



# Recognition of juvenile hawksbills *Eretmochelys imbricata* through face scale digitization and automated searching

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**ABSTRACT:** Advancements in digital photography have facilitated the use of photo-ID to track individual animals, making this technique of great value for conservation biology. However, the time required to manually match new photographs to those stored in a database is proportional to the size of the database. Therefore, there is need for investigating the potential to automate the searching processes through computerized means. We encountered hawksbill turtles *Eretmochelys imbricata* (n = 2) that were members of an ongoing study but had lost flipper tags and shell etchings. To identify individuals, we first manually searched photographs of turtles previously captured and released. Manual visual matching of the 2 turtles encountered was successful for 100% of tested photographs. To investigate automated recognition of turtles in a database, we used the spot recognition program, I<sup>3</sup>S, to digitize scutes on the dorsal and lateral surfaces of the head and to compare spot patterns through the automated system. I<sup>3</sup>S successfully identified the 2 return turtles as the same turtles identified by the manual visual matching method. To assess the ability of I<sup>3</sup>S to identify turtles both present in and absent from the database, we blind-tested a series of photographs of turtle heads and faces using both manual visual methods and I<sup>3</sup>S. With I<sup>3</sup>S, 84.6% of the computerized photos were successfully matched with photos in the database, with scores produced ranging from 0.069 to 0.435. This study showed the potential for using a photo-database for long-term identification of individual turtles, but that the usefulness of a photo-database depends on the quality of the photos and the flexibility of the computer program used.

**KEY WORDS:** Photo-identification · Automated searching · Sea turtles · Endangered species · Central America

## INTRODUCTION

The ability to recognize individual animals is a key feature in tracking individuals through various life-history stages, usually through capture-mark-recapture studies. Effective management of animal populations requires realistic estimates of population numbers. One way to gather information on popula-

tion numbers is through the identification of unique individuals. Thus, the value of an animal increases each time it can be identified and recovered for a specific research program. Artificial tagging of individual animals is common, having been carried out on a wide variety of organisms, such as birds (Verner et al. 2000, Bart et al. 2001, Zimmerman et al. 2009), the Florida manatee *Trichechus manatus latirostris*

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(Rathbun et al. 1995), the dugong *Dugong dugon* (Lanyon et al. 2002), and all species of sea turtles as far back as 1955 (Mrosovsky 1976, Carr et al. 1978, Hughes 1978, Carr 1986).

Sea turtles are among the many species for which long-term data collection is critical for species conservation and management. The majority of sea turtle identification programs utilize tags that consist of metal or plastic bands that are applied to the flipper. However, tag loss is an issue of concern for studies of sea turtle populations. While there is ample evidence that tag losses do occur with increased time between application and recovery (Mrosovsky 1976, Balazs 1982, Mrosovsky & Shettleworth 1982, Limpus 1992, Reisser et al. 2008), some reports have estimated that annual tag losses may range from 13% for tags placed in the pre-scale position, to 54% for tags placed between scales (Reisser et al. 2008), while Mrosovsky & Shettleworth (1982) reported tag losses as high as 38% over the first 500 d after tagging depending on the position of the tag on the front or rear flipper. Hughes (1978) reported that recovery rates of tags greatly improve when the position of tagging on leatherbacks is changed (moved from the front to the hind flipper). In any case, tag losses represent a substantial loss of data if individuals are rendered unidentifiable.

In addition to artificial tags, natural markings, scars, and patterns have been used in photographic indexes in a variety of animals, including long-lived species, such as the African elephant *Loxodonta africana* (Douglas-Hamilton 1973), the chimpanzee *Pan troglodytes* (Goodall 1986), the lion *Panthera leo* (Ogutu et al. 2006), several species of cetaceans (Thompson et al. 2000, Stevick et al. 2001, Frasier et al. 2009), and the sea otter *Enhydra lutris* (Gilkinson et al. 2007). Speed et al. (2007) used the computer spot recognition program Interactive Individual Identification System (I<sup>3</sup>S) to identify spot patterns on the whale shark *Rhincodon typus* and to test an information criterion algorithm. I<sup>3</sup>S has also been used for the identification of other organisms. Van Tienhoven et al. (2007) used the program to identify and match underwater photographs of the spotted raggedtooth shark *Carcharius taurus*, while Speed et al. (2007), Holmberg et al. (2009), and Riley et al. (2010) have all used the program to successfully identify individual whale sharks *R. typus*. This computer system has additionally been used by Caci et al. (2013) to identify individual cerambycid beetles (*Rosalia alpina*).

