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NOTE

I^3S Pattern as a mark–recapture tool to identify captured and free-swimming sea turtles: an assessment

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ABSTRACT: Identifying individual sea turtles is essential for understanding population dynamics and, in turn, planning conservation efforts. Traditionally, sea turtle individuals are identified through the application of external flipper tags and/or internal passive integrated transponders (PITs). However, sea turtle identification and consequently population studies are hampered by the loss of external flipper tags and migration of PITs. In this study, we assessed the accuracy and time efficiency of the Interactive Individual Identification System software (I^3S Pattern v. 4.02) to photo-identify facial patterns of immature captured and free-swimming green turtles *Chelonia mydas* and hawksbill turtles *Eretmochelys imbricata*. Using a library of 436 photos representing 189 sea turtle individuals, we evaluated the accuracy and time taken for I^3S Pattern to match individuals. A high proportion of individuals were successfully identified from photographs taken of captured turtles (97%) and free-swimming turtles (85%). I^3S reduced data analysis time by 80% when compared to the visual assessment of photos, and is further optimised when photographs are of increased quality. These results demonstrate that I^3S has great potential to contribute to population studies and management plans by facilitating both specialised research and citizen science programmes.

KEY WORDS: Interactive Individual Identification System · Photo-identification · Wildlife recognition software · Sea turtles · Mark–recapture studies

INTRODUCTION

The reliable identification of wildlife is essential to obtain knowledge on population demographics, reproduction patterns, life history, foraging behaviour, movement and population connectivity (Speed 2006). Mark–recapture programs are commonly used to identify individual animals, and can provide a better understanding of ecological and behavioural aspects that are essential for evaluating populations of endangered species, which is in turn crucial for meeting conservation objectives. These programs

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are especially useful for marine populations due to the difficulty of directly tracking and observing organisms underwater; for instance, sea turtles present complex life cycles and highly migratory behaviour, making them ideal candidates for mark–recapture studies aimed at evaluating growth rates, survival, residency, movements, foraging patterns, reproductive biology and population size (Dutton et al. 2005, Reisser et al. 2008, Schofield et al. 2008, 2017, Wood et al. 2013).

Sea turtle mark–recapture methods typically rely on artificial tags such as externally placed Inconel flipper tags and internally inserted passive integrated transponder (PIT) devices. While these tagging techniques are widely used, the long-term identification of individuals is hampered by high rates of tag loss, requiring frequent replacement. Reisser et al. (2008) showed that 58.3% of tags attached between the first 2 front flipper scales were lost, and 9.5% of tags attached in the pre-scale position of flippers were lost within a 3 yr period, leading to population size overestimates. Additionally, flipper tags can cause infections and stress during the nesting period (Speed et al. 2007). To alleviate issues associated with tag loss, PITs are being increasingly used in conjunction with flipper tags, but PITs can also cause infections in sea turtles (Gheorghiu et al. 2010). Some studies have used a combination of PITs, flipper tags and photo-identification to obtain novel insights into turtle populations (Dutton et al. 2005).

An alternative to artificial tags is the use of photographic identification (photo-ID), using natural features and markings of animals to aid in their individual recognition. Photo-ID is based on the identification of unique natural patterns on an individual and has been increasingly used in studies targeting marine animals such as dolphins (Thompson et al. 2000), whale sharks (Meekan et al. 2006) and sea turtles (Reisser et al. 2008). This method reduces the cost and problems associated with tag loss and minimizes animal manipulation (Schofield et al. 2008). Mark–recapture studies using photo-ID also permit multiple recaptures in different habitats and life stages, allowing monitoring of adult and immature turtles that would otherwise be difficult to capture. The widespread availability of digital cameras also provides a significant opportunity for encouraging citizen science contributions to sea turtle research.

Photo-ID methods have been used to visually compare pineal spots of leatherback turtles *Dermochelys coriacea* (Dutton et al. 2005) and facial profile scutes of loggerhead turtles *Caretta caretta* (Schofield et al. 2008), green turtles *Chelonia mydas* and hawksbill turtles *Eretmochelys imbricata* (Reisser et al. 2008). These have been based mostly on manual comparison of photos to identify individuals, which can become very time consuming when dealing with large populations with extensive databases and multiple recaptures. To rectify this, various automated recognition software packages have been developed to provide an effective mark–recapture method for sea turtles (Lloyd et al. 2012, Carter et al. 2014, Carpentier et al. 2016). Recently, the Interactive Individual Identification System (I^3S) has emerged as software that has the potential to identify sea turtles (Dunbar et al. 2014, Araujo et al. 2016). However, no studies have rigorously compared this software across varying sample sizes and multiple turtle species, nor explored its capabilities when presented with images of free-swimming turtles taken by non-specialists. Furthermore, the I^3S software includes a package ('Pattern') which is specifically designed to identify patterns characterised by multiple small spots on a curved identification area such as found on turtles, which has not been tested in any earlier studies. These issues are addressed in this study by using I^3S Pattern to analyse images, taken by both specialists and non-specialists, of captured and free-swimming individuals of 2 species of sea turtles to test the full potential of this technique in assisting sea turtle monitoring and research.

