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Investigating the viability of photo-identification as an objective tool to study endangered sea turtle populations

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ABSTRACT

We assessed the potential of using natural facial markings to identify individuals in an endangered breeding population of loggerhead sea turtles (*Caretta caretta*). We divided individual turtles into ten groups based on facial (post-ocular) scale patterns to facilitate rapid comparison of new images in a large photographic catalogue of known turtles (exceeding 400 unique individuals). The matching process was validated by using turtles marked with external flipper tags. An experienced observer achieved a mean 99% success in identifying individuals using photo-id. The reliability and wider utility of the technique was assessed through testing the ability of naïve and trained observers to (1) consistently allocate known (i.e. flipper tagged) individuals into the correct groups (2) correctly match known individuals within one group. In all trials the mean success rate in photographic sorting and matching ranged from 68-100%. A 20 minute training session was found to significantly improve observer ability, i.e the photo-id skills were rapidly acquired by inexperienced workers. Photo-id has the benefit of being suitable for male turtles, which do not come ashore to allow conventional tagging, and so are rarely identified. Photo-id may facilitate the assessment of the numbers of male and female turtles at breeding areas and allow adult sex ratios to be measured.

1. Introduction

The ability to identify individuals within a population is often a starting point for ecological and conservation studies (Thompson et al., 2000; Sibly et al., 2005; Lusseau et al., 2006; Bradshaw et al., 2007; McMahon et al., 2007). Realistic estimates of population size and life history parameters are central to effective wildlife management, but are often difficult to measure in long-lived and elusive migratory marine vertebrates (Caughley, 1994). Most studies with free-ranging animal populations rely on the physical capture of animals and the placement of artificial tags, brands or other objects to allow their subsequent identification (Wilson and Wilson, 1989; McMahon et al., 2007). Such approaches have often been used successfully although there are sometimes problems such as stress to the animals through capture, handling and tag attachment and impacts of the marker itself. For example flipper bands have been shown to increase mortality in penguins as have some flipper tags used in sea turtle research (Nichols and Seminoff, 1998; Dugger et al., 2006). Furthermore, the inevitable loss of identification markers (i.e. from incorrect attachment or being knocked/bitten off) (Limpus, 1992) can become problematic in some species, interrupting the continuity of long-term studies of long-lived species of conservation concern (Sibly et al., 2005).

An alternative to attaching markers to wildlife, is to use visual identification of individuals. The ability to recognize individuals from naturally occurring features has many advantages over conventional marking techniques including: animals are not physically captured, identifiable characteristics are stable over time, and the behaviour of the animal is less likely to be affected by the identification system (Hammond, 1990; Blackmer et al., 2000). Photographic identification, in which researchers photographically capture these natural markings to identify and re-identify individuals, has proven to be a useful tool in long-term monitoring of wild animal populations (Thompson et al., 2000; Forcada and Aguilar, 2003; Bradshaw et al., 2007). For example, whisker patterns are used in lions, facial scale patterns in sea turtles, pelage spot patterns in whale-sharks, fin shape and scarring in dolphins (Richardson et al., 2000; Thompson et al., 2000; Arzoumanian et al., 2005; Ogutu et al., 2006).

Many sea turtle research programmes use some form of conventional tagging method (i.e. plastic, monel, titanium) to obtain life history information about nesting females at breeding areas or of different age classes at foraging areas (Chaloupka and Limpus, 2001;

