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Short Communication

Further evidence of pigmentation change in white sharks, *Carcharodon carcharias*

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Abstract. Patterns of pigmentation are widely used for the identification of white sharks, with photographic databases often forming the basis for studies of population modelling, site fidelity and movement patterns. The permanence of these identifying markings is assumed to remain constant. Here, we present evidence of melanism resulting in a change in the shape and size of pigmentation markings on the lower caudal lobe of a female white shark. We found a 33% reduction in size of an islet over a 9-month period. The newly melanised region was 10% darker than the adjoining pigmented areas, and did not match the original pattern. Possible causes of the observed melanism are presented, and the implications for the reliability of using caudal-fin pigmentation patterns for identification purposes are discussed, with a combinational matching approach recommended.

Additional keywords: great white shark, markings, melanin, photographic ID.

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Introduction

The white shark, *Carcharodon carcharias*, occurs in coastal temperate and subtropical regions. The species is considered vulnerable to depletion in Australian waters, having low fecundity and slow growth rates (Bruce 1995), which, together with natural fluctuations in distribution, make changes in the population difficult to detect. The white shark was protected in Australian waters in 1996, with a White Shark Recovery Plan implemented to enable the population to recover to a level at which protection is no longer required (DEWHA 2010). Quantitative monitoring of change over time is underway, requiring an accurate methodology to identify individuals. Additionally, to minimise the human impacts on individual white sharks at aggregation areas, it is essential to understand the residency periods and site fidelity by individuals in each area. This too requires accurate identification of individuals on short (day-to-day) and long (year-to-year) time scales, which can be best achieved through a combination of tagging and photographic-identification (photo-ID) studies.

Photo ID has been used to estimate white shark population size (Chapple *et al.* 2011), as well as forming the basis for studies of population ecology, site fidelity and movement patterns in this species worldwide (Klimley and Anderson 1996; Strong *et al.* 1996; Bonfil *et al.* 2005; Domeier and Nasby-Lucas 2007; Robbins 2007; Anderson *et al.* 2011; Sosa-Nishizaki *et al.* 2012). Although such studies take divergent approaches to identification, using either dorsal-fin profiles (Anderson *et al.* 2011) or body pigmentation patterns (Domeier and Nasby-Lucas 2007) to identify individuals, the efficacy of both methods has been validated through confirmation of the permanence and uniqueness of identifying markings (Domeier and Nasby-Lucas 2007; Anderson *et al.* 2011). The trailing edge of the dorsal fin has proven to be stable, with no changes in the shape, size or arrangement of notches, providing positive identifications of individual white sharks for up to 22 years (Anderson *et al.* 2011). This method has been further proven as an identification key over a 5-year period by matching with genetic data (Gubili *et al.* 2009). The pigmentation patterns commonly observed on the dorsal fins, caudal fins and along the countershading boundary have been used to visually identify individuals over a 5-year period at Guadalupe Island (Domeier and Nasby-Lucas 2007). These individual marking patterns can be formed through scarring from mating and/or aggressive interactions, and by physiological and/or developmental processes.

Confirmation of resightings using photo-ID could be compromised if individuals cannot be matched with certainty, and significant changes to identifiable markings could prove problematic, equivalent to tag loss in a marker-tagging study (Marshall and Pierce 2012). The present study describes and discusses a temporal change in a caudal islet of a white shark and the implications for long-term photo ID of this species.

Materials and methods

White sharks attracted to a commercial cage-diving operation at the Neptune Islands, South Australia, were photographed over a 10-year period from 2001 to 2011. The timings and duration of visits of white sharks were recorded, and photographs taken of each individual sighted were processed and categorised to create a photographic database of 220 individual sharks (R. Robbins and A. Fox, unpubl. data).

