Sea Turtle Photo Identification: A Practical Guide

Preprint · February 2025

DOI: 10.13140/RG.2.2.15692.32648

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Sea Turtle Photo Identification: A Practical Guide

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1. Introduction

Photo-identification (photo-ID) refers to the task of identifying individual animals with the help of images based on the animals' unique external morphological characteristics which are typically stable across time. Photo-ID is a widespread technique for the study of a variety of wild animal populations. It does not only provide an alternative to traditional tagging techniques (attachment of artificial identifying markers to animals, e.g. metal tags, rings, bands), but it also complements them in various ways. This guide aims to provide researchers working in sea turtle conservation with essential information and guidelines for photo-ID when this is applied specifically to sea turtles:

- We highlight the most convenient sea turtle body parts amenable to photo-ID, emphasising particularities for all seven species.
- We outline efficient strategies for performing sea turtle photo-ID in practice, i.e. identifying the same individuals in different images (*matching*) – both using manual (visual inspection) and (semi-)automatic (computer-aided) methods.
- We recommend strategies for collecting, handling and storing sea turtle imaging data.

The origins of the technique can be traced from the 80s with the work of McDonald *et al.*, 1996, McDonald and Dutton, 1996 (Leatherback sea turtles, St. Croix, US Virgin Islands); and in the 90s with the work of Bennett *et al.*, 2000; Richardson *et al.*, 2000 (Green turtles, Hawaii, USA); Rodriguez and Martínez, 2000; (Leatherback sea turtles, Mexiquillo Beach, Mexico). In the early 00s, the technique began to gain popularity among sea turtle researchers, see Schofield *et al.*, 2004, Schofield *et al.*, 2008; (Loggerhead sea turtles, Zakynthos Island, Greece). One of the key factors that contributed to the increased use of the photo-ID technique has been the rise of digital imaging technologies, internet, and social media. The advances in the field of computer vision and machine learning have also led to the development of automatic techniques that speed up the identification process and facilitate the processing of thousands of images, (Pauwels *et al.*, 2008; Jean *et al.*, 2010; Dunbar *et al.*, 2014; Dunbar *et al.*, 2021; Čermák *et al.*, 2024b). Today, photo-ID is widely used in sea turtle research and conservation projects.

The popularity of sea turtle photo-ID stems from key advantages over traditional tagging methods (e.g. metal and PIT tags):

(i) The main sea turtle morphological patterns used for photo-ID (facial scales), apart from being unique to every individual, are also stable over time, thus, *tag-loss is not an issue*.

(ii) Photo-ID is the *least invasive identifying technique* with no need for capturing and handling the animal. Sea turtles can be "photo-tagged" from large distances and in adverse conditions.

(iii) Photo-ID can be performed by people after only some *minimal training*. Additionally, sea turtle images can be taken by even non-specialised citizens, leading to *increased data collection*.

(iv) Photo-ID can be more *cost-effective* than traditional tagging methods. High resolution camera equipment has become more affordable, which in the long run, may come at a lower price than acquiring metal tags (Buonantony, 2008). Data collection can be highly effective, especially via citizen scientists and online data mining efforts.

(v) "Photo-tagging" individuals requires *less time* than tagging using conventional tags (e.g. metal and PIT tags). This means that more individuals can be "photo-tagged" than "conventionally tagged" in the same period. This can be beneficial to researchers working in mass nesting areas or high-density foraging grounds.

As a result, sea turtle photo-ID reliably supports studies which cannot be done with traditional tagging methods, such as in-water behavioural studies (Schofield *et al.*, 2017; Schofield *et al.*, 2022), progress of diseases (e.g. Fibropapilloma) (Bennett *et al.*, 2000; Hancock *et al.*, 2023; Neves-Ferreira *et al.*, 2023), occurrence of injuries (Papafitsoros *et al.*, 2021; Schofield *et al.*, 2013), examining mating patterns (Papafitsoros *et al.*, 2022; Witzmann *et al.*, 2023; Witzmann *et al.*, 2024) and measuring ecotourism impact on individual turtles (Papafitsoros, 2015; Papafitsoros *et al.*, 2021; Hayes *et al.*, 2017; Griffin *et al.*, 2017; Köhnk and M., 2022). Classical capture-mark-recapture studies can also be performed using photo-ID, such as monitoring of nesting female sea turtles, population distribution and censuses (Neves-Ferreira *et al.*, 2023; Hudgins *et al.*, 2023; Hanna *et al.*, 2021; Williams *et al.*, 2017), estimating survival rates and breeding periodicity (Schofield *et al.*, 2020), identifying home ranges (Baumbach *et al.*, 2019) and detecting migrations (Papafitsoros, 2022; Benezech *et al.*, 2022). Photo-ID can additionally be combined with photogrammetry to infer growth rates of individual turtles with no animal handling (Araujo *et al.*, 2019).

