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Applying a fast, effective and reliable photographic identification system for green turtles in the waters near Luichiu Island, Taiwan

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ABSTRACT

Liuchiu Island of Pengtung County, Taiwan, is the only island host both foraging and nesting green turtles. Due to almost complete overlap of in-water study with the major tourism activities—in water observation of sea turtles on the island, an effective, stable and fast, non-invasive photo-ID system has been developed to estimate the size of this population. The characteristics of facial scales, such as size, shape and arrangement are used as the diagnostic tools. One hundred and six to one hundred and forty-two turtles, with minimum 6 and maximum 8 were males have been identified based on underwater photos collected from 2011 to 2013. The right and left facial scutes of most turtles are not identical suggesting that both sides of the head must be photographed in order to determine the population size of the turtles. Based on the frequency of observation, these three to five males and forty to seventy-two females or undetermined sex were assumed to be resident while four males and sixty-six to seventy female or undetermined sex turtles were assumed to be migrants. Repeated photographed suggests that at least portion of the resident turtle conduct seasonal migration around the island. Among all sections of the area surveyed, turtles were most concentrated from Beauty Cave to Vase Stone, and least numerous from Shan-fu Fishing Port to Clam Bay. This is the first photo-ID system developed in Taiwan. It will benefit sea turtle research in the future and enhance sea turtle conservation significantly.

1. Introduction

A first step in conserving populations is to identify individual animals in order to estimate the population size (Bradshaw et al., 2007; Lusseau et al., 2006; McMahon et al., 2007; Sibly et al., 2005; Thompson et al., 2000). The mark-and-recapture technique is widely used to estimate population sizes of wild animal populations (e.g. McMahon et al., 2007; Wilson and Wilson, 1989). For sea turtle research, the most common marking method has been flipper tags. However, particularly for longer periods including migrations, accuracy is affected by factors such as tag material deterioration, different environments encountered by animals migrating on different routes, variation in care taken during labeling, tag loss due to ontogenetic changes in individual animals and inability to read the tag information (Balazs, 1982; Bellini et al., 2001; Limpus, 1992; Mrosovsky and Shettleworth, 1982; Schofield et al., 2008; Van Dam and Diez, 1999). For these reasons, the mark-recapture method is mostly used to estimate the population size based on nesting females. In addition, the application of this technique in marine environments can be influenced by topographic features, hydrodynamic regime, budget and safety, which often bias the results of investigations (Balazs, 1999; Bellini et al., 2001; Hays et al., 2010; Jean et al., 2010; Mrosovsky, 1976; Reisser et al., 2008; Schofield et al., 2008; Witzell, 1998).

Photo identification (ID) is a non-invasive individual identification technique. It uses distinct and fixed morphological characters of the animals as the keys for individual identification. Once animals are mature, morphological characteristics tend to be stable, unless the animal is injured in this region. Thus, they can be used for individual identification (Bradshaw et al., 2007; Forcada and Aguilar, 2003; Reisser et al., 2008; Schofield et al., 2008; Thompson et al., 2000). A major advantage of photo ID is that researchers do not contact the animals directly after this system is established, thus reducing interference, stress and injury in the long run (Blackmer et al., 2000; Hammond, 1990). For large wildlife that is difficult to capture and tag, such as whales, photo ID is an easier way to identify individuals than physical capture. In addition, for long-lived and migratory marine animals, such as sea turtles, photo ID can provide a long-term and very stable identification method. It can add to and even replace tag labeling, reducing the loss of research data due to missing tags (Blackmer et al., 2000; Dunbar et al., 2014; Jean et al., 2010; Reisser et al., 2008; Rodriguez and Martinez, 2000; Schofield et al., 2008; Speed et al., 2007).

