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CATALOGUING, COMPARING AND MATCHING
OF PHOTOGRAPHICALLY IDENTIFIED GREAT WHITE
SHARKS (*CARCHARODON CARCHARIAS*)
USING A MULTI-FEATURE APPROACH

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Introduction

In South Africa long-term information on the population status of the white shark (*Carcharodon carcharias*), a vulnerable species (IUCN 2010), is currently derived from the capture of individuals in the Natal Sharks Board (NSB) bather protection nets off the coast of KwaZulu-Natal (Cliff et al. 1996; Dudley & Simpfendorfer 2006). The white shark was afforded protection in 1991 under the national fisheries legislation via the precautionary principle (Compagno 1991). It is clear that this invasive means of sampling the population is not conducive to conservation efforts. Low recapture rates associated with this method compromises population estimates due to low precision levels (Cliff et al. 1996), therefore making mark-recapture techniques attractive for populations that lack sufficient fisheries data (Anderson et al. 2011). A non-consumptive and more productive method for collecting long-term data on the population metrics and composition can be gained through photographic identification of unique individuals within a species (Arzoumanian et al. 2005).

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Photographic identification is both cost-effective and non-invasive, allowing the involvement of personnel that are not scientifically trained (Castro & Rosa 2005). Furthermore, it is particularly applicable to species that are not easily tagged due to their large size (Kohler & Turner 2001) or because subjects do not retain artificial markings for the duration of the study (Gamble et al. 2008). Photographic identification is a technique mainly used on species that have distinctive features, such as natural markings, which can be used to identify individuals (Stevick et al. 2001; Van Tienhoven et al. 2007). This technique has been used as a monitoring tool on a variety of marine and terrestrial species, although in the marine environment it has largely been applied to marine mammals (Karczmarski & Cockcroft 1998; Wilson et al. 1999; Hillman et al. 2003; Calambokidis et al. 2004; Mizroch et al. 2004; Coakes et al. 2005; Gilkinson et al. 2007). Despite its wide application on the latter, photographic identification has also been used on elasmobranchs such as whale sharks *Rhincodon typus* (Arzoumanian et al. 2005; Bradshaw et al. 2007; Rowat et al. 2007), raggedtooth sharks *Carcharias taurus* (Van Tienhoven et al. 2007; Bansemer & Bennet 2008), nurse sharks *Ginglymostoma cirratum* (Castro & Rosa 2005), manta rays *Manta alfredi* (Marshall et al. 2011) and white sharks (Anderson & Goldman 1996; Klimley & Anderson 1996; Domeier & Nasby-Lucas 2007; Sosa-Nishizaki et al. 2010; Anderson et al. 2011; Chapple et al. 2011).

The white shark was one of the first elasmobranch species on which photographic identification techniques were implemented (Anderson & Goldman 1996). Although white sharks are considered to be a wide-ranging species, individuals display strong inter-annual site fidelity at known aggregation sites thus making photographic identification techniques feasible for estimating population sizes (Strong et al. 1992; Cliff et al. 1996; Klimley & Anderson 1996; Goldman & Anderson 1999; Bonfil et al. 2005; Kock & Johnson 2006; Jorgensen et al. 2009; Sosa-Nishizaki et al. 2010; Anderson et al. 2011; Chapple et al. 2011).

In this paper a systematic approach for the manual identification of individual white sharks is presented using a multi-feature analysis (Gubili et al. 2009)

applied to the dorsal fin. The use of image database software for the creation and management of a photographic catalogue is evaluated. In addition, guidelines for manual fin-matching are given and potential concerns about this method are discussed. This paper is divided into two sections. The first section outlines basic operational knowledge for using Adobe Photoshop Lightroom 2 software. The second section instructs on how to apply the photographic identification technique described in this paper when using Adobe Photoshop Lightroom 2 as an organisational platform.