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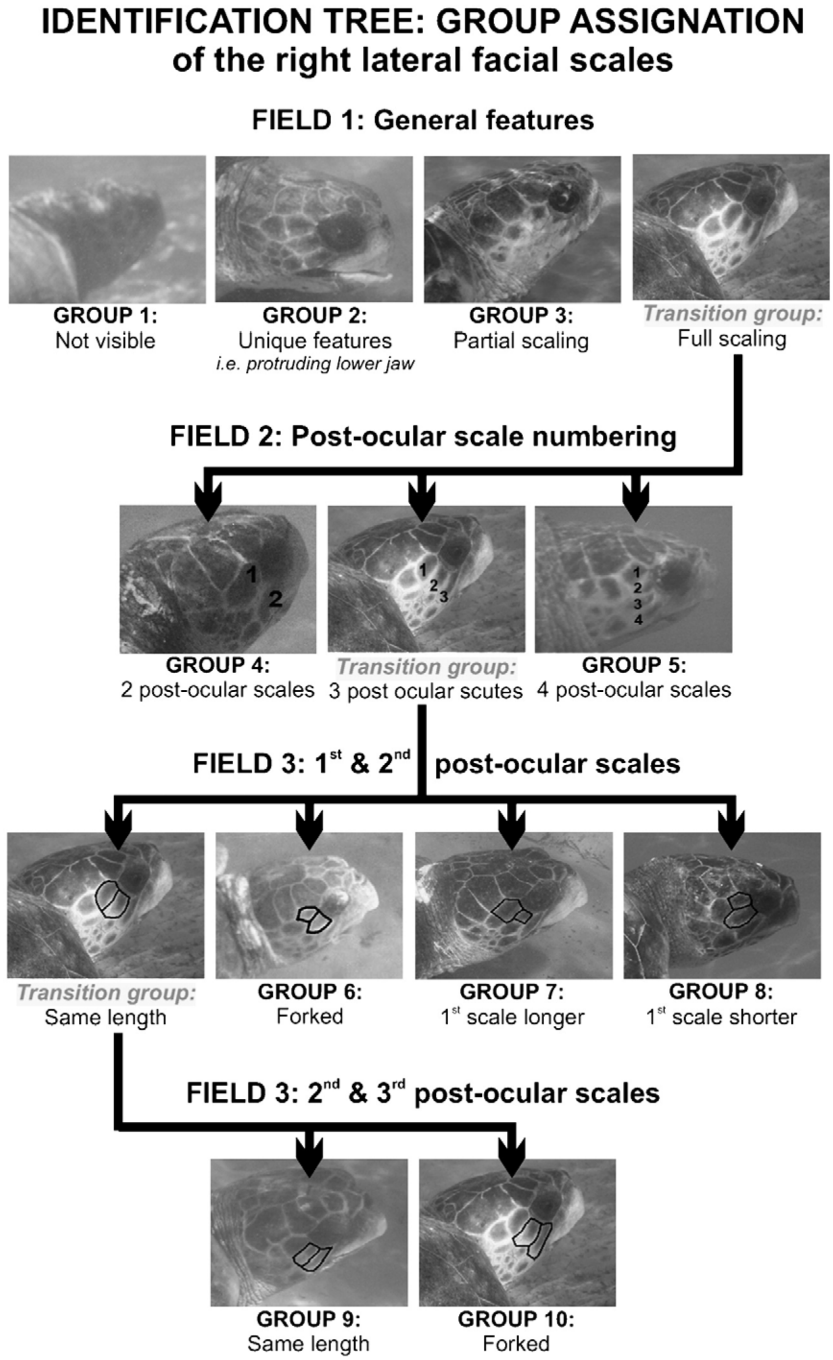

Fig. 1. Identification tree separating the turtle images into ten groups based on the relative shapes of the post-ocular scales.

Balazs and Chaloupka, 2004). Flipper tagging studies tend to preferentially target adult female turtles due to their accessibility on the nesting beaches, resulting in a skewed picture of the adult population structure. Furthermore, significant levels of tag loss often reduce the reliability and scientific value of data collected (Mrosovsky, 1976; Limpus, 1992; Witzell, 1998; Broderick and Godley, 1999). Alternative more endurable methods have recently been used, including passive integral transponders (PIT) (McDonald and Dutton, 1996), natural genetic markers (Bowen, 1995) and photo-identification using head scalation patterns (Richardson et al., 2000).

While photo-identification has been explored in several sea turtle species (Bennett et al., 1999; Richardson et al., 2000; Rodriguez and Sarti, 2000; Schofield et al., 2004; White, 2006; Wood, 2006), the utility of this approach as a bio-monitoring tool when population sizes are large has not been established. Furthermore while experienced workers may have a good ability to visually discriminate individuals (Douglas-Hamilton and Douglas-Hamilton, 1975), a photographic data base can potentially be used more widely, and have longevity beyond the career of the originator, if other users can be trained to reliably use the data-base. The aim of this work is to construct an objective tool based on photo-identification which is easy to use for experienced and non-experienced personnel and is credible and effective for individual recognition of male and female turtles for application in population bio-monitoring, behaviour studies and conservation. We therefore set out with two objectives; first to establish the utility of photo-identification in a large population by testing the technique at the Mediterranean's largest loggerhead turtle rookery, where several hundred turtles aggregate each summer; second to establish whether naïve users could easily and reliably learn to use photo-identification to recognise individual sea turtles.