The main morphological characters useful for sea turtle identification are the pattern, number, size and arrangement of facial scales. Previous studies have proved that it is very easy to photographically record and to re-identify individual turtles based on characteristic facial scales

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(Schofield et al., 2006). Furthermore, the high accuracy and durability of distinctive scale patterns allow researchers to determine population sizes, conduct behavioral analyses and determine migration patterns (Jean et al., 2010; Reisser et al., 2008; Schofield et al., 2008). For example, Schofield et al. (2008) photographed the facial scales of loggerhead sea turtles near Zakynthos Island, Greece, and developed a simple, effective and reliable individual identification system. They identified over 400 unique loggerhead turtles that frequent the island to breed each summer, and they proved with their high-quality photos that this system can guide any person in correctly identifying individual turtles. Reisser et al. (2008) also used photo ID to augment tag labeling for determining the population size of resident hawksbill and green sea turtles in Arvoredo Protected Area, Brazil. They also used photo ID to determine which individual turtles had lost tags. In recent years, Jean et al. (2010) collected facial photos of green and hawksbill sea turtles near Reunion, Mayotte and Mahe Islands in the western Indian Ocean and digitally encoded the facial characters into a computer. With powerful and fast computing capability, they were able to compare large volumes of photos and accelerate the identification processes.

Five species of sea turtles are found in Taiwan; namely green, loggerhead, hawksbill, olive ridley and leatherback sea turtles. Among them, green turtle is only species that nest in Taiwan (Cheng, 1995). Three main nesting site were identified; Wan-an Island of Penghu County, Lanyu Island of Taitung County and Liuchiu Island of Pentung County (King et al., 2013). Among three islands Liuchiu is the only island that host both foraging and nesting sites. Even though in water capture of sea turtle is legitimate with government license, it is rather infeasible in the study site. Underwater observation of green turtles in nearshore waters is a major tourist attraction for Liuchiu Island. Millions of tourists visit this island each year, resulting in almost complete overlap of in water study and tourist activities. In order to avoid conflict interests between research and tourism, photo ID becomes a compatible method to infer the population size of green turtle in the nearshore waters of Liuchiu Island.

Facial photographic images were taken from 2011 till 2013 in the nearshore waters of Liuchiu Island, and used for develop a photo identification database based on facial scute records. We used this database to infer population size and distribution of turtles on the island. We anticipate that this photo ID database will contribute towards informing conservation and management practices of the local government on the island.

2. Material and methods

2.1. Study site

Liuchiu Island (22° 19′ N, 120° 21′ E) is located approximately 14 km offshore to the south-southwest of Taiwan (King et al., 2013). Among the forty islands off Taiwan, Liuchiu is the only coral island. Its area is 6.802 km^2. The island is covered with coral limestone, and the coast is surrounded by uplifted coral reefs. The weather is warm and dry, and the water temperature is influenced by the tropical latitude and a branch of the Kuroshio. The seasonal variation of water temperature is minor; ranging from 23.7 °C in January to 29.6 °C in July (Institute of Marine Biology, Marine Ecology and Conservation Laboratory unpublished data, 2011 to 2014). Water depth is less than 20 m within 100 m distance from the shore (Wu, 2008).

2.2. Observation procedures

The observations were carried out from June 30, 2011 until July 19, 2013. In addition to intense investigations during the nesting seasons of 2011 and 2012, research was also carried out on 3- to 5-day surveys every two months during the other seasons. Surveying was done by both snorkeling and scuba diving. A CANON SLR camera, model G12 with a WP-DC24 waterproof housing, was used to photograph the right and left faces of resident green turtles. Prior to each survey, the date and survey site were recorded.

2.3. Survey section determination

Six sections around the island were chosen initially. They were (1) Beauty Cave to Vase Stone, (2) Jun-Au Beach to Lobster Cave, (3) Lobster Cave to Taipower Company, (4) Hai Mouth to Thick Stone Reef, (5) Thick Stone Reef to Daliao Fishing Port, and (6) Shan-fu Fishing Port to Clam Bay (Fig. 1).

The preliminary study showed that the surveys could be grouped into 4 instead of 6 sections. They were (I) Beauty Cave to Vase stone (red line in Fig. 1), (II) Jun-Au Beach to Taipower Company (blue line), (III) Hai Mouth to Daliao Fishing Port (black line), and (IV) Shan-fu Fishing Port to Clam Bay (green line). In each section, a zone 10 to 20 m from the shore was surveyed. The reasons for regrouping the survey sections are: (a) a commercial port lies between Vase Stone and Jun-Au Beach and between Taipower Company and Daliao Fishing Port; (b) distances from Hai Mouth to Clam Bay and from Shan-fu Fishing Port to Beauty Cave are long, with steep terrain and no access to the shore is available.

The section chosen for each survey depended on the sea conditions (current direction, tide, waves and underwater visibility) of each section and time available for survey (Table 1). The most suitable section was chosen for each survey. In cases when all sections were available, the one(s) with the fewest surveys was chosen.

