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Crowdsourcing conservation: unveiling Taiwan's sea turtle foraging grounds, emerging threats, and residency with broad societal engagement

Chia-Ling Fong[1,2,3,4], Daphne Z. Hoh[4,5], Huai Su[4], Peng-Yu Chen[4], Chia-Chen Tsai[4], Kelly W. H. Tseng[6], Hao-Chih Huang[6], Jun-Yi Wu[7], Yoko Nozawa[3,8,9] and Benny K. K. Chan[3*]

Abstract

Background Determining sea turtle foraging grounds, emerging threats, and population status are essential for conservation management. Crowdsourced science is a recently recognized approach that enables internet-based data collection, providing important contributions to scientific goals while also benefiting society and public education. This study is based on the published dataset from TurtleSpot Taiwan (2017–2022) with the aim to leverage crowdsourced data to determine sea turtle foraging grounds, emerging threats, demography, and residency patterns in Taiwan.

Results We identified three green turtle (*Chelonia mydas*) foraging grounds in Taiwan (Liuqiu Island, Kenting, and Green Island), defined as sites with > 100 sightings and > 50 individuals. Among all sites, Liuqiu Island contributed 77% of the total sightings, suggesting this island is a hotspot. Emerging threats to foraging aggregations of sea turtles in Taiwan were evident from the reported sightings, with ~ 10% of the total sightings involving turtles with fishing line entanglement, ingested debris, missing flippers, or injuries. Most of these sightings occurred in Liuqiu Island, indicating a significant level of human-turtle disturbance. Residency patterns identified from sighting data showed that 43.4% of individuals stayed in the same area for one or more years, with adult-sized turtle residency greater than that of immature turtles.

Conclusions Taiwan supports healthy foraging grounds for green turtles, where adults often stay for more than one year and with dynamic populations of younger individuals. However, despite a certain number of foraging green turtles observed in Liuqiu Island, many of these turtles displayed injuries. This high population density combined with increased injury frequency suggests that a comprehensive management plan for turtle foraging grounds is urgently needed, including measures to reduce boat speeds in hotspot areas and strict regulations on coastal human activity.

Keywords Photo-identification, *Chelonia mydas*, *Eretmochelys imbricata*, Citizen science, Foraging habitat, Demography

*Correspondence:
Benny K. K. Chan
chankk@gate.sinica.edu.tw

Full list of author information is available at the end of the article

Background

As migratory megafauna, sea turtles have a complex life cycle requiring unique life stage-dependent nesting and foraging habitats (i.e., hatchling, juvenile, sub-adult, and adult) [1]. Historically, sea turtle research and conservation efforts have focused on nesting habitats, while their foraging habitats are less understood [2, 3]. Determining the distribution of and the population dynamics within key foraging habitats has been recognized as a global research priority for sea turtle conservation [4], ecology, and conservation management. Despite significant progress in addressing these knowledge gaps, progress remains limited by a bias towards specific questions, species, and regions, highlighting the need for greater engagement with social sciences and a broader range of contributors [5].

Five of the world's seven sea turtle species – green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), loggerhead (*Caretta caretta*), olive ridley (*Lepidochelys olivacea*) and leatherback (*Dermochelys coriacea*) – have been recorded in the East Asia region [6]. Among these species, green and hawksbill turtles are the two most common species historically observed in the waters of Taiwan. Many studies have attempted to identify potential foraging grounds for green and hawksbill turtles in East Asia through various methods, including historical records, bycatch, mark-recapture studies, stable isotope analysis, and satellite tracking [7–10]; however, crucial information such as demography and residency of local aggregations remain lacking. This gap is understandable as both measures require direct in-water surveys and long-term mark-recapture studies, both of which are logistically challenging given the necessary person-hours and financial investments to provide the required resolution of data. Properly moderated citizen science and crowdsourced data collection projects can offer a way to alleviate these logistical hurdles and thereby address the standing knowledge gaps on both local and global scales.

Citizen science (CS) broadly refers to the engagement of the general public in scientific research and has existed for centuries in various forms [11] but has in recent decades expanded dramatically in both scope and application [12]. The current use of crowdsourced data through CS has proven powerful in generating ecological knowledge [13], improving conservation science, and enhancing environmental protection [14]. Crowdsourced science, a subset of CS that utilizing internet connectivity to recruit large groups of volunteers who would otherwise be disconnected for the purpose of problem-solving scientific projects, has the potential to expand societal participation and reduce associated costs of acquiring data [15].

While providing opportunities for increased data collection, including higher temporal and spatial resolution, with minimized logistical limitations to the researcher, CS and crowdsourced conservation projects have their own sets of challenges. These challenges include improving participant engagement and retention, establishing comprehensive project evaluations, and developing better communication strategies [16], while also mitigating potential challenges in data quality, and data coverage [17]. For crowdsourced science to provide data in both the quantity and quality needed for scientific purposes, it is necessary for projects to include standardized data collection protocols, means of quality-assurance, engaging community involvement (co-creation), and venues to share data and knowledge with the public [13, 18].

Photographic identification (photo-ID) methods that use unique body patterns for individual identification provide an innovative avenue for researchers and citizen scientists to study animals in their native habitats [19]. The distinctive facial and flipper scale patterns of sea turtles have been validated as reliable natural markers for studying their in-water biology and ecology [20–23]. The recent availability of digital platforms, affordable underwater cameras, and photo-ID software (e.g., I3S, HotSpotter, Internet of Turtles) facilitated the emergence of photo-ID CS projects to reveal the population status of foraging turtles [24–27].

TurtleSpot Taiwan is a crowdsourced conservation project launched in June 2017 on social media platform (https://www.facebook.com/groups/turtlespotintw; Facebook, Meta) with the dual aim of collectin g sighting reports of sea turtles for identifying foraging grounds in Taiwan and providing a portal for public education. Engaging over 20,000 group members, TurtleSpot Taiwan's key innovations were establishing a publicly accessible sea turtle photo-ID database website (https://turtlespottw.org/) that allows users to search and provide optional functions for users to identify their documented/photographed turtles. This database has standardized data collection protocols to enhance data quality, and employs numerous interactive measures to foster community engagement and enhance societal engagement.

