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Population Structure and Growth of Immature Green Turtles at Mantanani, Sabah, Malaysia

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Abstract.—In Southeast Asia, virtually all knowledge about sea turtle biology is derived via nesting beach studies. This study investigated life-stage parameters for a foraging population of immature Green Turtles *Chelonia mydas* off the coast of Borneo, Malaysia, to elucidate a significant portion of the at-sea life-stage component. Mark–recapture provided new data on localized movements between captures, growth, and residency period. Laparoscopic examination provided information on sex ratios and maturity. Turtles moved only an average of 380 m between recaptures and exhibited site-fidelity over several recaptures spanning up to two years. Size classes suggested all animals were juveniles and ranged from 38–80 cm CCL. Growth rates among recaptures averaged 3.6 cm yr^{-1}. Laparoscopic examinations of the gonads confirmed that all individuals were immature, with a sex ratio of 1M : 4F. These initial data on foraging *C. mydas* population structure and dynamics are of use for life-stage population models and turtle management and recovery planning.

Nesting turtle populations have been well documented in Southeast Asia (see Chan, 1990; Trono, 1991; Basintal and Lakim, 1993; Pilcher and Ismail, 2000; Limpus et al., 2001; and references therein), but scant information exists on foraging populations in the region. Demographic data are critical to determine how turtle populations will be influenced by various natural and anthropogenic stresses, yet there is no published information for Southeast Asian *Chelonia mydas* on sex ratios in the wild or on the dynamics of turtle populations with regard to growth, survival and sex ratios and no descriptions of nonadult components of the populations. These data are crucial and among the top knowledge priorities to understand the status of turtles in those life stages least studied by modern science.

Particularly lacking for Southeast Asia, long-term estimates of population abundance trends are needed to model sea turtle demography (sensu Chaloupka, 2002) and to develop a better understanding of long-term ecological processes (Inchausti and Halley, 2001). Population abundance estimates, such as those based on foraging ground capture–mark–recapture programs initiated in the present study, can provide detailed sex and age-class-specific demographic information (Limpus and Chaloupka, 1997; Chaloupka and Limpus, 2001, 2002).

Sea turtle population dynamics are the result of the interrelationship between natural and anthropogenic stressors that include environmental variability (including climate change), terrestrial habitat availability and quality, and direct and indirect fishing mortality (National Research Council, 1990; Lutcavage et al., 1997). Residence time at foraging habitats is likely also influenced by food availability and competition. Of interest to modern management are factors that drive both long-term population growth rates and short-term variability in populations (Heppell et al., 2003), but our understanding of these factors in Southeast Asia is limited both spatially and temporally. Few studies have lasted decades (temporally limited), and the handful of detailed studies have been confined to nesting beaches (spatially limited) or subject-specific pure research, with no data emerging on aspects of turtles' lives in the foraging grounds, where they spend the vast majority of their lives. The data provided by this two-year study represent the foundations for long-term demographic models for *C. mydas* in the region.

The current study gathered baseline information on foraging juvenile turtle populations that supply mature adults to regional nesting sites. The foraging ground surrounding Mantanani Island (Sabah, Malaysian Borneo), identified as a pilot project site for the study of Southeast Asian foraging turtle populations, is among the first documented foraging sites for Green Turtles in the region.

Materials and Methods

Captures of juvenile Green Turtles, *C. mydas*, were carried out around Mantanani Island (6.71°N, 116.35°E), northwest of Sabah, Malaysia, in December 2006; January, April, and October 2007; January, September, and December 2008; and February 2009. Mantanani Island is bordered by a 120-ha silt/sand lagoon on the southern side with patchy seagrasses (mostly *Halophila ovalis* and *Halophila uninervis*), where all turtle captures took place. The lagoon north of the island is mostly reef substrate, and no turtles were recorded there on any of the trips. A submerged reef surrounds the island and the southern lagoon, sloping gently to depths of 5–10 m before ending at a sandy substrate (Fig. 1).