2. Materials and methods

2.1. Study area and turtle population

Our study was conducted at Laganas Bay, Zakynthos island, Greece (37 °43'N 20 °53'E). Several hundred loggerhead sea turtles (*Caretta caretta*) annually aggregate in the near-shore waters of Laganas Bay to breed from late April to early August (Schofield et al., 2006; Schofield et al., 2007a).

2.2. Data source

Still photographs were taken of male and female loggerheads in the sea. An Olympus Digital 500 (5.0 megapixel) camera with underwater housing was used, while snorkeling at a distance of 2-7 m from the target animal. Images were collected between late April and early August during five years of surveying, 2003-2007. Animal gender was determined based on tail length dimorphism (Casale et al., 2005).

For the purpose of the trials, between one and five digital photographs were selected for each of 170 'confirmed' individuals, validated by the presence of external plastic flipper tags (attached within the framework of the NGO Archelon beach monitoring programme). The tags were attached prior to the onset of the study and the selected turtles retained the same tag(s) in all subsequent sightings as confirmation of their identity. All photographs were of the right lateral head region of the turtle, and were selected based on two criteria (1) all images of the same turtle were from different sighting events separated by at least 1 day, (2) only high digital photographs (300-pixel resolution) were used in which all facial scales were visible. Before use, each image was assigned a unique identification number.

2.3. Group-assignation and photographic matching

Using an identification tree split into four sequential fields, we divided individuals into ten groups based on the relative shapes of the post-ocular scales (Fig. 1). Each group contained < 100 individuals.

We used the lateral facial scale patterns to differentiate between different individuals within each group (Fig. 2a & b). Comparison and matching of photographs within each group was made by subjective observation of three different sets of facial scale groups: (1) the numbering and pattern of tympanic and central scales (2) the relative shapes of the sub-temporal scales, and (3) the relative shapes of the temporal scales. Within each group turtles are separated into 'male', 'female' and 'unknown' categories. This means that if the sex is not determined when the animal is photographed, the individual can be matched following separation into one of the groups.

2.4. Expert observer validation against flipper tagged turtles

The lead author (GS) who has observed turtles in the water for many years conducted a trial to validate her ability to consistently sort and match 200 photographs from known turtles identified with flipper tags. This trial was conducted twice with two different sets of 200 images (i) without and (ii) with the aid of the identification tree. In both versions, the observer was given a catalogue containing 50 unique turtle images. A separate set of 150 unsorted images was provided, each of which could be assigned as a 'new capture' or a 're-capture' when compared to the images in the primary catalogue (Table 1a). The average number of images per individual was 2.7 (range 1-5) for both data sets respectively. In both versions, the trial was repeated on three different occasions separated by an interval of at least one day. The time taken to complete each trial run was recorded.

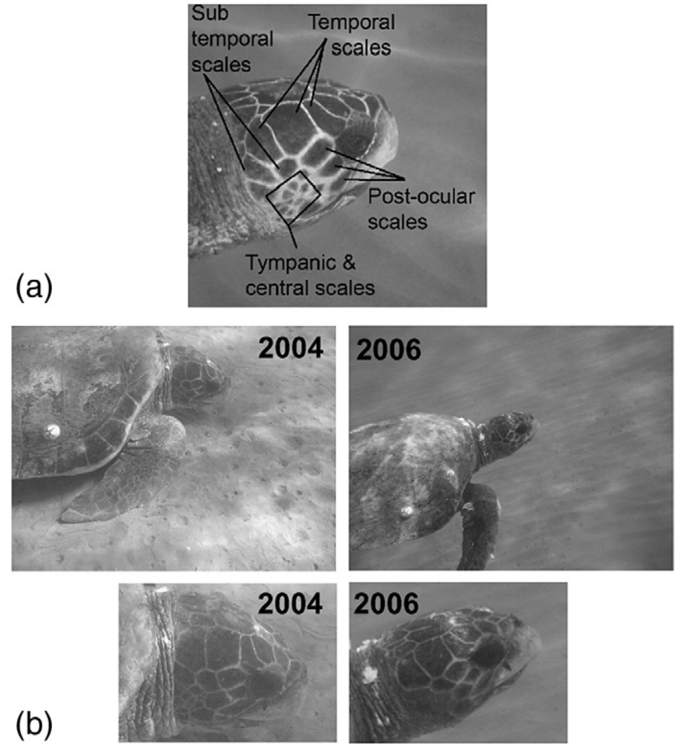

Fig. 2. (a) Lateral head scales of loggerhead turtle used for matching images in this study. (b) Sample lateral facial scale data sets from the photo-identification database. Raw images (top row) from newly submitted (right) and catalogued (left) encounters are processed by comparison of different sets of scale groups (bottom row).

