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Marine Turtle Nesting and Hatching in Tun Mustapha Park, Malaysia, Revealed by Community-Based Monitoring

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Abstract.—**Tun Mustapha Park (TMP) is a marine protected area in Malaysia where marine turtles are regularly sighted; however, more comprehensive and updated information about nesting marine turtles at Tun Mustapha Park is needed to help guide effective marine turtle conservation. Here, we present the first report on the status of marine turtle nesting and hatching at Tun Mustapha Park. World Wide Fund for Nature-Malaysia (WWF) in partnership with government agencies organized the local community-based monitoring that investigated 11 nesting beaches from 2009 to 2020 (12 y) and recorded the following results: 85 Green Turtle (*Chelonia mydas*), 23 Hawksbill Turtle (*Eretmochelys imbricata*), and three Olive Ridley Turtle (*Lepidochelys olivacea*) nests. Despite a small nesting population of marine turtles compared to other sites in Malaysia, the results showed differences in nesting seasonality and hatching success between Green and Hawksbill Turtles. The Green Turtles nest mainly between June and October, whereas the Hawksbill Turtles nest mainly between March and June. The average hatching success of hatchery-incubated Green Turtle nests (75.7 ± 20.6%; range, 28.9–100.0%, n = 23) was higher than Hawksbill Turtle nests (51.7 ± 23.7%; range, 2.1–92.5%, n = 10). Our study provides an up-to-date status on the nesting and hatching success of marine turtles at Tun Mustapha Park. It demonstrates that community-based monitoring is essential for the conservation of marine turtle populations in Sabah, Malaysia.**

Key Words.—Green Turtle; Hawksbill Turtle; marine protected area; Olive Ridley Turtle; Southeast Asia

Introduction

Five of the seven marine turtle species are known to nest in Southeast Asia: Green Turtles (*Chelonia mydas*), Hawksbill Turtles (*Eretmochelys imbricata*), Leatherback Turtles (*Dermochelys coriacea*), Loggerhead Turtles (*Caretta caretta*), and Olive Ridley Turtles (*Lepidochelys olivacea*; Thorbjarnarson et al. 2000; Shanker and Pilcher 2003; Ernst and Lovich 2009). The Green Turtle is the most common, and it is widely distributed in Malaysia (Chan 2006; Joseph et al. 2021), the Philippines (Trono 1991), Indonesia (Adyanna et al. 2007) and Thailand (Yasuda et al. 2006). The Green Turtle annual nest numbers can be up to 15,000 in Sabah Turtle Islands Park, Malaysia (Joseph et al. 2021) and 10,000 to 20,000 in Berau Islands, Indonesia (Adyanna et al. 2007). The Hawksbill Turtle is also common in Southeast Asia. However, nesting populations have dropped significantly compared to their historical levels in Terengganu, Malaysia (annual average of 45 nests in the 1980s to 17 nests in the 1990s; Chan 2006), despite several relatively stable populations such as Sabah Turtle Islands Park and Melaka, Malaysia (Salleh et al. 2017, 2018; Joseph et al. 2021). Southeast Asia was known for thriving Leatherback Turtle rookeries in the Northeast and East Indian Ocean and the South China region, but the population has dramatically fallen in Terengganu, Malaysia (10,000 annual nesting in the early 1950s, to less than a dozen in the 2000s; Nel 2012). The Olive Ridley Turtle nests in smaller numbers in Southeast Asia (an average of 10 nests in Indonesia in 1984; an average of 10 nests per year in Malaysia between 1998 and 1999 and in Thailand between 1996 and 2000; Abreu-Grobois and Plotkin 2008). Loggerhead Turtles nest in Myanmar, however, sometimes they are confused with the Olive Ridley Turtles (Thorbjarnarson et al. 2000), so there is no reliable data of the size of the population. All five species are on the Red List of the International Union for Conservation of Nature (IUCN 2022), with the Green Turtle categorized as Endangered, Hawksbill

Turtle as Critically Endangered, and the Olive Ridley Turtle and Loggerhead Turtle as Vulnerable. Globally, the Leatherback Turtle is categorized as Vulnerable, but the Pacific Ocean subpopulations are classified as Critically Endangered (Benson et al. 2020).

Marine turtle conservation in the state of Sabah, Malaysia (formerly known as North Borneo) started in 1927 during the administration of the North Borneo British Company, well before the formation of independent Malaysia in 1963 (Irwan et al. 2016). Selingaan, Bakkungan Kecil, and Gulisaan on the east coast of Sabah were declared a national park in 1977 and later established as the Sabah Turtle Islands Park (TIP; Irwan et al. 2016). After the establishment of TIP, marine turtle conservation activities, including evaluation of other areas to be marine protected areas for marine turtles, beach patrols, nesting female tagging programs, and nests incubation in hatcheries were then extended to other parts of Sabah such as Tun Mustapha Park (TMP, Fig. 1), the islands of Sandakan and Semporna, and Sipadan Island Park (Joseph et al. 2021). Marine turtles in Sabah are legally protected under the Wildlife Conservation Enactment and Parks Enactment that started in 1997 and 1984, respectively (Jani et al. 2020; Joseph et al. 2021).