Rodeo-style captures (see Limpus and Reed, 1985) were conducted from a 4.6-m boat with 60-hp engine weaving in and out from the shallowest waters (approximately 30 cm) to deeper waters (approximately 2.5 m) with limited visibility or where divers could not reach the turtles. Two bow observers searched for turtles, and each sighted turtle was pursued until it was either captured or lost. Capture selections were made regardless of the size or location of the turtle.

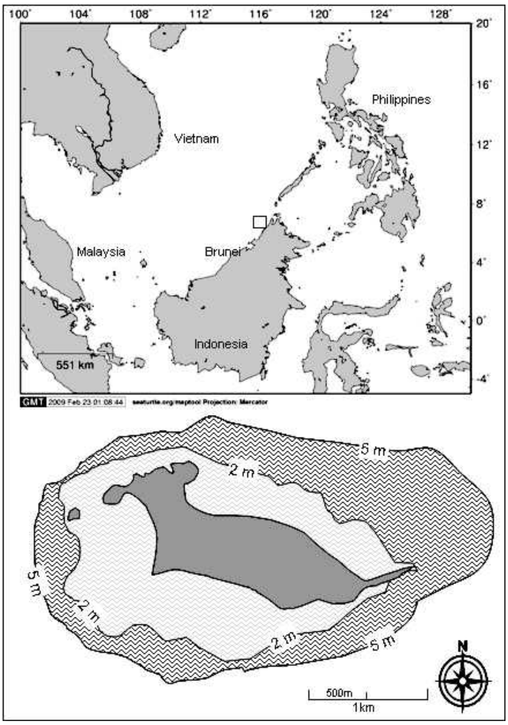

FIG. 1. Diagram of Mantanani Island off the north coast of Borneo. Juvenile Green Turtles were captured only in the shallow lagoon to the southeast of the island (base graphics from seaturtle.org Maptool, http://www.seaturtle.org/maptool/).

The time and location of turtle sightings were recorded as waypoints on a Garmin 168 12-channel GPS unit. Upon capture, the turtles were flipper-tagged using monel tags (until April 2007) or titanium tags (after October 2007). Upon return to the base vessel, turtles were weighed on a Salter spring balance (±0.1 kg) and measured for curved carapace length (CCL; ±0.1 cm). Only first-time capture data were used for size and mass analysis. Population size was approximated through capture–mark–recapture data using MARK Version 5.1 (White and Burnham, 1999).

Turtles were inspected for general appearance. External signs of damage or sickness were photographed, as well as healed incision scars of previously laparoscoped recaptured turtles. The turtles were examined internally using a BAK 30°, 5-mm × 30-cm laparoscope. Analgesics were not used to prevent masking of symptoms of or reactions to potential subcutaneous embolisms. We always verified that the trocar had penetrated the peritoneal cavity prior to proceeding with the internal examination, and records were kept on unintended intestinal perforations from the laparoscopy procedure. Turtles were scored for sex and appearance of gonads (oviduct size and shape, color of ovaries in females; testes size, shape and color, and shape of epididymis in males) following Miller and Limpus (2003). Following laparoscopic examination, two sutures of self-dissolving catgut were used to seal the 0.8–1.0 cm incision. Turtles were carefully returned to the sea within one to two hours of capture and their behavior observed as they swam away from the base vessel.

RESULTS AND DISCUSSION

Rodeo captures over eight 3-day trips of approximately 8–10 h of rodeo capture effort each trip resulted in a total of 118 captures, of which 75 were new turtles and 43 were recaptures of turtles previously tagged during the project. This represents a CPUE of 1.48–1.84 turtles per hour. Of the recaptured turtles, 28 (37.3%) were recaptured once, 11 (14.7%) were captured twice, and four (5.3%) were recaptured three times. No turtles tagged elsewhere were detected during the study. Distances between 43 capture and subsequent recaptures ranged from 31–1,760 m and averaged around 359 m (SD = 390 m), suggesting a degree of site fidelity even though they were all released following laparoscopic examinations at least 1,000–1,500 m away from where they were captured. The capture–mark–recapture data suggest a population of turtles in the shallow waters around Mantanani of around 187.3 (SE = 18.19) individuals (using MARK population estimate) and indicates turtles were able to return to areas where they were first captured.