2.4. Photo ID technique

The photo ID process is similar to Schofield et al. (2008) and used to classify the various morphological characters of lateral facial scales. Similarly to practice in fish taxonomy, we progressively divided the photos into smaller groups that shared more characters. Comparison and matching of photographs within each group were made by subjective observations of four different sets of facial scale group: 1. the number and size of postocular and central scales, and whether presence a scale between two scales stated above, 2. number of temporal scale, 3. number and size of tympanic scales, and 4. special facial scale arrangement. We also separate the male from female or undetermined sex. A tail extending significantly beyond the supracaudal scale indicates a male; otherwise the turtle is either a female or of undetermined sex. Detail of the identification tree refers to the supplementary online literature.

3. Results

3.1. Photo ID

Under the ideal situation, both faces of all turtles should be photographed in every occasion. However, due to limited manpower, only some were photographed on both faces, some were taken in

Table 1
The section visited in each survey and the number of survey conducted in each section per month during the study period.

month	# section/surveyed	# surveys/section/mo.
Jan	1	0.5
Feb	0	0
Mar	2	0.75
April	3	1
May	1	0.25
June	1	0.5
July	4	5.3
Aug	3	4.8
Sept	2	0.5
Oct	2	1.75
Nov	0	0
Dec	2	0.75

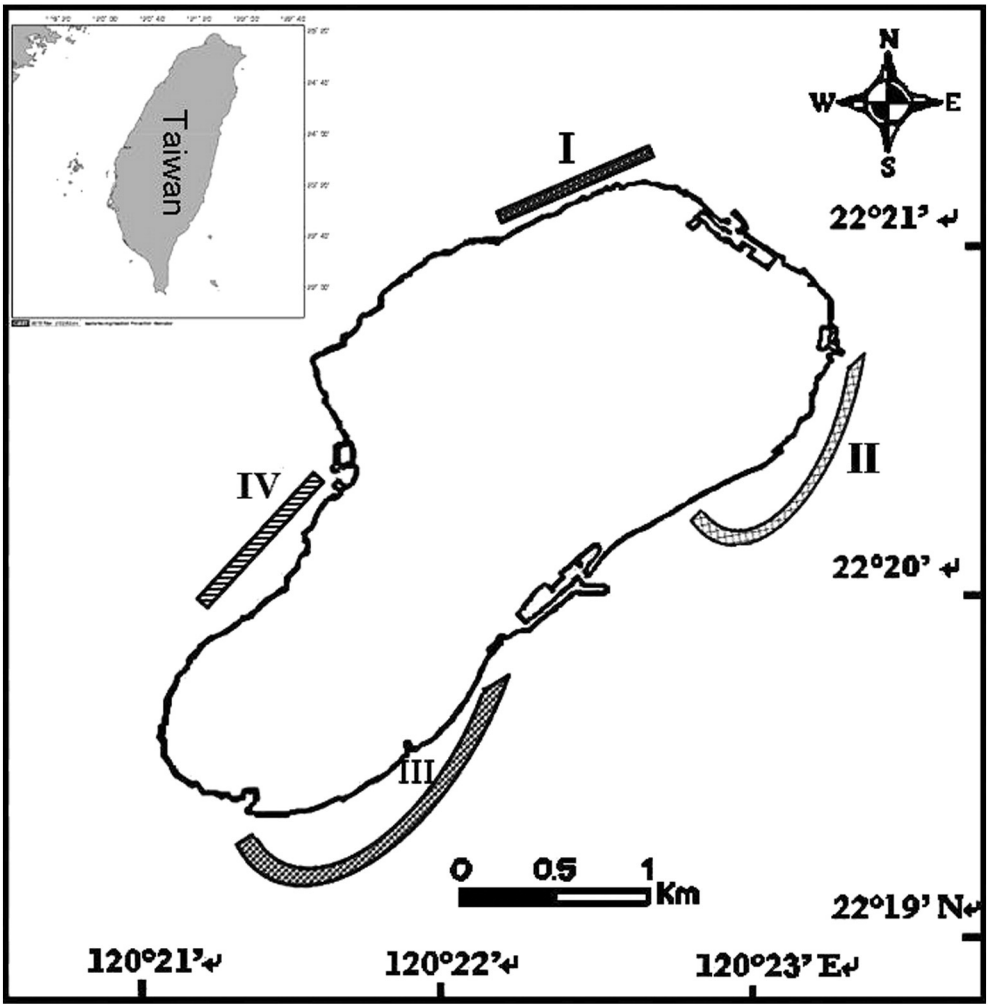

Fig. 1. Map of Liuchiu Island with the underwater survey sections labeled in different colors.

