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Long-term conservation efforts contribute to positive green turtle *Chelonia mydas* nesting trend at Tortuguero, Costa Rica

Sebastian Troëng *, Eddy Rankin

Caribbean Conservation Corporation, Apdo. Postal 246-2050, San Pedro, Costa Rica

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Abstract

Worldwide, green turtle *Chelonia mydas* populations have declined and the species is classified as globally endangered. Tortuguero, Costa Rica, hosts the largest remaining green turtle rookery in the Atlantic basin. Tortuguero green turtles have been hunted since pre-Columbian times. Monitoring and conservation of the green turtle population began in 1955. The long-term efforts provide an excellent opportunity to evaluate the success of sea turtle conservation action and policies. Nest counts conducted 1971–2003 were analyzed to: (1) determine the nesting trend, (2) estimate rookery size and (3) identify events and policy decisions influencing the trend. A nonparametric regression model indicates a 417% increase in nesting over the study period. Rookery size was defined as the mean number of nests 1999–2003 and estimated at 104,411 nests $year^{-1}$, corresponding to 17,402–37,290 nesting females $year^{-1}$. A comparison with 34 index populations verifies Tortuguero as one of the two largest green turtle rookeries worldwide. Events and policy decisions in Costa Rica, Nicaragua, and Panama that comprise the main nesting, feeding and mating grounds for the Tortuguero population are likely to have had the greatest influence on green turtle survivorship. Conservation efforts and policies catalyzing increased hatchling production and decreased adult and juvenile mortality since 1963 have contributed to the positive nesting trend. The trend demonstrates that long-term conservation efforts can reverse nesting declines and offers hope that adequate management can result in recuperation of endangered sea turtle species.

Keywords: *Chelonia mydas*; Green turtle; Tortuguero; Nesting trend; Recovery

1. Introduction

Worldwide, green turtle *Chelonia mydas* populations are conservatively estimated to have declined by 37–61% over the last 141 years (Seminoff, 2002). Consequently, the species is classified as globally endangered (IUCN, 2003). Extractive use of green turtles for eggs, meat and other products is believed to be the major reason for the decline (Seminoff, 2002).

The largest remaining green turtle rookery in the Atlantic basin is located at Tortuguero, Costa Rica (Fig. 1; Carr et al., 1978; Seminoff, 2002). There is a long history of green turtle use at Tortuguero. Turtles were hunted by indigenous groups before the arrival of Europeans (Lefevre, 1992). In 1596, the region was described as an important sea turtle nesting area (van Linschoten, 1934). By the second half of the 18th century, Spanish maps identify the location as Tortuguero, meaning "place of turtles" (San Martín-Suárez, 1787) and English maps refer to Turtle Boca (Smith-Speer, 1774). Carr (1956) documented organized collection of nesting turtles and records suggest that many green turtles were brought from Costa Rica to Cayman Islands (Anon, 1959). Until 1963, egg and turtle collection were conducted under license from the Municipality of Limón (Government of Costa Rica, 1928, 1953). Research and conservation efforts at Tortuguero began in 1955 (Carr et al., 1978) and have been conducted by the Caribbean Conservation Corporation since 1959. The green turtle nesting trend 1971–1996 has been described as encouraging (Bjorndal et al., 1999). For species with late maturity, conservation actions aimed at reproductive females and nests need to last decades to produce tangible results. The long-term efforts at Tortuguero provide an excellent opportunity to evaluate the success

* Corresponding author. Tel.: +506-297-2908; fax: +506-297-5510.
E-mail address: sebastian@cccturtle.org (S. Troëng).