2. Sea turtle body parts suitable for photo-ID

Facial scales

Performing photo-ID based on the turtle's facial polygonal scales (lateral and/or dorsal surfaces) has been the norm for all sea turtle species apart from leatherbacks. The facial pattern variability is usually rich-enough to distinguish individuals (but see our specific remarks for Hawksbills below). Moreover, the facial geometric patterns remain stable in sea turtles, even from the time when they hatch (Carpentier *et al.*, 2016). Notably, after decades of photo-ID practice and tens of thousands of individuals photo-identified globally, there have been no reports of two individuals being indistinguishable based on clear, high-resolution facial photos. In contrast, flipper scales are smaller than facial scales, making flipper-based photo-ID particularly challenging when photographs are of relatively low quality. Finally, taking photographs of turtle's faces is less challenging than other body parts with scales, (e.g. flippers), especially in adverse conditions (fast swimming turtles or during night nesting).

Left and right (dis-)similarity of lateral facial scales: The left and the right facial scales in individual sea turtles have in general a different scale pattern. Hence, both sides should be photographed and added to a photo-database to avoid the scenario in which different sides of the same individual are photographed at different times, prohibiting precise matching. However, we note that

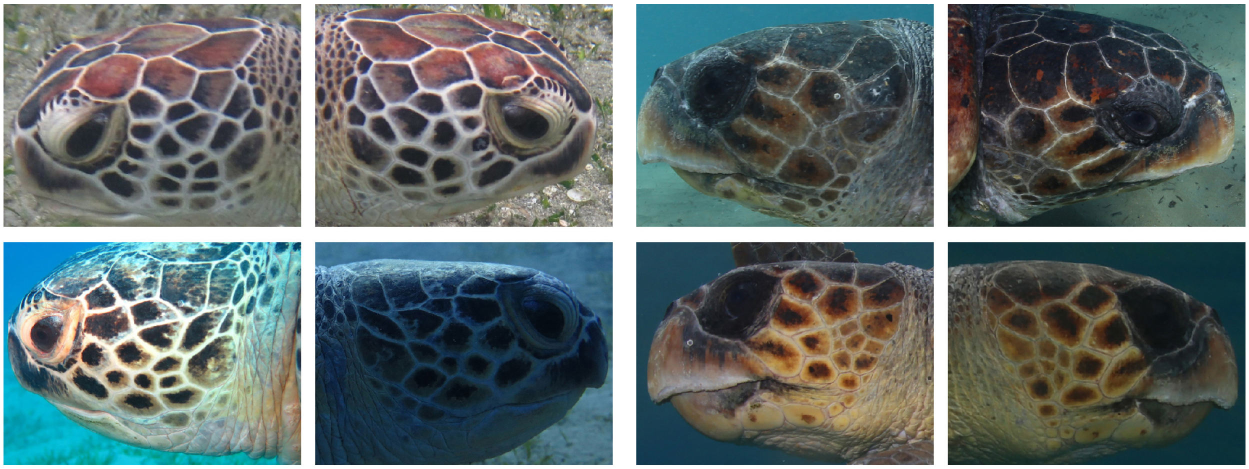

Figure 1. Examples of left and right head profiles of green and loggerhead sea turtles exhibiting similarities within individuals. Every row corresponds to a unique individual. Credits: Anna Grzeszczuk (top-left), Abdallah R. Taher (bottom-left), Kostas Papafitsoros (right)

at least in some sea turtle species/populations, the left and right profiles of an individual exhibit a higher degree of similarity than the profiles of different individuals (authors' personal observations), see Figure 1. For example, the non-modal pattern of 4 post-ocular scales in loggerheads, is more likely to appear on both sides of the head than on just one side. This type of information can also inform the photo-ID matching procedure, especially when images of one facial side are not available or are of low quality.

Lateral or dorsal facial scales for photo-ID? Depending on the adopted data collection method, it may be preferable to focus either on lateral or dorsal facial scales when performing photo-ID. Lateral facial images are typically used in in-water data collection as swimming and foraging sea turtles usually have their heads extended, allowing for a clear lateral view of the head. Additionally, when underwater, images of lateral facial scales can also be taken from farther distances than those of the dorsal surface. On the other hand, land/boat-based observers may opt for the dorsal surface as this is the most visible head feature when sea turtles surface to breathe. In that case, lateral headshots may provide incomplete views as tympanic and sub-temporal scales views may be obstructed by the water due to the angle of the head during breaths, see Figure 2. Drones are unable to focus on the lateral side of the head as this is not visible from above and, therefore, if undertaking drone studies, researchers should focus primarily on the dorsal surface to obtain the most useful photo-ID pictures (see one of the later sections of this guide). Finally, low scale variability of dorsal surfaces for some sea turtle species can also result in relying on lateral sides for photo-ID (see later section).

Flipper scales

Flipper scales have traditionally been underestimated as a location for identification in sea turtle photo-ID, due to many practical challenges: small size compared to facial scales, challenging manual visual inspection, difficulty of taking images perpendicular to the flipper due to movement and adverse conditions (low light and sand during nesting), as well as the occurrence of flipper loss. Furthermore, due to its limited use in photo-ID, the long-term stability of the geometric patterns of flipper scales, has not been established, even though it is expected. However, flippers might present

Figure 2. Example of obstruction of tympanic scales at the lateral surface of the head of a sea turtle during breath. With this type of data collection, photo-ID based on the dorsal surface might be preferable. Credits: Josh Witzmann

a useful addition to the photo-ID toolkit, since hind and front flipper scales typically present high pattern variability among individuals, which can be an advantage when the facial scales do not (e.g. hawksbills – see later section). Mills *et al.*, 2023 showed that certain automated photo-ID algorithms have higher accuracy on flipper than facial scales, something that however required high quality flipper images. Thus, while we still recommend that sea turtle photo-ID be based on facial scales, flipper scales may be a valuable secondary resource, especially when combined with head scales, and it has been shown to enhance matching accuracy in practice especially for hawksbill turtles (Micol Montagna, personal observation), see also Figure 3.