Hoh and Fong [28] and Hoh et al. [29] previously published occurrence open-access datasets from TurtleSpot Taiwan data between 2017 and 2022, along with metadata and data collection methodology. Here we provide the first analysis of these datasets and identify the foraging grounds, emerging threats, demography, and residency of sea turtles in Taiwan. To examine the effectiveness and scope of crowdsourced conservation, we further analyzed citizen scientist participation and retention trends over five years of TurtleSpot Taiwan's implementation.

Methods

Sea turtle sighting and distribution in Taiwan

A total of 760 sea turtle individuals were identified and documented on the photo-ID database of TurtleSpot Taiwan, including *C. mydas* ($n = 724$), *E. imbricata* ($n = 35$), and *L. olivacea* ($n = 1$). To study the diversity and abundance of different species of sea turtles around Taiwan, density distribution maps for all sea turtle sightings, individual turtles and participating citizen scientists were generated in R using mapdata (version 2.3.1), sf and ggplot2 [30–32], and modified with Affinity Designer (version 1.10.5).

Foraging grounds, demographic structure and residency of green and hawksbill turtles

Foraging grounds were identified as areas that have received a high number of sightings (> 100 sightings) and a stable number of local aggregations (> 50 individuals) over the monitored period. This study focused on evaluating foraging grounds, demographic structure and residency for green and hawksbill, as these species are the two most common sea turtles in Taiwan.

To determine the demographic structure of sea turtles, turtle body size was visually estimated from whole-body photographs and categorized into different life history stages (post-hatchling, juvenile, subadult, or adult), combined with the carapace color pattern and marginal scute roundness characteristics and descriptions provided by the reporters. Turtles that lacked a whole-body image and estimated size information were recorded as life stage 'unknown'. We used previously published straight carapace length (SCL) measurements and carapace characteristics to categorize all sighted turtles into putative age classes as follows: For green turtles, post-hatchling SCL of 10 to 20 cm, juvenile SCL < 65 cm with sunburst patterns on each scute, subadult SCL of 65 to 90 cm with camouflage patterns on each scute, and adult SCL > 95 cm with variously light and dark spotting on the carapace [33–35]. For hawksbill turtles, post-hatchling SCL of 8 to 22 cm, juvenile SCL of 23 to 50 cm, subadult SCL of 50 to 80 cm, and adult SCL > 80 cm [36–38]. For olive ridley turtles, adult SCL from 53 to 79 cm, with a median size of 60 cm at sexual maturity [39]. The identification of sex in adult-sized turtles was limited to males, defined as individuals having tail lengths exceeding 25 cm (visually longer than the rear flippers) [40]. Since it is not possible to definitively determine the sex and sexual maturity of sea turtles with short tails, turtles with tail lengths of 10 to 15 cm (visually shorter than rear flippers) or with no visible tail were classified as sex unknown.

To examine the residency of the sea turtles, minimum residency duration (MRD) of green and hawksbill turtles was calculated and plotted separately. The MRD for each turtle was estimated based on total duration (days) between the earliest and latest recorded sighting [25]. Individuals who stayed in the same area for more than 365 days (1 year) were considered residents. To study variations of MRD and number of sightings among estimated age-class groups (i.e., juvenile, subadult, or adult-sized), only green turtles were included due to low sample sizes for other species. Variations in MRD and the number of sightings per individual across different estimated age-class groups were examined using One-Way Analysis of Variance (One-Way ANOVA; factor: estimated age-class groups) in SigmaPlot 11 (Graffiti LLC). The dataset included 428 green turtle individuals from six areas: Northeastern coast, Penghu, Green Island, Liuqiu Island, Kenting, and Hualien. The MRD values passed the equal variance test ($p = 0.509$) without requiring transformations. The number of sightings per individuals were square root transformed twice and passed the equal variance test ($p = 0.118$).

Participation and retention of citizen scientists

The publicly accessible TurtleSpot photo-ID database website houses information and images of documented turtles, featuring a filter function that enables users to search using keywords (e.g., number of the post-ocular scutes, morphological features, location, species, age-class, turtle ID number, or turtle name). This allows citizen scientists to browse through the image database to manually identify the turtles they photographed. To assess citizen science participation, we counted the number of citizen scientists who attempted to identify the turtles they sighted at the individual level, using the photo-ID database website or other means. Regardless of identification accuracy, these attempts were used as an indicator of the involvement level of citizen scientists.

The number of new and retained citizen scientists from previous years was analyzed for each year from 2017 to 2022 to assess the recruitment and retention trends of TurtleSpot Taiwan. Retention of citizen scientists was calculated as the total duration (in days), including both the first and the last sightings reported by an individual to the Facebook Group. A Pearson correlation coefficient analysis was conducted to examine the correlation between the number of sightings contributed by each participant and their retention time, visualized with a scatter plot in SigmaPlot 11. To avoid bias, sightings directly provided by citizen scientists to us without posting to the Facebook Group were excluded from the above analysis.

Results

Distribution of foraging grounds and demographics of sea turtles

The majority of the sea turtle individuals identified from sightings were from Liuqiu Island (76.7%, $n = 584$

identified from 3,024 sightings), followed by Kenting (8.7%, *n* = 66 identified from 239 sightings) and Green Island (7.5%, *n* = 57 identified from 182 sightings), all of which serve as foraging grounds for green turtles (Fig. 1a). We observed a steady increase in the number of unique individuals recorded over time, with an average of 127 (range: 60 to 201) new individuals recorded each year (Fig. 1b), resulting in a total of 760 individuals as of May 2022. For the estimated age-class groups of *C. mydas*, 61.3% (*n* = 444) of documented turtles were juveniles, 26.2% (*n* = 190) were subadults, and 12.4% (*n* = 90) were adults (Fig. 1c). Among the adult-sized green turtles, 33 individuals were identified as males. For *E. imbricata*, 74.3% (*n* = 26) were juveniles, 17.1% (*n* = 6) were subadults, and 5.7% (*n* = 2) were adults (one identified male), with one individual identified as a post-hatchling (Fig. 1c).

