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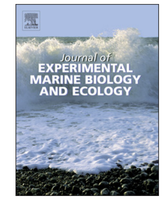

Stability of facial scale patterns on green sea turtles *Chelonia mydas* over time: A validation for the use of a photo-identification method

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ABSTRACT

Photographic identification (photo-ID) has been increasingly used as a reliable tool to track individuals over time, which provides essential knowledge on a species' population dynamics. For photo-ID to work, natural markings must be individual-specific and stable over time. In sea turtle research, the use of facial scale patterns has been proposed and tested as a reliable means for individual recognition. Nevertheless, as sea turtles are migratory and long-lived individuals, the stability of those patterns over long periods of time is yet to be confirmed to validate this method. Stability of facial scale patterns was evaluated on green sea turtles, *Chelonia mydas*, sighted and photographed in coastal waters of Reunion Island (21°06 S, 55°36 E) or reared in captivity. From 53 free-ranging individuals previously identified, 90 head profiles were selected based on the photographic quality and the distinctiveness of facial scale patterns. The time interval between two sightings of a same individual ranged from 2 (738d) to 11 years (3954d). Additionally, facial scale patterns of captive green turtles from two different age groups were compared: (1) from adult-sized individuals reared in captivity ($n = 13$) and (2) from hatchlings and then at later developmental stages (until 1800d) to assess the stability of facial scale patterns throughout early juvenile development ($n = 16$). In both the free-ranging and captive-reared groups, there were no significant changes in facial scale patterns over time. Conversely, changes in pigmentation were observed in free-ranging turtles at successive sightings and in captive-reared turtles at different developmental stages. These results on the stability of facial scale patterns over time, combined with previous findings on the uniqueness of patterns between individual green turtles, validate the method of using facial scale patterns as a long-term identification tool for green turtles. Nonetheless, the variability of pigmentation patterns should be kept in mind when using photo-identification on sea turtle species.

1. Introduction

Effective management and conservation practices for threatened species rely heavily on knowledge of population dynamics, which includes abundance and distribution, habitat use and life history parameters. Such information can be provided by capture-mark-recapture studies involving either applying artificial marks to an animal or using its natural body markings (i.e. pigmentation, spots, patterns) to allow individual recognition at successive sightings (Whitehead et al., 2000; Lettink and Armstrong, 2003; McMahon et al., 2007). Photographic identification (photo-ID), the method of using photographs of an animal's natural markings for individual identification, has been increasingly used as a reliable tool to track individuals over time (Frisch and Hobbs, 2007). The use of photo-ID offers many advantages over conventional tagging methods, as it is non-invasive, of low-cost, and reliable over long periods of time. While the reliability and effectiveness of photo-ID in population studies has been established for many terrestrial species (e.g. Kelly, 2001; Foster et al., 2007), enhancements of underwater photographic technology in the past decades have allowed its utilization to be extended to species living in the marine environment. For instance, natural pigment marks on the spotted ragged-tooth shark, *Carcharias taurus*, were demonstrated as reliable for individual identification over periods as long as 9 years ($n = 221$, Van Tienhoven et al., 2007). In the northern bottlenose whale, *Hyperoodon ampullatus*, back indentations, mottled patches and dorsal fin notches were distinctive enough between individuals to be used as natural markers for identification, and marks were relatively stable over a 9 year period ($\bar{x} = 14.5$ marks/individual; range 1–67, Gowans and Whitehead, 2001). In a study of the octopus, *Wunderpus photogenicus*, the configuration of white markings on the dorsal mantle was also found to be unique among individuals ($n = 15$, Huffard et al., 2008).

Identifying individuals using photo-ID may become time consuming as the number of photographs in the database increases. Additionally, an adequate training is required to become familiar with the key characteristics that should be examined in order to obtain correct matching. On the other hand, this method has proved to be a valuable tool for examining recaptures of individuals and studying species population dynamics. Consequently, it has launched a common effort among

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wildlife researchers to develop more systematic and automated pattern matching software (Arzoumanian et al., 2005; Speed et al., 2007; Town et al., 2013).

