Our ref: CORP F2017/000574
Your ref: SK17104

24 November 2017

Mr Stephan Knoll MP
Member for Schubert
129A Murray Street
TANUNDA SA 5352

Dear Mr Knoll

Determination under the *Freedom of Information Act 1991*

I refer to your application made under the *Freedom of Information Act 1991* which was received by Primary Industries and Regions SA (PIRSA) on 7 November 2017, seeking access to the following:

> *"Any report showing a relationship between Marine Parks and/or Sanctuary Zones and the number of detected sharks from 1 January 2013 until 1 July 2017."*

Accordingly, the following determination has been finalised.

I have located three documents that are captured within the scope of your request.

Determination

I have determined that access to the following documents is **granted in full**:

Doc No.	Description of document	No. of Pages
1	SARDI Publication No F2014/000801-1 – SARDI Research Report Series No 818 – December 2014 - Monitoring residency of white sharks, *Carcharodon charcharias* in relation to the cage-diving industry in the Neptune Islands Group Marine Park	75
2	SARDI Publication No F2015/000825-1 – SARDI Research Report Series No 893 – April 2016 - Residency and photographic identification of white sharks *Carcharodon charcharias* in the Neptune Islands Group Marine Park between 2013 and 2015	116
3	SARDI Publication No F2015/000825-2 – SARDI Research Report Series No 941 – March 2017 – Residency of white sharks *Carcharodon charcharias* in the Neptune Islands Group Marine Park during 2015-16	25

Shark sightings are logged with some location information on the PIRSA website: http://www.pir.sa.gov.au/fishing/fishwatch/sharks/shark_sightings_log, however, no information is recorded specifically relating to their relationship with marine parks/sanctuary zones.

If you are dissatisfied with this determination, you are entitled to exercise your right of review and appeal as outlined in the attached documentation, by completing the "Application for Review of Determination" and returning the completed form to:

Freedom of Information Principal Officer
Primary Industries and Regions SA
GPO Box 1671
ADELAIDE SA 5001

Should you require further information or clarification with respect to this matter, please contact Ms Lisa Farley, Freedom of Information and Privacy Officer on 8429 0422 or email PIRSA.FOI@sa.gov.au.

Yours sincerely

Deanna Fleming
Accredited Freedom of Information Officer
PRIMARY INDUSTRIES AND REGIONS SA

Marine Ecosystems

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

Rogers, P.J., Huveneers, C. and Beckmann, C.L.

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Government of South Australia
Department of Environment,
Water and Natural Resources

SOUTH
AUSTRALIA

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SARDI

SOUTH AUSTRALIAN
RESEARCH AND
DEVELOPMENT
INSTITUTE

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

Report to the Department of Environment, Water and Natural Resources
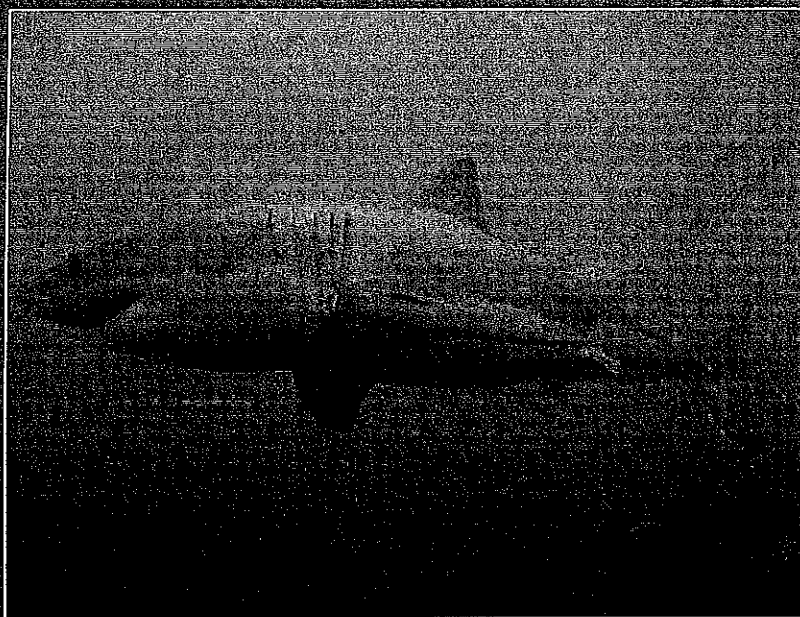
Rogers, P.J., Huveneers, C. and Beckmann, C.L.

SARDI Publication No. F2014/000801-1
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December 2014

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2. CONTRIBUTIONS

Formulation of project: C.H., P.R.

Funding: Primary Industries and Regions South Australia, South Australian Research and Development Institute, Marine Innovation Southern Australia, Department of Environment, Water and Natural Resources.

In-kind: Flinders University.

Management of project (Primary Investigator): P.R. (Feb–Dec 2014), C.H. (Sept 2013–Feb 2014).

Report preparation: P.R., C.H., C.B.

Fieldwork: C.H.

Data management: C.B.

Data provision: Acoustic data; VEMCO (Amirix).

Logbook - Rodney Fox Shark Expeditions, Calypso Charters, Adventure Bay Charters.

Video - Rodney Fox Shark Expeditions, Calypso Charters, Adventure Bay Charters.

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.

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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 ($200.year^{-1}$). 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.

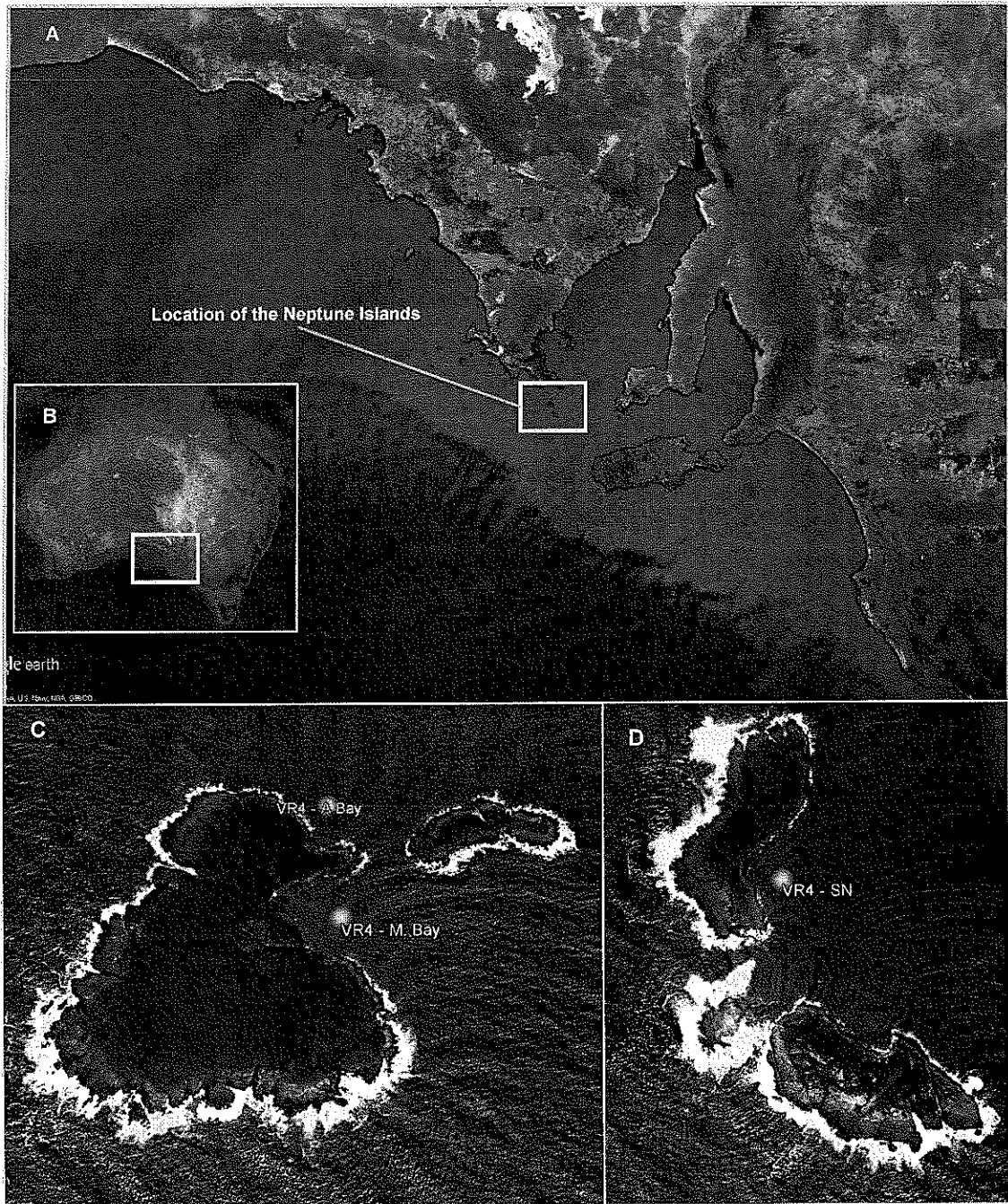Figure 1. Map A shows the location of the North and South Neptune Islands in continental shelf waters off South Australia (inset B). Map C shows the North Neptune Islands and the locations of two VR4 acoustic receivers in Action Bay (A. Bay) and Main Bay (M. Bay). Map D shows the South Neptune Islands 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):

$$CDF_b = \frac{B_b}{\mu}$$

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.

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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.
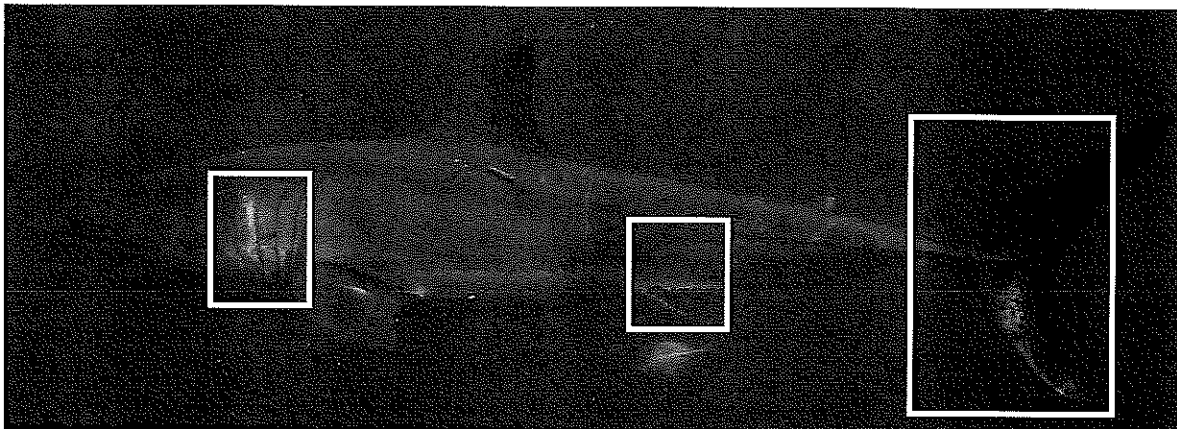

Figure 2. White shark showing characteristic pigmentation patterns on gill flaps, pelvic fin and lower caudal fin.

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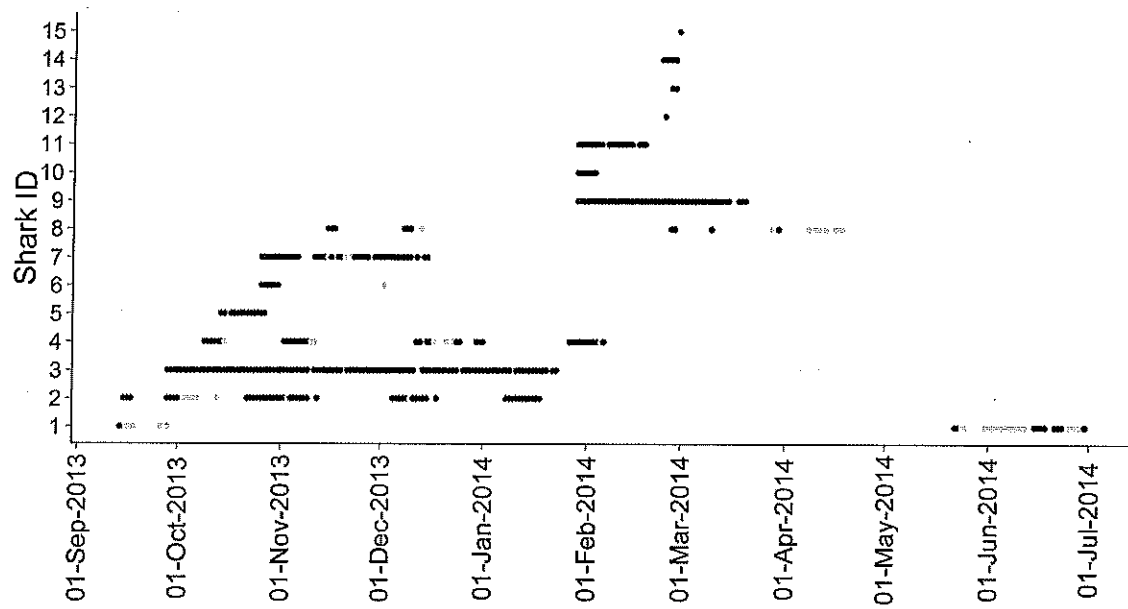
Figure 3. Daily detections for 15 white sharks at the North (black symbols) and South (grey symbols) Neptune Islands. Red symbol show dates when sharks were tagged.

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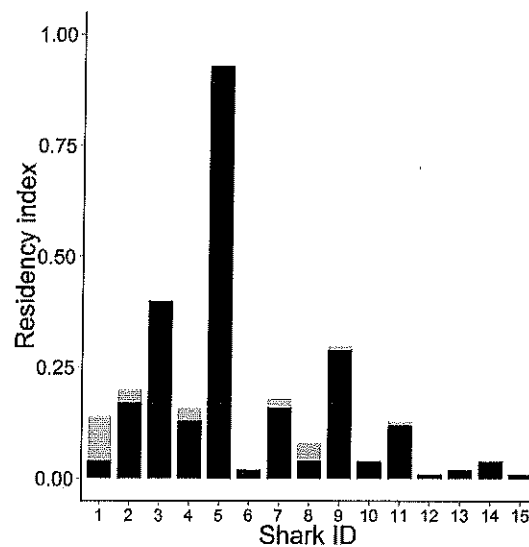[#] Indicates that monitoring detection has ended because of known shark mortality or due to tag shedding

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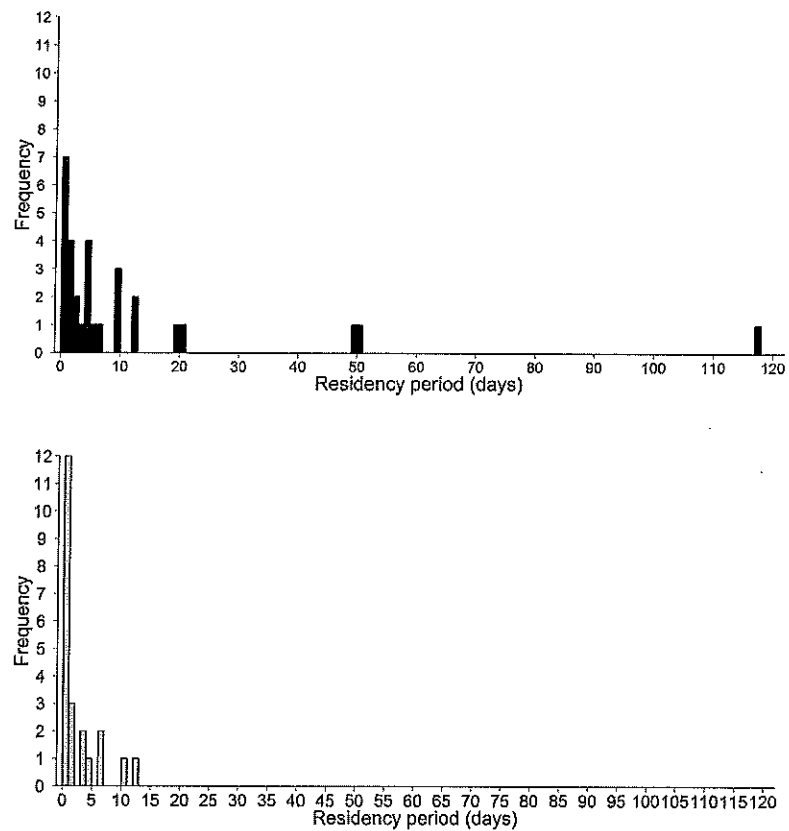
Figure 5. Residency period of white sharks (n = 15) at the (a) North (black bars), and (b) South Neptune Islands (grey bars) between September 2013 and June 2014.

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).

Shark ID	North							South						
	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	-	-	-	-	-	-	-	-	-	-	-	-

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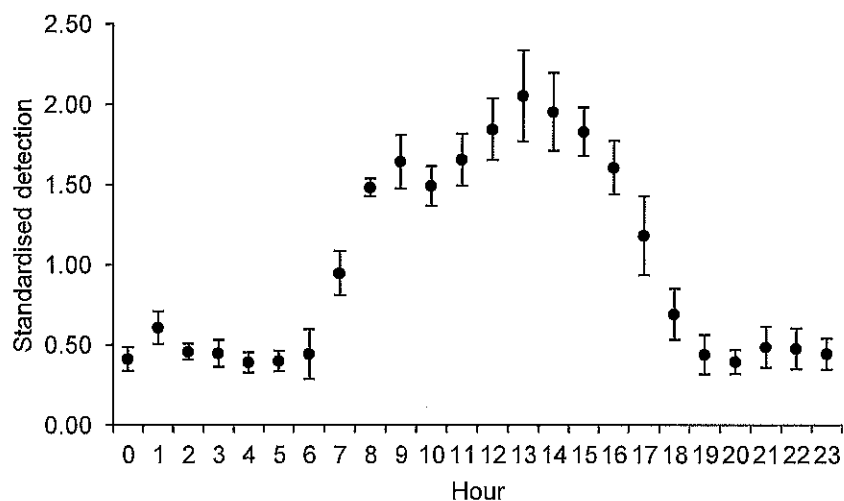
Figure 6. Mean standardised acoustic detections per hour for sentinel tags. Error bars represents ± 1 standard error of mean across all days.

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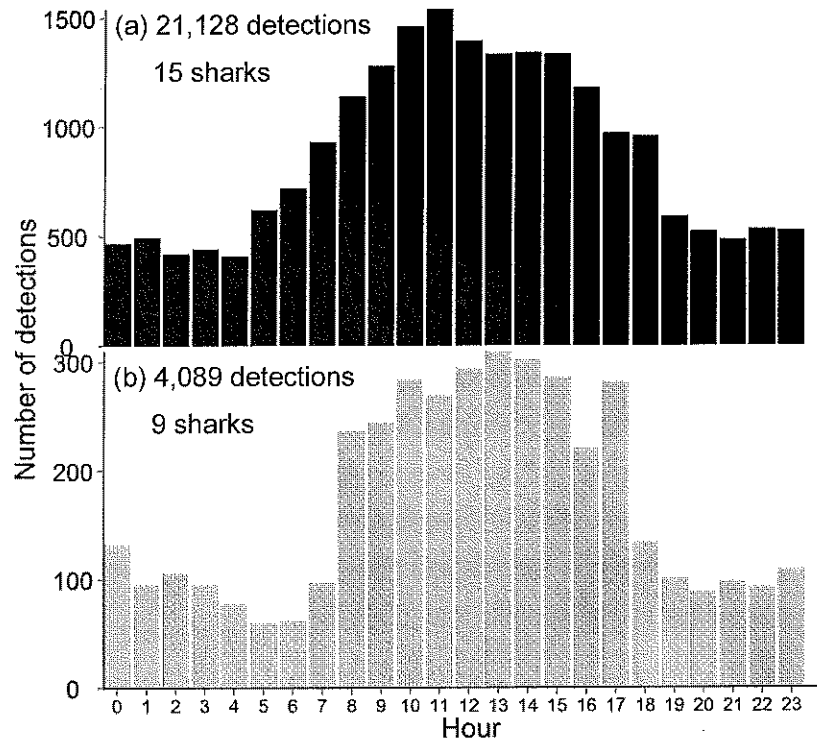
Figure 7. Un-standardised acoustic detections per hour for white sharks at the (a) North (black bars) and the (b) South Neptune Islands (grey bars).
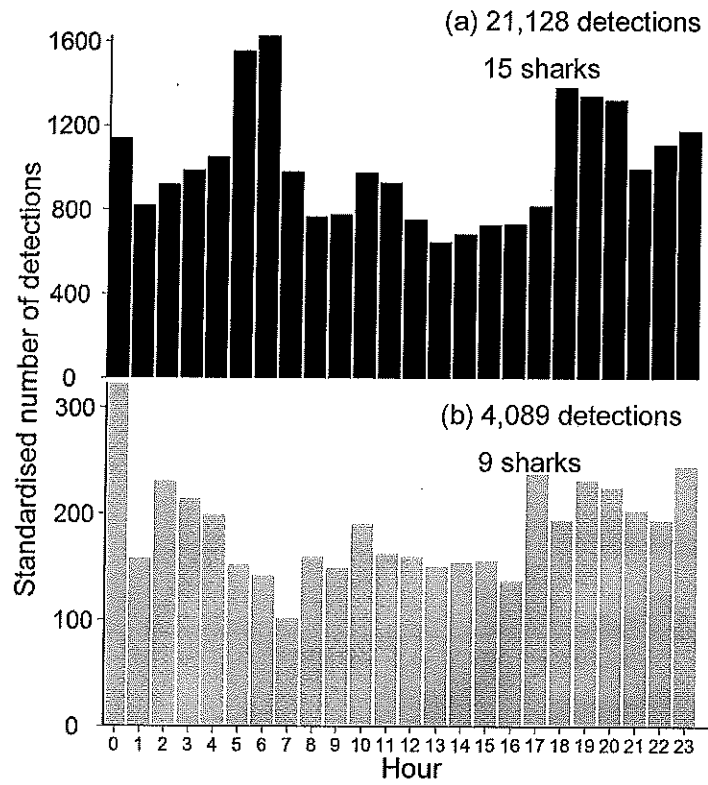
Figure 8. Mean standardised number of acoustic detections per hour for white sharks for (a) the North Neptune Islands (black bars) and (b) the South Neptune Islands (grey bars).
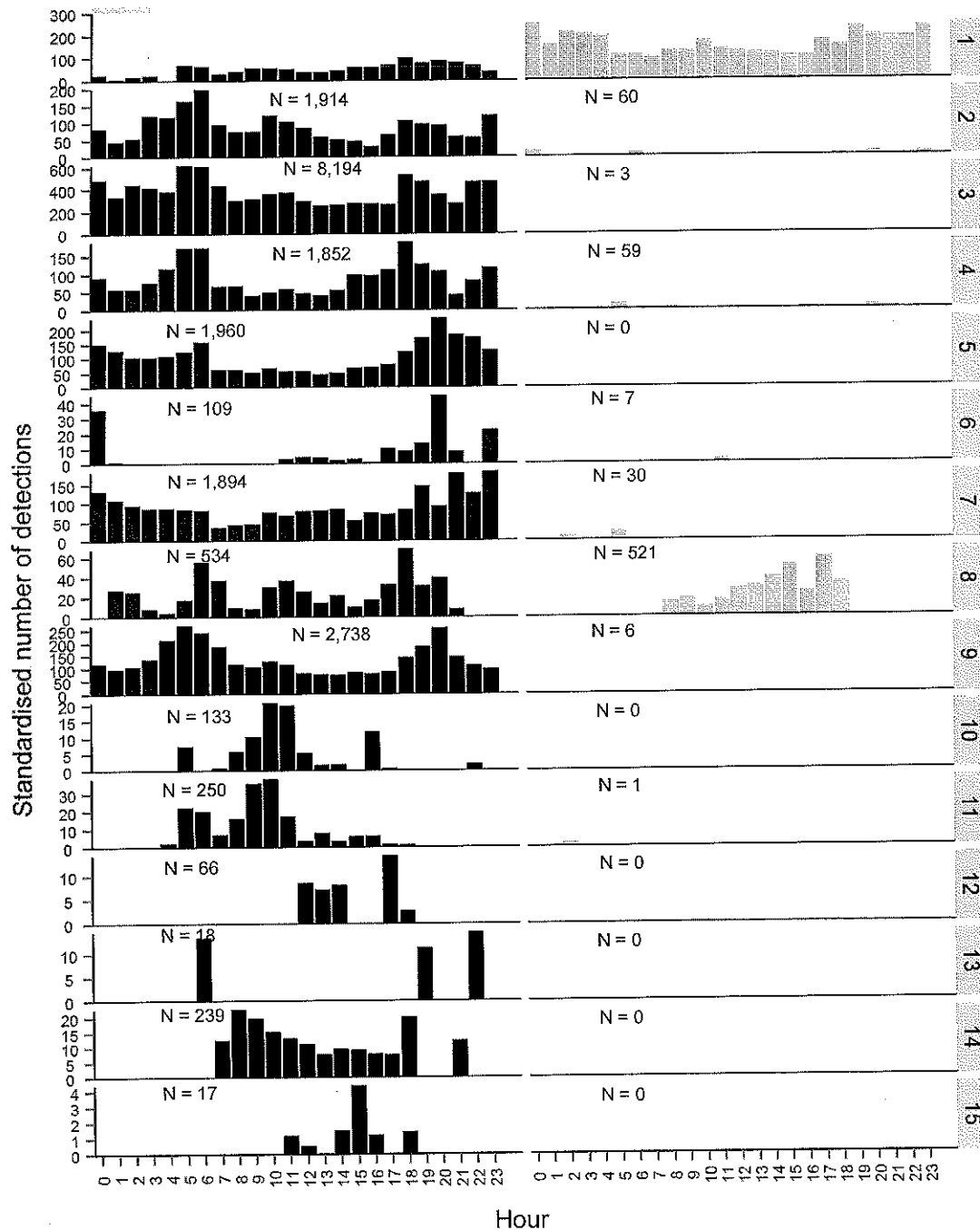
Figure 9. Mean number of standardised acoustic detections per hour for each white shark at the North Neptune Islands (black bars) and the South Neptune Islands (grey bars). N represents the number of acoustic detections of each shark. Numbers on the right-side y-axis represent the shark IDs.

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).

