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Comparison of industry-based data to monitor white shark cage-dive tourism

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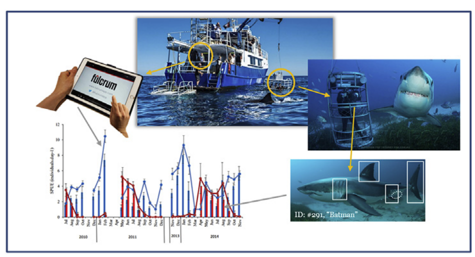
HIGHLIGHTS

- Logbook and photo-ID both revealed seasonal sex-biased changes in shark abundance.
- Photo-ID reports lower numbers of sharks, but provides additional parameters.
- We suggest that logbook reporting is the optimum long-term monitoring method.
- A combination of methods will enable an ongoing adaptive management framework.

GRAPHICAL ABSTRACT



Comparison of industry-based data to monitor white shark cage-dive tourism
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ABSTRACT

Although wildlife tourism is becoming increasingly popular worldwide, the industry has a potential to affect the fauna it targets. A variety of methods are used to monitor the activities and impacts of wildlife tourism. In South Australia, mandatory logbook reporting and the ability to photograph and identify individual sharks provides two industry-based data sources to monitor how cage-diving tourism may impact white sharks. Findings show that both methods can assess shark populations, and detect seasonal sex-biased changes in white shark abundance. Photo-ID significantly underestimates effort days and number of sharks sighted, and is considerably more labour-intensive, but allows accurate identification of individual sharks, facilitating additional analysis. The continued use of logbook reporting is the optimum long-term monitoring method, although we recommend the maintenance of a photographic database for periodic extraction of individual information. Combining these methods will facilitate an ongoing adaptive management framework, aiding the long-term sustainability of the industry.

1. Introduction

The white shark (*Carcharodon carcharias*; family: Lamnidae) is a generally solitary species which can travel thousands of kilometres per year (Bonfil, Francis, Duffy, Manning, & O'Brien, 2010; Bruce, Stevens, & Malcolm, 2006; Domeier & Nasby-Lucas, 2008). However, individuals periodically aggregate in some locations in response to seasonal increases in resource availability (Bruce & Bradford, 2012; Domeier & Nasby-Lucas, 2007; Klimley, Anderson, Pyle, & Henderson, 1992). White shark aggregations occur at several locations throughout the world, including mainland U.S.A.

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(Chapple et al., 2011), Mexico (Domeier & Nasby-Lucas, 2007), Hawaii (Weng & Honebrink, 2013), South Africa (Kock, O'Riain, Mauff, Kotze, & Griffiths, 2013), Australia (Bruce & Bradford, 2015; Robbins, Enarson, Bradford, Robbins, & Fox, 2015), and New Zealand (Francis, Duffy, & Lyon, 2015). The predictability of white shark aggregations has resulted in targeted wildlife tourism industries in places such as Australia (Bruce & Bradford, 2013; Huveneers et al., 2013), South Africa (Laroche, Kock, Dill, & Oosthuizen, 2007), the USA, Mexico (Nasby-Lucas & Domeier, 2012, pp. 381–392), and New Zealand (Francis et al., 2015). These industries allow close underwater encounters with white sharks in custom-built cages.

Wildlife tourism is often cited to facilitate increase public education and promote conservation awareness (Wilson & Tisdell, 2003; Zeppel, 2008), provide local economic benefits (Dwyer, Forsyth, & Dwyer, 2010; Wells, 1997), and increase psychological health benefits (Ballantyne, Packer, & Falk, 2011; Curtin, 2009). However, the industry can also threaten the wildlife and ecosystems it targets (for reviews see: Burgin & Hardiman, 2015; Green & Giese, 2004; Green & Higginbottom, 2001; Orams, 2002; Robbins, Huveneers, Parra, Möller, & Gillanders, 2017). With these concerns in mind, researchers have investigated a range of potential impacts on sharks, including physiological changes (Maljković & Côté, 2011; Semeniuk, Bourgron, Smith, & Rothley, 2009), behavioural changes (Barker, Peddemors, & Williamson, 2011a, 2011b; Smith, Scarpaci, & Otway, 2016), changes in seasonality, residency, or abundance (Bruce & Bradford, 2013; Laroche et al., 2007; Meyer, Dale, Papastamatiou, Whitney, & Holland, 2009), and disruptions to movement and space use (Corcoran et al., 2013; Fitzpatrick, Abrantes, Seymour, & Barnett, 2011; Huveneers et al., 2013) (for a review see: Brena, Mourier, Planes, & Clua, 2015; Gallagher et al., 2015). These studies have invariably concluded that anthropogenic impacts can be detrimental to sharks if unregulated or too frequent.

White shark cage-diving began in the late 1970s and has become a popular recreational activity, with opportunities in only a few countries where these sharks can be reliably observed (Apps, Dimmock, Lloyd, & Huveneers, 2016). Management of white shark cage-diving worldwide is guided by management plans and various legislative and regulatory instruments in each jurisdiction within which it occurs. These regulations mostly focus on limiting effort (i.e., number of operators), restricting the activity to certain sites and time periods), controls on equipment or other operational restrictions, and all have mandatory reporting and logbook requirements that monitors the activity of the industry (Bruce, 2015). The management objectives relating to cage-diving operations generally reflect legislative requirements to minimise possible deleterious effects on white sharks and the local marine environment.

In Australia, white shark cage-diving has occurred since the late 1970s in South Australia's Spencer Gulf and has become an economically important industry (Huveneers et al., 2017). However, the potential for cage-diving activities to negatively impact white sharks represents a concern in some jurisdictions (DSEWPaC, 2013; Robbins et al., 2017). For example, the increase in cage-diving effort in 2007 coincided with increases in white shark sighting rates and residency periods, and altered the fine-scale distribution of white sharks (Bruce & Bradford, 2013; Huveneers et al., 2013).