2.5. Naïve observer trials

2.5.1. Trial 1: separating turtles into groups

A trial was conducted to assess observer ability to allocate turtles into the correct groups when a reasonably large number of captures is involved (Supplementary Fig. 1). Each observer was given instructions on how to use the 'identification tree' and was asked to allocate 40 images into one or more groups (Table 1b), or state if unable to place the image. The average number of images per individual turtle was 1.3 (range 1- 2). The trial was conducted twice, separated by an interval of at least one day. In the first run of the trial, all observers (n=44) were inexperienced. Before the second run of the trial, part of the group (n=24) received training. The time taken to complete each trial was recorded.

2.5.2. Trial 2: matching turtles within groups

A trial was conducted to assess observer ability to correctly match turtles within one group when a reasonably large number of captures is involved (Supplementary Fig. 2). Each observer was given a catalogue containing 15 unique images. A separate set of 20 unsorted images was provided, each of which could be assigned as a 'new capture' or 're-capture' when matching against the provided catalogue (Table 1c). The average number of images per individual turtle was 1.8 (range 1-4). The trial was conducted twice, separated by an interval of at least one day. In the first run of the trial, all observers (n=49) were inexperienced. Before the second run of the trial, part of the group (n=23) received training. The time taken to complete each trial was recorded.

In all trials, the observers were permitted to re-order the displayed 'capture' images to assist with the sorting/matching process, and were allowed to set aside images given during sequential identification to return to at the end.

Table 1
The photographic image categories for each trial (a) expert observer validation (b) naïve observers separating images into groups (c) naïve observers matching turtles within groups

Table 1a

Trial type	Total Images	Database Images	Images to Match	Catalogue image matches					New catalogue Images	New catalogue image matches				
				0	1	2	3	4		0	1	2	3	4
Matching not Using groups	200	50	150	15	8	11	9	7	31	9	2	9	8	3
Matching by Using groups	200	50	150	12	12	17	6	3	35	5	7	11	8	4

Table 1b

Total Images	Database Images	Images to Match	Group matches										Singles	Duplicates
			1	2	3	4	5	6	7	8	9	10		
50	10	40	1	2	5	1	1	4	6	7	8	5	22	9

Table 1c

Total Images	Database Images	Images to Match	Catalogue image matches					New catalogue Images	New image matches				
			0	1	2	3	4		0	1	2	3	4
35	15	20	6	6	2	1	0	4	2	1	1	0	0

2.6. Trial analyses

To quantify observer ability, five photo-matching categories were defined; 1) a Match-Match (MM) indicates that the observer correctly matched the photograph to the correct group or individual, 2) the New-New (NN) category indicates that the observer correctly placed the photograph as a new group/individual not found in the existing database, 3) a New-Match (NM) category indicates that the observer correctly matched a new photograph to another newly added image to the database, 4) a False-Match (FM) was determined when an observer incorrectly matched a photograph to a different group/individual in the photographic database (false positive error), 5) a False-New (FN) category was defined as when an observer incorrectly classified a photograph as a new image but it was already in the photographic database (false negative error). We demonstrated the consistency and reproducibility of observer judgement within trials by providing multiple photographs of single individuals.

We used paired Students *t*-tests to examine the relative improvement in skill and time requirement within and between observer groups.

3. Results

3.1. Expert observer validation against flipper tagged turtles

The accuracy and consistency of photographic matching of turtles validated from flipper tags was extremely high; without use of identification tree (98%), with use of identification tree (100%). Incorrect matching occurred for the same three images in all three runs of the first version of the trial (without identification tree), with turtles being incorrectly specified as new captures (i.e. inflation of the population). The use of the identification tree to group turtles before matching resulted in turtles being matched at a significantly faster rate (paired Student's *t*-test, t=33.1, df=4, $P<0.001$) with a 50% reduction in matching time required; from 2.26 to 1.14 minutes per image (Table 2).

