

Seasonal Changes in the Serum Testosterone Titers of Loggerhead Sea Turtles Captured Along the Atlantic Coast of the United States

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ABSTRACT

Serum testosterone titers were recorded for loggerhead sea turtles, *Caretta caretta*, captured along the Atlantic coast of the United States. Immature females exhibited low testosterone titers throughout the year (<30.0 pg/mL). Immature males had significantly higher titers than females, ranging from 76.4 pg/mL to 557.5 pg/mL. The mean monthly titers of immature males fluctuated significantly during the year with the highest mean value recorded during August and the lowest during March. Adult males exhibited a wide range of titers (80.0 to 24,275.7 pg/mL). During certain months, adult males showed a distinct dichotomy in testosterone titers. These data suggest that some turtles were reproductively active and some were not. Our results suggest that reproductively active males appear to have high titers during February through April, followed by a significant decrease in titers during May. Adult female testosterone titers ranged from <41.4 pg/mL to 1209.1 pg/mL. Females sampled on the nesting beach had higher titers than adult females captured in the water during the same months. The mean monthly testosterone titers of adult females captured in the water changed significantly with time, increasing prior to the nesting season and then peaking during the middle of the nesting season. Our results are consistent with those recorded for captive green sea turtles. The possible roles of testosterone in specific reproductive events (i.e., migration, mating, and sperm and egg production) are discussed.

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INTRODUCTION

Seasonal changes in the circulating levels of testosterone have been recorded for only one species of sea turtle, the green sea turtle, *Chelonia mydas*, at the Cayman Turtle Farm, Ltd. (Licht et al. 1979, 1985). These studies, which did not include immature turtles, indicated that both adult males and adult females exhibit significant changes in serum testosterone titers during the year.

Adult males exhibited significant increases in testosterone titers during the premating season followed by a drop in testosterone titer just prior to and during the start of the mating season. Licht et al. (1985) suggest that these data support the hypothesis that spermatogenesis is seasonally coupled to a "prenuptial" androgen cycle. Additionally, their data indicated that the magnitude of the prebreeding testosterone titers positively correlates to the subsequent number of females mounted and the duration of mounting by a given male. This suggests that testosterone also has a role in mating behavior.

Adult female green turtles exhibited a significant rise in serum testosterone titers during the month prior to mating. Their titers appear to peak during the mating season, then decrease slightly (but not significantly) through the nesting season. The role of testosterone in the reproductive physiology and behavior of the female green sea turtle (if one exists) is not known. However, several researchers have suggested that testosterone in reproductively active freshwater turtles could act as a precursor for the estrogen needed in egg production (Callard et al. 1978; McPherson et al. 1982).

Studies of the captive green turtles at the Cayman Turtle Farm have provided insight into endocrine mechanisms involved in reproduction. However, endocrine cycles in captivity may not accurately reflect those of sea turtles in natural populations. Factors associated with captivity such as increased feeding, lack of migrations, and minimal thermal changes could alter normal endocrine cycles. This is evident when comparing intervals between nesting seasons for captive green sea turtles versus those in natural populations. The average interseasonal nesting interval for green sea turtles at the Cayman Turtle Farm is 1.4 years (Wood and Wood 1980), whereas green sea turtles nesting at Tortuguero and in Suriname average 2.33 and 3.14 years, respectively (Carr et al. 1978). Captivity also may affect the reproduction of male turtles. Licht et al. (1985) were able to correlate prebreeding testosterone titers to breeding behaviors for male turtles that were captured in the wild and taken to the Cayman Turtle Farm. However, these correlations were not detectable for farm-reared male turtles.

Considering the information above, endocrine studies of sea turtles from natural populations would be beneficial for several reasons. First, turtles from natural populations may provide a better model for examining hormones which may control certain reproductive events such as migration. Second, studies of turtles in natural populations would facilitate the evaluation of endocrine data from previous studies of captive turtles. Third, regardless of whether the hormone dynamics differ in turtles from natural populations as compared with those from captivity, studies on natural populations would provide a much needed increase in the baseline data on reproductive steroid dynamics in sea turtles. Lastly, the study of the reproductive hormone cycles of turtles in natural populations may provide information which will benefit present management programs for endangered populations. For these reasons, we have begun to analyze reproductive steroid levels of sea turtles captured in the wild. In the present study we provide data on seasonal changes in the testosterone titers of immature and adult loggerhead sea turtles, *Caretta caretta*, captured along the Atlantic coast of the United

States. We then discuss these data relative to observations and hypotheses on the general reproductive behavior and status of the turtles at the time they were captured.