In order to monitor white shark numbers, all South Australian shark cage-diving operators (SCDOs) have logged the daily number and sex of sharks sighted since 1999, including null values (Bruce & Bradford, 2015). These logs were originally managed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), but were transferred to the South Australian Research and Development Institute (SARDI) in November 2013, when they implemented a new electronic system allowing online data entry (Fulcrum™). This electronic logbook uses an phone application (app) that allows data to be entered and uploaded by operators, removing the need to collect paper forms and manually enter data recorded by the operators. It also allows almost immediate access to the data.

An alternative method being considered to monitor white shark numbers in South Australia is photographic identification (photo-ID). Photo-ID has been widely used to monitor and describe elasmobranch populations, and is considered robust at identifying individual white sharks over for at least 22 years (Anderson, Chapple, Jorgensen, Klimley, & Block, 2011; Marshall & Pierce, 2012). Photo-ID can be used to determine habitat use (Klimley & Anderson, 1996), describe population composition (Domeier & Nasby-Lucas, 2007; Jorgensen et al., 2009), and assess individual residency or site fidelity (Delaney, Johnson, Bester, & Gennari, 2012). The high number of photographic records regularly available from SCDOs makes this a viable alternative method to monitor white shark population.

The simultaneous availability of mandatory logbook reporting and photo-ID provides two alternative means to monitor aggregating white sharks. However, the suitability and value of information available from these methods has yet to be compared. This study examines the data obtained by both methods, and determines which is most suitable for ongoing monitoring and tourism management of white sharks at their Australian aggregation site. The study will achieve this by comparing: (1) the number of sampling days and number of sharks sighted per day; (2) the sex ratio of visiting sharks; (3) temporal trends in the number of sharks visiting the aggregation site; and (4) the number of days individual sharks were sighted (as a proxy for residency). The variables used to compare the two methods were selected based on the information recorded by the operators, and information used to regulate the cage-diving industry. We further included ecologically-relevant variables (e.g., sighting differences between sexes) commonly used to assess shark populations (e.g., Bruce & Bradford, 2015; Domeier & Nasby-Lucas, 2007; Kock et al., 2013; Robbins, 2007; Robbins & Booth, 2012).

2. Methods

2.1. Study area

Photographic and logbook data was collected at the Neptune Islands Group (Ron and Valerie Taylor) Marine Park, South Australia. These islands are situated ~60 km south of Port Lincoln on the Eyre Peninsula, and consist of the North Neptune Islands (35°149 S; 136°049 E) and South Neptune Islands (35°201 S; 136°060 E) (Fig. 1). This is the only Australian location where white shark commercial cage-diving operations are permitted, as described in Bruce and Bradford (2013) and Huveneers et al. (2013).

2.2. Photographic images

Photographic images were obtained from one of the three cage-diving operators permitted in the area, with the principal aim of capturing images of all sharks present each day. Underwater images were taken throughout the day from cages on the surface and close to the seabed by a single experienced crew member using a digital single-lens reflex (DLSR) camera with strobes. This operator was chosen due to their reliability in taking daily high-quality images. All images were taken during normal tourism operations between June 2010–December 2011 and July 2013–November 2014 (Table 1). Sufficient images from other periods were not available due to the photographer's absence on trips during those periods.

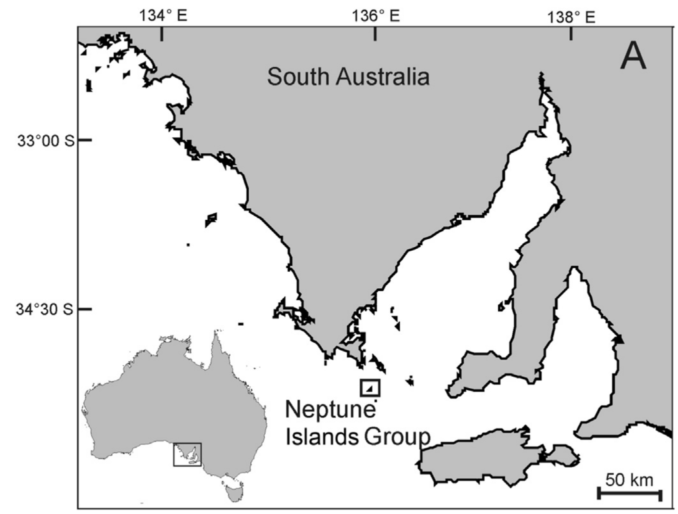

Fig. 1. Location of the Neptune Islands Group, where white shark cage-diving operations take place.

Individual white sharks were identified through markings on five morphological areas: caudal fin, pelvic fins, first dorsal fin (hereafter dorsal fin), gills, and pectoral fins (Fig. S1). Established *C. carcharias* identification methods were used (Anderson et al., 2011; Nasby-Lucas & Domeier, 2012, pp. 381–392), with individuals identified through their combination of pigmentation patterns (countershading, rosettes, islets, freckles, spots), notches or scoops, amputations, scoliosis, and scars (Table S1). As natural pigmentation patterns may gradually change in some individuals (Domeier & Nasby-Lucas, 2007; Robbins & Fox, 2013), the use of multiple morphological areas to identify and resight individuals reduces the likelihood of misidentifications (Gubili et al., 2009; Towner, Wcisel, Reisinger, Edwards, & Jewell, 2013). Side by side comparison of fin silhouettes (dorsal, caudal, or pectoral), ventral pigmentation patterns on pectoral fin tips, and image series or videos of sharks turning and showing both sides were used to link left- and right-hand sides of shark images. Sex was determined based on clasper presence. The size of sharks could not be reliably estimated due to a lack of reference objects in most images.

