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Using minimally invasive techniques to determine green sea turtle *Chelonia mydas* life-history parameters

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ABSTRACT

Determining the life history and population parameters of sea turtles typically involves the live capture of animals. Photo-identification (photo-ID) of free-ranging individuals is a cost-effective alternative to conventional tagging for mark-recapture studies that also minimises the risk of injury or stress to the animals. Paired laser-photogrammetry (photogrammetry) is a minimally invasive technique to size animals and has been proven effective in a range of different taxa. Photo-ID and photogrammetry were combined as minimally invasive techniques to determine life-history parameters of free-ranging green sea turtles *Chelonia mydas* at a site in Oslob, Cebu, Philippines. The pattern-recognition software I^3S Pattern was used to validate results and confirm visual matching. A total of 38 individuals were identified at the site through photo-ID. Facial scutes remained unchanged for a min. of 3.6 years. Photogrammetry was employed to measure straight carapace lengths (SCLs) of a sample of 17 individuals, with a mean straight carapace length of 52.5 ± SD 1.1 cm. Modified maximum likelihood methods were used to model mean residency of 873 d at the site, with *c.* 12 individuals present at any one time. Based on photogrammetry measurements, individuals at the site were found to be of immature age class. This, along with the extended residency times, indicates that the site could be an important developmental habitat. Photo-ID is a valid minimally invasive technique for identifying individual *C. mydas* for mark-recapture analyses. The use of paired laser photogrammetry for categorising the life-history stage of an aggregation of sea turtles is demonstrated for the first time. Identification of such developmental habitats through the employment of these minimally invasive techniques is useful for conservation of the species.

1. Introduction

Identification of individuals within a population is essential for ecological and demographic studies (Marshall and Pierce, 2012). For sea turtles, individual identification has typically relied on the attachment of plastic or metal tags to the flippers on purposely captured or incidentally caught animals (Balazs, 1999). However, this methodology typically involves the live capture and handling of the animals, which could result in injury and stress (Reisser et al., 2008). Additionally, tag retention is an important variable in mark-recapture studies (e.g. residency), which depends on multiple factors such as proper attachment, material, fouling, and placement amongst others (Limpus, 1992). Poor tag retention can consequently lead to limited usable data or interfere with long-term conservation studies (Rowat et al., 2009; Sibly et al., 2005).

Photographic identification (photo-ID) of individuals is a useful alternative to conventional tagging used on a wide array of marine and terrestrial species (Marshall and Pierce, 2012). This minimally invasive technique relies on identifiable features or markings that can be visually attained and captured. In whale sharks *Rhincodon typus* for example, the movement, residency and site fidelity can be investigated through photographic capture and recapture of individuals through the use of their unique dorsal spot patterns (Araujo et al., 2014; Holmberg et al., 2009). Certain assumptions need to be met in order for photo-ID to be used as a mark-recapture tool: individuals can be reliably distinguished amongst others, and individuals can be re-identified over time i.e. distinguishable features or markings do not change over time (Marshall and Pierce, 2012). Using photo-ID over conventional tagging omits the live capture of the animals, reducing the risk of injury and stress, and assuming that identifiable features are stable over time, eliminates the risk of 'tag loss' or lost identifications (Barrowman and Myers, 1996; Hammond et al., 1990). Photo-ID studies can also enlist the public as citizen scientists to broaden identification databases (Araujo et al., 2016; Germanov and Marshall, 2014).

Several studies on green turtles, *Chelonia mydas*, have focused on the use of photo-ID and validated it by comparing it to conventional tagging (Chew et al., 2015; Reisser et al., 2008; Schofield et al., 2008). Individual green turtles can be identified by the shape and arrangement of their facial scutes (Reisser et al., 2008). This method was tested and showed no changes in the arrangement and shape of the facial scutes for up to 11 years (Carpentier et al., 2016). This makes photo-id suitable for

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mark-recapture studies on green turtles, though caution should be taken when exploring longer datasets (Speed et al., 2007). Computer-aided recognition systems have been developed and are currently used in other marine species, such as whale sharks (Arzoumanian et al., 2005) and spotted raggedtoothed sharks *Carcharias taurus* (Van Tienhoven et al., 2007). These systems not only validate visual matches, but can also facilitate and therefore speed-up the matching process (Reisser et al., 2008).

Sizing animals is important to determine several life-history parameters necessary for their management. It is important to obtain accurate measurements of individual animals in order to determine size-at-maturity (Rohner et al., 2015), growth rates (Pilcher, 2010a) and possible signs of overexploitation (Bianchi et al., 2000). Size segregation is known to occur in sea turtles (Bowen et al., 1992), and it is therefore possible to infer the developmental stage of individuals based on size. Paired-laser photogrammetry (photogrammetry) has been used to accurately measure and determine life-history parameters of marine mammals (Webster et al., 2010) and elasmobranches (Deakos, 2010; O'Connell and Leurs, 2016; Rohner et al., 2015). Photogrammetry removes the need to physically capture an animal in order to measure it, and has been suggested as a suitable method to measure sea turtles (Williams et al., 2015).

