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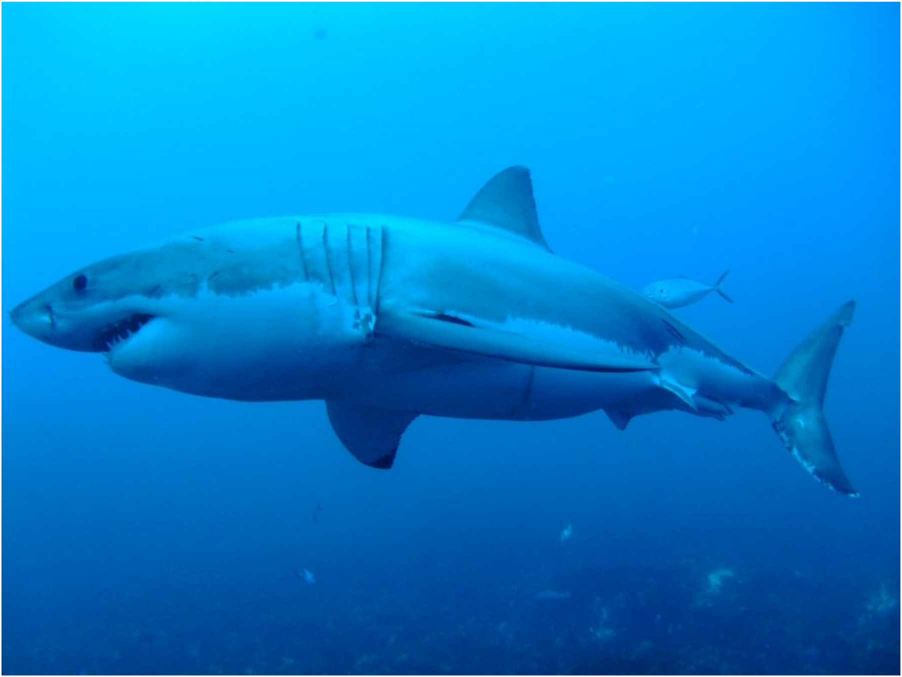
Monitoring residency of white sharks, *Carcharodon carcharias* in relation to the cage-diving industry in the Neptune Islands Group Marine Park



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SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

December 2014

Report to the Department of Environment, Water and Natural Resources

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This project was carried out under the Department of the Environment and Natural Resources permits Q26216-1 and Y26308-1, and PIRSA Exemption ME9902693. Tagging was undertaken under Flinders University ethics approval E398 and PIRSA Animal Ethics Committee permit 15/14.

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2. CONTRIBUTIONS

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Images - Calypso Charters, Adventure Bay Charters.

3. GLOSSARY

Array: Geographical area in which tagged organisms are likely to be detected by the acoustic receivers deployed within the area.

Berley: Fish based products used to create an odour trail to attract sharks.

Decision rules: Agreed management response according to a predefined circumstance or set of circumstances.

Detection: A set of pulses produced by transmitters, which is recognised and recorded by acoustic receiver.

Detectability: Ability of the acoustic receiver to detect the set of pulses produced by transmitters and to recognise it as valid. Detectability is affected by environmental conditions and distance between receivers and transmitters.

Detected residency index (RId): Calculated by dividing the number of days a shark was present by the total period during which sharks were detected.

False detection: When pulses from multiple transmitters are detected by a receiver at the same time and collide, leading to a “detection” that appears valid, but was never transmitted.

Highly Migratory Species: Species which perform cyclical movements between distinct geographical areas, some of which are coastal and oceanic regions that may represent breeding, foraging and aggregation areas.

Receiver: Acoustic monitor deployed underwater that listens for pulses produced by acoustic transmitters. When transmitters are within the detection range of the receivers, which varies with transmitter power and environmental conditions but can be up to 800–1000 m, the receivers records the identification number of the transmitter and time and date at which the pulse was received.

Residency period: Number of days between the first and last detection of a tagged shark, without any gaps in consecutive days of detection exceeding five days.

Residency index: Index quantifying the presence of tagged organisms by estimating the percentage of days an organisms was detected within a specific timeframe, e.g. between tagging and last detection. A value of 0 indicates that organisms were never detected and a value of 1 indicates that organisms were detected every day throughout the chosen timeframe.

Standardised detection: Number of detections standardised to account for the variability in detection probability.

Sentinel tags: Transmitter deployed for the purpose of monitoring temporal changes in detection probability.

Teaser bait: Baits tethered under floats at the surface to attract sharks near boats

Transmitter: Acoustic tag deployed on organisms to monitor their movements and residency. Transmitters produce a set of pulses every pre-determined intervals (e.g., every 2 minutes), which can be detected by acoustic receivers.

Overall residency index (RIo): Calculated by dividing the number of days a shark was present by the monitoring period, defined as the number of days between date of tagging and last download.

Radio-acoustic positioning system: Radio-acoustic positioning system that consists of three buoys deployed in a near equilateral triangle, and a shore station in line of sight. Buoys have a multi-directional hydrophone that detects acoustic signals from transmitters. The information is transmitted to a shore station via radio signals where the latitude and longitude of tagged animals is estimated based on arrival times of acoustic pulses at each buoy

4. EXECUTIVE SUMMARY

This report provides a summary of information on the implementation and evaluation of three methods for estimating residency of white sharks (*Carcharodon carcharias*) to monitor relationships with cage-diving tourism activities at the Neptune Islands Group Marine Park. It covers the monitoring period between September 2013 and July, 2014.

The methods implemented included acoustic telemetry, an electronic logbook (hereafter referred to as e-logbook) and web-linked data collection application, and a photo-ID catalogue using video and images provided by the operators.

Residency at the North and South Neptune Islands

Between 14 September 2013 and 28 February 2014, 15 white sharks ranging in size from ~200–450 cm total length were monitored using satellite-linked acoustic telemetry at the Neptune Islands.

Acoustically tagged white sharks exhibited individual variation in residency.

Residency periods of white sharks within the Neptune Islands (North and South combined) ranged from <1 to 117 d (mean = 12.6 ± 22.6, s.d).

Overall residency period was 11.9 ± 23.5 d at the North Neptune Islands.

The number of residency periods ranged from 1–6 days.shark^{-1}.

Most white sharks exhibited shorter (mean = 2.4 ± 3.6 d) residency periods at the South Neptune Islands compared with at North Neptune Island.

Estimates of residency at the Neptune Islands in 2013–14 were similar to those reported for 21 white sharks ranging in size from 2.8 to 4.8 m between December 2009 and April 2011 (Bruce and Bradford 2011). Those individuals had residency periods ranging from 1–92 d (mean = 21.0 ± 24.2 d) at the Neptune Islands (combined) (Bruce and Bradford 2011).

Electronic logbook

An electronic logbook (e-logbook) using iPads and the on-line Fulcrum™ application was developed and implemented with the assistance of the operators to provide daily data on the number of shark sightings and aspects of cage-diving operations.

The number of individual white sharks sighted by the three operators ranged from 0 to 20 sharks per day. The mean number of white sharks sighted per day during the reporting period was 5 ± 3.5 sharks.

A total of 1,364 hrs of berleying was reported across the industry.

Berley used to attract white sharks to cages included mince and frozen blood from southern bluefin tuna (*Thunnus maccoyii*).

Operators reported the use of 220 L of frozen tuna blood, 3,390 L of minced tuna and 5,920 L of 'unspecified tuna berley'.

Teaser baits used at the surface comprised either portions of whole southern bluefin tuna, or gills and entrails. A total of 100 southern bluefin tuna (~1.7 t) were used as teaser baits. A total of 323 individual Nally™ bins of frozen bins of gills and entrails (median wt per bin = 35.55 kg ea) were used at the surface for an estimated weight of 11.5 t.

Sound emission was reported to be used at the Neptune Islands for a total of 267 hours. Daily durations ranged between 1–7.25 hours (mean = 4.7 ± 1.5 hrs).

Establishment of an industry-based photo-ID catalogue

A catalogue of 162 individual sharks was created from digital images submitted by two operators. Images were obtained on 121 days between November 2013 and June 2014.

A total of 141 profiles require collection of additional left- and right-hand side images, and/or images of multiple characteristics.

Reliable and complete photo-ID profiles were created for 21 white sharks.

The mean daily number of white sharks recorded by operators was higher in the e-logbooks than determined from the photographs.

Preliminary results show that use of photo-ID in conjunction with satellite-linked acoustic telemetry and e-logbook data has potential to reduce sources of uncertainty associated with estimation of white shark residency.

Conclusions

The current SARDI program aims to evaluate acoustic telemetry data for a target of 50 white sharks by 2016. It will also integrate e-logbook and photo-ID data to estimate the annual fluctuations and confidence bounds associated with the size of the white shark population that visits the Neptune Islands Group Marine Park.

These steps will address the gaps in information required to undertake quantitative assessments of impacts of cage-diving activities on white sharks that visit the Neptune Islands Group Marine Park.

On the basis of the current body of knowledge of this industry, SARDI recommends that DEWNR: 1) continues to support monitoring of residency, behaviour and associated energetic requirements of white sharks in relation to human activities; 2) establish industry-governmental data-sharing arrangements pertaining to the use of images for identification and assessment of relative abundance of white sharks; 3) facilitates the revision of management decision rules that incorporate improved behavioural indicators in the *Great White Shark Tourism Policy*, and associated management documentation for the Neptune Islands Group Marine Park.

5. INTRODUCTION

5.1. Background

The white shark (*Carcharodon carcharias*) is protected under the *Fisheries Management Act* (2007) in South Australian State managed waters, and by the Australian Commonwealth Government *Environmental Protection, Biodiversity and Conservation Act* (1999) in Commonwealth waters. The species is also listed as Vulnerable under the International Union for Conservation of Nature Red List, and under International treaties of which the Australian Commonwealth Government is a signatory, including the *Convention on International Trade in Endangered Species, of Wild Fauna and Flora*, and *Convention on Conservation of Migratory Species of Wild Animals*. Australia is a signatory country to the *International Memorandum of Understanding (MOU) on the Conservation of Migratory Sharks*. The white shark is listed in Annex I of that MOU, of which the objectives include: to improve the understanding of migratory shark populations through research, monitoring and information exchange; to ensure that directed and non-directed fisheries for sharks are sustainable; to ensure to the extent practicable the protection of critical habitats and migratory corridors and critical life stages of sharks; to increase public awareness of threats to sharks and their habitats; to enhance public participation in conservation activities; and to enhance national, regional and international cooperation. Threats outlined in the *Recovery Plan for the White Shark* include the illegal trade for jaws and other derived products, mortality during shark control activities, bycatch in fisheries and cage-diving (Department of the Environment 2013). It is expected that cumulative human impacts can lead to consequences for long-lived, slow growing populations with low reproductive potential that have both migratory and residential contingents that exhibit predictable site fidelity.

Photo-identification can be used to estimate the fidelity of a species to a given location or region. This method relies on the premise that distinguishing markings are temporally stable (Stevick *et al.* 2001), and is considered to be most reliable when multiple physical characteristics and both sides of animals can be recorded (Domeier and Nasby-Lucas 2006). Photo-identification has previously been used to collect data on residency (Klimley and Anderson 1996), and movements, of white sharks (Anderson and Goldman 1996; Bonfil *et al.* 2005). Most studies use identifying characters such as distinguishing pigmented spots on dorsal and caudal fins, gill flaps, scars and other markings (Domeier and Nasby-Lucas 2006). Catalogues based on various combinations of images of dorsal fins, scars, and pigmentation on lower caudal fins have been established in the eastern Pacific (73 individuals) (Domeier and Nasby-Lucas 2006), South Africa (84 individuals) (Gubili *et al.* 2009), North-eastern Pacific Ocean (130 individuals) (Chapple *et al*. 2011), and South Australia (76 and 306 individuals, respectively) (Beckmann 2008; Robbins and Fox 2012a).

Elasmobranchs have well developed cognitive abilities and can associate human activities with provisioning, which may lead to impacts on individuals and their populations (Orams 2002; Clue *et al.* 2010). Shark behaviours that manifest as measurable periods of residency have been a key focus of research and monitoring of white sharks in South Australia (SA) for over a decade (e.g. Strong *et al.* 1996). Shark-related tourism has a long history and tourists have visited SA to see white sharks at the Neptune Islands since the 1970's. The SA white shark cage-diving industry was valued at $6M AUD to the regional economy in 2011 (Bradford and Robbins, 2013). Licensing arrangements are managed by the Department of Environment, Water and Natural Resources (DEWNR), and permits to discharge berley are managed by Primary Industries and Regions SA (PIRSA) Fisheries and Aquaculture. A need to assess potential ecosystem and population impacts of industry activities on this protected species became increasingly important since the establishment of SA's network of Marine Parks; the white shark cage-diving industry operates in the Neptune Island Group Marine Park in the North Neptune Island Sanctuary Zone (SZ).