In addition to identifying turtle foraging grounds, sighting data highlighted emerging threats to foraging aggregations of sea turtles in Taiwan, such as boat strikes, propeller injuries, and marine debris. Nearly 10% (*n* = 358) of total sightings involved turtles with fishing line entanglement or with ingested debris (i.e., plastic bags, fishing lines and ropes) observed protruding from the anus (1.5%, *n* = 53), missing flippers or injuries to flippers (3.2%, *n* = 116), or carapace injuries (5.3%, *n* = 189). There were 114 injury-related turtles, comprising 106 green turtles (346 sightings), 8 hawksbill turtles (10 sightings) and two sightings for which neither species nor individual was identified. Most of these sightings (93.3%, *n* = 334) were from 98 turtle individuals and occurred at Liuqiu Island (Table 1), indicating a significant level of human-turtle interaction in this area.

Minimum Resident Duration (MRD) of sea turtles

A total of 723 green turtles (sightings *n* = 3,201) and 35 hawksbill turtles (sightings *n* = 70) were included in MRD analysis after excluding records with incomplete date information (*n* = 5). Of these, 295 green and 22 hawksbill turtles were categorized as "non-resighted" because they were only sighted once (green *n* = 287; hawksbill *n* = 22) or only had multiple same-day sightings (green *n* = 8). The resighting rates of green and hawksbill turtles were 59.2% (*n* = 428) and 37.1% (*n* = 13), respectively, with the number of re-sightings per individual ranging from 2 to 47 (mean: 4.56, SD: 6.47). Among resighted green turtles (*n* = 428), 74.3% (*n* = 318) stayed in the same area for one or more years (i.e., resident turtle), and 25.7% (*n* = 110) stayed for less than one year (Fig. 2a). Resident green turtles (MRD ≥ one year) were mainly distributed in southern Taiwan (Fig. S2) at Liuqiu Island (*n* = 280), Kenting (*n* = 18), and Green Island (*n* = 15). Among resighted hawksbill turtles (*n* = 13), 15.4% (*n* = 2) stayed for less than one year (Fig. 2a) and 84.6% (*n* = 11) were resident turtles, mainly in Liuqiu Island (*n* = 6) (Fig. S2). Juvenile green turtles contributed more than half of the proportion of non-resighted, < 90 days, 90–364 days and 1–2 years groups (Fig. 2b). However, the proportion of turtles with larger body sizes (estimated as subadults and adults) generally increased with longer MRDs. In the > 2 years MRD category, juveniles accounted for 46.9%, while subadults and adult-sized turtles made up 28.8% and 24.3%, respectively (Fig. 2b). Green turtle mean MRD increased with age-class, from juvenile (775 days), subadult (882 days), to adult-sized turtles (1,182 days). Adult-sized turtles had significantly greater MRD than juveniles and subadults (One Way ANOVA, $F_{2, 425} = 13.36$, $p < 0.001$, SNK: adults > juveniles = subadults; Fig. 2c). Adult-sized turtles had a significantly higher resighting rate (average 10.12 times per individual) than both juveniles (5.71 times per individual) and subadults (6.75 times per individual) (One way ANOVA, $F_{2, 425} = 14.67$, $p < 0.001$, SNK: adults > juveniles = subadults; Fig. 2d).

Additionally, the longest MRD recorded to date was 3,502 days (ID: TW01G0049; 28 sightings), documented in an adult-sized green turtle with carapace injuries and scars, presumably female, from Liuqiu Island. The longest interval between two consecutive sightings was 1,604 days (ID: TW01G0034) documented in a subadult green turtle from Liuqiu Island. This single individual was recorded at a deep boat diving site, which is likely less frequently visited by divers, potentially explaining the extended gap between sightings.

Participation and retention of citizen scientists

From a total of 2,324 sightings contributed by 442 citizen scientists directly to the Facebook group platform, nearly 30% (*n* = 683) of the sightings were manually identified by 99 individual citizen scientists, indicating their engagement beyond mere data contribution. From June 2017 to May 2022, the annual number of turtle reporters ranged from 95 to 148, with an average of 122 ± 20 citizen scientists per year. In each year, about 67% of reporters were new participants (ranging from 61 to 75%), while 33% were retained from the previous years (Fig. 3a). The consistent influx of new participants in each year highlights sustained public interest in the initiative and the project's effectiveness in recruiting contributors. The number of sightings per citizen scientist ranged from 1 to 339, with 52.7% (*n* = 233, including one author) contributing a single sighting, 34.8% (*n* = 154) reporting 2–5 sightings, 11.1% (*n* = 49, including one author) reporting 6–50 sightings, and 1.4% (*n* = 6, including two authors) reporting more than 50 sightings (Table S1). These contributions accounted for 10%, 18.7%, 31.6%, and 39.7% of the total sightings, respectively. Participant retention duration ranged from one day to 1,789 days. Among the citizen scientists, 61.3% (*n* = 271, including one author)