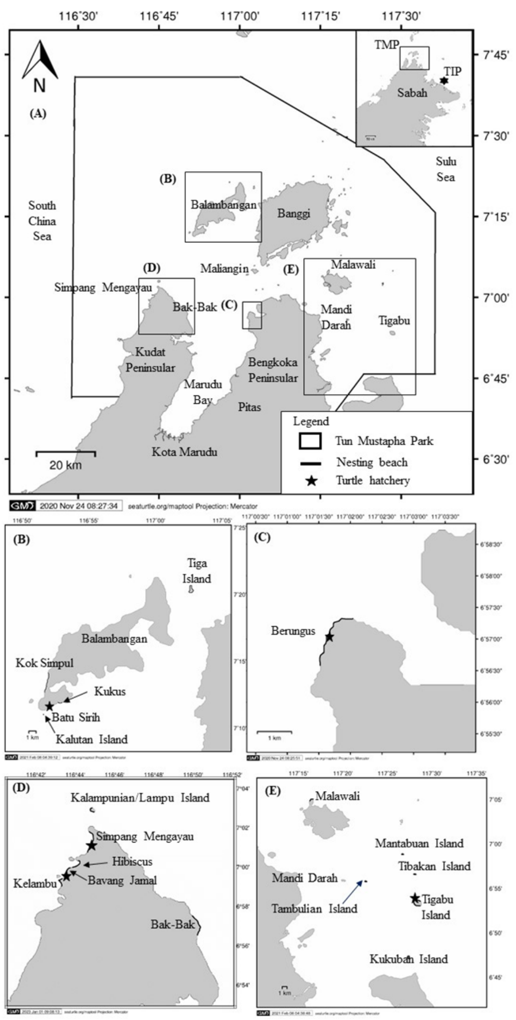

Figure 1. (A) Tun Mustapha Park (TMP) located in the state of Sabah in Malaysia. For the study period from 2009 to 2020, 11 nesting beaches were monitored. We clustered them into four major locations: (B) Balambangan Island, (C) Berungus, (D) Kudat Peninsular and (E) Tigabu Islands complex. Non-monitored nesting beaches are Bak-Bak, Hibiscus, Kalampunian/Lampu Island, Kelambu, Malawali Island and Tiga Island. The star symbol indicates the location of turtle hatcheries (TIP: Sabah Turtle Islands Park). (Maps produced using SEATURTLE.ORG Maptool).

Pushpa Palaniappan (unpubl. report) first identified Green and Hawksbill Turtle nesting beaches at Tun Mustapha Park in 2000 through interviews with relevant government agencies and fishers associations and in situ verification of beaches. Later, based on a semi-structured standardised questionnaire completed through individual and group interviews with coastal communities throughout Tun Mustapha Park in 2006 and 2007, Robecca Jumin et al. (unpubl. report) reported three species of marine turtles, the Green, Hawksbill, and Leatherback Turtles in Tun Mustapha Park, with the Green Turtle being the most common species. The Green and Hawksbill Turtles were reported to nest, and the Leatherback Turtles were sighted in the sea. Nesting beaches were reported on the mainland and the islands of Tun Mustapha Park, mainly on Banggi and surrounding islands and in areas between Mandi Darah and Tigabu Islands (Fig. 1) (Robecca Jumin et al. unpubl. report; Pushpa Palaniappan unpubl. report). Aside from nesting beaches, foraging grounds for Green and Hawksbill Turtles were reported around Maliangin Island and the coastal waters of Berungus Beach in Tun Mustapha Park (Robecca Jumin et al. unpubl. report).

In 2009, World Wide Fund-Malaysia initiated a community-based marine turtle monitoring and conservation programme in partnership with Sabah Parks, Sabah Wildlife Department and local communities (World Wide Fund-Malaysia pers. comm.). Here, we applied the results of these collective nesting beach monitoring efforts, collected between 2009 and 2020, to characterize the marine turtle nesting and hatching status in Tun Mustapha Park. To our knowledge, this is the first assessment of long-term spatial and temporal trends in marine turtle nesting and hatching activity in Tun Mustapha Park. This comprehensive and updated information is important to target effective conservation actions in Tun Mustapha Park.

Materials and Methods

Study site.—We conducted the study in Tun Mustapha Park (7°1'3.09" N, 117°2'37.21" E; Fig. 1), which is the second largest marine park in Malaysia (898,762.76 ha; Sabah Parks 2017). Tun Mustapha Park is located in the northern state of Sabah, consisting of the Kudat, Pitas and Kota Marudu districts. The park covers the coastal waters of the Kudat and Bengkoka Peninsulas and four island groups called the Banggi (51 islands), Balambangan (three islands), Malawali and the Tigabu Islands complex (seven islands; Robecca Jumin et al., unpubl. report; Fig. 1). The peninsulas and islands contained sandy beaches for marine turtle nesting. These beaches are predominantly inhabited by coastal villagers, with several other beaches used for small-scale recreational activities such as swimming, snorkeling, and beach camping.

Beach patrols, nesting activity, and spatio-temporal distribution.—Since 2009, World Wide Fund-Malaysia, Sabah Parks, Sabah Wildlife Department, Kudat Turtle Conservation Society (KTCS), and local communities have been monitoring beaches in Tun Mustapha Park. The monitoring started at one beach (Berungus) in 2009, and now the number of monitored beaches has increased to 11 nesting beaches. Honorary Wildlife Wardens in the local communities, trained by Sabah Wildlife Department, and Honorary Park Rangers, trained by Sabah Parks, monitored the beaches and operated hatcheries. Survey periods and efforts were diverse among beaches (daily to three times per week), but nocturnal or diurnal surveys were typically done once a day at each nesting beach (Table 1). Surveys were conducted using standardized nesting beach monitoring protocols, including recording the date, time, beach location, species identification, nest identification, relocation to hatcheries, and excavation (Sabah Wildlife Department 2016a,b).

When a turtle was encountered nesting on the beach, it was carefully approached from behind after oviposition was completed and backfilling the nest with sand was initiated. The wardens and rangers recorded the beach location, turtle species, date and time of encounter, and whether or not it was nesting. They then measured the curved carapace length (CCL) and the curved carapace width (CCW; Bolten 1999). Both carapace measurements were recorded to the nearest centimeter (cm) using a fibreglass tape measure (± 0.1 cm). The turtle was examined for the presence of existing flipper tags, and if no tags were found, two Inconel tags (Style 681, National Band and Tag Company, Newport, Kentucky, USA) were applied, with one tag attached proximally and adjacent to the first large scale on the posterior edge of each front flipper (Sabah Wildlife Department 2016b). The turtle was then left to crawl back to the sea. If the nesting event was missed, the nesting turtle species were identified based on the characteristics of the crawl tracks. Crawls and body pits were reported as landings and nesting events as nests (Sabah Wildlife Department 2016a).

We obtained 12 y of nesting and hatching data (2009–2020) at 11 beaches (total: 13.25 km of shoreline) from Sabah Parks, Sabah Wildlife Department, Kudat Turtle Conservation Society, and World Wide Fund-Malaysia. We clustered the 11 beaches into four major locations (Fig.1): (1) Balambangan Island (three beaches: Kalutan Island, Kok Simpul, and Kukus); (2) Berungus (one beach); (3) Kudat Peninsular (two beaches: Bavang Jamal and Simpang Mengayau); and (4) Tigabu Islands complex (five beaches: Kukuban Island, Mantabuan Island, Tambulian Island, Tibakan Island, and Tigabu Island). The same wardens or rangers patrolled some beaches close to each other on a single night. Hence those beaches were clustered based on locations. In addition to the systematic survey data, we also compiled opportunistic nesting reports from other beaches within Tun Mustapha Park. Systematic surveys were typically not conducted at these beaches because the number of nests was assumed to be low, but residents and tourism operators opportunistically reported the nesting activity to either Sabah Parks, Sabah Wildlife Department, World Wide Fund-Malaysia, or Kudat Turtle Conservation Society.