Previous satellite and acoustic telemetry studies suggest white sharks use a broad range of inshore coastal, continental shelf and oceanic habitats in the Great Australian Bight (Bruce *et al*. 2006) where they are associated with haul-outs and breeding colonies of the Australian sea lion *Neophoca cinerea* and New Zealand fur seal *Arctocephalus forsteri* (Bruce 1992; Strong *et al*. 1996; Bruce *et al.* 2005, 2011; Bruce and Bradford 2013). Predation on these pinnipeds is a major cause of injuries to Australian sea lion with 182 cases over 15 years being attributed to predatory encounters at a single colony on the south coast of Kangaroo Island (Shaunghnessy *et al.* 2007). Although there has been considerable investment in research on white sharks in South Australian waters, there are still substantial gaps in available information pertaining to the movements and habitat use in the Great Australian Bight, Spencer Gulf and Gulf St Vincent.

Long-term research programs based on acoustic telemetry and industry log-books provided residency estimates at the Neptune Islands that suggested cage-diving activities impacted the behaviour of white sharks (Bruce and Bradford 2011, 2013). Acoustic telemetry techniques have provided a vital decade-long information base-line with which to compare the results of future assessments of residency behaviour in relation to the cage-diving industry. White shark cage-diving activities have also been linked to changes in site-specific behaviour over small spatial scales (Huveneers *et al.* 2013). Management responses, including restrictions on numbers of operator licenses, operator days, and berley permits have reflected uncertainty associated with the impacts on shark behavior, and the need for ongoing assessment and development of suitable indicators and trigger points. Currently, the white shark cage-diving operators have an annual limit on the number of operator days ($200.\text{year}^{-1}$). Two operators, hereafter referred to as OP1 and OP2, have no limitations in terms of volumes of berley or the number of teaser baits that can be discharged over those days. One operator (OP3) does not use berley and uses underwater sound as an attractant. This practice has not previously been assessed.

5.2. Aims and Objectives

This report provides a summary of information on the implementation of three methods for estimating residency and quantifying behavioural impacts of cage-diving activities on white sharks at the Neptune Islands Group Marine Park. SARDI Aquatic Sciences was contracted by DEWNR to report on the monitoring period between September 2013 and July 2014.

Specific aims of this report were to:

1) Implement and compare the suitability of three methods for assessing the residency of white sharks that visit the Neptune Islands Group Marine Park. These included satellite-linked acoustic telemetry, a web-linked electronic logbook (hereafter referred to as the e-logbook), and photographic identification using digital video and photographic images provided by the operators.

2) Develop indicators of residency of white sharks that can be compared to historical patterns in the Neptune Islands Group Marine Park.

3) Use the methods in 1 and 2 to provide insights into the behavioural effects of cage-diving activities, on individual white sharks that visited the Neptune Islands Group Marine Park in the 2013–14 reporting period.

6. METHODS

6.1. Reporting period and geographical area

This report covers the period between 14 September 2013 and 30 June 2014. The Neptune Islands Group is located near the approach to Spencer Gulf, ~30 nm from Port Lincoln, South Australia, and 14 nm from the southern Australian mainland (Fig. 1). The group comprises the North and South Neptune Islands which are ~12 km apart. In 2014, the Neptune Islands were included within the South Australian Marine Park Network and named the Neptune Islands Group (Ron and Valarie Taylor) Maine Park. The North Neptune Islands have a Sanctuary Zone and a Restricted Access Zone that are within a broader Habitat Protection Zone. The South Neptune Islands have a Restricted Access Zone that is also within a broader Habitat Protection Zone (Neptune Islands Group (Ron and Valarie Taylor) Marine Park Management Plan Summary 2014). Cage-diving operators anchor in two bays, Action Bay and Main Bay at the North Neptune Islands, and in the eastern bay at the South Neptune Islands (Fig. 1).

6.2. Acoustic telemetry

Three satellite-linked VR4-Global near-real time acoustic receivers (Amirix, VEMCO Ltd., Halifax, Canada) were deployed within the Neptune Islands Group Marine Park using a similar mooring system to that described by Bradford *et al*. (2011). VR4-Global units use an Iridium satellite modem to remotely access detection data and send email notifications of tagged shark detections. One VR4-Global receiver was deployed at each of the main berleying sites at the North Neptune Islands group (Main Bay and Action Bay) and one at the South Neptune Islands group (Fig. 1). White sharks were tagged with V16-6H acoustic transmitters programmed to send signals at random intervals of 70–150 seconds (VEMCO Ltd., Halifax, Canada). Tags were deployed throughout the monitoring period depending on the number of sharks reported at the study site. Tags were tethered to a Domeier umbrella dart-tag head using a 10- to 15-cm-long stainless wire trace (1.6 mm diameter), and implanted in the dorsal musculature of sharks using a modified spear-gun applicator.

A

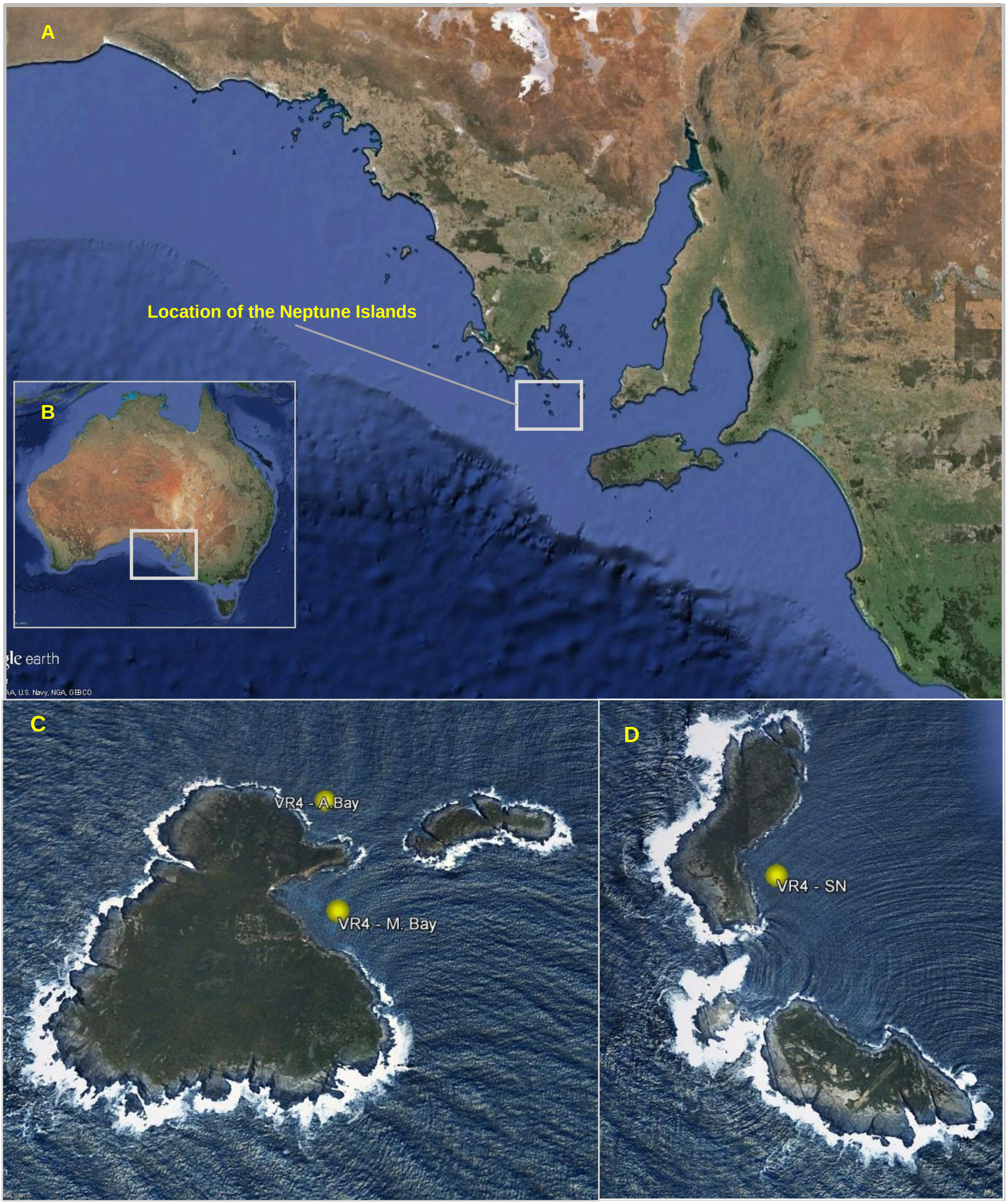

Figure 1. Map A shows the location of the North and South Neptune Islands in continental shelf waters off South Australia (inset B). Map C shows the North Neptune Islands and the locations of two VR4 acoustic receivers in Action Bay (A. Bay) and Main Bay (M. Bay). Map D shows the South Neptune Islands and the location of a single VR4 acoustic receiver (VR4-SN). (Images sourced from Google Earth Pro).

Detection summary and residency index

Tagged white sharks were considered ‘present’ in the array if detected at least twice within a 24-hour period. This eliminated the possibility of ‘false detections’ that can occur when there are multiple acoustic tags present within range of an array of receivers (Pincock 2011). Daily detection summaries were plotted to examine the pattern of overall presence of tagged sharks during the study period. For each of the North and South Neptune Island sites and combined regions, site fidelity of each tagged shark was quantified using two residency indices (RIs). The overall residency index (RI_o) was calculated by dividing the number of days a shark was present by the monitoring period, defined as the number of days between the date of tagging and the last download. When sharks were known to have shed their tag or died, the monitored period was calculated based on the last day individual sharks were sighted with their tags or the date of death. The detected residency index (RI_d) was calculated by dividing the number of days a shark was present by the period during which sharks were detected. The two residency indices were used because sharks can potentially either shed their tags or die. This can lead to under-estimation of RI_o, whereas use of RI_d can lead to over-estimation as this index does not account for individuals that naturally leave the monitored sites. The use of both estimates of residency accounted for potential biases, given that the ultimate fate of tags and tagged organisms is unknown. A value of 0 indicated no residency and a value of 1 indicated 100% residency.

Residency periods

For each tagged white shark, the number of consecutive days that individuals were present was calculated each time they entered the study area. A residency period was defined as the number of days between the first and last detection of a tagged shark, without any gaps in consecutive days of detection exceeding 5 days. A five-day period was selected on the basis of estimated transit times between the North and South Neptune Islands (Bruce and Bradford 2013). Where sharks were not detected over periods of >5 consecutive days, individuals were assumed to have left the Neptune Islands and any subsequent return was considered to represent a new residency period. Residency periods were estimated according to Bruce and Bradford (2013) to ensure findings were comparable with the historical timeseries.

Temporal variations in detection

The hourly temporal dynamics of shark residency were assessed for each shark by comparing the number of detections within each location per hour. Acoustic detectability can be affected by environmental conditions potentially biasing the probability of detecting a tagged shark in the proximity of a receiver (Payne *et al*. 2010; Gjelland and Hedger 2013). Five sentinel tags were deployed within the array for various durations to determine any temporal variation in acoustic detectability. To account for diel patterns in the number of detections, a corrected detection frequency for each hour was calculated for each sentinel tag using the formula of Payne *et al.* (2010):

$$\mathrm{CDF}_b = \frac{B_b}{\mu}$$

Where CDF is the corrected detection frequency for each hourly bin (b), μ is the overall mean hourly detection frequency and B is the mean detection frequency in each 24-hour bin for the sentinel tag. The total detection frequency of each hourly bin was divided by the CDF of the corresponding hourly bin from the sentinel tag (Payne *et al*. 2010), and is thereafter referred to as standardised number of detections. The standardised number of detections was calculated for each shark to avoid those with the most detections biasing investigation of temporal variation. Due to the strong diel variations in detection probability, timing of arrival and departure could not be estimated as it might have been biased by the differences in detection probability rather than actual arrival or departure of sharks at the Neptune Island Group.

Relationships between daily detections and cage-diving activity

The relationship between cage-diving activity and residency of white sharks was assessed by comparing the number of detections per day between days during which at least one operator was present (referred to as activity days) to days during which no operators were present (referred to as non-activity days). For each tagged shark, the number of detections was estimated for each detected day and categorised as being either from an activity or non-activity day using information provided in the operators' e-logbooks. For each activity and non-activity day, the mean number of detections was calculated for each shark. The same was then performed using a finer evaluator of cage-diving activity. Instead of comparing activity vs. non-activity days, the mean number of detections was compared according to the number of operators present and types of attractant used.

Specifically, we compared the number of detections when (1) no operators were present, (2) one berley operator was present, (3) one sound operator was present, (4) two berley operators were present, (5) one berley and one sound operator were present, and (6) all operators (two berley and one sound) were present. The relation between cage-diving industry activity and presence of sharks was also assessed by comparing the standardised number of detections for each hour on activity and non-activity days. Assessments were performed for the North and South Neptune Islands separately to allow comparison between the two locations.

6.3. Electronic Logbooks

Cage-diving operators were each issued with a mini-iPad loaded with the Fulcrum^{TM} application to input daily electronic logbook (e-logbook) entries. Regular follow-up telephone conversations took place between SARDI (C.B.) and white shark cage-diving operators for validation and quality assurance purposes.