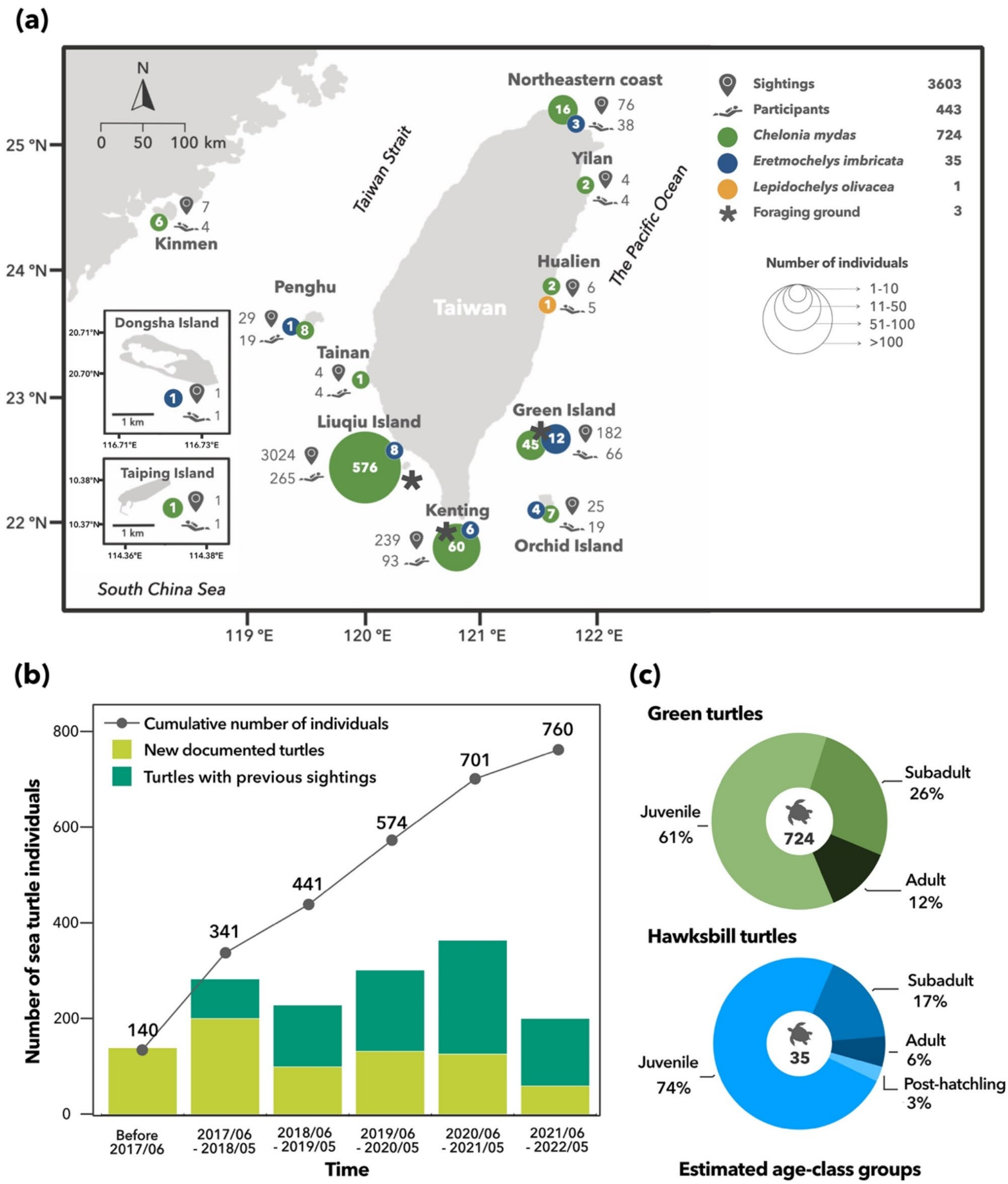

Fig. 1 Distribution of documented turtles around Taiwan, their annual population trends, and demographic structure. (**a**) Spatial distribution of sightings (pin marker symbol), participants (diver symbol), and documented turtles (circle). The color and size of the circle represent the species and the number of individuals, respectively. (**b**) Annual variations in numbers of sea turtle individuals and line chart showing the cumulative number of recorded turtles. (**c**) The proportion of estimated age-class groups of green and hawksbill turtles

Table 1 Number of injury-related sightings and turtle individuals at each location in Taiwan

Location	Total injury-related sightings	Unique individuals with injury-related sighting	Injury related sightings at each location (%)
Liuqiu Island	334	98	11.04
Kenting	8	5	3.35
Northeastern coast	4	1	5.26
Green Island	4	3	2.20
Kinmen	2	2	28.57
Orchid Island	2	2	8.00
Penghu	2	1	6.90
Dongsha	1	1	100.00
Yilan	1	1	25.00

contributed their sightings on a single day, while 19.9% ($n=88$) contributed within a one-year period (2 days – 1 year), 8.8% ($n=39$) contributed over 1 to 2 years, 3.8% ($n=17$) over 2 to 3 years and 4.5% ($n=20$, including one author) over 3 to 4 years. Lastly, 1.6% ($n=7$, including two authors) contributed sightings consistently across all five years (Table S1). A significant moderate positive correlation (Pearson correlation coefficient = 0.44, $p<0.001$) was observed between the number of sightings reported by each participant and their retention time (Fig. 3b).