Pigmentation/colourisation

Scale pigmentation/colourisation refers to any coloured features/patterns in the interior of a facial or flipper scale and could also facilitate the photo-ID process. However, while the geometrical scale patterns are stable throughout the turtle's life, pigmentation can evolve significantly at least in certain individuals, and thus relying on them for photo-ID can pose potential risks (Figure 4). The reasons for these colourisation changes is not well understood and occur potentially due to ageing, shifts in foraging habits, and varying sun exposure. However, attention should be paid to different lighting conditions during photographing (e.g. white balance), as together with low image quality, it can lead to erroneous perceptions of colour change. Thus, differences in pigmentation/colourisation between two images should not be a deciding factor for inferring a negative match (i.e. concluding that they belong to different individuals). Finally, individuals from certain populations (e.g. Mediterranean loggerheads), develop certain black spots in various places, (e.g. flippers and neck skin, Figure 5). These appear to be permanent, albeit may change shape (Kostas Papafitsoros, personal observations) and can also facilitate the photo-ID process, especially in photographs of low quality.

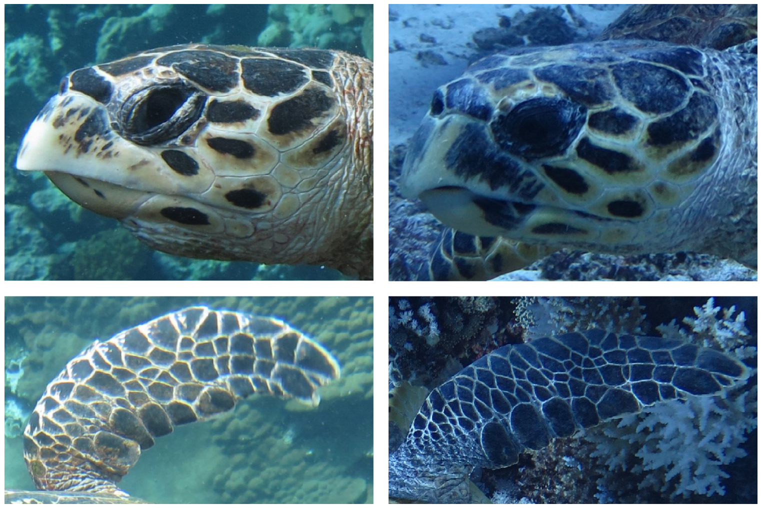

Figure 3. High lateral head surface pattern similarity between two different Hawksbill turtles. In this case the high variability of the flipper patterns can facilitate the photo-ID process. Credits: Mariska van der Paauw (left) and Abdallah R. Taher (right)

Figure 4. Change of head scale pigmentation for a green sea turtle. The time interval between the two photographs is 11 years. Credits: The Olive Ridley Project

Other resources: carapace patterns, barnacles, injuries

The use of the pigmentation pattern of the carapace scutes for photo-ID, has also been explored in some species (Tabuki *et al.*, 2021; green sea turtles), but nevertheless this is rarely used in long term studies. Sea turtles carry a variety of epibionts on their carapace and thus the relevant pattern may not be consistently visible, especially in species such as loggerheads or hawksbill turtles. Additionally, growth and the extent of deposition of keratin in carapace scutes has been shown to vary throughout each year and might be influenced by a variety of environmental factors which could lead to differences in pigmentation over time (Van Houtan *et al.*, 2016). Barnacles can significantly aid in photo-ID especially in low-quality images by comparing their relative positions on the turtles' bodies, albeit in short timescales (weeks). Even though, barnacles like *Chelonibia testudinaria* have the capability to move along their hosts (Moriarty *et al.*, 2008), it is rather the detachment of old and the growth of new barnacles that significantly alter their overall distribution on a sea turtle, making the long-term barnacle-based photo-ID prohibitive. Carapace injuries and

Figure 5. Black spots on the hind flipper of the loggerhead sea turtle. The time interval between the two photographs is 4 years. Credits: Kostas Papafitsoros

Figure 6. Carapace injury and recovery progression of a green turtle: comparison between 2017 (left) and 2022 (right). The individual exhibits complete healing of top carapace injury in 2022, yet distinctive marks from the back carapace injury persist. Credits: Sibylle Malinke (left), Ludwig Wieninger (right)

facial malformations provide sea turtles with distinguishing features greatly simplifying photo-ID, although over-relying on them should be avoided since subsequent healing or additional injuries could alter their appearance, Figure 6. For all the above reasons, we strongly recommend that in addition to the area in-focus for photo-ID, whole-body images should also be taken to record any of the above distinctive features, aiding in the matching process. This also allows the confirmation of new injuries and the monitoring of their healing.