Reproductive output.—Eggs from all nests were transferred to one of five hatcheries located at Batu Sirih,

Table 1. Summary of nesting beach surveys in Balambangan Island, Berungus, Kudat Peninsular, and Tigabu Islands complex, from 2009 to 2020 at Tun Mustapha Park (11 beaches; 6,024 survey days in total), Malaysia. At Kudat Pennisular, both Honorary Wildlife Wardens (HWW) and Park Rangers were investigators; otherwise only HWW were investigators at the other sites.

Locations	No. of beaches	Year	Month	No. of survey days (per year)	Time (h)
Balambangan Island	3	2019	March to September	135 d	0600–0800
Berungus	1	2009 to 2020	October to March	2,096 d (92–183)	0600–0800
Kudat Peninsular	2	2012 to 2020	January to December	2,915 d (180–365)	2000–0400
Tigabu Islands	5	2017 to 2020	March to September	878 d (184–280)	2000–0400
Total	11			6,024 d (92–365)	

Berungus, Simpang Mengayau, Bavang Jamal, and Tigabu (Fig. 1). The turtle nests were relocated following a standardized monitoring protocol, ideally within 2 h of oviposition to reduce disturbance to the egg incubation process (Sabah Wildlife Department 2016a). If nests were detected > 2 h after oviposition or during diurnal surveys, however, they were relocated due to the high risk of poaching if left in place. Eggs were carefully transferred into a pail and reburied in the hatchery sand. Egg clutches were reburied to a depth of about 75 cm for Green Turtles, and 45 cm for Hawksbill and Olive Ridleys turtles (Sabah Wildlife Department 2016a).

A mesh screen was used to surround each nest to contain emerging hatchlings, and the hatcheries were also covered with black netting to provide shade and avoid overheating the eggs. The nests were marked with a label containing the species, date, and number of eggs. Upon emergence, the date and number of live hatchlings were recorded. The hatchlings were then transferred into a pail for release in the evening. The nests were excavated on the 3rd day after the first hatchling emergence to determine egg survivorship (Sabah Wildlife Department 2016a). If no hatchling emerged, the wardens and rangers excavated the nest on the 70th day after the oviposition (Sabah Wildlife Department 2016a).

We evaluated the reproductive output using a formulae devised by Miller (1999):

$$\text{Total clutch size} = E + L + D + UD + UH + UHT + P$$

where E = emerged (hatchlings leaving or departed from the nest), L = live in the nest (live hatchlings left among shells and not in the neck of nest), D = dead in nest (dead hatchlings that have left their shells), UD = undeveloped (unhatched eggs with no obvious embryo), UH = unhatched (unhatched eggs with obvious embryo and excluding UHT), UHT = unhatched term (unhatched full-term embryo in eggshell or pipped with a small amount of external yolk material), and P = depredated (open, nearly complete shells containing egg residue). Once calculated, we used total clutch size to calculate:

$$\text{Hatching success (\%)} = [(E + L + D) / \text{Total clutch size}] \times 100$$

$$\text{Emergence success (\%)} = [E / \text{Total clutch size}] \times 100$$

Live hatchlings found during nest excavation were collected, counted, transferred into a pail and released in the evening. We calculated the incubation period from the date of the nest being laid until the date of the first hatchling emergence (Miller 1999). We also visited all the hatcheries to ensure their operations followed the guidelines provided by the Sabah Wildlife Department (Sabah Wildlife Department 2016a).

Poaching.—The wardens and rangers recorded poached nests if there was evidence of human removal of eggs (e.g., the presence of probing sticks, digging and broken eggshells, and human footprints around the nesting site). They distinguished poached nests from nests attacked by wild animals by confirming no footprints of animals such as dogs and monitor lizards.

Statistical analyses.—All data are reported as mean ± standard deviation (SD) unless otherwise stated. We carried out all statistical analyses using IBM SPSS Statistics for Windows, Version 28.0.1, Armonk, New York, USA. We tested for differences between Green Turtle and Hawksbill Turtle clutch size, hatching success, and emergence success of hatchlings using a non-parametric Mann-Whitney test. We also tested the differences in hatching success and hatchling emergence success between Green Turtle and Hawksbill Turtle nests in Tigabu hatchery using the Mann-Whitney test. We used Kruskal-Wallis to test for differences in hatching and hatchling emergence success of Green Turtle nests among hatcheries, and then pairwise Wilcoxon tests with Bonferroni corrections. We used an independent sample *t*-test to test differences in incubation periods between Green Turtle and Hawksbill Turtle nests for combined hatcheries. The test was selected based on the normality of data by the Shapiro-Wilk test. Due to the small sample size ($n = 3$), Olive Ridley Turtle nests were not included in the data analysis. For all tests, $\alpha = 0.05$.

Results

Species and spatio-temporal patterns.—We found three species of marine turtles nesting on beaches at Tun Mustapha Park. The Green Turtles, Hawksbill Turtles, and Olive Ridley Turtles nest on the beaches of the Kudat Peninsular and Tigabu Islands complex, and only one species, the Green Turtle, nests on Balambangan Island and Berungus (Fig.1). Among 149 reports (2009 to 2020), only 127 (85.2%) were considered nesting events. Of these nests, 85 (66.9%) were Green Turtles, 23 (18.1%) were Hawksbill Turtles, three (2.4%) were Olive Ridley Turtles, and 16 (12.6%) were unidentified due to egg poaching and obscured turtle tracks (Appendix Table 1).

Six Green Turtle nests were found on Balambangan Island in 2019. In Berungus, 14 Green Turtle nests were recorded (1.17 ± 1.95 nests per year; range, 0–6 nests) from 2009 to 2020. At Kudat Peninsular, 20 Green Turtle nests (2.22 ± 1.64 nests per year; range, 0–6 nests), three Hawksbill Turtle nests (0.33 ± 0.50 nests per year; range, 0–1 nest), and one Olive Ridley Turtle nest were recorded between 2012 to 2020. Only five nests were unidentified to species level (0.44 ± 0.53 nests per year; range, 0–1 nest). At Tigabu Islands complex, 45 Green Turtle nests (11.25 ± 4.65 nests per year; range, 5–16 nests), 20 Hawksbill Turtle nests (5.25 ± 1.26 nests per year; range, 4–7 nests), and two Olive Ridley Turtle nests (0.50 ± 0.58 nests per year; range, 0–1) were recorded from the year 2017 to 2020. Only 11 nests were unidentified to species level (2.75 ± 1.71 nests per year; range, 1–5 nests).