In sea turtle research, external tagging applied on flippers (e.g. plastic or metal Inconel) is still the identification method of choice for many monitoring programs throughout the world (Balazs, 1999) as it allows more direct identification over time. In contrast, the marking process may be disruptive due to the necessity of handling and restraining sea turtles for mark application (Bateson, 1977; Broderick and Godley, 1999; Wyneken et al., 2010) and tag loss is still an issue of concern (Limpus, 1992; Reisser et al., 2008). Moreover, tagging programs mainly target nesting females, as sea turtles are more easily accessible when coming ashore to lay their eggs, and less information is known on juveniles, males, and non-breeding female adults. To overcome these problems, the photo-ID approach has been proposed to identify and track sea turtles over time (Reisser et al., 2008; Schofield et al., 2008; Jean et al., 2010a). Photo-ID has allowed successful identification of leatherback sea turtles using their pineal spot, a pink spot overlying the pineal gland on the dorsal surface of their heads (McDonald and Dutton, 1996; Buonantony, 2008). For other sea turtle species that do not bear stable and unique pigmentation or spot patterns, the shape and arrangement of scales from each side of their head (hereafter referred as facial scale patterns) has been reported as a reliable means to identify individuals upon re-sighting (Reisser et al., 2008; Schofield et al., 2008; Jean et al., 2010a).

The uniqueness of facial scale patterns has been tested by using a combination of artificial tagging and facial profile photographs for green and hawksbill sea turtles (Reisser et al., 2008), and by testing the capability of naïve and trained operators to match individuals based on the facial scale patterns in loggerhead sea turtles (Schofield et al., 2008). Findings from these studies confirmed that facial scale patterns on both sides of their heads were distinctive enough to allow individual recognition for animals sighted over a period of 3 to 5 years, allowing researchers to start using photo-ID as a monitoring tool in sea turtle population studies. For instance, Hays et al. (2010) identified and tracked three male loggerheads using photo-ID to determine breeding periodicity and operational sex ratios in Zakynthos, Greece. In Honokawai, Hawaiian Islands, Photo-ID was used to identify green turtle individuals in order to investigate the propagation of fibropapilloma on affected individuals (Bennett et al., 2000). This method has also allowed the estimation of size for foraging turtle populations and to determine spatial distribution, residency times, and movement patterns of individuals among foraging areas in Reunion Island for both green and hawksbill turtles (Chassagneux et al., 2013) and recently in Luichiu Island, Taiwan, for green turtles (Su et al., 2015). While these investigations have already revealed precious information in population structure and dynamics, which is essential knowledge to implement adapted conservation measures, the long-term stability of facial scale patterns is yet to be confirmed to validate the use of this method in long-term monitoring studies (Pennycuick, 1978; Goodman Hall and Braun-McNeill, 2013). To date, profile stability has been indirectly evaluated for 1046 days for green sea turtles (Reisser et al., 2008) and for 1155d on hawksbill sea turtles (Dunbar et al., 2014), which are relatively short periods of time considering the highly migratory nature of turtles and the potentially long time intervals between individual re-sightings. Féliz et al. (2010) also noticed the stability of facial scale patterns on a hawksbill individual for ~6 years, but acknowledged a change in color markings in successive sightings. In a recent study by Chew et al. (2015) at Chagar Hutang, Malaysia, there were no changes in the shape and arrangement of facial scales from 12 hatchling green turtles reared in captivity over a 1-year study period. The lack of stability in natural markings over time can lead to misidentification resulting in biases in photo-ID analysis, especially for long-term open population studies (Stevick et al., 2001; Yoshizaki et al., 2009). Therefore, there is a need to clarify the persistence of facial scale patterns over longer periods of time.

This study reports on an investigation of the stability of facial scale patterns and scale shapes for foraging green turtles sighted and photographed several times over long periods in the waters of Reunion Island, a volcanic island located in the western Indian Ocean. Additionally, facial scale patterns of captive reared green turtles from two age groups were compared: in adults, for which photographs were available for several years, and in early juveniles, for which photographs were taken at emergence and then at later developmental stages allowing us to assess the stability of facial scale patterns throughout early developmental stages. Unless there is evidence of significant change over years, facial scale patterns may be used as a reliable long-term identification tool for sea turtles.

