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Using Photographic Identification to Monitor Sea Turtle Populations at Perhentian Islands Marine Park in Malaysia

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***Abstract*.—Perhentian Islands Marine Park is home to foraging and nesting Green Turtles (*Chelonia mydas*) and Hawksbill Turtles (*Eretmochelys imbricata*) but little information is available other than nesting trends and hatching success. We used photographic identification (photo-ID) methods to identify individuals and to determine their sex ratios, habitat use, and site fidelity. We collected 1,826 sightings between 2009 and 2015 from conservation projects (998 in-water sightings, 184 nesting sightings) and members of the public (639 in-water sightings, five nesting sightings), and used NaturePatternMatch (NPM) software and manual visual matching to identify individuals. We identified 120 (minimum) to 131 (maximum) individual Green Turtles, including a maximum of 17 males, 58 females and 56 turtles of unknown sex from both in-water and nesting beach sightings. We identified 20 (minimum) to 23 (maximum) individual Hawksbills of unknown sex from in-water sightings. Green Turtles were sighted most frequently at seagrass beds and Hawksbills only among coral reefs. We resighted 47 Greens and eight Hawksbills between one and 144 times (mean = 23.1 times). Nesting Greens also showed strong site fidelity, although the nesting home range for some individuals included different beaches on adjacent islands within approximately 30 km. We identified boat-related injuries in eight turtles and mortalities of two turtles. Our study suggests that photographs from conservation projects and members of the public were appropriate for photo-ID to provide information on the turtle populations in the Perhentian Islands Marine Park.**

Key Words.—Chelonia mydas; citizen science; computer-assisted pattern recognition; Eretmochelys imbricata; Green Turtle; Hawksbill Turtle; individual identification

Introduction

Basic biological, ecological, and population demographic information is essential to species conservation and management. The identification of individuals within a population allows the study of growth rates, age structure, sex ratios, survivorship, residency, distribution, movement patterns, and population size, which are important for ecological and behavioral studies (Wells and Scott 1990; Wilson et al. 2006; Holmberg et al. 2009; Bjorndal et al. 2013). In sea turtles, tagging using flipper tags and/or passive integrated transponder (PIT) tags are common methods used to recognize individuals and track their movements (Luschi et al. 1996; James et al. 2007). Tags of all types are more often applied to sexually mature female turtles due to ease of attachment during the nesting process. However, information on nesting females only may underestimate the population size due to the paucity of knowledge on adult males, sub-adults, and juveniles that spend most of their time at foraging grounds and out at sea (Schofield et al. 2008). More recently, photographic identification (photo-ID) has been increasingly used for in-water population and behavioral studies of sea turtles (Jean et al. 2010; Su et al. 2015; Araujo et al. 2016).

Photographic identification has been used in long-term studies of large and long-lived species (Würsig and Jefferson 1990; Baird et al. 2008). It is gaining popularity as a non-invasive alternative to tagging where animal capture and tag attachment is not feasible due to financial, logistical, or ethical reasons (Thompson and Wheeler 2008; Su et al. 2015). Many species bear unique markings or natural patterns that allow individuals to be identified from photographs, e.g., Tigers (*Panthera tigris*; Hiby et al. 2009) and Pink River Dolphins (*Inia goeffrensis*; Gomez-Salazar et al. 2011). In Cheloniidae, the facial scale patterns are unique to individuals and stable over a period of at least 3 y for Hawksbill Turtles (*Eretmochelys imbricata*; Dunbar et al. 2014) and up to 11 y for Green Turtles (*Chelonia mydas*; Carpentier et al. 2016). The scale patterns on the top of the head (Lloyd et al. 2012) and scute patterns on the carapace (Hall and McNeill 2013) are also useful for recognizing individual turtles. Other distinct features, such as barnacle patterns, could also help with identification (Hall and McNeill 2013). Several methods of photo-ID for sea turtles have been developed (see Reisser et al. 2008; Schofield et al. 2008; Jean et al. 2010; Lloyd et al. 2012; Su et al. 2015). Although not error free, computer-assisted identification systems can improve identification capability and accelerate the process, which is especially needed for large databases (Carter et al. 2014; Dunbar et al. 2014).

In many places, viewing of sea turtles on nesting beaches and in the water as a major tourist attraction has created an opportunity to use citizen scientists (volunteers and members of the public) in data collection for population studies (Campbell and Smith 2006; Bell et al. 2009; Williams et al. 2015). Citizen science can be defined as public participation in scientific research, often in collaboration with or under the supervision of researchers (Dickinson et al. 2010). It has educational value as it promotes knowledge and increases public awareness, engagement, and appreciation towards nature (Cohn 2008). Some photo-ID studies on land and in the water have used citizen scientists to collect photographs (Wee and Subaraj 2009; Carpentier et al. 2016). However, data gathered by citizen scientists may be inaccurate, inconsistent, or unreliable due to their limited or lack of knowledge, training, and motivation in scientific research, leading to difficulties during data analysis (Cohn 2008). Error and bias could occur from non-standardized sampling methods, non-uniform sampling effort across time and space, or erroneous reporting (Dickinson et al. 2010). Appropriate training and supervision can enhance the reliability of data collected by citizen scientists, providing invaluable data sets for researchers to study populations (Danielsen et al. 2014). If well trained and supervised, citizen science provides a cost-effective way of collecting data through increased manpower and sampling effort, allowing biodiversity monitoring over greater spatial and temporal extents (Goffredo et al. 2004).

Four species of sea turtles, Leatherback (*Dermochelys coriacea*), Olive Ridley (*Lepidochelys olivacea*), and Green and Hawksbill turtles, occur in the State of Terengganu in Malaysia, and only two species, Green and Hawksbill turtles, nest and reside in the waters of Perhentian Islands Marine Park (Chan 2006). Approximately 20–30% of all Green Turtle nesting reported in Terengganu occurs on these islands (Sarala Aikanathan and Jeanne Mortimer, unpubl. report). To protect nesting habitats and increase hatchling production, the Terengganu State Department of Fisheries (DoF) set up a hatchery and declared several high density nesting beaches as turtle sanctuaries (Siow and Moll 1982; Chan 2006). During the nesting season from April to October, DoF rangers patrol the beaches and relocate nests to the hatchery. Nesting data, such as counts of landings, nests, eggs incubated and hatchlings, serve as a baseline for monitoring nesting trends and hatching success. Little is known, however, about the in-water turtle populations because research and conservation work have focused mainly on nesting sites. Moreover, there is a lack of mark-recapture data.

We used photo-ID as an alternative to tagging, and we integrated citizen science to gather more sighting data on Green and Hawksbill turtles that is otherwise not possible with limited resources. The objective of this study was to assess nesting and in-water turtle populations of these species in the Perhentian Islands Marine Park using sightings data collected by conservation projects and members of the public. We used photo-ID methods to identify individual turtles for developing a sea turtle photo-ID database and to determine their sex ratios, habitat use, and site fidelity.

