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Nest Productivity for Green Turtles (*Chelonia mydas*) at Qilianyu of Xuande Islands, South China Sea, P.R. China: Preliminary Findings

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ABSTRACT. – **In August and September 2017, a total of 95 green turtle (*Chelonia mydas*) nests were geolocated on 5 islands of the Qilianyu cluster, Xuande Islands, South China Sea; North Island had the highest number of nests (n = 58) and nest density (18.5 nests/km). The number of eggs in each nest ranged from 58 to 131 (89 ± 20 [mean ± SD], n = 15), and the nest productivity was 14.8%–96.8% (70.7% ± 26.3%, n = 15). These data represent the first report for green turtle nesting in the Xuande Islands, and based on the number of nests recorded, the Qilianyu hosts the largest currently known green turtle nesting population in China.**

CHINESE ABSTRACT. – **研究团队于2017年8月和9月在中国南海宣德群岛的七连屿5个岛屿，通过GPS定位了95窝绿海龟蛋窝，其中北岛的蛋窝数最多 (58 窝)而且蛋窝的密度最高 (18.5窝/km)。每窝蛋数范围在 58–131枚 (平均89 ± 20, 15窝)，而龟蛋繁殖力范围在 14.8–96.8% (70.7% ± 26.3, 15窝)。这些数据首次呈现了宣德群岛绿海龟产卵状况，同时从蛋窝数可以确定七连屿是中国现有的最大的绿海龟产卵场。**

Green turtles (*Chelonia mydas*) have been documented nesting in southern China, including Guangdong Province (Chan et al. 2007), Hong Kong (Chan et al. 2007; Ng et al. 2014), Taiwan (Cheng 1997; Cheng et al. 2008, 2009; Lo et al. 2016), and the South China Sea (Anonymous 1975; Huang 1982; Cheng 1997, 2007; Chan et al. 2007). Nesting grounds for loggerhead (*Caretta caretta*) and hawksbill (*Eretmochelys imbricata*) turtles in China merit further confirmation (Chan et al. 2007; Wang and Li 2008).

Monitoring of the green turtle nesting grounds has been conducted in southern China, but so far efforts have not been undertaken in the South China Sea. Huidong in Guangdong Province, historically the largest known nesting ground in China, has been monitored by local officers for more than a decade. However, the estimated number of nests has seen a dramatic decline from 53 mean nests/yr (range, 19–83) in the 1980s, to 25 nests/yr (range, 1–61) in the 1990s, to fewer than 20 (range, 0–53) in the 2000s and fewer than 5 nests/yr (range, 0–10) in the 2010s, mainly because of past overharvesting for nesting females and eggs, coastal development, and pollution (Chan et al. 2007; Wang and Li 2008). In Lamma Island of Hong Kong, the estimated annual number of nests ranged from 8 to 0 from the 1990s, as reported by government officers (Chan et al. 2007; Ng et al. 2014). In Taiwan, the total number of annual nests are no more than 20 spread among the different islands (including Lanyu Island, Penghu Islands, and Xiaoliuqiu Island) (Chen and Cheng 1995; Cheng et al. 2008, 2009; Lo et al. 2016).

The Xisha Islands in the South China Sea are composed of over 100 small coral islands and sand cays, mostly arranged into 2 groups separated by 70 km: the Yongle Islands (Crescent Group) in the west and the Xuande Islands (Amphitrite Group) in the northeast (Fig. 1). Green turtle nesting at Jinqing Island (Drummond Island) and Chenhang Island (Duncan Island) of the Yongle Islands was first reported more than 4 decades ago (Anonymous 1975); however, the beaches used and the number of nests laid each year are still unknown. A short survey conducted in 2008 in the Xuande Islands recorded 49 green turtle nests among 10 islands, primarily in the Qilianyu (Seven Sisters Islands or Qilian Archipelago) (Wang and Li 2008). Since 2016, local government officers and trained fishers in Qilianyu have patrolled the islands and sand cays irregularly to count nests: 152 green turtle nests were recorded in 2016, 172 nests in 2017, and 112 nests in 2018. These nests were found among 7 islands of the Qilianyu island cluster, including North Island (shoreline length of 3.1 km along the high-tide line, area of 0.31 km^2), Middle Island (1.4 km, 0.11 km^2), South Island (1.8 km, 0.10 km^2), North Sand (0.6 km, 0.01 km^2), Middle Sand (0.9 km, 0.02 km^2), South Sand (1.0 km, 0.04 km^2), and West Sand (2.1 km, 0.26 km^2). In terms of the number of nests, Qilianyu represents the largest extant nesting ground for green turtles in China. However, little is known about green turtle nesting ecology throughout the Xisha Islands (Anonymous 1975; Huang 1982). This study was conducted at the Qilianyu cluster in August and September 2017. Our goals were to 1) geolocate nests at different islands and sand cays, 2) identify the islands and beaches with high numbers of nests and nest density for green turtles, and 3) investigate the number of eggs and nest productivity.