MATERIALS AND METHODS

Image acquisition

Images of immature green and hawksbill turtles were collected between 2005 and 2014 at 3 locations in Brazil: Arvoredo National Marine Reserve (27° 17′ S, 48° 28′ W), Abrolhos National Marine Park (17° 58′ S, 38° 42′ W) and São Pedro and São Paulo Archipelago (00° 55′ N, 29° 20′ W). These photos are part of a broader mark–recapture project that photographed immature sea turtles on land after in-water capture (Reisser et al. 2008). Captured turtles were measured (curved carapace length, CCL), tagged with passive Inconel marks style 681 (provided by Projeto Tamar-ICMBio) and photographed with a digital camera. For each turtle, both facial profiles (from eye to neck) were photographed in order to register the postorbital scales, which can assist in individual identification of sea turtles (Pritchard 1999). Each face profile was photographed at a distance of approximately 20 cm to minimize distortions caused by inclination, with a small ruler as a scale, and 2 or 3 facial profile photos were taken for each individual turtle. Photographs were compared with known matches based on tag numbers, to validate the method and determine the accuracy of I^{3}S Pattern photo recognition of sea turtles. Additionally, we evaluated underwater turtle photos taken opportunistically with digital cameras by scuba divers during recreational dives at the Arvoredo Marine Reserve. Identification of turtles photographed during dives could not be verified by tag numbers, but allowed us to assess the possibility of using I^{3}S Pattern to photo-ID sea turtles based on underwater photographs.

Animal handling was approved by Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), and conducted under SISBIO license no. 22504 by trained personnel.

Fingerprinting images

I^{3}S Pattern software uses a reference system consisting of 3 points on the animal's body that can be easily marked in every photo, known as 'fingerprints'. As suggested by den Hartog & Reijns (2014), we used the following points: the tip of the rhamphopheca (beak), the postorbital edge of the eye and the marginal sub-temporal scale intersecting the neck (Fig. 1). An area of interest was then manually drawn around the perimeter of the following facial scales: postorbital, tympanic/central, temporal and sub-temporal scales (Schofield et al. 2008). Within this perimeter, the software generates at least 12 elements (i.e. distinguishable features) to identify a unique pattern. Following the software designers' advice, a maximum of 35 elements (red circles) was set to ensure adequate elements were generated while optimising processing time.

Image matching

Images were matched by comparing individual fingerprints generated by I^{3}S against known matches in the database. The software calculates a distance metric, which is the sum of the distances between each key point pair divided by the square of the number of key point pairs (den Hartog & Reijns 2014). A list of rankings with 20 potential matches was created showing a similarity index, with the most likely match presenting the lowest score. The software then calculated the percentage of how many photos were matched for ranks 1, 3, 10 and 20.

Visual assessment

Visual assessment involved printing all above-water photographs, writing tag information on the back and visually comparing the shape and arrangement of facial scutes to match individual turtles (Reisser et al. 2008). The time taken for each individual identification was recorded, and the tag number was checked to confirm that the manual identification of the pair was correct.