Materials and Methods

Study site.—The Perhentian Islands Marine Park (5°53'49"N 102°43'45"E) is a tourist destination located in the South China Sea, 21 km off the mainland of Terengganu on the north-eastern coast of west Malaysia (Fig. 1A). The marine park consists of several islands, and only Perhentian Besar (867.3 ha) and Perhentian Kecil (524.8 ha) are inhabited. The islands lie on a shallow continental shelf extending from the mainland with an average maximum depth of 30 m (Simon Harding et al., unpubl. report), and experience a seasonal weather pattern with higher rainfall during the Northeast monsoon from October until March (Suhaila et al. 2010). The water temperature ranges from 26–31° C (Wetzelhuetter et al. 2014), and a thermocline is present at different depths in dispersed geographic areas (Simon Harding et al., unpubl. report). The horizontal underwater visibility varies spatially from 7.1–15.5 m (Simon Harding et al., unpubl. report); however, during the monsoon, the visibility can decrease. There are currents flowing northward (April to August) and southward (November to March) along the Terengganu coastline (Mohd Akhir 2012), but the islands are more exposed to local tidal currents that show no prevailing current direction (Simon Harding et al., unpubl. report).

Surrounding the islands are coral reefs, with the mainly fringing reefs sloping to a sandy bottom at 20 m and seamount type reefs (Toda et al. 2007; Simon Harding et al., unpubl. report). There are monospecific seagrass beds of *Enhalus acoroides* or *Halophila minor*, as well as mixed-species of the latter with *Halophila decipiens*, *Halophila ovalis*, and *Halodule pinifolia* (Muta Harah and Japar Sidek 2013). Habitat diversity is high and patchily distributed, ranging from areas unsuitable for benthic growth to those supporting high cover of benthic organisms (Simon Harding et al., unpubl. report). The islands were protected as a marine park in 1994 under the Malaysian Fisheries Act of 1985.

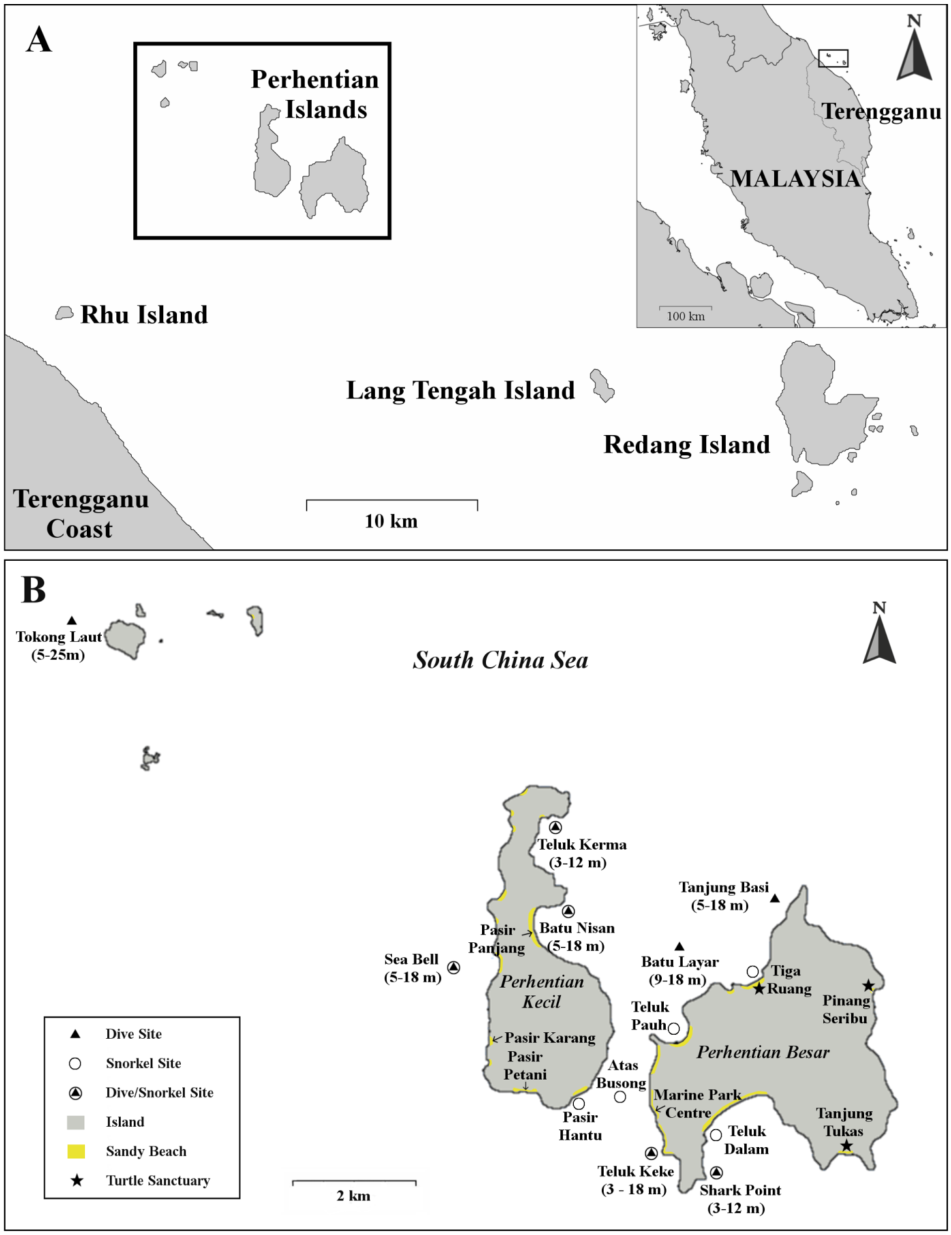

Figure 1. (A) The Perhentian Islands Marine Park within the Terengganu waters in peninsular Malaysia (SEATURTLE.ORG Maptool. 2002. SEATURTLE.ORG, Inc. Available from http://www.seaturtle.org/maptool/ [Accessed 06 December 2016]), and (B) the location of turtle sightings in the water and on beaches. Note: The snorkel site in front of Tiga Ruang Beach is also known as Tiga Ruang.

The law prohibits touching or taking of any marine resources whether alive or dead without permission, and it bans water skiing, speed boat racing, jet skiing, and fishing activities within a radius of two nautical miles from the lowest tide level of the islands. Less harmful activities such as snorkeling, scuba diving, swimming, underwater photography, and kayaking are allowed and occur before and after the monsoon from March to October. Peak tourist season is June to August with the annual number of tourists arriving to the marine park exceeding 100,000 since 2012, and increasing to 180,481 in 2015 (Department of Marine Park Malaysia, unpubl. data). There are at least 30 dive sites at natural and artificial reefs and no fewer than 13 snorkel sites, mostly around fringing reefs or seagrass areas adjacent to the beach (Tourism Planning Research Group, unpubl. report). Some of the sites are for diving and snorkeling, but snorkelers often stay in shallower areas.

Data from conservation projects.—The Perhentian Turtle Project (PTP) carried out photo-ID surveys at foraging and nesting grounds between April and mid-October 2015. In the first month, we trained four interns (who stayed for the whole study period) on snorkel surveys and beach monitoring, where they learned about species and track identification, biometric sampling, photo-ID methods, free diving, and record keeping. Twenty volunteers (who stayed 7–14 d) also received training but may not have acquired all the skills needed during their stay. Therefore, we conducted every survey in a team of two to three people where we and trained interns led and supervised the volunteers (if any) in data collection.