METHODS AND MATERIALS

The methods of capture, measurement, blood sampling, and radio-immunoassay are described by Wibbels et al. (1987). The intraassay coefficient of variation for the testosterone assays was 5.9% and the interassay coefficient of variation was 19.0%. One additional sampling location was used. Turtles nesting at Melbourne Beach, FL, were sampled after they finished covering their eggs. These nesting turtles had a tendency to contract their neck musculature when the sampling needle was inserted, thus making sampling difficult. Therefore, a modified method for nesting loggerheads was developed in which one side of the turtle was lifted until the plastron formed an angle of approximately 70 degrees with the ground. This caused the turtles to extend their necks, thus exposing the correct area for insertion of the blood sampling needle.

Prediction of adult or immature status

Turtles were predicted to be adults or immatures based on their straight carapace lengths. The minimum length chosen for an adult was 80 cm and the maximum length chosen for an immature was 76 cm. These maximum and minimum values were selected after considering the carapace lengths of nesting females along the Atlantic coast of the United States (Hirth 1980) and those of immature loggerheads which we have laparoscopically examined (Wibbels et al. 1987). Turtles between 76 and 80 cm were excluded from the analysis due to our inability to accurately predict if they were adults or immatures. The possibility that some immature turtles may have had carapace lengths of 80 cm or greater is addressed in the Discussion.

Prediction of immature sex

The sex of immature loggerheads captured in this study was predicted by a serum testosterone titer sexing technique (Wibbels et al. 1987).

Prediction of adult sex

Adult sea turtles have traditionally been sexed according to their tail lengths (Pritchard, et al. 1983). Males have long tails extending well past the posterior margin of the carapace, and females have short tails which extend approximately to the posterior margin of the carapace. Unfortunately, no studies have critically analyzed specific tail lengths of adults relative to known sexes. We considered adults with tail lengths of 25 cm or less to be females and those with tail lengths of 40 cm or greater to be males. Turtles with tail lengths between 25 cm and 40 cm were excluded from analysis.

RESULTS

Immature Turtles

The sex of 256 immature loggerheads was predicted using a testosterone sexing technique (Wibbels et al. 1987). Males exhibited significantly greater testosterone titers than females (*t*-test,

$P < 0.001$). Male titers ranged from 76.4 to 545.0 pg/mL, and female titers ranged from below the sensitivity of the assay (< 15.0 pg/mL when extracting 1.0 mL of serum) to 31.0 pg/mL. The mean serum testosterone titers of males and females, grouped by month, are shown on Figures 1 and 2, respectively. Comparisons of the females' monthly mean testosterone titers were not performed, since the majority of female titers were below the sensitivity of the assay. The monthly mean testosterone titers of the males (Fig. 1) exhibited significant changes (ANOVA, $P < 0.001$). Multiple comparisons of mean monthly values indicated that the testosterone titers of males captured during August and January were significantly higher than those of males captured during March ($P < 0.05$, Student-Newman-Kuels test). No other significant differences were detected among the monthly mean testosterone titers.

Adult turtles

Adult male testosterone titers ranged from 80.0 to 24,475.7 pg/mL. During several of the months, there appeared to be a distinct dichotomy in the titers. For example, during February 1982 two turtles captured had titers of 14,784.0 and 17,234.4 pg/mL, while the three other turtles captured that month had titers ranging from 181.9 to 256.5 pg/mL. Males captured during March 1983 exhibited a similar dichotomy. For this reason, males with relatively low titers (< 500 pg/mL) were grouped separately during our analysis. Figure 3 shows the mean testosterone titers of males captured at various times of the year. Males (with titers above 500 pg/mL) exhibited high titers during February and March. Titers then decreased significantly during May (ANOVA, $P < 0.001$). Males exhibiting relatively low testosterone titers (< 500 pg/mL) were captured during various months of the year.