2.3. Logbook data

Logbook data was obtained from the operator supplying photo-ID images, and was available for two study periods. Due to changes in industry reporting procedures, data from July 2010–December 2011 was derived from CSIRO logbooks (hereafter referred to as 'paper logbook'), and from Fulcrum™ logbooks (hereafter referred to as 'e-logbook') between November 2013–November 2014. Time periods where photo-ID and logbook data overlap are herein referred to as "comparative months" (Table 1). The number of individual sharks sighted each day (hereafter referred to as 'number of sightings') was estimated by experienced SCDO staff based on markings on the sharks' bodies, estimated size, and presence and position of tags. Sex was also recorded based on the presence or absence of claspers determined by both surface and underwater observations. Operators also noted the occurrence(s) of recognisable white sharks within e-logbook based on discernible markings or features. This information was not requested in the paper logbook.

2.4. Data analysis

Analyses were performed using IBM SPSS Statistics (v.23.0). All significance levels were set to $\alpha = 0.05$. Because the logbook data were obtained using two reporting means (paper-logbooks and e-logbooks), comparisons between logbook and photo-ID data were conducted separately for each logbook type in most analyses.

2.4.1. Sampling effort and shark sightings

The difference in the number of days data was collected per month, and the number of sharks sighted per day between photo-ID and logbook data were tested using paired *t*-tests. A linear regression was also used to assess whether a relationship in the number of shark sighted between the two data sources could be determined. Comparison of sex ratios derived from photo-ID and logbook data was performed for each period using a contingency table.

2.4.2. Temporal variation

Temporal variations in the difference in monthly mean number of sharks sighted (referred to as Sightings Per Unit Effort or SPUE) for each sex and for each method was assessed using a full factorial general liner model with sex and methods as fixed factors and month as a random factor. The model was simplified by using a backward-stepwise regression procedure that eliminated non-significant variables or interactions. The assumptions of homogeneity of variances and normal distribution of the data were checked prior to performing the analysis and model validity was determined by a visual inspection of the residuals of the saturated model.

2.4.3. Residency

The ability of photo-ID and e-logbooks to estimate the number of days over which recognisable white sharks were sighted at the

Table 1
Summary of data sets used for analysis based on white sharks (*Carcharodon carcharias*) presence at the Neptune Islands (South Australia) obtained through photo-ID and operator logbooks (paper- and e-logbooks). Time periods where logbook data overlaps with photo-ID data are referred to as "comparative months".

Dataset	2010							2011											
	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December
Photo-ID (full study period)	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X
Paper logbook		X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X
E-logbook																			

Dataset	2013						2014										
	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November
Photo-ID (full study period)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Paper logbook																	
E-logbook					X	X	X	X	X	X	X	X	X	X	X	X	X

Neptune Islands was compared for a subset of 52 individuals with highly discernible markings or features such as missing fin sections. The number of days these sharks were sighted at the Neptune Islands was compared using a linear regression and a paired *t*-test between photo-ID and the e-logbook. Using all photo-ID data (including non-comparative months), the number of days sighted and the period between first and last sighting was calculated for each shark. The frequency distribution of both these metrics was then compared between males and females using the independent samples Kolmogorov-Smirnov tests.

3. Results

3.1. Sampling effort

Photo-ID data was available for 316 days between June 2010–December 2011 and July 2013–November 2014. During this time, 282 individual sharks were identified from 272,583 images. Comparative logbook data was only available for the periods of July 2010–December 2011 (paper logbooks) and November 2013–November 2014 (e-logbooks). Months with both photo-ID and logbooks available (comparative months) provided 266 days' worth of photo-ID data and included 263 individual sharks (32 of which were seen during both comparative periods) (Table 2). Logbook records provided significantly higher sample days (323) than photo-ID (266) (paired *t*-test: $t_{26} = 2.777$, $p = 0.01$), due to markedly higher e-logbook sightings days in 2013–2014 (Table 2; paired *t*-test: 2010–2011: $t_{13} = 0.586$, $p = 0.568$; 2013–2014: $t_{12} = 3.304$, $p = 0.006$).

Photo-ID recorded 1214 shark sightings over the two comparative month periods, compared to 1984 sightings from operator logbooks. A maximum of 14 sharks were sighted in any day through photo-ID, while logbooks recorded a maximum of 17 and 20 individuals for paper- and e-logbooks, respectively. The number of sharks sighted per day over comparative months differed significantly between photo-ID (mean $= 4.56 \pm 0.19$ SE) and logbook data (mean $= 6.14 \pm 0.19$) (Fig. 2; paired *t*-test: $t_{238} = 11.845$, $p < 0.001$), with both methods agreeing on the number of sharks sighted on just 18% of days. During 2010–11, logbook data recorded between −5 and +8 more sightings than photo-ID (mean $= +1.78 \pm 0.17$ SE; paired *t*-test: $t_{143} = -10.54$, $p < 0.001$). During 2013–14, the difference similarly ranged from −6 to +8 more sightings by logbook records than photo-ID (mean $= +1.79 \pm 0.28$ SE; paired *t*-test: $t_{94} = -6.374$, $p < 0.001$). There was no predictable seasonal pattern in the differences between photo-ID and logbook sightings (Fig. 2).

The differences in the daily sightings between photo-ID and logbook methods increased with the numbers of sharks sighted, however the correlation between the two metrics was weak for both the paper-logbook and e-logbook (paper-logbook: $R^2 = 0.62$; e-logbook: $R^2 = 0.48$; Fig. 3).

3.2. Sex ratios

During the first comparative period (2010–2011), sex ratio based on photo-ID (1.84:1 M:F) was significantly different to the sex ratio from paper logbook (2.87:1) (contingency table: $\chi 2 = 16.05$, $p < 0.001$). However, in the second comparative time period (2013–2014), both methods provided similar sex ratios (Photo-ID: 2.98:1; e-logbook: 3.23:1; contingency table: $\chi 2 = 0.43$, $p = 0.51$).