A few investigators have recognized the uniqueness of scale patterns in cheloniids and have used photo-identification (ID) techniques to some extent in

identifying *Dermochelys coriacea* (McDonald & Dutton 1996, Day et al. 2005), *Caretta caretta* (Schofield et al. 2008, Hays et al. 2010), *Chelonia mydas* (Reisser et al. 2008, van de Merwe 2009, Lloyd et al. 2012), and *Eretmochelys imbricata* (Reisser et al. 2008, van de Merwe 2009). In these cases, photo-ID has been used to compare current photographs to previous photographs by reviewing the similarity of characteristic features, usually represented by scale patterns of the head or face. However, efforts to develop systematic techniques for the use of photo-ID in sea turtle research are still in developmental stages. The effort involved in manually reviewing digital photographs is prohibitive because of the tedious and pain-staking time required, especially when considering large digital databases of hundreds or thousands of photographs. Indeed, a systematic approach to using photo-IDs of sea turtles is generally lacking.

In the current study, we describe the use of a computer-assisted method to automatically search a relatively large database of digital photographs in an attempt to automate the matching process of photo-IDs for sea turtles. Our attempt to automate the process is intended to assist manual-visual identification by reducing the time required to perform the task. The ability to rapidly identify sea turtles world-wide through digital imagery holds great potential for expanding our understanding of turtle behaviors, movements, and migrations.

## MATERIALS AND METHODS

Our study site is located at Port Royal on the southeast coast of Roatán, Honduras (Fig. 1). Details of the habitat are provided in Dunbar et al. (2008) and Berube et al. (2012). We retrieved juvenile hawksbill sea turtles *Eretmochelys imbricata* from local fishers who incidentally captured turtles as bycatch along the reef flats of the area. Since the inception of the study in 2006, we have collected data on each turtle, including curved and straight carapace length and width, and body weight, and then applied Inconel 601-style flipper tags to the right front and right rear flippers (Dunbar 2006, Dunbar et al. 2008). We also etched an identification number into the second left lateral scute of the carapace with a dremel tool. The number was then painted in with White Out™, covered over with a thin layer of DAP Kwik Seal™ clear caulking, and allowed to dry in air. In addition, whenever turtles were captured we regularly took digital photographs of the dorsal surface of the head

and both right and left sides of the face of each turtle. These photographs were taken at a distance of approximately  $1 \pm 0.03$  m (dorsal) and  $0.03 \pm 0.01$  m (lateral) away from each subject while turtles were out of water. Photographs of each individual were kept in individual computer folders for each turtle.

### Manual-visual analysis of turtle returns

In July 2010, we received from local fishers 2 turtles that we recognized as members of the ongoing study by the faded etchings in the left lateral scutes and perforations left in the front and rear right flippers from the intentional removal of the tags. Although clearly part of the study, these turtles were unidentifiable from previous tags. We then took new digital photographs and manually searched our database of photographs to identify potential matches of old photographs with new ones. As with our previous method, these new photographs were likewise taken at a distance of approximately  $1 \pm 0.03$  m (dorsal) and  $0.03 \pm 0.01$  m (lateral) away from each subject while turtles were out of water. In order to quantify the effort per identified unit (EIU), we used the formula:

$$\text{EIU} = t_s(N) + t_v(n) + t_i \quad (1)$$

where  $t_s$  is the time (min) required to check 1 image for apparent matches from all images ( $N$ ) in the data-

base,  $t_v$  is the time (min) required to verify 1 match from  $n$  apparent matches, and  $t_i$  is the time (min) to initialize and finalize the search procedure.