Species-specific identifying patterns

Loggerheads: These are arguably the easiest sea turtle species to perform photo-ID on. Loggerheads have facial scale patterns of very high variability among individuals allowing for rapid positive/negative matching of individuals even in photos of moderate/low quality. They typically have a high number of tympanic scales in the lateral surface, as well as two sets of prefrontal and a frequent occurrence of inter-prefrontal scales on the dorsal surface of the head (Bolten and Witherington, 2003). Loggerheads also often have "orphan lines" in facial scales, as well as a plethora of patterns appearing only in a small percentage of individuals, allowing for efficient pattern categorisation, greatly facilitating and reducing the time required for photo-ID (see later section).

Greens: Greens possess only one set of prefrontal scales and lack inter-prefrontal scales which generally results in a reduced scale number on the dorsal surface of their heads (Wyneken, 2001). On the other hand, greens have a larger scale count on the lateral surfaces of their faces. Thus, unless images are collected via drones, we recommend that the lateral facial sides should be used for photo-ID. Green sea turtles typically possess 4 post-ocular scales, with 5 post-ocular scales also being common, followed by 3 and extremely rarely 6 or 2. We recommend an initial categorisation of the images according to the number of post-oculars to reduce the photo-ID matching time (see later sections).

Hawksbills: Hawksbill sea turtles exhibit much lower pattern variability among individuals and fewer facial scales compared to green and loggerheads, making photo-ID more challenging. Hawksbills show the main variability in lateral facial scales in the lower posterior tympanic region, an area often of uniform and lighter colour, which leads to the need for high-quality images for reliable individual identification. We recommend considering the integration of facial scales with flipper scales in order to enhance the matching accuracy in such cases (see Figure 3).

Olive & Kemp ridleys, Flatbacks: As a predominantly pelagic species, olive ridley turtles are rarely encountered in the water. Studies have implemented photo-ID to identify individual turtles on nesting beaches (Stelfox *et al.*, 2020) and sea turtle patients treated at rescue and rehabilitation centres (Olive Ridley Project, unpublished data). Olive ridleys show a similar degree of variability in lateral facial scales as loggerhead and green turtles, making visual identification quite feasible. Similar to olive ridley turtles, Kemp's ridleys and flatbacks are not encountered in-water very often. This is the main reason why they have not been the focus of photo-ID projects so far, but we recommend the exploration of this tool for beach monitoring.

Leatherbacks: The shape of the pink spot located above the pineal gland on the dorsal surface of the leatherbacks' head has been suggested as a focus point for photo-ID (McDonald and Dutton, 1996; Buonantony, 2008). However, even in the earliest relevant studies (McDonald and Dutton, 1996), concerns had been raised after observing changes to that shape over time. The frequency of these changes and how they could affect the success of photo-ID is not well-understood. The same is true for the characteristic white pigmentations that occur on the whole of leatherback's bodies. Long-term photo-ID studies are absent from the literature, most likely because in-water re-encounters of the same individuals are very rare. As a result, it is not currently clear how feasible and useful photo-ID is in leatherbacks.

3. Matching techniques

In essence, the task of photo-ID, can be performed in two main forms depending on whether the identity of an individual is inferred via pairwise comparisons of images or not:

- Given two images of sea turtles, one has to infer whether they represent the same individual (*positive match*) or not (*negative match*) by carefully inspecting the area in focus (e.g. the facial scales). Typically, one of the images contains a previously identified turtle and the other is a newly obtained image with a turtle that requires identification. In the computer science community this is often known as *image retrieval*.
- Given a newly obtained image of a turtle, the aim is to determine its identity, not by pairwise comparisons of images like previously described, but employing an identity inference algorithm using *high-level features*. This is known as *fine-grained classification*, and its mechanism is similar to the way that the human brain recognises faces. This method is also exploited by modern Artificial Intelligence (AI) techniques.