3.3. Temporal variation

Temporal variations in the monthly mean number of sharks was consistent across both methods but varied between sex (Table 3; Fig. 4). Male white shark abundance was highest between November to January, with marked reductions in March and April. The number of female white sharks sighted also showed a strong, albeit opposite seasonal pattern, with a well-defined peak of around four sharks sighted per day between April to July, and few individuals during summer months. As seen in the daily number of sharks (Fig. 4), logbook SPUE was consistently higher than Photo-ID SPUE, but the difference did not change across month or between sex (Table 3; Fig. 4). The low partial eta-squared of the factor *Method* suggests that the difference between methods was small.

3.4. Residency

Fifty-two sharks were identified and individually reported by the operator on e-logbooks, allowing us to estimate residency through both photo-ID and e-logbook. On average, sharks recorded through e-logbooks remained in the area for two days longer than estimates based on photo-ID, with this difference remaining consistent as the number of sighting increases (liner relationship;

Table 2
Summary sighting data of white sharks (*Carcharodon carcharias*) obtained from photo-ID and operator logbook (paper- and e-logbook data) from 2010–2011 and 2013–2014 at the Neptune Islands, South Australia. Total shark numbers are lower than the sum of each period as individuals sighted across both periods are only counted once. Comparative months are those with both photo-ID and logbook data available.

Sighting data parameter	Full study period	Jul 2010–Dec 2011 Comparative months		Nov 2013–Nov 2014 Comparative months	
	Photo-ID[a]	Photo-ID	Paper logbook (CSIRO)	Photo-ID	E-logbook (Fulcrum™)
Effort days	316	161	170	105	153
Number of male sightings	907	432	692	408	759
Number of female sightings	421	235	241	137	235
Number of unknown sex sightings	2	1	6	1	51
Total number of sightings	1330	668	939	546	1045
Maximum number of sightings (per day)	14	14	17	14	20
Number of male individuals	183	86	N/A[b]	109	N/A[b]
Number of female individuals	97	54	N/A[b]	44	N/A[b]
Number of unknown sex individuals	2	1	N/A[b]	1	N/A[b]
Total number of individuals	282	141	N/A[b]	154	N/A[b]
Number of recurring individuals between periods				32	

[a] The full study period encompasses the comparative months (Jul 2010–Dec 2011 and Nov 2013–Nov 2014) and additional months for which logbook data was not available (June 2010, and July 2013–October 2014).
[b] Due to the low number of sharks individually identified on operator logbooks, the number of individual sharks sighted across periods could not be determined from the logbook data.

