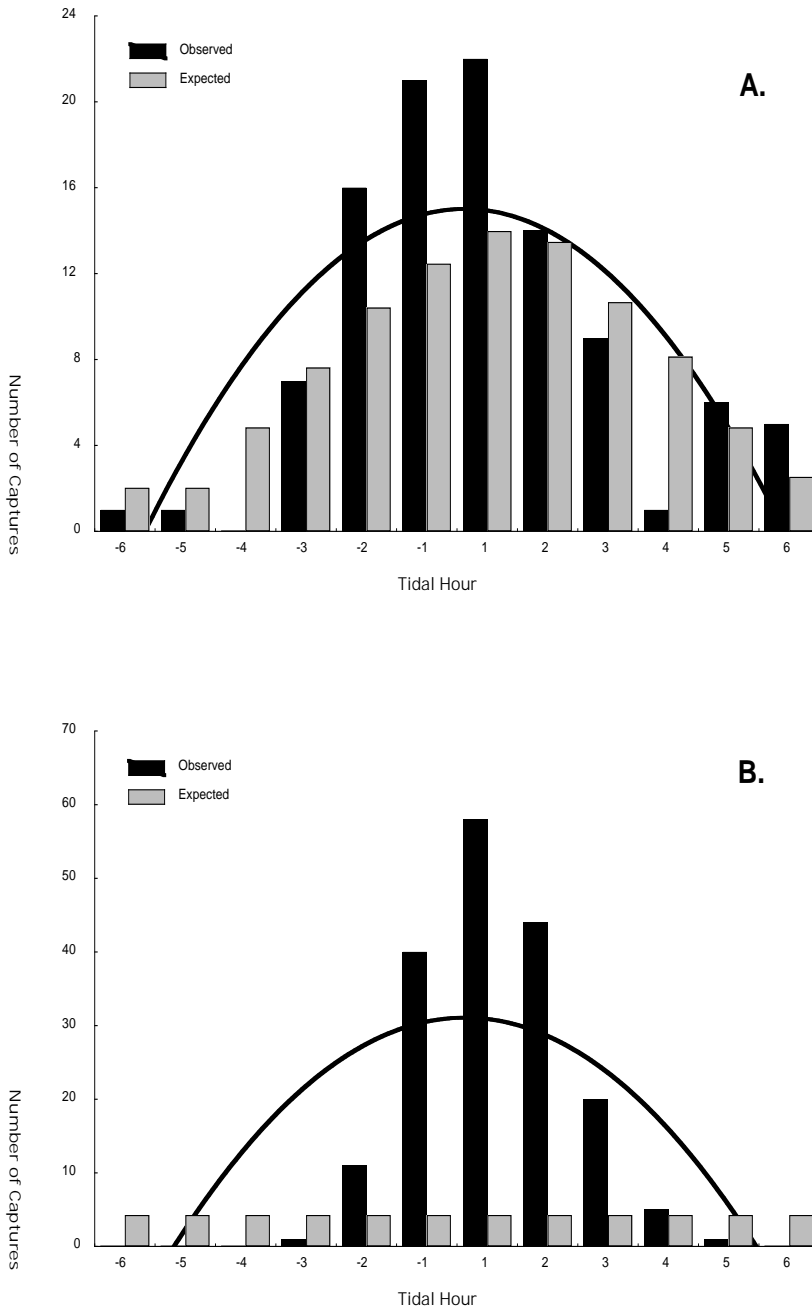
**Figure 9. Comparison of Daily Terrapin Capture Indices and Test Holes Found.** Correlation between daily capture index and number of test holes counted. (Pearson correlation,  $n = 46$ ,  $r = 0.48$ ,  $p < 0.05$ )



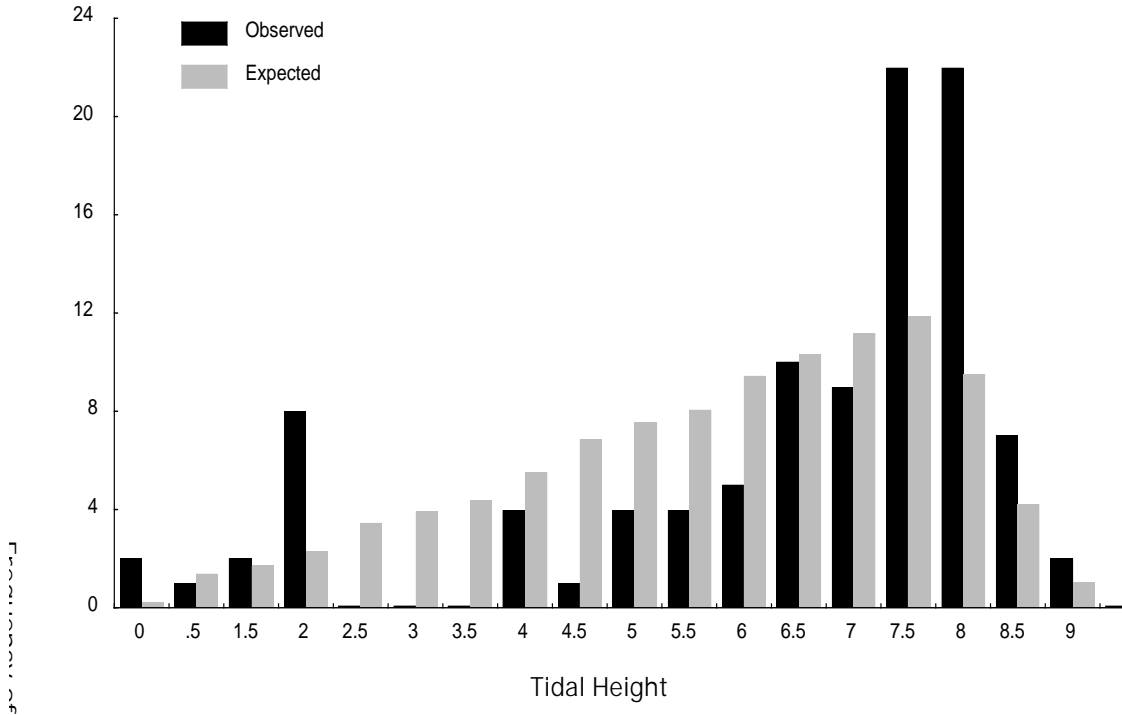
**Figure 10. Autocorrelation Results From Three Nesting Seasons.** Autocorrelation of **A.** 2002 CIB capture index **B.** 2002 test hole data **C.** 1999 JB capture index **D.** 2003 CIB captures. Significance of each is listed on Table 1.



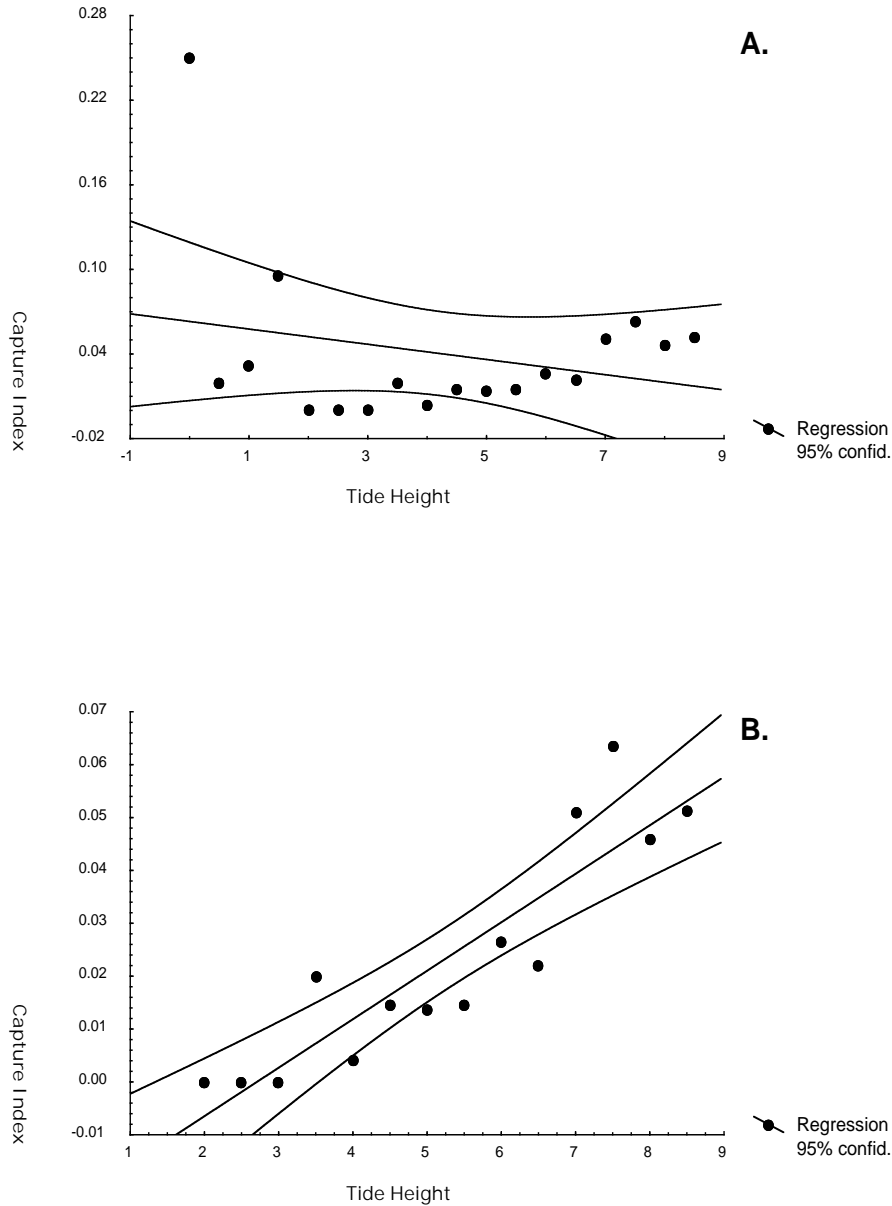