Methods. — The Qilianyu cluster within the Xuande Islands, Xisha Island, consists of several low, narrow islands and sand cays, connected by reefs (Fig. 1). This study was conducted at 5 islands of Qilianyu, including North Island, Middle Island, South Island, Middle Sand,

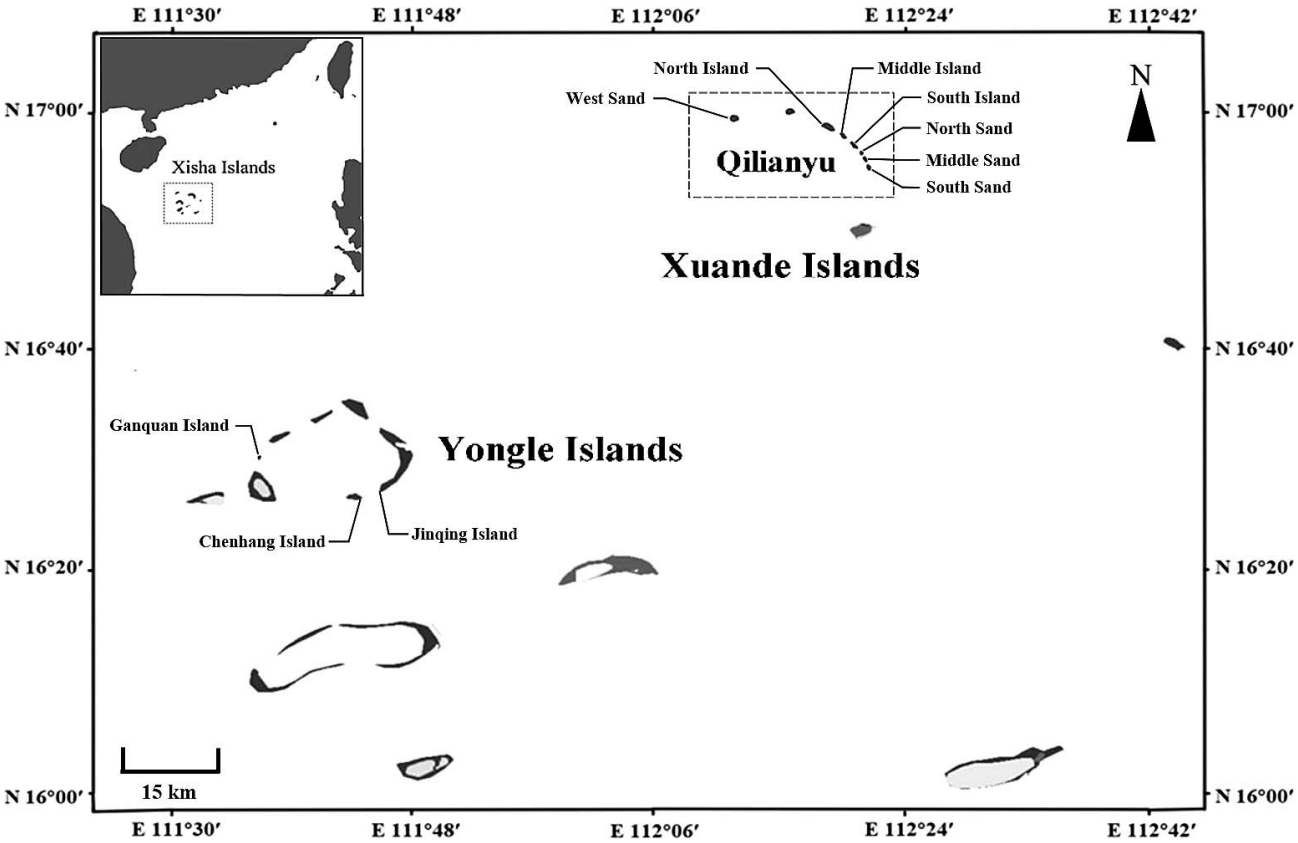

Figure 1. The Qilianyu cluster of Xuande Islands, Xisha Islands, South China Sea, China.

and South Sand. Because of local transportation limitation and weather, this study did not include West Sand, and no nests were found at North Sand in 2017 during sporadic check.

This study was conducted in August and September 2017 for a 3-wk period; daily patrols at North Island, where the fishers reside, and at intervals of 3–7 d on the other 4 islands, where no humans live. The study timing was within the nesting peak at Qilianyu based on local fishers' observations.

The nests reported here include those recorded by trained local officers and fishers prior to this study (as part of earlier monitoring efforts) as well as those found during this study. Geographical location for all marked nests was noted using a handheld GPS (Garmin Oregon 550). Maps of North Island, Middle Island, South Island, Middle Sand, and South Sand were made using Google Earth software (Google Earth Pro 7.1). Surfer software (Surfer 10.0) was used to label the nest locations based on GPS data. We calculated nest density (nests/km) for each island based on the number of nests recorded and the shoreline length (km) along the high-tide line.