sequence, while others were photographed only on one face. Based on both-face photograph pairs, we found that most turtles with markings on the two sides of the face are different to certain extent; scale shape, size and number all different. Only one out of 35 confirmed turtles has same marking on both sides of the head (2.9%). For the rest turtles, the number of different marking in all seven characters ranged from one to five. Thus, we separated the pair markings into high similarity, with only one different character (Fig. 2, (a) and (b)) which was 6 turtles, and low similarity, with more than two characters (Fig. 2, (c) and (d)) which was 28 turtles. Then, among 35 confirmed turtles, 17.1% had high similarity marking on both side of face and 80% had low similarity marking (Fig. 3). Thus, one cannot determine the population size based solely on photos of only one facial side; results were separated into left-face-only, right-face-only and both-faces-available groups.

Thirty-five turtles with both sides of face were confirmed, with 41 pairs excluded due either to repeatedly photographed or too blurred for identification. Among confirmed turtles, 5 were males. The rest were either female or undetermined sex. Sixty-one extra turtles with the left side of face were confirmed, with fifty-one excluded due either to repeatedly photographed or too blurred for identification. Among confirmed turtles, 6 were males. Forty-six extra turtles with the right side of face were confirmed, with fifty-one excluded due either to repeatedly photographed or too blurred for identification. Among confirmed turtles, 5 were males. The maximum number of definite unique turtles was 142, if every extra turtle confirmed from either side of face was different individual. The minimum number of definite unique turtle was 106, if all turtles with the right side of face confirmed were part of the turtles identified with the left side of face. Overall, about 6% of turtles photographed in this study were male.

3.2. Spatial distribution of green turtles in the nearshore waters of Liuchiu Island

From July 2011 till July 2013, 82 underwater surveys were conducted across the four sectors, with turtles being photographed in 60 surveys Most surveys were conducted in Sector 1 ($n = 41$ surveys), followed by sector II ($n = 16$ surveys), III ($n = 18$ surveys) and IV ($n = 7$ surveys). The greatest chance of sighting turtles was also ordered according to Sector I (56–71%), III (16–25%), II (6–17%) and IV (4–8%) (Fig. 4).

Among all the confirmed turtles, 77 were photographed more than one month across two-year study period (25 mo.), with 43 was photographed year around. Thus, a maximum of 77 and minimum of 43 turtles can be considered to possibly be residents, and the rest turtles can be considered to be possible migrants. Among them, minimum three and maximum five turtles were male and the rest was either female or undetermined sex.

4. Discussion

Over a two-year period, we have successfully identified a minimum of 106 turtles and maximum of 142 turtles, where minimum 6 and maximum 8 were males and the rest was either female or undetermined sex. Interestingly, most turtles with scute patterns were not similar on