Adult female loggerheads exhibited testosterone titers ranging from below the sensitivity of the assay (~ 40.0 pg/mL when extracting 0.5 mL of serum) to 1209.1 pg/mL. The monthly mean testosterone titers of the adult females are shown in Figure 4. Nesting female titers were significantly greater than those of females captured in the water during the same time period (*t*-test, $P < 0.001$). The monthly mean titers of females captured in the water exhibited significant changes (ANOVA, $P < 0.05$). Mean titers increased from May through June and then began to decrease through July and August. Significant changes were not detectable in the monthly mean testosterone titers of the nesting females ($P > 0.05$).

DISCUSSION

Immature loggerheads

The results indicate that immature female loggerheads have low testosterone titers throughout the year (< 30.0 pg/mL). Immature male loggerheads have significantly higher titers than immature females. The male testosterone titers exhibited significant seasonal fluctuations. However, the variability of titers during certain months combined with small sample sizes for several months prevents meaningful interpretation of these data relative to time of year.

Adult loggerhead sampling locations

The adult turtles used in this study were captured along the Atlantic coast of central Florida near natural nesting areas. All but one of the adult males and the majority of females captured in the water were netted in the Cape Canaveral Ship Channel. The adjacent

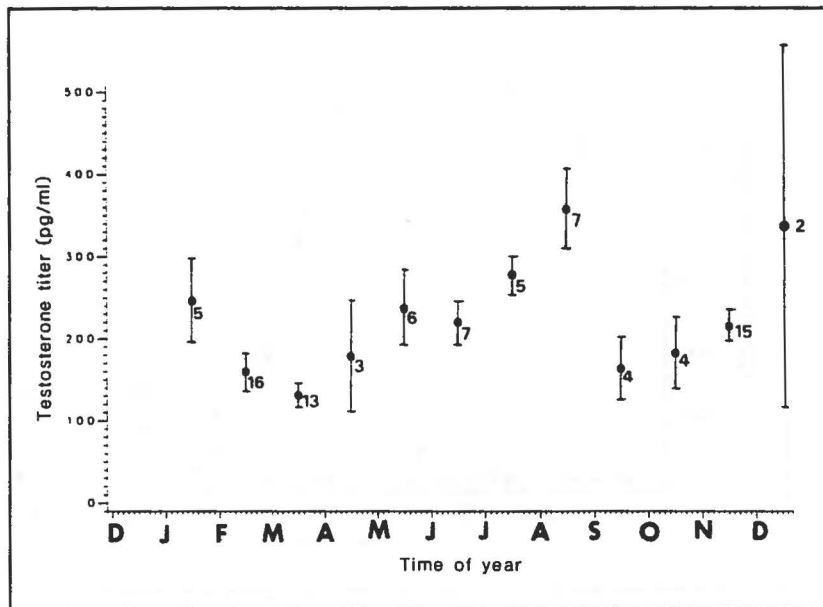


Figure 1—Mean monthly serum testosterone titers of immature male loggerheads captured along the Atlantic coast of the United States. Points represent maximum mean values since the majority of the titers were under the sensitivity of the radioimmunoassay. The number adjacent to each point indicates sample size. Standard errors of the means are represented by vertical lines.

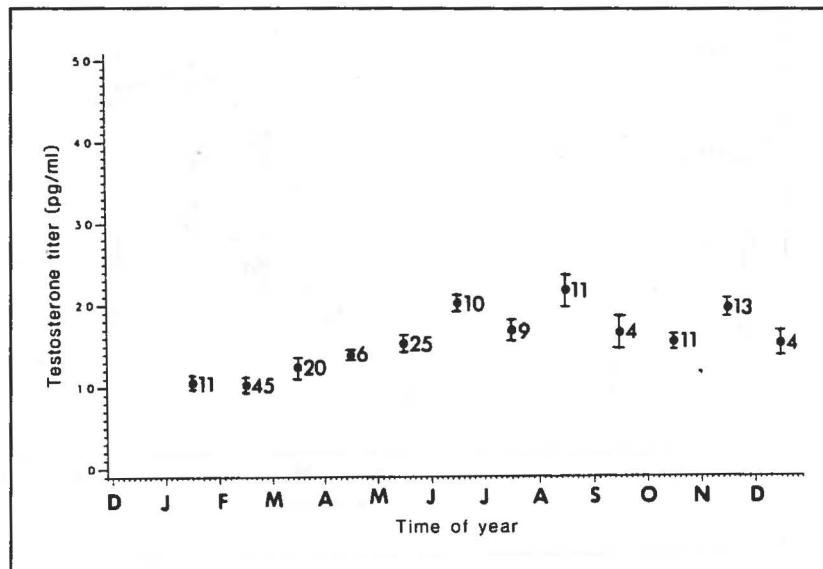


Figure 2—Mean monthly serum testosterone titers of immature female loggerheads captured along the Atlantic coast of the United States. The number adjacent to each point indicates sample size. Standard errors of the means are represented by vertical lines.