Discussion

Foraging sea turtles in Taiwan

Direct in-water sighting data showed that Taiwan's coastal waters, especially Liuqiu Island, Green Island, and Kenting, are foraging grounds for green turtles and host a smaller aggregation of hawksbill turtles, represented by individuals of all size groups but dominated by juveniles (61% and 74%, respectively). The foraging grounds of sea turtles surrounding Taiwan exhibit diverse ecological characteristics. Liuqiu Island and Kenting primarily feature fringing reefs, intertidal zones, and small sporadic seagrass beds along their coastlines. Many reefs in these areas are algae-dominated reefs, especially turf algae [41, 42] making them preferable foraging sites for herbivorous green turtles. This dominance of juveniles in foraging grounds is comparable to that of green turtles in the Japanese Kuroshima Islands (79.9% juveniles) and Yaeyama Islands (1995–2003: 88%; 2004–2016: 78%) to the north [43, 44], as well as Malaysian Mabul Island (78.9%) and Semporna (49%) to the south of Taiwan [45, 46]. In the Great Barrier Reef in Australia, foraging grounds typically host a greater mix of life stages, but with juveniles still comprising the majority (approximately 80.5%) [47]. The ratio of juveniles in Taiwan's coastal foraging aggregations (61%) lies in between the values at these other locations. The variation in juvenile dominance among regions may influenced by differences in habitat characteristics and food availability. For example, the foraging habitats in the Great Barrier Reef are coral reef dominated [47], while Kuroshima Islands and Yaeyama Islands feature coral reef habitats mixed with seagrass and algae [43, 44], and Semporna and Mabul Island combines coral reef with seagrass meadows [45, 46, 48, 49]. The foraging grounds in Taiwan are mainly algae-dominated reefs. Variations in food availability among these different habitats may contribute to the differences in the demography of sea turtles across regions. Temporal shifts in food availability can also contribute to different age-class demographics. In Bermuda, a decline in seagrass availability may have driven the emigration of juveniles before maturation, altering the demographic structure of the aggregation [50]. Mortality rates of turtles can also affect the demographic composition of foraging aggregations. For instance, in the Yaeyama Islands, the decline of the sea turtle fishery due to increased conservation awareness led to a 10% rise in the proportion of larger-sized turtles during 2004–2016 compared to earlier periods [44]. Establishing long-term monitoring programs in Taiwan could help track demographic shifts and provide insights into site-specific ecological roles.

Steady increases in newly sighted individuals each year and a high ratio of juvenile turtles suggest a healthy recruitment pattern in these foraging grounds [44]. Our study also found that adult-sized turtles have significantly longer residency durations and higher resighting frequencies than immature turtles. A similar trend of adults having higher residency indices than juveniles and subadult green turtles has been observed in Australian foraging grounds [51]. Lower resighting rates and shorter residency of juveniles and subadults suggest a more dynamic assemblage within these aggregations. Additionally, individual variability in home ranges and core areas [52–54] may influence the resighting probability in photo-ID-based surveys. However, current understanding of their habitat shifts in this region remains limited. Ng et al. [10] tracked four rehabilitated and released immature green turtles: one turtle released from Dongsha migrated to the Philippines over 143 days, while three turtles released from Kenting remained within Taiwanese waters (tracking duration ranging from 124 to 188 days). Two of these turtles returned from their release sites to the areas where they were originally found stranded or bycaught. These findings suggest that immature turtles can have high variability in home ranges or dynamic movement patterns, with some traveling large geographical distances, making them less frequently observed by volunteer turtle watchers.

Our study showed an increasing temporal trend in sea turtle residency over the past decade. Cheng et al. [55] surveyed 432 individual turtles at Liuqiu Island from 2011 to 2017 and found that around 10% remained for more