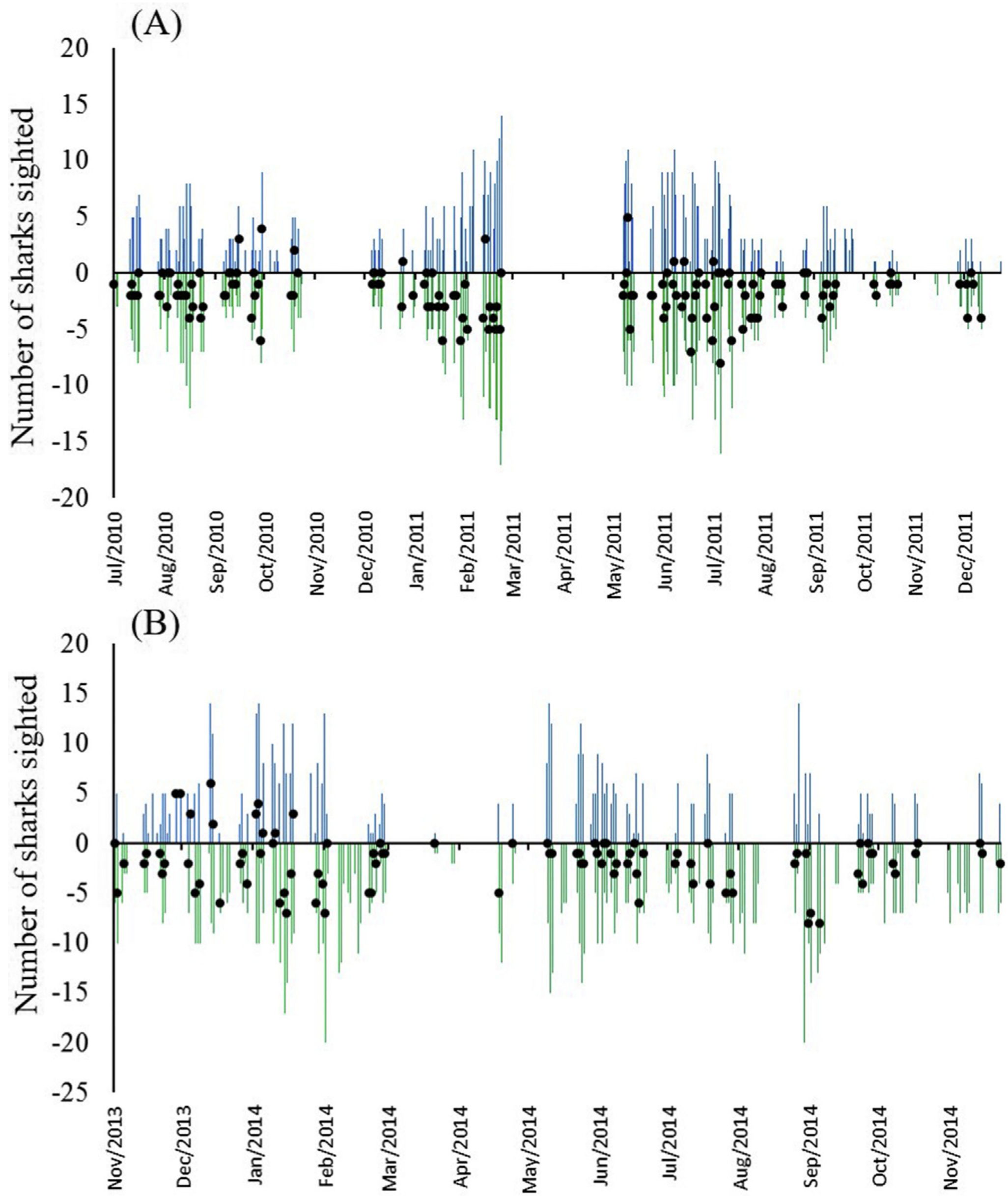

Fig. 2. Number of white sharks (*Carcharodon carcharias*) identified by photo-ID and recorded by operator logbook (paper- and e-logbook data) per day for the periods (A) July 2010–December 2011, and (B) November 2013–November 2014. Blue bars represent photo-ID sightings; green bars represent logbook sightings; black circles represent difference in sighting number between photo-ID and logbook data on days when data was available for both methods. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

$y = x + 2.01$; paired *t*-test: $t_{51} = -3.98$; $p < 0.001$; Fig. 5).

Based on the photo-ID data across the two periods, a more comprehensive record of individuals present at the Neptune Islands could be determined. Here, 75% ($n = 212$) of individuals were observed on multiple days, with the largest number of days sighted being 24 and 22 for males and females respectively (Fig. 6A). Frequency distribution of the number of sightings showed no difference between sexes (independent samples Kolmogorov-Smirnov test: $D_{47} = 0.577$, $p = 0.893$). The greatest number of days between first and last sightings was 1589 days. Sharks were most likely to have between 1 and 4 days between their first and last sightings, although clustering around 300–400 (~1 year), 1050–1150 (~three year) and 1450–1550 (~4 year) day periods indicated that some individuals arrived and left the Neptune Islands at regular frequencies (Fig. 6B). The frequency of days between first and last sighting was not significantly different between sexes (Fig. 6B; independent samples Kolmogorov-Smirnov test value of $D_{211} = 0.530$, $p = 0.941$).

4. Discussion

Ongoing expansion of the Australian white shark cage-diving industry has necessitated a more proactive approach of the industry to collect data and monitor shark population. Shark numbers at the Neptune Islands have traditionally been monitored through logbook records only. Our study compared an alternative photographic identification method to identify the strengths and weaknesses of both methods as a tool for industry monitoring. Both methods detect seasonal sex-biased changes in white shark abundance, however logbooks provide data on more days, and record a

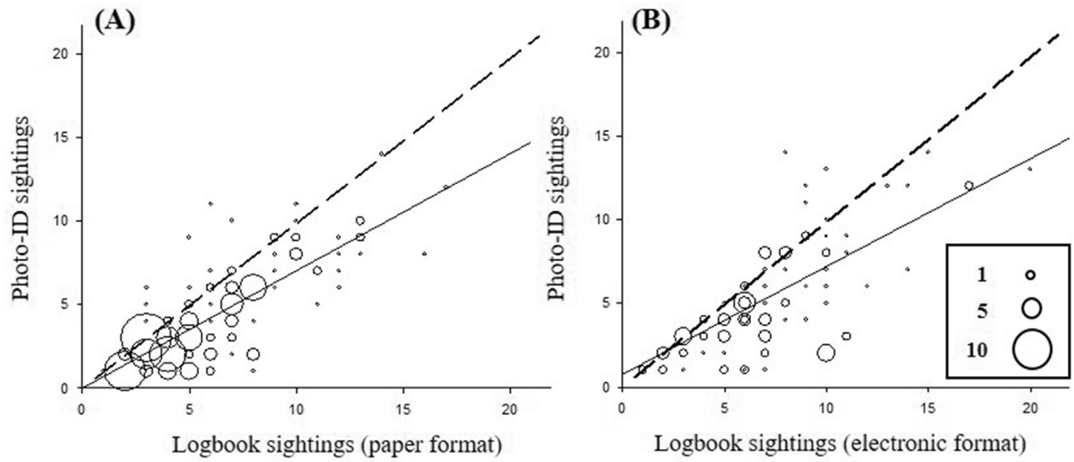

Fig. 3. Number of individual shark sightings compared across photo-ID and logbook data sources for the periods 2010–2011 (A, photo-ID vs. paper logbook; $R^2 = 0.62$) and 2013–2014 (B, photo-ID vs. e-logbook; $R^2 = 0.48$) at the Neptune Islands, South Australia. Dashed black line denotes theoretical 1:1 relationship; solid line represents linear regression; size of circles represent frequency, inset presents bubble scale; data reflects only days where data was available for both photo-ID and logbook data.

Table 3
Summary of the General Linear Model assessing the effects of sex, month, and methods on the monthly mean number of sharks sighted. Non-significant interactions were removed from the model using backward-stepwise regression procedure. df represents degrees of freedom, p-values in bold are significant values ($p < 0.05$), partial eta-squared represents a measure of effect size.

Factors	df	F-value	p-value	Partial eta-squared
Sex	1	4.220	0.064	0.273
Month	11	0.290	0.974	0.225
Method	1	8.506	**0.005**	0.091
Sex x month	11	11.999	<**0.001**	0.639

greater number of sharks sighted than photo-ID data. Photo-ID meanwhile, allows an increased ability to identify individual sharks, which permits a more thorough examination of individual patterns of occurrence.