The following parameters were recorded by operators during cage-diving activity days:

- Date
- Anchored location
- Time of arrival/departure
- Berleying start/finish time
- Amount and type of berley dispensed
- Number of teaser baits used
- Number of white sharks sighted

Appendix 1 shows the details associated with each of the parameters entered by operators during the reporting period. The number of pieces of tuna, gills and entrails used at the surface was used to estimate the number of teaser baits used. All estimates are considered to be conservative as not all days were completed for all parameter fields.

6.4. Photo Identification

Photographs were submitted by operators OP2 and OP3 as shark sightings through the e-logbook, or as a DVD of images for each individual trip. Photographic images were also obtained from video operated by cage-divers. No photographs were obtained from OP1. Date and location were recorded for each image. Photographs were analysed to determine how many individual sharks were sighted per day by each operator. Distinguishing marks, scars, tag locations and pigmentation patterns were compared to identify individuals as outlined in Domeier and Nasby-Lucas (2006). Sex was determined where possible through presence/absence of claspers. Underwater video was used by operators to record ~2 hours of footage twice per month. Footage was used to identify sharks using characteristic markings (Fig. 2). A photo-ID catalogue was created that included images of each individual linked to documented physical characteristics. Key words were included in the database to assist with searches and match known individuals. These included white lower caudal, white spot dorsal, caudal spot, and scarred gills. Dorsal fin profiles were not examined due to low image quality and a low number of photographs taken from above the water-line. Profiles were considered to be complete when quality images of the gills, pelvic fin and caudal fin zones were collected (Fig. 3). Profiles are now expected to be built on as sharks are re-sighted. Sharks were given independent identifier codes to link images by date. If there were only images of one side of an individual, the identification was deemed incomplete until further sightings/images to verify identifications. Estimates of total lengths were made when objects of a known-size were near observed and photographed sharks.

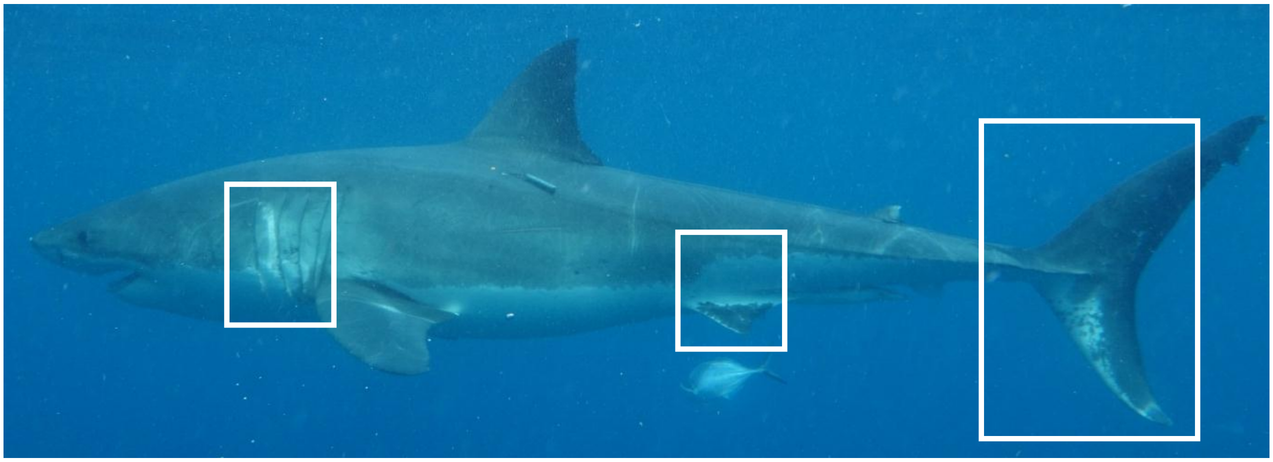

Figure 2. White shark showing characteristic pigmentation patterns on gill flaps, pelvic fin and lower caudal fin.

7. RESULTS

7.1. White shark residency

A total of 15 white sharks ranging in size from ~200 to 450 cm total length were tagged at the Neptune Islands between 14 September 2013 and 28 February 2014. Table 1 provides a summary of the deployment data for each tagged shark. All white sharks tagged were detected between September 2013 and June 2014; a total of 25,217 acoustic detections were recorded (mean = 1,681 ± 2,235 standard deviation, s.d.). Tagged white sharks were detected for periods ranging between 14 and 290 days (Table 1). Several contrasting patterns of detection were observed (Fig. 3). For example, Shark 3, 7, and 9 were detected nearly continuously at North Neptune Island. Visual records of Shark 3 showed it shed the tag by date and so its residency may have been underestimated. Shark 9 resided at the Neptune Islands for three month until March 2014 (Fig. 3). It was later found stranded close to Geraldton, Western Australia on 17 July 2014 with an Australian sea lion lodged in its throat near its gills. This may have impeded water flow through the gills and caused the death (Department of Fisheries WA 2014). Shark 2, 4, and 8 were only detected at the Neptune Islands for shorter periods but made several return visits, while Shark 6, 12, 13, 14 and 15 were only detected for a few days each. Shark 1 and 5 were detected for short periods after tagging, with Shark 1 returning to the North and South Neptune Islands following an eight month absence. Shark 5 did not return (Fig. 3).

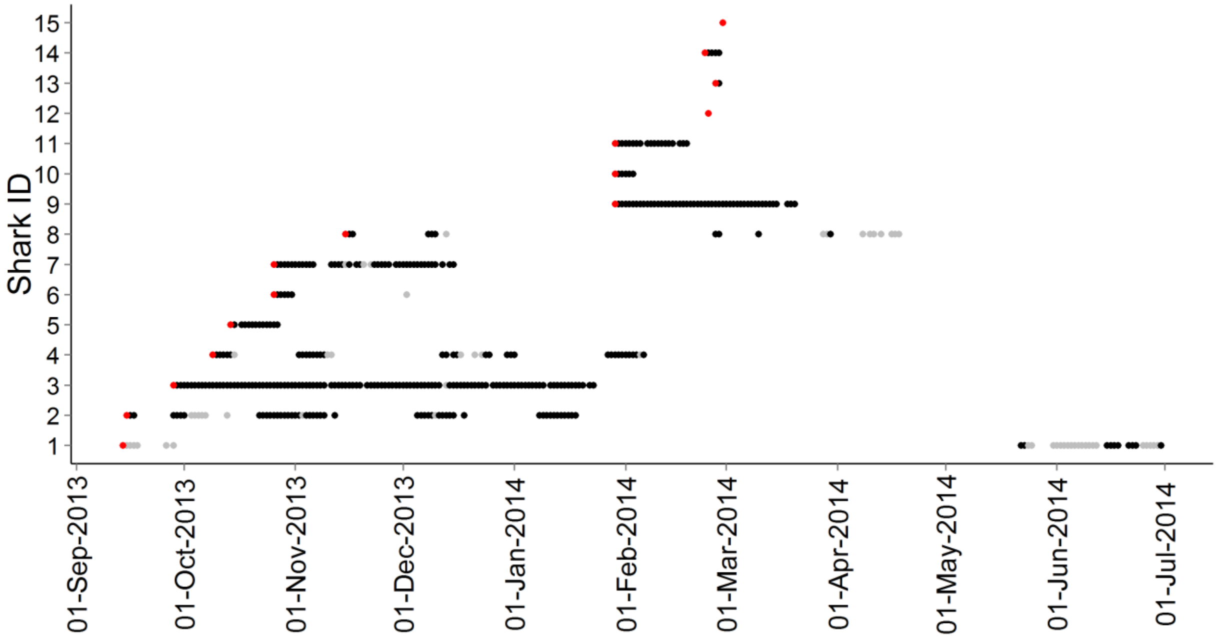

Figure 3. Daily detections for 15 white sharks at the North (black symbols) and South (grey symbols) Neptune Islands. Red symbol show dates when sharks were tagged.

Table 1: Detection and residency period summaries for white sharks (n = 15) tagged at the Neptune Islands (N = North, S = South). TL = total length (cm).

Shark	~TL	Sex	Tagged	Location	Period (d)	N detections			N days detected			Overall residency index			Detected residency index		
						Both	N	S	Both	N	S	Both	N	S	Both	N	S
1	410	F	14.9.13	S	290	4612	1210	3402	37	11	28	0.13	0.04	0.10	0.13	0.04	0.10
2	330	M	15.9.13	S	289	1974	1914	60	56	48	9	0.19	0.17	0.03	0.44	0.38	0.07
3[#]	450	M	28.9.13	N	276	8197	8194	3	112	111	1	0.41	0.4	0.00	0.95	0.94	0.01
4	410	M	9.1013	N	265	1911	1852	59	40	34	8	0.15	0.13	0.03	0.33	0.28	0.07
5[#]	450	M	14.10.13	N	14	1960	1960	*	13	13	*	0.93	0.93	*	0.93	0.93	*
6	300	M	26.10.13	N	248	116	109	7	7	6	1	0.03	0.02	0.00	0.18	0.16	0.03
7	450	M	26.10.13	N	248	1924	1894	30	42	40	4	0.17	0.16	0.02	0.82	0.78	0.08
8	200	M	15.11.13	N	228	1055	534	521	19	9	10	0.08	0.04	0.04	0.12	0.06	0.06
9[#]	400	M	29.01.14	N	170	2744	2738	6	49	49	1	0.29	0.29	0.01	0.96	0.96	0.02
10	350	M	29.01.14	N	153	133	133	*	6	6	*	0.04	0.04	*	1	1	*
11	380	M	29.01.14	N	153	251	250	1	19	19	1	0.12	0.12	0.01	0.9	0.9	0.05
12	240	M	24.02.14	N	127	66	66	*	1	1	*	0.01	0.01	*	1	1	*
13	450	F	26.02.14	N	125	18	18	*	2	2	*	0.02	0.02	*	1	1	*
14	430	M	23.02.14	N	128	239	239	*	5	5	*	0.04	0.04	*	1	1	*
15	300	M	28.02.14	N	123	17	17	*	1	1	*	0.01	0.01	*	1	1	*

* Indicates that shark was never detected

[#] Indicates that monitoring detection has ended because of known shark mortality or due to tag shedding

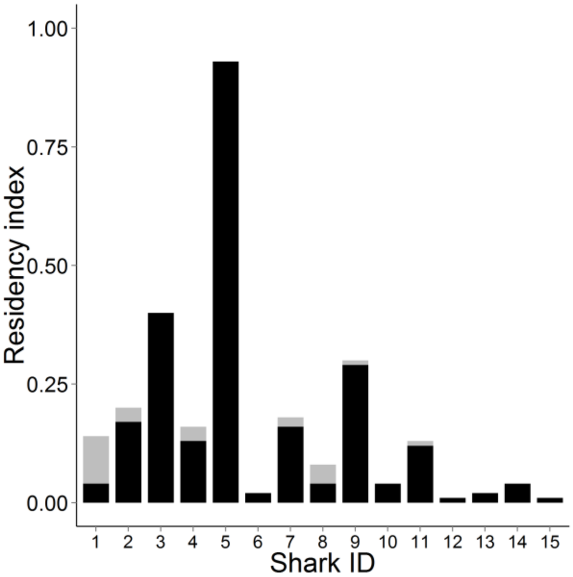

Figure 4. Residency index (overall) values for white sharks (n = 15) at the North (black bars) and South (grey bars) Neptune Islands.

Shark 1 and 2 were tagged at the South Neptune Islands and showed different patterns of daily detections and residency (Table 1, Fig. 3 and 4). Shark 1 was mostly detected at the South Neptune Islands, whereas Shark 2 was mostly detected at the North Neptune Islands. This shark underwent short duration movements to the South Neptune Islands. Five of the 13 white sharks that were tagged at the North Neptune Islands also visited the South Neptune Islands for short periods (Fig. 5).

The overall residency index of Shark 5 was close to one as it shed the tag after two weeks (Fig. 4). The mean overall residency index of the other white sharks was 0.12 ± 0.12. Variation between individuals was substantial (Table 1 and 2). Two sharks had residency indices >0.25, five were between 0.1–0.2, and the remaining seven were <0.1 (Fig. 5). Mean detected residency index was higher at 0.72 ± 0.36 (Table 1). This was influenced by white sharks that were only detected for a few days following tagging, and then left the Neptune Islands. After excluding these sharks from the analyses, the mean detected residency index value was 0.58 (± 0.37 SD).

Residency periods

Residency periods exhibited by white sharks at the North and South Neptune Islands combined ranged from <1 to 117 days (12.6 d ± 22.6; Fig. 4). Patterns varied between individuals and locations (Table 2). At the North Neptune Islands, the overall residency period was 11.9 ± 23.5 days and the number of residency periods ranged from 1–6 per individual (Table 2). Sixty percent of white sharks had a mean residency <5 days, and 20% had a mean residency at the Neptune Islands of >49 days. For most individuals, residency periods were shorter at the South Neptune Islands than at North Neptune Islands, where the overall residency period was 2.4 d ± 3.6 (Figs. 4 and 5; Table 2). However, residency periods of some individuals were greater at the South Neptune Islands. For example, mean residency period of Shark 1 was 4.5 days (n = 5) at the South Neptune Islands and 3.6 days (n = 3) at the North Neptune Islands, while Shark 2 had a mean residency period of 3.8 days (n = 3) at the South Neptune Islands and one day (n = 5) at the North Neptune Islands.