Nests were excavated and examined after 60 d, which is slightly longer than the typical incubation period for green turtles (i.e., 5–10 d beyond the hatching based on local fishers' experience). All empty eggshells, unhatched eggs, and dead and live hatchlings in the nests were quantified (Miller 1999). The total number of eggs in each nest was the sum of the numbers of empty eggshells and unhatched eggs. Nest productivity (%) for each nest was calculated as (the number of empty eggshells – the number of dead hatchlings in the nest)/(the total number of eggs) × 100.

Results. — A total of 95 nests were geolocated, including 58 nests at North Island, 20 nests at South Island, 8 nests at Middle Island, 6 nests at South Sand, and 3 nests at Middle Sand (Fig. 2). Most nests (95.8%) were above the high-tide line, close to or within vegetation; only 4 nests were below the high tide line.

North Island had the highest nest density with 18.5 nests/km, followed by South Island (10.9 nests/km), South Sand (5.8 nests/km), Middle Island (5.6 nests/km), and Middle Sand (3.4 nests/km) (Fig. 2). The nest density on the northwest beach of North Island had 63.9 nests/km (n = 40 nests).

The number of eggs per nest ranged from 58 to 131 (89 ± 20 [mean ± SD], n = 15), and nest productivity ranged from 14.8% to 98.2% (70.7% ± 26.3%, n = 15) (Table 1). Four nests had productivity less than 45%.

Discussion. — This is the first study addressing green turtle nest productivity at Qilianyu in the South China Sea, China. We found that North Island's northeast beach had the greatest number of nests (n = 40) and the highest nest density (63.9 nests/km) of all islands and beaches monitored during this research (Fig. 2). This finding suggests that North Island merits long-term monitoring to