Study Site

Mossel Bay ($34^{\circ}11' S$, $022^{\circ}09' E$) lies on the southern coast of South Africa and is a well-known white shark aggregation site. Mossel Bay boasts a Cape fur seal (*Arctocephalus pusillus pusillus*) colony of over 3000-5000 individuals, likely influencing the presence of white sharks in this area. Mossel Bay's white shark distribution is characterized by six core areas: Seal Island, Hartenbos, Railway Line, Kleinbrak, Blue Houses and Grootbrak (Fig. 1).

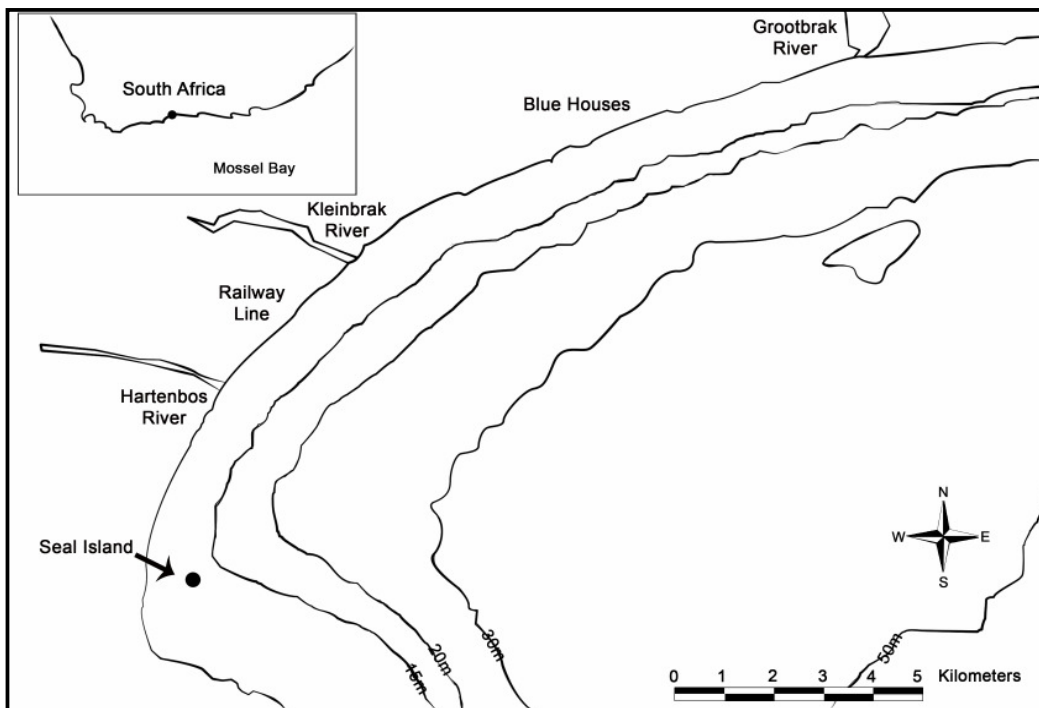


Figure 1. The six core areas i.e. Seal Island, Hartenbos, Railway Line, Kleinbrak, Blue Houses and Grootbrak.

Data Collection

When weather conditions permitted, a research vessel travelled to one of the six known aggregation sites in Mossel Bay (Fig. 1). White sharks were attracted to the vessel using a combination of chum and bait. Once an individual arrived at the vessel, the bait was used to entice the shark by gradually pulling the bait closer to the vessel so that its dorsal fin could break the sea surface sufficiently and in close proximity for it to be properly photographed. Simultaneously, an identification matrix was completed comprised of the following fields: shark reference number, shark total length (TL), sex, white pigment presence (left-hand side [LHS] and right-hand side [RHS] of dorsal fin, and caudal fin tip), black pigment presence (LHS and RHS of dorsal fin), and fin deformities.