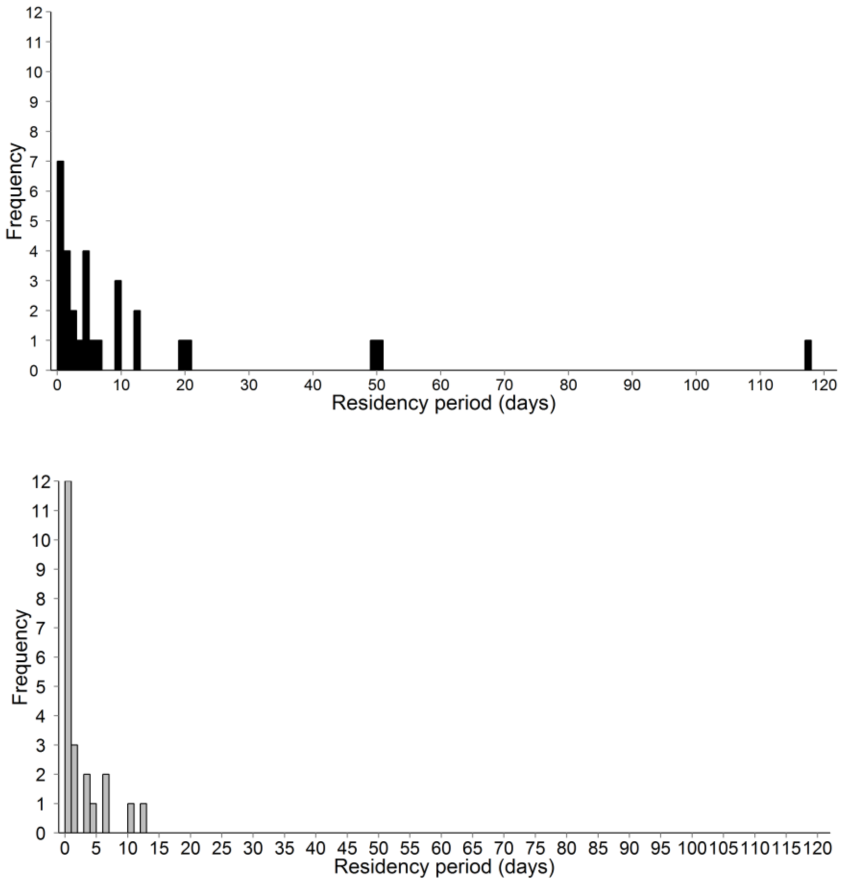

Figure 5. Residency period of white sharks (n = 15) at the (a) North (black bars), and (b) South Neptune Islands (grey bars) between September 2013 and June 2014.

Table 2. Summary statistics showing single residency estimates (Res. est.) and mean residency estimates (Mean res. est.) for white sharks (n =15) at the North and South Neptune Islands between 14 September 2013 and 28 February 2014. SD = standard deviation.*denotes where a shark only had a single residency period (no summary statistics calculated).

	North							**South**						
Shark ID	**N res. periods**	**Res. est. (d)**	**Mean res. est. (d)**	**Median**	**SD**	**min**	**max**	**N res. periods**	**Res. est. (d)**	**Mean res. est. (d)**	**Median**	**SD**	**min**	**max**
1	3	-	3.6	1	5.3	0.2	9.8	5	-	4.5	3.4	4.8	0.1	12.5
2	5	-	9.7	9.6	7.5	2.2	20.7	4	-	1.1	0.2	1.9	0	3.9
3	1	117.3	-	-	-	-	-	1	-	-	-	-	-	-
4	6	-	4.7	4.8	3.4	0.6	9.8	4	-	2	0.6	3.2	0	6.8
5	1	13	-	-	-	-	-				-	-	-	-
6	1	4.3	-	-	-	-	-	1	0.1		-	-	-	-
7	1	49.5	-	-	-	-	-	2		3.1	3.1	4.4	0	6.3
8	5	-	1	1	0.8	0.2	2.2	3		3.8	1.2	5.6	0	10.2
9	1	50	-	-	-	-	-	1	0.2	-	-	-	-	-
10	1	4.9	-	-	-	-	-		-	-	-	-	-	-
11	1	19.8	-	-	-	-	-	1	-	-	-	-	-	-
12	1	0.3	-	-	-	-	-	-	-	-	-	-	-	-
13	1	1	-	-		-	-	-	-	-	-	-	-	-
14	1	4.2	-	-	-	-	-	-	-	-	-	-	-	-
15	1	0.3	-	-	-		-	-	-	-	-	-	-	-

Variation in detection probability based on sentinel tag data

The five stationary sentinel tags inside the range of the receivers provided data that showed a consistent diel pattern in detection probability (Fig. 6). The highest number of detections occurred between 8 am and 5 pm. This is consistent with findings in Gulf St Vincent, Spencer Gulf and western Investigator Strait (Payne *et al*. 2010; Bryars *et al*. 2012; Huveneers *et al.* 2014). This diel pattern in detection probability was corrected to compare the number of detections of white sharks over 24 hour periods. Peaks in the un-standardised acoustic detection data for white sharks occurred at 11 am at the North Neptune Islands and 1 pm at South Neptune Islands (Fig. 7).

Standardisation of the white shark detection data using the stationary sentinel tag data revealed a diel pattern with highest shark detection frequencies occurring near dawn and dusk at the North Neptune Islands (Fig. 8), and between 5 pm and 4 am at the South Neptune Islands. Patterns of detections throughout the day were similar across individual white sharks that were regularly detected (>1,500 detections) (Figs. 8 and 9). Only one white shark was detected >1,500 times at the South Neptune Islands and this individual’s tag provided a similar pattern of detections as that provided by the sentinel tags (Fig. 9).

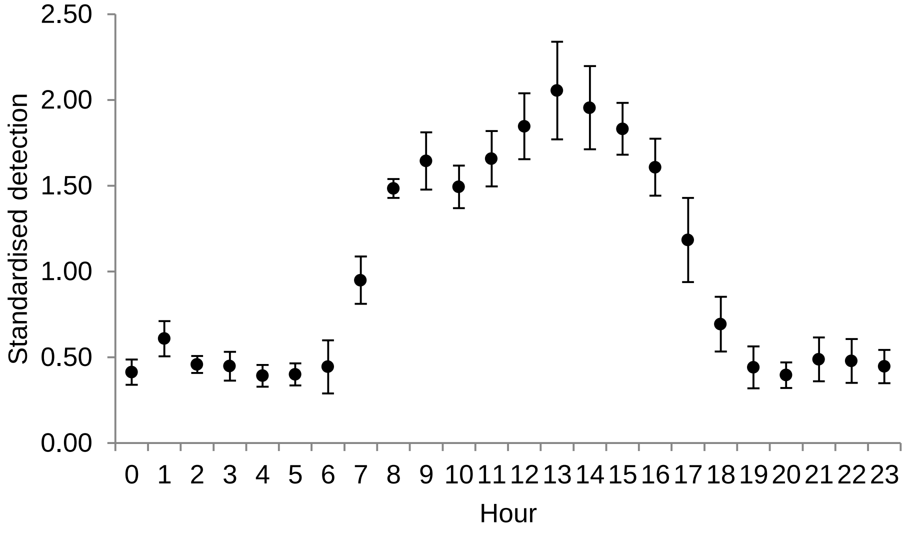

Figure 6. Mean standardised acoustic detections per hour for sentinel tags. Error bars represents ± 1 standard error of mean across all days.

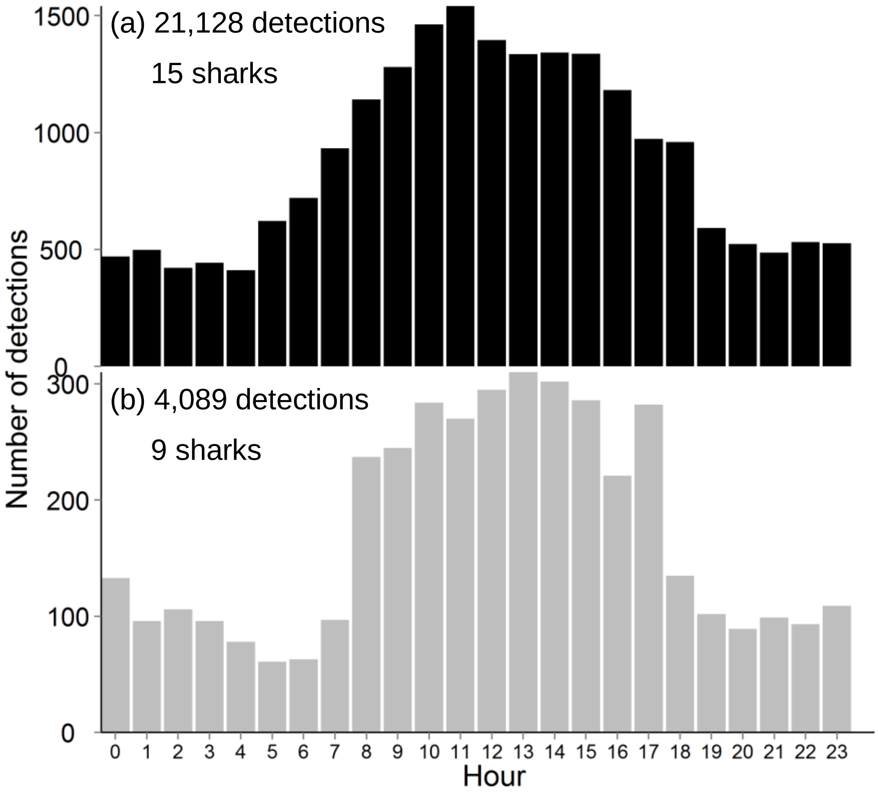

Figure 7. Un-standardised acoustic detections per hour for white sharks at the (a) North (black bars) and the (b) South Neptune Islands (grey bars).

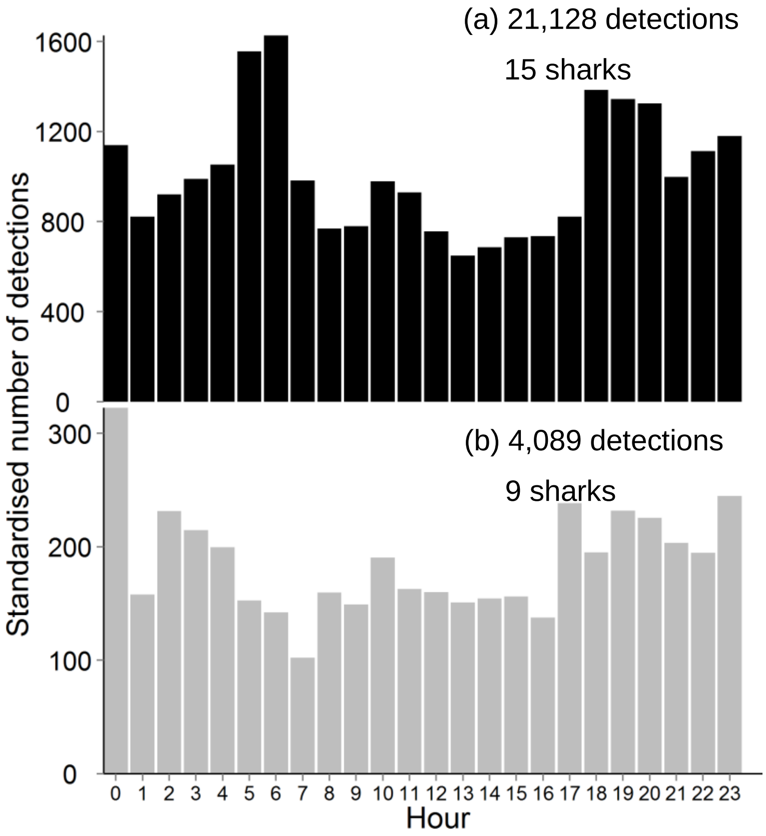

Figure 8. Mean standardised number of acoustic detections per hour for white sharks for (a) the North Neptune Islands (black bars) and (b) the South Neptune Islands (grey bars).