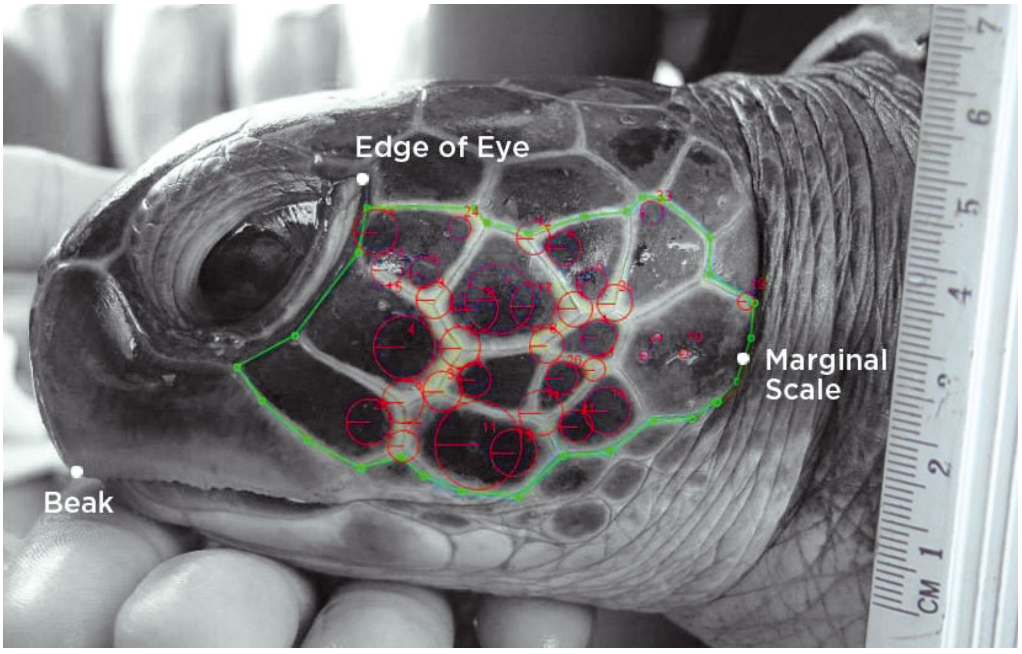

Fig. 1. Reference system for identifying the postorbital facial features of sea turtles. White dots illustrate the fingerprints, green line delineates the area of interest, and red circles show the elements/distinguishable features

Data analysis

Using the 'elaborate evaluation' function in I^{3}S Pattern, each fingerprint was matched against all photos in the database. For every positive match, the matching photo's rank, number of images of the same animal in the library, score and processing time were recorded. To validate the software as an adequate identification system for individual turtles, we (1) compared identification efficiency between 2 sea turtle species (green and hawksbill) through a *t*-test; (2) determined the percentage of tag-confirmed matches correctly identified by I^{3}S; and (3) compared the accuracy and time taken to identify a match in I^{3}S and visual assessments. The sample was divided into 5 subsets: 48, 100, 150, 200 and 318 images. The mean and standard deviation (SD) of the time taken to identify individuals was calculated for each of the 5 image subsets using the 'simple evaluation' function.

RESULTS

The above-water dataset comprised 318 photographs, with 211 photographs of 103 individual green turtles and 107 photographs of 53 individual hawksbill turtles. Captured green turtle CCL ranged from 32.0–83.0 cm (average 50.1 cm), and hawksbill CCL ranged from 36.0–59.5 cm (average 44.1 cm). The in-water dataset included 118 photographs, with 117 photographs of 32 green turtles and 1 photograph of 1 hawksbill turtle (Table 1). All images provided suitable postorbital scale patterns for photo-ID analysis. No significant difference in time taken for identification was detected between green and hawksbill turtle images, for both methods ($p = 0.714$, $n = 436$).

Considering the above-water photos, I^{3}S successfully recognised 307 out of 318 (97%) matches based on tag numbers within 20 ranked pictures, of which 291 (92%) were ranked in the first position. With respect to the underwater photos, I^{3}S correctly identified 101 out of 118 (86%) images within the top 20 ranked pictures, but only 56 images (48%) were ranked in the first position. Matches were 100% accurate when identification was done manually.

The plotted data showed a positive linear regression between the mean time taken and the number images identified for both manual ($F_{1,3} = 282.7$, $p < 0.00$, $R^2 = 0.99$) and I^{3}S ($F_{1,3} = 43.9$, $p < 0.01$, $R^2 = 0.94$) methods. Comparisons between the 2 methods indicated that the time taken to identify turtles using the manual method was significantly greater than using I^{3}S ($p < 0.05$; Fig. 2). I^{3}S software identified each image faster, with an image being correctly matched in a mean time of 13.5 ± 0.11 s, whilst visual identification took on average 56.6 ± 37 s per image (i.e. over 4 times slower). The error bars also indicate that there was greater variability in the time taken to match an image using the manual method, and this variability increased with the number of images processed (Fig. 2).

Table 1. Number of individuals and photos of green and hawksbill turtles taken above- and in-water at the 3 study sites in Brazil; n_{ind}: number of individuals, n_{photo}: number of photographs

	Green		Hawksbill	
	n_{ind}	n_{photo}	n_{ind}	n_{photo}
Above water				
Arvoredo Marine Reserve	103	211	4	8
Abrolhos Marine Park	–	–	42	84
Sao Pedro Sao Paulo Archipelago	–	–	7	15
In water				
Arvoredo Marine Reserve	32	117	1	1