**Figure 11. Distribution of Terrapin Captures in Comparison to the Lunar Cycle.** Observed terrapin captures (black bars) during each moon illumination bin are compared to the calculated expected captures (gray bars) throughout three seasons. **A.** 2002 CIB season (Chi square = 32.7, df = 9,  $p < 0.000$ ) **B.** 2003 CIB season (Chi square = 1359.7, df = 9,  $p < 0.000$ ) **C.** 1999 JB season (Chi square = 1598.2, df = 9,  $p < 0.000$ ).



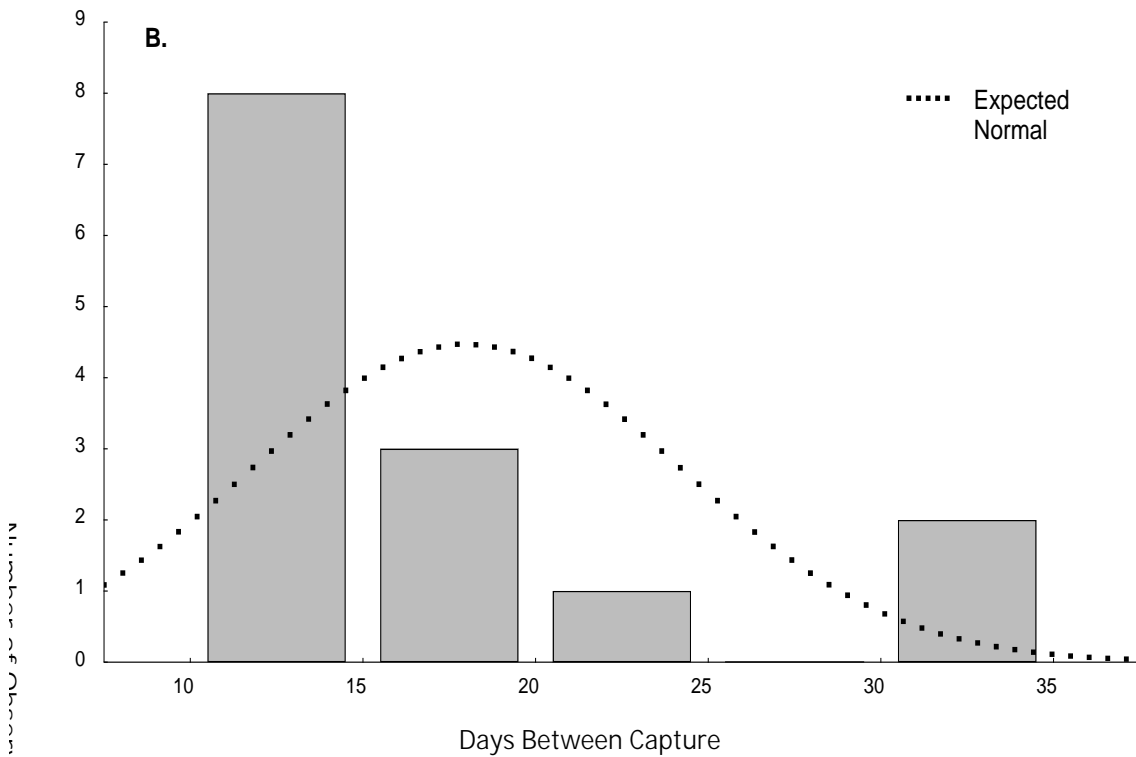
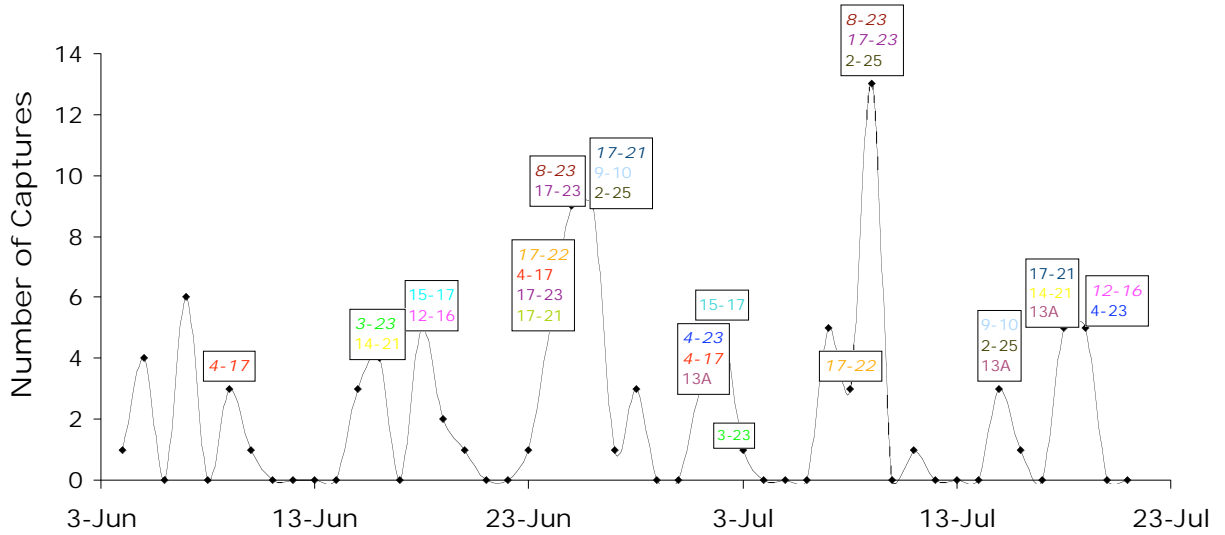
**Figure 12. Distribution of Terrapin Captures in Comparison to Time Around High Tide.** Observed terrapin captures (black bars) in comparison to the expected captures (gray bars) if captures are randomly