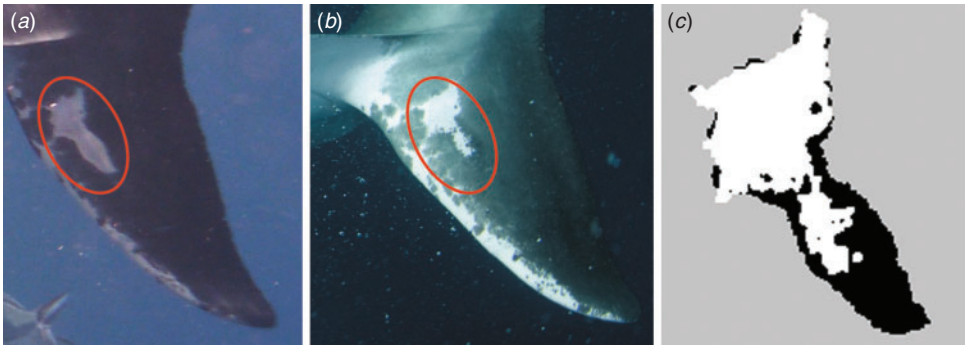

Fig. 1. Lower caudal fin of a 3.8-m female white shark, with islets circled in red, demonstrating the degree of melanism over time, with (*a*) a fin on 31 July 2011, (*b*) a fin on 23 April 2012 and (*c*) the difference in the area (33%) of the pigmentation islet; 2011 islet (■), 2012 islet (□).

An ~3.8-m total-length (TL) female white shark was initially photographed and tagged with a V16 tag (Vemco.com, accessed 17 August 2012) on 31 July 2011 at South Neptune Island. The resighting of this animal was photographically confirmed on 23 April 2012, through positive matching of the dorsal-fin profile and countershading boundary pigmentation patterns, and further confirmed after detection of the aforementioned tag on a VR4 receiver.

Because of the observed change in the caudal-fin markings of this individual, photographs of the countershading boundary along the length of the body, and the pigmentation patterns on the dorsal and caudal fins from each year were more intensively examined and compared, to determine the degree of pigmentation change. Photographs were processed and analysed using Photoshop (Adobe Photoshop CS2, Version 9.0.2, Adobe Systems Inc., San Jose, CA, USA). To calculate the difference in darkness between the 2011 unpigmented and 2012 newly pigmented areas, the image of the caudal fin taken in April 2012 was converted to greyscale and the lightness value (L) of the newly melanised and pre-existing adjacent melanised areas were measured and compared, where 0 = black and 100 = white. This was achieved by selecting the newly melanised area and applying an average blur function to obtain the mean L value for that area. This was repeated with the adjacent area on the caudal fin. The difference between these average L values gave the relative difference in tone between the two areas.

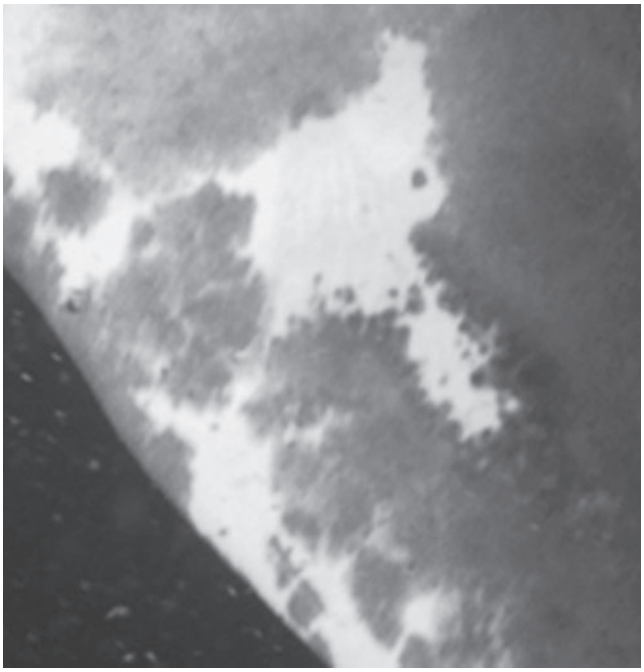

Fig. 2. Close-up of the lower caudal pigmentation on 23 April 2012, showing the darker tone of the new melanised area (L = 46), compared with the pre-existing melaniferous areas (L = 56).