We conducted one to two turtle photo-ID surveys a day for 5–7 d a week. Each survey lasted 2–3 h between 0900–1300 or 1400–1800. We surveyed predominantly around the seagrass area at Teluk Pauh (Fig. 1B) with one observer on a kayak to look out for turtles breathing at the water surface while the rest snorkeled to look for turtles underwater. The survey area where we haphazardly looked for turtles was approximately 4 ha and less than 10 m deep. As sightings of turtles were sporadic elsewhere, we surveyed other sites opportunistically. When a turtle was sighted, we free dived to around eye level of the turtle and photographed the right and left sides of the face from a minimum distance of 1.5 m. We also photographed the dorsal view of the turtle. We used four camera models to photograph in-water turtles (Canon PowerShot G15 and PowerShot G16 in their respective underwater housings, Canon, Inc., Ota, Tokyo, Japan; GoPro Hero 3, GoPro, Inc., San Mateo, California, USA; and Olympus TG-3, Olympus Corp., Shinjuku, Tokyo, Japan).

Every night during 1900–0800, we surveyed the beach with DoF rangers at Tiga Ruang Turtle Sanctuary (Fig. 1B). After encountered turtles had completed the oviposition process, we checked the turtles for tags and measured the curved carapace length. We then used a digital camera (Canon PowerShot G15, Canon PowerShot G16, or Olympus TG-3) to take facial photographs at approximately the eye level of the turtle from a distance of approximately 0.4 m without camera flash, but by shining a red LED headlight toward the head. An artificial light source was not necessary when photographing turtles after 0630. For all encountered in-water and nesting individuals, we recorded the tag number (if any) and sighting information, such as date, time, and location. In addition to the photographs collected in 2015, we also had photographs of in-water and nesting turtles taken opportunistically since 2012. During the study period, we also gave a briefing with instruction on photo-ID data collection to project leaders of three conservation projects who already had a background in marine biology and conservation, including beach monitoring experience and knowledge of species identification. They contributed sightings of nesting turtles, as well as photographs of turtles that they encountered during leisure snorkel and dive trips since 2011.

Data from the public.—Members of the public could submit photographs of turtles via the PTP email (turtle@ecoteer.com) and social media sites (e.g., Facebook and Instagram). There were posters and banners at various locations around the islands and at the mainland jetty to provide information on photo-ID, as well as illustrated guidelines to watch turtles. Upon receiving the photographs, we contacted the contributor to verify sightings information because photographs from social media sites did not have metadata. We recorded the sighting location as unknown for sightings with no location information or vague location descriptions, the sighting date as the month and year the photographs were taken if the date was unknown, the sighting time as day or night if the exact time was unknown, and the camera model if such information was available.

Photographic identification process.—We distinguished the sex of in-water turtles using tail length dimorphism whereby individuals with evidently longer tails that extended significantly beyond the carapace were identified as adult male (Wibbels 1999), otherwise they were assumed to be of undetermined sex or adult females if they had a tag from a nesting beach. We used the software NaturePatternMatch (NPM), which detects, recognizes, and compares natural patterns for individual identification (Stoddard et al. 2014). The NPM is a less-species specific adaptation of the Manta Matcher (MM) identification software for manta rays (*Manta* spp.; see Town et al. 2013). Other computer-aided identification systems tested on hard-shelled sea turtles require the user to manually select reference points (Dunbar et al. 2014), code (Jean et al. 2010), or outline the facial scales (Carter et al. 2014). Instead, the NPM uses the Scale-Invariant Feature Transform (SIFT) algorithm to automatically select distinct features for image matching (Lowe 2004). The selected features appeared to be robust to changes in location, scale, rotation, illumination, 3D viewpoint, noise, and occlusion (Lowe 2004, Stoddard et al. 2014). For example, the SIFT algorithm could detect distinct points from the pineal spots of Leatherback Turtles and recognize the same individual from photographs that varied in illumination, resolution, and viewing angle (Pauwels et al. 2008). It could also identify manta rays correctly despite the presence of occlusions (e.g., fish) and extreme image noise (Town et al. 2013). Thus, automated software using the SIFT algorithm could recognize individuals from photographs taken under challenging conditions underwater or at night.

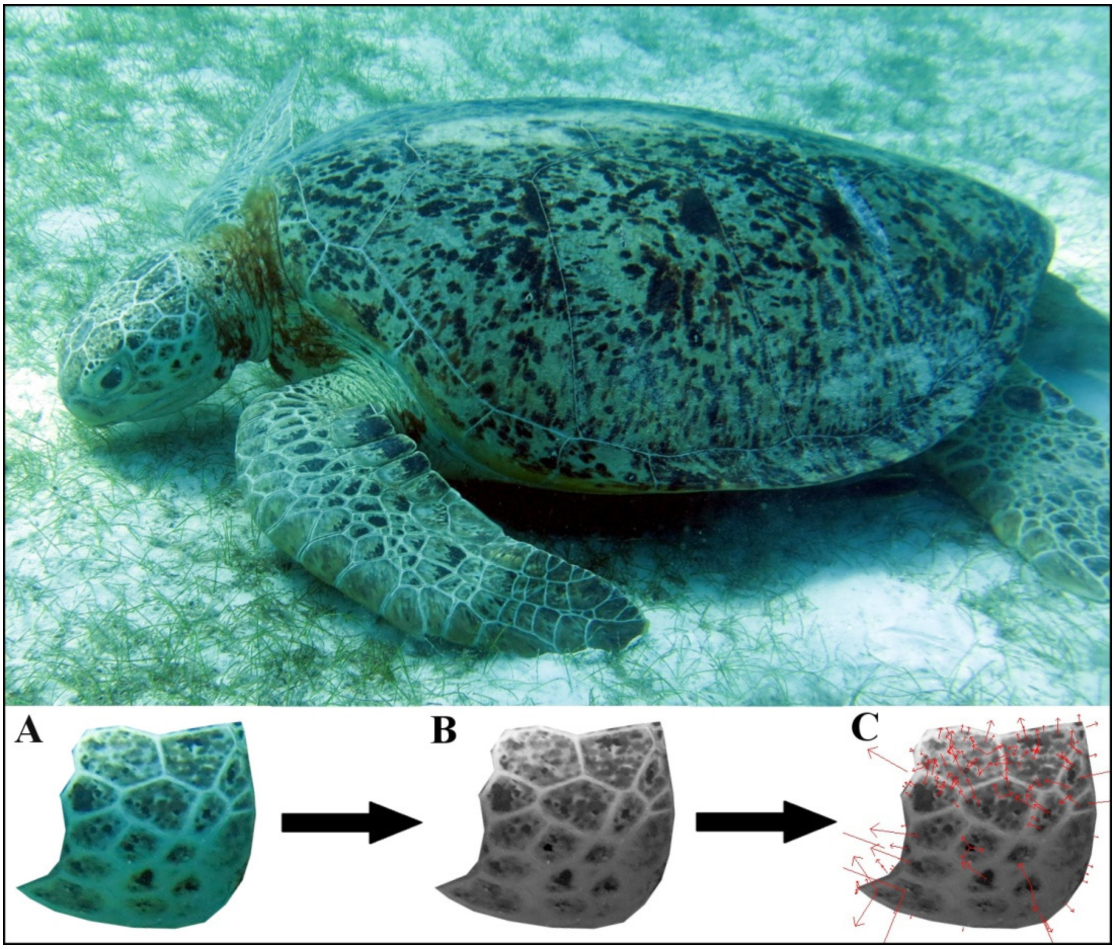

Figure 2. An example of the photo-ID process for a Green Turtle (*Chelonia mydas*) where a cropped image of the left facial scale (A) is converted into grayscale and enhanced (B) before NPM extracts distinct features using SIFT (C). (Photographed by Seh-Ling Long).