In the Philippines, sea turtles are protected under the Wildlife Resources Conservation and Protection Act of 2001 (Republic Act No. 9417). Thousands of female green turtles nest yearly at the Turtle Islands Heritage Protected Area (TIHPA), a bilaterally protected area in the southwestern Sulu Sea with the Government of Malaysia (Pilcher, 2007). *C. mydas* is widely distributed across the country although most studies have focused on nesting sites (Cruz, 2002). Pilcher (2010a) however, conducted a survey at the Tubbataha Reefs Natural Park, a UNESCO Heritage site within the Sulu Sea, and found >80% of ~250 *C. mydas* were immature. Similarly, Pilcher (2010b) confirmed that all individuals at a nearby site in Pulau Mantani, Sabah, Malaysia, were immature. Following a pelagic developmental stage, *C. mydas* recruits to neritic habitats after reaching a size of *c.* 20 cm (Meylan et al., 2011). The developmental, post-pelagic stage of green turtles in the Philippines remains unclear, as is their recruitment to foraging grounds. Addressing this lack of knowledge will help protect developmental habitats during the lesser-known years of *C. mydas*.

In the present study, the suitability of photo-ID and photogrammetry as minimally invasive techniques on free-swimming *C. mydas* to determine life-history parameters at a site in Oslob, Cebu, Philippines, is explored. Photo-ID data validated by the pattern-matching software I^3S Pattern (Van Tienhoven et al., 2007) was used to model residency patterns using maximum likelihood methods (Whitehead, 2001). The use of photogrammetry to obtain accurate measurements of free-swimming sea turtles, and determine maturity status, is tested for the first time.

2. Materials and methods

2.1. Study site

The study site is located in the village of Tan-awan, Oslob, on the south of Cebu Island. It is a demarked area and covers an extent of approx. 65,000 m^2. It contains extensive seagrass beds, which represent the majority of the substrate coverage between 3 and 7 m deep (Fig. 1). The deeper end of the demarked area is dominated by coral rubble and sparse reef between 8 and 11 m, after which older reef structures dominate, offering resting spaces for *C. mydas* from 12 to 16 m deep. Researchers snorkelled from shore and haphazardly surveyed for turtles within a demarked area (Fig. 1). Dedicated turtle photo-ID surveys for this study took place between July 1st 2014 and November 30th 2015. The site is also used for an extensive whale shark provisioning operation (see Araujo et al., 2014). Opportunistically taken turtle photo-ID images were also collected from researchers studying whale sharks, who had been onsite for >3 years.

2.2. Photographic identification and validation

Turtle photo-ID sessions were conducted four times a week for the duration of the study period. Each session lasted 1 h with two early sessions (6 to 9 am) and two later sessions (10 am to 1 pm). However, turtle photo-ID images were opportunistically collected on most days.

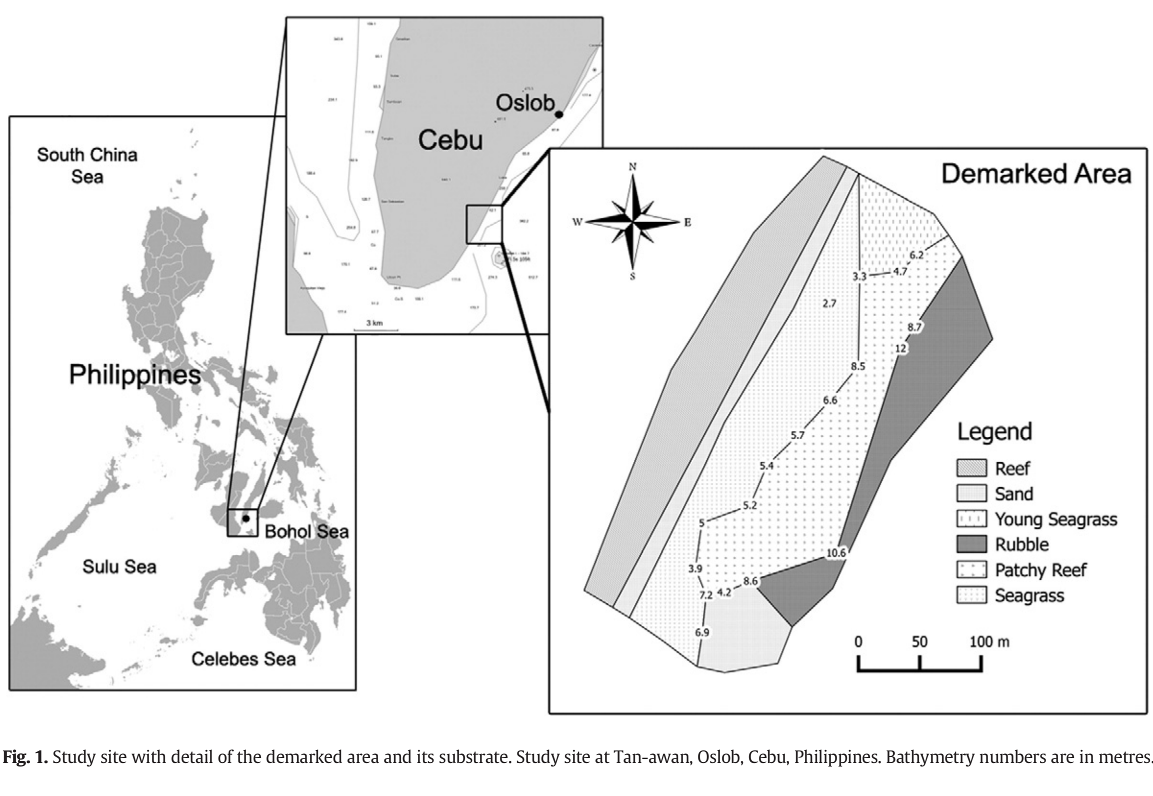

Fig. 1. Study site with detail of the demarked area and its substrate. Study site at Tan-awan, Oslob, Cebu, Philippines. Bathymetry numbers are in metres.