distributed during all tidal hours for the: (A.) CIB 2002 season (Chi square = 28.5, df = 11,  $p < .003$ ) and (B.) CIB 2003 season (Chi square = 1429.3, df = 11,  $p < 0.000$ ).



**Figure 13. Distribution of Terrapin Captures in Comparison to Tide Height.** Observed terrapin captures (black bars) are compared to an expected frequency (gray bars) of captures if they are distributed around all tide heights (Chi square = 80.0, df = 18,  $p < 0.000$ ).



**Figure 14. The Relationship Between Capture Index and Tide Height.** A regression analysis between the terrapin capture data which has been corrected for hours of effort and the tidal height. **A.** When the captures at all tidal heights are represented an anomalous event disguises the pattern observed (Regression,  $r = -0.248$ ,  $r^2 = -0.061$ ,  $p < 0.322$ ). **B.** When eliminating this event to compare intermediate tides with high tides a highly significant correlation is found (Regression,  $r = 0.898$ ,  $r^2 = 0.806$ ,  $p < 0.000$ ).



**Figure 15. Multiple Captures Within the 2002 CIB Nesting Season.** Recapture and double clutch frequency **A.** Illustrates multiple captures within the daily capture totals. Italicized/bold ID codes represent those individuals that deposited. **B.** Represents the average number of days between captures.