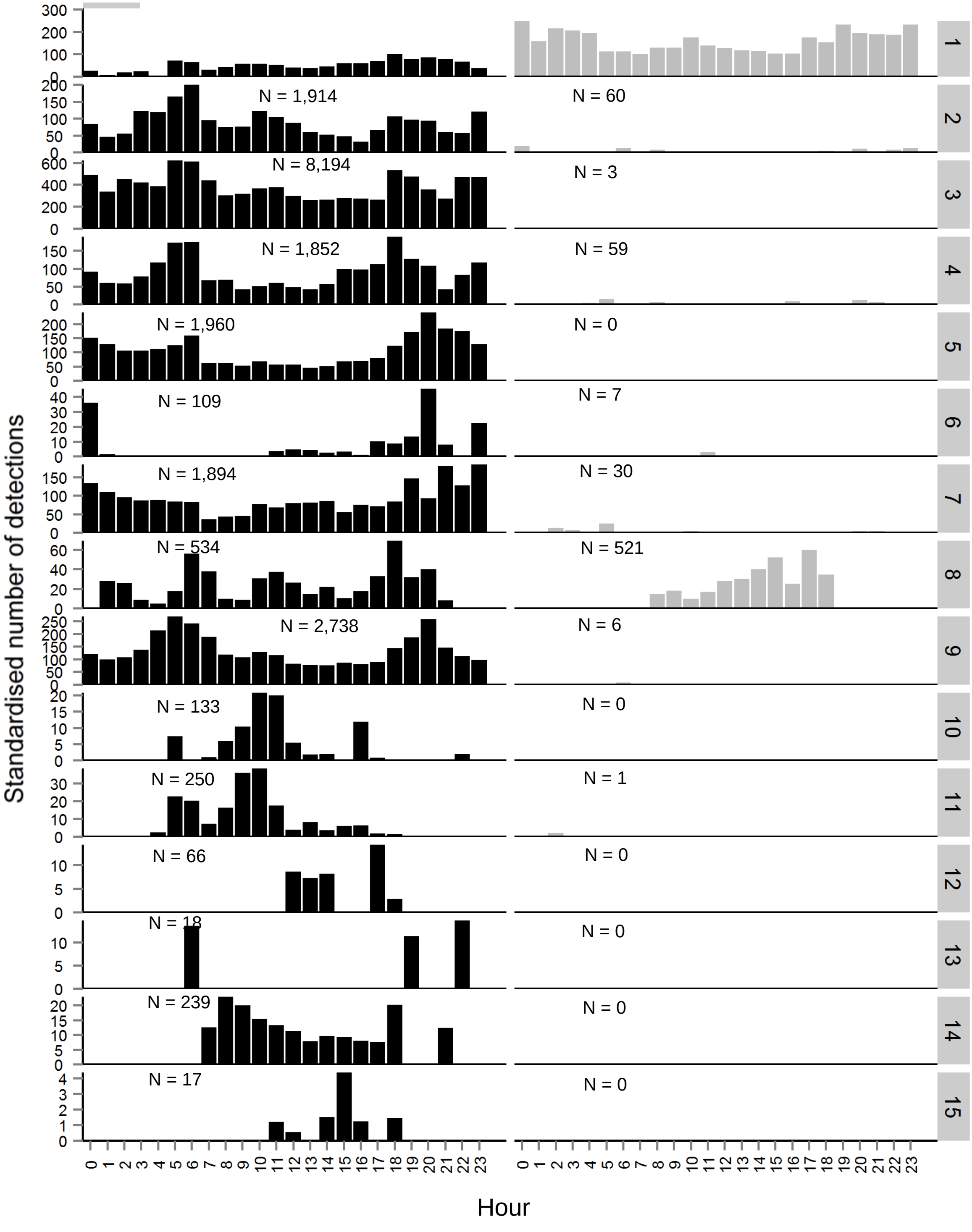

Figure 9. Mean number of standardised acoustic detections per hour for each white shark at the North Neptune Islands (black bars) and the South Neptune Islands (grey bars). N represents the number of acoustic detections of each shark. Numbers on the right-side y-axis represent the shark IDs.

Relationships between daily detections and cage-diving industry activity days

Shark 1, 3, 4, and 7 had more daily detections when cage-diving operators were present (activity days) at the North Neptune Islands than on non-activity days (Fig. 10a). Shark 10, 12, 13 and 15 were only present during activity days. There were no data to draw comparisons for Shark 5 and 6, and insufficient data to estimate error for Shark 8, 12, 14, and 15. Fewer individuals and shorter detection periods were recorded at the South Neptune Islands. Shark 1 and 8 were detected for sufficient time to compare detections between activity and non-activity days (Fig. 10b). Shark 1 was present more when cage-diving operators were present. There was no major difference in the number of detections per day for Shark 8 (Fig. 10b). Patterns of detection with type, and combination of activity are shown in Fig. 11. The ability to compare patterns of daily detections with type of activity was limited by the short monitoring period, and the fact that sharks were not all detected during each combination of, or single activity. There was a relatively consistent diel pattern in the standardised number of detections between the activity and non-activity days at the North Neptune Islands (Fig. 12). Peaks occurred early in the mornings and late in the afternoons. White sharks were detected more often during the day when operators were present (Fig. 12). Diel patterns were less consistent at the South Neptune Islands and had larger error estimates. This was reflective of fewer individuals being detected over shorter periods (Fig. 12).

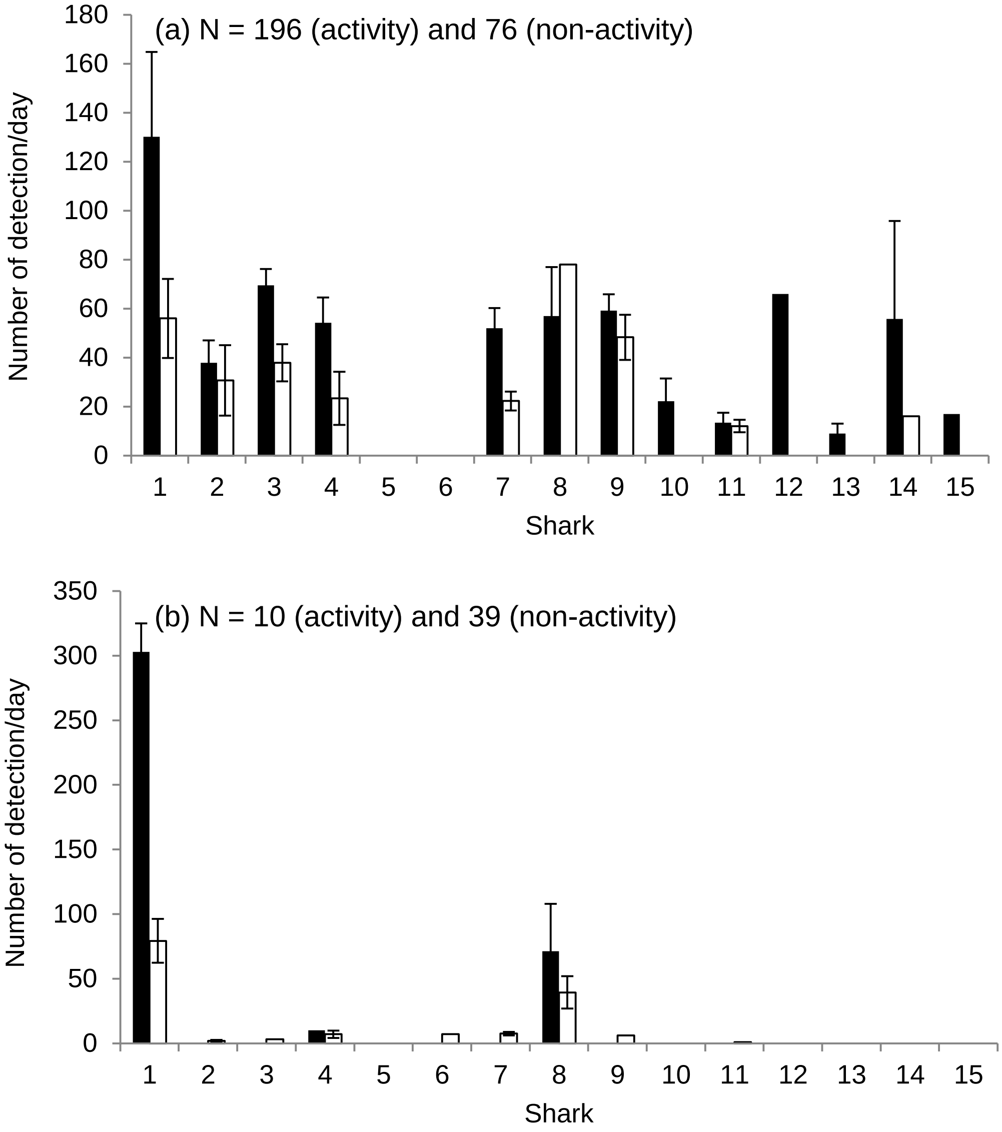

Figure 10. Standardised number of detections per day for each shark at the (a) North Neptune Islands and (b) South Neptune Islands during activity (black bars) and non-activity (white bars) days. Error bars represents standard error of mean. N represents number of days for which sharks were detected during activity and non-activity days.

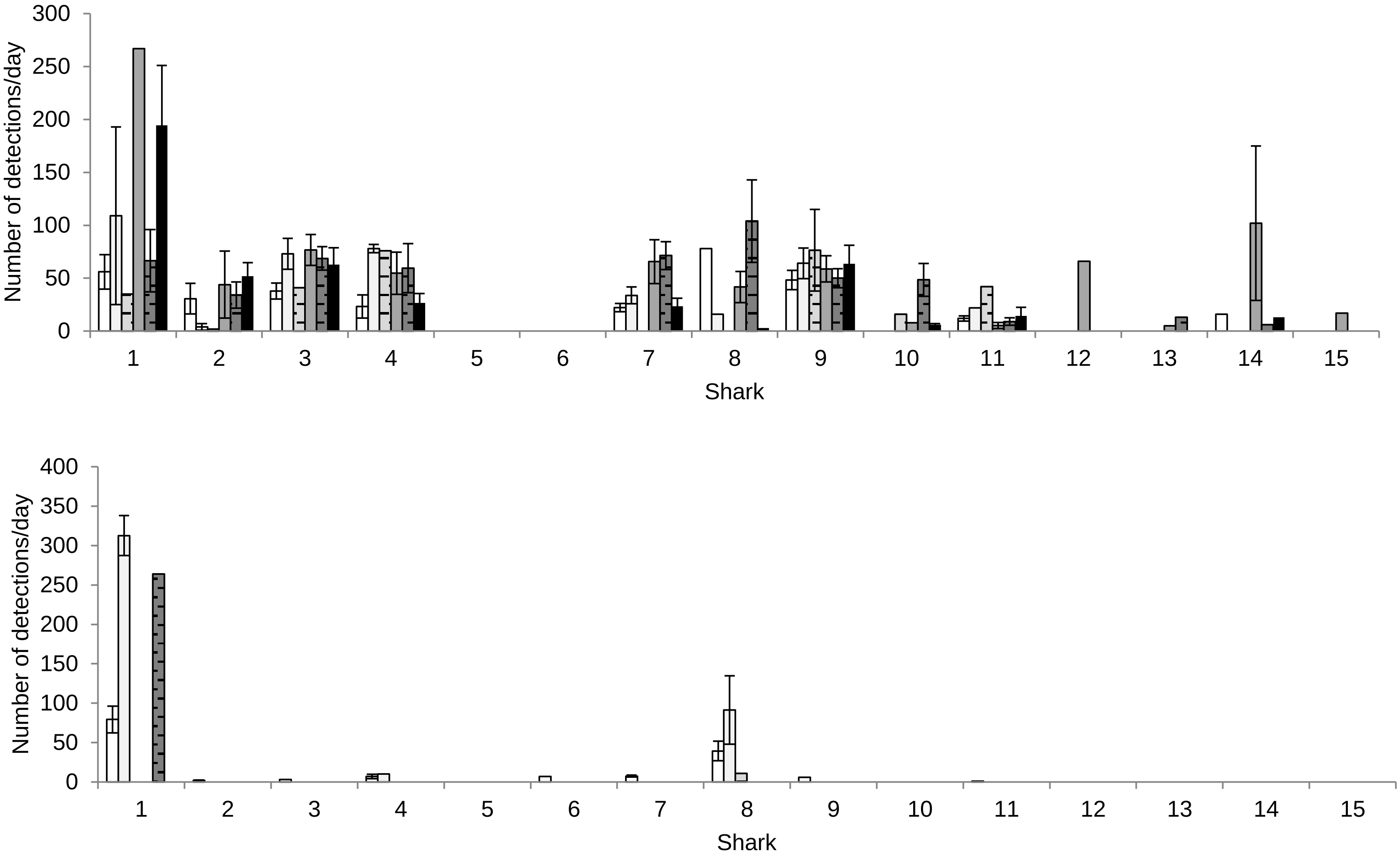

Figure 11. Standardised number of detection per day for each shark at the (a) North Neptune Islands and (b) South Neptune Islands during different levels of cage-diving operations. From left to right: no activity, one berley operator, one sound operator, two berley operator, one berley and one sound operator, two berley and one sound operator. Bars that include the operator which uses sound as an attractant have pattern inside the bar and the black bar (all three operators) Error bars represents standard error of mean.