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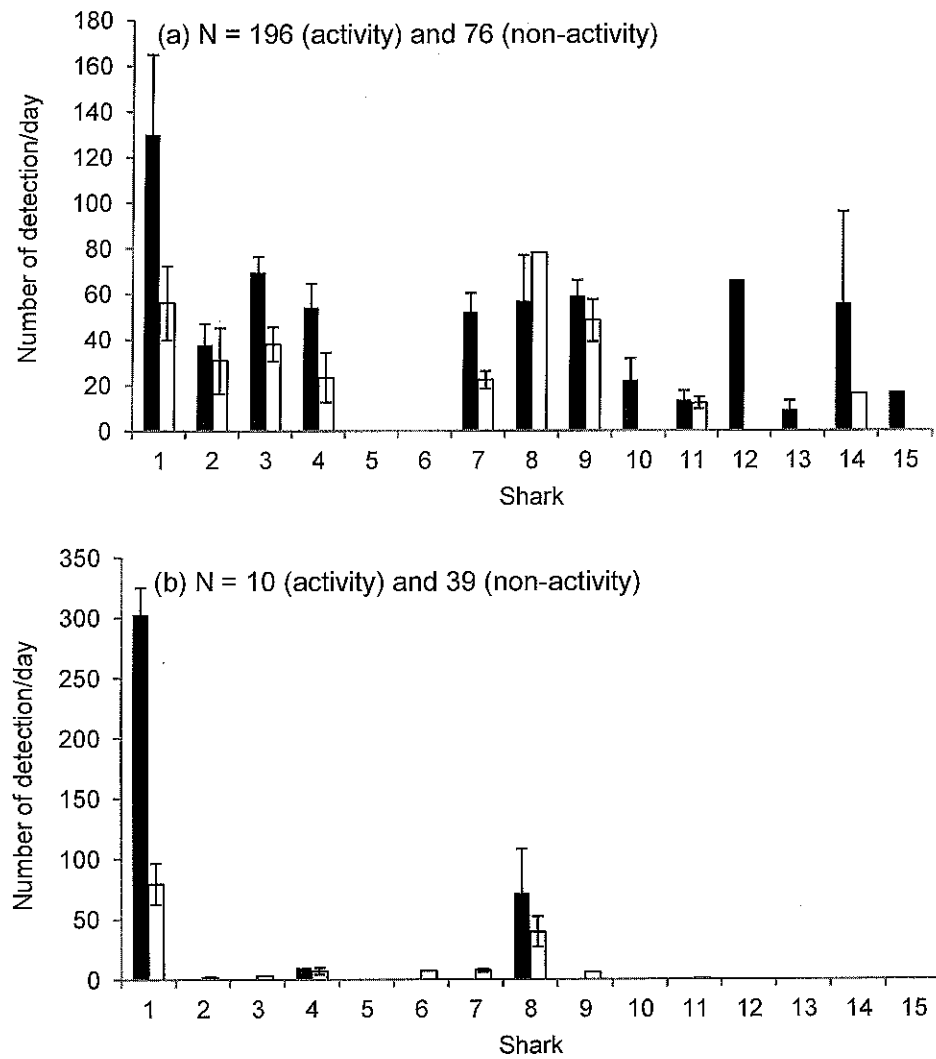
Figure 10. Standardised number of detections per day for each shark at the (a) North Neptune Islands and (b) South Neptune Islands during activity (black bars) and non-activity (white bars) days. Error bars represents standard error of mean. N represents number of days for which sharks were detected during activity and non-activity days.
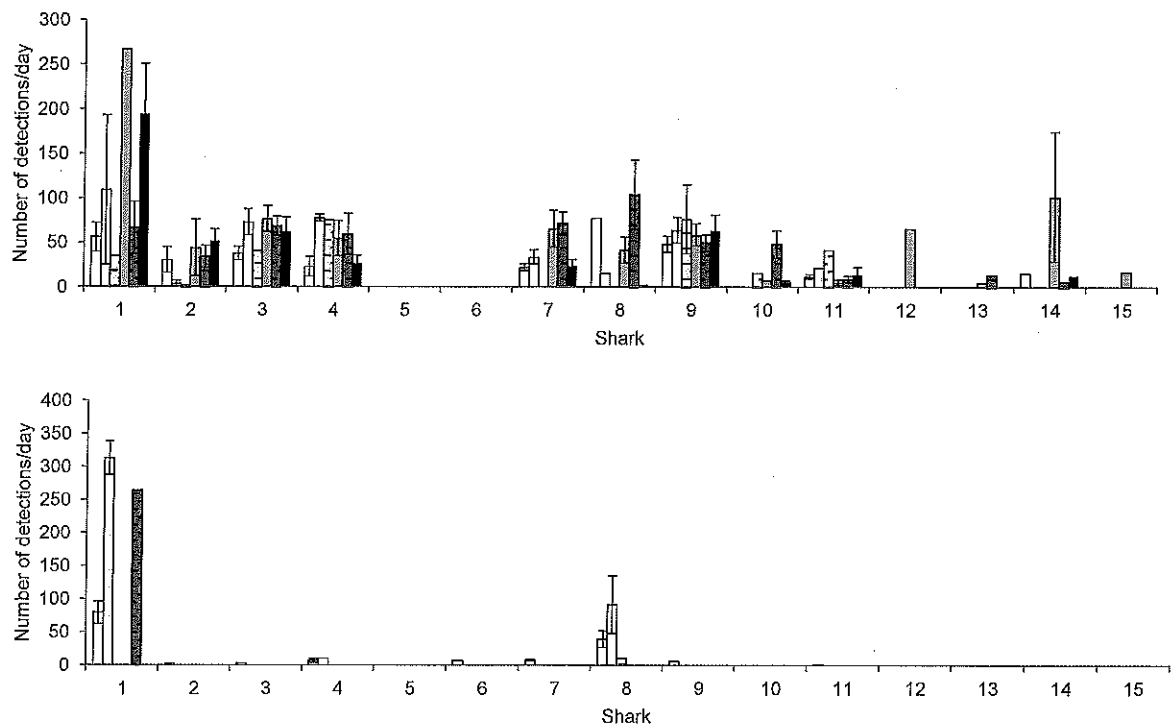
Figure 11. Standardised number of detection per day for each shark at the (a) North Neptune Islands and (b) South Neptune Islands during different levels of cage-diving operations. From left to right: no activity, one berley operator, one sound operator, two berley operator, one berley and one sound 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.
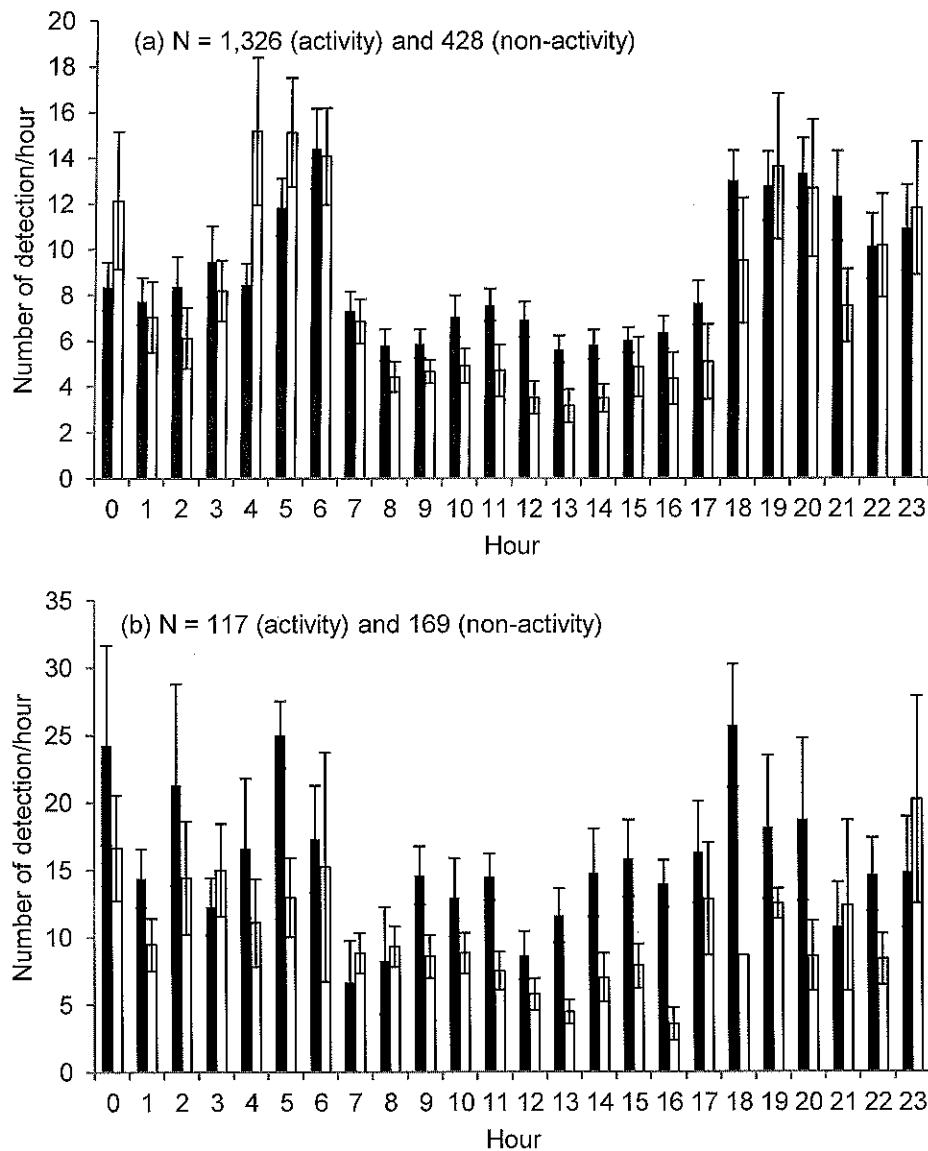
Figure 12. Standardised number of detections per hour at the (a) North Neptune Islands and (b) South Neptune Islands during activity (black bars) and non-activity (white bars) days. Error bars represents standard error of the mean. N represents number of hours for which sharks were detected during activity 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.
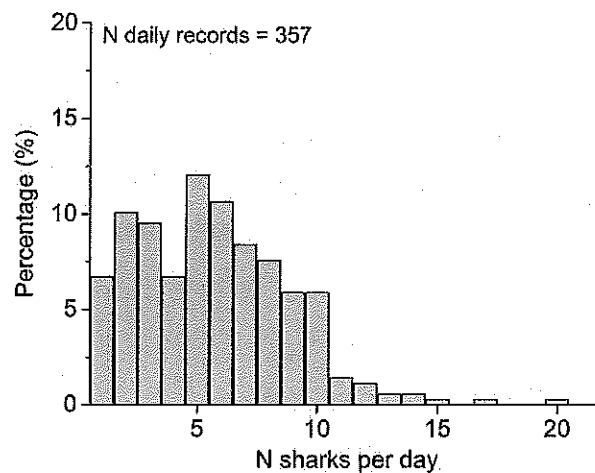
Figure 13. Percentage frequency of number of white sharks sighted per day by the three cage-diving operators.

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).
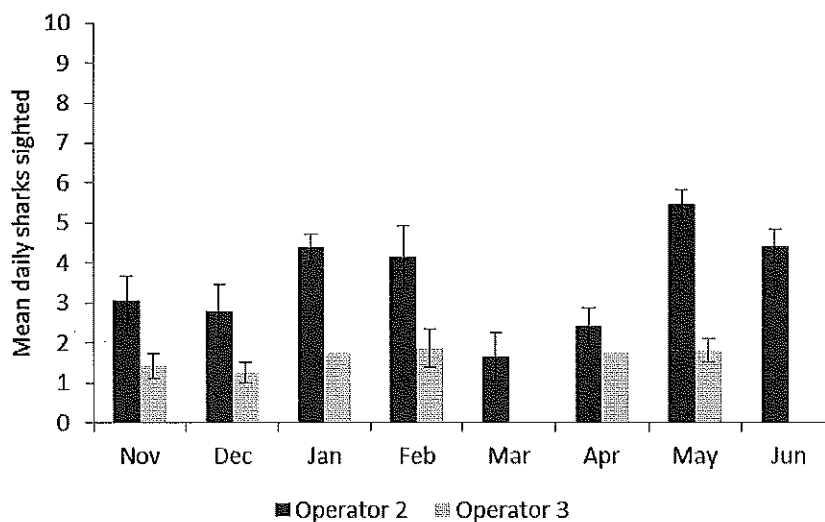
Figure 14. Mean number of sharks photographically identified per day in each month per operator. Error bars are ± 1 s.e.
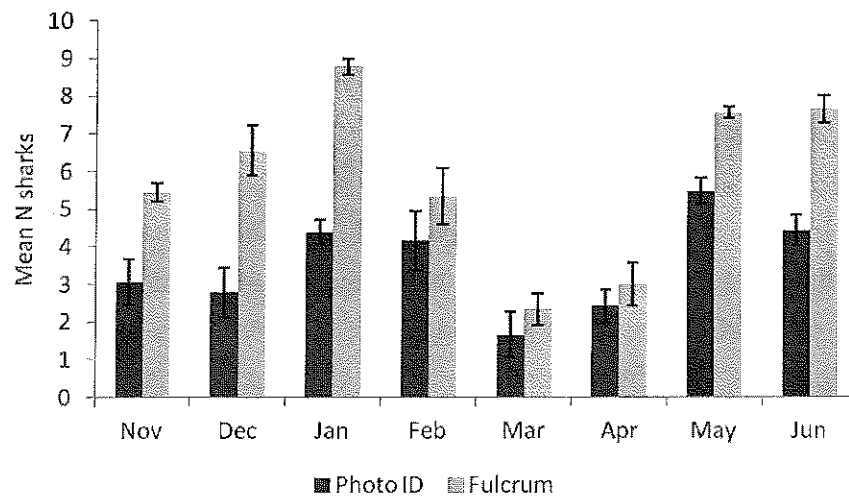
Figure 15. Mean number of sharks photographically identified and recorded in the e-logbooks per day in each month for operator 2. Error bars are ± 1 s.e.
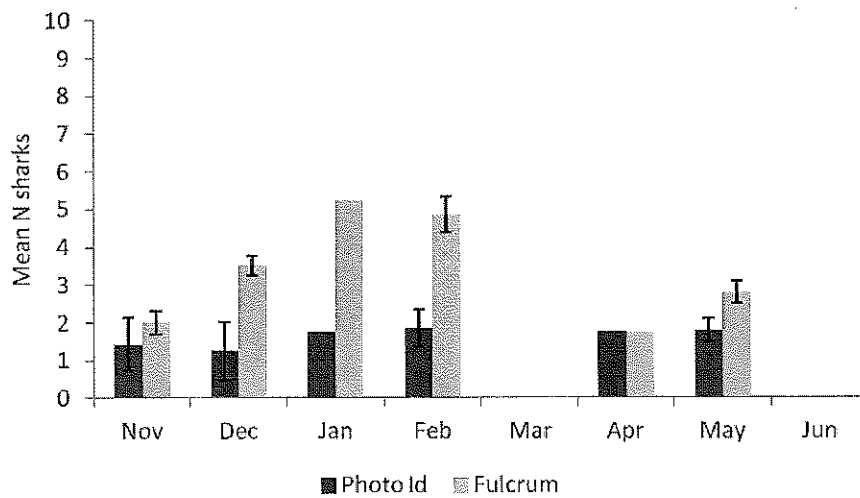
Figure 16. Mean number of sharks photographically identified and recorded in the e-logbooks per day in each month for operator 3. Error bars are ± 1 s.e.

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.

REFERENCES

Anderson, S. D., Chapple, T. K., Jorgensen, S. J., Klimley, A. P., Block, B. A. (2011). Long-term individual identification and site fidelity of white sharks, *Carcharodon carcharias*, off California using dorsal fins. *Marine Biology* 158, 1233–1237.

Anderson, S. D., Goldman, K. J. (1996) Photographic Evidence of White Shark Movement in California Waters. *California Fish and Game* 82, 182–186.

Beckmann, C. (2008). Using photographic identification to determine the behavioural ecology of the great white shark (*Carcharodon carcharias*). Honours Thesis. School of Biological Sciences. Flinders University. 86 pp.

Bonfil, R., Meyer, M., Scholl, M. C., Johnson, R., *et al.* (2005). Transoceanic migration, spatial dynamics and population linkages of white sharks. *Science* 310, 100–103.

Bradford, R. W, Bruce, B. D, McAuley, R. B., Robinson, G. (2011). An Evaluation of Passive Acoustic Monitoring Using Satellite Communication Technology for Near Real-Time Detection of Tagged Animals in a Marine Setting. *The Open Fish Science Journal* 4, 10–20.

Bradford, R., Robbins, R. (2013). A Rapid Assessment Technique to Assist Management of the White Shark (*Carcharodon carcharias*) Cage Dive Industry, South Australia. *The Open Fish Science Journal* 03/2013; 6:13-18. DOI: 10.2174/1874401X01306010013.

Bruce B. D. (1992). Preliminary observations on the biology of the white shark, *Carcharodon carcharias*, in South Australian waters. *Australian Journal of Marine and Freshwater Research* 43, 1–11.

Bruce, B. D., Stevens, J. D., Bradford, R. W. (2005). Site fidelity, residence times and home range patterns of white sharks around pinniped colonies. CSIRO Final Report to the Australian Government Department of the Environment and Heritage. 45 pp.

Bruce, B. D., Stevens, J.D., Malcolm, H. (2006). Movements and swimming behaviour of white sharks (*Carcharodon carcharias*) in Australian waters. *Marine Biology* 150, 161–172.

Bruce, B. D., Bradford, R. W. (2011). The effects of berleying on the distribution and behaviour of white sharks, *Carcharodon carcharias*, at the Neptune Islands, South Australia. Final Report to the Department of Environment and Natural Resources, South Australia, 50 pp.

Bruce, B. D., Bradford, R. W. (2013). The effects of shark cage-diving operations on the behaviour and movements of white sharks, *Carcharodon carcharias*, at the Neptune Islands, South Australia. *Marine Biology* 160, 889–907.

Brunnschweiler, J. M., Barnett, A. (2013). Opportunistic visitors: longterm behavioural response of bull sharks to food provisioning in Fiji. *PLoS ONE* 8:e58522.

Bryars, S., Rogers, P., Huveneers, C., Payne, N., Smith, I., McDonald, B. (2012) Small home range in southern Australia's largest resident reef fish, the western blue groper (*Achoerodus gouldii*): implications for adequacy of no-take marine protected areas. *Marine and Freshwater Research* 63, 552–563.

Chapple, T. K., Jorgensen, S. J., Anderson, S. D., Kanive, P. E., Klimley, A. P., Botsford, L. W., Block, B. A. (2011). A first estimate of white shark, *Carcharodon carcharias*, abundance off Central California. *Biology Letters* 7, 581–583.

CITES (2004). Convention of International Trade in Endangered Species of Wild Fauna and Flora - Appendix II Listing of the White Shark (revision 1). [Online]. Available from: http://www.environment.gov.au/coasts/publications/pubs/great-white-cites-appendix2-english.pdf.

Clua, E., Buray, N., Legendre, P., Mourier, J., Planes, S. (2010). Behavioural response of sicklefin lemon sharks *Negaprion acutidens* to underwater feeding for ecotourism purposes. *Marine Ecology Progress Series* 414, 257–266.

Department of the Environment (2013). Recovery Plan for the White Shark *(Carcharodon carcharias)*. *http://www.environment.gov.au/resource/recovery-plan-white-shark-carcharodon-carcharias*.

Department of Fisheries Western Australia (2014). http://www.fish.wa.gov.au/About-Us/Media-releases/Pages/Investigation-concluded-into-death-of-White-shark.aspx

Domeier, M. L., Nasby-Lucas, N. (2006). Annual resightings of photographically identified white sharks (*Carcharadon carcharias*) at an eastern Pacific aggregation site. *Marine Biology* 150, 977–984.

Fisheries Management Act
(2007).http://www.legislation.sa.gov.au/LZ/C/A/FISHERIES%20MANAGEMENT%20ACT%202007.aspx

Gjelland, K., Hedger, R. (2013). Environmental influence on transmitter detection probability in biotelemetry: developing a general model of acoustic transmission. *Methods in Ecology and Evolution* 4, 665–674.

Gubili, C., Johnson, R., Gennari, E., Oosthuizen, W., Kotze, D., Meyer, M., Sims., D, Jones, C., Noble, L. (2009). Concordance of genetic and fin photo identification in the great white shark, *Carcharodon carcharias* off Mossel Bay, South Africa. *Marine Biology*, 156, 2199–2207. doi:10.1007/s00227-009-1233-y.

Huveneers, C, Rogers, P. J., Beckmann, C., Semmens, J. M., Bruce, B. D., Seuront, L. (2013). The effects of cage-diving activities on the fine-scale swimming behaviour and space use of white shark. *Marine Biology* DOI 10.1007/s00227-013-2277-6.

Huveneers, C. H., Rogers, P. J., Drew, M. (2014). Monitoring shark species of conservation concern within the Adelaide metropolitan and Gulf St Vincent regions. Final Report to the Adelaide and Mount Lofty Ranges Natural Resources Management Board. SARDI Aquatic Sciences, Adelaide. SARDI Publication Number/ F2013/000716-1. SARDI Research Report Series No. 754. 89 pp.

IUCN (2014) Red List of Threatened Species (Year Assessed: 2005-10-01). *Carcharodon carcharias* http://www.iucnredlist.org/details/3855/0

Johnson, R., A Kock. 2006. South Africa's White Shark cage-diving industry - is their cause for concern? In Nel DC & Peschak TP (eds) Finding a balance: White shark conservation and recreational safety in the inshore waters of Cape Town, South Africa; proceedings of a specialist workshop. WWF South Africa Report Series - 2006/Marine/001.

Klimley, A. P., Anderson, S. D. (1996). Residency patterns of white sharks at the South Farallon Islands, California. In: Klimley AP, Ainley DG (eds) Great white sharks: the biology of *Carcharodon carcharias*. Academic, San Diego, pp 365–373.

Marshall, A. D., S. I. Pierce (2012). The use and abuse of photographic identification in sharks and rays. *Journal of Fish Biology* 80, 1361–1379.

Maljković, A., Côté, I. (2011) Effects of tourism-related provisioning on the trophic signatures and movement patterns of an apex predator, the Caribbean reef shark. *Biological Conservation* 144, 859–865.

Neptune Islands Group Ron and Valarie Taylor Marine Park Marine Park (2014). Management Plan Summary. 4 pp.

Orams, M. B. (2002). Feeding wildlife as a tourism attraction: a review of issues and impacts. *Tourism Management* 23, 281–293.

Payne, N., Gillanders, B. M., Webber, D., Semmens, J. M. (2010). "Interpreting diel activity patterns from acoustic telemetry: the need for controls." *Marine Ecology Progress Series* 419, 295–301.

Pincock, D. G. (2011). "False detections: what they are and how to remove them from detection data." DOC-004691 Version 02, April 13, 2011.

Robbins, R., Fox, A., (2012a). Use of the photographic identification of white sharks (*Carcharodon carcharias*) to determine seasonal abundance and site fidelity patterns, at the Neptune Islands, South Australia. Final Report to the Norman Wettenhall Foundation. Fox Shark Research Foundation. 22 pp.

Robbins, R., Fox, A. (2012b). Further evidence of pigmentation change in white sharks, *Carcharodon carcharias*. *Marine and Freshwater Research* 63, 1215–1217.

Semmens, J. M., Payne, N. L., Huveneers, C., Sims, D. W., and Bruce, B. D. (2013). Feeding requirements of white sharks may be higher than originally thought. *Scientific Reports,* 3, 1471. 4 pp. doi:10.1038/srep01471.

Shark-plan 2 (2012) National Plan of Action for the Conservation and Management of Sharks http://www.agriculture.gov.au/fisheries/environment/sharks/sharkplan2

Shaunghnessy, P. D., Dennis, T. E., and Beris, M. (2007). Predation on Australian sea lions *Neophoca cinerea* by white sharks *Carcharodon carcharias* in South Australia. *Australian Mammology* 29, 69–76.

Stevick, P. T., Palsboll, Per. J., Smith, T. D., Bravington, M. V., Hammond, P. S. (2001). Errors in identification using natural markings: rates, sources, and effects on capture-recapture estimates of abundance. *Canadian Journal of Fisheries and Aquatic Sciences* 58, 1861–1870.

Strong, W. R., Jr, Bruce, B. D., Nelson, D. R., Murphy, R. D. (1996). Population dynamics of white sharks in Spencer Gulf, South Australia. In: Klimley, A.P. & D.G. Ainley, eds. Great White Sharks: the Biology of *Carcharodon carcharias*. Page(s) 401–414. United States of America: Academic Press.

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

RF and CS
RF and CS
RF
RF
CS
RF
RF
CS
RF & CS
AB
AB
AB
	Amount of attractant
	     Berleying start time
	     Berleying stop time
	     Number of blood buckets used
	     Number of minced tuna buckets used
	     Amount of berley used (buckets)
	     Number of gills/entrails used on the surface (nally bins)
	     Number of gills/entrails used in bottom cage (nally bins)
	     Number of gills/entrails used (nally bins)
	     Number of tuna used for bait
	     Sound start time
	     Sound stop time
	     Sound characteristics

	Number of sharks sighted

RF
 	
RF and CS
	Shark details (Up to 20 sharks)
	     Name or description
	     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
	     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