The need to minimise the impact of tourism on the wildlife it targets is becoming increasingly recognised in wildlife tourism management plans. Accurate and timely reporting of operator activities and interactions with wildlife forms an integral component of managing tourism industries, and self-reporting by the industry is a cost-effective mean to collect such information. In South Australia, the managing authority has developed an adaptive management framework, in consultation with the industry and scientists, based on monitoring the residency of sharks in relation to the activity of the operators, with the latter obtained from self-reported logbooks. Although self-reporting can introduce biases, these can be limited by adequate verification of reporting. In addition to self-interest in maintaining natural resources, tourism industries also increasingly operate under a 'social license,' which is a societal expectation of commercial companies to display willingness to adhere or exceed the requirements of formal regulations (Cullen-Knox, Haward, Jabour, Ogier, & Tracey, 2017). This concept requires operators and industry to demonstrate a commitment to minimize their impacts and embrace reporting requirements that regulate their industry. Failing to do so will inevitably result in

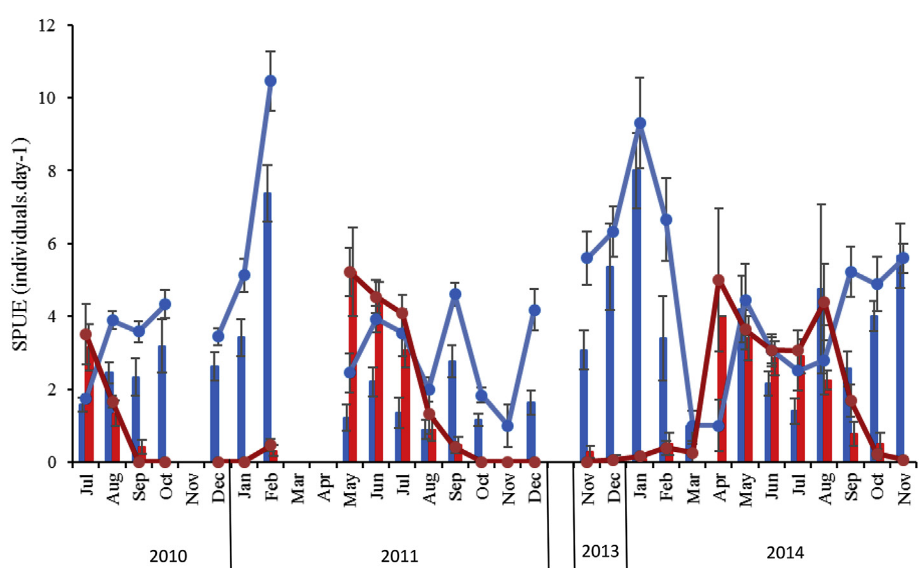

Fig. 4. Monthly Sightings Per Unit Effort (SPUE; indiv$\cdot$day^{-1}) of white sharks identified by photo-ID (bars) and logbook (line) methods. Blue represents males; red represents females. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

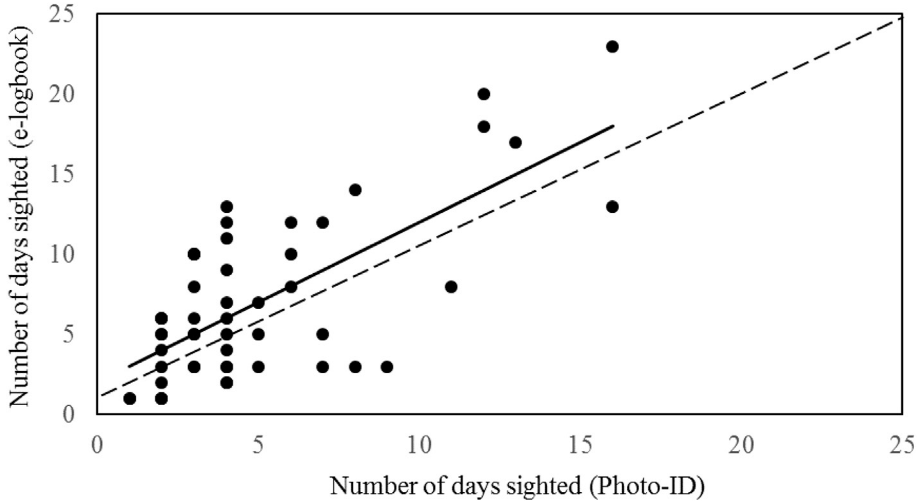

Fig. 5. Number of days sighted for recognisable sharks (residency) compared between photo-ID and e-logbook from the 2013–2014 period. Dashed black line denotes theoretical 1:1 relationship; solid line represents linear regression.