### Manual-visual analysis versus computer-assisted analysis of turtle returns

We then sought to digitize a standard set of scute patterns in an effort to automate the search system and to verify the results by manual inspection. Initially, we sought to digitize the scute pattern by digitally tracing the lines of a standard set of head and face scutes. However, we were unable to locate a computer program that would scan and match polygons from a photographic database. We used the program I<sup>3</sup>S (available from [www.reijns.com/i3s/](http://www.reijns.com/i3s/)) (den Hartog & Reijns 2007, Speed et al. 2007, van Tienhoven et al. 2007). While there are currently 4 versions of the software available ('Classic', 'Spot', 'Contour', and 'Pattern'), we used I<sup>3</sup>S Classic, the most recent version available at the time of the study, to digitize the head- and face-scale patterns of recaptured turtles, and compared these digitized files. I<sup>3</sup>S was built to assist photo-ID by decreasing the number of photographs used for the final manual photo-ID. Using this program, head and face scales of each individual turtle were spotted by clicking on the intersections between scales. A standard series of points on the dorsal view of the turtle head were marked with a digital spot where the angle of the scale line changes directions, making 17 points (Fig. 2). Three additional control points for the dorsal view were placed at the top of the prefrontal scale, and on the lateral parietal scales for a total of 20 points (Fig. 2). For lateral views, a standard could not be made, because each turtle has a unique set of lateral scutes differing in number and shape. Thus, for the lateral views, instead of a standard set number of points, as many points as possible were placed at the vertices of 5 standard scutes. The points were placed around each vertex of the 3 post-ocular scales and the 2 most superior scales that follow the post-ocular scale, creating a variation of spots depending on the scale patterns of unique individuals. For instance, in Fig. 3A the photograph was spotted with 18 spots unique to this individual, whereas in Fig. 3B the photograph was spotted with 20 spots unique to this turtle. Only vertices created by intersections of scales or between a scale and the beak were digitized. Despite these variations in spotting patterns, the selection method for these points is univocal; therefore, a given scale pattern may only yield 1 spot pattern. I<sup>3</sup>S takes into consideration how

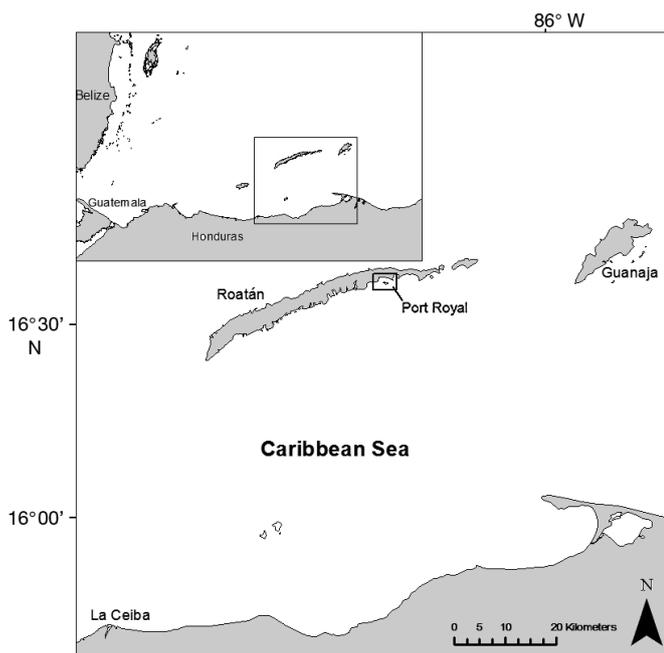


Fig. 1. Map of the study site on Roatán, among the Bay Islands of Honduras. Inset: north coast of Honduras and the Bay Islands



Fig. 2. *Eretmochelys imbricata*. The 17 standardized points for the dorsal view of the turtle head, along with the 3 control points used for the dorsal view of the turtle head when digitizing each turtle photograph for the database and test photographs. The first control point is placed on the top of the prefrontal scale, the second on the left lateral parietal scale, and the third on the right lateral parietal scale

many spots there are. Thus, the more variation in pattern and number of points, the easier it is for a correct match to be identified. If an unknown turtle is spotted with 15 points, the program tends to ignore individuals with more or fewer points. Since the location of points to be placed is set by the number of vertices around the chosen scales, new photographs of the unknown individual will be digitized with the same number of points as the photographs already present in the database, with the number of vertices unique to each individual. Control points for the lateral view were placed at the most superior point of the eye, the tip of the beak, and the farthest posterior point of the mouth line (Fig. 3A,B).