beaches on Cape Canaveral and Kennedy Space Center are major nesting areas for loggerheads (Ehrhart 1979; Hopkins and Richardson 1984). Scattered nesting occurs to the south of the channel for approximately 30 km (Hopkins and Richardson 1984). The densest nesting of loggerheads in the United States occurs 40 km south of the Cape Canaveral Ship Channel at Melbourne Beach (Hopkins and Richardson 1984), our sampling site for nesting females. Adult females tagged in the channel have primarily been recorded nesting on beaches of Cape Canaveral, Kennedy Space Center, and Melbourne Beach (Henwood 1987a). The data collected by Henwood

(1987b) indicate that adult males and adult females, as well as immatures, show movements into and out of the channel that correlate with time of year. Therefore, although this channel is anomalous in its large aggregation of loggerheads, turtles in the channel appear to be normal members of a population(s). The ten adult turtles not captured in the Canaveral ship channel or on the beach at Melbourne Beach were captured in the Indian River or at the power plant on Hutchinson Island. Both of these locations are also in close proximity to major loggerhead nesting beaches (Hopkins and Richardson 1984).

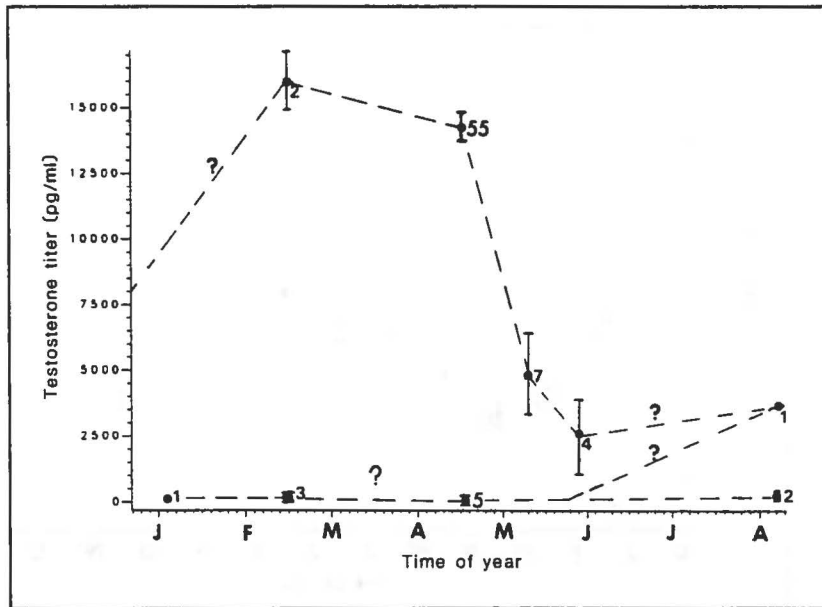


Figure 3—Mean monthly or semimonthly testosterone titers of adult male loggerheads captured along the Atlantic coast of central Florida. Males with titers <500 pg/mL were grouped separately. The number adjacent to each point indicates sample size. Standard errors of the means are represented by vertical lines.