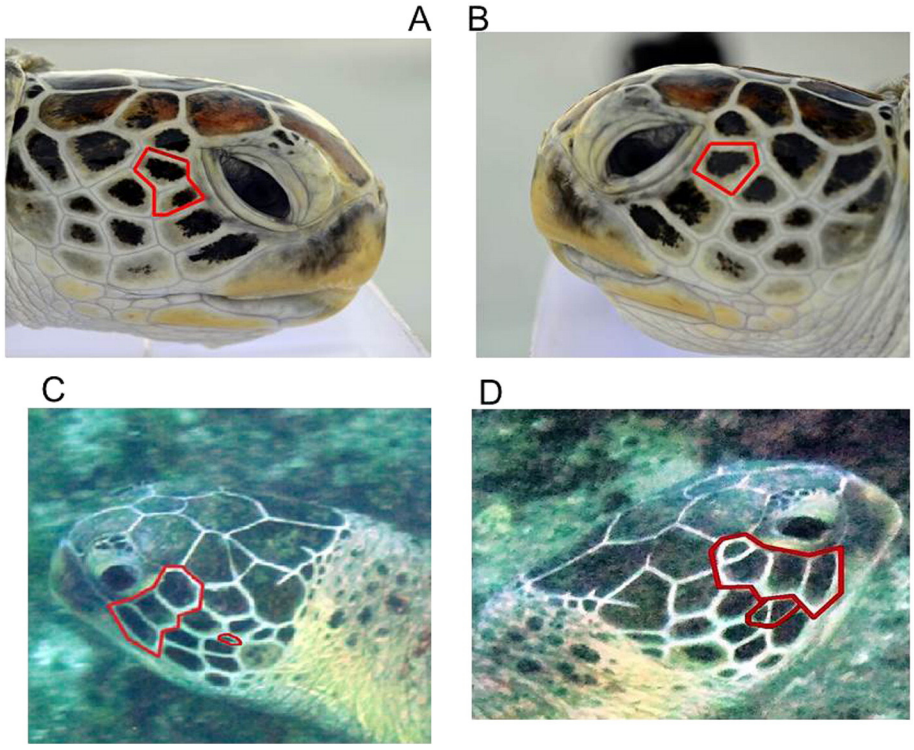

Fig. 2. Facial photos from both sides of the same turtle, which (A) and (B) showed the turtle with high similarity in morphological characters on both sides of faces while (C) and (D) showed the low similarity. In (A) indicates four postocular scales on the left side, and in (B) three postocular scales on the right side. In (C) indicates three postocular and one small scales in front of tympanic scales on the left side, and in (D) four postocular scales and two small central scales on the right side. The different shape and number of scale are marked in red outline.

both sides of the head, with 17.1% had high similarity (only one character was different) and 80% had low similarity (two or more characters were different) (Fig. 3). The likelihood of spotting turtles was greatest in section I (83%), with it being around 61% surveyed of all sectors. Three to five turtles were male and forty to seventy-two were either female or undetermined sex, which were photographed repeatedly in 14 months out of total 25 study months. Based on the frequency of observation, these three to five males and forty to seventy-two females or undetermined sex were assumed to be resident while four males and sixty-six to seventy female or undetermined sex turtles were assumed to be migrants. These turtles were primarily observed in section I (Beauty Cave to Vase Stone, 61%), with 25 turtles migrated across more than one section

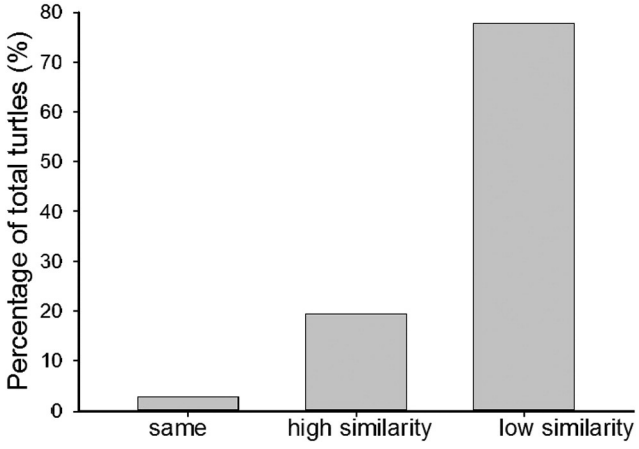

Fig. 3. Proportion of same, high similarity and low similarity in the size and arrange of scales between the left and right sides of face on the same turtle in the study area.

In this study, we have successfully used facial scute to identify turtles in natural environment. This is the first underwater photographic identification study ever conducted in Taiwan. However, what is of interest is the right and left facial scutes of most turtles are not identical. Among 36 confirmed turtles, 6 (17.1%) have high similarity on marking on both sides of face and 28(80%) had low similarity marking on both sides of face. This suggested that both sides of the head must be photographed in order to determine the population size of the turtles in the study area.