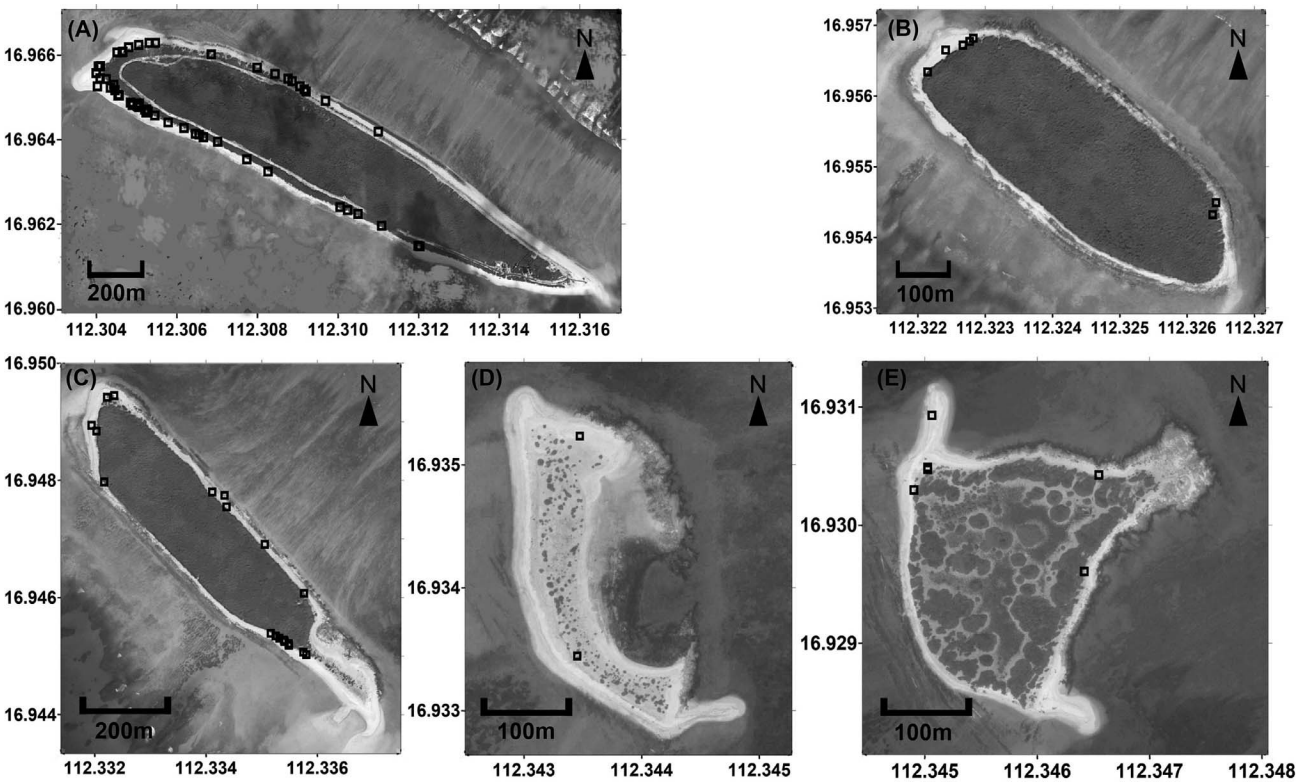

Figure 2. Locations of 95 nests (open squares) at 5 islands of Qilianyu, Xuande Islands, South China Sea. (A) North Island (n = 58 nests), (B) Middle Island (n = 8 nests), (C) South Island (n = 20 nests), (D) Middle Sand (n = 3 nests), and (E) South Sand (n = 6). The dark gray coloration to the interior of each island represents vegetation cover. In most areas, the dominant vegetation close to the coastline is *Scaevola sericea*.

understand the nest site selection mechanism of green turtles at this location.

Recent molecular analyses revealed the connectivity of green turtles from southern China (Ng et al. 2017). Foraging green turtles found in the East China Sea, Taiwan Strait, and northern South China Sea may come from nesting grounds within the region. Meanwhile, Borneo, Indonesia, Japan, Malaysia, Marshall, and Micronesia also may be the source of green turtles foraging in southern China. Therefore, the nesting females and foraging green turtles at Qilianyu merit further investigation to determine their origins and movement patterns.

Soft and porous beach sand is a necessary condition for the successful nesting and incubation sea turtles (Mortimer 1990). The islands with vegetative cover are also preferred by nesting green turtles (Bustard 1972; Mortimer 1982). In this study, we found that North Island, Middle Island, and South Island have well-growth vegetation throughout the entire islands and that the main species near the high-tide zone is *Scaevola sericea*, growing intensively (Fig. 2). These islands also have the greatest amount of green turtle nesting, perhaps because of the preferable beach characteristics and vegetation cover. In contrast, the beaches without nests were either full of coral rubble rather than soft sand, dominated by rocky reefs, or had less or no vegetation. The rocky reefs can block female turtle access to the beach; for example, during this study, we released 2 female turtles that were

Table 1. Nest productivity (n = 15 nests) at 5 islands of Qilianyu, Xuande Islands, South China Sea.