Elsewhere outside of the 11 monitored beaches at Tun Mustapha Park, there were 27 opportunistic reports between 2009 and 2020. The reports revealed 12 nesting events containing eight Green Turtle nests and four unidentified species nests. These reports were from Bak-Bak (one Green Turtle nest), Hibiscus (three Green Turtle nests and three nests of unknown species), Kalampunian/Lampu Island (one nest of unidentified species), Kelambu (two Green Turtle nests), Malawali Island (one Green Turtle nest), and Tiga Island (one Green Turtle nest).

Seasonality.—As data for nesting month was not recorded for seven Green Turtle and one Hawksbill Turtle nests, we analyzed 78 Green, 22 Hawksbill, and three Olive Ridley Turtle nests. The cumulative number of nests across all years (2009 to 2020) and 11 beaches within Tun Mustapha Park showed that Green Turtles nest year-round except in May (Fig. 2). Green Turtles nested mainly between June and October (n = 52; 66.7%), with the highest number of nests observed in September (n = 13; 1.00 ± 1.54 nests per month; range, 1–8 nests; Fig. 2). On the other hand, Hawksbill Turtles nested mainly between March and June (n = 20; 90.9%), with a peak in April (n = 9; 0.75 ± 1.29 nests per month; range, 0–9 nests; Fig. 2). Olive Ridley Turtle nests were found to nest in February, March and November. Due to the rare incidence of Olive Ridley Turtle nesting, it is difficult to ascertain its nesting season (Fig. 2).

Morphometrics and tag presence.—The wardens and rangers measured 11 Green Turtle nesters on Bavang Jamal (n = 1) and Tigabu Islands Complex (n = 10) and three Hawksbill Turtles and one Olive Ridley Turtle nesters on Tigabu Islands complex. The ranges of the CCL and CCW were 79.0–104.0 cm (n = 11) and 62.5–94.0 cm (n = 11; Green Turtles), 68.0–106.7 cm (n = 3) and 60.0–89.9 cm (n = 3; Hawksbill Turtles), and 94.0 cm and 81.0 cm (Olive Ridley Turtle), respectively (Table 2). A Green Turtle with existing tags was observed nested at Tigabu Islands complex on 31 October 2018 with tag numbers PH0955m and PH0956m, which are from the Philippine Turtle Islands. The turtle was found to be tagged on 13 October 2018 at the nesting beach of Langaan Island, part of the Philippine Turtle Islands Park (Sulu Sea; Rizza Fernandez-Salinas, pers. comm). After measurements, the turtle was left with the existing tags.

There were no recorded tag recaptures from the Tun Mustapha Park tagging program, partially due to incomplete night patrols and tag losses. Furthermore, the implementation of the tags on nesting females was found to be inconsistent. Hence, there were no data to be analyzed further.

Reproductive output.—The wardens and rangers examined the clutch sizes for 71 Green, 15 Hawksbill, and two Olive Ridley turtle nests (clutch size data of 12 Green Turtles, eight Hawksbill Turtles, and one Olive Ridley Turtle were not recorded). Hawksbill Turtles laid more eggs in a single nest than Green Turtles (Table 2), however, egg numbers were not significantly different between the Green and Hawksbill Turtles (W = 469, n = 71, 15, P = 0.473). The two Olive Ridley Turtles

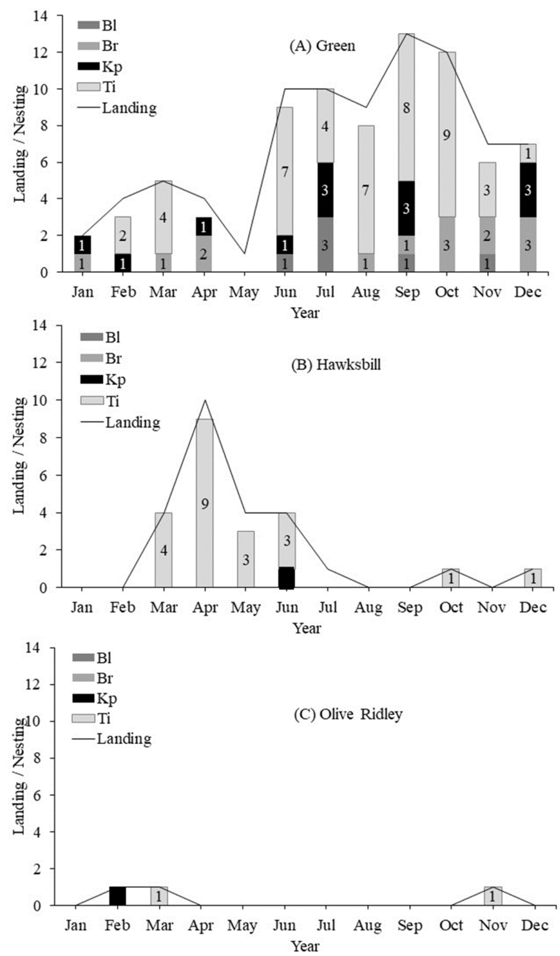

FIGURE 2. The cumulative number of reports (nesting and non-nesting events) and nesting per month for nest of (A) Green Turtles (*Chelonia mydas*; n = 78), (B) Hawksbill Turtles (*Eretmochelys imbricata*; n = 22), and (C) Olive Ridley Turtle (*Lepidochelys olivacea*; n = 3) from 2009 to 2020 in Balambangan Island (Bl), Berungus (Br), Kudat Peninsular (Kp), and Tigabu Islands complex (Ti) at Tun Mustapha Park, Malaysia.

Table 2. Morphometrics (curved carapace length, CCL; curved carapace width, CCW) (cm) and clutch size of nesting female Green Turtles (*Chelonia mydas*), Hawksbill Turtles (*Eretmochelys imbricata*), and Olive Ridley Turtles (*Lepidochelys olivacea*) in Tun Mustapha Park, Malaysia. The abbreviation SD = standard deviation.