The automated matching process consisted of (1) image preprocessing; (2) image enhancement; (3) feature detection and extraction (per left or right profile); and (4) feature matching. First, we cropped the left facial scales and rotated the cropped images to a horizontal angle using GNU Image Manipulation Program (GIMP) 2.8.14 (Free Software Foundation, Inc., Boston, Massachusetts, USA; Fig. 2A). Then, we used NPM, which converted the facial scale images to grayscale and enhanced the images after noise filter and contrast adjustment (Fig. 2B). The NPM software detected and extracted distinct features from the left facial scales using the SIFT algorithm (Lowe 2004; Fig. 2C), and matched the extracted features against the left face of all individuals in the database. It then displayed a ranked list of the left face matches from most to least similar based on a similarity score (0–1), along with a confidence score (0–1) to indicate how reliable the rankings are (Fig. 3A). We repeated the process for the right facial scales to get a ranked list of the right face matches (Fig. 3B). We visually checked the list for the correct match (if any) and looked through all the matches if the confidence score was low.

For photographs that did not show the facial scales clearly enough, we did visual comparison manually using an identification tree based on the (1) species; (2) sex; (3) number of post-ocular scales on the right and left faces; and/or (4) number of temporal and parietal scales on top of the head (modified from Schofield et al. 2008; Lloyd et al. 2012; Su et al. 2015). We used the facial scale patterns, as well as the natural markings and scars on the top of the head, shell, and flippers to identify individuals (Fig. 4). We identified an individual as a new turtle when we found no match, whereas a match from either side of the face indicated resighted turtles. We added every new turtle to a database and grouped them as identified individuals with photographs of both sides of the face, left side only, or right side only. We assigned new turtles an ID to specify the species, individual, and sex (if known), only if they were sighted alive with both sides of the face photographed. We gave new turtles with only one facial profile an ID after seeing

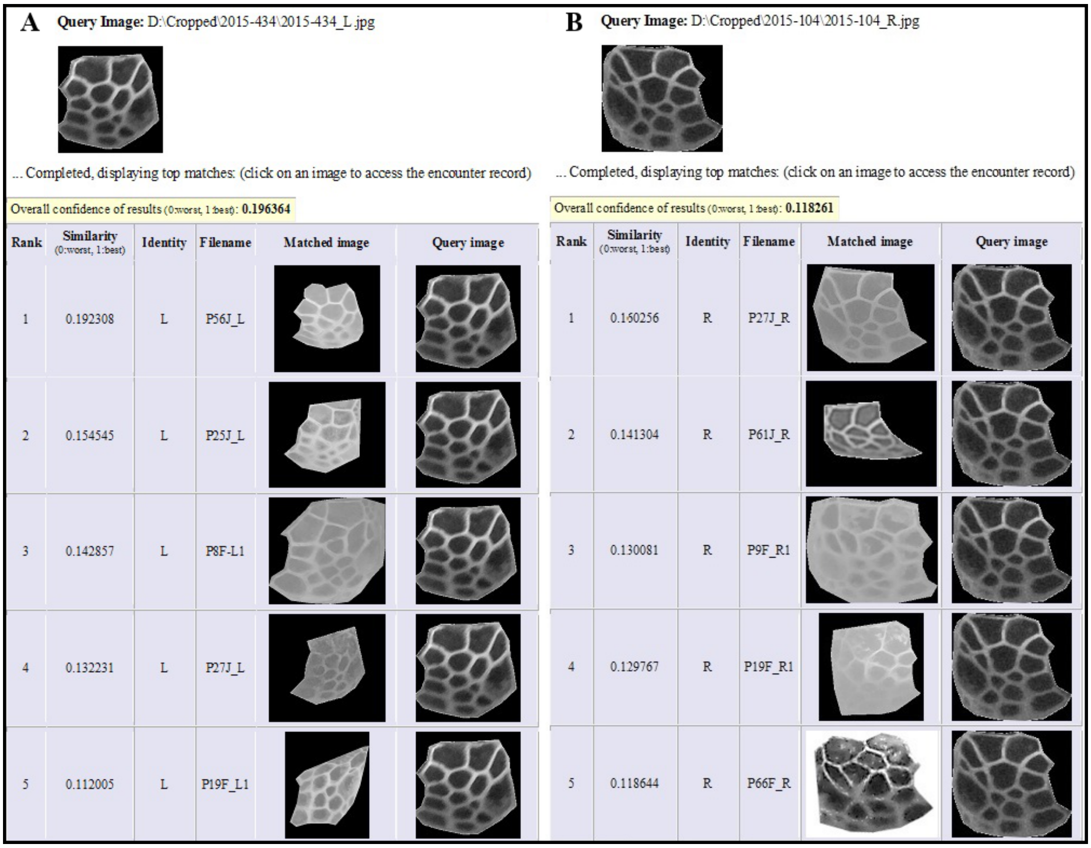

Figure 3. Examples of NPM output showing a ranked list of the left (A) or right face (B) matches based on a similarity score of 1 (perfect match) to 0 (no match). Every matched image shows the facial scales of a different individual. The filename is the turtle ID and the identity indicates the left (L) or right face profile (R). A high confidence score indicates that the query image is significantly more similar to the first-ranked matched image than any other images whereas a low confidence requires the user to check a larger number of matches for the correct match (Town et al. 2013). Here, the fourth-ranked and the first-ranked matches are the correct match for the left side (A) and right side (B), respectively, showing that the query images match individual P27.

them again with both sides of the face photographed. After the first observer identified the individual from a new sighting, a second observer checked to confirm the identity of the individual. To avoid errors and misidentification, we checked all of the sightings again to verify identifications.

Results

Sea turtle sightings.—We gathered 1,826 turtle sightings from conservation projects (n = 1,182) and members of the public (n = 644), which consisted of underwater sightings from 2009 to 2015 (n = 1,637) and nesting sightings from 2011 to 2015 (n = 189). All sightings occurred between the late January and early November. The locations of six underwater sightings and one nesting sighting were unknown whereas the remaining sightings were from 13 dive and/or snorkel sites (n = 1,631) and seven beaches (n = 188; Fig. 5). Due to inadequate information on sighting per unit effort and frequency per site, it was not possible to quantify efforts and abundance based on the number of sightings per site alone.

Individual recognition using photo-ID.—In-water sightings from both conservation projects (n = 998) and members of the public (n = 639) showed difficulties in capturing photographs from a standardized angle for observations where animals were moving constantly. Other factors, such as water visibility, light conditions, and whether or not the turtle was blocked by fish, also affected the quality of the photographs. By positioning the camera around the eye level of turtles, all nesting photographs (n = 184 sightings) from conservation projects showed the face of the turtle in close-up. Meanwhile, members of the public photographed nesting turtles (five sightings) from a standing position using flash. In nesting photographs, sometimes the retraction of the head of the turtle and sand covered a small part of the facial scales (90 sightings). Successful identification of both in-water and nesting sightings was possible using the NPM, as was manual matching,