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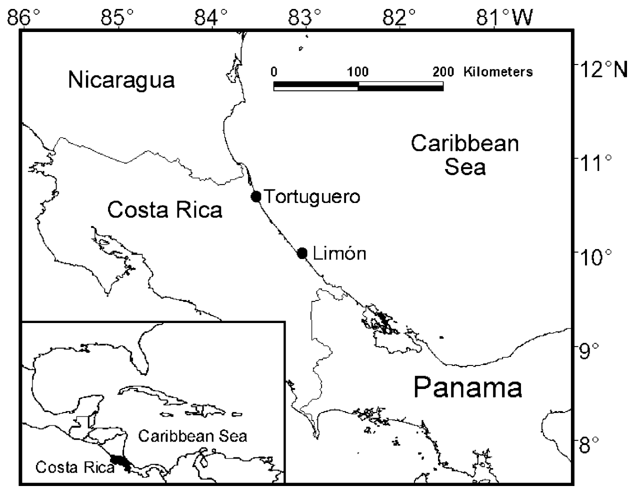

Fig. 1. Location of Tortuguero.

of conservation action and policies on green turtle nesting.

The green turtle nesting trend and rookery size at Tortuguero have implications for the global status of the species as well as for national and regional management. The rookery size is also relevant for the interpretation of genetic composition data collected at green turtle nesting and feeding grounds (Bowen et al., 1992; Bass et al., 1998; Lahanas et al., 1998).

The objectives of this paper are: (1) to update the green turtle nesting trend at Tortuguero thru 2003, (2) to estimate the size of the green turtle rookery and (3) to summarize conservation efforts and policy decisions that have influenced the nesting trend since the 1960s.

2. Methods

2.1. Nesting trend estimation

Nest transect surveys to record green turtle nests deposited the previous night have been conducted at approximately weekly intervals along 18 km of the Tortuguero beach since 1971. Since 1986, nest transect surveys have been conducted along the entire 35.6 km of beach between the Tortuguero rivermouth (N10°35.51, W083°31.40) and Parismina (N10°19.04, W083°21.39). In 1994, Jalova lagoon (N10°21.46, W083°23.41) opened up to the sea and the southern 6 km became separated from the main nesting beach. Nest transect surveys conducted between 1994–1996 and 1998 suggest that <1% of nests are now deposited south of Jalova lagoon. Therefore, 29.6 km surveys have been used as entire beach surveys since 1994. Nests were identified from soft sand thrown over the nest area during camouflaging and/or from the length difference between arrival and return tracks resulting from tidal wash during the extended nesting process (Hirth and Samson, 1987). During some surveys in 1995 ($n = 3$), 1996 ($n = 8$), 1997 ($n = 16$) and 1998 ($n = 1$), the northern 5.4 km of beach were not surveyed. Nest counts were corrected by adding the proportion of nests deposited along the northern 5.4 km, during the same month, as determined from surveys 1995 to 2001.

We used a General Additive Model (GAM) similar to that of Bjorndal et al. (1999) to fit a curve to nest transect survey results and produce nest estimates for each date (Hastie and Tibshirani, 1990). Our GAM model differed in that we used a robust quasi-likelihood error function. Also, we set artificial end dates with zero nesting as June 15 and November 1. Bjorndal et al. (1999) used May 30 and November 15 as nesting season end dates. Year round nest transect surveys 1997–2003 show that 99.0% of nests were deposited within the June 15–November 1 period (range 98.0–99.5%) and 99.6% were laid between May 30 and November 15 (range 98.6–99.9%). We evaluated the effect of the two sets of end dates by excluding results from surveys conducted pre-July 1 and post-October 15 and estimating annual nesting. The wider end dates consistently overestimated nesting ($n = 7$, mean +3045 nests, range +209 to +8175 nests). For five of the seven years with year round surveys, the narrower end dates produced annual nest estimates that were closer to the estimates calculated with all survey results included ($n = 7$, mean −1738 nests, range −5220 to +771 nests).

Fewer nest transect surveys were conducted during the early years of the study period (Table 1). For years with fewer nest transect surveys, wider end dates will overestimate nesting. Consequently, wider end dates will underestimate the increase in nesting during the study period.

The number of surveys varied between 8 and 20 (mean 14.6, SD 3.4) per nesting season (Table 1). End dates were weighted at 0.1 and survey results at 1.0 (Bjorndal et al., 1999). Negative estimates were trimmed from the beginning and end of each season. Annual nest numbers were calculated by integrating (interval 0.125) GAM estimates using Berkeley Madonna software (Macey et al., 2000).