	Green			Hawksbill			Olive Ridley	
Measurements	Mean ± SD	Range	n	Mean ± SD	Range	n	Value	n
CCL (cm)	94.6 ± 7.1	79.0–104.0	11	82.2 ± 21.3	68.0–106.7	3	94.0	1
CCW (cm)	83.3 ± 9.0	62.5–94.0	11	70.6 ± 15.9	60.0–89.9	3	81.0	1
Clutch size (number of eggs)	83.5 ± 34.8	3–169	71	93.7 ± 38.1	26–150	15	75, 83	2

nest were 75 and 83 eggs (Table 2). From the hatchery data available, we analyzed the incubation period from nests of 47 Green Turtle, 13 Hawksbill Turtle, and one Olive Ridley Turtle. Overall, the incubation period of Green Turtle nests rangesd from 43–68 d (n = 47; Appendix Table 2). The incubation period was similar among hatcheries: Balambangan (49–62 d, n = 5), Bavang Jamal (48–63 d, n = 8), Berungus (43–68 d, n = 10), Simpang Mengayau (52–63 d, n = 6), and Tigabu (44–64 d, n = 18). The incubation period of Hawksbill Turtle nests was 44 d (n = 1) and 46–64 d (n = 12) in Simpang Mengayau and Tigabu hatcheries, respectively (Appendix Table 2). The incubation period of the one Olive Ridley Turtle nest was 55 d (Appendix Table 2). The incubation period did not significantly differ between Green and Hawksbill Turtle nests (t = 0.644, df = 58, P = 0.522).

We evaluated the hatching and hatchling emergence success from 23 hatchery-incubated Green Turtle and 10 Hawksbill Turtle nests (hatching and hatchling emergence success data for 62 Green Turtles, 13 Hawksbill Turtles, and three Olive Ridley Turtle nests were not recorded). The overall hatching success of Green Turtle nests was 75.7% and was significantly higher than that of the 51.7% of Hawksbill Turtle nests (W = 175, n = 23, 10, P = 0.019; Table 3). The hatching success of Green Turtle nests did not significantly vary among hatcheries (χ^2 = 1.177, df = 2, P = 0.555; Table 3). Because all Hawksbill Turtle nests were incubated in Tigabu, the difference between hatcheries could not be tested in Hawksbill Turtles.

Overall Green Turtle hatchling emergence success of 68.6% was significantly higher than the 44.7% of Hawksbill Turtles (W = 171, n = 23, 10, P = 0.028; Table 3). The hatchling emergence success of Green Turtle nests differed signicantly among sites (χ^2 = 8.120, df = 2, P = 0.017). The success at Tigabu (75.5%) was significantly higher than at Berungus (21.2%; P = 0.002; Table 3). In Tigabu hatchery where both Green and Hakwsbill turtle nests were reported, there was a significant difference in the hatching success (W = 134, n = 17,10, P = 0.015) and the hatchling emergence success (W = 137, n = 17, 10, P = 0.008) between Green and Hawksbill Turtle nests (Table 3).

Poaching.—During the period studied, nests for 16 Green Turtles, seven Hawksbill Turtles, and one Olive Ridley Turtle (18.8% of the 85 Green Turtle nests, 30.4% of the 23 Hawksbill Turtle nests, and 33.3% of three Olive Ridley Turtle nests) had been poached before relocation to hatcheries. No disturbed nests by wild animals were recorded. Fourteen Green Turtle nests were poached at Tigabu Islands complex and two at Kudat Peninsular. There was no poaching of Green Turtle nests at Balambangan Island and Berungus. Meanwhile, poaching of seven Hawksbill and one

Table 3. Hatching and hatchling emergence success (%) of Green Turtles (*Chelonia mydas*; n = 23) and Hawksbill Turtles (*Eretmochelys imbricata*; n = 10). Turtle nests incubated in hatcheries at Tun Mustapha Park, Malaysia.

	Hatching success (%)		Hatchling emergence success (%)		
Areas	Mean ± SD	Range	Mean ± SD	Range	n
		Green Turtles			
Balambangan	76.3 ± 41.1	28.9–100.0	33.3 ± 57.7	0.0–100.0	3
Berungus	66.0 ± 25.3	38.1–87.4	21.2 ± 4.2	17.7–26.1	3
Tigabu	77.3 ± 16.5	33.3–100.0	75.5 ± 16.0	33.3–96.8	17
Total	75.7 ± 20.6	28.9–100.0	63.0 ± 31.0	0.0–100.0	23
		Hawksbill Turtles			
Tigabu	51.7 ± 23.7	2.1–92.5	44.7 ± 31.2	2.1–92.5	10

Olive Ridley Turtle nests occurred in Tigabu Islands complex.

Discussion

Nesting status and spatio-temporal distribution.—Our study provides comprehensive information on the nesting ecology of marine turtles at Tun Mustapha Park. We confirmed the nesting of Green Turtles and Hawksbill Turtles within Tun Mustapha Park and that Green Turtles are more common, as reported by Robecca Jumin et al. (unpubl. report) in 2006 and 2007. We also have documented the nesting of Olive Ridley Turtles within Tun Mustapha Park, something that was not recorded in previous reports. The number of Green and Hawksbill turtle nests in Tun Mustapha Park was very low compared to the annual nesting from rookeries in Southeast Asia, such as in Sabah Turtle Islands Park (14,000 Green Turtle nests per year, 200 Hawksbill Turtle nests per year), Philippine Turtle Islands Park (more than 1,000 nesting females per year), Penang (total 383 Green Turtle nests, 2010 to 2016), Terengganu (total 719 Green Turtle nests, 2007 to 2012), and Indonesia (93–812 Green Turtle nests per year, 2002 to 2006; Trono 1991; Adnyana et al. 2007; Abdul Mutalib et al. 2014; Salleh et al. 2020; Joseph et al. 2021). The poaching of eggs and nesting females for consumption and trade may be a reason for the lower nesting numbers at Tun Mustapha Park compared to other regions, but more investigation is needed to further assess this trend (Revuelta et al. 2012, 2013; Syed Abdullah 2016). Continuous monitoring of nests is important to understand the overall trend of the number of nests within Tun Mustapha Park.