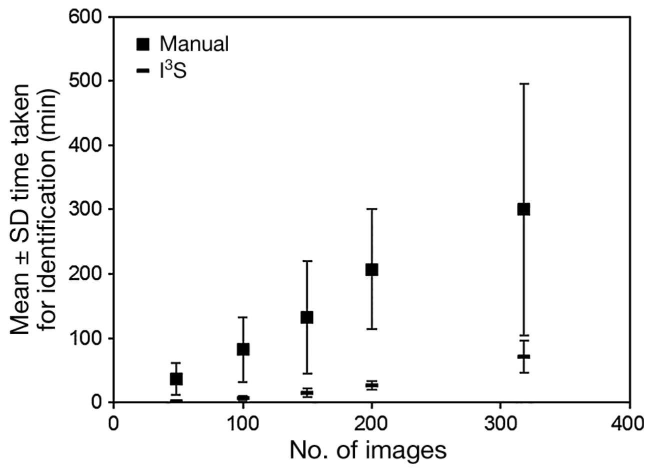

Fig. 2. Mean ± SD time spent using manual (square points) and Interactive Individual Identification System (I^{3}S) (line points) sea turtle photo-identification methods

DISCUSSION

To our knowledge, this is the first study to evaluate the use of I^{3}S Pattern software for identifying individual sea turtles. Our results indicate that this is an effective method to identify both green and hawksbill turtles based on their facial scales using images derived from both scientific surveys and members of the public. Given the ability of the software to rapidly recognise unique patterns from large photographic libraries, it evidently has the potential to be used as a non-invasive alternative to more intrusive approaches for identification of sea turtle individuals.

Sea turtle postorbital scales are considered to provide a stable long-term facial tag that does not change markedly over time, subject only to minor blemishes and scarring (Carpentier et al. 2016). The 92% accuracy in correctly identifying green and hawksbill turtles in the top ranked image using I^{3}S Pattern in this study was greater than the 85% accuracy associated with identifying green turtles using earlier variants of the software (I^{3}S Classic, Dunbar et al. 2014). The cause of the error is predominantly due to photo quality, with factors such as angular deviation from the object, over-exposure and flash all impairing the performance of I^{3}S (Rocha et al. 2013). This is also an issue with manual photo-ID, showing that photo quality is important regardless of the method (Schofield et al. 2008). The point cloud images generated by the software during this study showed that distance from the object also reduced the accuracy of I^{3}S assessment as fewer identifying points were recognised. However, the suppliers of images for this study did not have training in taking photos specifically for I^{3}S, indicating that the accuracy of the software could be further improved.

In this study, we used photographs of immature turtles in daylight conditions, which were shown to be ideal. Given that many images are taken of nesting turtles at night, the disturbance caused by camera flashes and other artificial light sources (Waayers 2010) means that infrared flashlights or night cameras are recommended for recording turtle facial profiles. Underwater photography is also challenging due to water turbidity, light attenuation and water movement, which was reflected in the lower percentage of images being correctly identified. These issues were evident in this study, with a considerable increase in error associated with accurate first ranking of underwater photos. Nevertheless, the software was able to correctly recognise 86% of images in the top 20 ranked matches, demonstrating its potential to reduce the time and costs associated with visual identification using underwater imagery through filtering out non-matching photographs.

Photo-ID methods can be used to improve our understanding of resident and regional movements of free-swimming turtles. This method relies less on the capture and handling of turtles from a boat and the need to retag individuals, which would assist in increasing the number of mark–recaptures in the long-term (see Carpentier et al. 2016). Given that green and hawksbill turtles have relatively small home ranges (Makowski et al. 2006), underwater photo-ID with GPS coordinates has the potential to generate site-specific datasets, providing a more comprehensive understanding of resident home ranges. Photo-ID methods will also provide better understand the movements and resident behaviours of male turtles, which continues to be a large knowledge gap in sea turtle ecology (Schofield et al. 2008), and provide further insight into sex ratios of adult and immature turtles (Schofield et al. 2017) at specific sites.

While this study did not evaluate multiple recaptures, other research has shown that the matching performance of I^{3}S increases as more images of the same animal are added to the database (Rocha et al. 2013, Dunbar et al. 2014). The present study demonstrates that I^{3}S Pattern can be used with a high degree of reliability in using images supplied through citizen science programmes or dive tourism companies to monitor populations of both green and hawksbill turtles. The use of an automated photo identification method can clearly create opportunities for much broader datasets to be generated with photographs taken and shared by citizen scientists (Conrad & Hilchey 2011), and includes the possibility of developing and efficiently using web-based systems for uploading photos of sea turtles encountered on the beach or whilst diving. By teaching local communities and tourists how to take suitable photos of sea turtles (Jean et al. 2010), the efficiency of automated identification of individuals will improve over time. In short, I^{3}S is a valuable tool that can improve our understanding of sea turtle population dynamics, which will help plan future conservation efforts for these reptiles.

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