A nonparametric regression model using BayesX with Markov field random smoothness priors and a Bayesian smoothing spline was employed to calculate trends with 95% credible intervals (Fahrmeir and Lang, 2001; Balazs and Chaloupka, 2004).

2.2. Rookery size estimation

Remigration intervals vary (Carr and Carr, 1970) but Tortuguero green turtles do not often nest in consecutive years (Carr et al., 1978). Therefore, rookery size was estimated as the mean number of green turtle nests year^{-1} deposited along the entire beach 1999–2003 (Seminoff, 2002).

Table 1
Nest transect surveys used in trend analysis

Year	Surveys
1971	8
1972	17
1973	13
1974	10
1975	12
1976	14
1977	17
1978	16
1979	15
1980	11
1981	11
1982	10
1983	12
1984	13
1985	10
1986	12
1987	12
1988	18
1990	12
1989	11
1991	15
1992	15
1993	18
1994	16
1995	17
1996	15
1997	18
1998	19
1999	19
2000	20
2001	19
2002	17
2003	20

3. Results

3.1. Nesting trend estimation

Green turtle nest numbers display large interannual variation at the Tortuguero rookery (Fig. 2). However, the long-term nesting trend is clearly positive. The nesting trend for the northern 18 km of beach suggests that green turtle nesting has increased with an estimated 471% since 1971. Nesting along the entire beach has increased with an estimated 61% since 1986.

3.2. Rookery size estimation

For 1999–2003, we estimate a mean of 104,411 green turtle nests year^{-1} deposited along the entire Tortuguero beach (range 37,395–149,569 nests). Carr et al. (1978) calculated a mean of 2.8 nests per female green turtle at Tortuguero. Bjorndal et al. (1999) did not consider the Carr et al. (1978) estimate reliable due to tag loss and suggested clutch frequency may be as high as six nests per female. By using these estimates as upper and lower limits for clutch frequency, we estimate a mean of 17,402–37,290 nesting females year^{-1}.

4. Discussion

4.1. Nesting trend estimation

The large interannual variation in green turtle nesting observed at Tortuguero demonstrates the importance of long-term data sets to determine sea turtle nesting trends. The increasing nesting trend suggests that conservation efforts have been successful. Although very positive, the Tortuguero trend should be interpreted cautiously and within a historical context. Bjorndal et al. (1999) pointed out that if clutch frequency varies between years, the increase in nesting does not necessarily reflect an increase in females. In addition, environmental variables may influence the number of turtles ready to nest in a given year (Chaloupka, 2001; Solow et al., 2002). If the mean remigration interval has decreased as a result of environmental change, an increase in nesting would occur without an increase in females (Hays, 2000; Broderick et al., 2001).

The rookery size and the increase in nesting are promising signs of recovery, but the green turtle population may still be far from its historical size. Jackson (1997) estimated that adult green turtles may have numbered 33–39 million in pre-Columbian times. Bjorndal et al. (2000) suggested that the carrying capacity for the Caribbean might be as many as 16,104,000–585,948,000 green turtles. Also, the nesting trend only reflects the change in one lifestage of the complex lifecycle of green turtles. Population trends for male and juvenile green turtles are currently not available. Lagueux (1998) showed that large juveniles make up the largest part of the green turtle catch in Nicaragua. Additional green turtle fishing throughout the Caribbean may remove many large juveniles from the population. This would not result in a nesting decline at Tortuguero for several years, until recruitment into the adult population starts to diminish significantly (Mortimer, 1995). Fishing pressure is a cause for concern as the annual survivorship for reproductively active females from the Tortuguero population, estimated at 0.80–0.82 (Solow et al., 2002; Campbell, 2003), is lower than the 0.95 annual adult survivorship rate estimated for the southern Great Barrier reef, Australia green turtle population (Chaloupka, 2002).