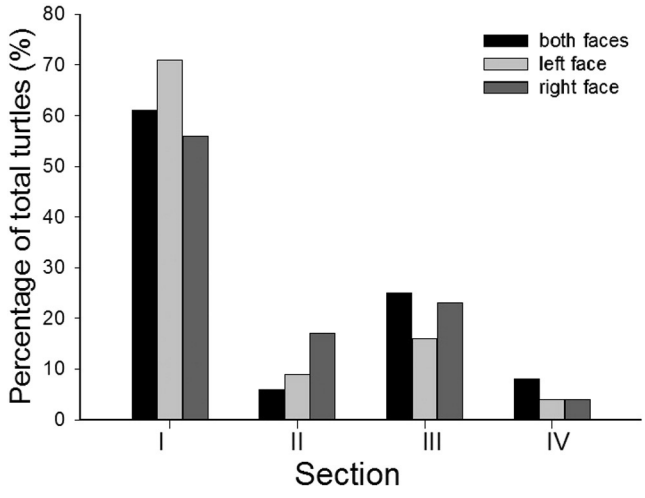

Fig. 4. Percentage of total green turtles in each section in waters of Liuchiu Island. Dark bars represent turtles photographed on both sides of the head, grey bars represent turtles photographed on the left side only, and dark grey bar represents turtles photographed on the right side only.

4.1. Population size estimation and spatial distribution of green turtles in nearshore waters of Liuchiu Island

Even though a population of 106 to 142 turtles was estimated in this study, we did not photograph all of the turtles in the nearshore waters of Liuchiu Island. Furthermore, only a small portion of the turtles were photographed on both sides of face. Turtles identified based on facial scales of only one side might be misidentified as different from a turtle classified based on the scales of the other side. Thus, the population size of the residential turtles in the waters of Liuchiu Island may not be exactly 106 to 142 turtles.

Surveys from left, right and both sides of the face all showed that, turtles are most concentrated in section I, Beauty Cave to Vase Stone, and least abundant in section IV, Shan-fu Fishing port to Clam Bay (Fig. 4). This result is consistent with observations by commercial divers. However, among 82 surveys, 41 were in section I (50%), and decreased with the decreasing surveys. Thus, it is possible that the greater number of surveys in that section resulted in higher numbers of turtles counted there. In the future, more surveys should be carried out in the other sections to confirm the results of this study.

Even though capture-mark-recapture is the most reliable method to identify the population dynamics and area used by the animals (e.g. Wilson and Wilson, 1989; McMahon et al., 2007). However, it is not quite feasible to this study, because the study site is almost complete overlap with the in water observation of sea turtle, the major tourism on the island. Under this limitation, the most compatible method is to adopt the facial ID system. By identifying individual animal without physical contact, we were able to determine the area 1—Beauty Cave to Vase Stone, that is the major area used by the green turtles in the nearshore waters of Liuchiu Island. Repeated photographing revealed that 32% of the turtle migrated to more than one area in the same or different seasons. This suggests that at least portion of the resident turtle conduct seasonal migration around the island. Even though the nesting season lasts for 3 to 4 months, none of the nesters was observed during the survey. It is possible that these turtles stayed in the offshore deeper water during the interesting period to avoid the nearshore tourism activities.

4.2. Conservation and management implications

The photo-ID system can act as a quantitative tool to re-evaluate the local, regional and international, even the global sea turtle conservation status, and further strengthen international marine protection policies (Fagan and Holmes, 2006; Schofield et al., 2008; Sibly et al., 2005; Thompson et al., 2000). For example, by setting up a photo-ID database from nesting, by-catch, stranding and residential turtles, along with the time and site of photos, behavioral notes, etc. we can cooperate with the relevant foreign databases to determine turtle migration routes, compare habitats in the waters of many nations and identify feeding areas with nesting sites. Then, a better conservation strategy can be achieved.

These permanent photo databases can assist with tracking migrants and with analysis of the sites visited by individual sea turtles in the past. It also can assist other researches, such as description of behavior modes, ecological risks, changes in body condition and influences from human activities (Bennett et al., 2000; Burger and Garber, 1995; Lusseau et al., 2006; Pettis et al., 2004).

Facial photo-ID systems provide a new non-invasive method to estimate sea turtle populations in Taiwan. Liuchiu Island of Pengtung County is an important nearshore marine habitat for green turtles. One can observe hatchling, adolescent, immature and mature green turtles in its nearshore waters. One can also observe many behaviors of green turtles, such as feeding, chasing and resting. With the dramatic increase in tourist activity on the island, we must actively manage and conserve sea turtle populations in order to prevent deterioration of this precious endangered resource. The photo-ID system will be useful not only for Liuchiu Island, but for sea turtle research in other areas and strengthen efforts for conservation of sea turtles in Taiwan.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jembe.2015.03.003.

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