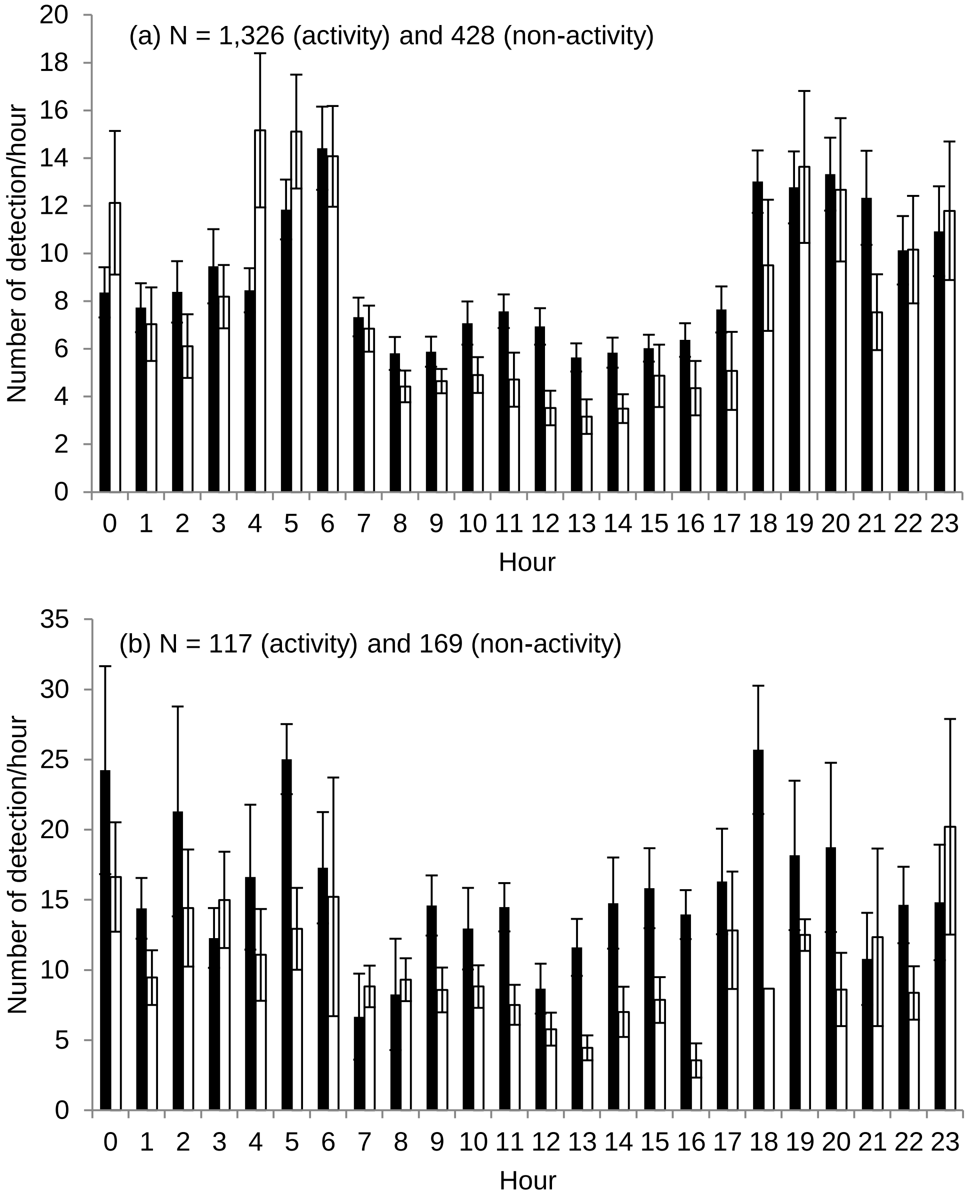

Figure 12. Standardised number of detections per hour at the (a) North Neptune Islands and (b) South Neptune Islands during activity (black bars) and non-activity (white bars) days. Error bars represents standard error of the mean. N represents number of hours for which sharks were detected during activity and non-activity days.

7.2. Electronic logbook

The e-logbook supported by the Fulcrum™ application was used by the white shark cage-diving industry operators to collect data on key operating parameters during the reporting period between 1 November 2013 and 30 June 2014.

Number of white sharks sighted

The number of individual white sharks sighted ranged from 0 to 20 per day based on 357 daily records (Fig. 13). Peaks were recorded during January-February. The overall mean number of white sharks sighted per day during the reporting period was 5 ± 3.5.

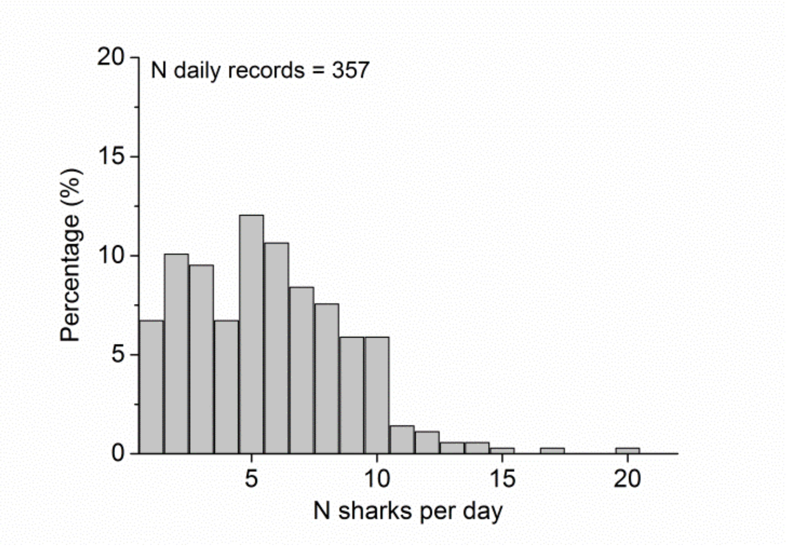

Figure 13. Percentage frequency of number of white sharks sighted per day by the three cage-diving operators.

Time spent berleying

Time spent berleying reported ranged from 0 to 13:25 hours per day (220 records, 169 operator days). Mean and median times spent berleying per day were 6:11 ± 0.1 s.d., and 5:50 hours, respectively. Across the industry, operators reported a total of 1,364 hours of berleying.

Berley input

Berley used to attract white sharks to cages at the Neptune Islands included mince and frozen blood from southern bluefin tuna. Operators reported the use of 220 L of frozen tuna blood, 3,390 L of minced tuna and 5,920 L of unspecified' tuna berley. The overall total of frozen blood, minced tuna and unspecified tuna berley was 9,530 L.

A total of 93.5 individual Nally™ bins of frozen bins of gills and entrails (median wt per bin = 35.55 kg each) were used in a bottom cage for an estimated weight of 3.33 t in 8 months.

Teaser baits

Teaser baits used at the surface comprised either portions of whole southern bluefin tuna, or gills and entrails (stomach, intestine, liver and spleen). A total of 100 southern bluefin tuna (~1.7 t) were used as teaser baits. A total of 323 individual Nally™ bins of frozen bins of gills and entrails (median wt per bin = 35.55 kg each) were used at the surface for an estimated weight of 11.5 t. (both operators pooled, n = 169 reported days/dates).

Sound usage

Sound emission was reported to be used at the Neptune Islands for a total of 267 hours. The daily durations ranged between 1–7.25 hours (mean daily duration = 4.7 ± 1.5 hours).

7.3. Photo Identification

Sightings: photos vs e-logbook

Photographs of white sharks were obtained on 121 days during November 2013 to June 2014. This included all photographs taken on 112 of 159 days in which OP2 was present and selected photos of individual sharks recorded in the e-logbook by OP3 on 38 of 107 days where they were on site. For OP2, the highest number of individual white sharks identified per day was in May 2014 and the lowest numbers were observed in March and April 2014 (Fig. 14). OP3 recorded similar numbers of individual sharks across months, with an average of two sharks per day in January, February, April and May 2014 (Fig. 14).

The mean number of sharks per operator was higher in the e-logbooks than in the photographs obtained by OP2 and OP3, which reflects the additional time and effort it takes to provide photographs (Figs.15 and 16). The highest number of sharks identified in e-logbooks was nine per day in January compared to the mean of four per day that could be reliably identified using images (Fig. 15). While a mean of five sharks per day was identified by OP3 in the e-logbook in January and February, a mean of two individuals could be reliably identified using photographs (Fig. 16).

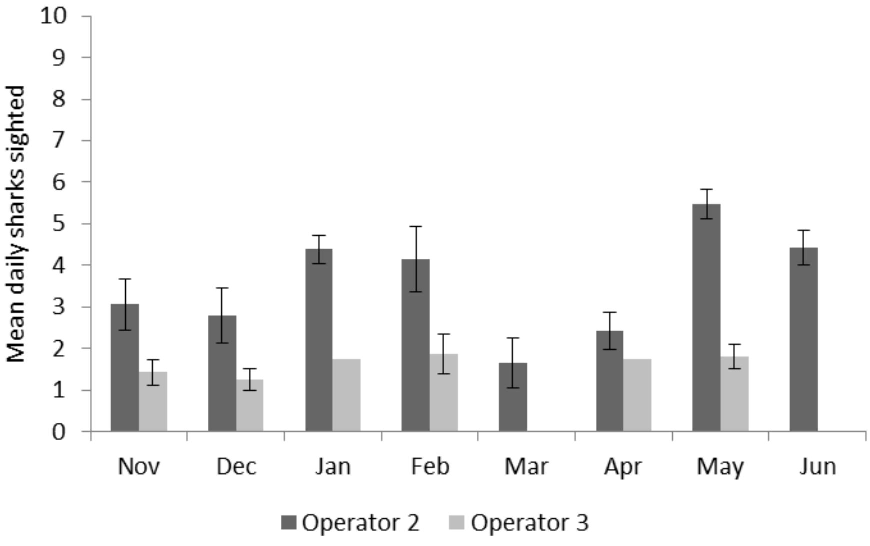

Figure 14. Mean number of sharks photographically identified per day in each month per operator. Error bars are ± 1 s.e.

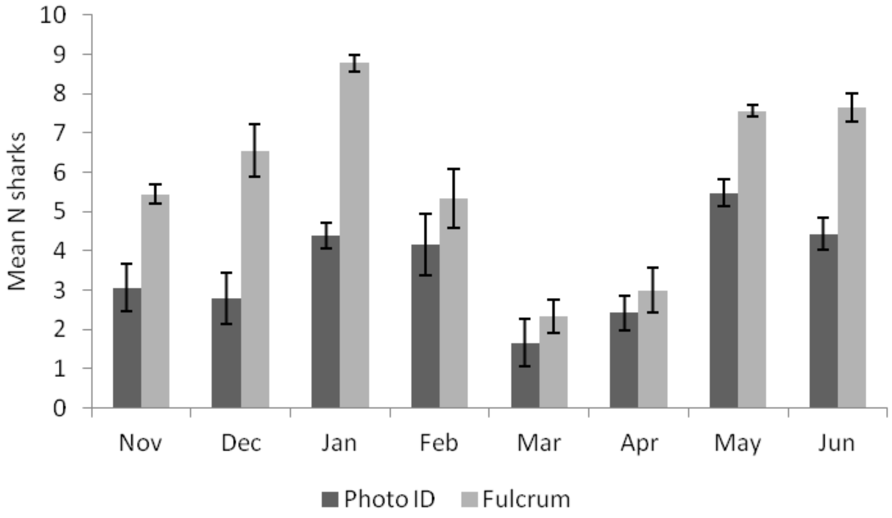

Figure 15. Mean number of sharks photographically identified and recorded in the e-logbooks per day in each month for operator 2. Error bars are ± 1 s.e.

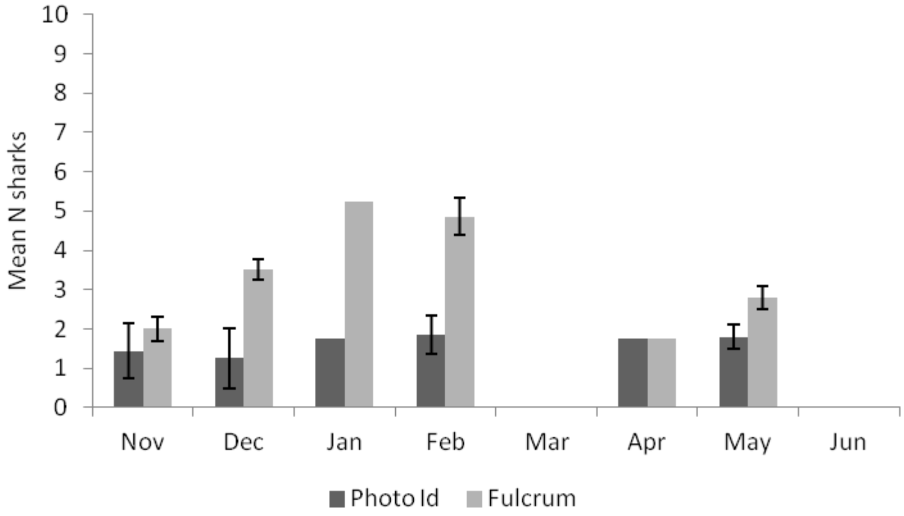

Figure 16. Mean number of sharks photographically identified and recorded in the e-logbooks per day in each month for operator 3. Error bars are ± 1 s.e.

Photo ID catalogue - Sightings

From photographs submitted by operators, a 'living catalogue' of individual white sharks was established (see Appendix 2). Complete validated profiles were collected for 21 individual sharks where both sides were recorded, including images suitable to compare the gill, pelvic and caudal regions (Table 3). Sex was determined for 12 of these sharks. In total, the photo-ID catalogue contains 121 left side images, 113 right side images and 70 images of both sides of the same sharks. The photo-ID catalogue will be refined as additional photos are obtained. Nine underwater video sessions were completed encompassing ~20 hours of footage (Appendix 3). Of the nine sessions captured, only three videos had white sharks present. Examples of white sharks with complete photo-ID profiles are provided in Appendix 4.