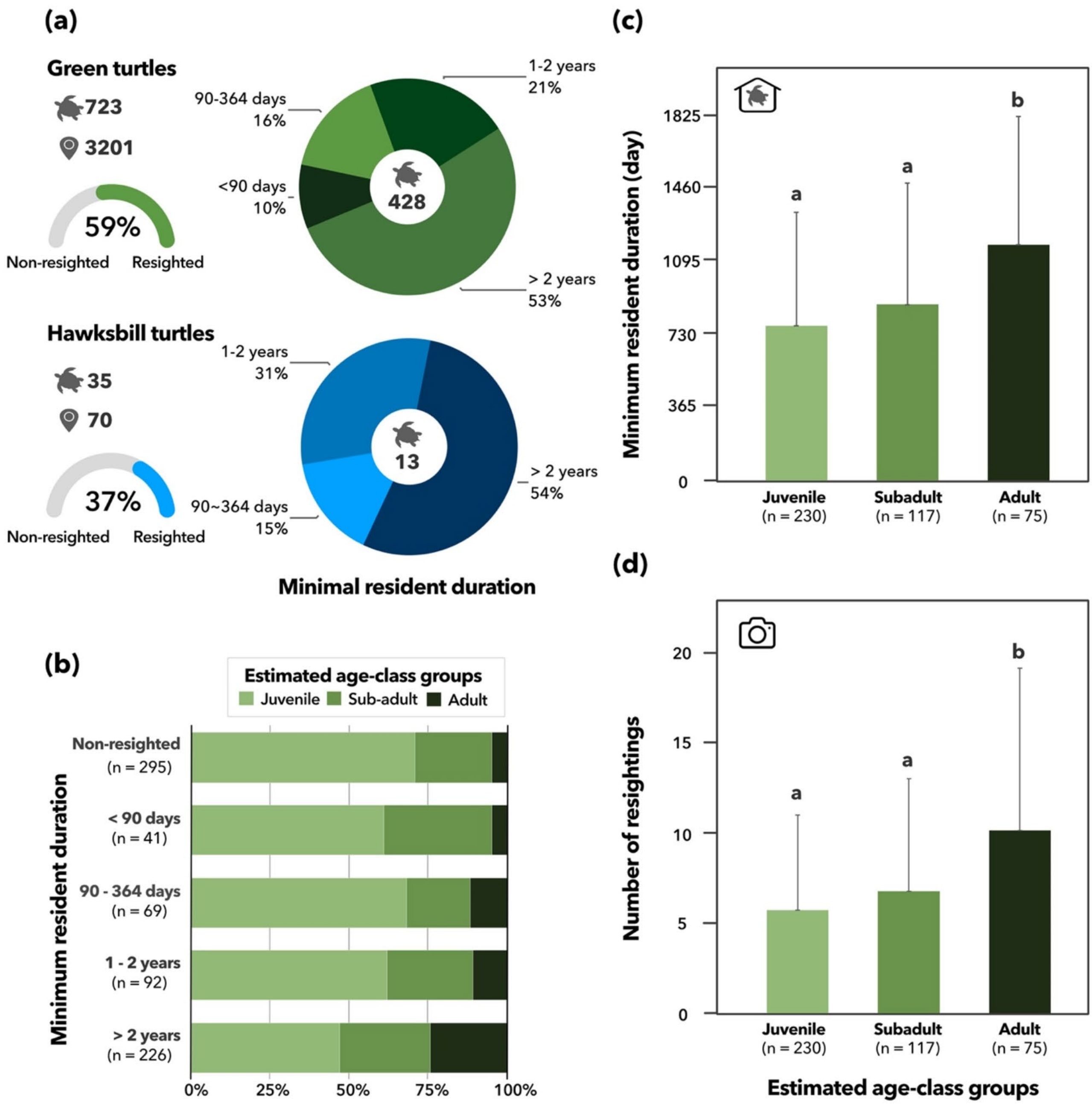

Fig. 2 The minimum resident duration (MRD) and demographic structure of turtles. (**a**) MRD of green and hawksbill turtles by MRD groups. (**b**) The percentage of green turtles in estimated age-class groups with different MRD. (**c**) Mean (+ SD) of MRD across estimated age-classes of green turtles. a and b denote different groupings identified from post-hoc SNK tests following One-Way ANOVA. (**d**) Mean (+ SD) of number of resightings per individual across estimated age-class groups of green turtles

than one year. Our study found that from 2017 to 2022, of 584 identified individuals, 49% stayed for over a year. It is possible that the habitat conditions of Liuqiu Island have become more suitable for foraging turtles since 2017. Two adult-sized turtles (short tail, presumed female) with flipper tags from the Secretariat of the Pacific Regional Environmental Programme (SPREP) were sighted in Liuqiu Island multiple times each between 2017 and 2022 and 2022, respectively, indicating this foraging ground is also utilized by adults following ontogenetic emigration. This suggests that the foraging grounds around Taiwan, particularly Liuqiu Island, support all turtle life stages of turtles and are therefore of heightened conservation importance.

Our study also identified a small number of resident turtles on the northeastern coast of Taiwan which

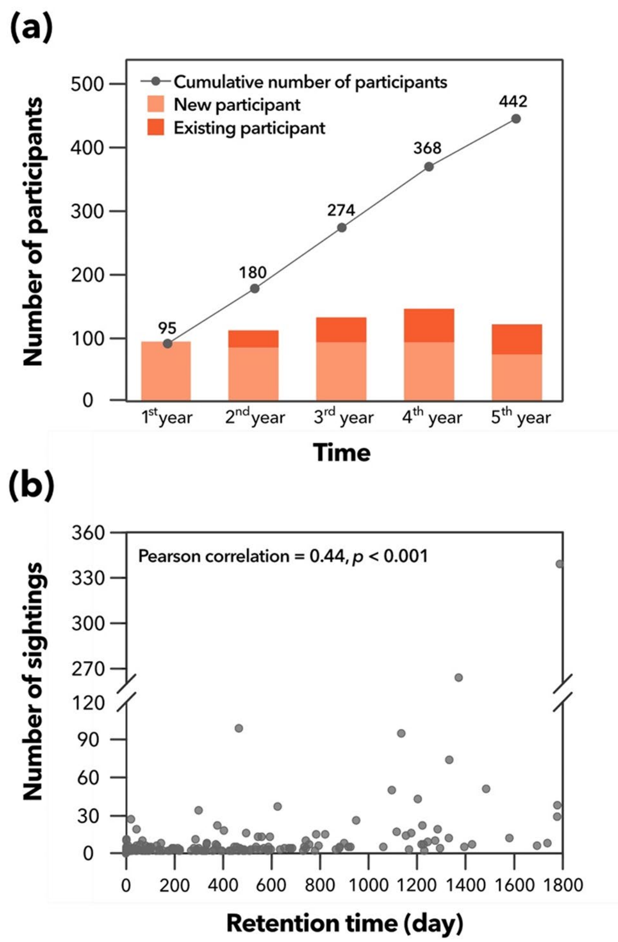

Fig. 3 Citizen scientists' participation in TurtleSpot Taiwan. (**a**) Bar charts showing the annual number of participants between June 2017 and May 2022 and line chart showing the cumulative number of participants. (**b**) Scatter plots between the number of sightings contributed by each participant and their retention time

supports previous suggestions [56] that this area could be a foraging ground for green turtles. The benthic community on the northeastern coast consists mainly of turf algae, macroalgae, and non-reefal coral communities [42], which may contain a high abundance of Rhodophyta and Chlorophyta, the main diet of green turtles in reef ecosystems [57].

One factor to consider is that the foraging grounds identified in this study may be biased toward sites more accessible for diving. For instance, Penghu has a notable number of sea turtles documented through fishing industry bycatch [56] but showed low sightings in our data. This may be due to the high turbidity of Penghu's waters, which likely increased the difficulty of sighting and recording turtles in the area. Potential biases can occur in opportunistic observation databases, such as over-representation of common species [58] and over-sampling of accessible locations [59] due to uneven sampling efforts. However, such bias can be mitigated by applying photo-ID at the individual level in this study, thereby reducing the likelihood of overestimation. In contrast, Liuqiu Island, a popular diving destination with frequent turtle encounters, yielded significantly more sightings. This higher resolution data enabled more reliable estimates of residency and population trends, offering a closer reflection of reality-based population distribution.