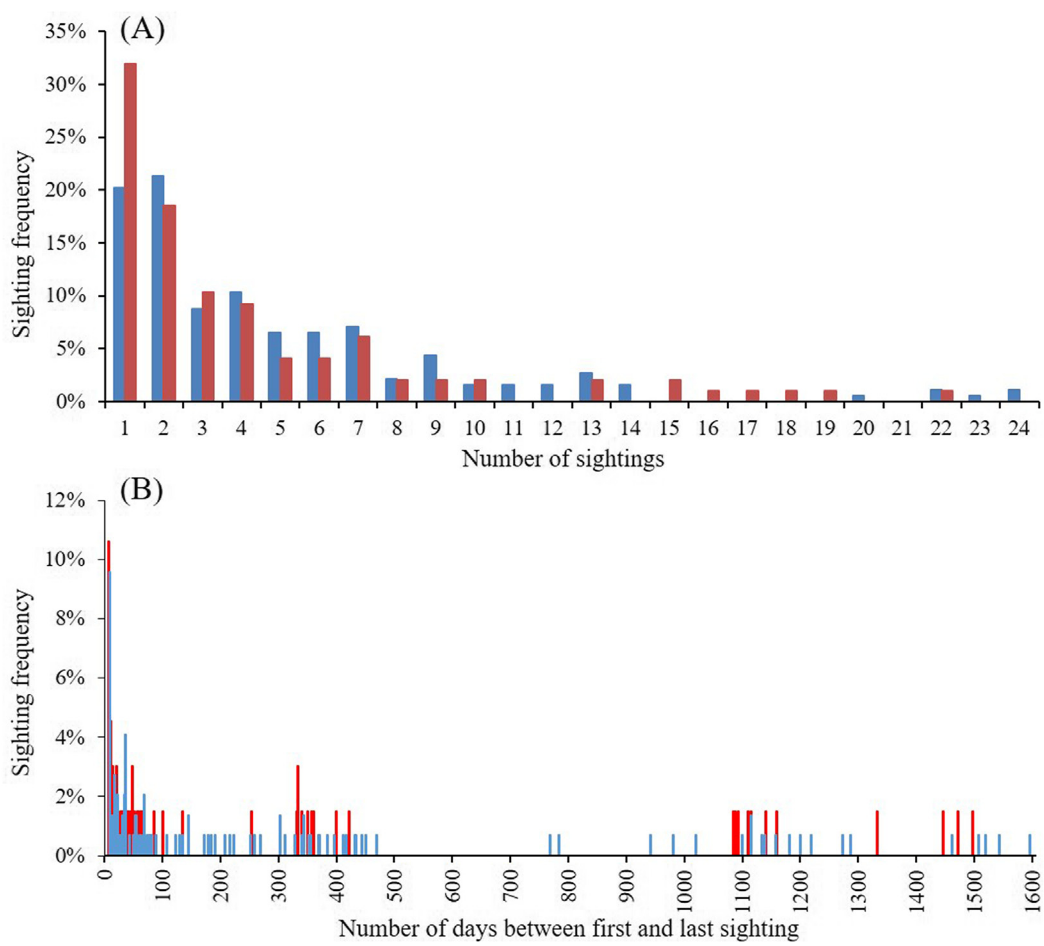

Fig. 6. (A) Sighting frequency by sex of photographically identified individual white sharks (*Carcharodon carcharias*) and (B) number of days between first and last detection over two study periods (2010–2011, 2013–2014). Blue bars represent males; red bars represent females. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

strengthening calls for the industry to be further restricted, or at worst to be shut down. This is especially the case for the use of marine resources, where social licenses have increasingly influenced government decisions (Cullen-Knox et al., 2017).

In the case of the South Australian white shark cage-diving industry, the question regulators and government face is what is the most appropriate tool(s) to monitor the industry? Mandatory daily logbooks should accurately represent the number of days which operators are present at the Neptune Islands, including days with zero shark sightings reported. This information is not possible to discern from photo-ID alone, as photograph-free days may reflect an absence of sharks, or an absence of photographs capturing animals present. The greater number of logbook days than photo-ID in the second comparative time period may, therefore, either reflect poorer photographing conditions, or a decreased interest or motivation from the photographer. Weaning of interest often occurs when data is collected by the general public, such as in citizen-science projects (Huveneers, Luo, Otway, & Harcourt, 2009). If photo-ID is to be considered as an ongoing method to monitor white shark populations, appropriate mechanisms are necessary to ensure that shark-free days are differentiated from days when sharks are present, but no photographs are collected. However, this could be as simple as a standardised “null” photograph to indicate the date of any shark-free days.

Logbook reporting identified a greater number of sharks than photo-ID, which may be occurring for two, non-mutually exclusive, reasons. Operators may report individual sharks as multiple individuals, due to difficulties in ascertaining their identity. Alternatively, photo-ID may underestimate the number of sharks present due to the difficulties of capturing a suitable image of each shark present each day. The differences between photo-ID and logbook reporting are not systematic, preventing extrapolation of the number of sharks present between methods. Prior to the implementation of e-logbooks (allowing identity of individual sharks to be recorded), photo-ID was the only method to obtain information about individuals. However, e-logbook reporting of individuals was only possible for easily-recognisable sharks, providing residency information for approximately one third of sharks identified through photo-ID within the same period. Although photo-ID identified a greater number of sharks, sharks were sighted for less days compared to e-logbooks. This might be due to the need for the operator to take a suitable photograph of the shark to allow recording through the photo-ID method, while a single sighting of the individual is enough to be recorded on the e-logbook. Alternatively, *in situ* shark identification can over-estimate residency because of similar-looking sharks if sufficient time and care is not taken with every identification.

Identification of individuals over extended periods allows the residency of individuals to be assessed (Bruce & Bradford, 2012; Delaney et al., 2012; Robbins et al., 2015). The residency and period between first and last sighting of sharks identified using photo-ID concurs with previously suggested white shark movement patterns in Australia, showing that white sharks can undertake large-scale seasonal migrations interspersed with periods of temporary residency (Bruce et al., 2006; McAuley et al., 2017). While some individuals showed extended durations at the Neptune Islands, others were only sighted on a small number of occasions, suggesting that two types of individuals may be visiting the Neptune Islands: temporary resident and transient sharks. Although industry-based estimates likely err on the conservative side, with animal sightings limited to times the SCDOs are on site, these findings support previous movement patterns found using acoustic telemetry at and around the Neptune Islands area (Bruce & Bradford, 2013; Robbins et al., 2015). Photographic records can also be used for network analysis to determine the strength of movement patterns among individuals (Jacoby, Busawon, & Sims, 2010; Mourier, Vercelloni, & Planes, 2012). The use of photographic records can further be used as a form of tag-recapture data to estimate population sizes (Kanive et al., 2015; Towner et al., 2013). None of these analyses can be performed using logbook data alone.