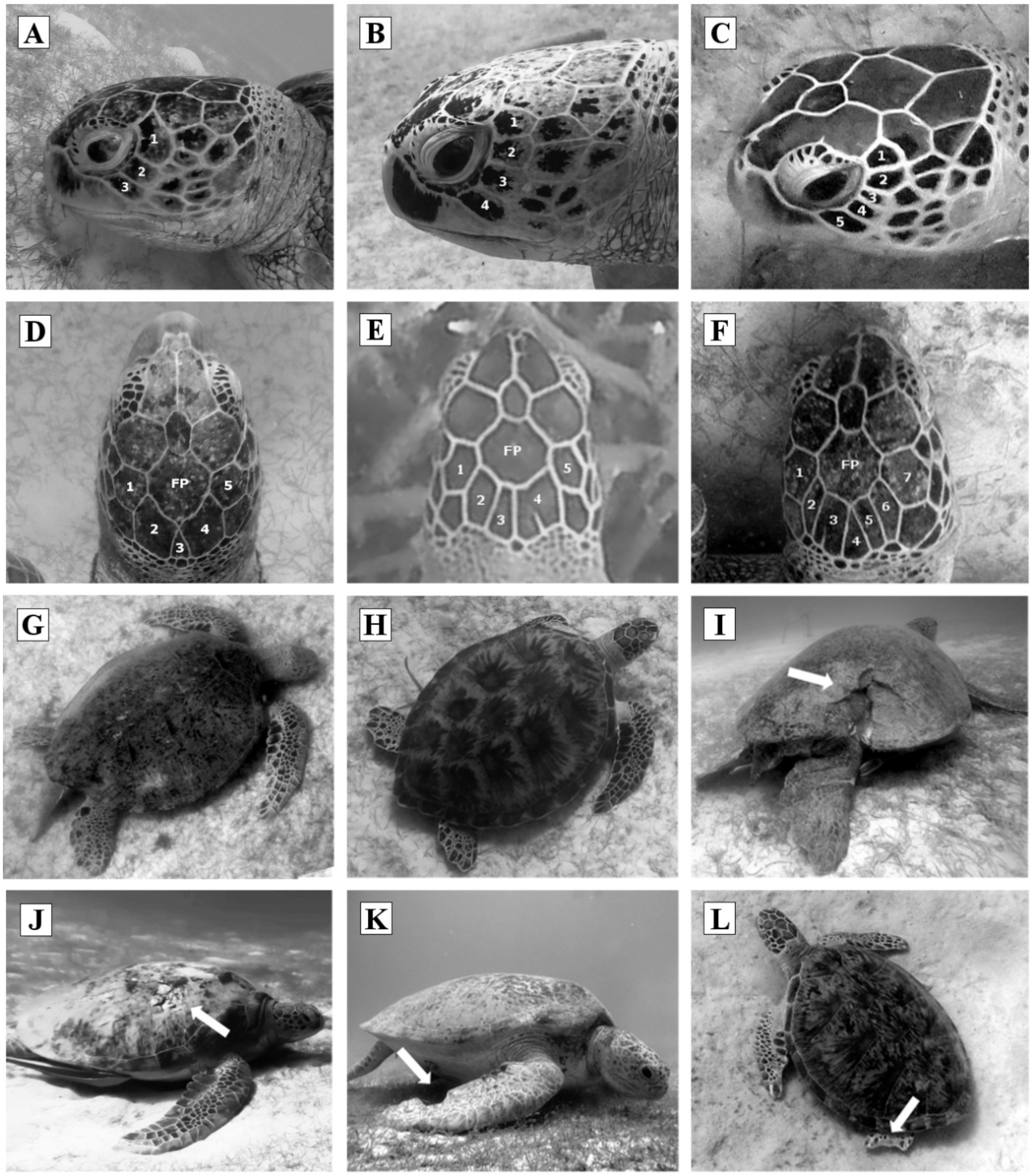

FIGURE 4. Examples of natural markings and scars used for identification: the number, shape and arrangement of the facial scale patterns (A, B, C showing the number of post-ocular scales) and at the top of the head (D, E, F showing the number of temporal and parietal scales surrounding the frontoparietal [FP] scale), the natural markings (G, H) and injuries (I, J) on the shell, or missing a portion of the front (K) or rear flippers (L). (Fig. 1A photographed by Thomas Brown, Fig. 1B photographed by Charlotte. E. Babbs, Fig. 1C and 1I photographed by Nicholas J. Tolen, Fig. 1D photographed by Andrea Szalai, Fig. 1E photographed by Kevin Heitzman, Fig. 1F photographed by Nazirul A. Amin, Fig. 1G photographed by Seh-Ling Long, Fig. 1H and 1L photographed by Petros Persad, Fig. 1J photographed by William Forster, and Fig. 1K photographed by Rahmat A. Wahab).

so long as photographs were not overly out of focus and taken at a horizontal and vertical angle of < 45° where the majority of the facial scales were visible. For in-water sightings, the scale patterns on top of the head, scute patterns of the carapace, barnacle patterns, injuries, and scars, were also useful for identification. Of the total sightings, 79 (4.3%) were not recognizable because the photographs were too blurred, including the only two nesting sightings of Hawksbill Turtles.

The left and right facial patterns were non-identical for all identified turtles of both species. Identification of resighted turtles was possible using only one side of the face, as long as both sides of the facial profile were already available in the database. Unlike Green Turtles, the facial scales of Hawksbills showed higher similarity among individuals and had a smaller number of facial scales and features for matching. They also showed less variation in the number and shape of the post-ocular,