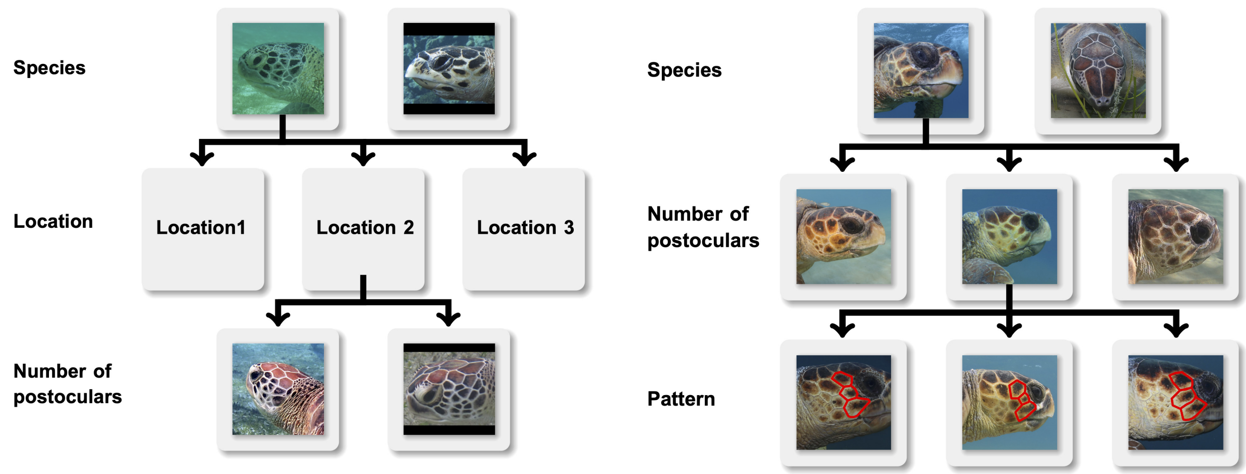

Figure 7. Examples of *divide-and-conquer* strategies aiming to reduce the time for photo-ID matching. Left: Categorisation based on species, locations and number post-ocular scales. Right: Categorisation based on species, number and pattern of post-ocular scales.

In practice sea turtle photo-ID is almost always performed through an image retrieval setting. At a given time, one has built a database of images of N unique individuals. It is then convenient to form additional area-specific-databases of N images each, with each area-specific-databases containing N images of a specific focus area, (e.g. the right/left/dorsal facial surfaces) each image belonging to a unique individual. Then given a new image showing, for example a right lateral profile, one has to visually inspect every pair (first bullet point above) between this image and the corresponding sub-database until a match is achieved. The visual inspection is typically done based on the geometric pattern of scales, but also on other features as previously discussed. If no match is achieved, we recommend that the procedure is repeated for at least one more area in focus (typically in this case the left lateral profile) since a match could be missed due to low image quality or even the complete absence in the database of the individual's right profile.

Since N can be very large (in the order of 1,000 or 10,000) we recommend a *divide-and-conquer* strategy, by splitting every area-specific-database to k sub-databases each containing $n_1, n_2, \ldots, n_k$ individuals where crucially every n_i is smaller than N by one or more orders of magnitude. These sub-databases (in practice sub-folders) can be based for instance on the number of post-oculars scales or on a finer scale categorisation of facial scales (Figure 7). It is thus important to know the salient morphological characteristics of the population. That is, which scale patterns consistently appear in individuals, which ones are standard, and which ones are rare. It can also be useful to further sub-divide based on locations (assuming that individuals of the focal population are loyal to nesting/foraging grounds), and sex (if available) (Figure 7).

This divide-and-conquer strategy is not only useful when manual matching is used but can also greatly benefit automated techniques by reducing their processing time. Furthermore, we stress that despite the great advances of automated photo-ID software, there will always be some false negative matches missed by any software, and a subsequent failure to identify a sea turtle which nevertheless exists in the database. As a result, while the power of automated techniques lies in rapid positive matching, negative matches should be taken with caution and verified with manual techniques. In that case, categorisation of the photo-database can be of great help.

Automated techniques

Adopting and integrating automated techniques to sea turtle photo-ID projects can greatly accelerate the matching process, especially in the large data regime. Here, we provide the essential information and resources regarding these techniques, and we also refer the interested reader to the supplementary material of Buteler *et al.*, 2022, for a summary of automated photo-ID methods for sea turtles, including a comprehensive list of references.

A number of automated methods for photo-ID rely on a manual annotation of the intersection points between the facial or flippers scales (hence they are in fact *semi*-automated). Then the photo-ID problem is reduced to comparison of single points (Figure 8a). Methods in this category include the I3S software (Van Tienhoven *et al.*, 2007; Dunbar *et al.*, 2014) available at https://reijns.com/i3s and APHIS (Moya *et al.*, 2015; Gatto *et al.*, 2018). While these methods work well with photos taken in ideal conditions (e.g. directly perpendicular to the scales), limitations arise as the intersections of points are not always visible in images, especially blurry ones or with low resolution.

On the other hand, the TORSOOI system (https://torsooi.com), Jean *et al.*, 2010, assigns a unique code-number to every facial pattern (Figure 8b). The assignment is done after performing a visual inspection and it is based on the position and the shapes of the scales. Thus, again the scales and their edges must be clearly visible.

A large family of methods rely on the Scale Invariant Feature Transform (SIFT), a classical tool from the field of computer vision (Lowe, 2004) as well as its variants. SIFT detects a series of keypoints (i.e. areas/features in the animal bodies that contain interesting information and are invariant to the viewing angle; Figure 8c). Once these keypoints are detected, they are used for comparing pairs of images and ranking potential matches. SIFT-based methods are very general, are applied not only to sea turtle photo-ID and essentially require no human input, even though isolating the focal identifying area (e.g. cropping the head) is very helpful. The most widely applied of these methods is Hotspotter (Crall *et al.*, 2013; Dunbar *et al.*, 2021), and its successor, the Image Based Ecological Information System (IBEIS; Crall, 2017), which is conveniently integrated into the user-friendly platform *Internet of Turtles* by WildMe (https://iot.wildbook.org, see also Leslie *et al.*, 2016).