N|7

© Calypso Star Charters

© Adventure Bay Charters
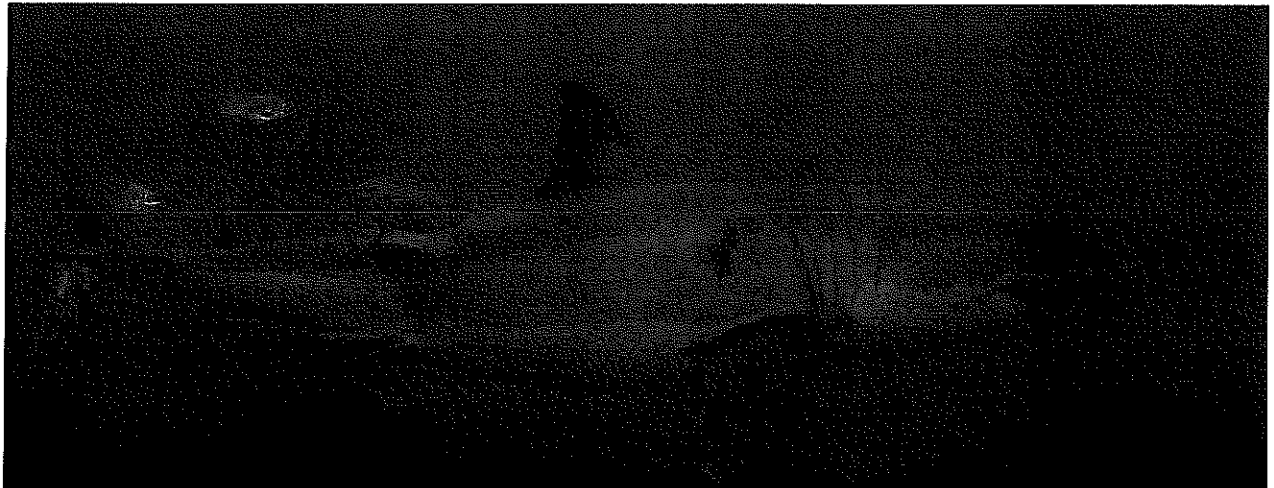
NI11
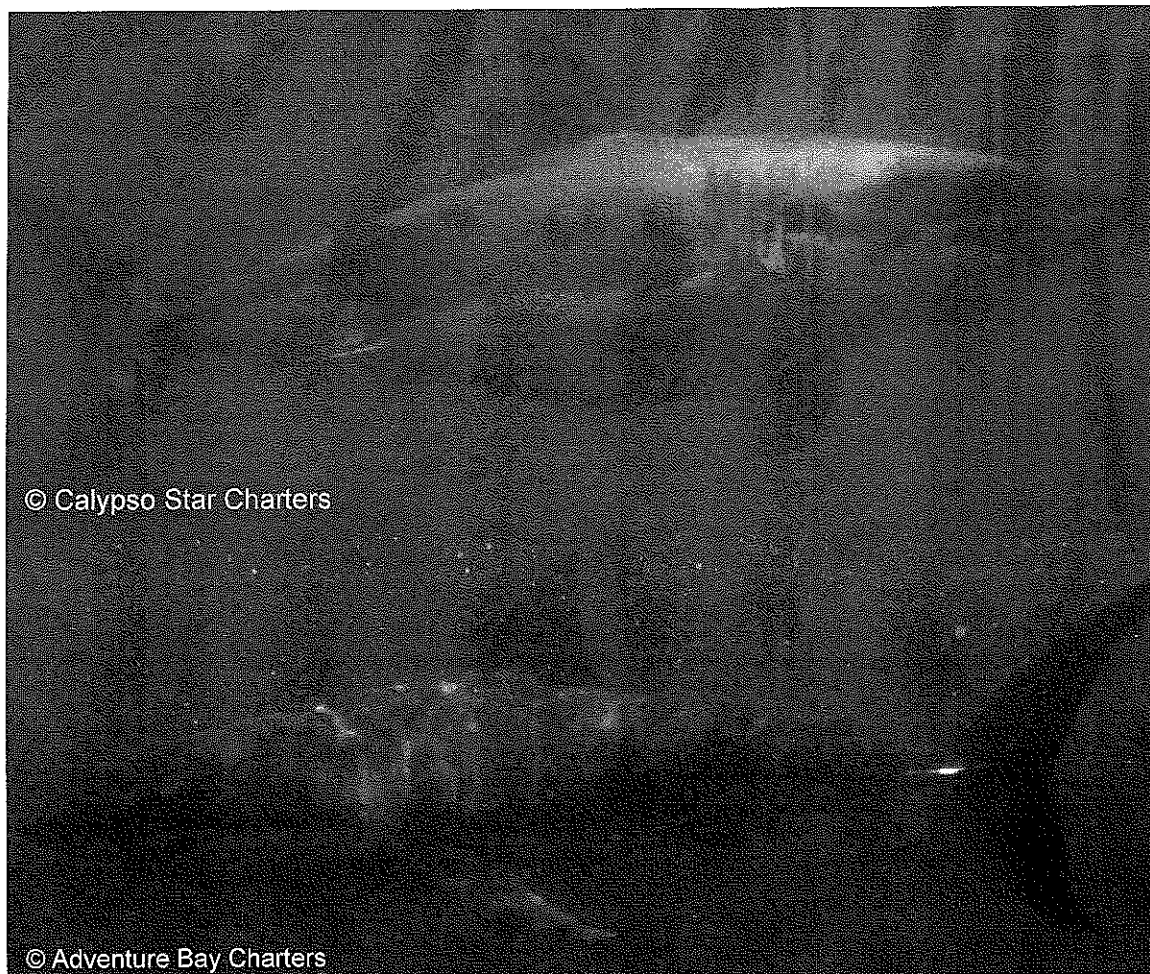
NI21
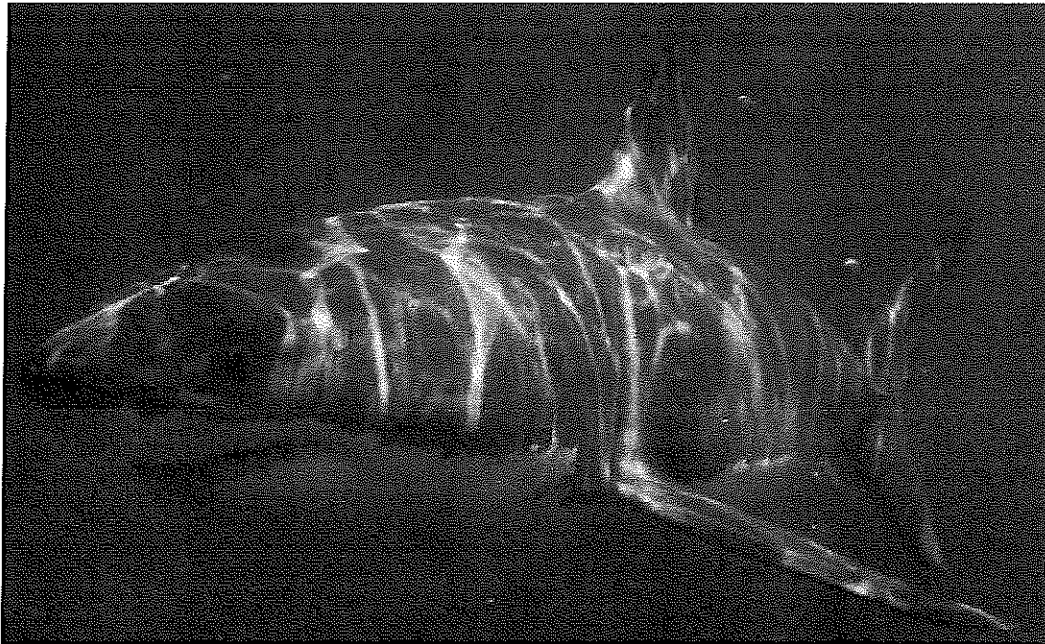
© Calypso Star Charters
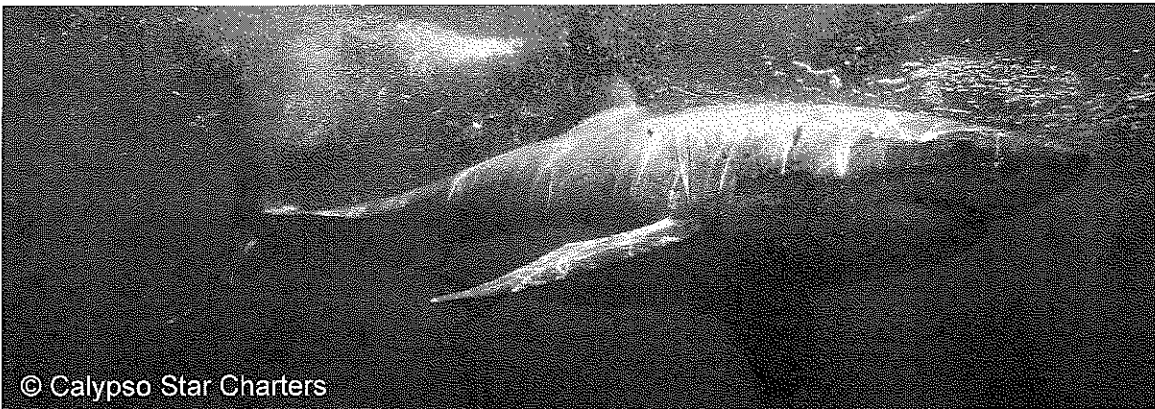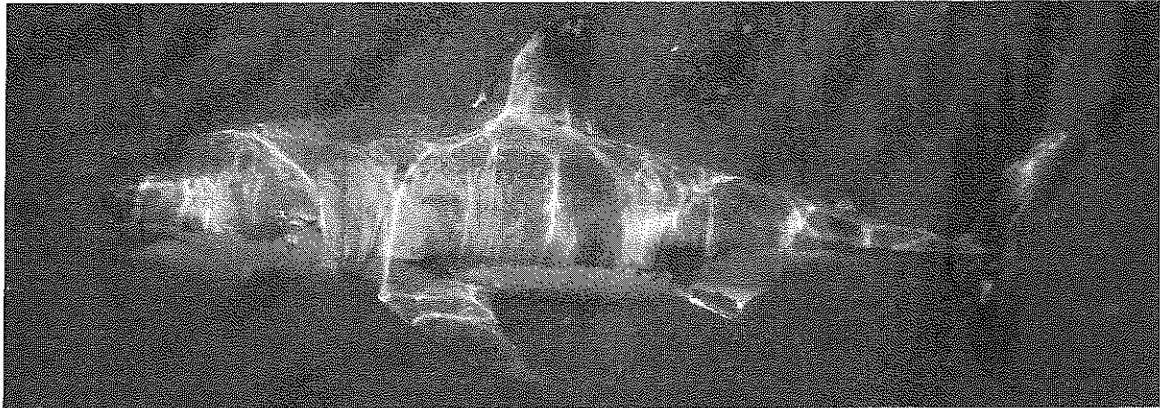
NI26
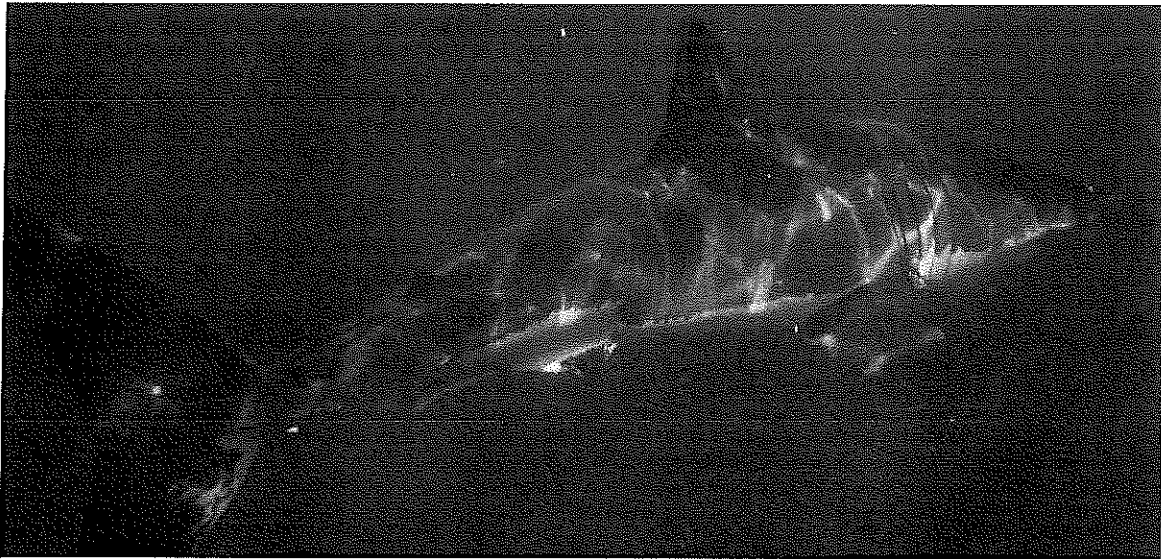
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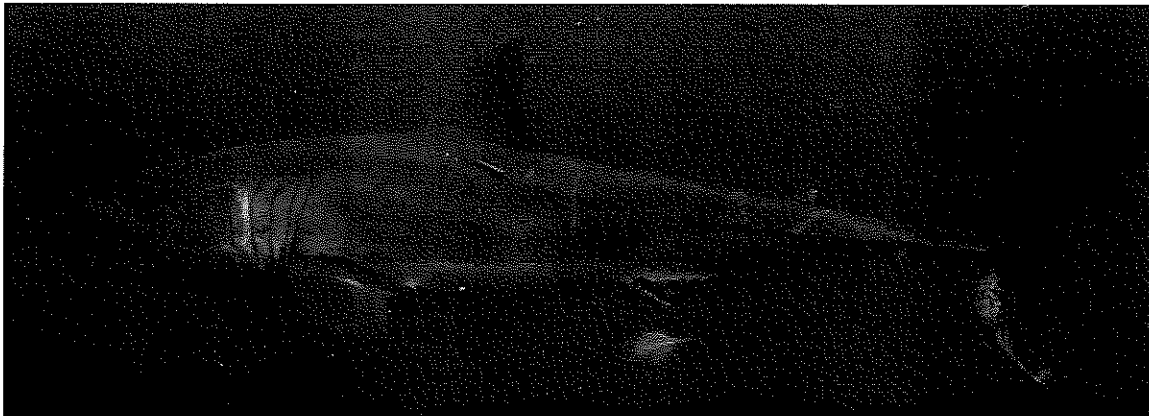
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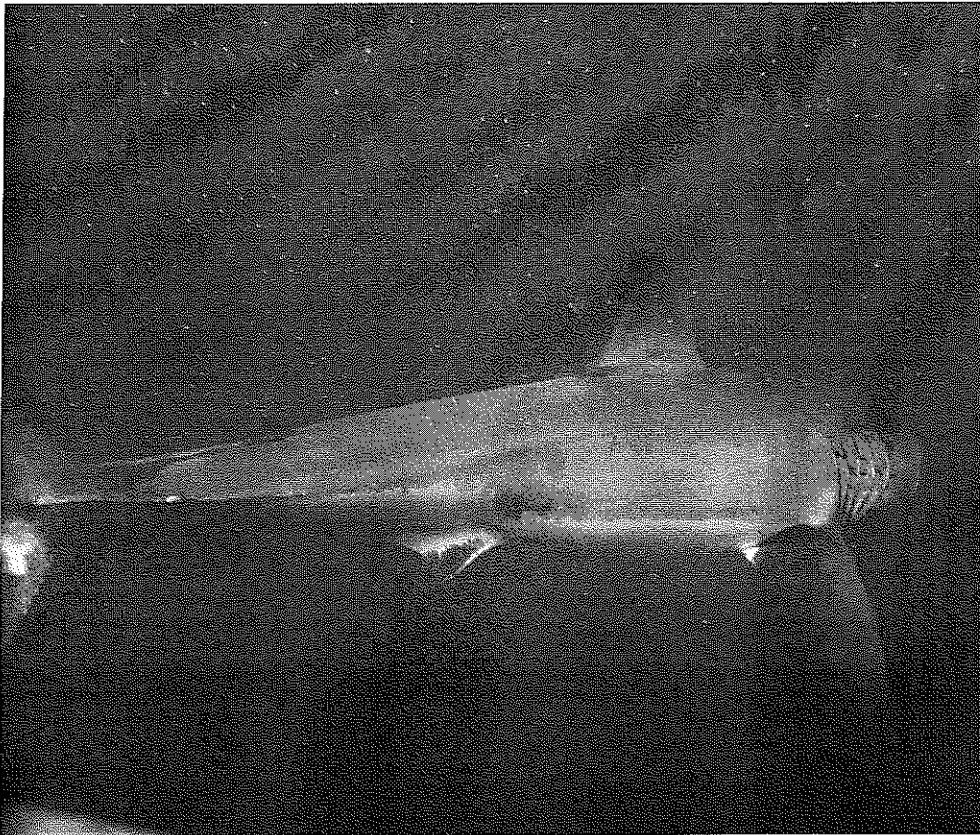
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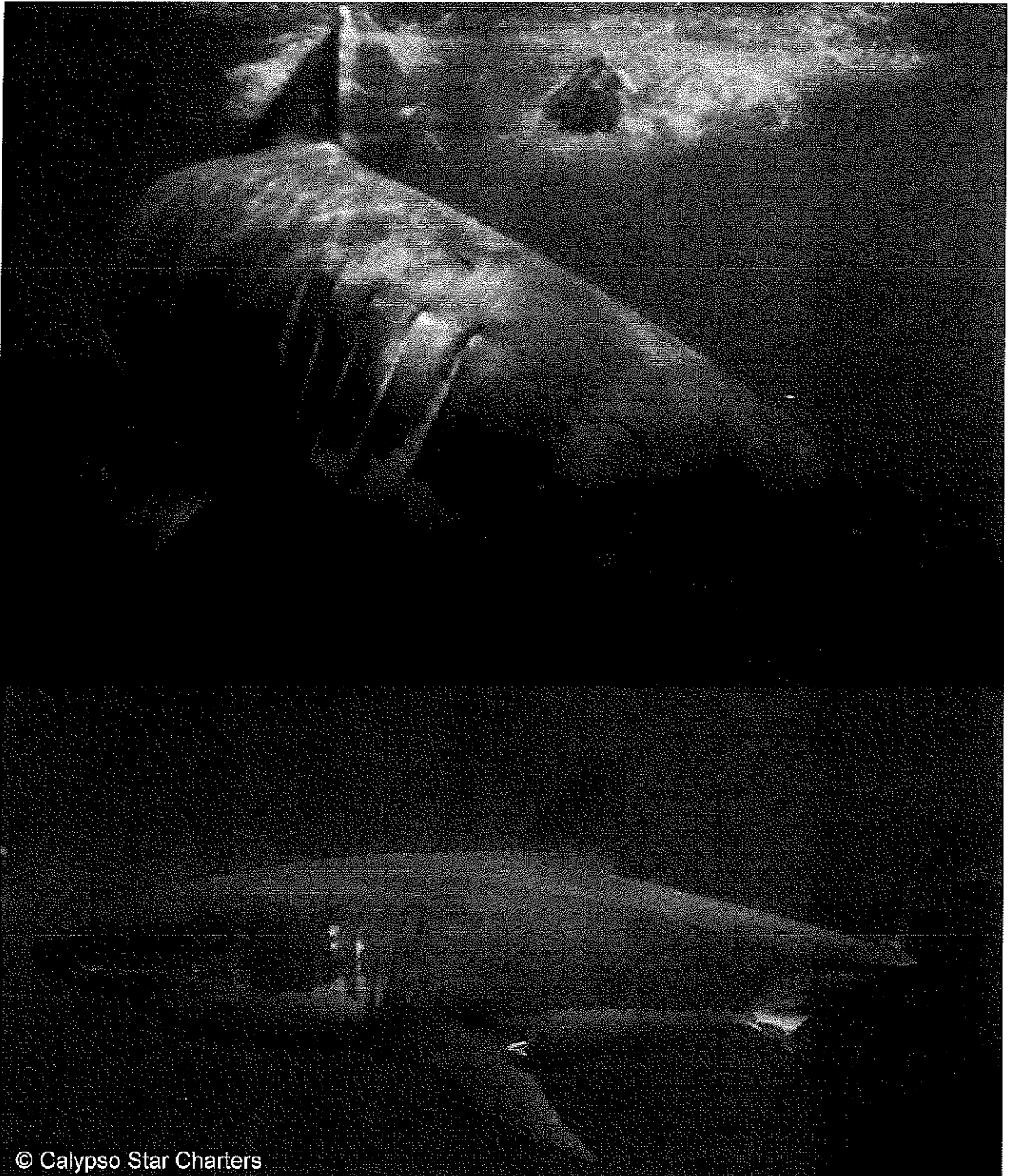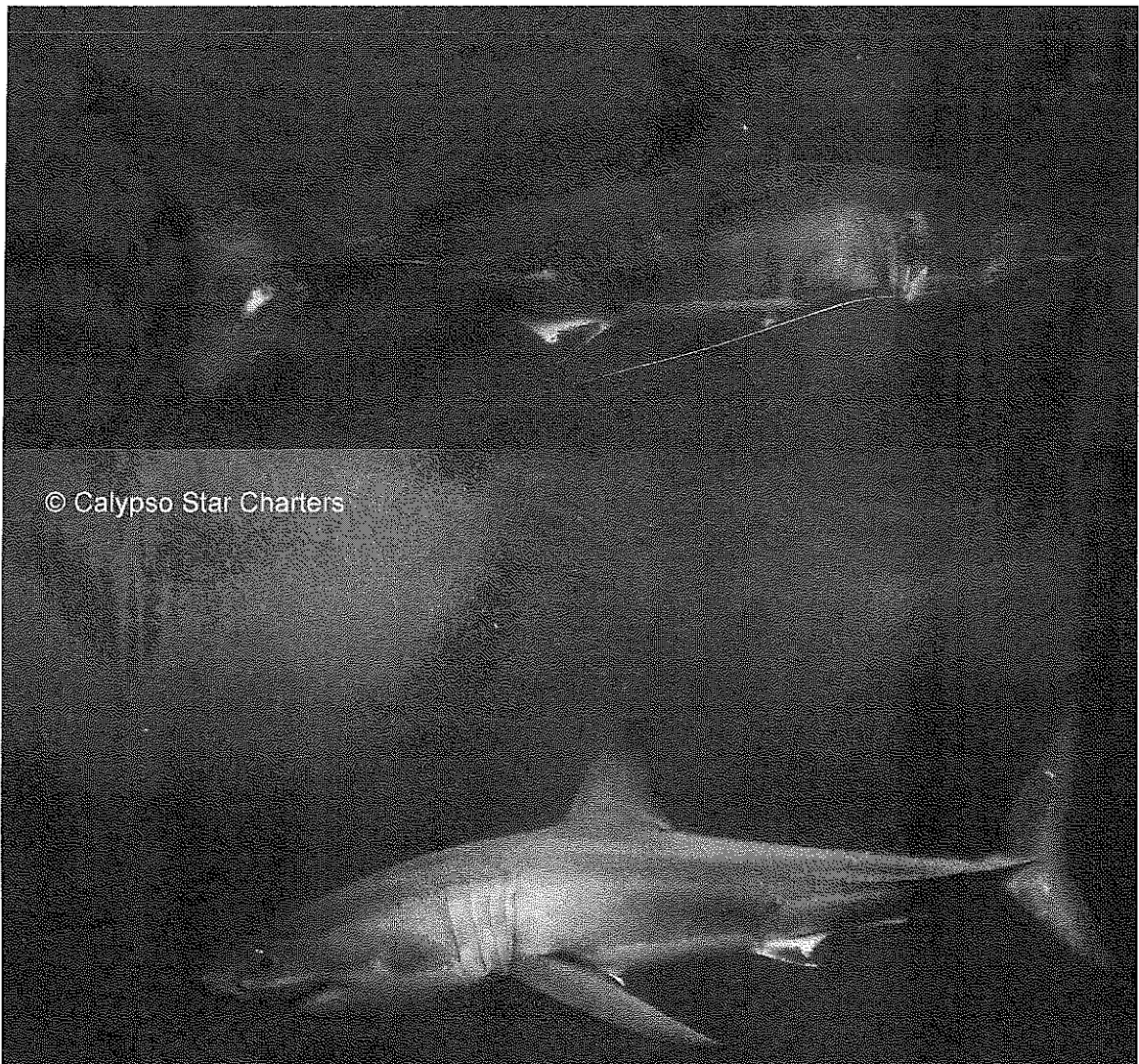
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NI86

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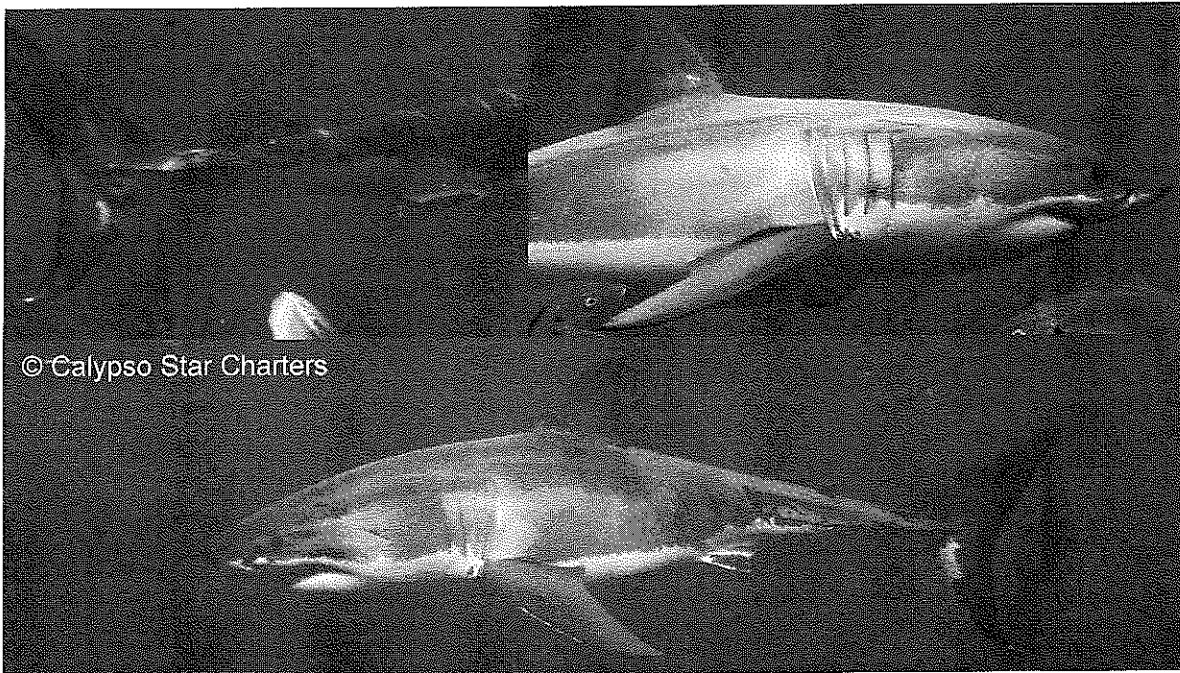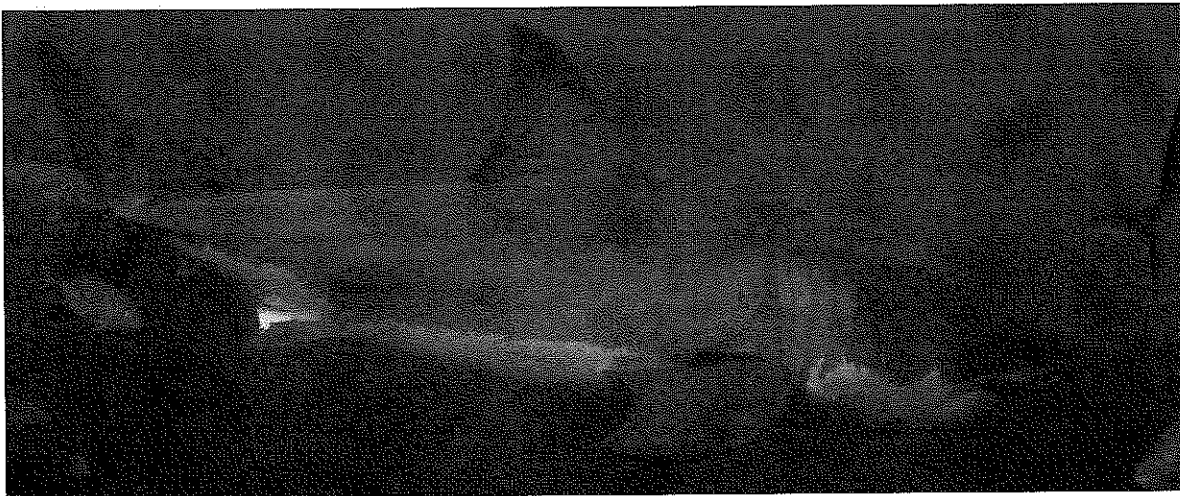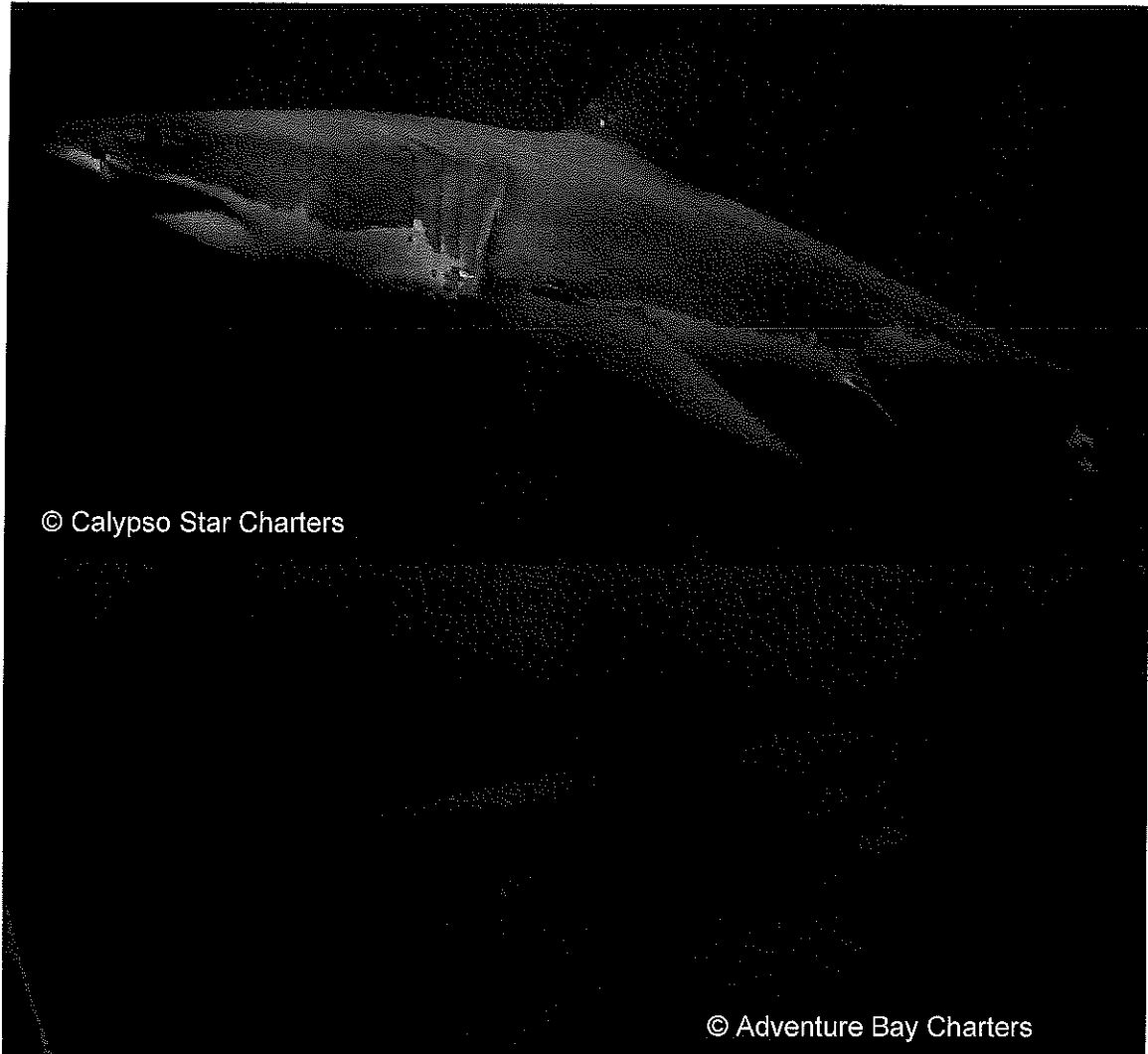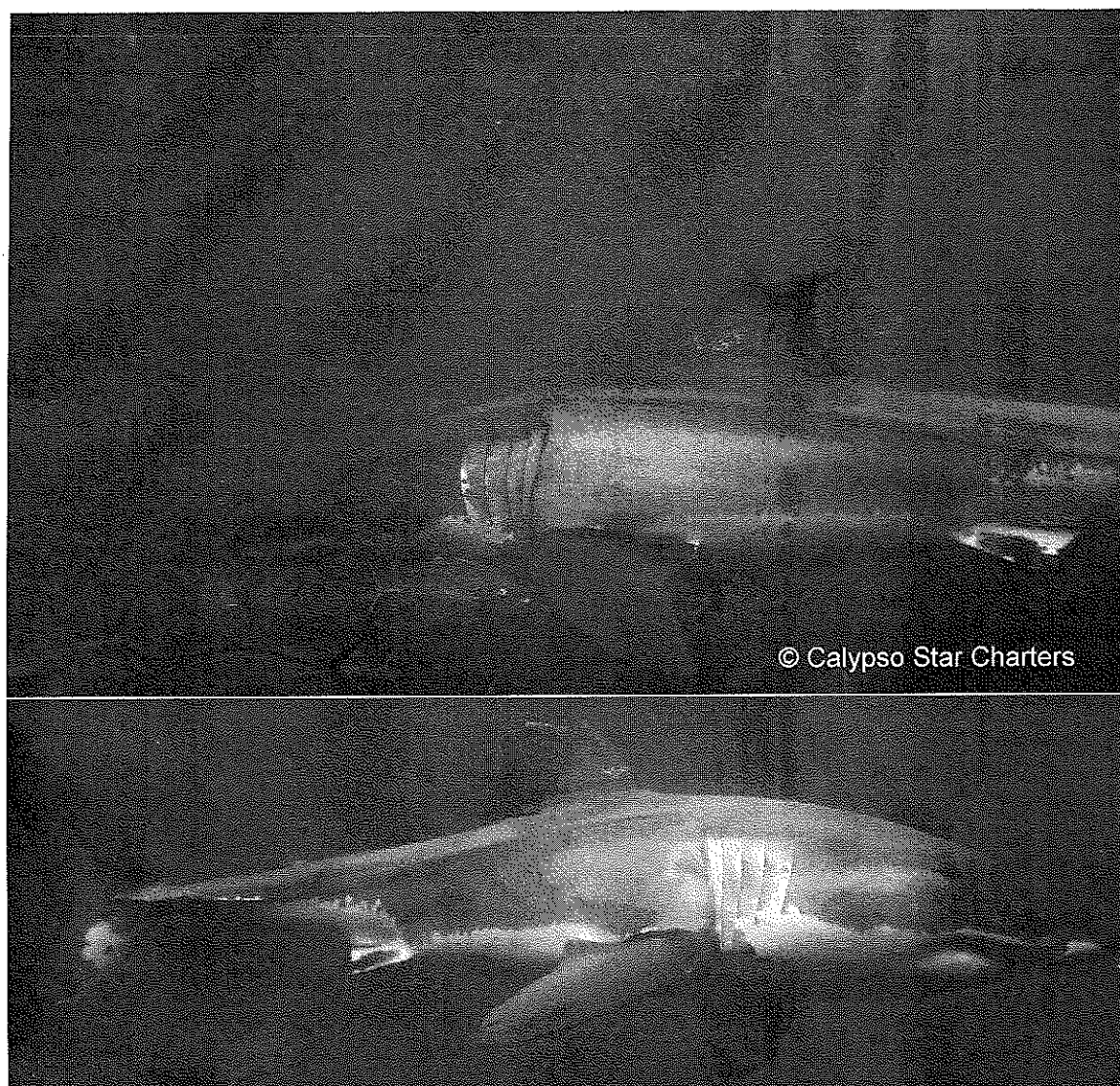
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NI122