Two hundred turtles (approximately 600 photographs) were marked with spots, and the database was then used to test the ability of I<sup>3</sup>S to correctly identify those turtles.

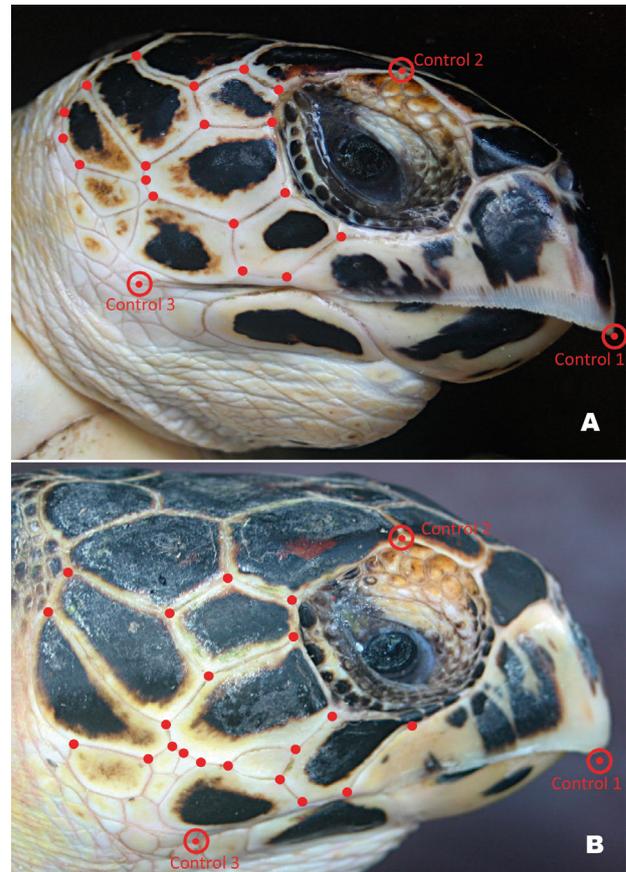


Fig. 3. *Eretmochelys imbricata*. Examples of digital points used for the lateral view of the turtle head, with the 3 control points. The first point was located at the tip of the beak; the second, at the most superior point of the eye; and the third, at the farthest edge of the tympanic scales. (For details of analysis see 'Materials and methods'.) Shown are turtles (A) with 18 points, and (B) with 20 points

### Manual-visual versus computer-assisted testing

Test photographs of 28 dorsal and lateral views of turtles were randomly chosen from the compilation of photographs on file (different from those spotted [digitized] in the database), or randomly selected from the Internet. We tested photographs through a 1-way blind test by having one author choose the test photographs from the database and one of the other authors run the test through manual and automated (I<sup>3</sup>S) searching. In this way the person who supplied the photographs always knew the correct identification of the turtle photographs.

These photographs were then spotted and analytically compared by I<sup>3</sup>S to test the effectiveness of this comparison method. To compare potential matches, the program uses the following distance metric to determine the closeness of the matched spots:

$$\frac{\sum_{i=1}^n \text{dist}(i)}{n^2} \quad (2)$$

where  $n$  is the number of spot pairs, and  $\text{dist}(i)$  is the distance between each spot pair.

If 2 photographs have a large number of matched spot pairs, a low score will be generated due to the short distance between each spot and its match. A score of  $<1$  is a strong match. We then visually compared the 2 photographs (test photograph and matched result). The array of spots can be put together so that visual comparison of the spot matches can be seen (Fig. 4). The program accepts 2 spots as matches if the distance of the spot to an alternate spot is at least double the distance of the current match.