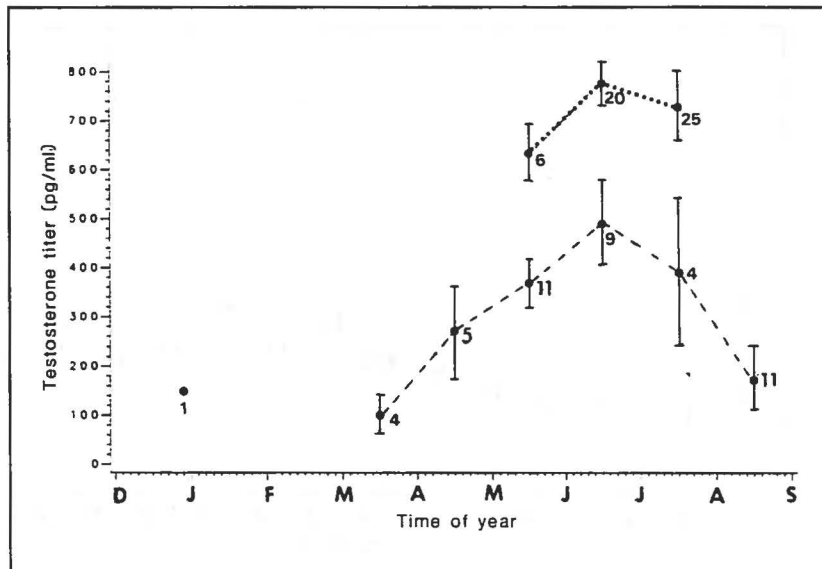


Figure 4—Mean monthly testosterone titers of adult female loggerheads captured along the Atlantic coast of central Florida. Dotted line connects means of nesting turtles, and dashed line connects means of turtles captured in the water. The number adjacent to each point indicates sample size. The means for March, April, and May each include one titer that was under the sensitivity of the assay; the mean for August includes three titers that were under the sensitivity of the assay. Standard errors of the means are represented by vertical lines.

Adult male loggerheads

Adult males exhibited a dichotomy in testosterone titers. It is possible that some of these males were immature. However, some of the turtles with low titers were well over the minimum size criteria we chose. For example, a turtle with a low titer during March had a straight carapace length of 97.0 cm and a tail length of 50.8 cm. Therefore, this suggests that at least some of the males sampled

in this study may have multiannual reproductive intervals. While it is well documented that adult female sea turtles possess multiannual reproductive intervals, this subject is difficult to address in adult males. To substantiate that a male is reproductively active during a given year, it will be necessary to determine an accurate indicator for reproductive status. Observations of mating behavior could verify reproductive status; unfortunately, the time and location of mating have not been well documented in any sea turtle

population. Our results indicate that, at least during certain months of the year, testosterone titer might indicate whether a male is reproductively active. Thus, testosterone titer could prove to be a useful tool in studying the reproductive ecology of male sea turtles.

Adult males which appeared reproductively active exhibited high levels of testosterone during February and April, followed by a significant decrease during May (Fig. 3). Licht et al. (1985) recorded a similar monthly pattern for captive green turtles, but mean monthly values were higher (as high as $\sim 38,000$ pg/mL). Additionally, titers of male loggerheads in this study decrease significantly over a shorter time period (one month) compared with captive green turtles (two months). However, these differences may be attributed to factors such as temperature, effects of captivity, or interspecific disparities. Nevertheless, our adult male data appear strikingly similar to those recorded for captive green turtles. Unfortunately, our data set contain only a few adult males captured during the months of June through January, and therefore do not permit the determination of when testosterone titers begin to increase in a reproductively active male. Licht et al. (1985) found that titers in captive green sea turtles began increasing in January.

Henwood (1987b) found that adult male loggerheads begin migrating into the Cape Canaveral Ship Channel during February. By April, the number of adult males in the channel reaches a maximum. Then, during May, it drops precipitously, resulting in only a few males being present in June. Comparison of our data with that of Henwood suggests that many of the males migrating into the channel between February and April have high testosterone titers. Although we have no data on gonadal weights, we speculate that these high titers may play a role in spermatogenesis, as suggested by Licht et al. (1985) for the green sea turtle. The influx of adult males with high testosterone titers into the channel also suggests the possibility that testosterone may be important for inducing migration. This subject has not been studied in turtles but has received some attention in fish, where a variety of studies suggest that testosterone may have a role in regulating migratory behavior (reviewed by Woodhead 1975).

The time and location of the mating of adult loggerheads along the Atlantic coast of the United States has not been documented. Henwood et al. (1987b) indicates that during March, when large numbers of adult males are present in the Canaveral Channel, there are few adult females. However, the number of adult females increased significantly during May, the month when males begin to leave the channel. This indicates that mating could occur, at least in the Cape Canaveral Ship Channel, during the month of May. Captive green sea turtles, which have mated for more than 100 minutes, nest an average of $28.4 (\pm 11.4)$ days after mating (Wood and Wood 1980). If loggerheads behave in a similar fashion (and other aspects of their reproductive ecology do appear similar), then one would expect mating to occur in late April and May, since nesting begins in mid-May and becomes heavy during June. This predicted mating period would coincide with the arrival of females in the Cape Canaveral Ship Channel and with the decrease in male testosterone titers. Licht et al. (1985) recorded similar drops in the testosterone titers of male green sea turtles prior to and during the start of the mating season. Mating male green turtles captured off the west coast of Mexico had higher testosterone titers than did mating males at the Cayman Turtle Farm (Licht et al. 1980). Therefore, it is possible that these wild green turtles were mating earlier (relative to the expected decline in testosterone) than captive turtles. Therefore, our testosterone data, together with data on captive green turtles (Wood and Wood 1980; Licht et al. 1979, 1985), data on mating male green turtles in the wild (Licht et al.