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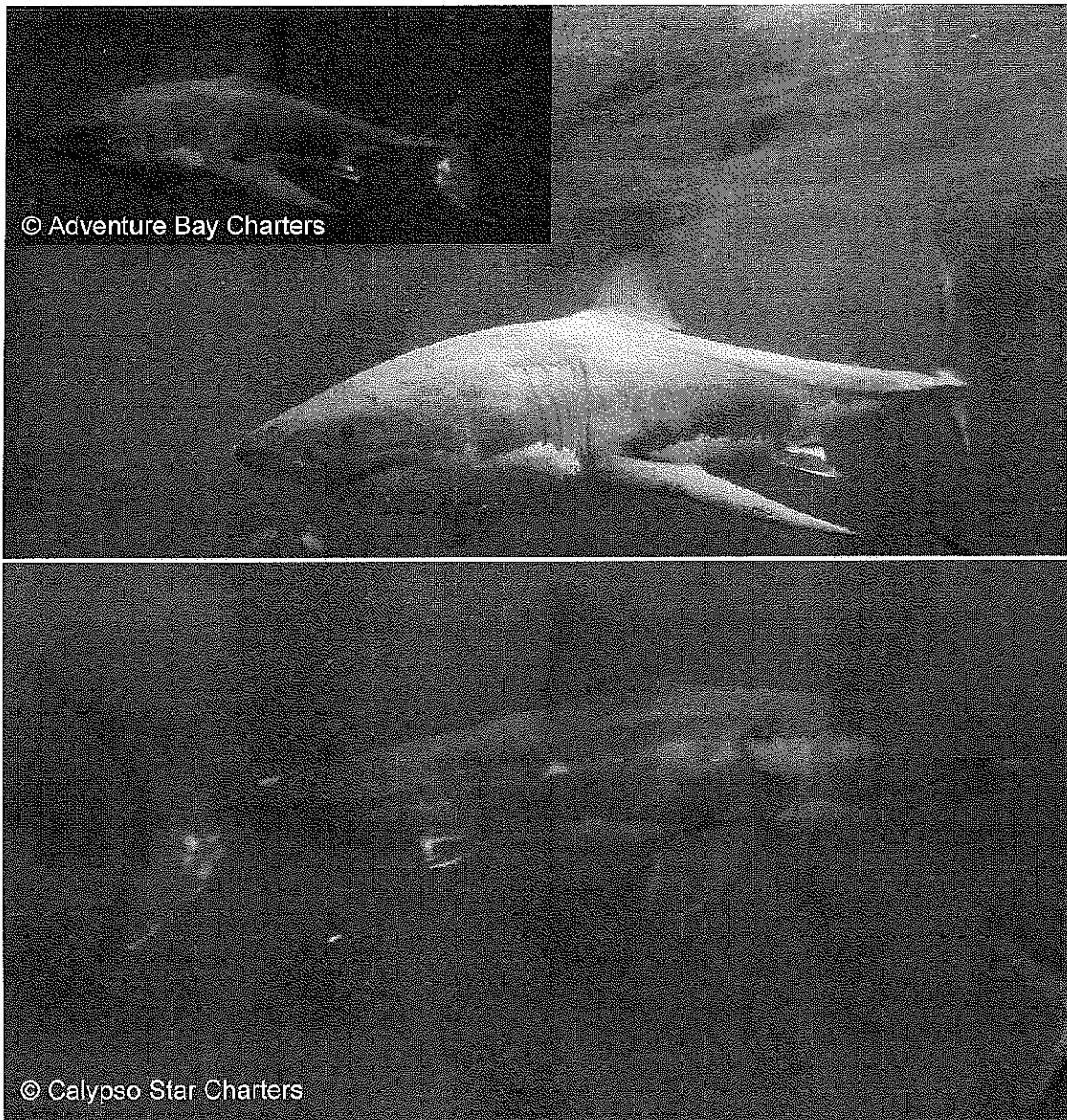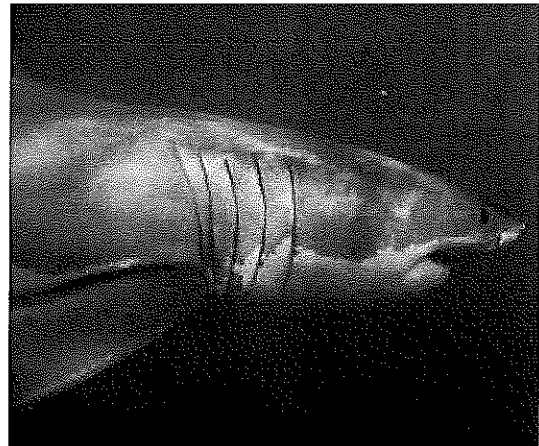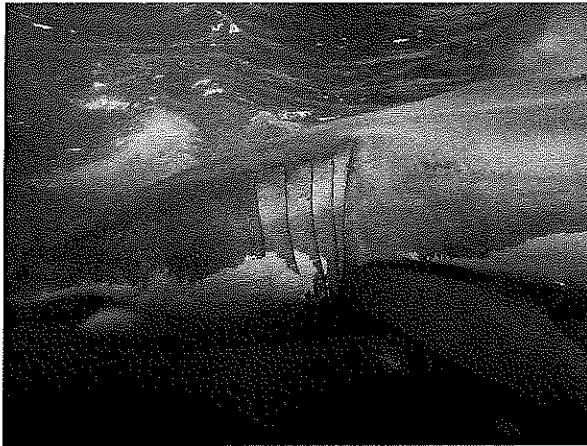
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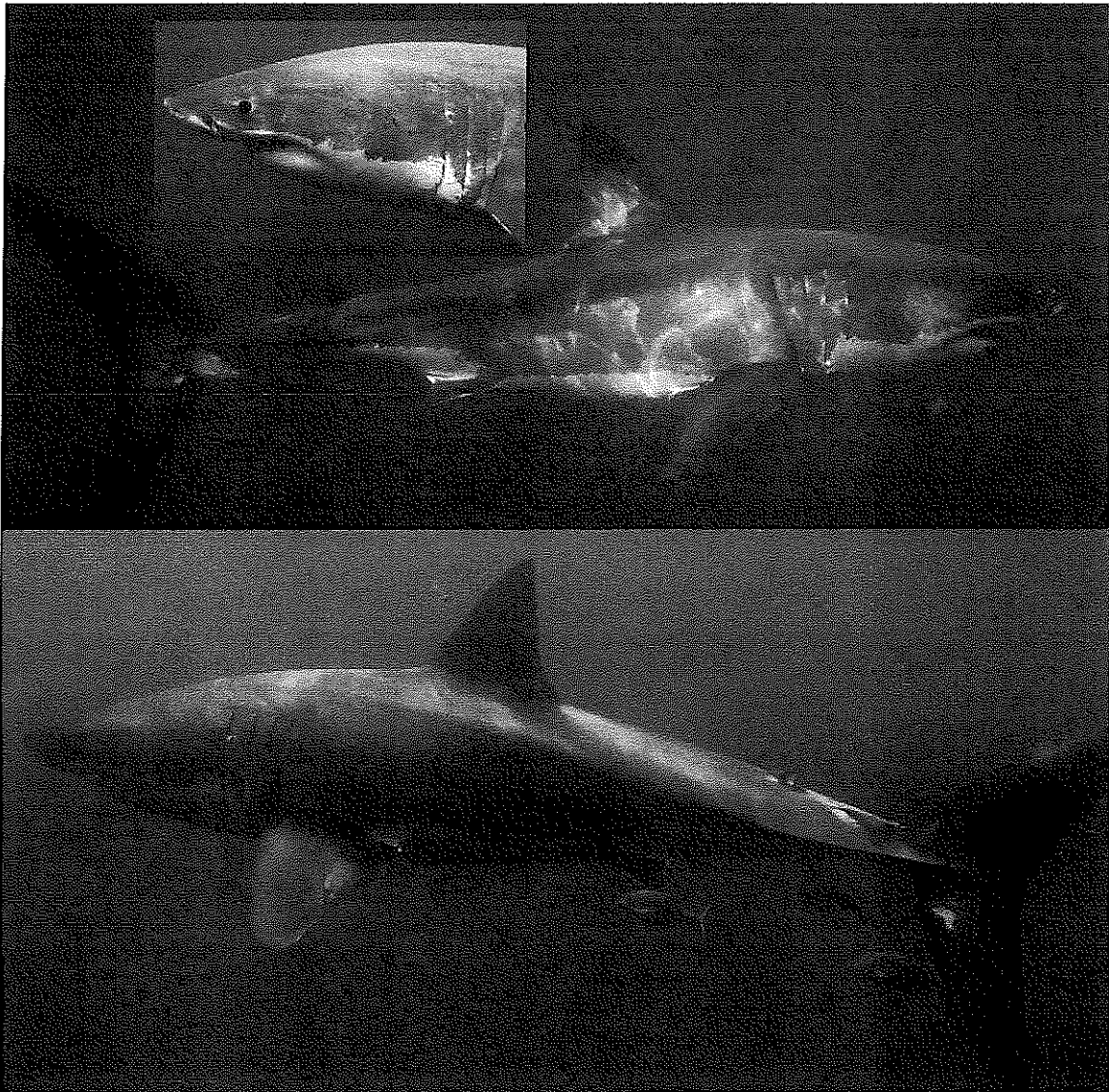
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Residency and photographic identification of white sharks *Carcharodon carcharias* in the Neptune Islands Group Marine Park between 2013 and 2015
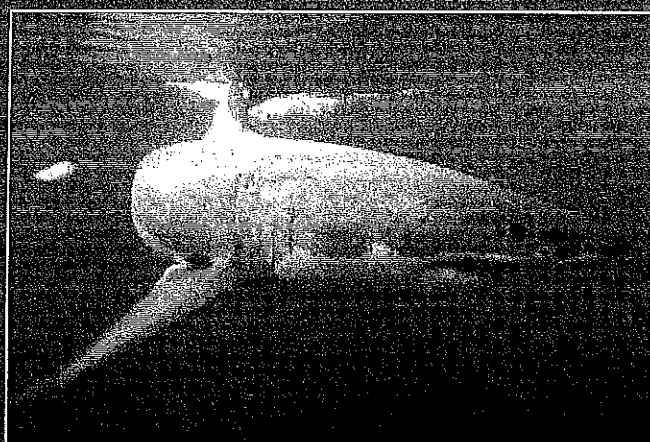
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SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

April 2016

Report to Department of Environment, Water and Natural Resources

PREMIUM
FOOD AND WINE FROM OUR
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Residency and photographic identification of white sharks *Carcharodon carcharias* in the Neptune Islands Group Marine Park between 2013 and 2015

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GLOSSARY

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

Berley: Fish-based minced products used to attract sharks to the vessel.

Detection: A set of pulses produced by transmitters that is identified and recorded by acoustic receivers.

Highly Migratory Species: Species that 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 a transmitter is within the detection range of a receiver, it records the date, time and identification number of the transmitter when acoustic pulses are received. Detection range varies with transmitter power and environmental conditions and can be 800–1000 m.

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

Teaser bait: Baits tethered under floats at the surface to attract sharks to within the vicinity of boat and underwater viewing cages.

Transmitter: Acoustic tag deployed on sharks 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 receiver

EXECUTIVE SUMMARY

The primary aim of this report is to provide estimates of residency for white sharks (*Carcharodon carcharias*) in the Neptune Islands Group Marine Park between a) 14 September 2013 and 30 June 2014, b) 1 July 2014 and 30 June 2015 and c) across the complete time series from 14 September 2013 to 30 June 2015. The report also describes preliminary results from analysis of the South Australian Research and Development Institute (SARDI) white shark photographic identification catalogue, and summarises daily electronic logbook (e-logbook) data describing white shark cage-diving industry activities.

A total of 37 white sharks ranging in size from ~180–450 cm total length were monitored using acoustic telemetry between 14 September 2013 and 30 June 2015. Mean residency estimates for each shark at the North Neptune Islands ranged from 0.3 to 117.3 days in 2013–14, and 0–52.1 days in 2014–15. The mean residency estimate averaged across sharks at the North Neptune Islands was 18.9±31.7 days (mean ± standard deviation; n=15) in 2013–14 and 9.1 ± 12.3 days (n=25) in 2014–15. The mean residency estimate for the South Neptune Islands was 1.7±1.8 days (range: 0–4.5; n=9) in 2013–14 and 9.3±14.8 days (range: 0–64.9; n=22) days in 2014–15.

On 2 February 2015, a visit by killer whales (*Orchinus orca*) was reported at the North Neptune Islands. Acoustic telemetry data indicated that five tagged white sharks were present on 1 February 2015. All tagged individuals had departed the Neptune Islands Group Marine Park by 3 February 2015. No tagged white sharks were detected on acoustic receivers until late April 2015.

The e-logbook showed that reported numbers of individual white sharks sighted per day ranged from 0 to 14 individuals (mean sightings=5±3 sharks per day) between 1 July 2014 and 30 June 2015. Operators reported using 12,100 litres of berley, 6,598 sets of southern bluefin tuna (SBT) gills and entrails and 1,551 portions of SBT as teaser baits between 1 July 2014 and 30 June 2015. Use of sound emission was reported on 87 days between 1 July 2014 and 30 June 2015. Durations of sound use ranged between 10 minutes–6:45 hours.

A photographic identification catalogue was established for white sharks that visited the Neptune Islands Group Marine Park between 4 October 2013 and 31 October 2014 based on analysis of 35,904 images. Complete photo-identification profiles were compiled for 78 sharks. An estimated 21% of the white sharks identified using photographic identification were electronically tagged.

A quantitative analysis of the residency of white sharks in the Neptune Islands Group Marine Park, cage-diving industry activities, environmental, and demographic factors will be completed using three years of data in 2016.

1. INTRODUCTION

1.1 Background

The white shark (*Carcharodon carcharias*) is a large, highly migratory pelagic shark species found throughout South Australia's gulf, continental shelf and oceanic ecosystems (Bruce *et al.* 2006). Considerable community interest in conservation and management of this species stems from its propensity to interact with humans that use the marine environment. Studies of white sharks suggest the species plays a key role as a top predator in southern hemisphere ecosystems (Hussey *et al.* 2012), yet is highly vulnerable to sources of additional mortality (Rogers *et al.* 2013).

The white shark is listed globally as Threatened (Vulnerable) under the International Union for Conservation of Nature Red List (IUCN), and under the *Convention on International Trade in Endangered Species, of Wild Fauna and Flora*, and *Convention on Conservation of Migratory Species of Wild Animals*. In mid-1999, the white shark was listed under the Australian Commonwealth Government *Environmental Protection, Biodiversity and Conservation Act* (1999) following evidence of population declines derived from beach meshing data, game fishing records, and anecdotal sighting frequencies (White Shark Recovery Plan 2002). In South Australian State waters, the white shark is protected under the *Fisheries Management Act* (2007) regulated by PIRSA Fisheries and Aquaculture.

Subsequent to the EPBC Act listing, a recovery plan with objectives aimed at supporting white shark population growth was developed in 2002 (Environment Australia 2002, White Shark Recovery Plan). The plan was reviewed and its objectives were revised in 2008. Priorities and objectives of both plans included the identification, investigation, and management of the impacts of tourism on white sharks. The revised plan lists one of the objectives and the priorities for State and Commonwealth research organisations as: Investigate and manage (and where necessary reduce) the impact of tourism on the white shark (Department of the Environment 2013, Recovery Plan for the White Shark). Actions within these objectives incorporate the need to: 1) investigate impacts of increased cage-diving activity and develop appropriate management responses if required, 2) maintain daily e-logbook reporting of white

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shark interactions by cage- dive operators, and 3) engage cage-dive operators in shark research and education programs (Department of the Environment 2013, Recovery Plan for the White Shark). The Department of Environment Water and Natural Resources (DEWNR) Great White Shark Tourism Policy aims to minimise the potential impacts of activities associated with the white shark cage-diving industry in the Neptune Islands Group Marine Park on this State protected and EPBC listed species. This policy aims to develop and maintain the industry in a manner agreed to be in accordance with the Act, whilst supporting and facilitating the Commonwealth Government Recovery Plan objectives.

The white shark cage-diving industry is one of five key marine-based wildlife tourism ventures in South Australia that is managed by DEWNR. The others include southern right whale (*Eubalaena australis*) viewing at Head of Bight, swimming with Australian sea lions (ASL) (*Neophoca cinerea*) at Hopkins Island, Spencer Gulf and Bairds Bay, Eyre Peninsula and ASL viewing and educative interpretation at Seal Bay, Kangaroo Island. The white shark cage-diving industry is only licensed to operate in the Neptune Islands Group Marine Park. Prior to 2011, the industry comprised two licensed operators in the Neptune Islands Conservation Park with exemptions to use berley to attract white sharks to vessel for viewing by customers. A third operator joined the white shark cage-diving industry in 2011, and is only licensed to use sound to attract white sharks (Bradford and Robbins 2013).

Acoustic tagging techniques have been used to collect information on the residency behavior of white sharks in relation to white shark cage-diving industry operations at the Neptune Islands Group Marine Park and Dangerous Reef since the early 2000s (Bruce and Bradford 2011, 2013; Rogers *et al.* 2014; Robbins *et al.* 2015). Long-term tagging programs (Bruce and Bradford 2011, 2013), and studies of the fine-scale three dimensional variation in movements (Huveneers *et al.* 2013) have shown that cage-diving activities are associated with behavioral modification of individual white sharks, however, the potential impacts on population-level processes remain poorly understood. Residency is a quantitative behavioural indicator that allows researchers to develop time budgets for individual sharks, and it has been shown to be sensitive to changes in tourism activities (Bruce and Bradford 2011). Annual acoustic telemetry-based mean estimates of residency of white sharks in the Neptune Islands Group Marine Park inform decision points that underpin the draft management decision-making framework outlined by Smith and Page (2015).

SARDI and the cage-diving industry have developed a collaborative, long-term photographic identification catalogue of white sharks that visit the Neptune Islands Group Marine Park to

assess alternative methods for estimating residency. Establishment of this method was based on previous photo-identification studies (Anderson and Goldman 1996; Klimley and Anderson 1996; Bonfil *et al.* 2005; Domeier and Nasby-Lucas 2006). Photographic identification is being used to estimate the minimum number of white sharks that visit the Neptune Islands Group Marine Park on operator days, and to record re-sights of known individuals. In the longer term, this catalogue will be used to evaluate if this method provides suitable and cost-effective assessments of residency on operator days that can be used to compare with telemetry-based estimates.

Aims and Objectives

This report provides an update of information on white sharks and the white shark cage-diving industry in the Neptune Islands Group Marine Park. Specifically, this includes:

1. Estimates of residency of white sharks during three periods including, a) 14 September 2013 to 30 June 2014, b) 1 July 2014 to 30 June 2015 and c) the complete time series from 14 September 2013 to 30 June 2015.
2. Patterns of sightings of white sharks collected using e-logbooks between 2014 and 2015;
3. Summaries of daily activities of the white shark cage-diving industry collected using e-logbooks between 2014 and 2015;
4. Photographic-identification, re-sight and sex ratio information derived from images provided by operators in the white shark cage-diving industry.

2. METHODS

2.1 Reporting periods

Residency estimates presented in this report were based on white sharks tagged in the Neptune Islands Group Marine Park between September 2013 and May 2015 (n=37). Estimates of residency are provided for three periods to encompass the start of the monitoring period: (1) 14 September 2013 to 30 June 2014, the most recent season (2) 1 July 2014 to 30 June 2015, and (3) the complete time series from 14 September 2013 to 30 June 2015.

2.2 Geographical area

The Neptune Islands Group (Ron and Valarie Taylor) Marine Park 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 Neptune Islands Group Marine Park was proclaimed in October 2014. The group comprises the North and South Neptune Islands, which are ~12 km apart. There is a Sanctuary Zone (SZ), Restricted Access Zone (RAZ) and Habitat Protection Zone (HPZ) at the North Neptune Islands and RAZ and HPZ at the South Neptune Islands (Marine Park Management Plan Summary 2014). Cage-diving operators mostly 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).

2.3 Acoustic telemetry

Receiver deployments

Three satellite-linked VR4-Global (VR4G) near-real time acoustic receivers (Amirix, VEMCO Ltd., Halifax, Canada) were deployed at the North and South Neptune Island Groups using a mooring system similar to that described in Bradford *et al.* (2011). The VR4G receivers used an Iridium satellite modem to remotely access tag detection data.

In September 2013, two VR4G receivers were deployed at Main Bay and Action Bay at the North Neptune Islands, and a third was deployed in the embayment on the north-east side of the South Neptune Islands (Fig. 1). Technical issues occurred with the VR4G system between mid-November 2014 and late January 2015. Faults were detected in the VR4G receiver in Action Bay in November 2014, in Main Bay in mid-January 2015, and at the South Neptune Islands in June 2015. The VR4Gs at the North Neptune Islands were replaced with Vemco VR2AR (acoustic release) receivers that were moored on the bottom with polystyrene rock lobster floats in January 2015. The VR4Gs at the North Neptune Islands were recovered in March 2015 using *RV Ngerin.* In July 2015, the two VR2ARs at the North Neptune Islands

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were recovered and the detection data were retrieved. The remaining VR4G and mooring at the South Neptune Islands was also recovered in July 2015. Three VR2W receivers, demarcated with 70 cm surface floats with navigation beacons on 50 mm diameter multi-strand rope attached to train wheel weights were deployed in the three bays within the two island groups.

Transmitter deployments

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 plastic umbrella dart using a 10- to 15-cm-long stainless wire leader (1.6 mm diameter), and implanted in the dorsal musculature of white sharks from the vessel using an aluminium pole and applicator, or from the dive cage using a modified spear-gun and applicator.

2.4   Detection summary and residency

Tagged white sharks were considered 'present' in the array if detected at least twice within a 24-hour period (Pincock 2011). Daily detection summaries were plotted to examine the pattern of overall presence of tagged sharks during the study period. A residency period was calculated based on the number of days between the first and last detection of a tagged shark in the study area(s), where no gaps in consecutive days of detection were >5 days, defined as a 'residency period' (Bruce and Bradford 2013). A period of five days was allowed for sharks remaining in the vicinity of the Neptune Islands Group but without registering detections at either island. If sharks were not detected for periods of greater than five consecutive days they were assumed to have left the island group and any subsequent return was considered to represent a new residency period.

The previous report (Rogers *et al.* 2014) presented mean residency estimates averaged across all sharks. This approach was adopted due to the low sample size of tagged sharks in the first year of monitoring, e.g., nine tagged individuals were detected at the South Neptune Islands Group in 2013–14. In this report, we present residency estimates based on the grand (overall) mean of individual estimates for each tagged shark. This method was reapplied to data for the 2013–14 monitoring period to allow direct comparison with the estimates for 2014–
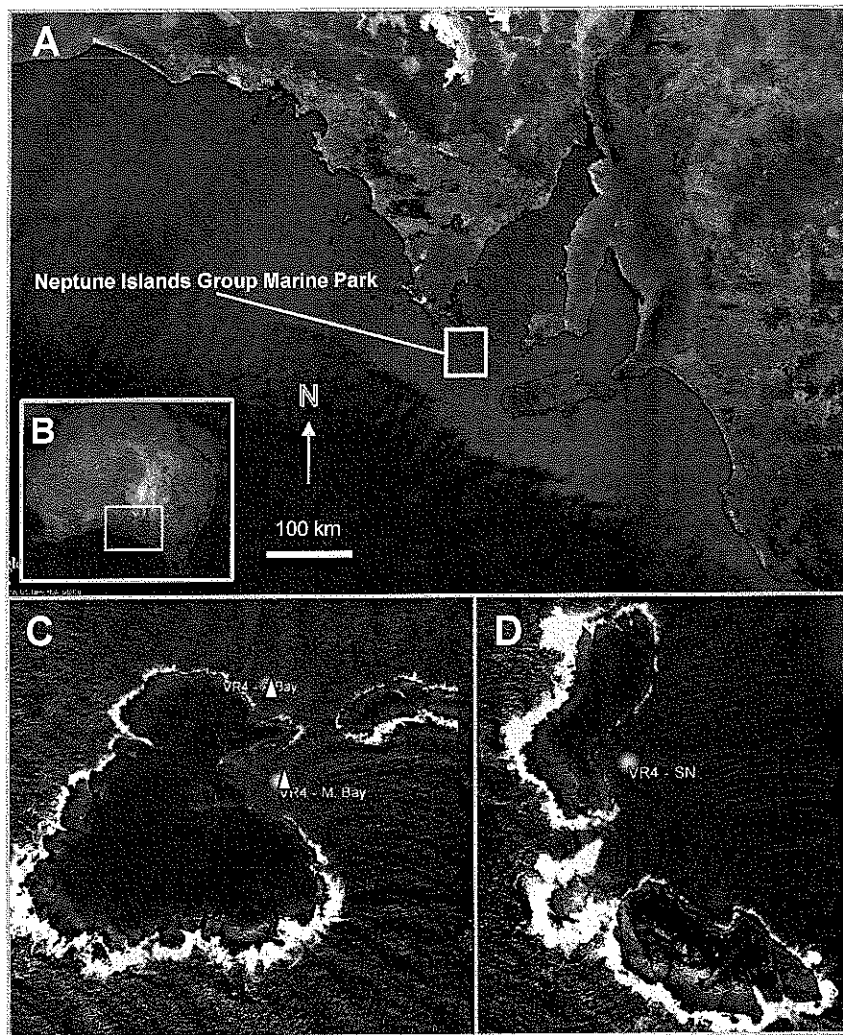
Figure 1. Map A shows the location of the North and South Neptune Islands in continental shelf waters off southern Eyre Peninsula, South Australia. Inset B shows the location of the monitoring area in relation to South Australia. Map C shows the North Neptune Islands and the locations of two VR4 acoustic receivers (yellow symbols) and VR2AR (acoustic release) (white symbol) 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).

2.5 Electronic Logbooks

White shark cage-diving operators were issued with a mini-iPad loaded with the Fulcrum[TM] application to input voluntary daily electronic logbook (e-logbook) entries in September 2013. Regular follow-up telephone conversations took place between SARDI and white shark cage-diving industry operators for data validation and quality assurance purposes. Development of the structure and fields in the e-logbook is described in Rogers *et al.* (2014).

The e-logbook was used to collect data on daily activities and sighting frequency of white sharks between 1 July 2014 and 30 June 2015.

2.6 Photo Identification

Photographs and videos of white sharks were submitted to SARDI by operators between 4 October 2013 and 31 October 2014 with date and location data for each image. Photo-ID and 'Orphan' catalogues were created that included images of each individual linked to documented physical characteristics. If there were only images of one side of an individual, the images set and associated meta-data were classified as an 'orphan' until further images and information were available to verify an identification. Distinguishing marks, scars, tag locations and pigmentation patterns (Fig. 2) were compared to identify individuals as outlined in Domeier and Nasby-Lucas (2006). Sex of photographed sharks was determined where possible through the presence and absence of claspers. Each shark was assigned a unique alpha-numeric identification code (e.g. NI001) to match the date data. The pigment patterns on the gills, pelvic and caudal fins were assigned a unique numerical characteristics code to aid searching the catalogue. This code was based on the following: LG • LP • LC x or RG • RP • RC x where LG=left gill, LP=left pelvic region and LC=left side caudal fin, and RG=right gill, RP=right pelvic region and RC=right side caudal fin. The degree of pigmentation in each region was scaled as 0 (not visible), 1, 2, 3 or 4 based on the methods of Domeier and Nasby-Lucas (2006). Only caudal fins had classification 4 assigned. Keywords used to identify and re-sight known-ID individuals included, Lscar: left scar Rscar: right scar, Lscr: left scratch, Rscr: right scratch, LT: left tag, RT: right tag, DT: dorsal tag, Wspot: white spot, fin damage, colorations, and tag scars.

Dorsal fin profiles were not used due to low image quality and a lack of images taken from above the water-line. Identification profiles were considered to be complete when quality images of the gills, pelvic fin and caudal fin zones were collected. Some images were digitally enhanced using Photoshop and IrfanView software. Once all images were assigned, groups of left or right images were matched with known-ID sharks in the two catalogues. After comparing all the group pictures on the sorting sheet, the photos fell into 1 of 3 categories: 1) match an existing shark ID, 2) match an existing orphan, 3) new complete ID shark or new orphan if insufficient information was available for a positive identification.
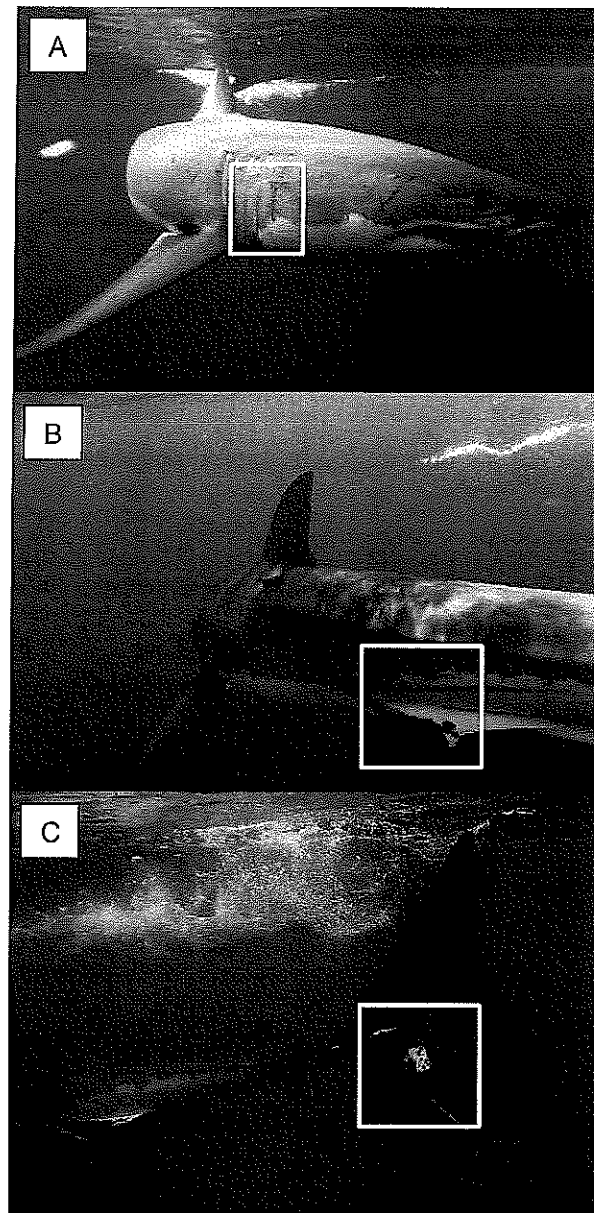
Figure 2. Examples of physical characteristics including. (A) gill flaps, (B) pelvic fin/area and (C) caudal fins used for identification of white sharks visiting the Neptune Islands Group Marine Park (following Domeier and Nasby-Lucas 2006).

3. RESULTS

3.1   Acoustic transmitter deployments

A total of 37 white sharks (8 females, 24 males, 5 unknown sex) ranging in size from 180 to 450 cm total length were tagged in the Neptune Islands Group Marine Park using V16 acoustic transmitters between 14 September 2013 and 7 May 2015 (Table 1).

3.2   Acoustic detections

A total of 74,758 acoustic detections were recorded (Table 2). Of these, 50,124 (67%) detections were recorded on two receivers at the North Neptune Islands and 24,634 (33%) were recorded on one receiver at the South Neptune Islands (Table 2).

Seasonal patterns in detections

Between September and November 2013 (spring), infrequent acoustic detections were recorded for eight white sharks. Six individuals were present in summer 2013–14 (Fig. 3). Detections were less frequent between March and June 2014 (autumn and early winter) with only three sharks detected. Eight sharks were detected between August and September (mid- to late-winter) 2014. Ten and 12 white sharks, respectively, were detected between October and November 2014 (spring) and December to February 2014–15 (summer). In late January and early February 2015 (late summer), six sharks were detected. Three were tagged in January 2015, while the other three were tagged in October 2013, February 2014 and November 2014. All individuals left the range of the receivers between 27 January and 2 February, and four departed from the North Neptune Islands on the 2 or 3 February. No white sharks were detected until late April when one was detected briefly at the North and South Neptune Islands. In May 2015, 13 white sharks were detected and eight individuals were detected in June.

Return visitors

Of the 15 white sharks tagged during September 2013 to June 2014, five sharks, including shark 1, 4, 6, 12, and 14 were detected again during 2014–15, and three shed their tag (Shark 3, 5, and 9) (Fig. 3). This showed that a minimum of 42% of the white sharks present in 2013–14 were return visitors.