The head- and face-scale patterns of 28 turtles were manually and visually compared to those of turtles in the database. Of the 28 tests performed using both

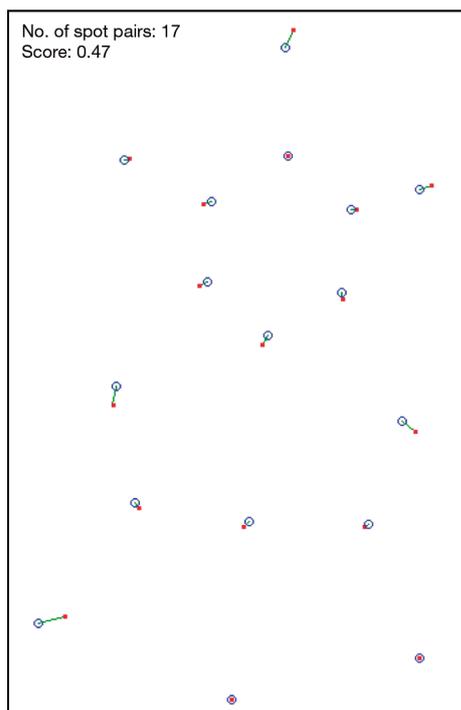


Fig. 4. *Eretmochelys imbricata*. The spot cloud which compares the unknown test individual with a possible match in the database (found individual). This one compares the match between the dorsal view photographs of the same individual (TIN #059) from 2007 and 2010. The red dot array shows the digitized spots of the 2007 photograph, while the blue circles denote those of the 2010 photograph. The lines in between some dots and circles mean that the distances between the spots are close enough to be considered matching. The score of 0.47, where any score  $<1$  denotes a strong match, means that the I<sup>3</sup>S program correctly matched these photographs of the same individual

manual-visual analysis and computer-assisted analysis, 15 of the test animals did not already have photographs in the database. Photographs of these test animals were either photographs of the dorsal surface of hawksbill heads randomly selected from the Internet ( $n = 3$ ), or were photographs of new project turtles that had not previously been captured at the project site ( $n = 12$ ). These tests were analyzed independently of the test photographs of turtles that were already in the photo-database.

The proportion of agreement of visual comparisons was compared with computerized matching results presented by I<sup>3</sup>S.

### Statistical analyses

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) Version 20.0 (IBM 2011). Descriptive statistics are given as counts of turtles identified for both the computer-aided matching as well as for visual matching. Kappa statistics were used to measure the agreement between the 2 methods of measurements. In addition, sensitivity was used to assess the validity of visual and computerized methods.

We used an independent sample  $t$ -test to compare the means of match scores between test photographs of turtles already in the database and test photographs of turtles that were new to the database. Of the 13 test turtles with previous photographs in the database, we excluded 2 of these (Test Turtles 2 and 4) as outliers from the I<sup>3</sup>S mean match score because both the database and test photographs were very small, of sufficiently poor quality and resolution that consistent digital spotting could not clearly be accomplished, and before and after photographs were taken at drastically different angles.

Significance level was set at  $\alpha = 0.05$ .

## RESULTS

### Manual-visual analysis of turtle returns

After manually comparing new head- and face-scale photographs of *Eretmochelys imbricata* with several hundred photographs already in the project database, we were able to positively identify both of the turtles returned to the study in Roatán through manual-visual analysis of unique markings and scars on the dorsal surface of the head (Fig. S1 in the Supplement at [www.int-res.com/articles/suppl/n026p137](http://www.int-res.com/articles/suppl/n026p137)

Table 1. Details of hawksbill turtles *Eretmochelys imbricata* released in 2007 that returned to the study site in Roatán in 2010. Both turtles were identified as juveniles, due to size, and were captured, released, and recaptured in the same area of Port Royal. Dates are mm/dd/yy. CCL<sub>min</sub>: minimum curved carapace length

Database turtle ID no.	Date captured	Capture CCL <sub>min</sub> (cm)	Date released	Release weight (kg)	Date recaptured	Recapture CCL <sub>min</sub> (cm)	Release weight (kg)
TIN 050-07	6/22/07	23.8	9/03/07	1.2	7/05/10	46.6	8.6
TIN 059-07	11/15/07	26.6	11/15/07	2.3	7/01/10	41.6	8.5

[\\_supp.pdf](#)) and other areas of the body. However, this process required approximately 180 min of manually searching the photographic database. The resultant time to identify individuals was 90 min for each turtle. Details of release dates, morphometrics, and re-release dates are provided in Table 1, while photos used for comparisons are provided in Fig. S2 in the Supplement.