4.2. Rookery size estimation

The rookery size estimate is based on the assumption that nest counts are accurate. It is logistically very challenging to dig up and verify that eggs have been laid for each track recorded as a nest. Hence, this crucial assumption has not been tested.

Our rookery size estimate of 17,402–37,290 females year^{-1} is greater than previous estimates of 14,000 females year^{-1} (Lahanas et al., 1998), 5000–23,000

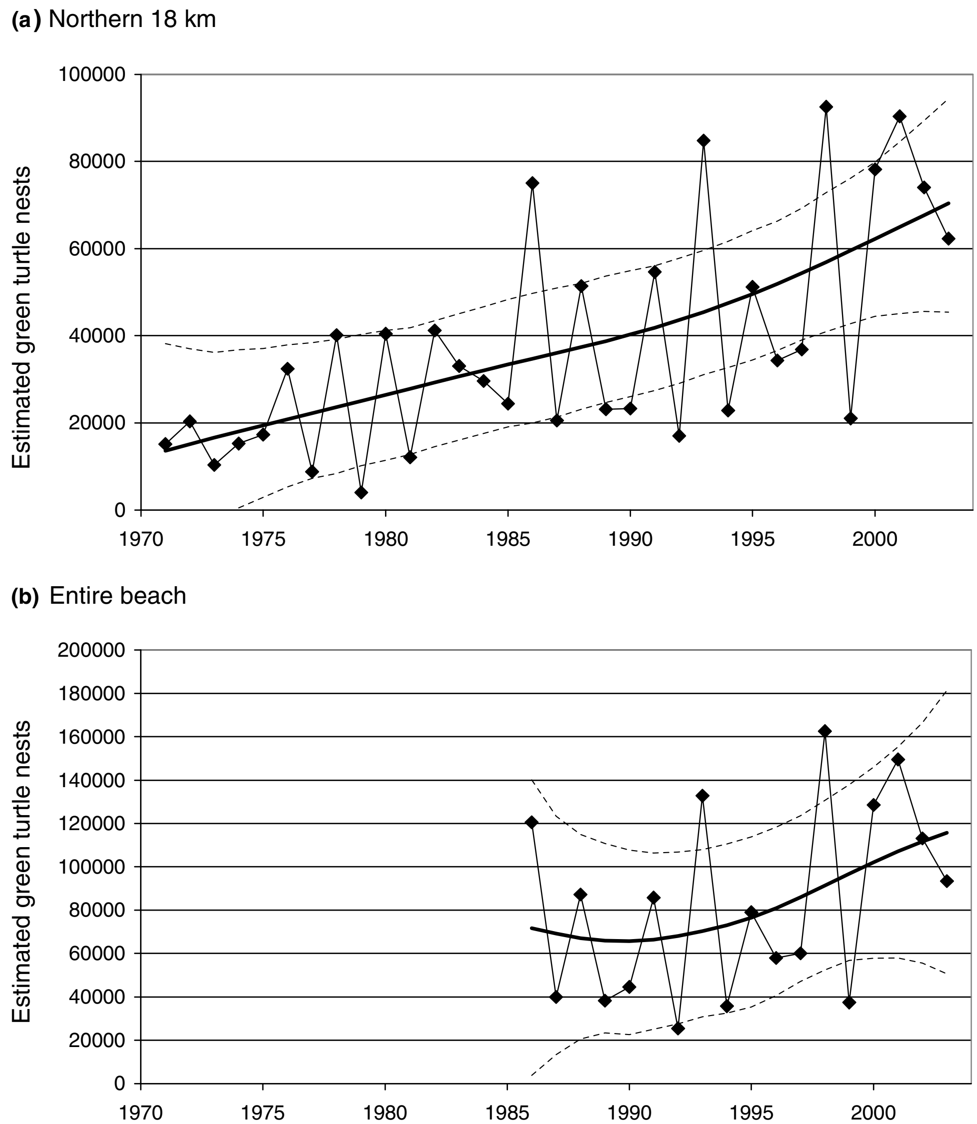

Fig. 2. (a,b) Green turtle nesting trend at Tortuguero, Costa Rica.

females year^{-1} (Bowen et al., 1992), and 5723–23,142 females year^{-1} (Carr et al., 1978). The explanation is the increase in nesting over the past 32 years.