Table 1. White shark acoustic transmitter deployment information between 14 September 2013 and 7 May 2015. Total length=TL, Female=F, Male=M, and NS=not sexed. Locations are shown as South Neptune Islands=SNI, and North Neptune Islands=NNI.

Shark#	TL	Sex	Date deployed	Location deployed
1	410	F	14/09/13	SNI
2	330	M	15/09/13	SNI
3	450	M	28/09/13	NNI
4	410	M	9/10/13	NNI
5	450	M	14/10/13	NNI
6	300	M	26/10/13	NNI
7	450	M	26/10/13	NNI
8	200	M	15/11/13	NNI
9	400	M	29/01/14	NNI
10	350	M	29/01/14	NNI
11	380	M	29/01/14	NNI
14	430	M	23/02/14	NNI
12	240	M	24/02/14	NNI
13	450	F	26/02/14	NNI
15	300	M	28/02/14	NNI
16	360	M	19/07/14	SNI
17	390	F	19/07/14	SNI
18	330	M	20/07/14	SNI
19	370	F	20/07/14	SNI
20	420	M	21/07/14	NNI
21	400	M	18/10/14	SNI
22	300	F	19/10/14	NNI
23	450	M	19/10/14	NNI
24	3500	M	15/11/14	NNI
25	380	M	15/11/14	NNI
26	320	M	16/11/14	NNI
27	390	M	24/01/15	NNI
28	370	M	24/01/15	NNI
29	270	M	24/01/15	NNI
30	420	F	2/05/15	SNI
31	180	F	6/05/15	SNI
32	420	F	6/05/15	SNI
33	450	NS	7/05/15	SNI
34	260	NS	7/05/15	SNI
35	300	NS	7/05/15	SNI
36	340	NS	7/05/15	SNI
37	280	NS	7/05/15	SNI

Table 2. Detections for white sharks at the Neptune Islands Group Marine Park. South Neptune Islands=SNI, and North Neptune Islands=NNI.

Shark#	Location tagged	N of detections			N of days detected		
		Both	N	S	Both	N	S
1	SNI	11769	1346	10423	96	20	81
2	SNI	1888	1828	60	56	48	9
3	NNI	7884	7882	2	112	111	1
4	NNI	2448	2364	84	63	53	12
5	NNI	1813	1813	*	13	13	*
6	NNI	5678	2902	2776	96	62	34
7	NNI	1787	1769	18	42	40	4
8	NNI	863	479	384	19	9	10
9	NNI	2557	2553	4	49	49	1
10	NNI	131	131	*	6	6	*
11	NNI	208	207	1	19	19	1
14	NNI	1328	913	415	39	27	13
12	NNI	14	14	*	2	2	*
13	NNI	1196	1196	*	15	15	*
15	NNI	17	17	*	1	1	*
16	SNI	5804	5195	609	70	60	11
17	SNI	1248	48	1200	25	5	21
18	SNI	6053	5598	455	53	47	6
19	SNI	736	140	596	25	8	18
20	NNI	3202	3187	15	52	51	2
21	SNI	618	5	613	26	2	24
22	NNI	4	4	*	1	1	*
23	NNI	1821	1815	6	26	26	1
24	NNI	497	349	148	32	19	13
25	NNI	139	137	2	6	5	1
26	NNI	145	145	*	5	5	*
27	NNI	58	58	*	3	3	*
28	NNI	354	354	*	10	10	*
29	NNI	269	259	10	7	6	1
30	SNI	1644	81	1563	27	2	25
31	SNI	726	100	626	7	3	4
32	SNI	2772	*	2772	24	*	24
33	SNI	119	24	95	2	1	1
34	SNI	2489	1234	1255	31	14	18
35	SNI	94	*	94	1	*	1
36	SNI	1891	1612	279	34	29	6
37	SNI	4494	4365	129	47	45	2

3.3   Residency patterns

Residency estimates for white sharks at the North Neptune Islands ranged from 0.3 to 117.3 days in 2013–14, and 0–52.1 days in 2014–15. The mean residency estimate averaged across all sharks at the North Neptune Islands was 18.9±31.7 days (mean ± standard deviation; n=15) in 2013–14 and 9.1± 12.3 days (n=25) in 2014–15. The mean residency estimate for the South Neptune Islands was 1.7±1.8 days (range: 0–4.5; n=9) in 2013–14 and 9.3±14.8 days (range: 0–64.9; n=22) days in 2014–15. Table 3 provides mean residency estimates for the North and South Neptune Islands for 2013–14, 2014–15 and 2013–15. Appendix 1 shows the residency estimates for individual white sharks at the North Neptune Islands in the 2013–14 and 2014–15 seasons. Appendix 2 shows a summary of residency statistics for the North and South Neptune Islands between 2013 and 2015. Figure 4 shows the frequency of residency periods for white sharks at the South and North Neptune Islands between 2014 and 2015.

Table 3. Mean estimates of residency at the North and South Neptune Islands during three periods, including 2013–14, 2014–15, and the complete time series of 2013–15.

Location	2013–14	2014–15	2013–15
North Neptune Islands	18.9±31.7	9.1±12.3	14.0±23.1
South Neptune Islands	1.7±1.8	9.3±14.8	5.9±7.7
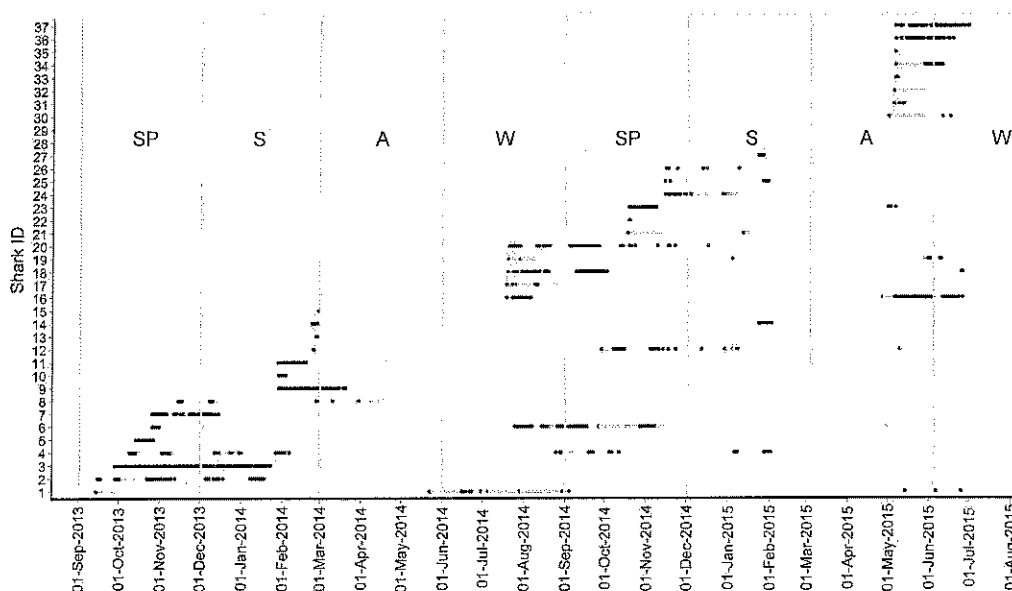
Figure 3. Daily detection summaries for white sharks at the North (black symbols) and South Neptune Islands (grey symbols) between 2013 and 2015. Red symbols indicate the tagging dates. Austral seasons are indicated by labels in grey rectangles, where SP=spring, S=summer, W=winter and A=autumn.

17
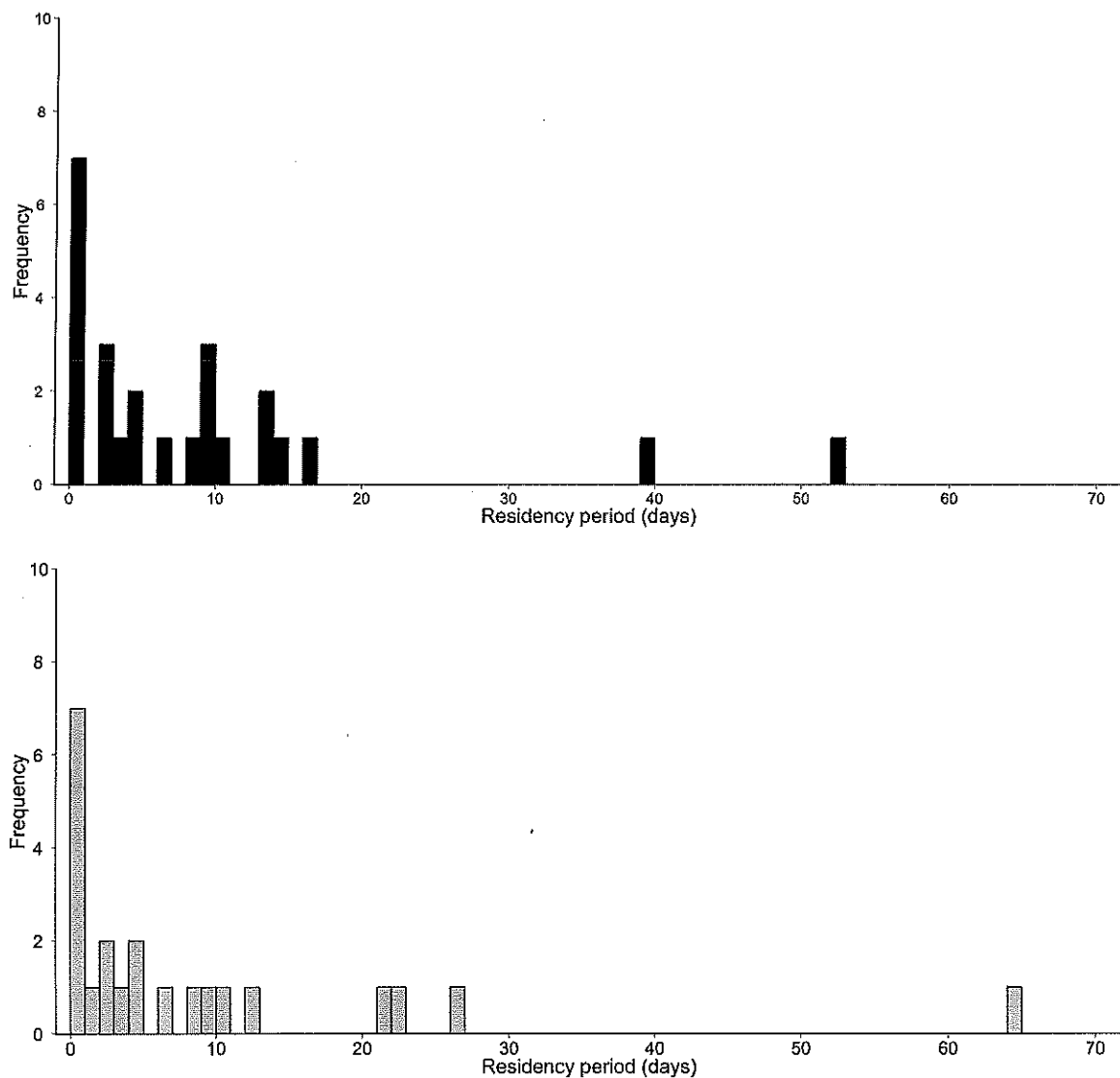
Figure 4. Frequency of residency periods averaged across sharks in the Neptune Islands Group Marine Park between 2014 and 2015. North Neptune Islands=black bars and the South Neptune Islands=grey bars.

3.4   Electronic logbook

Sighting frequency and seasonality

Reported estimates of the counts of individual white sharks sighted per day ranged from 0 to 14, based on 406 records provided (Fig. 5). Peaks in daily shark sightings occurred during the August to September and December to January periods. Lowest frequencies of daily sightings occurred between February and April. The overall mean number of sightings was 5±3 sharks per day.

Killer whale visit

A killer whale visit was reported by two operators on 2 February 2015 at the North Neptune Islands. This month had low reported days onsite by the three operators of 9, 3 and 2 days, respectively, mean=4.7±3.8 d; 60% lower than the overall annual mean number of days onsite (mean=11.9±5.4 d) based on the number of effort days when sightings were reported (shown under *x*-axis, Fig. 5).

Berley and teaser bait use

The white shark cage-diving industry reported the use of 12,100 litres of berley, 6,598 sets of southern bluefin tuna (SBT) gills and entrails, and 1,551 individual portions of SBT between 1 July 2014 and 30 June 2015. The proportion of SBT teaser baits or gills and entrails recovered (not consumed) or consumed by white sharks and/or other shark and teleost species is unknown.

Sound use

Use of sound emission to attract white sharks to the vessel at the Neptune Islands was reported on 87 operating days. Sound durations ranged between 10 minutes and 6 hours 45 minutes per day. A total of 98% of the sound was emitted at the North Neptune Islands, with the remaining 2% emitted at the South Neptune Islands.
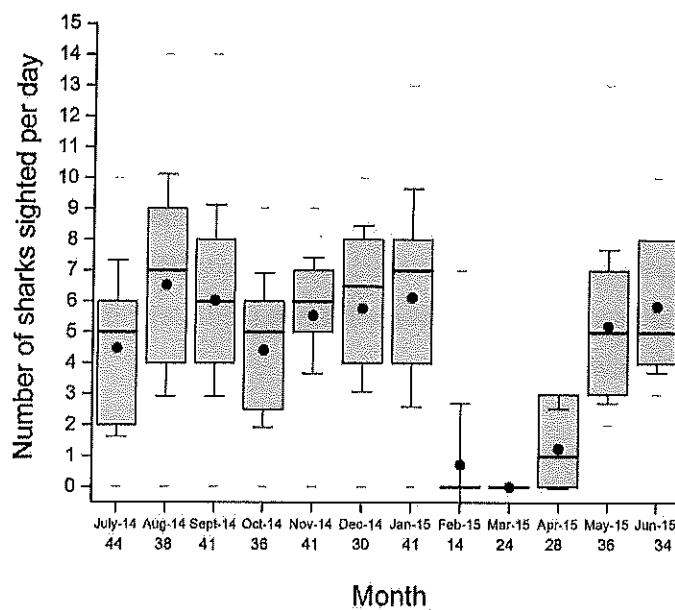
Figure 5. Mean daily sightings of white sharks reported in e-logbook by three operators and between 1 July 2014 and 30 June 2015. Number of sighting days reported by month is shown under the x-axis.

3.5   Photographic identification

A photographic identification catalogue was established for white sharks that visited the Neptune Islands between 4 October 2013 and 31 October 2014 based on analysis of 35,904 images provided by operators. Complete profiles were developed for 78 individual white sharks (Appendix 3). Each individual was given an alpha-numeric identification code. A further 28 'orphan' or incomplete images sets were established for other white sharks based on preliminary identification of one side of the body. Based on the minimum number of complete identifications, and the maximum number provided by the addition of the 'orphans', we estimate that ~106 white sharks visited the Neptune Islands Group Marine Park over the 12-month period during operator days.

Sex ratio

Sex ratios of white sharks identified at the Neptune Islands during the October 2013 to October 2014 period were skewed slightly toward males (1.1: 0.9, N=37 M, 33 F and 8 unsexed). Insufficient gender data were available to statistically assess annual, seasonal or monthly trends in sex ratios. Length estimates were not made due to difficulties associated with accurately estimating the size of free-swimming sharks from images.

Physical characteristics

Evidence of bite marks and lacerations from con-specifics, scars and physical evidence of human interactions was present on white sharks recorded in the photo-ID catalogue. These included the presence of fin damage and/or partial loss, dermal scrapes, bites on gill flaps (Fig. 6), deep scars, ropes and fishing hooks. Some characteristics were not considered to be temporally stable, and whilst they were used to cross-reference the identification of some individuals, they were not used as primary tools for verification.

Re-sights

Re-sight data of known-ID individuals were processed from 4 August to 31 October 2014. A total of 27 of the 78 profiled white sharks were re-sighted by operators over durations ranging between 1 and 12 days (mean=5±3.35 d; median=3). A total of 21% of the white sharks identified in the photo-identification catalogue had been electronically tagged. Re-sight durations were not inclusive of time gaps between the first and last sightings as consecutive daily re-sighting may be biased by gaps in operator days and resultant photographic coverage, the potential for different sharks to interact with vessels, and behavioural and demographic factors that may influence the frequency at which certain sharks approach within a suitable proximity of vessels to be photographed.

21
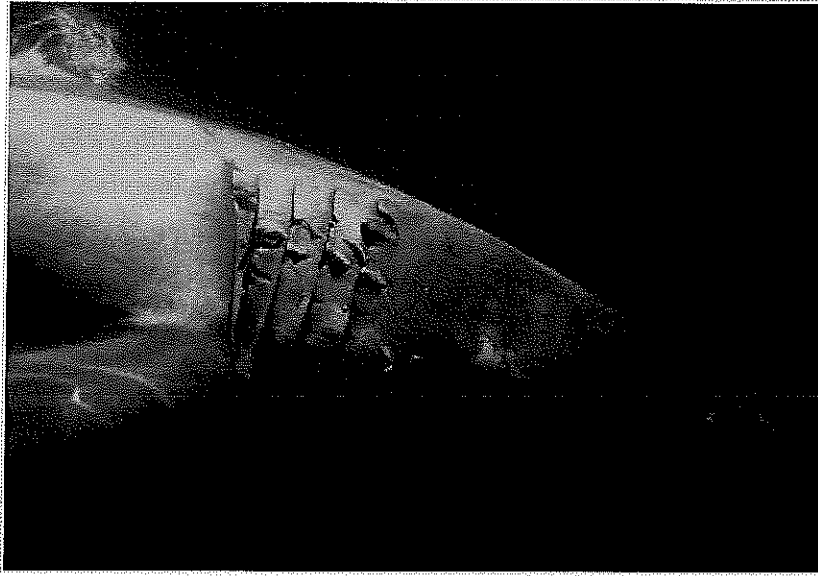
Figure 6. Bite marks on the gill flaps of a white shark at the Neptune Islands.

4. DISCUSSION

Estimates of white shark residency

Estimates of white shark residency at the North Neptune Islands varied substantially from 0.3–117.3 days (mean=18.9 days) in 2013–14 to 0–52.1 days (mean=9.1 days) in 2014–15. During the previous monitoring period between December 2009 and April 2011, residency estimates for the Neptune Islands system (combined) ranged between 1 and 92 days (mean =21.0 days), and the duration of visits at the North Neptune Islands ranged from 1 to 52 consecutive days (mean=11.0 days) (Bruce and Bradford 2011). Potential factors explaining this observed variation in residency between years and within and between individual(s) are difficult to uncouple, yet could include combinations of social, demographic factors, and density-dependent processes, prey selection, migration dynamics and effects of cage-diving and other human activities (Bruce *et al.* 2006; Bruce and Bradford 2015). As the sample size of tagged white sharks increases, there will be greater opportunity to address these questions. In 2014–15, the presence of revisiting tagged white sharks from the previous seasons was encouraging from the perspective of assessing the retention rates of externally deployed acoustic tags, which is important when assessing the viability of the current tagging approaches.

Killer whale visit

Killer whales have been observed to interact with, and predate upon pelagic sharks, including white sharks at Southeast Farallon Island, California (Pyle *et al.* 1999), common threshers (*Alopias vulpinus*), smooth hammerhead (*Sphyrna zygaena*) (Visser 2005), and shortfin makos (*Isurus oxyrinchus*) in New Zealand (Visser *et al.* 2000). Killer whales were reported to be present at the North Neptune Islands on 2 February 2015. Up until late January 2015, six tagged white sharks were being detected at the North Neptune Islands. Five tagged sharks were present on 1 February 2015. All tagged individuals departed from the Neptune Islands Group Marine Park on either the 2nd or 3rd of February. Subsequent to the visit by killer whales, no tagged white sharks were detected until late April, ~13 arrived in May, and eight in June that included four tagged during winter 2014. Following reported sighting of the killer whales, the e-logbook data showed a reduction in mean daily sightings of white sharks at the Neptune Islands for 12 weeks. Further analysis of the e-logbook and acoustic data relating to the reported killer whale visit will be completed in 2016–17.

E-logbook data

Operator collected e-logbook data continued to be an important step in the process of monitoring visits by white sharks and cage-diving industry activities at the Neptune Islands during the operator days. E-logbook data allowed the estimation of the annual input of berley and teaser baits into the marine ecosystem in the Neptune Islands Group Marine Park. There remains a lack of information regarding the consumption rates of berley and teaser baits by white sharks and other visiting and residential marine species in the Neptune Islands Group Marine Park. Berley and teaser bait input was the subject of discussions between managers, scientists and white shark cage-diving industry operators in 2014–15, and has been the subject of previous discussions relating to changing patterns of residency and potential impacts on ecosystem functioning/predator prey dynamism (Laroche *et al.* 2007; Bruce and Bradford 2011). A recent review of the e-logbook included addition of measures of the consumption of teaser baits in 2015–16. Steps are being taken to develop an industry Code of Conduct, and review management processes to reduce berley inputs and minimise the frequency at which teaser baits are consumed.

White shark photographic identification catalogue

The white shark photographic identification catalogue was developed in 2013 and now integrates analysis of >35,000 individual images. Development of this catalogue was based on the methods outlined in the study of Domeier and Nasby-Lucas (2006). This led to the identification of 78 individual white sharks that visited the Neptune Islands Group Marine Park during operator days over the period from 4 October 2013 and 31 October 2014. Previous studies identified 76 white sharks during operator days on one vessel between January 2006 and December 2007 (Beckmann 2008), and 306 immature and mature-sized individuals over two longer periods between 2001–03 and 2009–11 at the Neptune Islands (Robbins and Fox 2012a). Whilst this method has inherent uncertainties with regard to temporal stability of some features (Robbins *et al.* 2012b), it has potential benefits for future ongoing monitoring of re-sights and provision of alternative biological indicators. An important component of assessing the ongoing utility of this method is weighing up the staff costs to operators and scientific personnel required to process the images relative to the logistical costs of established methods for estimating residency, including the use of acoustic telemetry. Prioritisation of future resources toward research and monitoring in the Neptune Islands Group Marine Park should scale the acoustic tagging-based residency estimates higher than collection of further photo-identification data.

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Future directions

A quantitative analysis of the relationships between residency of white sharks in the Neptune Islands Group Marine Park, cage-diving industry activities, environmental and demographic factors will be undertaken using three years of data in 2016. SARDI is currently undertaking research to assess residency of white sharks in several areas where the white shark cage-diving industry does not operate. This will provide valuable information with which to assess the relative importance of the Neptune Islands Group Marine Park compared to other habitats in Spencer Gulf and the Great Australian Bight.

5. REFERENCES

Anderson, S.D., Chapple, T.K., Jorgensen, S.J., Klimley, A.P., Block, B.A. (2011). Long-term individual identification and site fidelity of white sharks, *Carcharodon carcharias*, off California using dorsal fins. *Marine Biology* 158, 1233–1237.

Anderson, S.D., and Goldman, K.J. (1996) Photographic Evidence of White Shark Movement in California Waters. *California Fish and Game* 82, 182–186.

Beckmann, C. (2008). Using photographic identification to determine the behavioural ecology of the great white shark (*Carcharodon carcharias*). Honours Thesis. School of Biological Sciences. Flinders University. 86 pp.

Bradford, R.W, Bruce, B.D, McAuley, R.B., Robinson, G. (2011). An Evaluation of Passive Acoustic Monitoring Using Satellite Communication Technology for Near Real-Time Detection of Tagged Animals in a Marine Setting. *The Open Fish Science Journal* 4, 10–20.

Bradford, R.W., and Robbins, R. (2013). A Rapid Assessment Technique to Assist Management of the White Shark (*Carcharodon carcharias*) Cage Dive Industry, South Australia. *The Open Fish Science Journal* 03/2013; 6:13-18. DOI: 10.2174/1874401X01306010013.

Bruce, B.D., Stevens, J.D., Bradford, R.W. (2005). Site fidelity, residence times and home range patterns of white sharks around pinniped colonies. CSIRO Final Report to the Australian Government Department of the Environment and Heritage. 45 pp.

Bruce, B.D., and Bradford, R.W. (2011). The effects of berleying on the distribution and behaviour of white sharks, *Carcharodon carcharias*, at the Neptune Islands, South Australia. Final Report to the Department of Environment and Natural Resources, South Australia, 50 pp.

Bruce, B., and Bradford, R. (2015). Segregation or aggregation? Sex-specific patterns in the seasonal occurrence of white sharks *Carcharodon carcharias* at the Neptune Islands, South Australia. *Journal of Fish Biology* 87, 1355–1370.

CITES (2004). Convention of International Trade in Endangered Species of Wild Fauna and Flora - Appendix II Listing of the White Shark (revision 1). [Online]. Available from: http://www.environment.gov.au/coasts/publications/pubs/great-white-cites-appendix2-english.pdf.

Department of the Environment (2013). Recovery Plan for the White Shark *(Carcharodon carcharias)*. *http://www.environment.gov.au/resource/recovery-plan-white-shark-carcharodon-carcharias*.

Environment Australia (2002). White Shark *(Carcharodon carcharias)* Recovery Plan. July 2002. Marine Conservation Branch. 43 pp.

Domeier, M. L., Nasby-Lucas, N. (2006). Annual resightings of photographically identified white sharks *(Carcharadon carcharias)* at an eastern Pacific aggregation site. *Marine Biology* 150, 977–984.

Fisheries Management Act. (2007). http://www.legislation.sa.gov.au/LZ/C/A/FISHERIES%20MANAGEMENT%20ACT%202007.aspx

Hussey, N. E., McCann, H. M., Cliff, G., Dudley, S. F. J., Wintner, S. P., Fisk, A. T. (2012) Size-Based Analysis of Diet and Trophic Position of the White Shark *(Carcharodon carcharias)* in South African Waters. Ed. Michael L. Domeier. In: Global perspectives on the biology and life history of the great white shark. Chapter 3. Pg 27–49.

Huveneers, C, Rogers, P. J., Beckmann, C., Semmens, J. M., Bruce, B. D., Seuront, L. (2013). The effects of cage-diving activities on the fine-scale swimming behaviour and space use of white shark. *Marine Biology* DOI 10.1007/s00227-013-2277-6.

IUCN (2014) Red List of Threatened Species (Year Assessed: 2005-10-01). *Carcharodon carcharias* http://www.iucnredlist.org/details/3855/0

Klimley, A. P., Anderson, S. D. (1996). Residency patterns of white sharks at the South Farallon Islands, California. In: Klimley AP, Ainley DG (eds) Great white sharks: the biology of *Carcharodon carcharias*. Academic, San Diego, pp 365–373.

Laroche, R. K, Kock, A. A., Dill, L. M., Oosthuizen, W. H. (2007) Effects of provisioning ecotourism activity on the behaviour of white sharks, *Carcharodon carcharias*. *Marine Ecology Progress Series* 338,199–209.

Neptune Islands Group Ron and Valarie Taylor Marine Park Marine Park (2014). Management Plan Summary. 4 pp.

Pincock, D. G. (2011). False detections: what they are and how to remove them from detection data. DOC-004691 Version 02, April 13, 2011.

Pyle, P., Schramm, M. J., Keiper, C., and Anderson, S. D. (1999). Predation on a white shark (*Carcharodon carcharias*) by a killer whale (*Orchinus orca*) and a possible case of competitive displacement. Marine Mammal Science 15 (2), 563–568.

Robbins, R. L., Enarson, M., Bradford, R. W., Robbins, W. D. and Fox. A. G. (2015). Residency and Local Connectivity of White Sharks at Liguanea Island: A second aggregation site in South Australia? *The Open Fish Science Journal* 8, 23–29.

Robbins, R., Fox, A., (2012a). Use of the photographic identification of white sharks (*Carcharodon carcharias*) to determine seasonal abundance and site fidelity patterns, at the Neptune Islands, South Australia. Final Report to the Norman Wettenhall Foundation. Fox Shark Research Foundation. 22 pp.

Robbins, R., Fox, A. (2012b). Further evidence of pigmentation change in white sharks, *Carcharodon carcharias*. *Marine and Freshwater Research* 63, 1215–1217.

Rogers, P.J., Huveneers, C., Goldsworthy, S. D., Cheung, W. W. L., Jones, G. K., Mitchell, J. G., and Seuront, L. (2013). Population metrics and movement of two sympatric carcharhinids: a comparison of the vulnerability of pelagic sharks of the southern Australian gulfs and shelves. *Marine and Freshwater Research*. dx.doi.org/10.1071/MF11234.

Rogers, P.J., Huveneers, C, and Beckmann, C. (2014). Monitoring residency of white sharks, *Carcharodon carcharias* in relation to the cage-diving industry in the Neptune Islands Group Marine Park. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2014/000801-1. SARDI Research Report Series No. 818. 75pp.

Smith, J. K. and Page, B. (2015). Decision points for White Shark Tourism Policy, DEWNR Technical note 2015/09, Government of South Australia, through the Department of Environment, Water and Natural Resources, Adelaide. 12 pp.

Visser, I. N., Berghan, J., van Meurs, R. and Fertl, D. (2000). Killer whale (*Orchinus orca*) predation on a shortfin mako shark (*Isurus oxyrinchus*) in New Zealand waters. *Aquatic Mammals* 26(3). 229–231.

Visser, I. N. (2005). First observation of feeding on thresher (*Alopias vulpinus*) and hammerhead (*Sphyrna zygaena*) sharks by killer whales (*Orchinus orca*), which specialise on elasmobranchs as prey. *Aquatic Mammals* 3 (1) 83–88.

Appendix 1. Summary statistics showing residency estimates for white sharks at the North Neptune Islands (n=25) *denotes log transformed estimates as per decision points outlined in Smith and Page (2015).

Shark ID	2013–14	2014–15	Log10 2013–14	Log10 2014–15
1	3.6	1.0	0.6	0.0
2	9.7		1.0	
3	117.3		2.1	
4	4.7	4.2	0.7	0.6
5	13.0		1.1	
6	4.3	10.8	0.6	1.0
7	49.5		1.7	
8	1.0		0.0	
9	50.0		1.7	
10	4.9		0.7	
11	19.8		1.3	
12	0.3	4.7	-0.5	0.7
13	1.0		0.0	
14	4.2	9.0	0.6	1.0
15	0.3		-0.5	
16		14.4		1.2
17		2.5		0.4
18		16.8		1.2
19		0.9		-0.1
20		6.3		0.8
21		0.5		-0.3
22		0.0		-2.2
23		13.0		1.1
24		9.5		1.0
25		2.2		0.4
26		0.9		-0.1
27		3.0		0.5
28		8.9		0.9
29		10.0		1.0
30		0.2		-0.7
31		4.0		0.6
32				
33		0.1		-1.0
34		13.5		1.1
35				
36		39.2		1.6
37		52.1		1.7

Appendix 2. Summary statistics showing residency estimates (Res. est.) and mean residency estimates (Mean res. est.) for tagged white sharks at the North and South Neptune Islands between 14 September 2013 and 30 June 2015. SD=standard deviation.