Table 3. Complete photo identifications and re-sights of white sharks (n = 21) at the Neptune Islands between 1 November 2013 and 30 June 2014. M = male, F = female, U = sex unknown.

Shark ID	Sex	First sighting	Last sighting	Time between re-sights (days)
NI1	M	1/11/2013	16/01/2014	76
NI2	M	2/11/2013	21/06/2014	231
NI3	M	1/11/2013	14/02/2014	105
NI7	F	3/11/2013	3/02/2014	92
NI11	M	9/11/2013	13/01/2014	65
NI21	M	18/11/2013	31/01/2014	74
NI26	M	22/11/2013	14/02/2014	84
NI30	M	19/12/2013	9/03/2014	80
NI59	M	26/01/2014	17/02/2014	22
NI79	M	2/02/2014	17/02/2014	15
NI86	M	16/02/2014	17/02/2014	1
NI89	M	16/02/2014	16/02/2014	0
NI94	U	26/02/2014	21/06/2014	115
NI96	U	27/02/2014	28/02/2014	1
NI110	U	26/04/2014	4/05/2014	8
NI113	U	1/05/2014	3/06/2014	33
NI119	U	26/04/2014	9/06/2014	44
NI120	U	1/05/2014	2/06/2014	32
NI122	U	6/05/2014	3/06/2014	28
NI132	U	19/05/2014	21/06/2014	33
NI148	U	31/05/2014	21/06/2014	21

8. DISCUSSION

The Department of Environment Water and Natural Resources (DEWNR) *Great White Shark Tourism Policy* aims to limit potential impacts of activities associated with white shark cage-diving in the Neptune Islands Group Marine Park. Estimates of residency of tagged white sharks form the scientific basis of the State Government’s decision-making process for this listed, threatened and protected species.

This report provides a summary of information on the development of three methods for assessing the potential impacts of cage-diving activities on white sharks that use the Neptune Islands Group Marine Park. Specifically, we provide insights into the behaviours of white sharks that interact with cage-diving activities to varying levels, including residency patterns for 15 individuals. We also summarise new information collected using a new web-linked e-logbook, and an industry-based photo-ID catalogue.

Temporal comparison of acoustic telemetry-based residency estimates

During the reporting period in 2013–14, the range of residency estimates for individual white sharks of <1 to 117 days (mean = 12.6 ± 22.6 days; n = 15 sharks) was similar (1–92 days; mean = 21 ± 24 days; n = 21 sharks; 2.8 to 4.8 m, TL) to that reported over the period between December 2009 and April 2011 (Bruce and Bradford 2011). The mean residency estimate calculated for all individuals was lower (*c.f.* previous data), however, this comparison should be viewed with caution due to the unequal sample sizes of sharks tagged and the shorter period monitored to generate the preliminary data reported here for 2013–14 (8 months *c.f.* 16 months, Bruce and Bradford 2011).

Recent fine scale behavioural assessments of white sharks showed the timing of cage-diving operator activities correlated with changes in the surface swimming behaviours of white sharks at the Neptune Islands (Huveneers *et al.* 2013). This previous study found tagged white sharks stayed >30 m from the operators on 21% of days they were detected, yet also spent a significant amount of time in closer proximity. The variation in behaviour between individual sharks was notable, highlighting the complexity of the relationships between cage-diving activities and behaviours.

A substantial body of evidence collected during acoustic telemetry-based monitoring at cage-diving sites in South Africa suggests that residency patterns of white sharks are both complex and individually variable (Johnson and Kock 2006). Major findings of this former study were: high cage-diving activity areas can elicit a high degree of residency; and sharks with high levels of experience can also spend less time interacting, especially if predictability of reward, such as through consumption of teaser baits is reduced. The weight of the historical data suggests individuals can become habituated to combinations of exposure to repeated visual and olfactory stimuli to industry activities that involve a level of provisioning (Johnson and Kock 2006). Individual-level variability in response to human activities that include provisioning for tourism purposes have also been observed in the sicklefin lemon shark (*Negaprion acutidens*) (Clua *et al.* 2010), Caribbean reef shark (*Carcharhinus perezi*) (Maljković and Côté 2011), and bull shark (*Carcharhinus leucas*) (Brunnschweiler and Barnett 2013).

Relationships between daily detections and cage-diving industry activity days

During the 2013–14 monitoring period, the number of daily acoustic detections was highest for four white sharks during cage-diving activity days at the North Neptune Islands. There were insufficient data available to draw comparisons for the remaining tagged individuals; some did not spend significant time at the North Neptune Islands, and only two individuals with short detection periods were recorded at the South Neptune Islands. When cage-diving was separated into type and combinations of activities, it was apparent that valuable behavioural insights will be gained when sufficient data are available to perform robust statistical comparisons. This quantitative modeling will be undertaken in the next report.

During two periods between April 2001 and March/May 2003, tagged white sharks spent 1.35 to 5.45 more time inside the Main Bay during berleying periods (Bruce *et al*. 2005). Individual variation in the relationships between daily detections and cage-diving industry berleying days was also prominent. The follow-up study found the distribution of white shark activity was also responsive to berleying activities, and made the important point that many monitoring studies of existing berley and teaser bait-reward-based ecotourism ventures lack suitable control sites, and/or before data (Bruce and Bradford 2013). SARDI is currently addressing this knowledge gap by deploying acoustic equipment at several other sites where cage diving does not occur.

Electronic logbook

The number of white sharks sighted and recorded in the e-logbook peaked at 20 individuals (OP1) in February and 12 (OP2) in January with 357 daily records logged (mean sightings per day of 5 ± 3.5), which was higher than those reported using photo-ID. Overall, this shows operator observational data will continue to form an important part of the process required to estimate the magnitude of the contingent of the South-west Australian white shark population that visits the Neptune Islands. Daily activities of the white shark cage-diving industry include berleying and use of teaser baits comprised of portions or the gills and entrails of southern bluefin tuna suspended under floats at the surface. The activity of using teaser baits to enhance customer satisfaction by attracting sharks close to dive cages has been highlighted previously as requiring further consideration (Bruce and Bradford 2011). Over the 2013–14 reporting period, the e-logbook data allowed the estimation of the annual output and use of berley and teaser baits. These data represent the previously missing baseline for this industry. There is currently a lack of information regarding the potential ecological impacts of berley input on the North Neptune Island marine ecosystem, nor is there information regarding the potential impacts of provisioning on white sharks, bony fish and other elasmobranchs. The current berley and teaser bait input levels require further discussion with industry and marine resource managers, as does the degree of daily consumption of teaser baits and potential energetic implications for visiting and semi-resident white sharks.

Photographic identification

There are no direct estimates of the size of the South-west Australian white shark population(s), nor is there an estimate of the size of the contingent of the population(s) that visits and uses the Neptune Islands. Application of photo-ID for estimating relative abundance (and residency) of white sharks based on mark-recapture methodologies relies on the satisfaction of key assumptions. These include that individual sharks can be distinguished through distinctive patterns, and that these individuals can be readily re-sighted and re-identified over a range of time frames (Anderson *et al.* 2011; Marshall and Piece 2012). This method has significant potential to subsequently underpin mark-recapture based estimates of relative abundance. A previous study developed a quantitative photo-ID system that was used to identify 76 individual white sharks between January 2006 and December 2007 at the Neptune Islands (Beckmann 2008). While uncertainty has been highlighted regarding temporal constancy of lower caudal markings (n = 1) (Robbins and Fox 2012b), other published studies also incorporated images of gill flaps, dorsal fins and other temporally stable physical characteristics (Domeier and Nasby-Lucas 2006). Recently, preliminary photo-ID data (images) were used to identify 306 white sharks (immature and mature-sized) over two periods between 2001–2003 and 2009–2011 at the Neptune Islands (Robbins and Fox 2012a). SARDI initiated development of an industry-wide photo-ID catalogue in September 2013, and 21 sharks were identified (with 162 awaiting further confirmation) to provide positive subsequent matches or resights based on >100 images sets provided by two cage-diving operators. Steps are being taken to combine all existing images with the aim of estimating the relative abundance of white sharks that visit the Neptune Islands by 2016. The long-term aim will be the development of a *Pubic National White Shark Photo-ID Catalogue* to be available on-line to log ‘new sharks’ and register possible re-sights. This could be developed to incorporate a public portal so customers of white shark cage-diving charters can lodge images or video for subsequent screening and matching to the catalogue.

Conclusion

This report provides an update of residency estimates for white sharks that are currently being monitored using satellite linked acoustic telemetry at the Neptune Islands. Over the 2014–2016 period, this research program will aim to integrate and evaluate satellite-linked acoustic telemetry data for at least 60 white sharks, conduct detailed analyses of operator electronic logbook data, and use photo-ID to estimate the size of the visiting component of the South-west white shark population. This series of steps addresses some of the significant gaps in information required to undertake robust assessments of the impacts of cage-diving activities on the white shark population that visits the Neptune Islands Group Marine Park, whilst also addressing key priorities in the *Recovery Plan for the White Shark* and the *National Plan of Action for the Conservation and Management of Sharks 2012* (Shark-plan 2).

On the basis of the preliminary findings of this report, and the valuable baseline data provided by Bruce and Bradford (2011, 2013), SARDI recommends that DEWNR:

1) Establish arrangements pertaining to the provision and use of images (by individual trip) specifically for identification and assessment of relative abundance of white sharks that visit the Neptune Islands Group Marine Park;
2) Facilitates the development of a suite of management decision rules that incorporate behavioural indicators and triggers for incorporation in the *Great White Shark Tourism Policy* and associated management documentation for the Neptune Islands Group Marine Park;
3) Support further research to determine the linkages and relative importance of the Neptune Islands Group as a stop-off point during broad-scale movement and migratory phases;
4) Continues to support monitoring of residency, interactive behavior and associated energetic requirements of white sharks (e.g. Semmens *et al.* 2013) in relation to shark tourism activities.

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APPENDIX 1. FIELDS RECORDED IN E-LOGBOOK.

Visibility rules	Field
	Date of Operation
	Name of Recorder
	Cage-diving operator
	-Adventure Bay
	-Calypso Star
	-Rodney Fox Shark Expeditions
	Number of passengers
	Number of domestic passengers
	Number of international passengers
	Manual GPS location
	Arrival time
	Departure time Arrival time
	Amount of attractant
RF and CS	Berleying start time
RF and CS	Berleying stop time
RF	Number of blood buckets used
RF	Number of minced tuna buckets used
CS	Amount of berley used (buckets)
RF	Number of gills/entrails used on the surface (nally bins)
RF	Number of gills/entrails used in bottom cage (nally bins)
CS	Number of gills/entrails used (nally bins)
RF & CS	Number of tuna used for bait
AB	Sound start time
AB	Sound stop time
AB	Sound characteristics
	Number of sharks sighted
	Shark details (Up to 20 sharks)
	Name or description
RF	Sighting type
	-Surface dive only
	-Bottom dive only
	-Both surface and bottom dive
	Time of first sighting
	Sex
	-Male
	-Female
	-Unknown
	Estimated size (m)
	Tag details
	-Tag visible LHS
	-Tag visible RHS
	-No tag visible
	Photo associated with sighting
	Activity level
	-Less than four passes
	-4-10 passes without directed swimming towards bait or speakers
	-4-10 passes with at least one pass directed towards bait or speakers
	-11-20 passes with at least one pass directed towards bait or speakers
	-More than 20 passes with frequent intent towards baits or speakers
RF and CS	Bait
	-No bait taken
	-1-5 baits taken
	-6-10 baits taken
	-More than 10 baits taken
	Enter any other comments
	Enter number of other shark sighted
	Bronze whaler sharks
	Mako sharks
	Other

APPENDIX 2. WHITE SHARK PHOTO-ID CATALOGUE.