Sex was determined by the presence of claspers for males and the absence of claspers for females. Total length was estimated by experienced observers when a shark swam adjacent to a plumbing pipe of known length i.e. 200 cm, attached parallel to the vessel. Estimated total length was divided into eight categories i.e. 125 – 174 cm, 175 – 224 cm, 225 – 274 cm, 275 – 324 cm, 325 – 374 cm, 375 – 424 cm, 425 – 474 cm, 475 – 524 cm. In addition, during each sampling occasion the following environmental parameters were recorded: sea surface temperature (SST), vertical water visibility (Secchi disk), wind speed (knots), wind direction and atmospheric conditions (rain, overcast, partly cloudy or clear).

Single-lens reflex (SLR) digital cameras with a resolution of over 10 mega pixels were used to take the photographs. Identity (ID) photographs were only taken when the subject was in close proximity to the vessel and the dorsal fin was perpendicular to the sea surface. When conditions permitted, both sides of the dorsal fin were photographed. Experienced and trained photographers were used to take ID photographs. The SLR cameras were set to shutter priority and a minimum shutter speed of 1/400 per second was used to ensure crispness of photographs.

SECTION ONE

Adobe Photoshop Lightroom 2

Adobe Photoshop Lightroom 2, subsequently referred to as Lightroom 2, is a software program developed specifically for the organisation of large photographic databases. It is designed for post-production work on digital photographs and to prepare images for further development in Adobe Photoshop software. The main features in Lightroom 2 are *Library* (review of image collection and optional application of organisational tags), *Develop* (editing tools), *Slideshow* (tools and export features), *Print* (layout options and preferences for printing) and *Web* (automatic gallery creation and upload functions). Thus, Lightroom 2 is not a fine-tuning program, but merely a platform that photographers can use to organise and apply simple manipulations to their photographs. A great feature of Lightroom 2 is that any changes and progress made is saved automatically by the program. In addition, Lightroom 2 facilitates non-destructive editing of image files i.e. the adjustments are only visible in the program itself while the original file remains intact. A project in Lightroom 2 is referred to as a *Catalog* which stores all the metadata regarding a particular project. *Metadata* refers to all the information relating to the manipulations that have been applied to a photograph and any keywords, colour labels and/or ratings that have been assigned to it. Lightroom 2 is sensitive to filepath changes, so if any folder or file names are altered, the program will not automatically pick this up – any changes made will have to be synchronized.

Interface

The Lightroom 2 interface is fairly simple to understand and is divided into four key areas i.e. the Module Picker, the Main Content Area, the Panels and the Filmstrip. The menu bar at the top represents the general menu standard in all programs. Below this, to the right, the secondary menu bar is located i.e. the *Module Picker*, which facilitates navigation between the main functions in Lightroom 2. The *Library* and *Develop* tabs represent the two main functions that will be used for maintaining a photographic identification database. The *Main Content Area* is bordered on either side by the *Panels* and represents

the view chamber. When switching between the Library and Develop tabs, this viewing chamber remains constant whilst the left and right panels change. Located below the Main Content Area is the *Filmstrip* which displays an overview of all the photographs from a selected folder. Just above this, there is a *Filter* menu which can be toggled to display selected photographs.

The Library tool bar is located below the Main Content Area and is composed of a series of icons. The first four icons adjust the view i.e. Grid View (all images in a selected folder are arranged in the view chamber in grid format), Loupe View (a single selected image will be displayed), Compare View (two selected images will be displayed in a split screen format) and Survey View (similar to the compare view but is not limited to two images). The next two icons are flags i.e. a white flag and a reject flag. The next five icons are a row of stars and can be used for rating. Following this is a selection of colour labels i.e. red, yellow, green, blue, purple, white and black. Lastly, there are two arrows which can be used to rotate the image 90° at a time in the respective direction.

When the Library module is selected, the left panel has the *Navigator* box at the top which displays the selected photograph. There are different options that can be toggled to alter the zoom i.e. Fit, Fill, 1:1 and 1:x (custom). Below this is the *Catalog* box which offers the following options: *All Photographs*, *Quick Collection +*, *Previous Import* and *Already In Catalog*. The last box is *Folders* and provides a hierarchical breakdown of the directory structure of all the images uploaded into Lightroom 2. At the bottom of this left panel there are two quick tabs i.e. *Import* and *Export*, which are used to upload and save photographs, respectively. There are more specific import and export options available under the *File* tab in the primary menu bar. When exporting photographs, options are available to alter the file name and/or create specific folders in which to save them.