Both photo-ID and logbook data detected an overall male bias. Sex ratio was similar between the two methods in the second period, but in the first period paper-logbook suggested a greater sex ratio bias than found with photo-ID. This was due to paper-logbook recording the same number of females but more males than photo-ID. The reason for such discrepancy between the two periods is unknown. Highly predictable seasonality has been documented in white shark presence at most aggregation sites (Domeier & Nasby-Lucas, 2008; Klimley et al., 1992; Kock et al., 2013). Although white sharks can be observed at the Neptune Islands throughout the year, seasonal variation in the abundance of males and females was detected by both methods. The peak male and female sightings during the austral summer and winter, respectively, paralleled previous studies in the region (Bruce & Bradford, 2015; Robbins & Booth, 2012), giving us confidence in both methods to detect such broad trends. The timing of peak female sightings at the North Neptune Islands in winter coincides with the weaning of resident long nose fur seal pups (*Arctocephalus forsteri*) when they venture away from the protection of rock pools (Robbins, 2007; Shaughnessy & McKeown, 2002). In contrast, male abundance is highest when the larger females are not present.

Photo-ID provides a higher level of identification accuracy than logbook data, and provides a permanent visual record of individuals. However, it requires considerably more resources to process images. Photo-ID analysis for the present study was undertaken by two near full-time staff, assisted by 10 volunteers over 12 months. Automated and semi-automated systems have been developed to reduce the time-consuming labour required to manually go through and identify individuals from photo-ID (Hughes & Burghardt, 2017; Van Tienhoven, Den Hartog, Reijns, & Peddemors, 2007). Many of these systems, however, rely on only one identifying feature (e.g., dorsal fin shape), limiting the photos that could be used to identify white sharks. Trials using automated systems led to a reduced the number of identified white sharks compared to the manual method due to photos which were unsuitable for the automated system being sufficient to manually identify individuals using a combination of features. Both photo-IDs and visual identifications for logbooks are affected by water visibility, inadequate field-of-view, or body distortion due to shark movements, resulting in heterogeneity in capture probability, i.e. differences in the likelihood of individuals to be identified (Marshall & Pierce, 2012; Speed, Meekan, & Bradshaw, 2007). However, photo-ID images would likely be analysed well after the time the images were taken. Thus, the ability to accurately identify an individual would be hampered by the photo-ID reviewer being reliant on only the images in front of them, rather than being there at the time. However, this method does allow reviewers to study the images at a more relaxed pace and in a more controlled environment than real-time observers. Biases in conditions and techniques may be avoided by using methods not requiring visual identification such as acoustic telemetry (e.g., Dudgeon, Pollock, Braccini, Semmens, & Barnett, 2015).

Our study provided a valuable comparison of the data obtained from the logbooks and photo-ID of a single SCDO. This operator was selected based on their consistent high-quality photographs. The quality of images and their suitability for photo-ID will, however, vary between photographers. This reduces our ability to generalise the findings from this study to other situations, and highlights the need for high-quality images when using photo-ID. Collection of such images is often reliant on non-research individuals, and while we were fortunate, the opportunity here will not always be present. We were also unable to collect data throughout the entire study period, with no images available between December 2011 and July 2013 due to the photographer not being present on cage-diving trips. This further demonstrates the limitation of this method when relying on individuals outside the control of researchers. We were, however, still able to collect data across 29 months which was sufficient to compare monitoring methods. Future studies should compare the quality of photographs obtained from different photographers or operators to determine the influence of photograph quality on the data collected from photo-ID.

Daily logbooks may not give the same level of detail as photo-ID, but provide an inexpensive and rapid record of shark numbers and sexes, an ongoing account of relative shark abundance (Bruce & Bradford, 2013), and can provide information about residency of easily identifiable sharks. The electronic Fulcrum™ application better suits the needs of the SCDO crew members (Fox pers. comm. 2015), due to its ease of use, time-efficiency, and real-time online data upload. The success of the logbook system implemented in South Australia is noted for its ability to yield accurate and practicable data for long-term studies of the industry (Bruce & Bradford, 2013, 2015), and is currently being recommended to replace traditional paper-format versions in California, Mexico, New Zealand, and South Africa (Bruce, 2015).

We demonstrate that both photo-ID and industry logbooks can provide valuable information key to understanding and monitoring the presence of white sharks at the Neptune Islands. Photo-ID provides the benefits of tracking total shark numbers in the area over time, determining individual long-term site use, and facilitation of further analysis such as network analysis or mark-recapture studies. However, the overriding limitation of this technique is the processing time required. In contrast, logbooks are completed on a daily basis in the field, and are a less-demanding approach for the continual monitoring of the number and sex of sharks over time. Ancillary information such as global positioning system (GPS) position, time of shark occurrences, estimated shark size, quantity of bait/attractants used, and shark behaviour can also be incorporated into the logbooks. The choice of the best method depends on what information is required and the costs involved. Based on the results from the present study, the following is proposed as the most efficient means to monitor white sharks cage-diving industries:

1) Logbook data (preferably electronic) is the optimum long-term monitoring method for white shark cage-diving in terms of cost and efficiency, and should be the primary means to monitor this tourism industry. This system is the fastest survey method, data is available with minimal delay, and it allows additional information such as sex and size to be collected. While operators are comfortable with estimating shark size (Fox & Wright, pers. comm.), these estimates should be validated to ensure accuracy. This system also allows the opportunity to record other variables such as time sighted, approximate proximity to the boat, attractant used, and bait consumption. However, care must be taken not to request too much information from operators, to ensure the reliability of information reported.
2) Although shark numbers should primarily be monitored through logbook records, a photographic database of white sharks should also be periodically maintained to enable estimates of residency and relative population size. Consistent data collection is essential over time to ensure accurate capture of new and recurring individuals. However, due to the time commitments of updating such a database, a 12-month photo-ID study could occur every 2–3 years.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.tourman.2017.12.002.

Author contribution

CH and WR designed the study, LN and AS processed the photo-IDs, LN and CH analysed the data, LN, CH, and WR wrote the manuscript.

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