Finally, we mention the recent rapid development of artificial intelligence, in particular deep neural networks, has also given rise to a plethora of algorithms for sea turtle photo-ID. In particular, even since the beginning of writing this chapter, several such state-of-the-art methods have emerged following the so-called *deep feature-based* approaches (Čermák *et al.*, 2024b; Čermák *et al.*, 2024a as well as MiewID, Otarashvili *et al.*, 2024). In these approaches, a deep neural network is optimised in order to learn to represent images of individuals via a deep feature vector (*a deep embedding*) of typically much lower dimension than the images themselves. In order to do so and learn how to efficiently encode the identifying characteristics of individual animals, these algorithms are trained on large available datasets (i.e. images for which the depicted animals' identities are known; Figure 8d). Once these deep feature vectors are calculated for every image in the database as well as for the query image, then potential matches are ranked based on the similarity of these vectors under some suitable metric.

We close this section by stressing that each sea turtle photo-ID project is unique in terms of data collection and quality, and extensive comparisons of different methods for a variety of datasets are currently missing. We thus encourage projects to follow a holistic approach, exploring different options and relying on a combination of manual and automated techniques. We also encourage researchers to make their photo-databases publicly available for method training and testing, as for instance in Adam *et al.*, 2024.

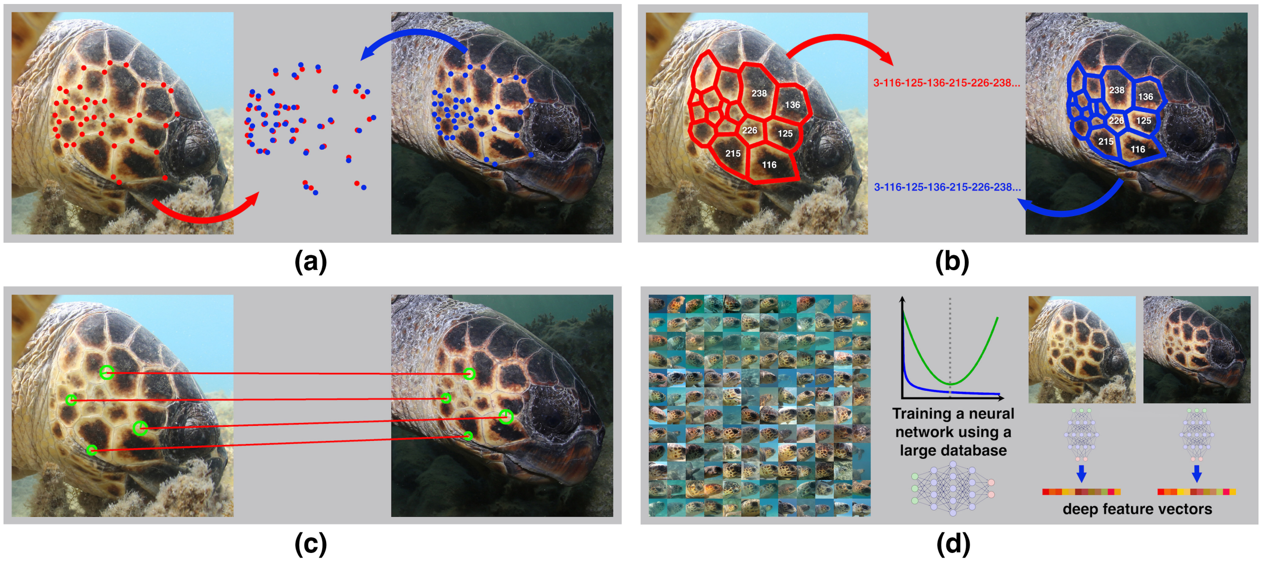

Figure 8. Illustration of the several different approaches of automated sea turtle photo-ID methods: (a) Annotation and comparison of intersection points between the scales (e.g. I^{3}S, APHIS). (b) Assignment and comparison of unique code-numbers to every facial pattern, based on the position and the shapes of the scales (TORSOOI). (c) Extraction and comparison of local image features of salient characteristics, such as SIFT keypoints (e.g. Hotspotter). (d) Employing deep neural networks trained on large databases to represent images of an individuals via deep feature vectors which are then compared to each other.

4. General instructions for collecting photo-ID data

The importance of good image quality for sea turtle photo-ID cannot be overstated. We advise to opt for the best camera equipment (e.g. a modern DSLR or mirrorless camera) and the best image quality possible. Capturing high-quality images suitable for photo-ID demands the use of advanced camera equipment capable of swift focus adjustments, especially when photographing turtles in motion. Photographs that are blurry, out of focus, taken at oblique angles, will always challenge subsequent manual or automatic matches. Fast shutter speeds should be used at all times in order to avoid blurry photos, even if this results in darker ones, since it is much easier to increase the brightness than deblur the photos during post-processing. Optimally, photos should be taken perpendicular to the body surface to maximise the visibility of the unique patterns on the turtle's body.

Below we provide some specific guidelines depending on the data collection method that is adopted. We note that these guidelines do not supersede any existing or future laws and policies regarding approaching or handling sea turtles.