Habitat connectivity

Sightings of sea turtles with flipper tags can provide valuable information about their previous foraging grounds or nesting sites, offering insights into habitat connectivity. This project recovered five turtles with flipper tags, three of which had visible tag numbers: An olive ridley turtle (PH1004M/PH1005M) originally tagged and released from Cabangan, Zambales, the Philippines, in January 2018, was found alive (bycatch) in September 2018 along the east coast of Taiwan (Hualien County); a subadult green turtle (KK3 0125) originally tagged and released from Ishigaki Island, Okinawa, Japan, in 2003 was found alive (bycatch) in 2020 along the east coast of Taiwan (Hualien County); a green turtle (R36192; https://turtlespottw.org/turtle-profile/TW01G0082), was an adult nesting female from Ulithi Atoll, Yap State, Federated States of Micronesia, where it nested in 2006 and 2012. Notably, this third turtle was first observed at Liuqiu Island in 2011 and has been frequently seen foraging at the same site from June 2017 to May 2022, indicating that this individual has migrated between Ulithi Atoll and Liuchiu Island (2,500 km apart) at least twice (Fig. 4). In additional, both front flipper tags (R36192/R36191) of this turtle were intact during its first sighting in 2011. By 2017, only one tag (R36192) remained, which was subsequently lost in Feb 2020. The information gleaned from these tagged turtles corroborates previous studies using satellite tracking and molecular techniques, which demonstrated that Yap in the Federated States of Micronesia and Yaeyama of Japan are potential source rookeries for the green turtle foraging aggregations around Taiwan [6, 60]. These observations underscore the importance of understanding sea turtle migratory patterns and habitat use across international boundaries and highlight the scientific significance of the collective efforts of citizen scientists to enhance the conservation of sea turtles.

Operation and maintenance of an extensive crowdsourced conservation network

After seven years of operation (as of 19 August 2024), TurtleSpot Taiwan Facebook Group has more than 21,723 members from diverse sectors of society, including SCUBA and free divers, scientists, schoolteachers, and students, among other members of the general public. Member profile data described a diverse cohort of participants, with a nearly even male-to-female ratio

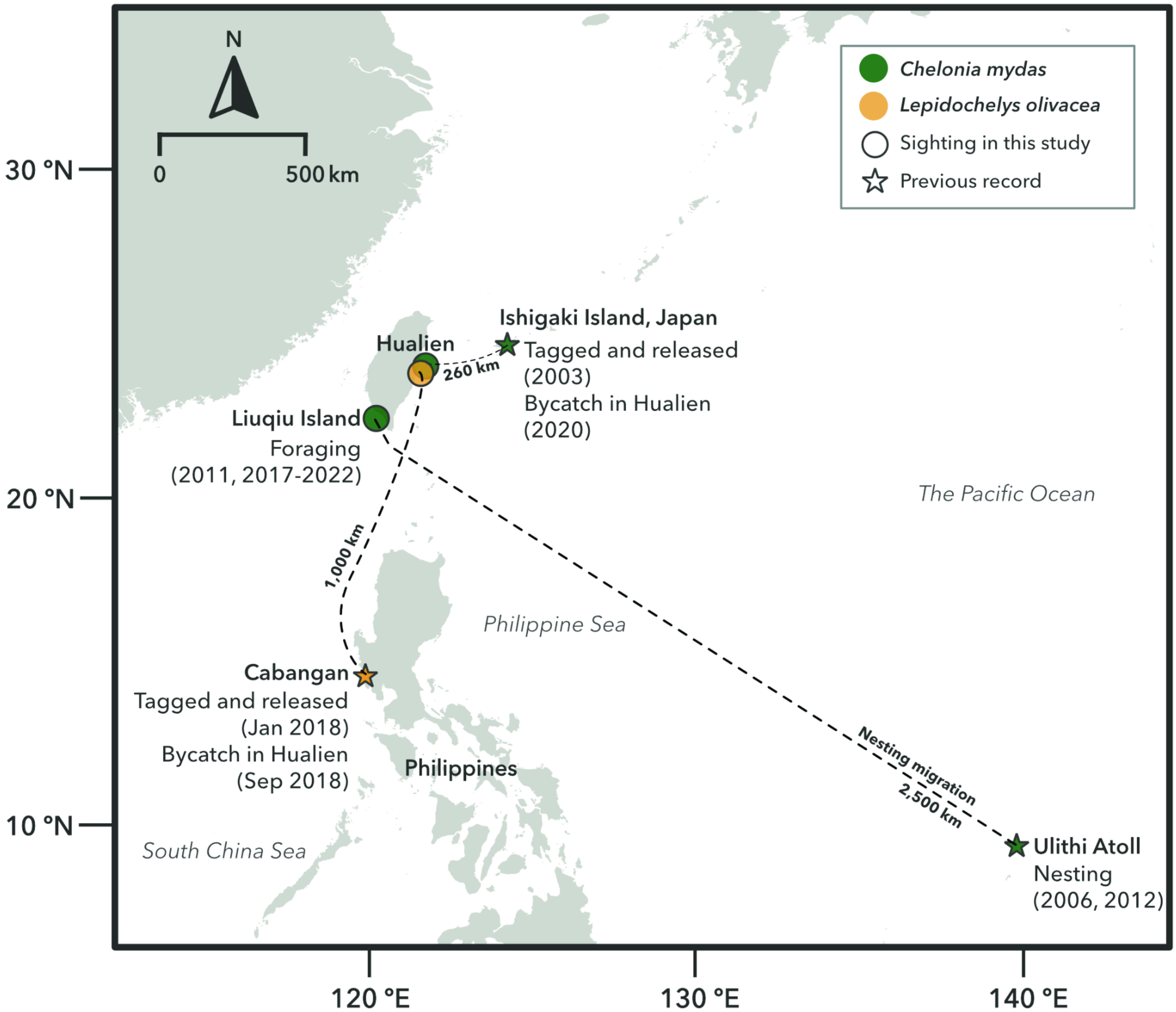

Fig. 4 Connectivity of sea turtle foraging grounds and nesting sites identified through flipper tag recoveries. Colors indicate the species of turtle individuals and shapes indicate the location of the sighting and tagging history

(45% and 55%, respectively), an age range of 13 to +65 years old (majority within the 35–44 range; 39%). However, only about 2% of these members have actively contributed turtle sightings, indicating that much of the engagement represents passive support, such as expressing interest in the initiative, rather than active participation. This low proportion of contributors may also stem from logistical barriers associated with data collection, as accessing turtles in their natural habitats typically requires SCUBA diving or snorkeling, which may limit broader involvement.