A comparison between our estimate and 34 index populations (Seminoff, 2002) indicates that Tortuguero and Raine Island, Australia, represent the two largest green turtle rookeries worldwide.

4.3. Conservation efforts and policy decisions affecting trend

The Tortuguero green turtle population's main nesting, feeding and mating grounds are located in Costa Rica, Nicaragua, and Panama (Carr et al., 1978). Recaptures of tagged green turtle females in these three countries make up 92.3% of all Tortuguero green turtle tag returns (Caribbean Conservation Corporation, Unpublished data). Therefore, events and policy decisions in these countries are likely to have had the greatest impacts on green turtle use and survivorship. Key policy decisions include the ban on egg and turtle collection at Tortuguero in 1963 (Government of Costa Rica, 1963), the prohibition of export of calipee in 1969 (Government of Costa Rica, 1969), the declaration of Tortuguero National Park by executive decree in 1970 (Government of Costa Rica, 1970) and by law in 1975 (Legislative Assembly, 1975). These decisions contributed to improved protection for green turtles on and in the vicinity of the nesting beach. Hatching success data were not available until 1977 (Fowler, 1979) so the exact effect of the policy decisions on hatchling production remains unknown. However, the strengthening of protection in the 1960s and 1970s is likely to have contributed to increased hatchling production. Caribbean green turtles may take 26+ years to reach sexual maturity (Frazer and Ladner, 1986; Zug and Glor, 1998;

Bjorndal et al., 2000). Therefore, increased hatchling production since 1963 could have contributed to increased recruitment to the adult population and explain the increase in nesting since the late 1980s. The 1983 executive decree (Government of Costa Rica, 1983), modified in 1988 (Government of Costa Rica, 1988) that allowed fishermen from Limón, Costa Rica, an annual catch of 1800 green turtles, may have increased extractive use and hence had a negative effect on adult survivorship. Increased illegal hunting of green turtles in the mid-1990s (Troëng, 1998) also negatively affected adult female survivorship. Development of ecotourism activities in Tortuguero, since the mid-1980s, has provided alternative livelihoods for many villagers and has lessened the impact of extractive use on the rookery (Troëng et al., 2002). The ban on green turtle fishing (Costa Rican Fisheries Institute, 1999; Sala IV, 1999) coupled with increased enforcement are likely to have diminished hunting and increased adult survivorship in Costa Rica since 1999 (Troëng et al., 2002).

In Nicaragua, important policy decisions include the ban on Cayman Island turtle fishing vessels by the mid-1960s and the subsequent domestic processing of green turtles for export between 1968 and 1976 (Nietschmann, 1973; Lagueux, 1998). Nietschmann (1973) estimates that up to 10,000 green turtles were captured annually between 1969 and 1971. Nicaragua became a signatory to the Convention on International Trade in Endangered Species of Fauna and Flora (CITES) in 1977 (Hemley, 1994) and export was discontinued. The civil war 1980–1988 resulted in the relocation of some coastal communities and fewer turtles were caught (Lagueux, 1998). Since the conflict ended, green turtle fishing for domestic consumption has increased (Lagueux, 1998). In 1996, an estimated 10,166 green turtles were caught (Lagueux, 1998). The capture levels in Nicaragua may now be higher than ever (Lagueux, 1998).

Changes in legislation and conservation efforts in other Caribbean nations may also have contributed to the increase in nesting. The declaration of marine protected areas, strengthening of national and international legislation throughout the wider Caribbean region have resulted in greater protection for green turtles and their habitats and consequently have contributed to improve survivorship rates.

The Tortuguero green turtle trend demonstrates that long-term conservation efforts can reverse nesting declines and offers hope that adequate management can result in recuperation of endangered sea turtle species.

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