In-water surveys

As a researcher performing in-water surveys in order to collect photo-ID data, it is important to be familiar with the in-water behaviour patterns of the individuals of the focal population. Behavioural variations, contingent upon individual, population, and location characteristics, necessitate tailored approaches. We recommend commencing capturing photographs or videos as soon as the turtle comes into view, increasing the likelihood of obtaining close-up shots even if the turtle decides to move away. This approach ensures a series of photographs/frames, enhancing the chances of acquiring the best possible shots with the individual in focus. In general, a slow and inconspicuous approach is recommended in order to increase the possibility of capturing more photographs of good quality. Signs of disturbance, such as tilting the carapace after being approached from the sides and performing circular movements can make it very difficult to approach the turtle from both sides. This may be overcome by approaching the individual directly from above and swiftly position the camera at the desirable head side. We stress however, that these type of approaches for taking photos should not be communicated to citizen scientists.

Night surveys

To date very few studies have successfully used photo-ID to identify nesting individuals (Valdés *et al.*, 2014; Chew *et al.*, 2015). To minimise the risk of disrupting nesting behaviour, researchers should follow similar steps as when applying traditional tags and wait for the egg-laying process to be completed (Balazs, 1999). To ensure photos of maximum quality, we recommend that a continuous dim light source is used to maximise the visibility of the facial scales, using a camera that combines high sensitivity (ISO) with low noise, avoiding flash photography. The use of infrared or thermal cameras may also be considered although, the use of these cameras has not so far been explored for photo-ID purposes. When artificial lights are used, we recommend that photos are taken directly after the egg-laying stage is completed (covering) and before the onset of camouflage to ensure minimum movement of the head. However, note that photographs can also be taken during the egg-laying process, using a high sensitivity camera, a low aperture, and exploiting some minimal ambient light (e.g. moon). It is recommended to remove any sand and/or epibionts that are obstructing the clear view of the scales (Valdés *et al.*, 2014; Buteler *et al.*, 2022). However, we stress that although the percentage of usable photos increases when sand/epibionts are removed, successful identification of nesting turtles is possible without this removal based on some clean part of the focal identifying area.

Photographing turtles out of the water

Incorporating photo-ID in studies that relying on taking turtles out of the water (e.g. via snorkelling, (free-) diving or using the rodeo technique), has the advantage that it allows researchers to reduce the effect tag loss has on the results of the study (Reisser *et al.*, 2008). As these studies are usually conducted during daytime hours, light is not a limiting factor to consider. Instead, researchers should ensure that the following criteria are met when pictures are taken:

- Any epibionts/algae obstructing clear view of the scales are removed.
- An individual's head is fully extended to ensure the neck is not covering the scales.
- The camera's/researcher's shadow is not visible in the picture.
- The head is kept still while the picture is taken to prevent the picture from being blurry.

Drones

Drones are becoming more affordable, allowing researchers to rely on them to conduct a variety of sea turtle studies (Rees *et al.*, 2018). Drones have been used successfully to conduct photo-ID studies in marine mammals (Landeo-Yauri *et al.*, 2020; Ryan *et al.*, 2022) and have recently also been used to photo-ID sea turtles (Comis *et al.*, 2022; Figure 9). There are several benefits to using drones for photo-ID over the previous data collection methods:

- They allow researchers to identify individuals over large areas with minimal effort.
- Drones can help researchers monitor skittish individuals who would usually flee when approached by snorkellers or boats.
- Drones allow researchers to locate and photo-ID individuals involved in a range of behavioural events (e.g. mating and antagonistic interactions over foraging resources) with minimal/no disruption.

Drones are relatively easy to set up and only require minimal training in order to be familiar with the different controls. We recommend the use of small, simple quadcopters (e.g. DJI mini) that can hover and remain stable during small gusts of wind. Smaller drones produce less upward propulsion and therefore can hover closer to the surface without producing ripples that could impede the view. Searching for turtles over a large area is best done by flying at an altitude of 30 metres, while having the camera angled between 35°-80° to the flight direction. These settings allow scanning of a large area while also minimising the effects of surface glare, which can be further reduced by conducting studies shortly after sunrise or shortly before sunset. When a sea turtle is located, the drone should be hovered directly above the individual and the camera should be angled down to 90°. Then the drone should be dropped slowly to an altitude of approximately 3-4 metres if the individual is on the surface and 2-3 metres if it is below the surface. Photo-ID with drones works best in shallow areas (1-2 metres) where high-quality head pictures can be taken through the water column (Josh Witzmann, personal observation). Digital zoom allows the drone pilot to have a clear view of the individual, yet this reduces the resolution of the image making identification harder.

We recommend recording a video of the turtle (e.g. 4k video at 40 frames per second) rather than try to photograph in order not to miss the optimal angle of the head. After filming the encounter, the desired frame can easily be extracted with minimal quality loss in standard video software.

Citizen science & data mining

Incorporating citizen science into sea turtle photo-ID projects is an excellent way to augment the photo-database and involve the public in conservation and research as it requires minimal expertise and training (Montagna *et al.*, 2017; Hudgins *et al.*, 2017). Clear and previously tested protocols should be adopted and made accessible to a broad audience (Bonney *et al.*, 2009). Apart from sea turtle photographs, mandatory submission data could include date, location, photographer's name, permission to use the photographs, as well as the option to share additional data for more experienced contributors. Furthermore, the importance of maintaining image quality and resolution during submission should be emphasized.