3.2. Naïve observer trials

3.2.1. Trial 1: separating turtles into groups

In the first run of the trials when all observers were naïve, a mean accuracy of 69% was obtained with observers taking 42 minutes on average to complete the trial. Student t-tests indicated no significant difference in ability in the first run of the trial between those that did and did not receive subsequent training (Student's *t*-test, t=0.18, df=42, P=0.8). Repetition of the trials, indicated a slightly significant improvement in the untrained group (mean 76%, paired Student's *t*-test, t=2.11, df=38, P=0.04) and a highly significant improvement in the trained group (mean 83%, paired Student's *t*-test, t=4.27, df=46, $P<0.0001$). Trial repetitions took an average 30 minutes in both trained and untrained groups and were not found to be significant in either group.

3.2.2. Trial 2: matching turtles within groups

In the first run of the trials when all observers were naïve, a mean accuracy of 71% was obtained with observers taking 47 minutes on average to complete the trial. Student t-tests indicated no significant difference in ability in the first run of the trial between those that did and did not receive training (Student's *t*-test, t=0.07, df=47, P=0.07). Repetition of the trials, indicated no significant improvement in the untrained group (mean 78%, Student's *t*-test, t=1.57, df=50, P=0.1) and a highly significant improvement in the trained group (mean 87%, Student's *t*-test, t=3.74, df=44, $P<0.0001$). Trial repetitions took an average 37 minutes in both trained and untrained groups and were not found to be significant in either group.

Table 2
Expert observer validation of photo-identificationt technique using confirmed turtle images

Task	Run	Time to Complete / min	Matching time per image / min	Images to match / trial	Average correct photo-matches	Average false matches (false positive errors)	Average failed matches (false negative errors)	Per trial group percentage success
Matching	1	346	2.3	150	146	0	4	97
Without	2	333	2.2	150	147	0	3	98
Grouping	3	345	2.3	150	147	0	3	98
Matching	1	178	1.18	150	150	0	0	100
With	2	168	1.12	150	150	0	0	100
Grouping	3	172	1.14	150	150	0	0	100

In the first run of the trials when all observers were naïve, 32% of the images matched incorrectly, of which 16% were false negative (no match found), 28% were false positives (new images matched with existing) and 56% of the images were mis-matched existing images. In the second run of the trials, there was no significant difference in the untrained group, whereas in the trained group a significant decline in false positive (Student's *t*-test, $t=3.04$, $df=44$, $P=0.004$) and mis-matching (Student's *t*-test, $t=2.62$, $df=44$, $P<0.001$) was found.

4. Discussion

Photo-identification of natural markings is increasingly being used to collect data on individual animals for application to demographic studies (Thompson et al., 2000; Lusseau et al., 2006; Bradshaw et al., 2007). Although information obtained from photo-identification is highly valuable (Hammond, 1990; Blackmer et al., 2000), processing data in large catalogues can be labour-intensive and subject to human error (Kelly, 2001). Through the use of trials, our study demonstrated the validity (i.e. accuracy) and reliability (i.e. precision) of natural markings for assignation of individual loggerhead sea turtles to groups according to a simple identification tree, and that once an image has been assigned to a group, its markings can be used to correctly match it to existing catalogue images of the same individual present in that group.

The size of sea turtle populations is typically assessed by counting tracks of females on nesting beaches (Demetropoulos and Hadjichristophorou, 1995; Godley et al., 2001; Broderick et al., 2002; Margaritoulis, 2005). However this ignores the size of the male component of the adult population. Yet, identifying male turtles is also important to assess population size and sex ratio. It relatively easy to estimate hatchling sex ratios by, for example, recording incubation temperatures or incubation durations (Broderick et al., 2001a; Zbinden et al., 2007). Furthermore it is possible to reconstruct long-term trends in hatchling sex ratios from environmental proxies such as air temperature (Hays et al., 2003). However, how hatchling sex ratio projects through to adult sex ratio is not known. Hence nothing is known about long-term trends in adult sex ratios for sea turtles and implications of climate change for this important demographic parameter. Photo-id, when combined with in-water surveys, clearly has the potential to start providing estimates of the number of males at breeding sites and hence also adult sex ratios.