Results and discussion

Only one of the 220 sharks identified in the study exhibited a change in caudal-fin pigmentation pattern, despite ~75% of identified sharks bearing pigmentations markings on their lower caudal fin. Domeier and Nasby-Lucas (2007) reported a similar occurrence of melanistic change in the size of gill spots from two white sharks from Guadalupe Island, Mexico, but the degree of change in the current study was notably more pronounced and extensive. From July 2011 to April 2012, there was a 33% reduction in the area of the white pattern on the lower caudal fin (Fig. 1). The newly pigmented area was darker (L = 46%) than the pre-existing melaniferous regions on the caudal fin (L = 56%), resulting in a 10% difference in tone between these two areas (Fig. 2). Comparison of photographs taken of other regions on the body in 2011 with those taken in 2012 showed no pigmentation changes, indicating that only the area on the caudal fin was subject to pigmentation change in this individual. Although it could be suggested that a healing injury is responsible for this observed change, there was no evidence of injury or scarring on the caudal fin of this individual in either year she was photographed.

Physiologically, melanism is caused by dispersion of melanin within the melanophores in the skin (Bagnara and Hadley 1973). Melanism can be attributed to environmental factors, such as cold temperatures (Trullas *et al.* 2007). Conversely, juvenile scalloped hammerhead sharks (*Sphyrna lewini*) have been observed to become darker with increasing exposure to solar radiation (Lowe and Goodman-Lowe 1996), much the same way as humans tan in the sun. Alternatively, melanism

could be a by-product of other processes regulated by the endocrine system. The pituitary gland, regulated by the hypothalamus, is responsible for morphological colour changes in sharks through the release of melanin-stimulating hormone (MSH) (Prota 1992). Because of the location of the increased melanin in the present study (i.e. lower caudal fin), and lack of darkening elsewhere on the body, it is unlikely that exposure to increased UV radiation would have lead to the increased concentration in melanin seen here. Thus, we hypothesise a temperature- or endocrine-based change, leading to the changes we observed. It is of note that some white sharks have dark spots laterally, much akin to freckles, which can extend from the gill region to the caudal keel (R. Robbins, pers. obs.), and which have been observed to change in size and shape of over time (Domeier and Nasby-Lucas 2007). It is reasonable to suggest that the same processes that caused melanisation of the caudal fin in the present study, are also responsible for the growth and colour change of these localised spots.

The evidence presented here indicates that caudal markings should be used with caution because of the potential for significant changes that could lead to false identification of individuals. Pigmentation patterns in this species have been assumed to be relatively stable and are used to confirm resightings of individuals on both short- and long-terms scales. Although Domeier and Nasby-Lucas (2007) noted slight changes in the pigmented gill spots in white sharks at Guadalupe Island, these authors considered that this change did not compromise the identification of individuals, and described an overall stability of pigment patterns, including those on the caudal fins. After initial identification, resightings were able to be confirmed from a single photograph of the caudal fin, gill flaps or pelvic fins (Domeier and Nasby-Lucas 2007). However, the change observed in the present study suggests that, at least for caudal fins, a single photograph or partial image may not be sufficient to ensure a a positive identification.

Changes in markings were not detected on any other area of the body and the increased pigmentation in the individual studied here was specifically localised to the caudal fin. This may suggest that the countershading boundary and pigmentation patterns on other body regions are stable and can reliably be used in photo ID; however, confirmation requires further analysis. We suggest that multiple parameters should be assessed when matching individuals, to ensure that the validity of photo ID is not compromised, and recommend that dorsal-fin profiles be prioritised because of their proven reliability and longevity (Anderson *et al.* 2011). The phenomenon described here appears to be unique to this one individual and has not been previously observed in other animals, despite >10 years of photographic records. However, it is possible that with more intensive examination of the images collected, further examples will become evident. Investigating possible relationships between the extent and degree of change in pigmentation patterns with shark size, degree of scarring and parasitism will be the focus of future work.

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