The right panel houses the *Histogram* box at the top which displays a graphic breakdown of the composition of the photograph in terms of the relation of the three primary colours i.e. red, blue and yellow. At the bottom of the Histogram

box the basic camera settings under which the photograph was taken are displayed e.g. shutter speed. The next box is *Quick Develop* which provides options for basic manipulations e.g. white balance, however, the *Develop* module has a more extensive range of options which are likely more preferable. The third box is *Keywording* in which keywords are assigned through manual input. Next is the *Keyword List* box in which a list of keyword tags can be created and assigned to selected photographs simply by checking them. The last box is *Metadata* which provides general information about the selected photograph e.g. file name, and has fields that may be edited e.g. caption. At the very bottom are two quick tabs i.e. *Sync Settings* and *Sync Metadata*.

When the *Develop* module is selected, the *Navigator* box at the top remains the same. The *Presets* box below the latter allows the application of default or customised presets. The last box is *History* which tracks all the manipulations that have been applied. At the very bottom are two quick tabs i.e. *Copy* and *Paste*, which allows executed manipulations to be copied from one photograph and pasted onto another.

For the right panel, the *Histogram* box remains largely the same, with the addition of five icons representing the following functions: *cropping*, *spot removal*, *red eye correction*, *graduated filter* and *adjustment brush*. Below this are a series of editing boxes i.e. *Basic*, *Tone Curve*, *HSL / Color / Grayscale*, *Split Toning*, *Detail*, *Vignettes* and *Camera Calibration*. At the bottom are two quick tabs i.e. *Previous* (similar to the common “Undo” option) and *Reset* (facilitates the reversion to the original image).

Import Photographs and Synchronize Folders

There are two main ways in which folders, and subsequently photographs, can be entered in Lightroom 2 – via importing images and folders, or synchronising folders. The *Import* option from the left panel (under the *Library* tab) or the *File* tab (on the main menu bar) can be used to upload folders and images into Lightroom 2. Another option is to right-click on the relevant folder under the *Folders* box (the left panel under the *Library* tab) where a menu will

be displayed from which the “*Synchronize Folder*” option should be selected. Lightroom 2 will automatically read any changes made to the selected folder and calculate how many photographs need to be imported and/or removed. Simply click the “*Synchronize*” option and Lightroom 2 will do the rest.

SECTION TWO

Photo Selection Process

Subsequently, the photographs were entered into a catalogue (created using Adobe Photoshop Lightroom 2) containing all the previously recorded individuals, arranged in a hierarchical format in the following manner: year, month, day, and individual specimen which was assigned a reference number for that particular day i.e. 00x-ddmmyy. A keyword system was developed containing the following fields i.e. white pigmentation, black pigmentation, fin amputations, notch structure, total length, sex, and tag presence (Table 1). Lightroom 2 has a built-in filter in which fields can be selected to reduce the number of potential candidates. Once matches were found through the correlation of key words, they were either confirmed or rejected through visual discernment. Confirmed matches were based on as many distinguishing features as possible, thus reducing the possibility of false positives (Gubili et al. 2009). Affirmative matches were assigned the same reference number. If no matches were located, the shark was assigned a new reference number i.e. WS-00X. Every two months, all the photographs for identified individuals were double-checked to reduce false positives and pseudo-replication.