Green Turtles appeared to nest year-round in the areas studied, with the highest number of nests observed from June to October. We acknowledge that survey months were different among beaches, yet this year-round nesting concurs with studies elsewhere in Sabah (Migliaccio et al. 2020; Joseph et al. 2021) as well as the greater Southeast Asia region (Adyanna et al. 2007; Appendix Table 3). Hawksbill Turtles generally were found to nest earlier than Green Turtles, from March to June in Tun Mustapha Park, as reported elsewhere in Sabah (Migliaccio et al. 2020; Joseph et al. 2021; Appendix Table 3). The difference in seasonality between Green and Hawksbill Turtles was also previously reported in Melaka, Negeri Sembilan (Malaysia) and D'Arros Island, Amirantes Group (Seychelles; Mortimer et al. 1993, 2011). Hawksbill Turtles in Tun Mustapha Park seemed to prefer the dry season (February to May; average monthly precipitation: 91–150 mm), as previously reported in northern Australia (Hoenner et al. 2016). In contrast, although Green Turtles nested year around, they mainly nested during the wet season (June to October; average monthly precipitation: 185–282 mm) when the sea surface temperature was relatively high (average 30° C; https://www.met.gov.my/en/). Peaks of nesting of Green Turtles and Hawksbill Turtles can either be due to changes in sea surface temperature and/or precipitation levels corresponding to the dry or wet season, or to differences among regions and populations (Mortimer and Bresson 1999; Lauret-Stepler et al. 2007; Dalleau et al. 2012; Hoenner et al. 2016). We could not

Table 4. Morphometrics (curved carapace length, CCL; curved carapace width, CCW) and reproductive outcome comparison for Green Turtles (*Chelonia mydas*) nesting in rookeries in Southeast Asian region (Sabah Turtle Islands Park, Malaysia; Penang, Malaysia; Turtle Islands, Philippines) and Western Pacific regions (Hawaii, USA; Great Barrier Reef, Australia, Commonwealth of the Northern Mariana Islands [CNMI], Micronesia). References for information are a Joseph et al. (2021); b Juanita Joseph (unpubl. report); c Salleh et al. (2020); d Salleh et al. (2019); e Trono (1991); f Balazs (1980); g Balazs et al. (2015); h Limpus (2009); i Limpus et al. (2003); j Summers et al. (2018).

Trait	Sabah Turtle Islands Park, Malaysia [a, b]	Penang, Malaysia [c, d]	Turtle Islands, Philippines [e]	Hawaii, USA [f, g]	Great Barrier Reef, Australia [h, i]	CNMI, Micronesia [j]
CCL (cm)	98.6 ± 5.9 (76.0–118.5)	101.0 ± 5.1 (90.0–110.0)	99.5	97.0 (78–113)	107 ± 5.5 (91–124)	102.2 ± 4.7 (87.1–111)
CCW (cm)	87.2 ± 5.7 (70.0–109.5)	89.3 ± 7.3 (67.5–102.0)	87.6	91.2 (80–107)	98.1 ± 5.04 (82.3–115.5)	92.5 ± 4.9 (76.7–103.2)
Clutch size	84.3 ± 21.8 (15–178)	110.42 ± 21.84	95.6	104 (38–145)	115.2 ± 27.9 (42–195)	93.5 ± 21.4 (32–186)
Incubation duration (d)	53.1 ± 4.2 (40–69)	--	54.3	--	--	--
Hatchery hatching success (%)	76 (53–85)	52	87.1	--	--	--
Hatchery hatchling emergence success (%)	--	--	85.7	--	--	--

confirm the existence of Leatherback Turtles reported previously (Robecca Jumin et al. unpubl. report), but we have documented the nesting of Olive Ridley Turtles in Tun Mustapha Park. Olive Ridley Turtles are generally not abundant in Southeast Asia (Chan 2006); thus, it is difficult to evaluate the population status of this species.

Reproductive output.—The mean clutch size (83.84 ± 33.20 eggs per nest) and incubation period (55.15 ± 6.21 d) of Green Turtles in Tun Mustapha Park are within ranges reported for the Southeast Asia region (Trono 1991; Pilcher and Basintal 2000; Joseph et al. 2021) but lower than other regions in Australia and Hawaii (Limpus 2009; Balazs et al. 2015; Table 4). The recorded three eggs in a Green Turtle nest could represent interrupted or an abnormal clutch (Bjorndal and Carr 1989; Almeida et al. 2011). The mean CCL of nesting Green Turtles in Tun Mustapha Park is 94.6 cm (range: 79.0–104.0 cm; n = 11), and is comparably smaller than the mean CCL reported elsewhere in the Southeast Asia region, such as in Sabah Turtle Islands Park (98.6 cm; Joseph et al. 2021), Penang (101.0 cm; Salleh et al. 2020), and the Philippines (99.5 cm; Trono 1991), and other Western Pacific regions such as Australia (107.0 cm; Limpus 2009), Hawaii (97.0 cm; Balazs et al. 2015) and Micronesia (102.2 cm; Summers et al. 2018). It is possible that the smaller mean CCL found here might be due to the small number of carapace measurements (n = 11) in this study, but it is worth reporting as smaller CCL is often associated with smaller clutch size (Mortimer et al. 2022). Bjorndal et al. (2011) suggested that the body size differences between nesting populations of marine turtles can also be driven by population density at foraging grounds, where the growth rate had been observed to be low in high density populations due to the factor of nutrition limitations. We do not know the foraging grounds of Green Turtles nesting at Tun Mustapha Park, however, and this is something that needs further investigation.

The mean CCL of nesting Hawksbill Turtles at Tun Mustapha Park is within the ranges reported for the Southeast Asian and the Western Pacific Ocean regions (Dobbs et al. 1999; Prakash et al. 2020; Gaos et al. 2021; Joseph et al. 2021; Appendix Table 4). The incubation period of Hawksbill Turtles at Tun Mustapha Park (53.92 ± 5.50 d) was also within the ranges reported for the Southeast Asian hatcheries (Pilcher and Basintal 2000; Appendix Table 4). The mean clutch size for Hawksbill Turtles in Tun Mustapha Park (93.73 ± 38.14 eggs) is smaller than that in Southeast Asia (Salleh et al. 2017; Joseph et al. 2021) and those in South Pacific and Western Pacific Ocean regions (Dobbs et al.1999; Prakash et al. 2020; Gaos et al. 2021; Appendix Table 4). It is difficult to infer the reasons due to limited samples on clutch size; however, body size or body condition is known to influence the clutch size in marine turtles (van Buskirk and Crowder 1994; Pilcher and Basintal 2000; Broderick et al. 2003).