Shark ID	North Neptune Islands							South Neptune Islands						
	N res. Periods	Res. est. (days)	Mean res. est. (days)	median	sd	min	max	N res. Periods	Res. est. (days)	Mean res. est. (days)	median	sd	min	max
1	9	-	2.4	0.6	3.5	0.0	9.8	5	-	17.7	3.4	30.0	0.1	70.8
2	5	-	9.7	9.6	7.5	2.2	20.7	4	-	1.1	0.2	1.9	0.0	3.9
3	1	117.3	-	-	-	-	-	1	0.0	-	-	-	-	-
4	11	-	4.5	4.2	2.8	0.6	9.8	6	-	2.0	0.8	2.7	0.0	6.8
5	1	13.0	-	-	-	-	-	-	-	-	-	-	-	-
6	6	-	9.7	9.3	7.5	0.7	21.2	5	-	6.9	0.7	12.4	0.1	28.9
7	1	49.5	-	-	-	-	-	2	-	3.1	3.1	4.4	0.0	6.3
8	5	-	1.0	1.0	0.8	0.2	2.2	3	-	3.8	1.2	5.6	0.0	10.2
9	1	50.0	-	-	-	-	-	1	0.2	-	-	-	-	-
10	1	4.9	-	-	-	-	-	-	-	-	-	-	-	-
11	1	19.8	-	-	-	-	-	1	0.0	-	-	-	-	-
12	8	-	4.1	0.7	5.3	0.0	12.8	6	-	1.7	0.0	2.9	0.0	6.8
13	1	1.0	-	-	-	-	-	-	-	-	-	-	-	-
14	2	-	6.6	6.6	3.4	4.2	9.0	-	-	-	-	-	-	-
15	1	0.3	-	-	-	-	-	-	-	-	-	-	-	-
16	4	-	14.4	14.3	11.4	0.4	28.3	2	-	4.8	4.8	2.4	3.1	6.5
17	2	-	2.5	2.5	1.0	1.8	3.2	2	-	10.4	10.4	12.6	1.5	19.3
18	3	-	16.8	22.6	13.3	1.6	26.2	2	-	2.3	2.3	1.3	1.4	3.2
19	4	-	0.9	0.7	0.9	0.0	2.1	2	-	9.9	9.9	14.1	0.0	19.9

20	8	-	6.3	4.2	7.4	0.1	22.5	2	-	0.1	0.1	0.2	0.0	0.3
21	1	0.5	-	-	-	-	-	2	-	12.8	12.8	17.0	0.8	24.9
22	1	0.0	-	-	-	-	-	-	-	-	-	-	-	-
23	2	-	13.0	13.0	9.7	6.2	19.8	1	0.0	-	-	-	-	-
24	2	-	9.5	9.5	11.2	1.5	17.4	4	-	3.3	2.0	4.3	0.0	9.3
25	2	-	2.2	2.2	3.2	0.0	4.5	1	0.0	-	-	-	-	-
26	4	-	0.9	0.2	1.5	0.0	3.1	-	-	-	-	-	-	-
27	1	3.0	-	-	-	-	-	-	-	-	-	-	-	-
28	1	8.9	-	-	-	-	-	-	-	-	-	-	-	-
29	1	10.0	-	-	-	-	-	1	0.3	-	-	-	-	-
30	2	-	0.2	0.2	0.1	0.1	0.3	1	26.9	-	-	-	-	-
31	1	4.0	-	-	-	-	-	1	4.9	-	-	-	-	-
32	-	-	-	-	-	-	-	1	22.8	-	-	-	-	-
33	1	0.1	-	-	-	-	-	1	0.2	-	-	-	-	-
34	1	13.5	-	-	-	-	-	1	21.8	-	-	-	-	-
35	-	-	-	-	-	-	-	1	0.3	-	-	-	-	-
36	1	39.2	-	-	-	-	-	1	6.0	-	-	-	-	-
37	1	52.1	-	-	-	-	-	1	1.0	-	-	-	-	-

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Appendix 3. White shark photo identification catalogue summary. November 2013 to November 2014. Photos shown represent samples of those held in the catalogue for each individual (n=78).
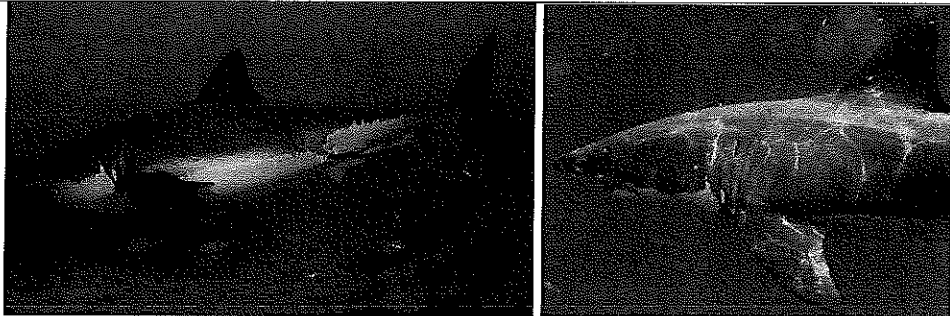
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Pigmented Regions Types	LG2LP1LC2
RS photo	
Pigmented Regions Types	RG2RP2RC2
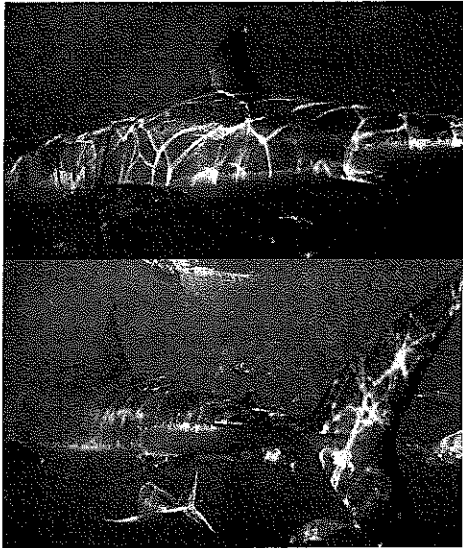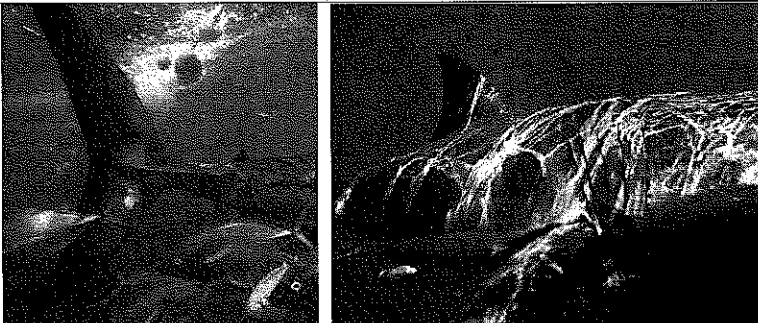
Photo ID	NI002
LS photo	
Pigmented Regions Types	LG2LP2LC0
RS photo	
Pigmented Regions Types	RG2RP3RC4
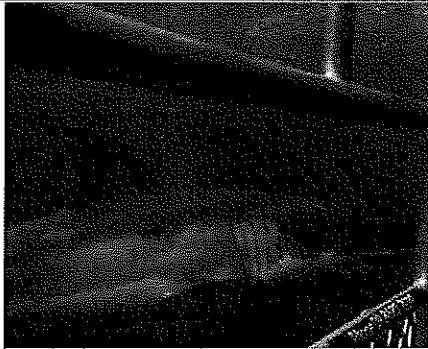
Photo ID	NI003
LS photo	
Pigmented Regions Types	LG3LP1LC0
RS photo	
Pigmented Regions Types	RG3RP2RC2
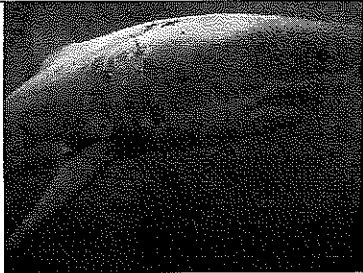
Photo ID	NI004
LS photo	
Pigmented Regions Types	LG1LP0LC0
RS photo	
Pigmented Regions Types	RG1RP0RC0
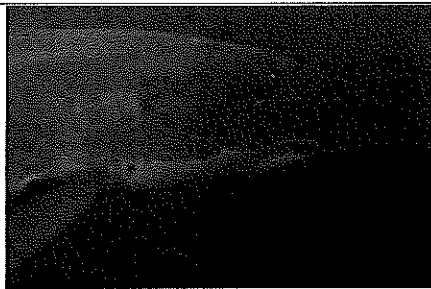
Photo ID	NI005
LS photo	
Pigmented Regions Types	LG2LP0LC0
RS photo	
Pigmented Regions Types	RG3RP1RC4
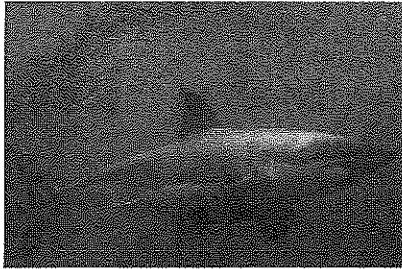
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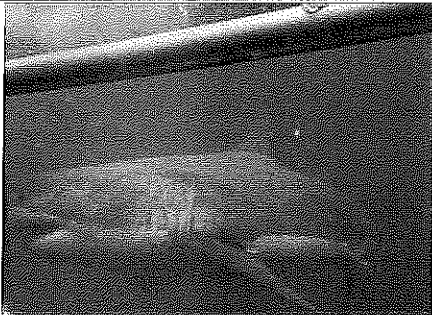
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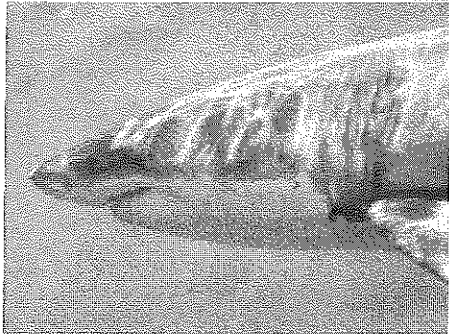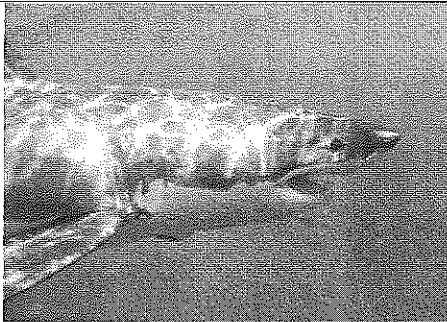
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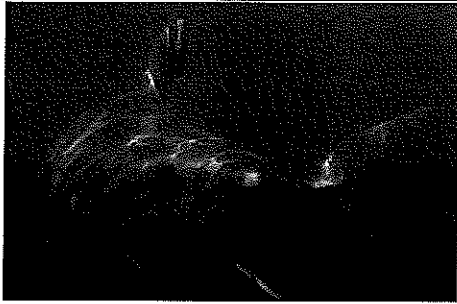
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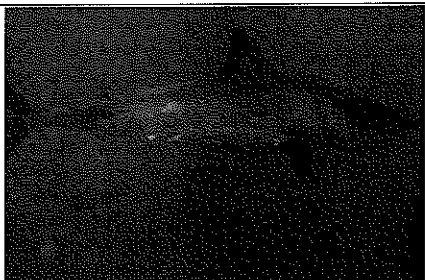
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RS photo	
Pigmented Regions Types	RG2RP1RC4

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RS photo	
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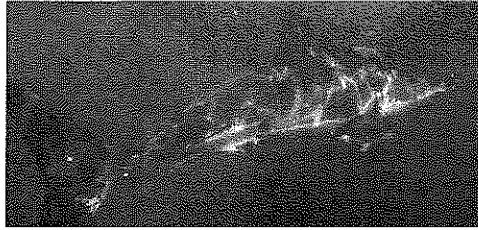
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Pigmented Regions Types	RG3RP2RC4

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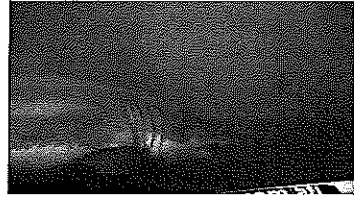
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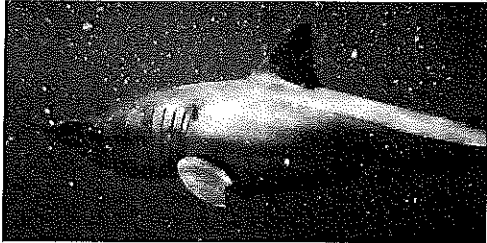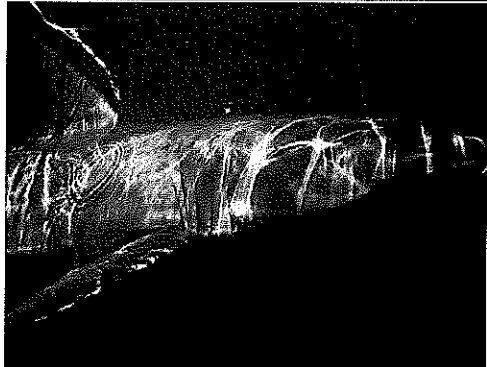
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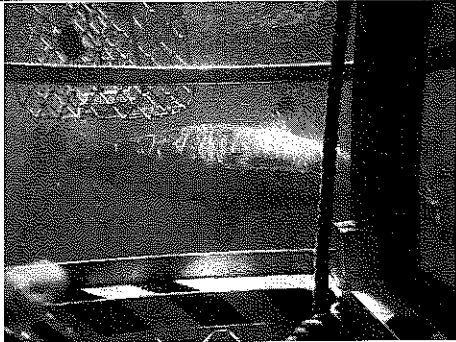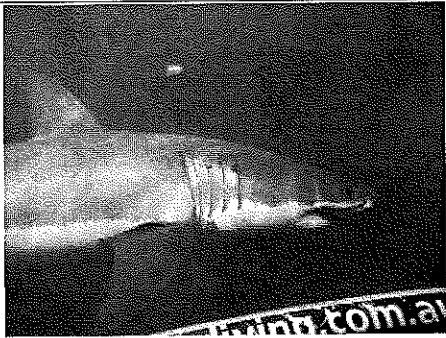
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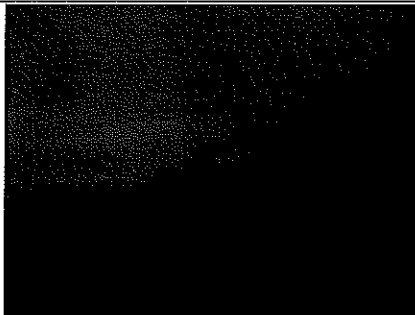
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Photo ID	NI045
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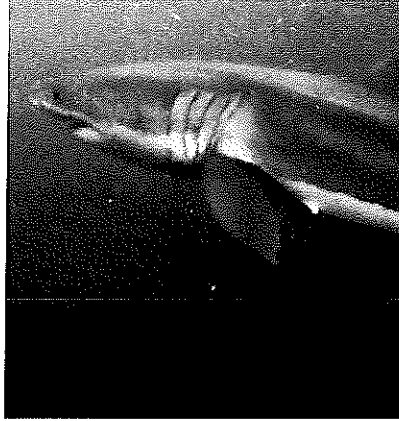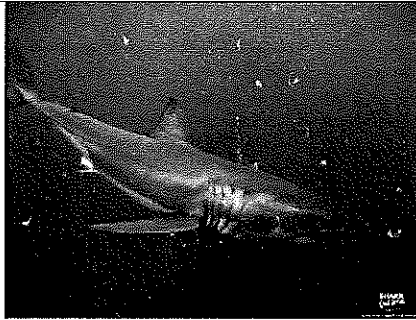
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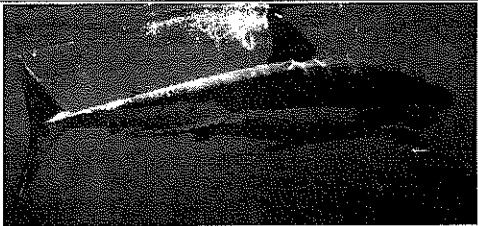
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Pigmented Regions Types	RG3RP2RC4

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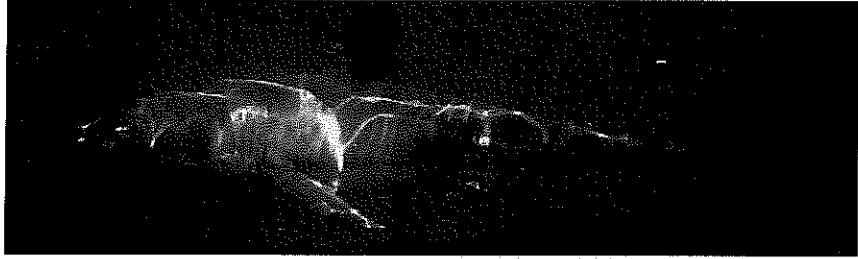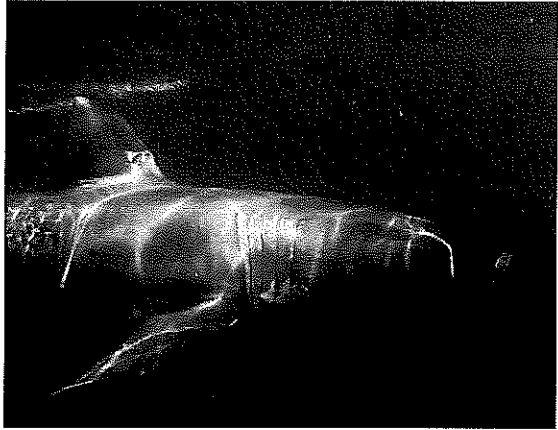
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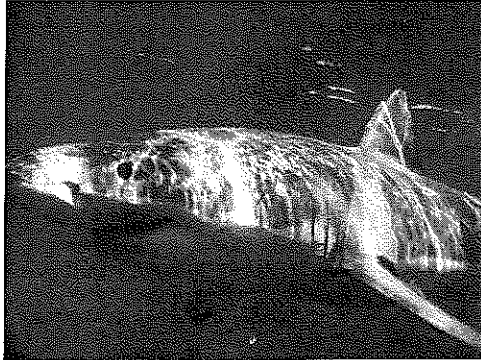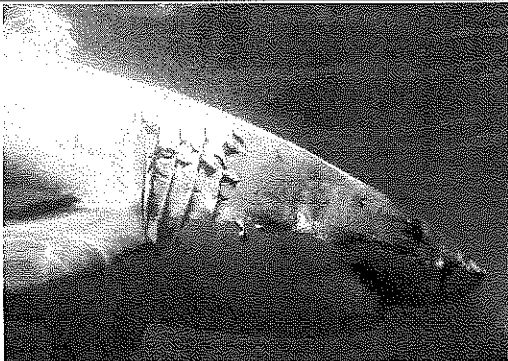
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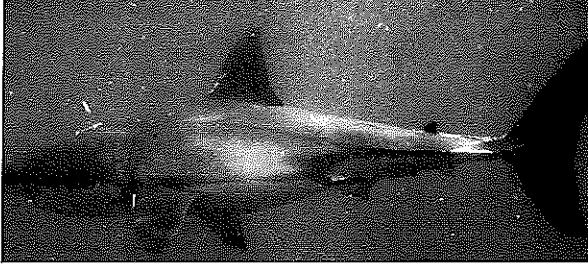
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Pigmented Regions Types	RG1RP1RC1

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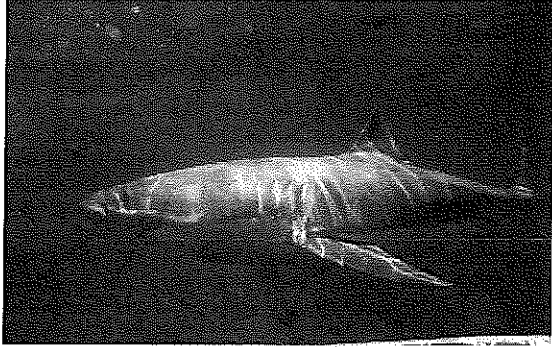
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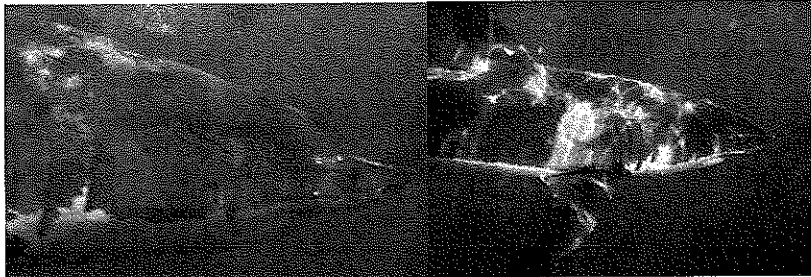
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Photo ID	NI080
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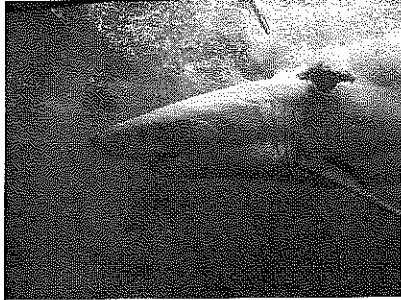
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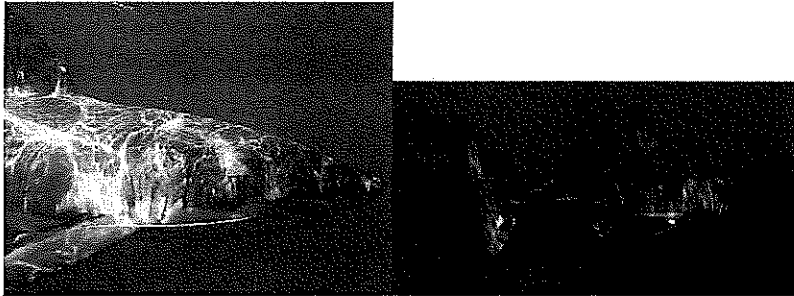
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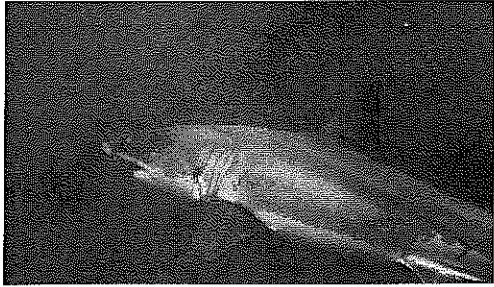
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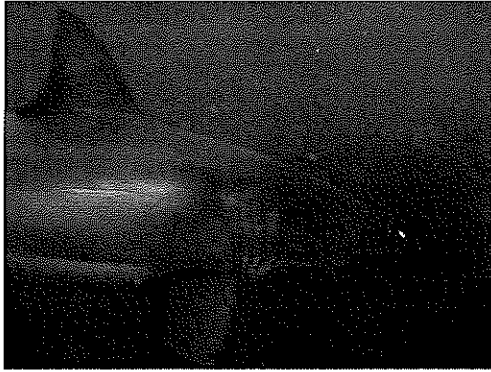
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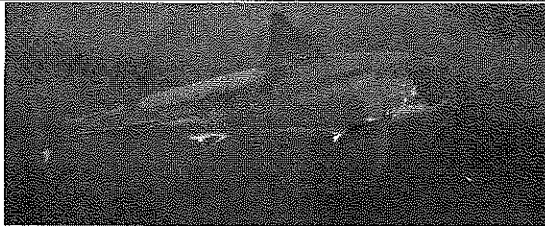
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Pigmented Regions Types	RG3RP3RC4

Photo ID	NI090
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Pigmented Regions Types	LG2LP0LC0
RS photo	
Pigmented Regions Types	RG2RP1RC0

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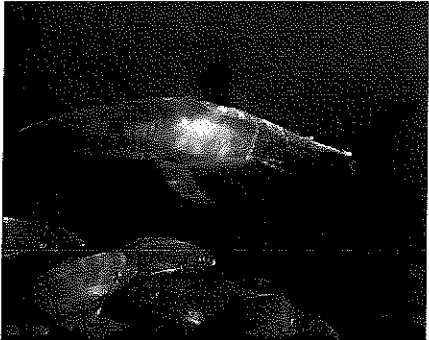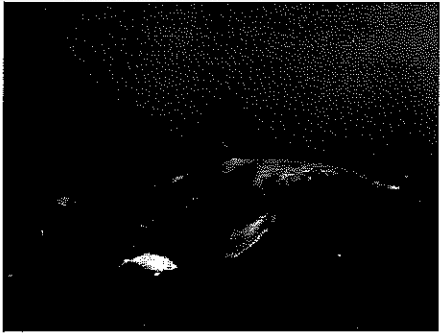
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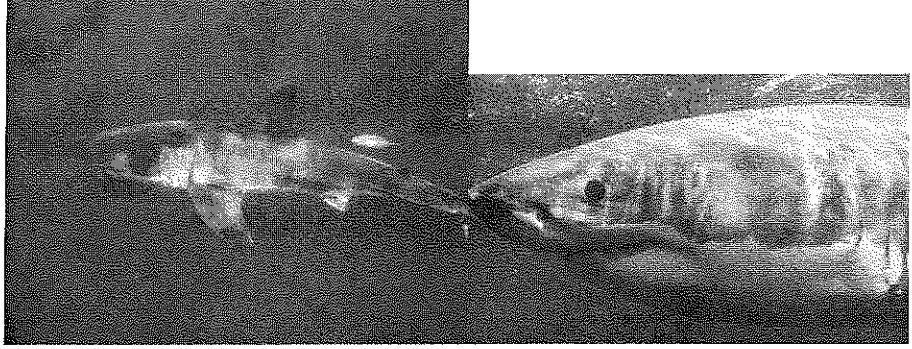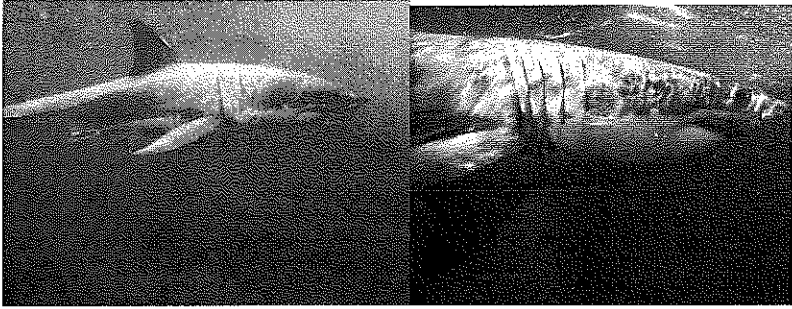
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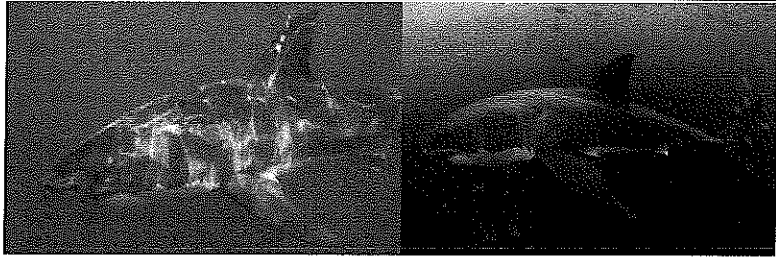
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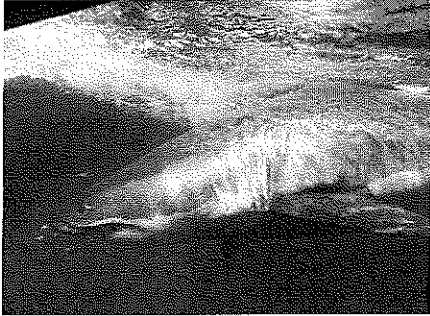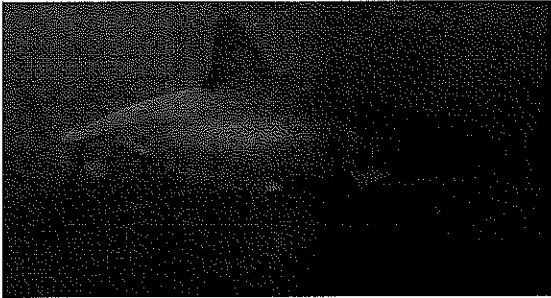
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Pigmented Regions Types	RG3RP2RC1
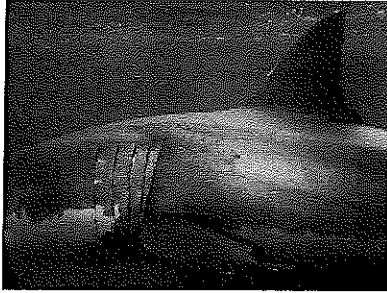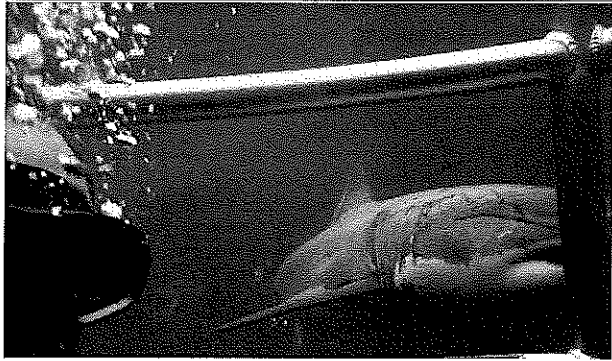
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Pigmented Regions Types	RG2RP1RC4
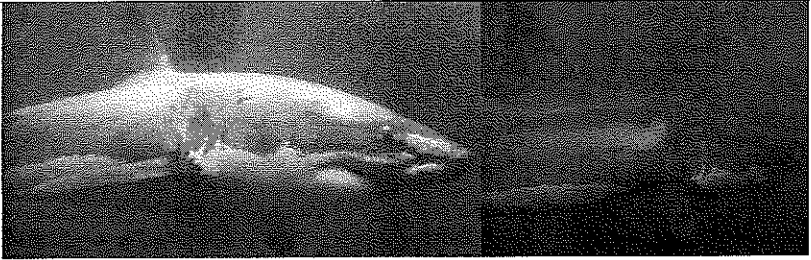
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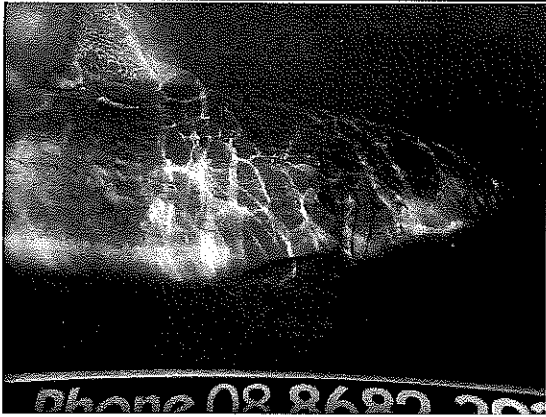
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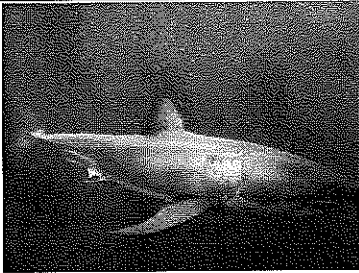
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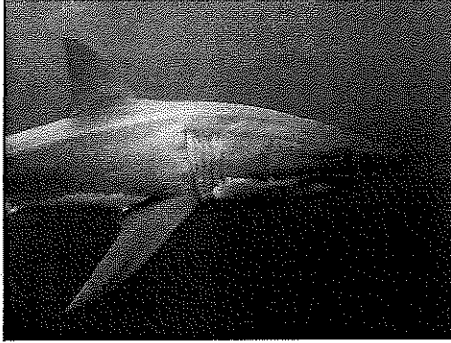
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Pigmented Regions Types	LG3LP1LC0
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Pigmented Regions Types	RG1RP1RC3
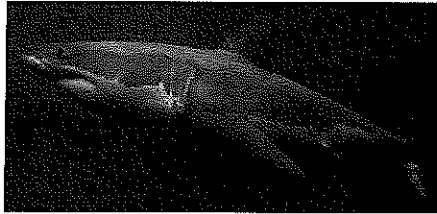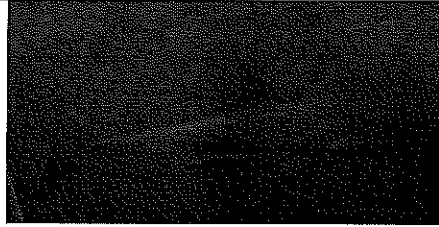
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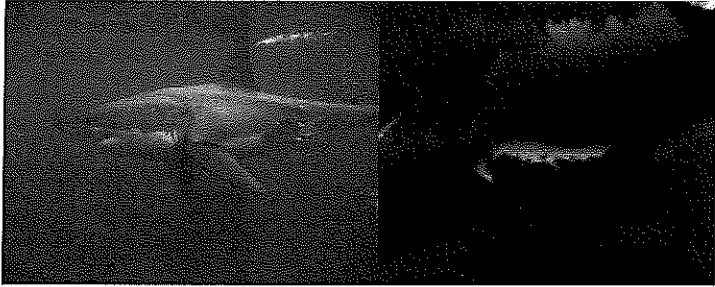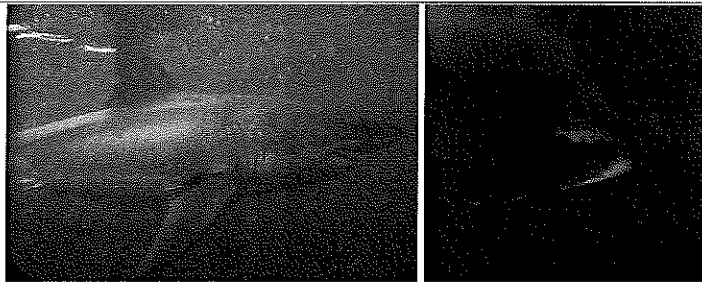
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Pigmented Regions Types	RG3RP1RC4
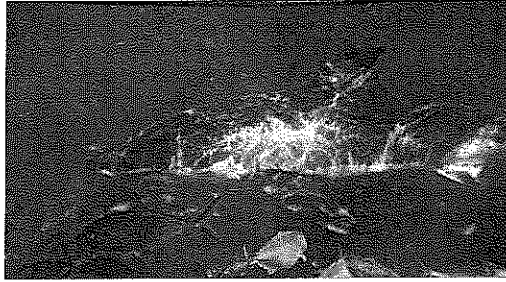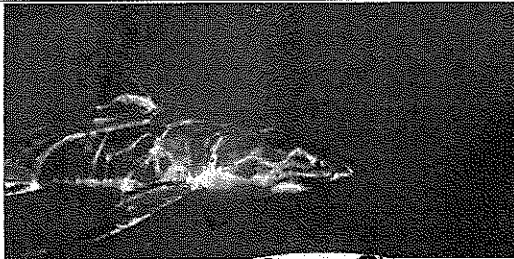
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RS photo	
Pigmented Regions Types	RG2RP0RC0