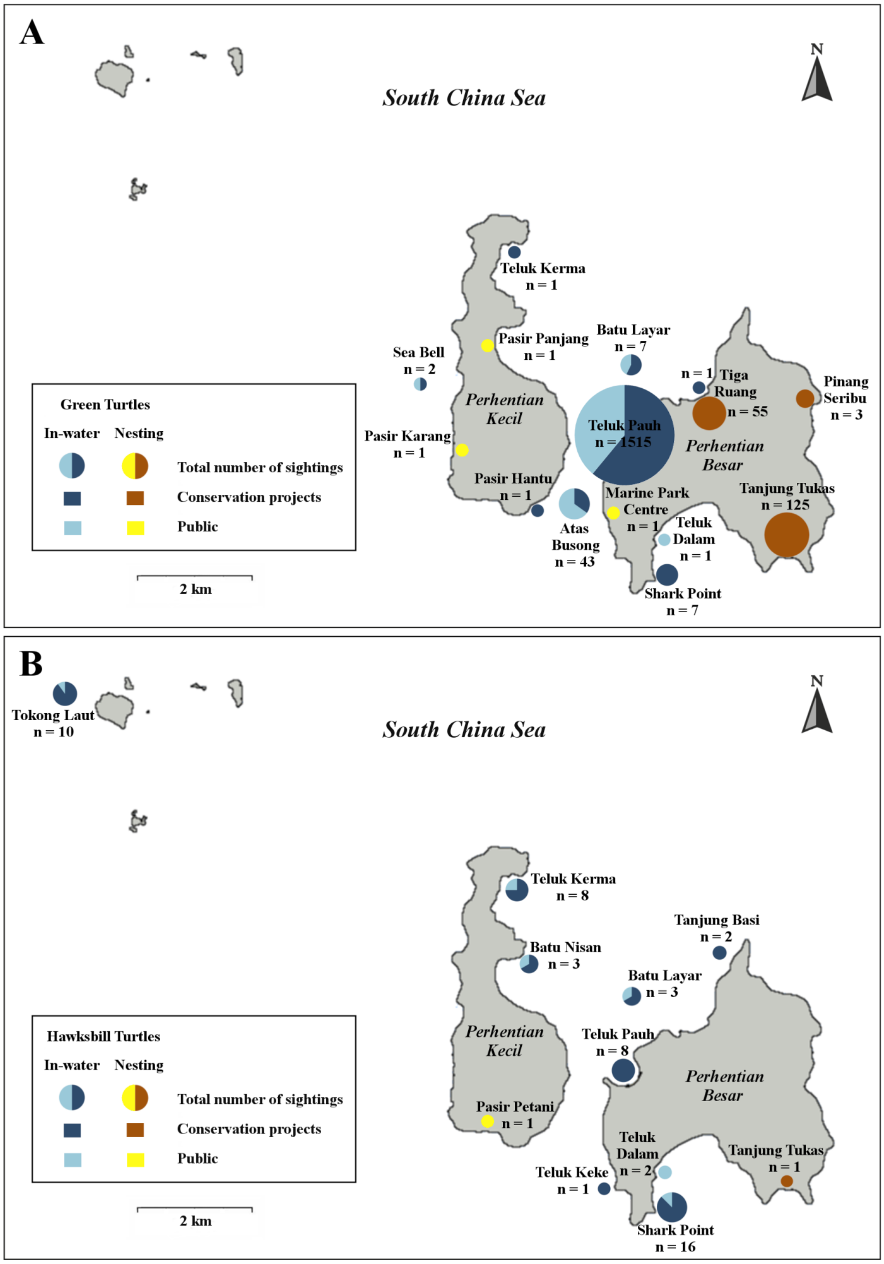

Figure 5. (A) The distribution of Green Turtles (*Chelonia mydas*) and (B) Hawksbill Turtles (*Eretmochelys imbricata*) in the Perhentian Islands Marine Park based on sightings from conservation projects and public individuals between 2009 and 2015.

temporal and sub-temporal scales, and thus, required the combination of all scales including the tympanic and central scales for identification. Time intervals between the first and last sightings of resighted turtles varied from 5–2,212 d for Green Turtles (78 turtles) and 8–490 d for Hawksbill Turtles (eight turtles). During this period, there were no changes in the shape and arrangement of the scales on the face.

Overall, we identified 96.2% of the sightings from conservation projects and 94.7% from the public, adding up to 1,747 sightings. This total represented 96.1% of the Green Turtle sightings (n = 1,766) and 81.7% of the Hawksbill Turtle sightings (n = 60), which belonged to 115 turtles with left and right profiles (104 Greens and 11 Hawksbills), 22 turtles with left profile only (13 Greens and nine Hawksbills) and 17 turtles with right profile only (14 Greens and three Hawksbills; Table 1). There were 1,567 resightings of Green Turtles, of which 127 were repeated sightings of the same turtles on the same day. In contrast, all 26 Hawksbill resightings occurred on different days. All the single-profile turtles were seen only once. The identified turtles in the water

Table 1. Numbers of identified Green Turtles (*Chelonia mydas*) and Hawksbill Turtles (*Eretmochelys imbricata*) in the water and on nesting beaches of the Perhentians, Malaysia, based on their facial profiles and the minimum (min.) and maximum (max.) numbers of unique individuals.

		Green Turtles					Hawksbill Turtles				
		Facial profile					Facial profile				
Population	Sex	Both sides	Left side	Right side	Min.	Max.	Both sides	Left side	Right side	Min.	Max.
In-water	Male	14	1	2	16	17	-	-	-	-	-
	Female	1	-	-	1	1	-	-	-	-	-
	Unknown	42	8	6	50	56	11	9	3	20	23
Nesting	Female	47	4	6	53	57	-	-	-	-	-
Total		104	13	14	120	131	11	9	3	20	23

were not the same individuals as the turtles identified on nesting beaches.

In-water Green Turtles.—There were 57 Green Turtles with photographs of both facial profiles, and of these, 14 were males, one was female, and the remaining 42 were of unknown sex. Of nine turtles with the left profile only, one was a male, and of eight turtles with the right profile only, there were two males (Table 1). The maximum number of individual turtles was 74, while the minimum number of individual turtles was 67 if the right-profile male and unknown sex turtles were the same individuals as the left-profile male and unknown sex turtles. About 80% of the Green Turtles occurred in mixed seagrass beds at depths of about 3–11 m, mainly feeding at Teluk Pauh and Atas Busong. The rest occurred on coral reefs at Batu Layar and Shark Point where the depths varied from 5–15 m. Only two turtles found at a seagrass area at Teluk Pauh were also sighted on coral reefs at Batu Layar, which is about 1.1 km away. Forty seven turtles were resighted up to 144 times (mean = 23.1, SD = 32.7) at the same site on different days over about 6.1 y. Two of the resighted turtles had a tag on both front flippers but we could trace the tags of only one turtle to its original tagging source. One of them was tagged by the Sea Turtle Research Unit of the Universiti Malaysia Terengganu (SEATRU UMT) when it nested approximately 30 km away at Redang Island (Fig. 1A) between May and July 2013. This turtle was first seen in the water at Teluk Pauh in September 2009 and was resighted foraging at the same site every year during 2012–2015 between April and October, except in 2013 where there was only one sighting in September. It had an injury on its carapace when photographed in September 2015 (Fig. 4I). Eight other resighted turtles also had healed or new injuries with six of them showing evidence of boat strikes or propeller cuts (Fig. 4J–L). Furthermore, there were four sightings of dead Green Turtles, and photographs revealed boat-related injuries on two of them, while cause of death was unknown for the other two. Of four mortalities, one turtle had decomposed beyond recognition. One turtle matched an individual from the database, which was spotted three times at Teluk Pauh. We presumed the remaining two turtles to be new individuals because there was no match in the photo-ID database.

In-water Hawksbill Turtles.—There were 11 Hawksbill Turtles with both facial profiles, nine with the left profile only and three with the right profile only (Table 1). There could have been a maximum of 23 individual turtles or a minimum of 20 turtles, if all three right-profile turtles were the same individuals as the left-profile turtles. The sex of all the Hawksbill Turtles was unknown. The observed Hawksbills occurred on coral reefs that were 5–15 m deep. Eight turtles were seen at the same site two to six times on different days over a period of 490 d between 2014 and 2015. Only one of the resighted turtles used two different sites that are about 3.7 km apart, namely Teluk Kerma and Teluk Pauh. One Hawksbill Turtle was missing a portion of the shell at its left rear flipper.

Nesting Green Turtles.—We identified 47 individual female turtles with photographs of both facial profiles, plus four turtles with the left profile only and six turtles with the right profile only (Table 1). If all of these turtles were different individuals, there was a maximum of 57 nesting turtles. If all turtles with the left profile only were the same individuals as the right-profile turtles, there was a minimum of 53 nesting turtles. There were no remigrants over the 5-y period. All the turtles were sighted once, except for 31 turtles that laid between two to nine nests within a season in 2015. The time interval between the first and subsequent sighting of the same turtle ranged from 1–65 d. Of these renesters, 25 nested on one specific beach, while the other six turtles nested on multiple beaches in the Perhentians. Three renesters had tags from the DoF, and records were found for two of them. Both were tagged while nesting at Redang

Island in 2009 and 2010, respectively, and were among the six females that used multiple nesting sites in the Perhentians in 2015.

Discussion

Photographic identification provided a way to assess two distinct in-water and nesting sea turtle populations in the Perhentian Islands Marine Park. Between 2009 and 2015, there were 67–74 Green Turtles including 16–17 adult males and one adult female sighted in the water, and 20–23 Hawksbill Turtles of undetermined sex sighted between 2014 and 2015. There were another 53–57 female Green Turtles that nested from 2011 to 2015. For in-water turtles, we could distinguish adult males using tail length dimorphism and adult females by tracing tags to a nesting site. The rest could either be sexually immature males or females of different life stages (i.e., juvenile, sub-adult, or adult). Measuring turtle carapace length using paired-laser photogrammetry could provide more information on population structure and size distributions to determine which size classes occupy an area (Araujo et al. 2016).