Size and mass analysis was conducted only for first-time captures. The average carapace length was 47.4 cm (SD = 6.60, range = 36.0–79.9, $N = 75$) and average mass was 12.1 kg (SD = 6.90, range = 5.5–60.0, $N = 75$) as depicted in Figure 2, differentiating between sexes. Males were slightly smaller than females (ANOVA: $F_{69,14} = 3.003$, $P = 0.087$), although this is possibly a function of the small sample size for males (15). Four recruits to the foraging population were identified through clean, unscratched plastrons (indicating a lack of benthic resting behavior). The new recruits measured an average CCL of 38.1 cm (SD = 1.51, range = 36.0–39.5) and weighed an average 6.38 kg (SD = 0.65, range = 5.5–7.0). These results compare to Pacific Green Turtle recruits (~35 cm CCL, ~5 kg), approximated to be around 6 yr of age Balazs and Chaloupka, 2004), and also with Green Turtles at Fog Bay, Australia, which recruited at about 38 cm (Whiting and Guinea, 1998), and at Shoalwater Bay, Australia, where they recruit also at approximately 40 cm (Limpus et al., 2005) and at ~5–6 yr of age.

Growth rates were evident in 17 of the recaptures, with intervals between initial capture and subsequent recapture ranging from 47–661 days. The average growth rate for all individuals was 3.60 cm yr^{-1}. The exclusion of the one negative growth point results in only marginally higher mean (3.84 cm yr^{-1}); but given the accuracy and double measurement practices (± 1 mm), it is most likely that the turtle simply did not grow at all. These growth rates were significantly higher (one sample *t*-test: $t_{16} = 0.76$, $P = 0.228$) than the 1.43 cm yr^{-1} for larger, immature turtles in the Southern Great Barrier Reef (Limpus, 1979) and also higher than the 2.3 cm yr^{-1} to 2.7 cm yr^{-1} for similar-sized *C. mydas* in Florida (Bresette and Gorham, 2001). However, they are significantly lower than 5.3 cm yr^{-1} ($t_6 = -0.593$, $P = 0.280$) reported for Florida by Mendonca (1981).

Turtles recruit at around 38 cm CCL and are generally absent after 62 cm CCL, suggesting a

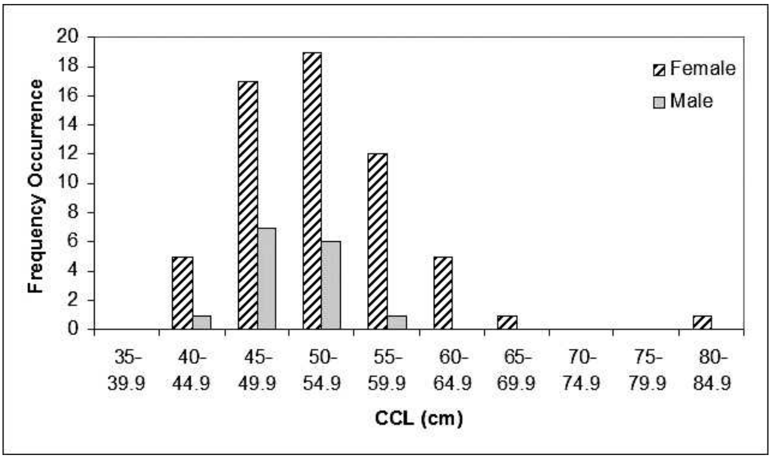

FIG. 2. Length distribution for Green Turtles at Mantanani, December 2006 to February 2009.