2. Materials and methods

2.1. Study area and population status

Reunion Island (21°06 S, 55°36 E) is an insular region of France located in the western Indian Ocean, 800 km east of Madagascar (Fig. 1). Although it was once an important nesting site for green sea turtles in the 17th and 18th centuries, intensive human exploitation for their meat, eggs and shells, and coastal urbanization have caused the nesting population to decline drastically (Frazier, 1975; Bertrand et al., 1986). In the past two decades, beach restoration and sea turtle conservation efforts have allowed some recovery of the nesting green turtle population (~1 nesting turtle/year, Ciccione and Bourjea, 2006; Ciccione and Bourjea, 2010), and a significant increase in foraging green and hawksbill sea turtle population size has been observed since 1998 (Jean et al., 2010b). In 2008, an online regional database called TORSOOI (TORtues marines du Sud-Ouest de l'Océan Indien – Marine Turtles of the South West Indian Ocean) was developed to store and manage sea turtle data in the area. As part of this program, a computer-assisted tool was implemented to facilitate the entry and analysis of sea turtle photo-ID data. The protocol for photograph preparation and photographic identification using this program is detailed in Jean et al. (2010a). Essentially, it is based on a scale mapping code system that integrates the location and shape of the scales on lateral portions of the head. Particularly, it focuses on the delimitation of these scales with outlines drawn according to scale edges resulting in a unique code for each sea turtle head profile. This code is then used for the recognition process and allows quick identification of individuals. Over the past decades, more than 300 green and

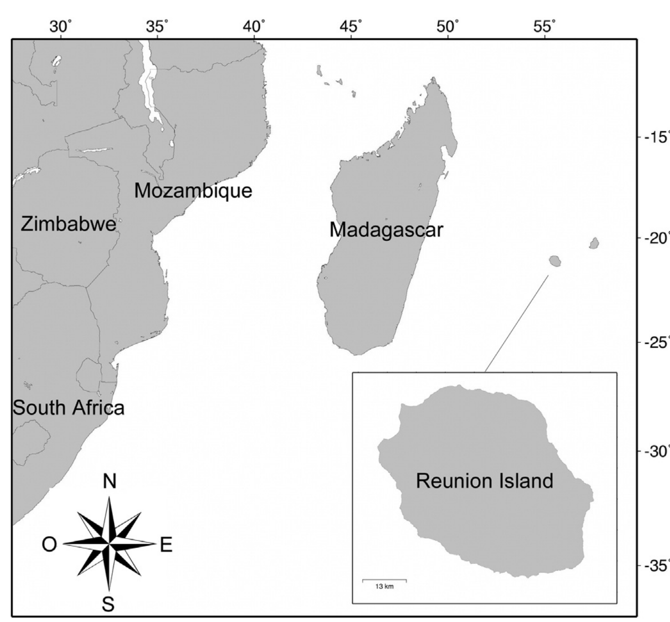

Fig. 1. Study area in the western Indian Ocean.

hawksbill sea turtles have been successfully identified and tracked using this program in the waters of Reunion Island (Chassagneux et al., 2013).

2.2. Data collection and analysis

Profile photographs involved in this study were related to two different categories of individuals: free-ranging green turtles sighted and photographed by local divers voluntarily involved in the citizen science program of photo-ID, and captive green turtles raised or rehabilitated in Kelonia (the sea turtle observatory and recovery center at Reunion Island). Free-ranging individuals were mainly late juveniles with a small proportion of male and female adults photographed while foraging, resting, swimming, or breeding along Reunion Island's coastal waters. Profile photographs of captive green turtles came from two age groups. The first group consisted of adult turtles that had been reared since their emergence at the center when it was still a sea turtle farm (known as the Coral Farm, in existence from 1977 to 1994, then converted into a conservation and awareness center). While no photographs from these adults were taken at their emergence or at early developmental stages, photographs have been taken since the conversion of the turtle farm to a conservation center (Kelonia) with a care center acknowledged by the French Ministry of the Environment in 2004. Additionally, as part of the stranding sea turtles rescue program undertaken by Kelonia, hatchlings emerging from nests laid on Reunion Island and judged too fragile to survive (e.g. poorly healed umbilicus, shell deformation) are kept at the sea turtle clinic until judged healthy enough by a veterinarian to be released (Approval permit N°09–1405/SG/DRCTCV, French Ministry of the Environment). In addition to size (Straight Carapace Length, SCL) and weight measurements made for growth monitoring, photographs of each profile from these turtles were taken regularly from their emergence to their release day, which provided this study with a large number of photographs showing the evolution of facial scale patterns during early juvenile developmental stages. These photographs were analyzed in the same way as free-ranging sea turtle profiles.