In-water turtles.—Green Turtles were the predominant species sighted at seagrass beds, with a few observed in coral reef areas, whereas sightings of Hawksbills occurred only in coral reef areas. All resighted individuals displayed high levels of fidelity to a particular site, and only a few were seen at more than one site. Studies have shown that sea turtle habitat use and movement patterns within a foraging home range are related to their diet (León and Bjorndal 2002; Read and Limpus 2002), the availability of food (Makowski et al. 2006; Berube et al. 2012), and shelter (Makowski et al. 2006). Sea turtles may have more than one preferred site within their foraging range (Seminoff and Jones 2006) and they can develop fidelity to specific foraging areas when there are sufficient resources (Makowski et al. 2006). Green Turtles in the western South Atlantic spent a longer time in shallow areas where food was more abundant than turtles in areas where food was less abundant (Reisser et al. 2013). Although Green Turtles feed primarily on seagrass, they are known to also feed on algae found in coral reef areas (Read and Limpus 2002). Hawksbill Turtles were found more frequently at rocky reef areas compared to sandy bottom areas off the North Pacific coast of Costa Rica, presumably because the rocky reefs sustained a higher diversity of Hawksbill prey species, including sponges, algae, and invertebrates (Carrión-Cortez et al. 2013). The sighting of Green Turtles mostly at seagrass beds and Hawksbill Turtles only in coral reef areas in the Perhentians could also be related to their diet and the availability of food within an area to which they repeatedly returned.

One Green Turtle photographed at an in-water site had flipper tags from a nesting beach 30 km away from the Perhentians. It nested at Redang Island between May and July 2013 and was found at the same foraging site in the Perhentians before (2009 and 2012) and after (September 2013 onwards) nesting, suggesting short distance migrations between foraging and nesting grounds. Previous satellite tracking of five nesting Green Turtles from Redang Island showed only long distance post-nesting migrations over 670 to 1,700 km to foraging grounds in neighboring countries, and no turtles moved northward (Papi et al. 1995; Luschi et al. 1996). Post-nesting Green Turtles tracked from mainland Terengganu had also migrated long distances to foraging grounds (van de Merwe et al. 2009). Short-distance migrations are less well known among Green Turtle populations in our study region, but have been previously reported elsewhere. One example is the Green Turtles that Whiting et al. (2008) tracked from Cocos (Keeling) Islands where all six migrated fewer than 40 km to foraging areas after nesting. Green Turtles nesting in the Galapagos Islands have also been observed to reside within 75 km of the nesting beach (Seminoff et al. 2008). In Costa Rica, some post-nesting Green Turtles moved to foraging grounds as close as 5 km to the nesting beach, while some turtles migrated as far as 1,086 km (Blanco et al. 2012). Migration has a high energy cost, and is affected by various factors, including body size, energy, and mortality cost (Alerstam et al. 2003). Short-distance migrations require less energy and can occur if foraging and nesting grounds are in close proximity (Whiting et al. 2008). Because the turtle tagged on Redang Island showed residency at its foraging ground, the Perhentian Islands probably met its resource needs, such as adequate food and shelter. It may be a fitness strategy for the turtle that saves energy by performing short-distance migrations between foraging and nesting grounds.

Photographs showed boat strikes and propeller cut injuries in eight turtles and mortalities in two turtles in the Perhentians. With rapid tourism development, injuries to and mortalities of resident turtles due to increased boat traffic around the islands may affect breeding populations elsewhere. We did not examine the nesting turtles for injuries, but they could also be vulnerable to boat strikes because nesting turtles usually stay close to the nesting beach during breeding season (van de Merwe et al. 2009). So far there are no regulations for speed limits in the Perhentian Islands Marine Park and beyond two nautical miles from the islands. As Green Turtles cannot avoid boats moving faster than 4 km/h (Hazel et al. 2007), designation of conservation zones to regulate boat activities, such as limiting the boat speed and boat density, are possible actions that can be taken, as in National Marine Park of

Zakynthos, Greece, to mitigate boat impacts to turtles in nearshore foraging grounds (Schofield et al. 2013). However, sufficient evidence-based information that is site-specific, such as seasonal differences in the use of an area by turtles and boats, is required to appropriately make such recommendations (Schofield et al. 2013).

Nesting turtles.—Green Turtles were the most frequently sighted species in nesting areas. The majority of renesters showed strong site fidelity returning to the same beach, while only some individuals showed weaker nesting site fidelity by nesting on multiple beaches. Evidence from tagged females indicated that some turtles nesting at Perhentian Islands had nested at Redang Island in previous years. This suggests that the nesting season home ranges of some adult females span across islands within a range of 30 km. It is well-established that Green Turtles possess a high degree of fidelity in returning to previous nesting grounds (Plotkin 2003) as well as their natal rookeries for nesting (Allard et al. 1994). They may return to a specific nesting site (Luschi et al. 1996; Ekanayake et al. 2010), or use multiple nest sites within a considerable area spanning a few hundred kilometers (Bjorndal et al. 1983). As there are also other islands in the vicinity of the Perhentians, it is possible that the rookery consists of a number of different nesting beaches on any of those islands. There were female Green Turtles returning to the Perhentians to nest again within one nesting season. However, due to inadequate and incomplete data prior to 2015, there was no record showing that nesting females from the photo-ID database were remigrants returning to the Perhentians for nesting in subsequent years. Thus, long-term monitoring initiatives and mark-recapture data will greatly contribute to understanding the nesting population in the Perhentians.

Considerations for using photo-ID.—Most photo-ID studies on hard-shelled sea turtles have used facial scale patterns for recognizing individuals photographed underwater (Reisser et al. 2008; Jean et al. 2010; Chassagneux et al. 2013; Su et al. 2015; Carpentier et al. 2016), out of water (Dunbar et al. 2014), and on nesting beaches at night (Valdés et al. 2014; Chew et al. 2015). Lloyd et al. (2012), Hall and McNeill (2013), and Dunbar et al. (2014) showed that individual identification is also possible using photographs of the dorsal view of the head and carapace. For nesting turtles, we only used the facial scale patterns to identify individuals because only the facial scales of turtles illuminated by the headlight were visible in nesting photographs. We were also better able to photograph the face of every nesting turtle close-up (as close as 0.4 m) compared to constantly moving in-water turtles. In-water photographs showed facial scales at varying angles, but other visible features, such as the scales on the top of the head and scute patterns of the carapace, could aid with identification. These features were less available for nesting turtles because of the difficulties in photographing the dorsal view of the head and shell using headlights as a light source and when the turtles were camouflaging their nests. The sand that landed on the head and shell further limited the observation of the scale and scute patterns.

Natural markings need to be stable throughout the lifespan of an animal to use these features to consistently identify individuals in a population. In our study, the facial scales were the most reliable features to identify in-water and nesting individuals of both species because the patterns were distinct for every individual and remained the same over at least 2,212 d for Green Turtles and 490 d for Hawksbill Turtles. Carpentier et al. (2016) also showed that individual Green Turtles were distinguishable from their facial scale patterns over 3,954 d (almost 11 y), while the longest period recorded for Hawksbills was 1,155 d (Dunbar et al. 2014). Obtaining both left and right facial profiles was important to avoid double-counting and to successfully identify a new turtle. Once we had photographically documented the left and right profiles of an individual, we were able to identify resighted turtles even if only one side of the face was photographed. Others have also stressed the importance of photographing both sides of the face to increase successful identification (Chew et al. 2015; Su et al. 2015).