#### Manual-visual analysis versus computer-assisted analysis of turtle returns

In the case of the 2 turtles that returned to the study site in Roatán, I<sup>3</sup>S provided a list of 50 possible matches to new photographs from a pool of approximately 600 photographs already in the database,

with the most likely match (smallest score) presented at the top of the list.

In the results generated by the program, red dots represented the unknown test turtle's spots, while blue circles represented the spots of the matching individual. Green relation lines between spots represent matching spot pairs (Fig. 4). The process of selecting several potential matches from all digital photographs took only a matter of 0.5 min using I<sup>3</sup>S. However, these potential matches through I<sup>3</sup>S required further analyses using manual-visual techniques. Still, the combined process of computer-assisted searching and manual-visual analysis of potential matches resulted in an identification time of only 8 min. Utilizing I<sup>3</sup>S reduced the time required for identification through manual searching alone by 82 min.

Table 2. Identification numbers selected as matches by both the manual-visual and computer-assisted (I<sup>3</sup>S) methods for blind tests of hawksbill turtles *Eretmochelys imbricata* whose photographs were already in the photographic database. The I<sup>3</sup>S match score, derived from the distance matrix for each computer match, is provided in the last column. Rows in **bold** print are false positives by the I<sup>3</sup>S method. Rows in *italic* print are false positives by the manual-visual method

Test turtle	Database turtle ID no.	Manual-visual method	I <sup>3</sup> S method	I <sup>3</sup> S match score
1	TIN 075-08	TIN 075-08	TIN 075-08	0.164
2	<b>TIN 102-10</b>	<b>TIN 102-10</b>	<b>TIN 091-10</b>	<b>2.076</b>
3	TIN 037-06	TIN 037-06	TIN 037-06	0.101
4	<b>TIN 045-06</b>	<b>TIN 045-06</b>	<b>TIN 039-06</b>	<b>3.983</b>
5	TIN 095-09	TIN 095-09	TIN 095-09	0.069
6	TIN 044-06	TIN 044-06	TIN 044-06	0.191
7	<i>TIN 048-07</i>	<i>TIN 055-07</i>	<i>TIN 048-07</i>	<i>0.347</i>
9	TIN 083-08	TIN 083-08	TIN 083-08	0.293
10	TIN 048-07	TIN 048-07	TIN 048-07	0.178
11	TIN 054-07	TIN 054-07	TIN 054-07	0.155
13	TIN 077-08	TIN 077-08	TIN 077-08	0.264
14	TIN 068-08	TIN 068-08	TIN 068-08	0.404
16	TIN 101-10	TIN 101-10	TIN 101-10	0.435
Positive matches		92.3% (12 of 13)	84.6% (11 of 13)	Avg. score <sup>a</sup> (0.236)
<sup>a</sup> Test Turtles 2 and 3 were excluded as outliers				

#### Manual-visual versus computer-assisted testing

Percent matches from both computer-aided matching and human visual matching of test turtles are presented in Table 2 for all 13 new turtle photos in the database. When identified by the I<sup>3</sup>S computer-aided method, measures of sensitivity of these tests showed 84.6% of turtles were correctly matched, while visual matching yielded 92.3%. The average match score provided by I<sup>3</sup>S for turtles found in the database was 0.236, with a range of 0.069 to 0.435.