residence period of up to 6–7 yr (at a steady growth rate of 3.6 cm yr^{-1}). Although some turtles were recaptured after 550–600 days, the majority of recaptures suggest that residence times may be shorter than this (mode = 329 days). The capture–mark–recapture data along with the continued arrival of new recruits and the upper limits on CCL (only one ''large'' turtle was captured during the study) suggest that these turtles may be using the site as a temporary juvenile foraging ground where they settle after the oceanic development phase, feed on the limited nutrients for a few years, and move on to more productive foraging grounds once food resources become limiting some 1–6 yr later. Larger turtles may inhabit deeper reef-bordering waters surrounding the islands (only one has been sighted since the inception of the project), but it is uncertain why these larger turtles do not venture up and over the reef as they do off similar reefs in Sabah (such as on Sipadan Island, pers. obs.).

Laparoscopic examination identified that all individuals were sexually immature, with narrow 1–2 mm straight white oviducts in females, flat testes and epididymis not obviously ridged in males. Only one of these turtles exceeded 65 cm in CCL (Fig. 2). The sex ratio was 15 males to 60 females (1M : 4F). These findings were significantly female biased compared to a 1 : 2 ratio ($\chi^2 = 5.82$, $P < 0.01$) and a 1 : 5 ratio ($\chi^2 = 0.31$, $P > 0.05$) but not significantly different from a 1 : 3 ratio ($\chi^2 = 1.15$, $P > 0.05$). This female-biased population structure was also significantly more female-biased ($\chi^2 = 5.57$, $P < 0.05$) than the 1M : 2F ratio recorded for primarily juvenile and prepubescent turtles from Moreton Bay, Australia (Limpus et al., 1994) and the adult sex ratio of 1.0M : 3.3F ($\chi^2 = 0.59$, $P < 0.05$) recorded at Shoalwater Bay (Limpus et al., 2005) but not significantly different to the juvenile sex ratio 1.0M: 1.7F ($\chi^2 = 2.69$, $P > 0.05$) recorded at Shoalwater Bay (Limpus et al., 2005). There was no significant variance among sex ratios when these were subdivided by 5-cm CCL size classes (ANOVA: $F_{1,74} = 3.003$, $P = 0.09$). The 80% female bias warrants further investigation, because long-term use of hatcheries in the region have released many cohorts of female-only hatchlings (Tiwol and Cabanban, 2000). With molecular sequencing methods, the genetic stock and origin of these juveniles will soon be identified to eventually link this population to potential impacts through hatchery activities in the region.

Of the 75 laparoscopy procedures, four resulted in the trocar and cannula penetrating the intestinal tract during insertion. All four of these animals were considered ''healthy'' at capture (not emaciated) and it is likely the cause of the perforation was a section of intestinal tract running close to the peritoneal membrane and a deeper than normal insertion of the scope apparatus. Of these turtles, one was subsequently recaptured three times, the first being 144 days after the procedure. She was not measured at that time. She was then recaptured again after another 185 days during which she had grown by 3.3-cm CCL and 3.3 kg. She was then recaptured after another 332 days, with an increase of 1.1-cm CCL and 1.8 kg. At all recaptures, her behavior was normal and active. Overall, the turtle was seen over a span of 661 days. This information indicates turtles are able to survive accidental intestinal perforations and continue to grow. A second turtle was recaptured twice subsequently (after four and 10 months) in apparently healthy condition. No growth or mass increase data exists for this turtle. Techniques were modified following these injuries to allow for a shorter insertion at a slightly more oblique angle inward toward the spine, and no further instances were recorded. Long-term studies of this kind in Australia have also revealed that such puncture wounds can heal (C. Limpus, pers. comm.; Dobbs et al., 2007). Each examination was invariably completed within approximately 3–5 min.

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