Despite strategies developed to increase public participation [61–63], recruitment and retention of citizen scientists remains an ongoing challenge that limits the efficacy and usefulness of many existing projects. To maintain recruitment, TurtleSpot Taiwan actively engages the public through in-person workshops, educational outreach events, and online interactions, such as inviting citizen scientists to name the turtles they reported and providing feedback and photo-ID results to sighting posts. These initiatives likely contributed to the good number of recruitments of new participants, with nearly two-thirds of participants each year being newcomers. However, our analysis on participant retention revealed that most participants (52%) contributed only once and only a small proportion (12.4%) contributed more than five reports. Correlation analysis indicated that participants with multiple contributions tended to remain active in TurtleSpot Taiwan for longer periods. For instance, 70% of those contributing more than five reports demonstrated retention of over one year. Similar patterns were also identified in other studies, where most contributors participated only once and with minimal effort, while a relatively small percentage of contributors showed higher activity [64, 65]. Meanwhile, although 52% of participants were single-time contributors, this ratio is still lower compared to other environmental CS projects, where single-time contributors often account for higher proportions (e.g., 72%; [65]). To increase participation and retention levels, conducting surveys or interviews to understand the motivations of citizen scientists [66], more regular updates on the project's progress, and a system of milestones to encourage sustained engagement can be further integrated into the current project's framework.

Conservation implications

Our analyses found that nearly 10% of sightings included observations of at least one category of injury. These injured turtles could be due to human prejudice, as citizen scientists are more prone to report rare and charismatic species or events [67, 68], leading to over-reporting of injured turtles; however, it also suggests increased human activity and tourism [69] may be stressing local foraging aggregations, similar to the effect seen in other regions [70]. These data suggest that a comprehensive management plan is urgently needed, including measures to reduce boat speeds in hotspot areas and strict regulations on coastal human activity (e.g., rock fishing, sewage treatment, and coastal construction) to benefit these flagship species and the broader marine ecosystem.

Conservation efforts can make use of crowdsourced data to complement field-based research by covering a larger geographic area while engaging a broader public in conservation efforts. However, achieving high-quality spatial data requires substantial resource investment, including building strong community partnerships [71]. Working toward a community contributory approach in the main foraging grounds (e.g., Liuqiu Island, Kenting, Green Island, and the northeastern coast), where local participants are actively involved in data collection, analysis, or decision-making, should be the conservation focus moving forward. The present crowdsourced conservation platform can further develop for international collaboration projects studying global sea turtle foraging grounds or contribute to the Internet of Turtle, a web-based photo-ID system with a worldwide database [72]. Our study provides evidence that this citizen science platform is important in providing reliable, long-term global monitoring data for tracking changes in sea turtle aggregations and foraging grounds, enabling adaptive management strategies that can respond effectively to global climate change issues.

Abbreviations

CS	Citizen science
Photo-ID	Photographic identification
MRD	Minimum resident duration
GBIF	Global Biodiversity Information Facility
SCUBA	Self-Contained Underwater Breathing Apparatus

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12862-025-02354-2.

Supplementary Material 1

Supplementary Material 2

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Author contributions

CLF, DZH, HS, and PYC initiated the CS project and were responsible for the conceptualization, data curation, data analysis, funding acquisition, methodology, and project administration. CCT, KWHT, and HCH contributed to data curation and data analysis. CLF wrote the main manuscript, conducted formal analysis, and prepared figures and tables. JYW contributed to statistical analysis and the preparation of Fig. 4. DZH, YN, and BKKC contributed to the manuscript editing. YN and BKKC provided resources and supervised analysis and manuscript preparation. All authors reviewed and approved the final version of the manuscript.

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Data availability

The sea turtle occurrence dataset is available at the Global Biodiversity Information Facility portal (https://doi.org/10.15468/43z4mj) and with data structure details (https://doi.org/10.3897/BDJ.10.e90196). The analysis data is available via the GitHub repository (https://github.com/TurtleSpot-Taiwan/2024_Fong_5yearsTurtleSpot).

Declarations

Ethics approval and consent to participate

The dataset used for the ecological analysis in this study has been published on GBIF [28], with its structure detailed in [29], contributing to open data framework of this citizen science project. The participants of this citizen science project were provided informed consent to agree to the project's objectives, data collection methods, and potential uses of their contributions. The project was conducted in adherence to the National Wildlife Conservation Act of Taiwan to ensure the ethical treatment of sea turtles. This project has not involved any human participation, human tissue, or human experiments, and there is therefore no need for approval from any ethical issues committee.

Consent for publication
Not applicable.

AI use
AI prompts from Grammarly software (Grammarly, Inc.) were utilized to enhance the writing process, particularly using prompts to improve text grammar.

Competing interests
The authors declare no competing interests.

Author details
[1]Biodiversity Program, Taiwan International Graduate Program Program, Academia Sinica, Taipei, Taiwan
[2]Department of Life Science, National Taiwan Normal University, Taipei, Taiwan
[3]Biodiversity Research Center, Academia Sinica, Taipei, Taiwan
[4]TurtleSpot Taiwan, Pingtung, Taiwan
[5]Taiwan Biodiversity Information Facility, Biodiversity Research Center, Academia Sinica, Taipei, Taiwan
[6]Independent Researcher, Taipei, Taiwan
[7]School of Forestry and Resource Conservation, National Taiwan University, Taipei, Taiwan
[8]Tropical Biosphere Research Center, University of the Ryukyus, Okinawa, Japan
[9]Department of Marine Science, Faculty of Fisheries and Marine Science, Universitas Diponegoro, Semarang, Indonesia

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