Turtle profile photographs were collected directly into the TORSOOI database and selected based on three main criteria: (1) photographs of high quality (good lighting, in focus, no or very low glare), (2) facial scale outlines clearly visible to the eye, and (3) photographs of an individual's profile in subsequent sightings separated by at least 2 years (>730d). Before analysis and following the TORSOOI photograph preparation protocol (Jean et al., 2010a), photographs were cropped as a square to keep only the part of the head showing the profile, and the angle was corrected so that the profile was as horizontal as possible. As both profiles of the same turtle display a unique scale pattern, right and left profiles were analyzed separately for each individual. If one individual had more than two photographs of the same profile available, the photograph with the longest time interval from the initial sighting was used, except when the selection requirements were not met. Facial scale patterns of the first and last photograph of a single profile were examined visually and variations were quantified. Variations measured consisted of changes in the number of edges of a scale, separation or merging of two scales, and changes in the size of an incomplete edge (i.e. edge not entirely separating two sides of a scale). To estimate the extension or shortening of incomplete edges (IE), a proportion was given to the length of the IE based on the distance between the two sides of the scale. If the proportion covered by the IE was more prominent on the latest photograph than on the first, the IE was counted as an extending IE. Conversely, if the proportion of the IE was reduced, it was counted as a shortening IE. When the proportion did not differ over time, it was counted as unchanged. As such, a profile was considered as unchanged over time when scales forming a profile had the same number of edges on the first and last photograph, and when positions of scales within the profiles and the size of an IE (when applicable) had not changed. In cases of the observation of changes on a profile, the other profile (e.g. left if the changing profile is on the right side) was checked to confirm it was not from another individual's profile.

Additionally, the variation in pigmentation over time was checked. Each profile was given a color change designation based on the degree of variation observed. Variations within scales were evaluated visually, and pigmentation change of a scale was counted when one or more dark spots within the scale had expanded or reduced over time, or when the color of a scale had entirely darkened or brightened over time. Degrees of change ranged from (1) when less than 5 scales showed a pigmentation change, (2) when 5 to 9 scales had changed pigmentation, (3) when 10 to 14 scales had changed pigmentation, and (4) when 15 or more scales had changed pigmentation. To examine possible relationships between scale pigmentation changes and the time spent between two photographs, a Pearson's correlation was used ($\alpha = 0.05$). Variations in the shape of scales (stretching, rotation) were not examined as this criteria is not directly involved in the map-coding process used for the program, and may be considered a less discriminating characteristic in the recognition process.

3. Results

3.1. Free-ranging sea turtles

Overall, 90 green sea turtle profiles representing 53 free-ranging individuals were analyzed with the first and last sightings ($n = 45$ pairs of right profiles, $n = 45$ pairs of left profiles, Table 1). Of all profiles, 72 were from juveniles, 5 were from adults (curved carapace length ≥ 80 cm), and 13 from unknown stage individuals. The time interval between each pairs of profile photographs ranged from 2 to 11 years (723d to 4073d). Visual comparison of these photographs concluded that from all profiles analyzed, there were no changes in the number of edges of scales, and no splitting or merging of scales (e.g. Fig. 2). From 31 profiles that had at least one incomplete edge (e.g. Fig. 3A), two incomplete edges had changed length in subsequent years ($n = 1$ extending and $n = 1$ shortening, over 1448d and 1986d time intervals, respectively).

For the analysis of pigmentation change within scales, many profile photographs selected for scale pattern comparison had to be removed because coloration was not clearly displayed mainly due to the blue generated on underwater pictures. A total of 50 profile pairs were selected for a visual evaluation of pigmentation change. For 20 profiles

Table 1
Distribution of all green turtle profiles analyzed in this study ($n = 149$). The time interval corresponds to the time (rounded to year) spent between the first and last profile photographs. Photographs were taken from 2004 to 2015. Individuals were divided into two age classes based on their estimated or measured curved carapace length (CCL), and counted as juveniles when CCL < 80 cm, as adults when CCL ≥ 80 cm, and as unknown when CCL could not be estimated.

	Time interval (years)	Juveniles		Adults		Unknown	
		Right	Left	Right	Left	Right	Left
Free-ranging turtles	11	1	1	2	–	–	–
	8	1	2	–	–	–	–
	7	1	1	1	1	–	–
	6	4	2	–	-	1	1
	5	3	4	–	1	1	1
	4	8	10	–	–	-	1
	3	10	13	–	–	3	–
	2	7	4	–	–	2	3
	Total	35	37	3	2	7	6
		72		5		13	
				90			
Captive-reared turtles	11	–	–	2	2	–	–
	5	2	2	12	11	–	–
	3	14	14	–	–	–	–
	Total	16	16	14	13		
		32		27			
				59			