As well as a lack of information on adult sex ratios, there is also very little known in general about the ecology of male turtles. Direct observations have been used to infer mating seasonality and the departure time of male turtles from breeding areas (e.g. Godley et al., 2002), while paternity in clutches can be assessed without sampling adult males themselves from which inferences about male-female encounters and male movements (Lee et al., 2007; Lee, 2008) can be made. However, very few male turtles are identified by tagging because this requires logistically challenging capture at sea (e.g. Hays et al., 2001; James et al., 2005) as males very rarely emerge onto land (but see Rice & Balazs, 2008). Photo identification will allow a new era of experimental and ecological studies of male turtles, allowing, for example, the behaviours of known individuals to be assessed (Schofield et al., 2006; Schofield et al., 2007b). In addition, photo-identification will allow the interval between successive breeding seasons (the remigration interval) to be established. For female turtles, remigration intervals may be several years, presumably because it takes a long time for individuals to attain a threshold body condition before they embark on breeding migrations (e.g. Broderick et al., 2001b; Hays, 2000; Chaloupka et al., 2008). However, the remigration interval of male turtles are poorly understood, although it is possible that they may be appreciably shorter that for females (Chaloupka and Limpus, 2001), since males do not invest resources in egg production and hence they may lose less condition during breeding seasons.

The accuracy and reliability of photographic matching may be impeded by image quality (i.e. light intensity and sea clarity in underwater photographs) and/or database size (Whitehead et al., 1997; Forcada and Aguilar, 2003; Beekmans et al., 2005). As a consequence, mistakes may result in the wrong inferences being made about the biology of animals. For example, false negative errors (failing to find a match) inflate population estimates, while false positive errors (matching new individuals to an existing database image) deflate population estimates. We recorded a very low error rate during the course of the trials, with that of false positive errors (matching two photographs from different animals) being slightly more frequent than false negative errors. Hence, the accumulation of errors over time in our database, leading to over or under estimations of population size (Stevick *et al.*, 2001), is likely to be negligible.

Our results showed that while in all trials the success rate in photographic matching was very high, experience and training improved the reliability to match individuals (Douglas-Hamilton and Douglas-Hamilton, 1975). Furthermore, at present we have overcome the difficulty of manually comparing and matching a large volume of photographic images (>400) by dividing turtles into several groups of <100 based on variations in one set of facial features. As our photographic catalogue expands, it may become necessary to developed a computer-assisted matching programme, as has been designed for several other vertebrate species with large photographic population databases (Kelly, 2001; Hillman et al., 2003; Beekmans et al., 2005). However, confirmation is required of the stability of the natural features (i.e. colouration and relative scale sizes) being used (Forcada and Aguilar, 2003; Arzoumanian et al., 2005).

Accurate information about the population structure and ecology is not only vital to address the conservation needs of the Zakynthos sea turtle rookery, but could serve as an indicator of adult survival after departure from the breeding area (Chaloupka and Limpus, 2002). Such insights could provide a quantitative foundation for the re-evaluation of the regional, national and global conservation status of this species, thus strengthening international maritime protection policies amongst Mediterranean countries (Thompson et al., 2000; Sibly et al., 2005; Fagan and Holmes, 2006). For example, the creation of photo-libraries at local, national and regional scales, within which individual life-histories of individuals could be developed as well as knowledge about small and large scale migrations of male and female turtles, e.g. between islands or across the Mediterranean basin and how this impacts micro and macro population dynamics. The permanency of photographic data not only permits retrospective analyses as research objectives evolve, but also provides an opportunity to investigate other parameters that may also influence species conservation management and ecological risk assessments such as site fidelity, patterns of interaction, physical condition, health indicators and the impact of anthropogenic activity (Burger and Garber, 1995; Bennett et al., 1999; Pettis et al., 2004; Lusseau et al., 2006).

In conclusion, our study has validated the accuracy, reliability and ease of training of using natural facial markings to identify individuals in a breeding population of loggerhead sea turtles. Within the framework of a long-term monitoring programme, our photographic matching technique could potentially be used to obtain new insights about sea turtle population trends, behaviour, ecology and conservation status. Ultimately, appropriate wildlife management depends on the acquisition of realistic life history information, and photo-identification is a proven technique, facilitating the continuity of long-term studies for long-lived species of conservation concern.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jembe.2008.04.005.

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