Hatching success for hatchery-incubated Green Turtle nests in Tun Mustapha Park (75.7%) was similar to Sabah Turtle Islands Park (Joseph et al. 2021), higher than Penang (Salleh et al. 2019), but lower than the Philippine Turtle Islands (Trono 1991; Table 4). Hatching success for hatchery-incubated Hawksbill Turtles in Tun Mustapha Park (51.69%) was also comparable to Sabah Turtle Islands Park (Joseph et al. 2021), but lower than in Labuan (Ghazali and Jamil 2019; Appendix Table 4). The significant difference in hatching success between Green and Hawksbill Turtles in Tun Mustapha Park suggests that Hawksbill turtles might be more vulnerable to egg rotation or relocation. Furthermore, Hawksbill Turtle eggs might also be affected by temperature because of the shallower depth of eggs in the hatchery (45 cm) than Green Turtles (75 cm; Glen et al. 2005; van De Merwe et al. 2006). Although egg relocation is a common strategy for conserving marine turtles under high poaching or predation risks (Pfaller et al. 2008), there may be disadvantages when relocating eggs inappropriately. For example, embryonic mortality of eggs may be high when eggs are planted in hatchery < 5 h after oviposition, and sex ratios of hatchlings can be skewed if the nest temperatures within a hatchery differ from those on the natural beach, as observed at Smith Island and Cuthbert Bay of Andaman Island in 2000 nesting season (Mortimer 1999; Shanker et al. 2003; Phillott and Shanker 2018). Consulting hatcheries that report the high hatching success of Hawksbill Turtles (Ghazali and Jamil 2019) may help establish species-specific protocols to improve hatching success rates.

Hatchling emergence success was generally comparable to hatching success, but the Green Turtles in the Berungus hatchery were relatively low (hatching success: 66.0%; hatchling emergence success: 21.7%). It is difficult to infer the reason from the small number of nests in this hatchery, but improper hatchery operations may have led to low hatchling emergence success. For example, inappropriate depth of eggs may lead to low hatchling emergence success (Glen et al. 2005; van De Merwe et al. 2006). The hatcheries have been operating with the Sabah Wildlife Department guidelines since 2016; however, during our visit to all hatcheries, we found that several hatcheries were not appropriately built according to the guidelines and were also not well-maintained. Before 2016, there were no guidelines by relevant government agencies were developed. The low hatching rates of Hawksbill Turtle nests are alarming as a minimum 70% hatching success rate is needed to maintain population stability (Ali et al. 2004); hence improvements are needed. Suggested improvements include more training on best hatchery practices, sufficient equipment and materials for hatchery operations and nesting female taggings, sufficient patrollers to prevent nest poaching and ensure nesting females were not missed, and periodic evaluation of hatchery operations and supervision by relevant government authorities for annual improvement.

Conservation implication and conclusion.—Our study fills a significant gap in understanding the nesting status and conservation needs of marine turtles at Tun Mustapha Park. In contrast to the large turtle rookeries in Sabah Turtle Islands Park (Joseph et al. 2021), Tun Mustapha Park hosts only a small number of nesting turtles, however, the number of nests reported has been increasing over the years. Despite Tun Mustapha Park being declared a marine protected area in 2016, poaching of marine turtle eggs is still high in Tun Mustapha Park, and therefore, it is crucial to protect and conserve marine turtles in the area.

Our results were made possible through the significant contribution of local communities participating in nesting surveys to collect data and hatchery operation for egg incubation. The approach used here, involving local communities, should be encouraged in marine turtle conservation, especially when enforcement and monitoring resources of government agencies are limited (Olendo et al. 2017). Awareness and initiatives of local communities are important for marine turtle conservation and reducing poaching (Phillott and Shanker 2018); thus, continuing community participation is important not only for a better understanding of the nesting activities of marine turtles through data collection but also for reducing poaching.

As opportunistic reports from beaches that were not systematically surveyed, we suggest expanding the community-based monitoring at other nesting beaches in Tun Mustapha Park. In addition, beach surveys on Maliangin and Banggi Islands (north of Tun Mustapha Park), where quantitative information on marine turtles is scarce, will contribute to a more comprehensive understanding of marine turtle nesting in Tun Mustapha Park. Expanding beach patrolling, nest incubation efforts, and proper hatchery operations are also necessary for successful marine turtle conservation in Tun Mustapha Park.

Marine turtles use coastal areas of Tun Mustapha Park not only as reproductive grounds but also as foraging grounds (Joseph et al. 2019); however, bycatch in commercial fisheries and destructive fish bombing is a major concern in this region (Beliku and Salleh 2013). A large number of Green Turtle carcasses were found in 2014 at Tiga Island in Tun Mustapha Park, confirmed as poaching through interviews (Joseph et al. 2019), indicating that illegal harvesting does occurr within Tun Mustapha Park or nearby areas. Two of the Green Turtle carcasses found in 2014 were observed to have tags, one previously tagged and nested in Sabah Turtle Islands Park and one from the Philippines (Joseph et al. 2019). This indicates that the waters around Tun Mustapha Park are also used as foraging habitats for marine turtles from nearby rookeries. Marine turtles in Tun Mustapha Park, particularly Hawksbill Turtles, have been illegally traded to the neighboring Philippines (Antonio and Matillano 2016), and thus patrols and enforcement in coastal areas (turtle foraging areas) are also necessary.

Foraging marine turtles and nesting populations have spatially complex relationships (Joseph et al. 2016; Nishizawa et al. 2016, 2018), and further studies, such as genetic analysis, satellite telemetry, tag and recapture, and in-water monitoring should be conducted to understand the linkages between nesting and foraging grounds in Tun Mustapha Park. A female Green Turtle that was first tagged 13 October 2018 at the nesting beach of Langaan Island, part of the Philippine Turtle Islands Park (Sulu Sea), was later found nesting in Tigabu Island (Rizza Fernandez-Salinas, pers. comm) 31 October 2018. This suggests the nesting of at least some Green Turtles in Tun Mustapha Park could belong to the same management unit as the neighboring Philippine Turtle Islands Park. Collaboration of government agencies, non-government agencies, and local communities, including international cooperation, is necessary for effective marine turtle conservation in Southeast Asia.