Photo ID	NI116
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RS photo	
Pigmented Regions Types	RG2RP0RC0
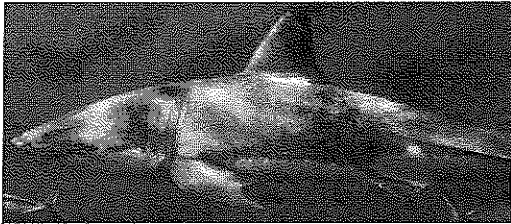
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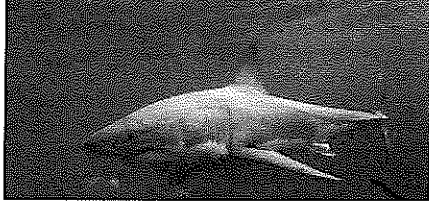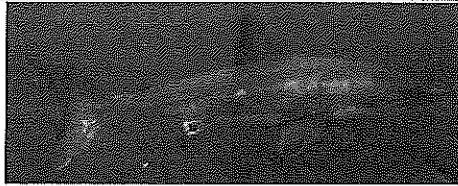
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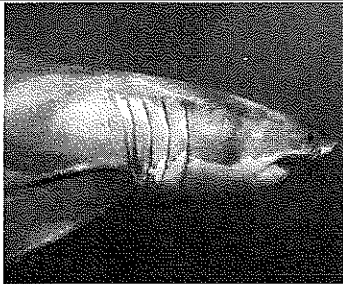
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Pigmented Regions Types	RG3RP2RC4

Photo ID	NI128
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Pigmented Regions Types	LG3LP3LC2
RS photo	
Pigmented Regions Types	RG3RP0RC0

Photo ID	NI131
LS photo	
Pigmented Regions Types	LG3LP1LC0
RS photo	
Pigmented Regions Types	RG2RP3RC4
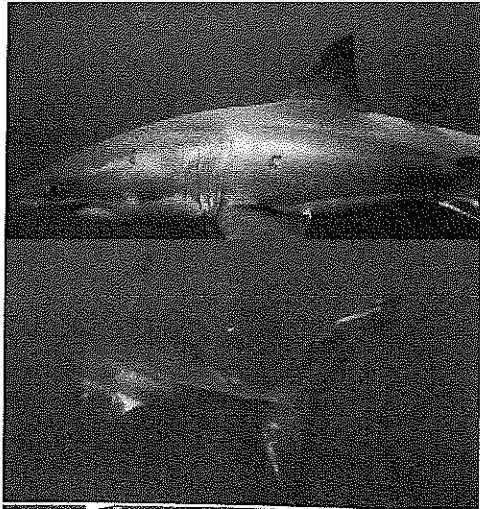
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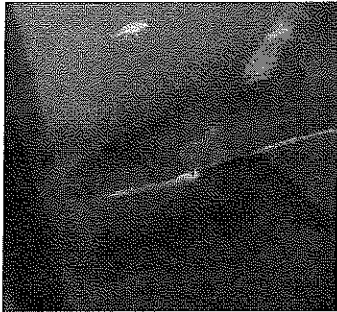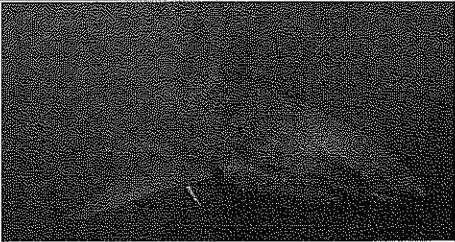
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RS photo	
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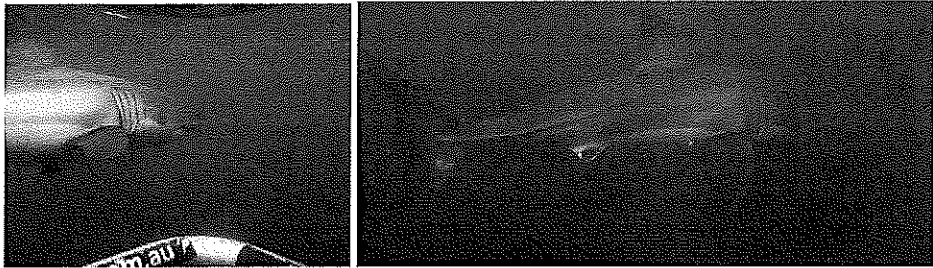
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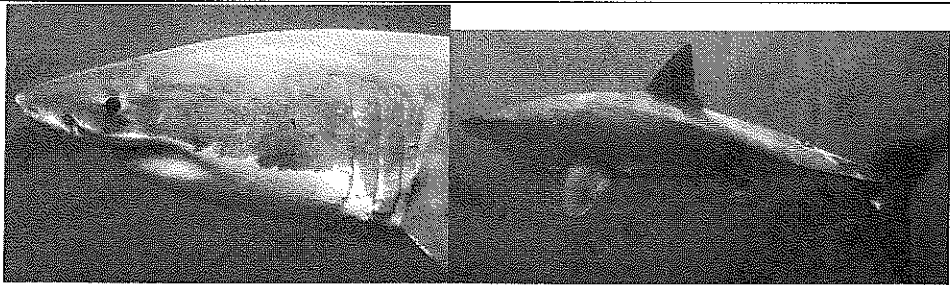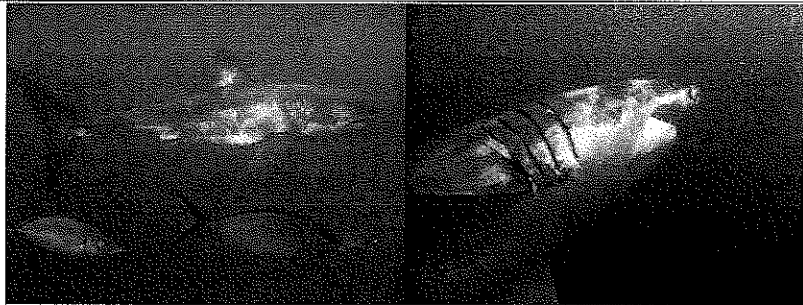
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Pigmented Regions Types	RG2RP1RC2
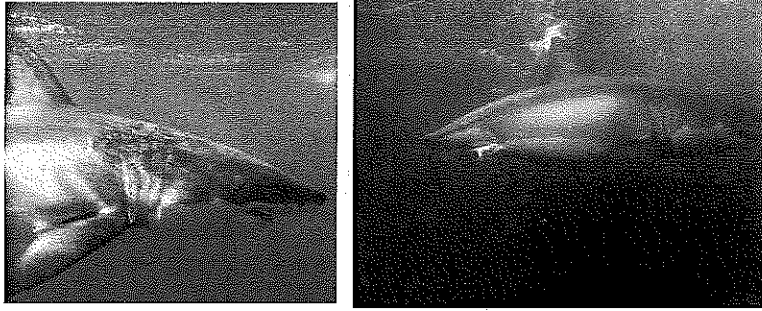
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Pigmented Regions Types	RG2RP1RC0
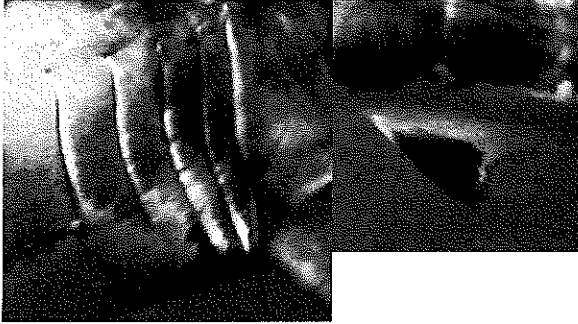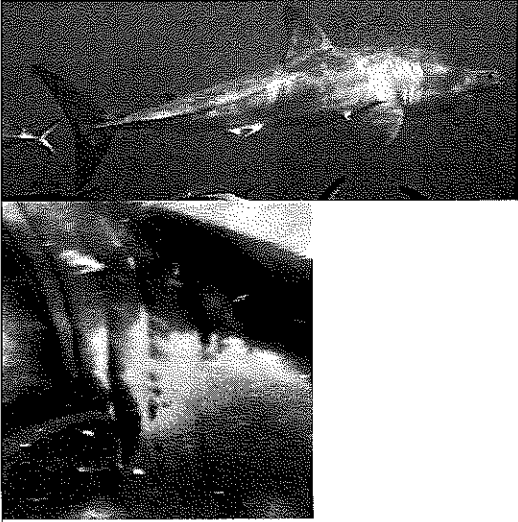
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Pigmented Regions Types	RG3RP3RC2
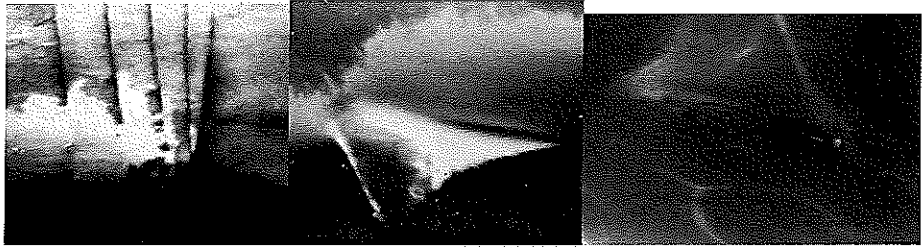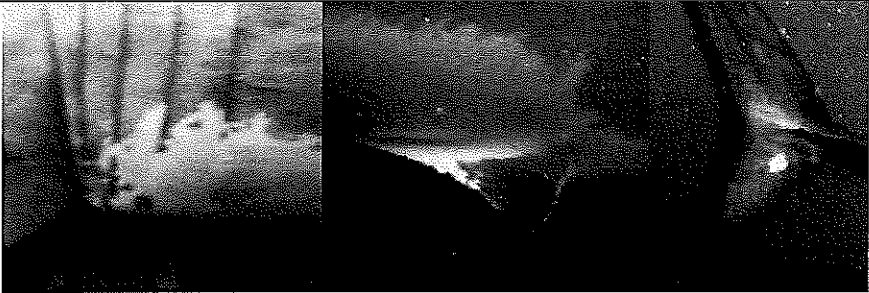
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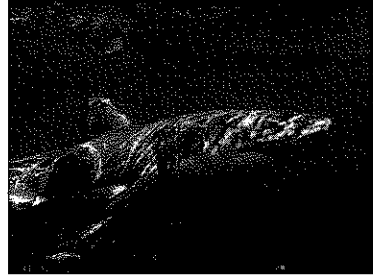
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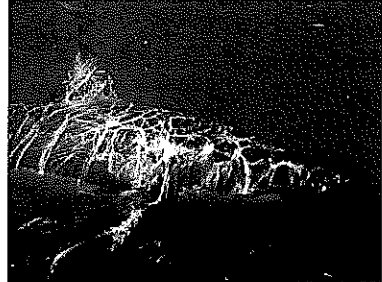
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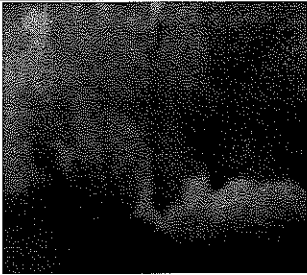
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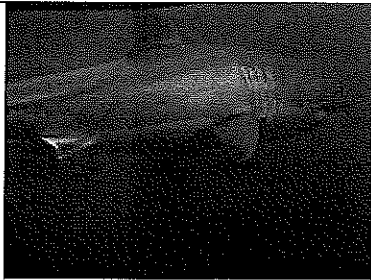
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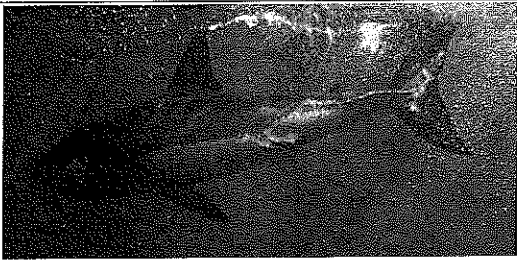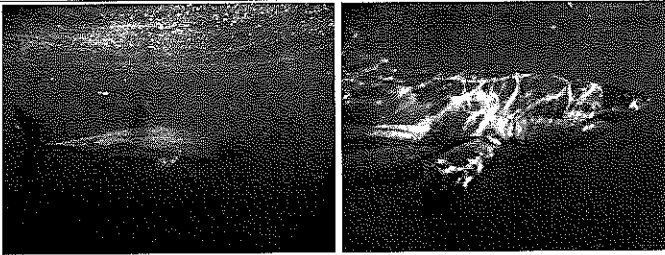
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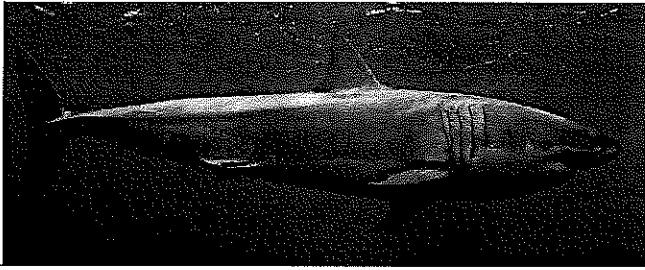
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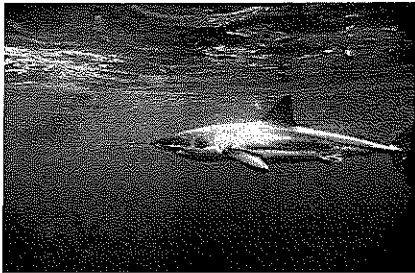
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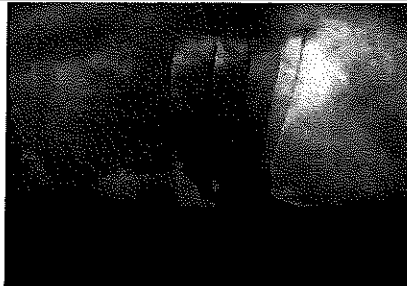
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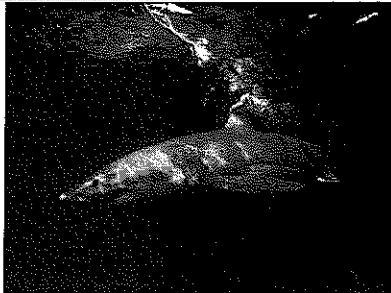
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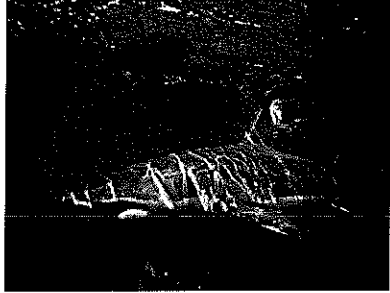
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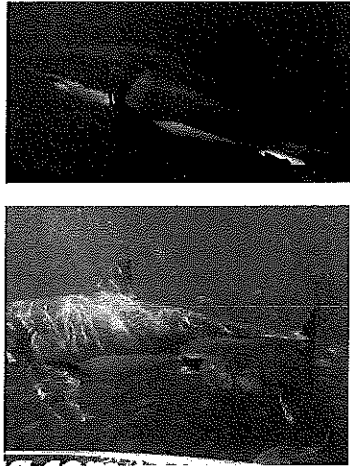
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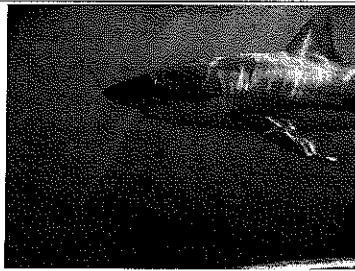
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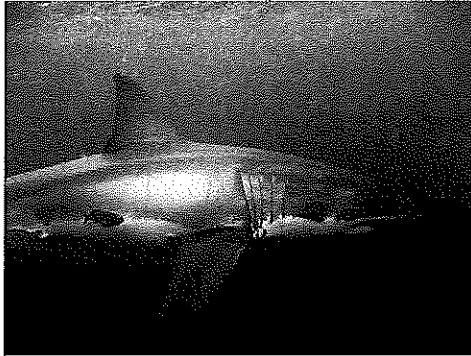
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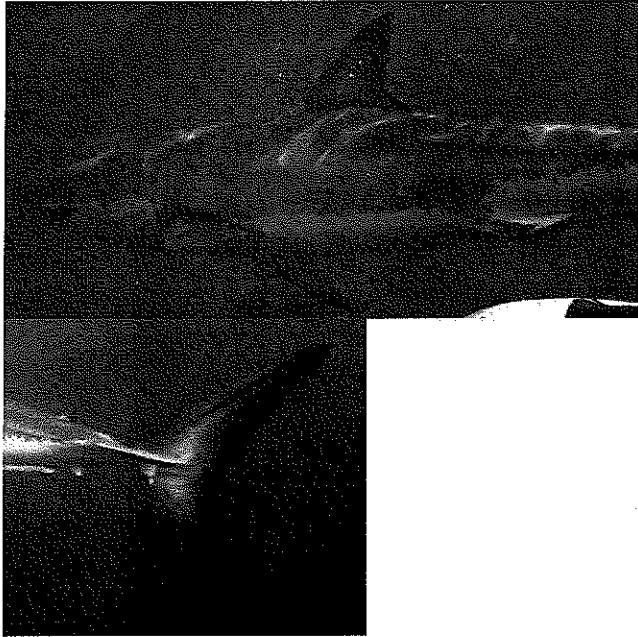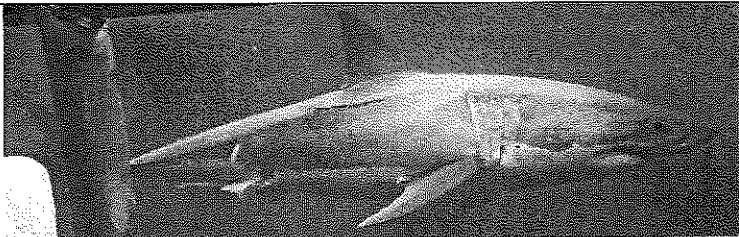
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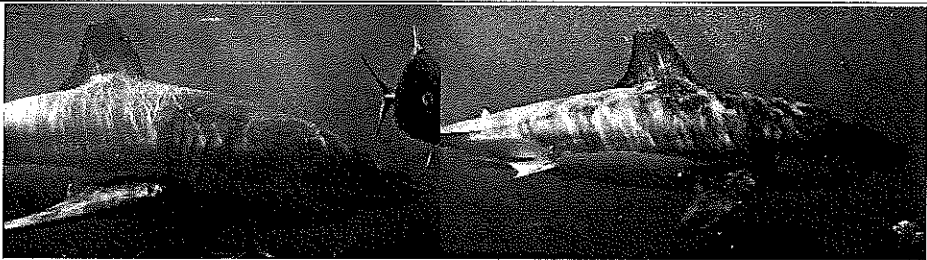
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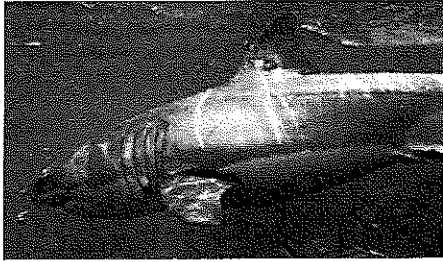
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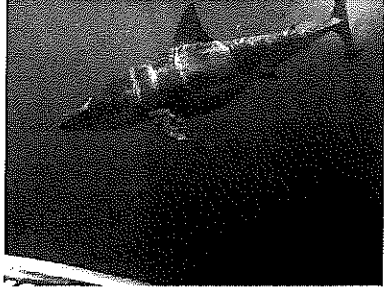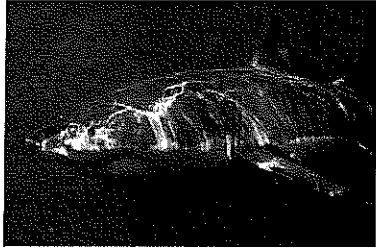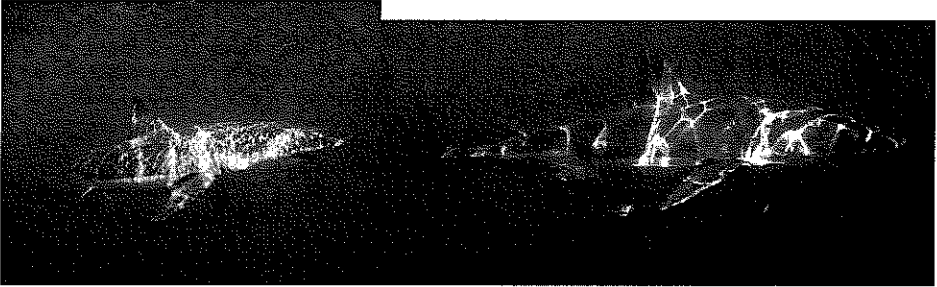
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Marine Ecosystems

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Rogers, P. J.

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SARDI Aquatics Sciences
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Report to Department of Environment, Water and Natural Resources

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EXECUTIVE SUMMARY

This report provides estimates of residency of tagged white sharks (*Carcharodon carcharias*) and a summary of electronic logbook data describing cage-diving activities in the Neptune Islands Group Marine Park between July 2015 and July 2016.

A total of 55 white sharks of ~1.8–5.0 m total length (TL) were tagged using acoustic transmitters at the Neptune Islands (n = 44) and in Spencer Gulf (n = 11) between 2013 and 2015.

Residency was estimated for 19 tagged sharks (1.8–4.5 m TL) at the North Neptune Islands and 17 tagged sharks (1.8–5.0 m TL) at the South Neptune Islands.

Mean residency estimates averaged across all tagged sharks were 10.8 ± 11.4 d (S.D.) (range 0–32.8 d, median = 5 d) at the North Neptune Islands, and 7.2 ± 8.4 d (range = 0.1–24.7 d, median = 3.7 d) at the South Neptune Islands between 2015–16.

Residency of white sharks increased from the previous year *(c.f.* 9.1 ± 12.3 d) at the North Neptune Islands, and decreased (*c.f.* 9.3 ± 14.8 d) at the South Neptune Islands.

Electronic logbooks indicated the cage-diving industry used 11.36 kilo-litres of berley, ~11.6 t of southern bluefin tuna (SBT) (*Thunnus maccoyii*) gills and entrails, and ~0.49 t of whole SBT between 1 July 2015 and 30 June 2016.

Electronic logbooks showed ~68% of baits deployed during cage-diving activities were consumed by white sharks.

Residency estimates, bait consumption and berley input rates provided in this report suggest there remains a need to improve the Code of Practice for this economically important tourism industry. SARDI, DEWNR and industry took steps to refine the Code of Practice in 2015.

1. INTRODUCTION

1.1 Background

The white shark *Carcharodon carcharias* is a listed Threatened species under the Australian Commonwealth Government *Environmental Protection, Biodiversity and Conservation* Act (1999). In South Australian State managed waters, the species is protected under the *Fisheries Management Act* (2007) regulated by PIRSA Fisheries and Aquaculture. Australian Commonwealth government species recovery plan objectives (5.1–5.3) include the identification and management of the impacts of tourism on white sharks (Department of the Environment 2013). One objective of the plan is to investigate, manage and where necessary reduce the impact of tourism on the white shark.

White shark cage-diving tourism industries are located in Australia, California, New Zealand, Mexico and South Africa. Behavioural responses to cage-diving activities by white sharks are well-documented (Bruce, 2015). The South Australian cage-diving tourism industry is the only operation of its kind in Australian waters. Compliance and management of the South Australian white shark cage-diving industry is undertaken by the Department of Environment Water and Natural Resources (DEWNR). The industry is comprised of two licensed operators with exemptions to use baits and berley to attract sharks to vessels, and a third operator that can only use sound as an attractant. Operators are licensed to conduct these activities in the Neptune Islands Group Marine Park (Fig. 1). These offshore islands are also the locations of long-nosed fur seal *Arctocephalus forsteri* breeding colonies; recent estimates of pup abundance were 4,669 pups at the North Neptune Islands and 3,210 pups at South Neptune Islands (Shaughnessy *et al.* 2014).

Between 2013 and 2016, SARDI Aquatic Sciences developed, managed and refined a real-time electronic logbook (e-logbook) system to collect shark sighting and cage-diving activity data. Logbook-based recording of white shark sightings and operator effort was also recorded during previous monitoring programs (Bruce and Bradford 2011). Following consultation and feed-back from DEWNR and industry, improvements were made to the initial version of the e-logbook, which was described in Rogers *et al.* (2014). During 2013–16, SARDI also used acoustic telemetry to collect time-series data to estimate the primary white shark behavioural indicator (mean residency) to inform decision points underpinning the management process for the Neptune Islands Group Marine Park (Smith and Page 2015).