Shark ID	Sex	First sighting	Last sighting	Operator Photos	LHS photo	RHS photo	ID status
NI1	Male	1/11/2013	16/01/2014	OP2	y	y	Complete
NI2	Male	2/11/2013	21/06/2014	OP2	y	y	Complete
NI3	Male	1/11/2013	14/02/2014	OP2	y	y	Complete
NI4	Male	2/11/2013	24/11/2013	OP2&3	y	y	Incomplete
NI5	Male	1/11/2013	2/11/2013	OP2&3	y	y	Incomplete
NI6	Male	3/11/2013	3/11/2013	OP2	y	n	Incomplete
NI7	Female	3/11/2013	3/02/2014	OP2&3	y	y	Complete
NI8		7/12/2014	7/12/2014	OP2	n	y	Incomplete
NI9	Male	21/11/2014	21/11/2014	OP3	n	y	Incomplete
NI10	Male	7/12/2014	18/12/2014	OP2	n	y	Incomplete
NI11	Male	9/11/2014	13/01/2014	OP2	y	y	Complete
NI12	Male	9/11/2013	15/12/2013	OP2	n	y	Incomplete
NI13	Male	4/11/2013	4/11/2013	OP2	y	y	Incomplete
NI14		1/12/2013	1/12/2013	OP2	n	y	Incomplete
NI15		15/12/2013	15/12/2013	OP2	n	y	Incomplete
NI16		10/11/2013	11/11/2013	OP2	y	y	Incomplete
NI17		10/11/2013	10/11/2013	OP2	n	y	Incomplete
NI18	Male	15/11/2013	18/11/2013	OP2	n	y	Incomplete
NI19		15/11/2013	8/12/2013	OP2	y	n	Incomplete
NI20		17/11/2013	18/11/2013	OP2&3	y	y	Incomplete
NI21	Male	18/11/2013	31/01/2014	OP2	y	y	Complete
NI22	Male	18/11/2013	25/01/2014	OP2	y	n	Incomplete
NI23	Male	25/11/2014	31/12/2014	OP2	n	y	Incomplete
NI24	Male	9/11/2013	18/11/2013	OP2	y	y	Incomplete
NI25	Male	2/11/2013	8/12/2013	OP2	y	y	Incomplete
NI26	Male	22/11/2013	14/02/2014	OP2	y	y	Complete
NI27	Male	1/12/2013	1/12/2013	OP2	y	y	Incomplete
NI28		2/12/2013	2/12/2013	OP2	y	y	Incomplete
NI29	Male	2/12/2013	3/01/2014	OP2	y	y	Incomplete
NI30	Male	19/12/2013	9/03/2014	OP2&3	y	y	Complete
NI31	Male	2/02/2014	2/02/2014	OP2	y	n	Incomplete
NI32		13/01/2014	8/12/2014	OP2	y	y	Incomplete
NI33		15/12/2013	15/12/2013	OP2	n	y	Incomplete
NI34	Male	15/12/2013	15/12/2013	OP2	y	n	Incomplete
NI35	Male	15/12/2013	16/12/2013	OP2&3	y	n	Incomplete
NI36	Male	16/12/2013	21/02/2014	OP2&3	y	y	Incomplete
NI37	Male	15/11/2013	22/12/2013	OP2	y	y	Incomplete
NI38		18/12/2013	18/12/2013	OP2	n	y	Incomplete
NI39	Female	22/12/2013	15/01/2014	OP2	n	y	Incomplete
NI40		22/12/2013	15/01/2014	OP2	y	y	Incomplete
NI41		13/01/2014	13/01/2014	OP2	n	y	Incomplete
NI42	male	11/01/2014	15/01/2014	OP2	y	y	Incomplete

NI43		22/12/2013	22/12/2013	OP2	y	n	Incomplete
NI44		22/12/2013	22/12/2013	OP2	y	n	Incomplete
NI45	male	12/01/2014	16/02/2014	OP2	y	y	Incomplete
NI46	male	13/01/2014	13/01/2014	OP3	n	y	Incomplete
NI47		8/12/2013	8/12/2013	OP2	y	n	Incomplete
NI48	male	13/01/2014	13/01/2014	OP2	y	y	Incomplete
NI49	female	1/11/2014	1/11/2014	OP3	y	n	Incomplete
NI50		10/11/2013	9/12/2014	OP2&3	y	y	Incomplete
NI51		29/11/2013	29/11/2013	OP3	y	n	Incomplete
NI52	male	13/01/2014	2/02/2014	OP2	y	y	Incomplete
NI53	male	16/01/2014	16/01/2014	OP2	y	n	Incomplete
NI54		16/01/2014	9/02/2014	OP2	n	y	Incomplete
NI55		13/01/2014	24/01/2014	OP2&3	y	n	Incomplete
NI56	male	24/01/2014	8/02/2014	OP2	y	y	Incomplete
NI57		26/01/2014	26/01/2014	OP2	n	y	Incomplete
NI58		27/01/2014	7/02/2014	OP2	n	y	Incomplete
NI59	male	26/01/2014	17/02/2014	OP2	y	y	Complete
NI60		27/01/2014	27/01/2014	OP2	y	n	Incomplete
NI61		27/01/2014	27/01/2014	OP2	y	n	Incomplete
NI62	male	27/01/2014	27/01/2014	OP2	y	y	Incomplete
NI63		11/01/2014	11/01/2014	OP2	n	y	Incomplete
NI64	male	9/11/2014	9/11/2014	OP3	y	n	Incomplete
NI65		27/01/2014	27/01/2014	OP2	n	y	Incomplete
NI66		27/01/2014	22/02/2014	OP2	y	n	Incomplete
NI67	male	27/01/2014	27/01/2014	OP2	y	y	Incomplete
NI68	male	29/01/2014	2/02/2014	OP2	y	n	Incomplete
NI69		30/01/2014	30/01/2014	OP2	y	y	Incomplete
NI70		24/01/2014	24/01/2014	OP2	y	n	Incomplete
NI71	male	29/01/2014	29/01/2014	OP3	y	y	Incomplete
NI72	Male	23/05/2014	24/05/2014	OP2&3	y	n	Incomplete
NI73	male	25/01/2014	25/01/2014	OP3	y	n	Incomplete
NI74	Male	13/02/2014	13/02/2014	OP3	n	y	Incomplete
NI75		1/02/2014	1/02/2014	OP3	y	y	Incomplete
NI76		1/02/2014	1/02/2014	OP3	y	n	Incomplete
NI77		2/02/2014	2/02/2014	OP3	y	n	Incomplete
NI78		2/02/2014	2/02/2014	OP2	y	y	Incomplete
NI79	male	2/02/2014	17/02/2014	OP2&3	y	y	Complete
NI80	male	2/02/2014	12/02/2014	OP2&3	y	y	Incomplete
NI81		12/02/2014	12/02/2014	OP2	y	n	Incomplete
NI82		14/02/2014	14/02/2014	OP2	y	n	Incomplete
NI83	male	14/02/2014	14/02/2014	OP2	y	n	Incomplete
NI84	male	15/02/2014	16/02/2014	OP2	y	y	Incomplete
NI85	female	17/02/2014	17/02/2014	OP2	y	n	Incomplete
NI86	male	16/02/2014	17/02/2014	OP2&3	y	y	Complete
NI87		16/02/2014	16/02/2014	OP2	y	y	Incomplete
NI88		16/02/2014	16/02/2014	OP2	y	y	Incomplete

NI89	male	16/02/2014	16/02/2014	OP2	y	y	Complete
NI90		16/02/2014	16/02/2014	OP2	y	y	Incomplete
NI91		17/02/2014	17/02/2014	OP2	y	y	Incomplete
NI92		26/02/2014	27/02/2014	OP2	y	y	Incomplete
NI93		1/05/2014	1/05/2014	OP2	y	n	Incomplete
NI94		26/02/2014	21/06/2014	OP2&3	y	y	Complete
NI95		1/03/2014	1/03/2014	OP2	y	y	Incomplete
NI96		27/02/2014	28/02/2014	OP2	y	y	Complete
NI97		9/03/2014	9/03/2014	OP2	y	n	Incomplete
NI98		30/03/2014	30/03/2014	OP2	y	y	Incomplete
NI99		20/04/2014	23/04/2014	OP2	n	y	Incomplete
NI100		20/04/2014	5/06/2014	OP2	y	y	Incomplete
NI101		20/04/2014	22/04/2014	OP2	y	y	Incomplete
NI102		23/02/2014	23/02/2014	OP2	y	y	Incomplete
NI103		23/04/2014	23/04/2014	OP2	y	n	Incomplete
NI104		21/04/2014	23/04/2014	OP2&3	y	y	Incomplete
NI105		23/04/2014	23/04/2014	OP2	n	y	Incomplete
NI106		23/04/2014	25/04/2014	OP2	y	n	Incomplete
NI107	male	23/04/2014	26/04/2014	OP2	y	y	Incomplete
NI108		21/04/2014	26/05/2014	OP2	y	y	Incomplete
NI109		28/04/2014	14/06/2014	OP2	y	y	Incomplete
NI110		26/04/2014	4/05/2014	OP3	y	y	Complete
NI111		1/05/2014	30/06/2014	OP2	y	y	Incomplete
NI112		1/05/2014	18/05/2014	OP2	y	y	Incomplete
NI113		1/05/2014	3/06/2014	OP2&3	y	y	Complete
NI114		2/05/2014	2/05/2014	OP2	y	n	Incomplete
NI115		3/05/2014	3/05/2014	OP2	n	y	Incomplete
NI116		1/05/2014	4/05/2014	OP2&3	y	y	Incomplete
NI117		2/05/2014	30/05/2014	OP2	n	y	Incomplete
NI118		26/04/2014	26/04/2014	OP3	y	n	Incomplete
NI119		26/04/2014	9/06/2014	OP2&3	y	y	Complete
NI120		1/05/2014	2/06/2014	OP2&3	y	y	Complete
NI121		6/05/2014	6/05/2014	OP2	n	y	Incomplete
NI122		6/05/2014	3/06/2014	OP2	y	y	Complete
NI123		6/05/2014	6/05/2014	OP2	y	n	Incomplete
NI124		21/05/2014	21/05/2014	OP3	n	y	Incomplete
NI125	female	6/05/2014	23/05/2014	OP2&3	n	y	Incomplete
NI126		6/05/2014	6/05/2014	OP2	y	n	Incomplete
NI127		7/05/2014	7/05/2014	OP2	y	n	Incomplete
NI128	male	18/05/2014	23/05/2014	OP2	y	y	Incomplete
NI129		18/05/2014	18/05/2014	OP2	y	n	Incomplete
NI130		18/05/2014	30/06/2014	OP2	y	y	Incomplete
NI131	male	19/05/2014	21/06/2014	OP2	y	y	Incomplete
NI132		19/05/2014	21/06/2014	OP2	y	y	Complete
NI133		21/05/2014	23/05/2014	OP2	n	y	Incomplete
NI134		23/05/2014	23/05/2014	OP2	y	n	Incomplete

NI135		24/05/2014	24/05/2014	OP2	y	n	Incomplete
NI136		24/05/2014	24/05/2014	OP2	n	y	Incomplete
NI137		24/05/2014	3/06/2014	OP2	n	y	Incomplete
NI138		24/05/2014	24/05/2014	OP2	n	y	Incomplete
NI139		24/05/2014	30/06/2014	OP2	n	y	Incomplete
NI140		24/05/2014	24/05/2014	OP2	y	n	Incomplete
NI141		24/05/2014	24/05/2014	OP2	y	n	Incomplete
NI142		25/05/2014	25/05/2014	OP2	y	n	Incomplete
NI143		25/05/2014	26/05/2014	OP2	y	y	Incomplete
NI144		30/05/2014	30/05/2014	OP2	y	n	Incomplete
NI145		30/05/2014	14/06/2014	OP2	y	y	Incomplete
NI146		30/05/2014	30/05/2014	OP2	n	y	Incomplete
NI147		30/05/2014	30/05/2014	OP2	n	y	Incomplete
NI148		31/05/2014	21/06/2014	OP2	y	y	Complete
NI149		31/05/2014	31/05/2014	OP2	y	n	Incomplete
NI150		31/05/2014	30/06/2014	OP2	y	n	Incomplete
NI151	male	3/06/2014	3/06/2014	OP2	n	y	Incomplete
NI152		8/06/2014	21/06/2014	OP2	n	y	Incomplete
NI153		8/06/2014	8/06/2014	OP2	y	n	Incomplete
NI154		8/06/2014	8/06/2014	OP2	n	y	Incomplete
NI155		14/06/2014	21/06/2014	OP2	n	y	Incomplete
NI156		14/06/2014	14/06/2014	OP2	y	n	Incomplete
NI157		15/06/2014	21/06/2014	OP2	y	y	Incomplete
NI158		21/06/2014	21/06/2014	OP2	y	n	Incomplete
NI159		21/06/2014	21/06/2014	OP2	n	y	Incomplete
NI160		21/06/2014	21/06/2014	OP2	y	n	Incomplete
NI161		30/06/2014	30/06/2014	OP2	n	y	Incomplete
NI162		30/06/2014	30/06/2014	OP2	n	y	Incomplete

APPENDIX 3. VIDEO FOOTAGE COLLECTED BY OPERATORS TO IDENTIFY WHITE SHARKS.

Operator	**Date/Month**	**Female**	**Male**	**Unknown**	**# sharks**	**Duration (minutes)**
1	14-Oct-13				0	158
1	19-Oct-13		1		0	43
3	Nov-13				0	43
3	Dec-13				0	111
3	Jan-13				0	159
3	1- Feb-14		5		5	148
3	8-Feb-14		1	1	2	129
3	March-14				0	176
3	April-14				0	171
3	May-14				0	39

APPENDIX 4. EXAMPLES OF WHITE SHARKS WITH COMPLETE PHOTO-ID IMAGE PROFILES.

NI2

NI3

© Calypso Star Charters

NI7

© Calypso Star Charters

© Adventure Bay Charters

NI11

NI21

NI26

NI30 [deceased; WA]

© Calypso Star Charters

NI59

NI79

© Calypso Star Charters

NI86

© Calypso Star Charters

NI89

© Calypso Star Charters

NI94

© Calypso Star Charters

NI96

NI110

© Calypso Star Charters

© Adventure Bay Charters

NI113

NI119

© Calypso Star Charters

NI120

© Adventure Bay Charters

© Calypso Star Charters

NI122

NI132

© Calypso Star Charters

NI148