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Irwan Isnain was a respected marine turtle biologist who conducted extensive research on marine turtles in Sabah while working with Sabah Parks, Malaysia. He held a B.Sc. degree in Marine Science from Universiti Malaysia Sabah. His passion for his work made him a highly respected figure in the marine turtle conservation community of Malaysia. Regrettably, he passed away in September 2022 while pursuing his Master of Science degree at the Universiti Malaysia Sabah. Irwan leaves behind an outstanding legacy in the field of marine turtle conservation. (Photographed by Sabah Parks).

Hussien Muin has dedicated 35 y of service to the Sabah Wildlife Department, currently holding the position of Wildlife Officer at the Sandakan Wildlife Department. Since 2017, he has also been serving as the Marine Turtle Species Manager in Sabah under the department. His role entails the enforcement of wildlife legislation and direct involvement in monitoring marine turtle conservation activities carried out by communities and tourism operators in Sabah. Hussien has represented and participated in turtle conservation management programs at state, national, and regional levels. (Photograph courtesy of Sabah Wildlife Department).

Appendices

Appendix Table 1. Summary of annual nesting numbers Green Turtles (*Chelonia mydas*), Hawksbill Turtles (*Eretmochelys imbricata*), and Olive Ridley Turtles (*Lepidochelys olivacea*) in Balambangan Island, (Bl) Berungus (Br), Kudat Peninsular (Kp), and Tigabu Islands complex (Ti), from 2009 to 2020 at Tun Mustapha Park, Malaysia (n = 127).

	Green				Hawksbill				Olive Ridley				Unidentified species			
Year	Bl	Br	Kp	Ti	Bl	Br	Kp	Ti	Bl	Br	Kp	Ti	Bl	Br	Kp	Ti
2009	--	2	--	--	--	--	--	--	--	--	--	--	--	--	1	--
2010	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--
2011	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2012	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--
2013	--	--	6	--	--	--	1	--	--	--	--	--	--	--	1	--
2014	--	6	2	--	--	--	1	--	--	--	--	--	--	--	--	--
2015	--	--	3	--	--	--	--	--	--	--	--	--	--	--	--	--
2016	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--
2017	--	--	2	11	--	--	1	4	--	--	--	1	--	--	1	5
2018	--	4		5	--	--	--	7	--	--	1	--	--	--	--	3
2019	6	1	2	13	--	--	--	5	--	--	--	1	--	--	1	2
2020	--	--	2	16	--	--	--	4	--	--	--	--	--	--	1	1
Total/Beach	6	14	20	45	0	0	3	20	0	0	1	2	0	0	5	11
Total/Species	85				23				3				16			

Appendix Table 2. Incubation period (d) of nests of Green Turtles (*Chelonia mydas*; n = 47), Hawksbill Turtles (*Eretmochelys imrbicata*; n = 13), and Olive Ridley Turtles (*Lepidochelys olivacea*; n = 1) incubated in Balambangan, Bavang Jamal, Berungus, Simpang Mengayau, and Tigabu hatcheries at Tun Mustapha Park, Malaysia.

	Green			Hawksbill			Olive Ridley	
Hatchery	Mean ± SD	Range	n	Mean ± SD / Value	Range	n	Value	n
Balambangan	54.2 ± 4.9	49–62	5	--	--	--	--	--
Bavang Jamal	56.5 ± 5.7	48–63	8	--	--	--	55	1
Berungus	57.1 ± 8.8	43–68	10	--	--	--	--	--
Simpang Mengayau	56.8 ± 4.8	52–63	6	44	--	1	--	--
Tigabu	53.2 ± 5.4	44–64	18	54.7 ± 4.8	46–64	12	--	--
Total	55.2 ± 6.2	43–68	47	53.9 ± 5.5	44–64	13	55	1

Appendix Table 3. Peak nesting months and nesting season for Green and Hawksbill Turtles nesting in Tun Mustapha Park and other rookeries in Southeast Asian region (Pom-Pom Island, Malaysia; Sabah Turtle Islands Park, Malaysia; Berau Conservation Area, Indonesia).

	Green		Hawksbill	
Area	Nesting season (peak months)	Reference	Nesting season (peak months)	Reference
Tun Mustapha Park, Malaysia	Year-round (June to October)	This study	March to December except August and September (May to June)	This study
Pom-Pom Island, Malaysia	Year-round (May to September)	Migliaccio et al. (2020)	January to October (May to August)	Migliaccio et al. (2021)
Sabah Turtle Islands Park, Malaysia	Year-round (May to August)	Joseph et al. (2021)	Year-round (Febuary to April)	Joseph et al. (2021)
Bearu Conservation Area, Indonesia	Year-round (May to October)	Adnyana et al. (2007)	--	--

Appendix Table 4. Morphometrics (curved carapace length, CCL; curved carapace width, CCW) and reproductive outcome comparison for Hawksbill Turtles nesting in rookeries in Southeast Asian region (Sabah Turtle Islands Park, Malaysia; Melaka, Malaysia; Labuan, Malaysia) and Western Pacific regions (Hawaii, USA; Fiji Islands; Milman Island, Australia). References for information are a Joseph et al. (2021); b Juanita Joseph (unpubl. report); c Pilcher and Ali (1999); d Salleh et al. (2017); e Ghazali and Jamil (2019); f Gaos et al. (2021); g Prakash et al. (2020); h Dobbs et al. (1999).

Trait	Sabah Turtle Islands Park, Malaysia [a, b, c]	Melaka, Malaysia [d]	Labuan, Malaysia [e]	Hawaii, USA [f]	Fiji Islands [g]	Milman Island, Australia [h]
CCL (cm)	79.8 ± 8.9 (58.0–110.0)	--	--	86.6 ± 6.0 (71.0–104.0)	81.5 ± 3.7	81.6 ± 3.67 (63.5–91.9)
CCW (cm)	69.2 ± 10.3 (47.0–100.7)	--	--	--	--	70.7 ± 3.88 (53.4–82.5)
Clutch size	119.5 ± 32.7 (39–200)	123.5 ± 32.3 (9–212)	--	168.9 ± 37.1 (34–299)	121 ± 35	122 ± 23.8 (18–215)
Incubation duration (d)	53.7 ± 5.06 (43–80)	--	--	--	--	--
Hatchery hatching success (%)	67 (50–85)	--	91.56	--	--	--
Hatchery hatchling emergence success (%)	46.6 ± 27.6 (0.6–100.0)	--	--	--	--	--