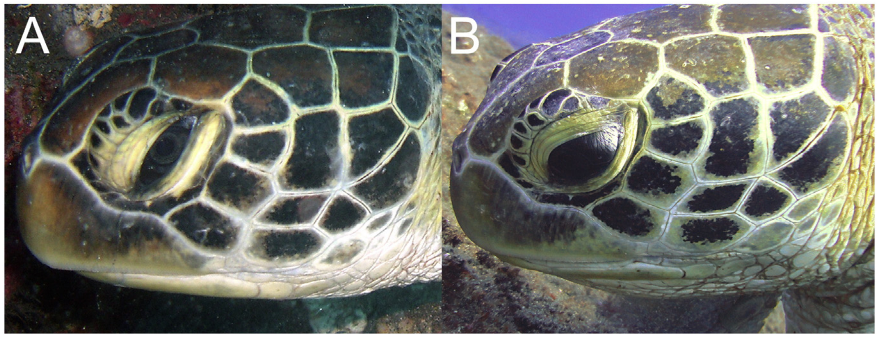

Fig. 2. Example of a late juvenile green sea turtle left profile with unchanged facial scale patterns over a 1675d (~ 5 years) time interval. Photographs A and B were taken on the 21/06/2007 and the 21/01/2012, respectively. The only change observed is related to the pigmentation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

with time intervals between two profile photographs ranging from 2 to 11 years (752d to 3954d), there were no changes in pigmentation for any scale. Fourteen profiles had less than 5 scales changing coloration over time (ranked as degree of change 1 in the analysis). For 9 profiles, between 5 and 9 scales had changed pigmentation (degree of change 2), and 5 profiles had between 10 and 14 scales with pigmentation change (degree of change 3). Two profiles (from the same individual) had all scales change color over a period of 6 years (degree of change 4). There were no relationships between the degrees of pigmentation changes assigned to profiles and the time spent between two photographs (Pearson correlation, $r^2 = 0.17$, $P = 0.22$).

3.2. Captive-reared sea turtles

Sixteen early juveniles and 13 adult green sea turtles were included in the study, and both profiles of each individual were analyzed (except for one adult for which only the right profile was available; Table 1). No variation was observed in the scale patterns for adult captive individuals. Conversely, all adult profiles showed some degree of pigmentation change over time, except one adult for which scale color remained unchanged over 5 years (1986d). Juveniles emerged from two different nests on 02/03/2010 ($n = 2$) and 21/11/2011 ($n = 14$). Individuals from the first nest are still kept in the sea turtle clinic as they both have permanent handicapping defects that preclude their potential survival in the wild. Mean SCL increase for these individuals was 53.7 cm (SD = 5.7) between the first and last photographs. One individual from the second nest was released on 18/04/2014 (877d after emergence), and had a mean SCL increase of 41.7 cm between the first and last photographs. Eight individuals were measured and photographed at their release day (between the 15/09/2014 and 12/12/2014), and had a mean SCL increase of 48.5 cm (SD = 4.4). The last five individuals were still held at the sea turtle clinic at the time of this study. They were measured and photographed on the 24/02/2015 (1123d after emergence) and had a mean SCL increase of 50.1 cm (SD = 3.2). Although there were no changes in the number of edges of a scale in all profiles analyzed from emergence to last photograph and measurement ($n = 32$), there were noticeable changes in the length and shape of some scales. Scales were extended horizontally in older developmental stages compared to their emergence day (Fig. 4). For only one individual, one edge separating two scales located close to the neck attenuated with time until it