1980), and the data on adult loggerhead movement patterns (Henwood 1987b) strongly suggest that the most probable time for the mating of these loggerheads would be late April through May. The significant drop in the testosterone of adult males during this time period suggests that this hormone is not directly regulating mating behavior. However, Licht et al. (1985) found that the premating peak in the testosterone titers of green sea turtles positively correlated to the number of females mounted and the total mounting time of a given male. Furthermore, Owens (1976) showed that injections of testosterone could induce mating behavior in immature male green sea turtles.

Adult female loggerheads

Henwood (1987b) found that the number of adult females in the Cape Canaveral Ship Channel increases sharply during May, remains high during June, and then decreases through July and August. Additionally, his tag recovery data verify that many of these turtles nest on nearby beaches. Comparing our results with his data suggests that testosterone titers are increasing as the adult females move into the channel during May (Fig. 4). Titers appear to remain high through June and July, and then decrease toward the end of the nesting season. Figure 4 indicates that nesting females have higher titers than those captured in the water. We speculate that this may result, at least partially, from capturing turtles which are at various reproductive stages. For example, the group of females captured in the water during July could be composed of turtles that are between nestings and turtles that have already nested for the last time. Additionally, it is possible that some of the females were still immature or were adults which were not reproductively active during the year they were captured. Regardless, the results indicate that testosterone titers increase prior to the nesting season and then remain elevated through the nesting season. Licht et al. (1979) recorded similar data for captive green sea turtles except that their titers were highest during mating, then decreased slightly, but not significantly, during nesting. However, with wild green sea turtles, Licht et al. (1980) recorded higher testosterone titers for nesting turtles than for mating turtles.

During May, when large numbers of females begin moving into the Cape Canaveral Ship Channel, testosterone titers appear to be increasing. Therefore, as with adult males, it is possible that testosterone may have a role in migratory behavior. Licht et al. (1979) suggest that increased testosterone could also facilitate mating behavior in female green sea turtles. If loggerheads mate prior to the nesting season (as do captive green sea turtles) then our data indicate that testosterone titer is increasing during the time of mating. The affects of androgens on female mating behavior have not been studied in turtles, but androgens have been shown to stimulate receptivity in some lizards (Nobel and Greenberg 1940).

The female loggerheads' elevation in testosterone titer prior to the nesting season is similar to that recorded for two other multi-clutched turtles, the green sea turtle (Licht et al. 1979) and the stinkpot turtle, *Sternotherus odoratus* (McPherson et al. 1982). Callard et al. (1978) suggest that increases in testosterone in the painted turtle, *Chrysemys picta*, could be related to its ability to act as a precursor for the synthesis of estrogen, which is important in the mobilization of vitellogenin from the liver and subsequent egg production (Ho et al. 1982). McPherson et al. (1982) concurred with this hypothesis and speculated that multiclutched turtles may have an increased ability to aromatize testosterone to estrogen, allowing for a more compact interval between nestings. Additional studies correlating the female loggerheads' testosterone and estrogen

titers could provide insight into the question of whether or not aromatization is an important adaptive mechanism in egg production.

Testosterone as an indicator of reproductive status

Results indicate that testosterone titer could be used, during certain months to determine if an adult male is reproductively active. Because adult females exhibited elevated titers prior to and during nesting season, their testosterone titers also have the potential of being used as an indicator of reproductive activity during this time period. However, further evaluation of female titers is necessary because the individuals captured in the water exhibited a wide but continual range of titers. This prevented the accurate prediction of reproductively active versus reproductively inactive individuals. In summary, the testosterone titers show strong potential as a tool for evaluating reproductive status. By collecting blood samples during tagging and netting projects, much new information could be generated which would provide a better understanding of the reproductive ecology of sea turtles and thus facilitate the enhancement of management strategies for endangered populations.

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