Rating, Cropping and Selecting

Under the *Library* tab, every photograph in each individual folder i.e. 00x-ddmmyy, is rated on a scale from 1-star to 5-stars. 1-starred photographs are those deemed completely useless e.g. images that are underwater or underexposed beyond correction, and 5-stars are assigned to photographs in which the entire dorsal fin is completely out of the water and perpendicular to the sea-surface, as well as sufficiently exposed and in-focus. Essentially, one star is gained for sufficient quality in (a) exposure, (b) composition, (c) focus,

(d) protrusion of dorsal fin out of the water and (e) orientation of dorsal fin. Once all the photographs have been rated all those that have been awarded with 3-stars or higher are cropped using the cropping function under the *Develop* tab. In addition, photographs may subsequently be manipulated to improve clarity and exposure where necessary. Switching back to the *Library* tab, the filter just above the *Filmstrip* is used to find the best photograph for both the left-hand side and the right-hand side of the dorsal fin, if both sides were photographed. Only photographs that are rated with three stars or higher are used for matching. Once the best photograph for each side has been selected, a colour label is applied. A red colour label is applied if the photograph has been rated with either four- or five-stars, and a yellow colour label is applied if the photograph has been rated with three stars. If the only photograph available is useless or difficult to match, it is assigned a green colour label and flagged with the reject flag.

Applying Keywords

Keywords are only applied to photographs that have been assigned a red or yellow colour label. Most of the information required for key-wording is obtained from the individual identification matrix data sheet with the exception of Black Pigment and Notches. Many white sharks have small black pigments present on the dorsal fin as well as shallow notches on the dorsal trailing edge. As these keywords are only used for filtering for potential candidates, only black pigments and notches that are equal to, or exceed, a certain size are acknowledged.

Once an affirmative match has been made the appropriate keyword tag e.g. WS-028, under the keyword *GWS Number* is applied. If the dorsal fin represents a new individual, a new keyword tag is created by right-clicking next to the keyword *GWS Number* and selecting the *Create Keyword Tag inside "GWS Number"* option, after which a window will pop-up prompting for the relevant information to be filled in; click *Create* to complete the action.

Keyword List

The following table is a breakdown of the list of keywords that have been created for the photographic identification database (Table 1.).

Table 1. List of keywords for dorsal photographic identification

Amputations		
	Caud Amp-A	Caudal Amputation Absent
	Caud Amp-P	Caudal Amputation Present
	Dorsal Amp-A	Dorsal Amputation Absent
	Dorsal Amp-P	Dorsal Amputation Present
	Pec-LHS Amp-A	Pectoral Left-Hand Side Absent
	Pec-LHS Amp-P	Pectoral Left-Hand Side Present
	Pec-RHS Amp-A	Pectoral Right-Hand Side Absent
	Pec-RHS Amp-P	Pectoral Right-Hand Side Present
Black Pigment		
	BP-LHS-A	Black Pigment Left-Hand Side Absent
	BP-LHS-P	Black Pigment Left-Hand Side Present
	BP-RHS-A	Black Pigment Right-Hand Side Absent
	BP-RHS-P	Black Pigment Right-Hand Side Present
Gender		
	Female	
	Male	
GWS Number		Unique Identification Code
	WS-001	Example
Notches		
	BN-A	Bottom Notch Absent
	BN-P	Bottom Notch Present
	MN-A	Middle Notch Absent
	MN-P	Middle Notch Present
	TN-A	Top Notch Absent
	TN-P	Top Notch Present

Side		
	LHS	Left-Hand Side
	RHS	Right-Hand Side
Tagging		
	Tag-Pres	Tag Present
Total Length		
	TL-125-274	Total Length 125-274 cm
	TL-275-374	Total Length 275-374 cm
	TL-375-524	Total Length 375-524 cm
White Pigment		
	WP-Caud-A	White Pigment Caudal Tip Absent
	WP-Caud-P	White Pigment Caudal Tip Present
	WP-LHS-A	White Pigment Left-Hand Side Absent
	WP-LHS-P	White Pigment Left-Hand Side Present
	WP-RHS-A	White Pigment Right-Hand Side Absent
	WP-RHS-P	White Pigment Right-Hand Side Present

Applying The Filter

Under the *Library* tab, the photograph that is to be matched is selected and then all the folders that are to be searched for potential matches are highlighted on the left panel. When the *Grid View* option is selected, the *Library Filter* will be displayed at the top of the view chamber, which has the following fields: *Text*, *Attribute*, *Metadata* and *None*. The red and yellow colour labels, under the *Attribute* field, should be selected. Under the *Metadata* field, the filter for each column should be set to *Keyword* so that the keywords applied to each photograph can be used to filter for potential candidates. Each column represents a single field that can be filtered for and a maximum of nine columns can be used for filtering. The right panel will display all the information and keywords assigned to the highlighted photograph. This is useful when selecting features that need to be filtered for.