Island	No. of nests	No. of eggshells/nest	No. of dead eggs/nest	Total no. of eggs/nest, range (mean ± SD)	No. of dead hatchlings/nest	Nest productivity, range (mean ± SD) (%)
North Island	5	53–94	0–78	66–131 (96.4 ± 23.7)	0–3	40.5–96.8 (79.1 ± 22.1)
Middle Island	5	31–88	9–68	80–106 (95.8.4 ± 9.6)	0–4	29.3–89.7 (65.7 ± 28.5)
South Island	3	39–62	14–19	58–76 (69.0 ± 7.2)	0–1	67.2–81.6 (74.3 ± 7.2)
Middle Sand	1	107	2	109	0	98.2
South Sand	1	9	52	61	0	14.8
Mean ± SD				89.2 ± 20.1		70.7 ± 26.3

blocked from reaching offshore waters due to the presence of rocky reefs. We encourage further studies on the effects of beach characteristics (i.e., reef presence, vegetation cover, current velocity, and direction) on green turtle nesting activity at this and other sites in the region. For example, the beach with the highest nest density at North Island merits investigation to understand the nest site selection mechanism of green turtles.

Numerous abiotic and biotic factors can influence the nest productivity. In a study on the Galápagos Islands, the nest productivity varied significantly among beaches, years, day of oviposition, and nest habitat (Zárate et al. 2013). Sand salinity, temperature, and gas exchange associated directly with the period of incubation also influence the nest productivity (Bustard and Greenham 1968; Ackerman 1980; Yntema and Mrosovsky 1982; Foley et al. 2007). In this study, nest productivity of green turtles averaged 70.7% ± 26.3% (mean ± SD), with the highest at North Island (79.1% ± 22.1%, $n = 5$) and the lowest at Middle Island (65.7% ± 28.5%, $n = 5$); Middle Sand and South Sand were not included in this analysis because only 1 nest was excavated (Table 1). The results are within the range of nest productivity values (41.7%–89.0%) reported for green turtles at various nesting sites worldwide (Hirth 1997; Zárate et al. 2013).

Among the 15 nests excavated in this study, 4 had nest productivity less than 45%; all 4 were scattered among North Island, Middle Island, and South Sand. These low-productivity nests were either located below the high-tide line ($n = 3$) or the embryos were undeveloped for unknown reasons ($n = 1$) (Table 1; Fig. 2). Long-term monitoring is needed at Qilianyu, and abiotic and biotic data, such as sand size, nest temperature, salinity and humidity, and predation, should be collected to better understand the variation of nest productivity at Qilianyu and to identify the main factors that influence the nest productivity.

Human impacts on the green turtle nesting grounds of Qilianyu are minimal owing to the relative seclusion of the islands as well as the difficult access due to firm management practices. There is an absence of extensive human activity throughout the Qilianyu Islands. For example, of the 5 islands with green turtle nests, only North Island has a village. However, this settlement has fewer than 10 people living there year-round and is located in the southeast portion of the island, away from the highest-density nest beach, which is located to the northwest (Fig. 2). Moreover, this village has low or no beach lighting, which is ideal for nesting turtles (Witherington and Martin 2000). Instead, the main threat of disturbance to green turtles at Qilianyu comes from the small-engine boats owned by local fishers who spearfish around the islands and reefs at night.

To understand the status of the nesting grounds for green turtles at Qilianyu, the nest productivity studies and long-term monitoring should continue. Nesting habitat characteristics, including vegetation, sand particles, humidity, and oceanography at different islands, should be examined to understand the nest site selection mechanism of local green turtles. We also recommend nesting beach monitoring and research at the Yongle Islands and elsewhere in the South China Sea.

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