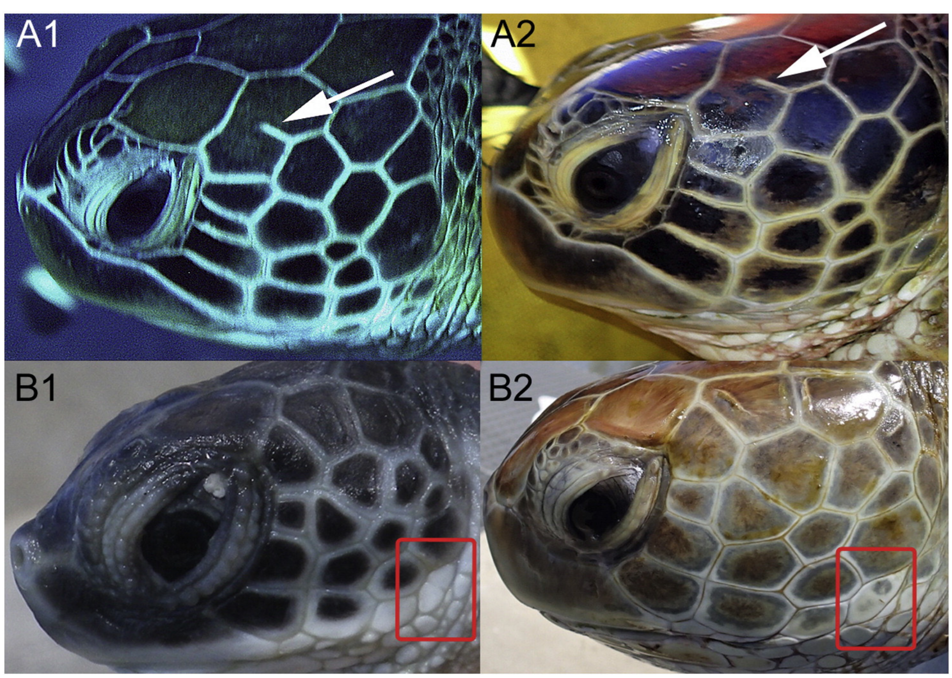

Fig. 3. Special cases in the evolution of green sea turtle facial scale patterns over time. Photographs represent a free-ranging individual (series A) and a captive-reared individual (series B) with time intervals of 1310d and 1034d, respectively. Series A shows an example of an unchanged incomplete edge over time (indicated by the white arrows). Series B illustrates an example of two scales merging into one throughout development (indicated by the red squares). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

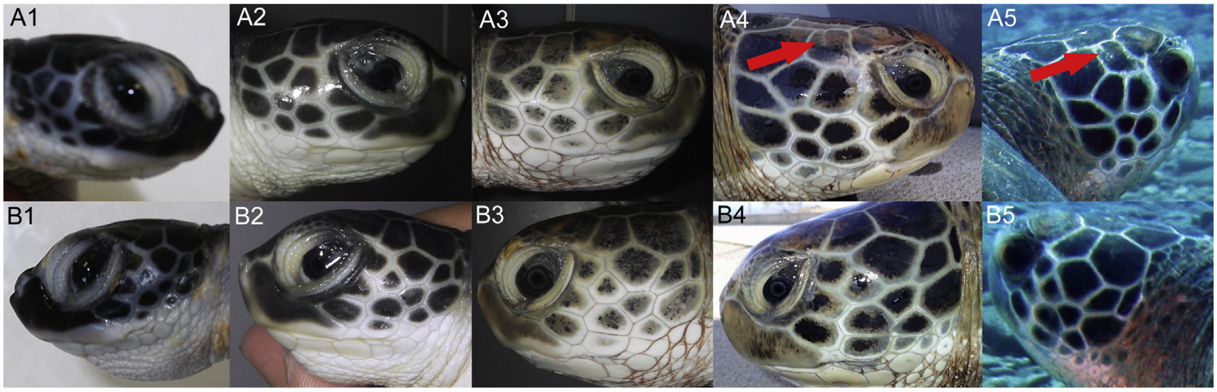

Fig. 4. Right (A) and left (B) profiles of a green sea turtle at different developmental stages (Straight Carapace Length (SCL) indicated as a reference of growth). 1: Emergence day (24/11/2011; SCL = 5.1 cm), 2: 111th day (14/03/2012; SCL = 11.6 cm), 3: 366th day (24/11/2012; SCL = 23.5 cm) and 4: 1114th day (12/12/2014; SCL = 62.0 cm). The fifth photograph (5) corresponds to the first time this individual was sighted in the wild after release (1136d, 03/01/2015). Note that scales became lighter at first (for 14 scales), and then after darkened again (for 16 scales). The (red) arrow indicates the extension of an incomplete edge. This individual was the only case of appearance of an incomplete edge observed among the study sample. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

completely disappeared, and was counted as one merging of two scales (Fig. 3B). It was the only merging case observed in the entire study sample. Conversely for one other individual, one incomplete edge appeared and extended over time (Fig. 4A). As for adults, there were also distinct changes in scale pigmentation in subsequent months and years (Fig. 4). In this case, scales became lighter at first (for 14 scales Fig. 4A), and then after darkened again (for 16 scales, Fig. 4A). This was observed for both profiles of this individual. From all profiles selected for the pigmentation change analysis on both captive-reared adults and juveniles, there were no relationships between the degrees of pigmentation changes assigned to profiles and the time spent between two photographs (Pearson correlation, $r^2 = 0.23$, P = 0.25).