One can also utilize social media platforms to receive sighting reports either via direct requests or via data mining techniques (e.g. dedicated searches using hashtags (#); Papafitsoros *et al.*, 2021; Read and Jean, 2021). However, a drawback of using social media platforms, such as Facebook and Instagram, to collect sightings reports is the potential loss of photo quality due to image compression. It is essential to weigh the advantages of increased engagement and discussion against the disadvantages of potential image quality loss when selecting a platform. Additionally, data retrieved from these platforms should be handled with caution, since they may be handled by profit-oriented companies with varying usage rights and availability of their content. This can also pose challenges for long-term projects and the reproducibility of research findings (Toivonen *et al.*, 2019).

It is also best to consider combining in-person training for a more impactful approach with online strategies for broader reach. To maintain the retention of citizen scientists specific to photo-ID

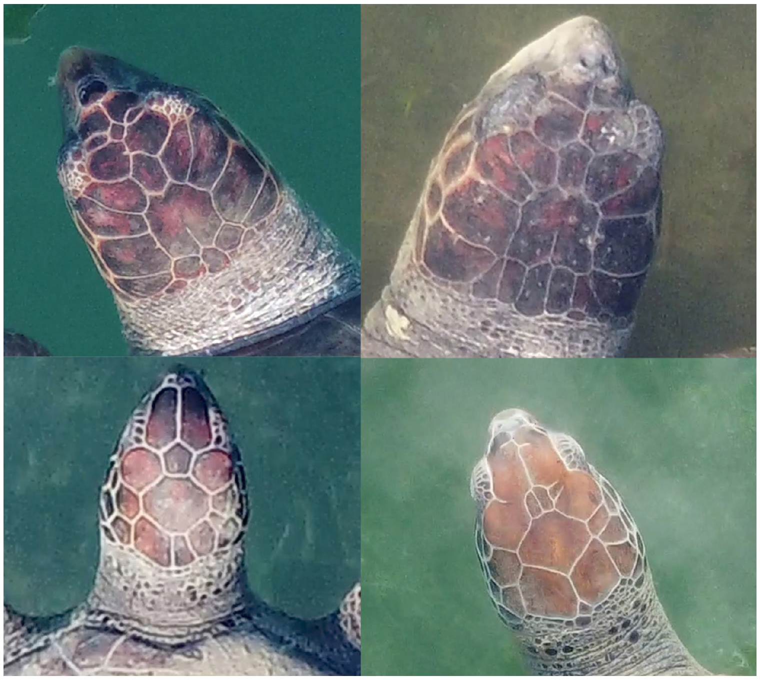

Figure 9. Headshots of two different loggerhead and green sea turtles taken using a drone showing their feasibility for photo-ID. Pictures taken with DJI mini 2 at a height of 2-3 metres and 1x zoom. Credits: Josh Witzmann

projects, one can introduce incentives, such as the opportunity to name and/or receive the history of the turtle one has spotted.

5. Data management

Database management and open data

Prior to designing a photo-ID project, the aim of data collection should be properly determined, as a first step in designing an effective data management system. A photo-ID project typically involves two types of data: the original photos and its associated metadata. Image data can quickly accumulate in significant file sizes, especially due to the ever-increasing image quality and resolution. To ensure image data retention and reproducibility, it is crucial to establish a consistent, uniform, and unique image naming system. Text data on the other hand, are typically recorded in a spreadsheet. Each project is strongly encouraged to establish standardized data entry and processing forms to ensure accurate recording of all data and prevent loss of information. For instance, the *Internet of Turtles* offers a "Wildbook" Standard Format data template for reporting sea turtle sightings (available for download at https://iot.wildbook.org).

The amount of data associated with each sea turtle encounter varies based on the objectives of a photo-ID project. Regular backup of both the raw images and text data, both online and offline, is essential. Contributions to global (e.g. *Internet of Turtles*) and regional databases (e.g. TORSOOI) to further maximise the value and impact of the data collected should be considered (open data policies). Projects can make their photo-ID data public through interactive websites (Hoh and Fong, 2022) but also available at dedicated dataset pages (e.g. https://www.kaggle.com/datasets) for automated method development and evaluation (Adam *et al.*, 2024).

Making the data FAIR (Findable, Accessible, Interoperable, and Reusable; Wilkinson *et al.*, 2016) comes with multiple benefits. For instance, publishing turtle occurrence data to platforms like the Global Biodiversity Information Facility (GBIF) and/or Ocean Biodiversity Information System (OBIS) as a public dataset is highly recommended (Hoh and Fong, 2022). These global biodiversity data portals follow the Darwin Core Standard for recording biodiversity occurrence data, promoting interoperability that facilitate further research and data utilisation. Before publishing, there is an opportunity to manage, clean, and standardise the data for various purposes, yielding multiple benefits for the public to use, and for one's project particularly in data management. Additionally, these public datasets can also serve as an alternative backup, and version control is typically available for convenience in data management.

Finally, we note that while one usually does not need a permit for photo-ID research, data consent is needed when data are collected from third parties.

Acknowledgements: We would like to thank Dr. Stephen G. Dunbar and Dr. Tyffen Read for carefully reading this chapter, for making useful remarks and suggesting improvements.

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