Always start by first filtering for White Pigment i.e. WP-Caud-A/P, WP-LHS-AP and WP-RHS-A/P. The next feature to filter for is Amputations only if there are any amputations present, otherwise filter for Notches next i.e. BN-A/P, MN-A/P and TN-A/P. As the database grows, the amount of potential candidates will increase accordingly. If there are still far too many potential candidates, the next feature to filter for is Black Pigment i.e. BP-LHS-A/P and BP-RHS-A/P. Side is useless if that particular side has not previously been photographed before. If the individual has a tag, this may reduce the number of potential candidates, however, that is dependant on whether the individual had previously been photographed with a tag present. Once filtering for potential candidates has been completed the task of finding an affirmative match may commence.

Fin Matching

The *Compare View* option at the bottom of the view chamber should be selected. The photograph that is to be matched will be displayed on the left-hand side in the *Select* box and the potential candidate will be displayed on the right-hand side in the *Candidate* box. All the photographs of the potential candidates will be displayed in the *Filmstrip* below the view chamber. The latest photograph is found at the extremity to the right and the oldest photograph is found at the extremity to the left.

If the photograph represents a new individual, it is assigned a new white shark number under the *GWS Number* keyword e.g. WS-087. However, if an affirmative match is found, the candidate photograph is highlighted and under the *GWS Number* keyword the dropdown list is opened to locate the keyword tag that had been assigned to that candidate. Subsequently, this keyword tag is applied to the photograph that was to be matched. The keyword tag is then opened to ensure that all the dorsal fins with that particular unique code represent the same individual and that the match is successful. If the match was unsuccessful, the keyword tag is removed from the photograph and the matching process continues.

Basic Tips For Fin Matching

Dorsal fin matching through visual discernment is a dynamic process. The following are a few tips that should aid in the reduction of pseudo-replication and to prevent misidentifications. The most important feature to look at when trying to match dorsal fins is the dorsal trailing edge. Although it can and does change, it is very rare that the entire dorsal trailing edge will change – usually, only a section will be altered. An effective means of comparing the dorsal trailing edge of two individuals is to find a pattern in the notch structure. Notches can and do change with time, thus it is important to keep an open mind when searching through potential candidates. Notches are likely a result of wear-and-tear but may also arise from the negative effects of parasites attached to the dorsal trailing edge. Thus, do not rule out potential candidates whose trailing edges do not look exactly the same. Scarring, and to a greater degree trauma-induced wounds can be used to affirm matches. However, it is important to keep in mind the duration of such markings, as the previous photograph of that individual may not have had any scars or wounds present. Another sound feature to consider is black pigmentation. The smaller black pigments are not always evident in every photograph, likely due to the dorsal fin being wet coupled with the ambient light conditions at the time. Nevertheless, if present, black pigmentation can be used to confirm matches in instances of doubt.

Conclusion

The absence of dorsal fin-matching software for white sharks has subsequently led to the creation of this photographic identification technique. Consequently, the use of image database software such as Adobe Photoshop Lightroom 2 represents an effective medium to facilitate the compilation of a photographic identification catalogue. A significant hindrance for the proposed fin-matching process is that it is time-consuming due to the manual-nature of the method. In addition, the constant possibility of the notch structure being partially altered presents its own challenges when distinguishing between individuals, thus a keen eye is required to pick up any changes. Although successful identification of distinct individuals is shown to be possible using a

multi-feature approach, experience is certainly a key factor to effectively identify unique individuals and can only be gained through consistent practice.

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