4. Discussion

Overall, from the entire study sample ($n = 149$ profiles), only four changes were observed on different individuals: two on free-ranging adults (one extending IE and one shortening IE) and two on captive-reared juveniles (one merging of two scales and the appearance of an IE showed on Figs. 3B and 4A, respectively). For all other individuals, profiles were stable over time, as well for early juveniles as for late juveniles or adults. These results are consistent with previous published findings showing that facial scale patterns were stable over 1046d on green sea turtles (Reisser et al., 2008) and 1155d on hawksbill sea turtles (Dunbar et al., 2014). Chew et al. (2015) also showed that there was no change in the shape and arrangement of scales on hatchlings raised in captivity for one year ($n = 12$), which goes along with results of this study on captive-reared juveniles. While this study's photographs were carefully selected following quality requirements, the extension and shortening of an incomplete edge recorded on two free-ranging sea turtle profiles might be the result of distortions or differences in underwater conditions (e.g. lighting, water quality). The sudden appearance of an incomplete edge on one captive-reared individual (Fig. 4, A4) could either be a scale separation developing or a scar. As this IE appears one year after the previous photograph, it is likely to be a scar, as a developing incomplete edge would have been expected to start from a small primer with a well-marked outline. Here, there is only a superficial and irregular line, in contrast to the IEs observed on other profiles (e.g. Fig. 3A). Overall, the recorded changes on profiles over time were small and often limited to a single change on one of the numerous scales building an entire profile. Hence, given the high stability of the majority of facial scale patterns, we consider the minor changes recorded on profiles to be negligible for individual recognition over long periods. Similarly, in a study of the white shark, *Carcharodon carcharias*, dorsal fin morphology was found to be stable over a period of 16–22 years ($n = 5$, Anderson et al., 2011). For two individuals, new notches had appeared on the trailing edge of the dorsal fin over the study period, but these did not prevent accurate individual identification. In the zebra shark, *Stegostoma fasciatum*, pigmentation patterns were shown to be unique and stable for up to 810d, allowing the identification of 327 individuals (Dudgeon et al., 2008). For the tiger, *Panthera tigris*, stripe patterns were sufficiently unique to permit individual identification and tracking over a period of 9 years ($n = 74$, Karanth et al., 2006).

Evidences of changes in facial scale pigmentation were observed on sea turtles at different life stages. These changes were hard to evaluate on the free-ranging group as many parameters may have affected color perception on underwater photographs, and may have biased our observations on pigmentation changes. As light is absorbed and scattered when propagating through water, colors perceived become progressively bluer with depth (Tyler and Smith, 1970), which makes color changes in sea turtle skin and scales difficult to evaluate from photographs taken underwater. The density of particles suspended in the water may also differ greatly depending on sighting locations, depth, and turbidity, affecting the colors perceived on photographs. Additionally, photographs of free-ranging sea turtles used in this study came from different cameras, each with its own lighting and contrast parameters, which might have influenced resulting photographs. The analysis of the color change on free-ranging sea turtle head scales can be improved by considering these limitations in future studies before making conclusions on pigmentation variation occurring in the wild. A potential means to measure the surface of pigmentation change within a photograph can be analyzed using specific software (such as Vidana 1.0; Walker, 2011). Additionally, colors resulting from different lighting and depth situation could be balanced on photographs using photographic software to prevent miscounting of pigmentation changes. Considering such color adjustments were not performed in the current study, caution should be used when interpreting results on color pigmentation on free-ranging individuals. For the captive-reared group, with the confidence that photographs were taken in the same lighting conditions and the same camera settings, the results confirm that pigmentation varied throughout different developmental stages. Although there are no published reports of color changes in sea turtle skin and shell, this phenomenon has been commonly observed in the wild in sea turtles from pelagic and coastal foraging areas. These color changes occur initially over a few months and then slowly continue throughout the decades as turtles grow (Limpus, pers. comm.). In Chelonians, pigmentation variation has been documented on the carapaces of Northern Spider Tortoises (*Pyxis arachnoides brygooi*, Walker, 2011) and on the plastrons of Hawaiian green sea turtles during early life stages (Balazs, 1986). Several hypotheses have been proposed to explain the pigmentation variation occurring in the skins or carapaces of reptiles.

Scale pigmentation of an individual can differ to adapt to habitat changes in early life stages and to be less visible to predators (Carr, 1969). It may also be a natural response to changes in lighting conditions (Woolley, 1957; Walker, 2011). Little is known about the mechanisms that are responsible for pigment changes.