The head and shell scale patterns, injuries, scars, coloration, and epibionts (e.g., barnacles) served as complementary and secondary features to aid with identification. Instantaneous recognition of certain individuals with obvious markings was possible. However, this could lead to a bias towards recognizing easily identifiable individuals in poor-quality photographs (Davies et al. 2012). These secondary features helped with the identification of turtles within a season, but to use them to identify individuals over time could be challenging because some of these features may change (Hall and McNeill 2013). For example, some scars could be permanent, but injuries could change throughout the healing process. Furthermore, using solely the scales on the top of the head to recognize individuals resulted in a lower successful identification rate, and Lloyd et al. (2012) suggested using the shell markings for distinguishing individuals sharing similar head patterns. The secondary features alone might not be sufficient to successfully identify most individuals, but using them along with the facial scales could increase successful identification.

For both species, manual matching was faster when there were fewer than 20 individuals in the database. Manual matching becomes more time consuming and labor-intensive with large amounts of photographs

(Arzoumanian et al. 2005; Chew et al. 2015), in which the time used to manually match new photographs is proportional to the size of the database (Dunbar et al. 2014). When the database increased, automated matching reduced the amount of time used to manually search through every individual in the database. The NPM was less suitable for Hawksbill Turtles due to the considerably smaller database, and manual matching was faster. The smaller number of scales and a high similarity in facial patterns shared by all Hawksbill Turtles could also possibly result in the NPM producing fewer distinguishable features between individuals and a lower successful identification rate.

Automated identification software can deal with photographs taken under challenging conditions (Pauwels et al. 2008; Town et al. 2013) while reducing the time required to match a new photograph against all individuals in the database (Carter et al. 2014; Dunbar et al. 2014). However, the quality of photographs is critical when using software because poor-quality photographs can reduce the match success (Kelly 2001; Speed et al. 2007). Moreover, software also produced false positive matches when matching individuals not previously in the database, whereas visual matching resulted in a high number of correct matches (Dunbar et al. 2014). Successful identifications were usually possible using visual matching even if photographs were not clear enough for software identification (Davies et al. 2012). Considering the drawbacks and restrictions of both methods, we combined the use of automated pattern matching software and manual visual comparison for matching in-water and nesting photographs of highly variable quality.

Citizen science.—Our results indicated that photographs gathered by the public can be as useful as those collected by trained personnel from conservation projects. Providing information and training on photo-ID data collection helps ensure that photographs are suitable for photo-ID. Even so, there are limitations and biases for using photo-ID and opportunistic citizen science data. For example, some individuals in the wild can become accustomed to human presence (Whittaker and Knight 1998), and therefore are more likely to be photographed than those that avoid humans (Kostas 2015). Such bias associated with photo-ID could lead to heterogeneity in sighting probabilities, which will underestimate the actual population (Sosa-Nishizaki et al. 2012). The use of citizen science could also result in observation and geographical biases from uneven sighting efforts over time (Bell et al. 2009) and at different sites (Dennis and Thomas 2000), depending on the weather conditions (Koss et al. 2009), availability and behavior (e.g., motivations and preferences) of citizen scientists (Koss et al. 2009; Isaac and Pocock 2015; Boakes et al. 2016). In Reunion Island, the turtle distribution increased with sighting efforts that were dependent on the weather and tourism activity (Chassagneux et al. 2013). Similarly, the sighting efforts by citizen scientists in the Perhentians were restricted to areas for diving and snorkeling during the tourist season. Therefore, the turtle distribution patterns in our study probably did not reflect the true distribution of turtles in the Perhentians.

Furthermore, reporting bias could happen when citizen scientists provide inadequate or incomplete information (Isaac and Pocock 2015). In our study, the sighting information from citizen scientists was not always available or accurate. Tourists reported the location using English names that were not standardized and could be misleading. For example, Turtle Beach could mean any of the nesting beaches, while Turtle Point might be the seagrass areas of Teluk Pauh or Atas Busong. Additionally, tourists from different countries had different time zones set on their cameras, which resulted in incorrect sighting date and time. We could resolve this, but not always, through confirmation with the tourists. Although citizen scientists used different types of cameras, identification was possible as long as the photographs were not blurry, and the facial scales were visible. Receiving photographs in their original size could increase successful identification because there were differences in the image size and quality between photographs submitted through email and social media. The image size of photographs received through social media had been reduced whereas photographs received through email remained bit-for-bit identical to the originals. We also lacked data on the sighting efforts by citizen scientists (i.e., time per dive/snorkel and frequency per site), which is often an issue associated with using citizen science (Richardson et al. 2012; Williams et al. 2015). Hence, increased survey time and frequency and/or density of turtles per site could contribute to a higher number of sightings at a particular site in the Perhentians, although additional data are required to determine this.

The photo-ID method is less invasive than capture and tagging methods, but there might be impacts of human-sea turtle interactions from photographing sea turtles. Bell et al. (2009) observed that Hawksbill Turtles were less disturbed by divers than Green Turtles in Cayman Islands. At Mayotte Island, Green Turtles generally avoided snorkelers except for one location where they seemed to be unaffected by human presence (Roos et al. 2005). The different responses to human presence imply that interactions with humans may alter (Meadows 2004; Taquet et al. 2006) or even negatively impact turtle behaviors (e.g., Hawksbills spent less time searching for food, feeding and breathing when divers approached them; Hayes et al. 2016). Apart from that, the presence and behavior of tourists, including the use of flash cameras, could disturb nesting turtles (Jacobson and Lopez 1994; Waayers et al. 2008). Thus, it requires training to know when and how to photograph nesting turtles at night. The use of citizen science in photo-ID can be useful in studying sea turtles in water and on nesting beaches but practical guidelines, training, and supervision are needed to minimize human impacts and ensure that the data collection is reliable.

Conservation management implications.—A photo-ID database provided information on the in-water and nesting sea turtle populations in the Perhentian Islands Marine Park, including the number of individuals, sex ratios, habitat use, and threats from human-sea turtle interactions. Photographic identification also provides mark-recapture data useful for future population models to estimate population parameters, such as abundance, survival, recruitment, residency, and population size, and growth rate, as demonstrated in the studies of other species, e.g., whales (Gowans et al. 2000) and sharks (Holmberg et al. 2009; Gore et al. 2016). All of this information can contribute towards informing local governments in developing sustainable tourism, conservation, and management practices in marine parks. Thus, photo-ID can be a useful tool for long-term population monitoring, assessing emerging or dominant threats, and evaluating conservation status. Increased sighting efforts at other beaches and in other nearshore and deeper waters, as well as during the off-tourist season, can enhance understanding of the temporal and spatial turtle distributions, site fidelity, and movement patterns in the marine park. However, due to the weather conditions during the Northeast monsoon, poor water visibility could impede the use of photo-ID. Regional collaboration to share photo-ID databases would enable the tracking of turtles to determine connectivity between foraging and nesting sites at a regional scale (Schofield et al. 2008; Dunbar et al. 2014; Su et al. 2015). Such understanding could then be used to assist in the development of regional management and conservation plans for sea turtles.

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