Movements of white sharks are generally comprised of three phases off southern Australia. These include temporary fidelity to areas where suitable prey is located (e.g. pinniped colonies and snapper aggregation areas), continental shelf transitory (and presumed prey searching) phases, and shelf slope and oceanic transitory/sub-tropical migratory phases (Bruce *et al.* 2006). Acoustic telemetry has been used to collect information on the temporary fidelity

(residency) phases of white sharks that interact with cage-diving operations at the Neptune Islands Group Marine Park and Dangerous Reef since the early 2000s (Bruce and Bradford 2011, 2013; Rogers *et al.* 2014; Rogers and Huveneers 2016). Residency integrates visitation and fidelity information for individuals over time-scales that match those of cage-diving operations, and represents a practical metric for management purposes.

Aims and Objectives

This report provides:

- Estimates of residency of white sharks in the Neptune Islands Group Marine Park in 2015–16.
- Summaries of e-logbook data describing daily activities of the white shark cage-diving operators (use of bait and berley), and observed patterns of shark presence-absence in 2015–16.

2. METHODS

2.1 Geographical area

The Neptune Islands Group (Ron and Valarie Taylor) Marine Park is located in continental shelf waters near the approach to Spencer Gulf, South Australia (Fig. 1). This offshore island complex of limestone-capped granite mounds is located 26–37 km off southern Eyre Peninsula. The North Neptune Islands comprises two islands and has Sanctuary, Restricted Access and Habitat Protection Zones. The South Neptune Islands comprise three islands and has Restricted Access and Habitat Protection Zones (www.environment.sa.gov.au/marine parks). Cage-diving operators mostly anchor their vessels on the lee-sides at Action Bay and Main Bay at the North Neptune Islands, and in the East Bay at the South Neptune Islands (Fig. 1). The seafloor in these deep-water bays is comprised of combinations of seagrass, sand and rocky substrates.

2.2 Acoustic telemetry

Receiver deployments

Two Vemco VR2W (Halifax, Canada) acoustic receivers, with surface moorings were deployed in Main Bay (between the eastern and western cracks) and Action Bay (at the southern end) in the North Neptune Islands on 30 June 2015 (Fig. 1). A third receiver and surface mooring configuration was deployed the same day in East Bay at the South Neptune Islands. Moorings were demarcated with 70 cm surface floats with navigation beacons, and anchored with 50 mm diameter multi-strand rope attached to train wheels (Fig. 2). Receivers were attached to mooring ropes at distances ~3 m from the seafloor using crimped stainless steel wire.

Transmitter deployments

A total of 55 white sharks ranging in size between 1.8 and 5.0 m total length (TL) were tagged in the Neptune Islands Group Marine Park and southern Spencer Gulf between 14 September 2011 and 30 December 2015 (Table 1), with V16 acoustic transmitters (VEMCO Ltd., Halifax, Canada) (hereafter referred to as 'tags'). Tags were tethered to a plastic umbrella dart using 10–15 cm long and 1.6 mm diameter stainless wire leaders. An aluminum tag-pole and applicator were used to implant the umbrella dart in the dorsal musculature of free-swimming white sharks. A small number of tags were deployed from dive cages using a hand-held pneumatic applicator. Sharks were attracted within range of the vessels for tagging using baits comprising gills or portions of southern bluefin tuna attached by sisal rope under a small buoy. Baits were deployed and retrieved using 10 to 14 mm diameter ropes. All efforts were made

to minimise the consumption of baits during the tagging processes, including the use of experienced taggers and bait-handlers, observers and avoidance of tagging during low light conditions.

2.3 Residency

Residency estimates of tagged white sharks presented in this report are for the monitoring period of 30 June 2015 to 16 July 2016. Tagged white sharks were considered 'present' if ≥2 acoustic detections were recorded on the moored receivers within 24 hours (Pincock 2011). Residency periods were estimated from the number of days between the first and last detection of a tagged white shark in the study area (at either the North or South Neptune Islands), where no gaps in consecutive days (d) of detections were >5 days. In the case of individuals returning following periods >5 days, the individual(s) were assumed to have left the Neptune Islands and subsequent return(s) were defined as a new residency period(s) (Bruce and Bradford 2013). Residency estimates were based on the grand mean of individual estimates following Rogers and Huveneers (2016).

2.4 Electronic logbooks

In September 2013, cage-diving operators were issued with a mini-iPad™ loaded with the Fulcrum™ application to record daily electronic logbook (e-logbook) entries. Development of the e-logbook is described in Rogers *et al.* (2014). E-logbooks were used to record data on daily operator activities and sighting frequency of white sharks between 1 July 2015 and 30 June 2016. Data fields were refined to include bait consumption data in August 2015. We define an 'interaction' as the consumption of a bait.
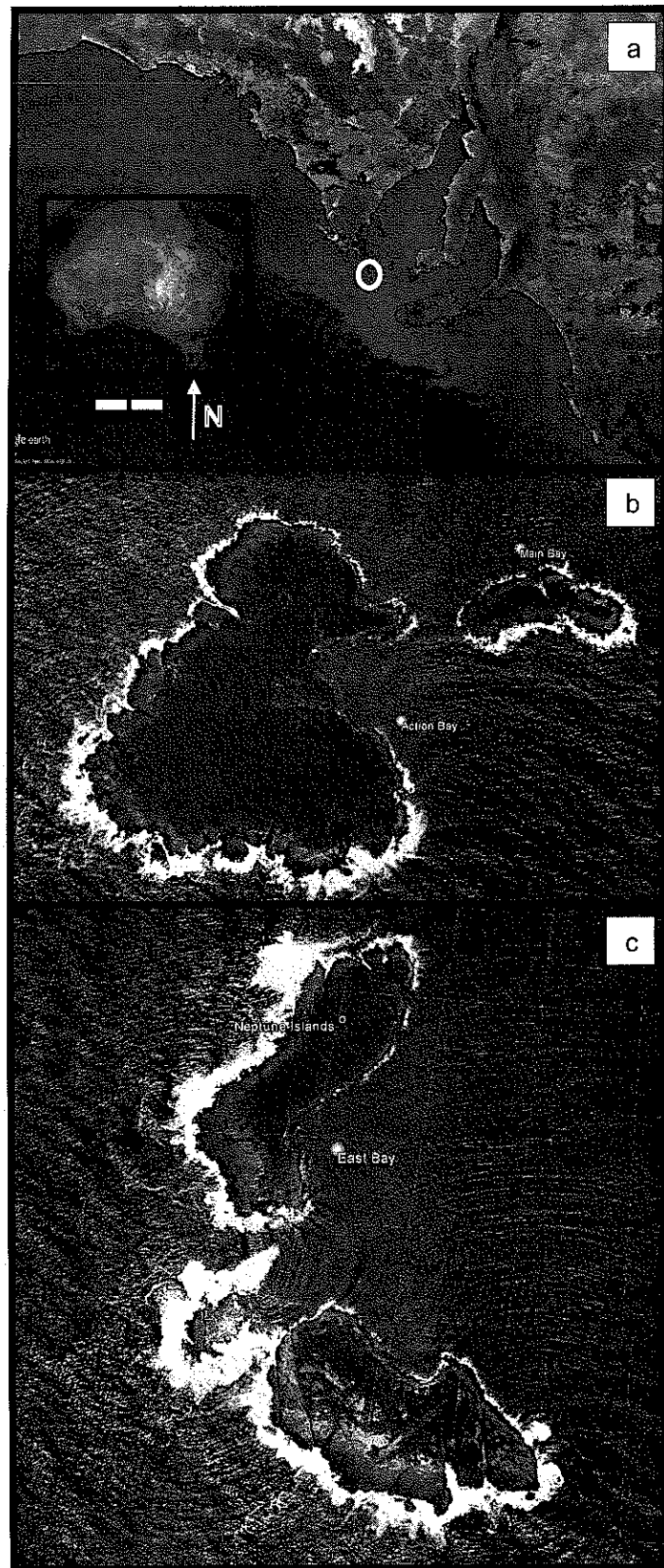
Figure 1. (a) Location of the study site (yellow ellipse) in the Neptune Islands Group Marine Park in shelf waters of South Australia and (b) acoustic receivers deployed at the North and (c) South Neptune Islands. Scale bar (a) = 100 km. Source: Google Earth Pro, 2016.

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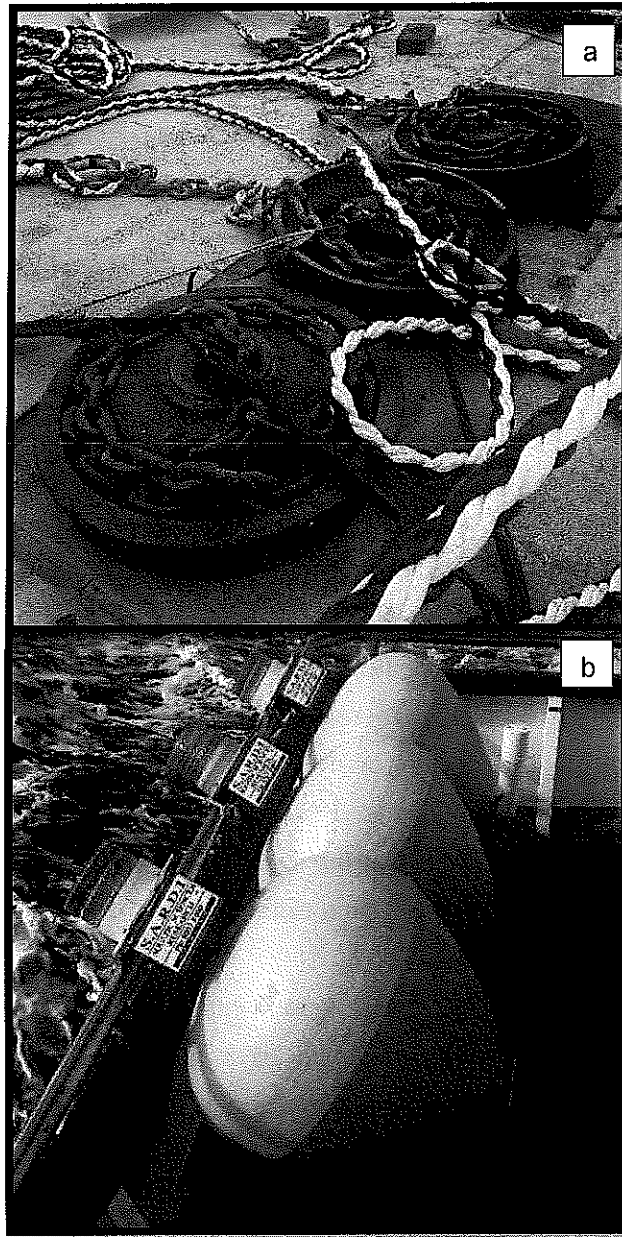
Figure 2. Mooring configurations (a) and navigation marker buoys (b) used to anchor the acoustic receivers in the Neptune Islands Group during 2015–16.

3 RESULTS

3.1 Acoustic tag deployments

A total of 55 white sharks ranging in size from ~1.8–5.0 m total length (TL) were tagged between 14 September 2013 and 30 December 2015 (Table 1). Tag deployments took place at North Neptune Islands (n = 33, 60%), South Neptune Islands (n = 11, 20%) and in Spencer Gulf (n = 11, 20%) between 13 September 2013 and 30 December 2015 (Table 1). Tagged sharks included 16 females, 32 males and seven unsexed. A total of 26 sharks were tagged in 2015 (Table 1).

3.2 Acoustic receiver and dataset recoveries

The mooring and receiver in the Main Bay at the North Neptune Islands was lost during poor weather in September 2015. This equipment was not recovered despite reports that the navigation marker buoy was observed drifting at the surface.

The mooring line and receiver moored in Action Bay was entangled in the anchor chain of an operator vessel during a gale event in July 2016. The navigation marker buoy was removed and the mooring line and receiver were released. The complete mooring line, weight and receiver were recovered by an operator on 16 July 2016. The last useable detection data on the Action Bay receiver (e.g. ≥2 detections. d^{-1}) were recorded on 16 July 2016.

The receiver and mooring in East Bay at the South Neptune Islands was recovered on 14 September 2016. The last useable detection data (e.g. ≥2 detections. d^{-1}) on the East Bay receiver were recorded on 17 June 2016.

A total of 41,763 acoustic detections from tagged white sharks between 14 September 2013 and 30 December 2015 were recorded during 2015–16. These were comprised of 24,957 (59.8%) detections at the North Neptune Islands and 16,806 (40.2%) detections at the South Neptune Islands.

Table 1. Acoustic tag deployment statistics between 2013 and 2015. TL = total length, F=female, M=male and US = unsexed. Continued over page.

Shark ID	Est. TL	Sex	Tag deployment date	Deploy location/area
1	4.1	F	14 Sep 13	South Neptune Islands
2	3.3	M	15 Sep 13	South Neptune Islands
3	4.5	M	28 Sep 13	North Neptune Islands
4	4.1	M	09 Oct 13	North Neptune Islands
5	4.5	M	14 Oct 13	North Neptune Islands
6	4.5	M	26 Oct 13	North Neptune Islands
7	3.0	M	26 Oct 13	North Neptune Islands
8	2.0	US	15 Nov 13	North Neptune Islands
9	2.4	F	16 Jan 14	Spencer Gulf
10	2.4	F	16 Jan 14	Spencer Gulf
11	2.9	F	16 Jan 14	Spencer Gulf
12	3.5	M	29 Jan 14	North Neptune Islands
13	4.0	M	29 Jan 14	North Neptune Islands
14	3.8	M	29 Jan 14	North Neptune Islands
15	4.3	M	23 Feb 14	North Neptune Islands
16	2.4	M	24 Feb 14	North Neptune Islands
17	4.5	F	26 Feb 14	North Neptune Islands
18	3.0	M	28 Feb 14	North Neptune Islands
19	3.6	M	19 Jul 14	North Neptune Islands
20	3.9	F	19 Jul 14	North Neptune Islands
21	3.3	M	20 Jul 14	North Neptune Islands
22	3.7	F	20 Jul 14	North Neptune Islands
23	4.2	M	21 Jul 14	North Neptune Islands
24	4.0	M	18 Oct 14	South Neptune Islands
25	3.0	F	19 Oct 14	North Neptune Islands
26	4.5	M	19 Oct 14	North Neptune Islands
27	3.5	M	15 Nov 14	North Neptune Islands
28	3.8	M	15 Nov 14	North Neptune Islands
29	3.2	M	16 Nov 14	North Neptune Islands
30	3.9	M	24 Jan 15	North Neptune Islands
31	3.7	M	24 Jan 15	North Neptune Islands
32	2.7	M	24 Jan 15	North Neptune Islands
33	4.2	F	02 May 15	South Neptune Islands
34	1.8	F	06 May 15	South Neptune Islands
35	4.2	F	06 May 15	South Neptune Islands
36	4.5	US	07 May 15	South Neptune Islands
37	2.6	US	07 May 15	South Neptune Islands
38	3.0	US	07 May 15	South Neptune Islands
39	3.4	US	07 May 15	South Neptune Islands
40	2.8	US	07 May 15	South Neptune Islands
41	3.3	F	18 Jul 15	Spencer Gulf
42	5.0	F	19 Jul 15	Spencer Gulf
43	4.2	US	22 Jul 15	Spencer Gulf

Table 1.cont.

Shark ID	Est. TL	Sex	Tag deployment date	Deploy location/area
44	3.8	F	23 Jul 15	Spencer Gulf
45	2.6	M	23 Jul 15	Spencer Gulf
46	2.6	M	05 Aug 15	Spencer Gulf
47	4.6	F	07 Aug 15	Spencer Gulf
48	3.5	F	08 Aug 15	Spencer Gulf
49	3.9	M	08 Nov 15	North Neptune Islands
50	3.2	M	08 Nov 15	North Neptune Islands
51	3.0	M	17 Dec 15	North Neptune Islands
52	3.0	M	17 Dec 15	North Neptune Islands
53	2.8	M	17 Dec 15	North Neptune Islands
54	3.4	M	30 Dec 15	North Neptune Islands
55	3.5	M	30 Dec 15	North Neptune Islands

3.5 Demography

North Neptune Islands

Tagged white sharks (n = 19) for which residency was estimated at the North Neptune Islands ranged between 1.8 and 4.5 m TL (Table 2). There was one shark in the 1–1.9 m size category, five of 2–2.9 m, nine of 3–3.9 m, four of 4–4.9 m and none that were 5–5.9 m (Fig. 3). Fourteen were male, three were female and two were un-sexed.

South Neptune Islands

Tagged white sharks (n = 17) for which residency was estimated at the South Neptune Islands ranged between 1.8 and 5.0 m TL (Table 3). There was one shark in the 1–1.9 m size category, two of 2–2.9 m, eight of 3–3.9 m, five of 4–4.9 m and one was 5–5.9 m (Fig. 3). Eleven were male, five were female and one was un-sexed.
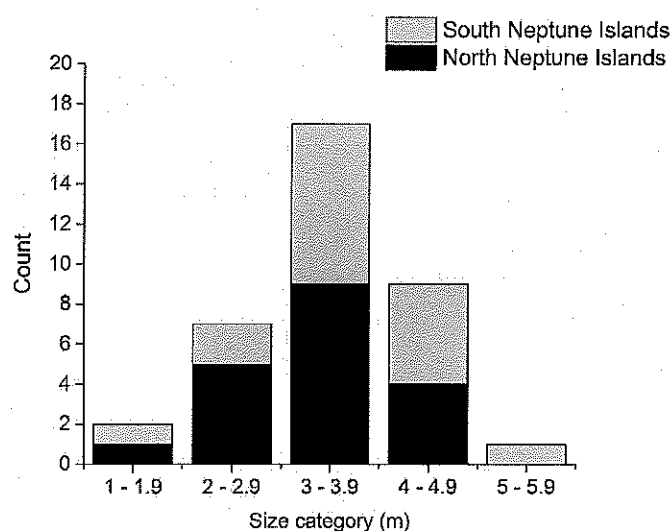
Figure 3. Size categories of white sharks for which residency was estimated at the North and South Neptune Islands.

3.6 Residency

North Neptune Islands

Mean residency of white sharks detected at the North Neptune Islands was calculated using 45 residency periods in 2015–16 (Table 2). The mean residency estimate (averaged across all sharks detected) at the North Neptune Islands was 10.8 ± 11.4 d (S.D.) (Table 2). The range of residency estimates spanned <0.1–32.8 d (median = 5 d). Log^{10} overall (grand) mean residency was 0.36 ± 1.32 (Table 2).

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South Neptune Islands

Mean residency of white sharks detected at the South Neptune Islands was calculated using 33 residency periods in 2015–16 (Table 3). The mean residency estimate (averaged across all sharks detected) at the South Neptune Islands was 7.2 ± 8.4 d (Table 3). The range of residency estimates spanned 0.1–24.7 d (median = 3.7 d). $\log^{10}$ overall (grand) mean residency was 0.47 ± 0.71 (Table 3).

Table 2. Residency statistics for white sharks detected at the North Neptune Islands between 2015 and 2016. Standard deviation = S.D. Residency and Log^{10} values represent means where N periods >1. Log^{10} residency is provided to 2 d.p. following Smith and Page (2015).

Shark # at site	Size category (m)	Residency (d)	Log^{10} residency	N periods
1	4–4.9	32.8	1.52	3
2	4–4.9	8.6	0.93	5
3	3–3.9	9.6	0.98	1
4	2–2.9	0.8	-0.11	1
5	2–2.9	<0.1	-2.84	2
6	3–3.9	10.8	1.03	5
7	3–3.9	24.1	1.38	1
8	4–4.9	2.9	0.47	2
9	3–3.9	21.6	1.33	1
10	4–4.9	24.9	1.40	4
11	3–3.9	3.8	0.58	4
12	1–1.9	3.6	0.56	5
13	2–2.9	1.3	0.13	2
14	2–2.9	31.0	1.49	1
15	3–3.9	5.0	0.70	2
16	3–3.9	1.6	0.21	3
17	3–3.9	<0.1	-2.33	1
18	2–2.9	<0.1	-2.00	1
19	3–3.9	22.0	1.34	1
Sum				45
Grand mean		10.8	0.36	2
Median		5.0	0.70	2
Min		0.	-2.84	1
Max		32.8	1.52	5
S.D.		11.4	1.32	1.5

Table 3. Residency statistics for white sharks detected at the South Neptune Islands between 2015 and 2016. Standard deviation = s.d. Residency and $\log^{10}$ values represent means where N periods >1. $\log^{10}$ residency is provided to 2 d.p. following Smith and Page (2015).

Shark # at site	Size category (m)	Residency (d)	Log ^{10} residency	N periods
1	4–4.9	6.8	0.83	2
2	4– 4.9	0.2	-0.68	1
3	3–3.9	2.3	0.35	1
4	2–2.9	1.5	0.18	2
5	3–3.9	4.4	0.64	5
6	3–3.9	6.5	0.82	1
7	4–4.9	7.5	0.88	3
8	3–3.9	1.2	0.10	1
9	4–4.9	1.7	0.22	3
10	3–3.9	3.7	0.56	3
11	1–1.9	19.0	1.28	3
12	4–4.9	24.7	1.39	1
13	2–2.9	22.4	1.35	1
14	5–5.9	0.5	-0.27	1
15	3–3.9	1.7	0.22	3
16	3–3.9	18.8	1.27	1
17	3–3.9	0.1	-1.06	1
Sum				33
Grand mean		7.2	0.47	2
Median		3.7	0.56	1
Min		0.1	-1.06	1
Max		24.7	1.39	5
S.D.		8.4	0.71	1.2

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3.8 Electronic logbook

E-logbook information describing cage-diving industry activities comprised 419 records provided by operators from 1 July 2015 to 30 June 2016.

Sighting frequency

Reported daily sightings ranged from 0–19 white sharks (n = 384 records, mean = 3.5 ± 2.9) in 2015–16 (Fig. 4). Peaks in mean daily sightings were during July, December and May. Lowest daily sightings occurred in September, February and March.
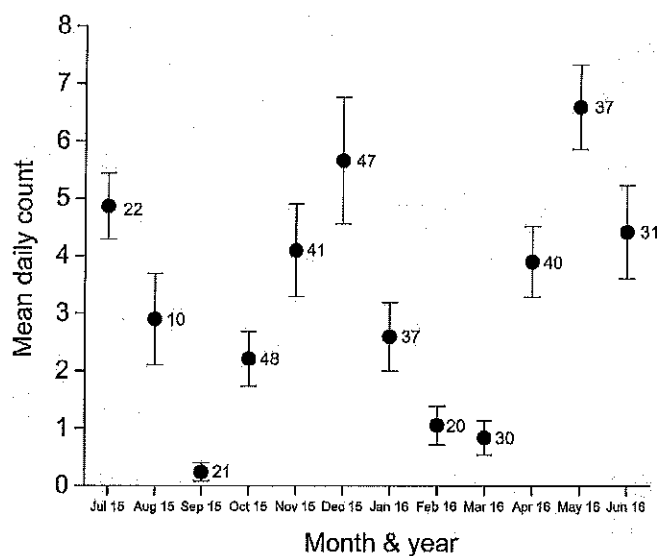
Figure 4. Mean daily sightings of white sharks in the Neptune Islands Group Marine Park in 2015–16. Error bars represent 95% confidence intervals for mean daily count data. Numbers next to each point show the sample size of reported sightings during each month.

Berley and bait use

The white shark cage-diving industry reported using 11.36 kilo-litres of berley, ~11.6 t of SBT gills and entrails, and ~0.49 t of whole SBT between 1 July 2015 and 30 June 2016. A total of 1,096 of 1,608 (~68%) gills, entrails and SBT portions used as baits were consumed by sharks between 13 August 2015 and 30 June 2016.

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4. DISCUSSION

Residency

In 2014, SARDI highlighted the need for development of decision-rules that incorporate behavioural triggers for management of the white shark cage-diving industry in the Neptune Islands Group Marine Park (Rogers *et al.* 2014). Smith and Page (2015) developed decision points for the cage-diving industry and residency estimates remained central to this management option. The overall (grand) mean estimate of residency of white sharks at the North Neptune Islands was 10.8 ± 11.4 days in 2015–16, representing an increase from 9.1 ± 12.3 days in 2014–15 (Rogers and Huveneers 2016) (Table 4). The 2015–16 log-normal residency estimate for the North Neptune Islands was lower than the estimate for the previous year, and that of the baseline period of 2001–02 (Table 4) (Smith and Page 2015). Notably, the standard deviation was higher in 2015–16 than for the previous time-series, indicating higher individual variation and statistical uncertainty (Table 4). Comparisons of residency estimates between years should be interpreted in view of several potential biases driven by the timing of tagging of each individual (sharks are tagged across extended periods), the chance of tag loss or mortality, differential impacts of biological and mechanical noise on tag-receiver performance, and broad-scale migrations of tagged individuals that may extend beyond the monitoring time-frames.

Table 4. Estimates of overall mean and Log^{10} residency of white sharks detected at the North Neptune Islands. *Shows CSIRO estimates from Bruce and Bradford (2011, 2013) as summarised in Smith and Page (2015).

Time series	Residency (d)	*s. d.*	Log^{10} residency	*s. d.*
2001–02 (baseline)	9.7	13.7	0.65	0.56
2009–11	23.0	18.2	1.24	0.34
2013–14	18.9	31.7	0.73	0.78
2014–15	9.1	12.3	0.50	0.87
2015–16	10.8	11.4	0.36	1.32

Cage-diving industry activities

Operator e-logbook data continued to be an important tool for monitoring the seasonal patterns of visits by white sharks, and cage-diving industry activities at the Neptune Islands during operator days. Data describing bait consumption and berley use can inform discussions regarding interaction levels, and inputs to the marine park during the ongoing refinement of management strategies for the industry. Summaries of e-logbook data showed the cage-diving industry reported using 11.36 kilo-litres of berley and ~11.6 t of SBT gills and entrails, which

was a reduction compared to during the previous year (*c.f.* 12.1 kilo-litres and 23.5 t). During 2015–16 (from August), a total of 1096 (68%) baits deployed by operators were consumed by sharks, which suggests training of bait-handlers and improvements to on-board infrastructure (e.g. gantry height to increase bait-handler and observer vision) needs to be considered to minimise interaction levels and provisioning of baits.

Peaks in mean daily sightings occurred in July, December and May, and lowest daily sightings occurred in September, February, and March, with the seasonal timing of the low period in late summer-autumn being consistent with the previous year (Rogers and Huveneers 2016). Reported daily sightings provided by operators had a mean of four white sharks per day across all months, which is consistent with the long-term trends in the island group (Bruce and Bradford 2015). However, there were >15 days when 10–19 different white sharks were observed by cage-diving operators, which is high compared to other cage-diving sites and may have individual social and behavioural impacts, as well as drive periodic ecological change within the marine park, such as predation on resident pinnipeds.

Conclusions

Whilst there are several implicit challenges in monitoring the fidelity behavior of this highly migratory marine species in offshore environments, mean residency continues to be the most suitable indicator of long-term behavioural patterns of white sharks that interact with the cage-diving industry in the Neptune Islands Group Marine Park. Residency increased marginally at the North Neptune Islands, and declined at the South Neptune Islands in 2015–16 when compared to the previous monitoring period. Variability between-individuals was considerable, which supports use of adaptive management approaches outlined by Smith and Page (2015). SARDI is currently examining acoustic telemetry data for tagged white sharks at sites where no cage-diving occurs, including other offshore island pinniped colonies, deep-water migration pathways and areas used by other marine industries.

The need to mitigate impacts on the behavior of white sharks that interact with the cage-diving industry is included within objectives of the Australian Commonwealth Government recovery plan for this listed and protected species. In support of specific objectives of the recovery plan (5.1 and 5.2), SARDI, DEWNR and industry took steps to refine the Code of Practice, and improve the e-logbook to allow improved resolution of interaction levels during 2015–16.

REFERENCES

Bruce, B.D., Stevens, J.D., Malcolm, H. 2006. Movements and swimming behaviour of white sharks (*Carcharodon carcharias*) in Australian waters. *Marine Biology* 150, 161–172.

Bruce, B.D., Bradford, R.W. 2011. The effects of berleying on the distribution and behaviour of white sharks, *Carcharodon carcharias*, at the Neptune Islands, South Australia. Final Report to the Department of Environment and Natural Resources, South Australia, 50 pp.

Bruce, B.D., Bradford, R.W. 2013. The effects of shark cage-diving operations on the behavior and movements of white sharks, *Carcharodon carcharias*, at the Neptune Islands, South Australia. *Marine Biology* 160, 889–907.

Bruce, B., Bradford, R. 2015. Segregation or aggregation? Sex-specific patterns in the seasonal occurrence of white sharks *Carcharodon carcharias* at the Neptune Islands, South Australia. *Journal of Fish Biology* 87, 1355–1370.

Bruce, B.D. 2015. A review of cage diving impacts on white shark behavior and recommendations for research and the industry's management in New Zealand. CSIRO (Hobart Tasmania). Report to the Department of Conservation *Te Papa Atawhai*. 27 pp.

Department of the Environment 2013. Recovery Plan for the White Shark *(Carcharodon carcharias)*. *www.environment.gov.au/resource/recovery-plan-white-shark-carcharodon-carcharias*

National Parks 2016. www.environment.sa.gov.au/marine parks

Pincock, D.G. 2011. False detections: what they are and how to remove them from detection data. DOC-004691 Version 02, April 13, 2011.

Rogers, P.J., Huveneers, C, Beckmann, C. 2014. Monitoring residency of white sharks, *Carcharodon carcharias* in relation to the cage-diving industry in the Neptune Islands Group Marine Park. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2014/000801-1. SARDI Research Report Series No. 818. 75pp.

Rogers, P.J., Huveneers, C. 2016. Residency and photographic identification of white sharks *Carcharodon carcharias* in the Neptune Islands Group Marine Park between 2013 and 2015. Report to Department of Environment, Water and Natural Resources. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2015/000825-1. SARDI Research Report Series No. 893. 108pp.

Smith, J.K. Page, B. 2015. Decision Points for White Shark Tourism Policy, DEWNR Technical Note 2015/09, Government of South Australia, through the Department of Environment, Water and Natural Resources, Adelaide. 12 pp.

Shaughnessy, P.D., Goldsworthy, S.D., and Mackay, A.I. (2014). Status and trends in abundance of New Zealand fur seal populations in South Australia. Final report to the Australian Marine Mammal Centre. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2014.000338-1. SARDI Report Series No. 781. 33 pp.