Most photographs used in this study were supplied voluntarily by local divers, making the sea turtle photo-ID program in Reunion Island a successful example of the integration of citizen science (i.e. the participation of the general public in data collection for scientific purposes) in sea turtle research. The implication of divers as a source for the collection of sea turtle data has been increasing since 2004 in Reunion Island, from 2 divers providing their photographs to the program in 2003 to 46 divers in 2010. To date, more than 98 divers have participated in the sea turtle monitoring program (Chassagneux et al., 2013). Incorporating recreational divers data into sea turtle monitoring programs has also proven effective in the Cayman Islands (Bell et al., 2008) and in Inhambane Province, Mozambique (Williams et al., 2015). Citizen science offers many benefits for sea turtle research and conservation, as it may provide almost continuous data for a broad range of locations, as well as increasing public awareness of the conservation status of these endangered species (Jean et al., 2010a). Little training is required as divers need only to take photographs or movies of turtles sighted. Photographs then allow trained staff or investigators to accurately identify the species, record physical abnormalities, determine the sex (when possible), and identify the individuals using photo-ID programs. To our knowledge, three computer-aided identification programs have been successfully tested on sea turtles species: the TORSOOI program on green and hawksbill sea turtles (Jean et al., 2010a), I^{3}S program on hawksbill turtles (Dunbar et al., 2014) and MYDAS, using artificial neural networks on green sea turtles (Carter et al., 2014). These programs, however, require some image pre-processing (e.g. cropping, rotation and contrast corrections) and a trained operator must still either select the scales or spot the intersections between scales manually, which can become a challenging and time-consuming task with a rapidly growing library of photographs (Kelly, 2001; Schofield et al., 2008). The validation of the use of photo-ID methods on green sea turtles is motivation for the development of automated programs that would require less participation from the user and that could be more practical and applicable for large data sets in less amounts of time. The development of such programs will encourage their applications in long-term studies in a more systematic manner and may allow individuals identification and tracking on a global scale.

The evolution of profiles is an ongoing study, as sea turtle photographs from Reunion Island are received and analyzed on a regular basis. As the foraging sea turtle population in Reunion Island mainly consists of late juveniles, our findings on facial scale stability on free-ranging sea turtle focused mostly on this age class, and far fewer photographs were obtained for adult individuals ($n = 5$ free-ranging adults, $n = 13$ captive adults). Observations of facial scale patterns on foraging or nesting adult sea turtles showed that scale edges may look like they have separated into pieces or may attenuate with time, complicating the delimitation of scales for the investigator (Jean, unpublished data). Data from additional years will confirm the stability of profiles with longer periods of time, and ultimately, it may be able to confirm the stability of facial scale patterns throughout the long lives of turtles. The application of photo-ID on nesting beaches may allow the investigation of scale pattern evolution in breeding females over long periods of time. This approach was recently tested successfully on a green turtle nesting population at Chagar Hutang, Malaysia, where, from 43 nesting females cataloged, seven were re-identified in their successive nesting season using photo-ID (Chew et al., 2015). Nonetheless, taking photographs of nesting females may be challenging as facial scale patterns must be cleared of sand before taking the photograph (Jean et al., 2010a). As noted by Reisser et al. (2008), it may also require the use of camera flashes, and the stress that may be caused to nesting females requires further investigation.

5. Conclusions

These results on the stability of facial scale patterns over time, combined with previous findings on the uniqueness of patterns between individual green sea turtles, validate the value of facial scale shapes as natural marks for continuous individual recognition in long-term population studies. The photo-ID approach for sea turtle identification holds potential to revolutionize sea turtle data collection and monitoring for many reasons. First, underwater digital imagery capture and image-processing software are enhancing rapidly and becoming more accessible to a broad range of conservation actors. The acquisition of high-resolution digital cameras is becoming less expensive and its investment may progressively compensate the cost of tagging materials and sea turtle capture logistics. Second, photo-ID allows the participation of local divers, snorkelers, fishermen or anyone who may encounter sea turtles, contributing to public awareness about conservation issues. Third, it eliminates the problems due to tag loss, such as the underestimation or over-estimation of population size and the interruption of long-term studies continuity, even if tags will remain useful in short-term studies needing rapid identification. Finally, as far as photographers not disturbing sea turtles while taking their profile photograph, photo-ID is a completely non-invasive technique which is of particular interest for species of conservation concern, such as sea turtles. Information obtained from photo-ID is highly valuable as it can help the development of effective conservation plans.

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