Of the turtles tested that were not previously in the photo-database (n = 15), we found that 86.7% were correctly identified as having 'no match' in the database, and 13.3% (2 of 15) were misidentified as having a match in the database (false positives) by the manual-visual method (Table 3,

Table 3. Identification numbers of potential matches for photographs of hawksbill turtles *Eretmochelys imbricata* not previously in the project database (NID) and tested by both manual-visual and computer-assisted (I<sup>3</sup>S) methods. The I<sup>3</sup>S match score, derived from the distance matrix for each computer match, is provided in the last column. Rows in *italic* print are false positives by the manual-visual method

Test Turtle	Database turtle ID no.	Manual-visual method	I <sup>3</sup> S method	I <sup>3</sup> S match score
8	NID	No match	TIN 053-07	1.505
12	NID	No match	TIN 075-08	0.268
15	NID	No match	TIN 103-10	0.321
17	TIN 114-11	No match	TIN 076-08	1.478
18	TIN 115-11	No match	TIN 084-08	0.675
19	TIN 116-11	No match	TIN 059-07	0.956
20	TIN 117-11	No match	TIN 091-09	0.726
21	TIN 118-11	No match	TIN 054-07	1.345
22	TIN 119-11	No match	TIN 061-07	0.903
23	<i>TIN 120-11</i>	<i>TIN 075-08</i>	<i>TIN 028-06</i>	<i>0.417</i>
24	TIN 121-11	No match	TIN 096-09	0.690
25	<i>TIN 122-11</i>	<i>TIN 081-08</i>	<i>TIN 041-06</i>	<i>0.825</i>
26	TIN 123-11	No match	TIN 024-06	0.806
27	TIN 124-11	No match	TIN 084-08	0.722
28	TIN 125-11	No match	TIN 108-10	0.633
Positive matches		86.7 % (13 of 15)	0 % (0 of 15)	Avg. score (0.818)

Fig. S3 in the Supplement). However, when the I<sup>3</sup>S program was presented with the same 15 photographs, all resulting matches were false positives (Table 3).

There was a significantly higher mean I<sup>3</sup>S test score ( $t_{18} = 5.57$ ,  $p < 0.001$ ) for matches of photographs of animals that were not in the database ( $0.818 \pm 0.379$ ) versus I<sup>3</sup>S test scores for animals that were in the database ( $0.236 \pm 0.121$ ).

## DISCUSSION

We have provided results of tests utilizing computer-assisted searching techniques for sea turtle head and face recognition. The current study adds sea turtles to the list of animals for which I<sup>3</sup>S can be successfully utilized to reduce the amount of time used to manually search photo-databases. In the current study, we used photographs taken at relatively consistent distances away from our turtles (*Eretmochelys imbricata*) out of water. This method, therefore, has the potential for improving the success rate of the computer program to detect subject matches. Nevertheless, we provide evidence that computer-assisted, automated searching of photographic databases is possible, although at this stage it may still require the specificity and selectivity provided by

manual-visual analysis of potential matches selected by the program I<sup>3</sup>S. We found that matching by I<sup>3</sup>S could be maximized if photographs were taken at right angles to the plane of the turtle and from approximately the same distance. However, this is likely to be done consistently only in a context where turtles are above water, as in the current study, and less likely to be possible while diving or snorkeling. While removing turtles from the water may be considered 'non-natural,' nesting turtles do provide unique opportunities to collect specific photographs in natural, but above-water situations. Still, the ultimate goal of photo-identification is to minimize disturbance and capture photographs of the animal in its natural habitat for subsequent identification. While other studies have successfully utilized in-water digital photography to identify recaptured sea turtles (McDonald & Dutton 1996, Reisser et al. 2008, Schofield et

al. 2008, Hays et al. 2010, Lloyd et al. 2012), few other reports have been published on efforts to utilize computerized techniques to automate the process of searching large photographic databases (Buonanantony 2008, Pauwels et al. 2008, Jean et al. 2010, Lloyd et al. 2012).

In sea turtle research, there is need to repeatedly identify the same individuals over time, providing long-term and potentially valuable information on individual habits, biology, and life history. This ability is sometimes hampered by the loss of external tags (Balazs 1982, Mrosovsky & Shettleworth 1982, Reisser et al. 2008), which may be lost, torn off, or intentionally removed, and the loss of natural, intentional, or injury markings, which may grow out or heal over time (Hendrickson & Hendrickson 1981, Bentivegna et al. 1993, Troëng et al. 2006). Advances in digital photography have provided the means of capturing high-resolution images, both on land and under water. In some cases, natural markings have been successfully used to assess various life-history processes in sea turtles. For example, Schofield et al. (2008, 2009) and Hays et al. (2010) used underwater photographs to accurately identify individual scale patterns of adult loggerhead sea turtles *Caretta caretta* and to analyze spatial use and breeding periodicity of male and female loggerheads off the coast of Greece. The capacity to manually match new pho-

tographs of individuals with previous photographs of the same individual is highly useful, although the time required to accomplish such a task is proportional to the number of photographs in a project database (van Tienhoven et al. 2007). Still, the ability to match photographs from a single individual at different times and locations can provide information that is, at present, difficult to gather remotely. For instance, while analytical programs, such as MARK (Gary White; Colorado State University), are able to analyze capture-mark-recapture data at a single location, this type of analysis provides no information regarding where the animal has moved in the intervening days, months, or years.

Advances in satellite telemetry have resulted in the ability to remotely track animals great distances over long periods of time (Hays et al. 2001, Horrocks et al. 2001, Coyne & Godley 2005, Troëng et al. 2005, Blumenthal et al. 2006, Godley et al. 2008, van Dam et al. 2008). However, aside from time-depth recordings (van Dam & Diez 1997, Houghton et al. 2000, Schofield et al. 2007), satellite data are unable to provide details of the exact locations and activities of the animals in the locations where transmissions originate. On the other hand, digital photography has become a tool used by divers, snorkelers, and individuals attending nesting beaches around the world. With the ability to rapidly upload and retrieve digital images from around the world, there is great potential for photographically tracking animals in good detail.

### Program limitations and perspectives

While I<sup>3</sup>S provides an excellent means to automate rapid searches of photographic databases, reducing the manual and visual time required to identify individuals, it likewise has some limitations in its application for consistent identifications of turtles as a stand-alone automated search system. Our results suggest that this program has some limitations in specificity and selectivity, which, on its own, may not consistently result in high levels of confidence in resulting photographic matches. This is in contrast to manual-visual matches made by humans, who, instead of using similarities in intersection spots, are able to distinguish turtle heads and faces using unique, yet subtle similarities and differences present in features such as marks, scars, and scale shapes. Our photographs were taken above water, representing non-natural conditions. Photographs taken in natural underwater conditions present the additional challenges of ripple patterns, distortions, and light varia-

tions, which may involve further challenges for automating this and other computer photographic searching and matching processes.

Another limitation of the program is that it does not currently have a setting in which the computer presents a result of 'no match' when the distance matrix calculation goes above a specified cutoff value. The result of this is that the program makes selections of matching photographs that are, to the human eye, clearly mismatched. Thus, the program provides false positives when there is no matching individual in the database.

A final and fairly important limitation is the apparent imprecision of the program to distinguish between the same series of digital spots on the same turtle when photographs are taken from slightly different angles or distances. Thus, photographs used with this program must be repeatedly taken at right angles to the surface of the animal (or at least in a very similar orientation) and from approximately the same distance away. This, in some ways, limits the ability of the program to make consistently repeatable identifications when using photographs from sources outside of a specific project methodology. However, this problem is not unique to I<sup>3</sup>S (Arzoumanian et al. 2005) and is likely to be encountered in the use of any current computer-assisted, automated photo-ID system.

Computer-assisted photographic analysis appears, at this stage, to be limited mainly by the development of programs that are both flexible enough and specific enough to correctly identify subjects irrespective of photograph angle, lighting, and clarity. However, we found I<sup>3</sup>S to be extremely useful in reducing the time required for searching photographs, and believe that, with further developments of this user-friendly program in the areas of specificity and reliability while being able to utilize digital images from a wide range of views and with varying quality, this system may have far-reaching implications for identifying turtles on a global scale, significantly increasing our ability to track turtles throughout different life-history stages.

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