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Residency of white sharks *Carcharodon carcharias* in the Neptune Islands Group Marine Park during 2015–16

Rogers, P. J.

SARDI Publication No. F2015/000825-2
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SARDI Aquatics Sciences
PO Box 120 Henley Beach SA5 022

March 2017

Report to Department of Environment, Water and Natural Resources

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

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

SOUTH AUSTRALIA

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SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

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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 Ac*t (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.

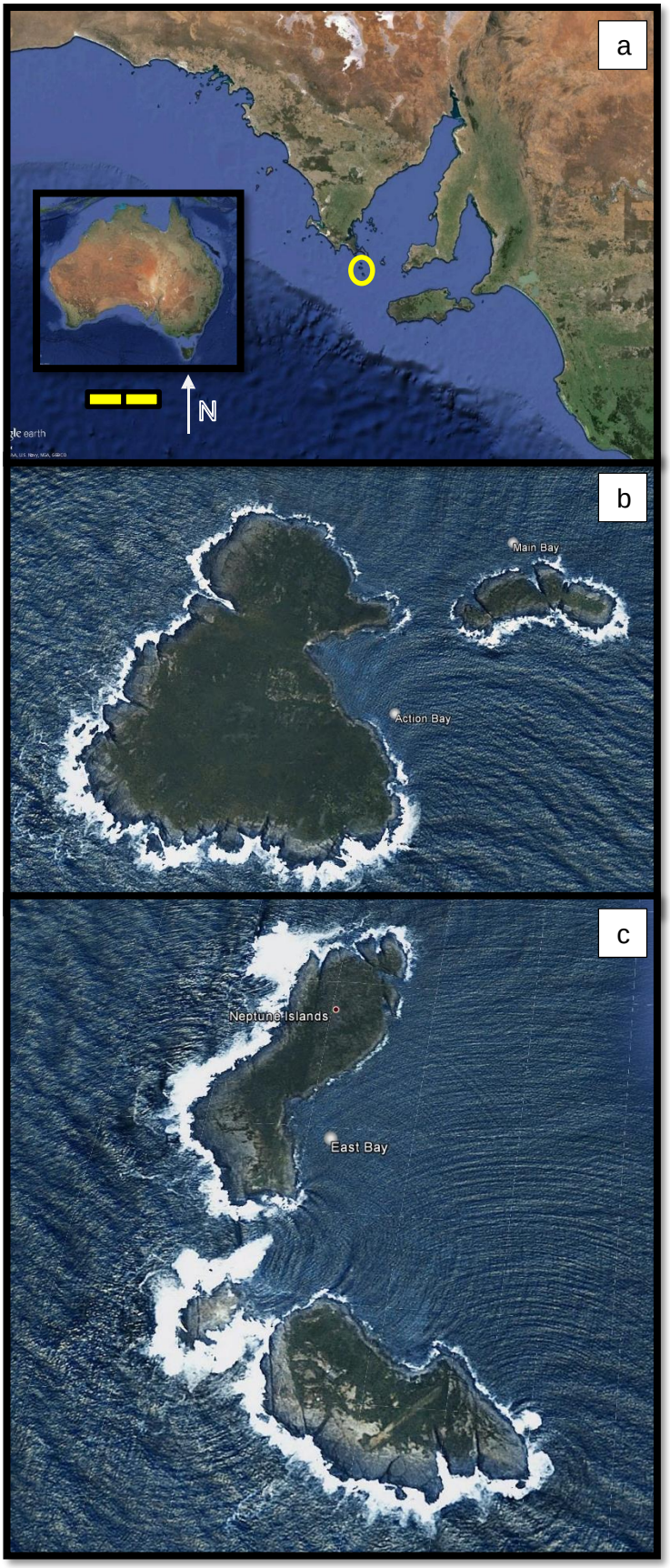

Figure 1. (a) Location of the study site (yellow ellipse) in the Neptune Islands Group Marine Park in shelf waters of South Australia and (b) acoustic receivers deployed at the North and (c) South Neptune Islands. Scale bar (a) = 100 km. Source: Google Earth Pro, 2016.

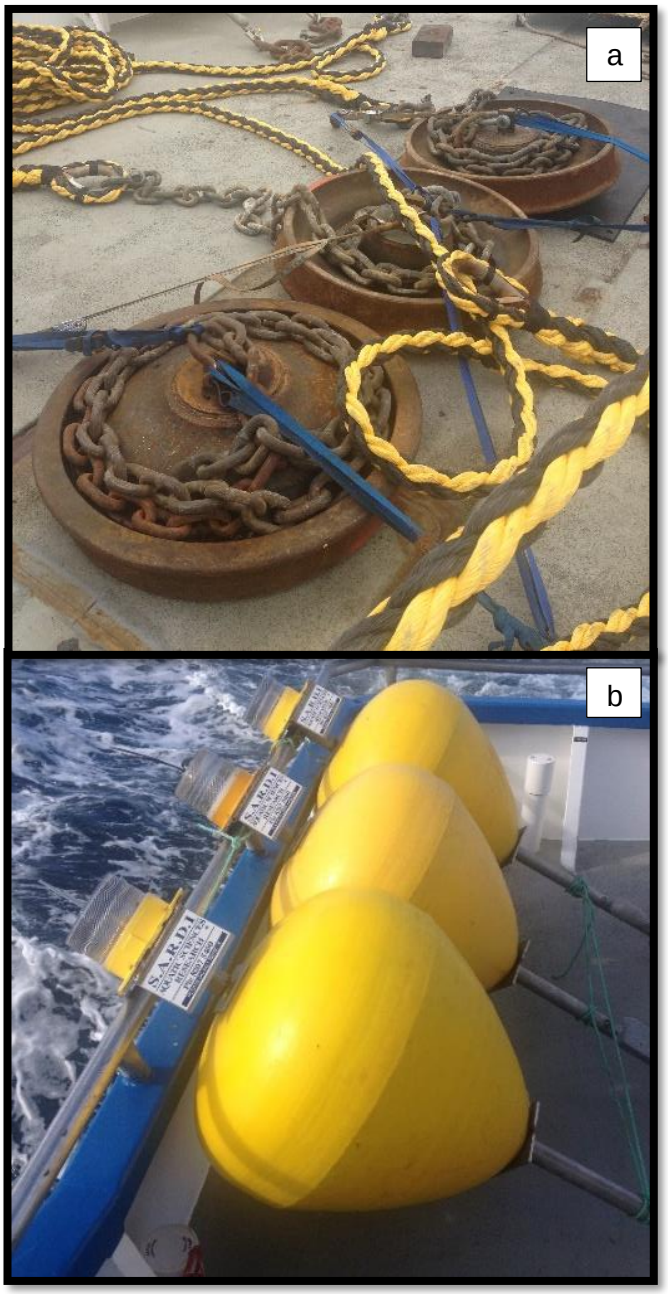

Figure 2. Mooring configurations (a) and navigation marker buoys (b) used to anchor the acoustic receivers in the Neptune Islands Group during 2015–16.

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.

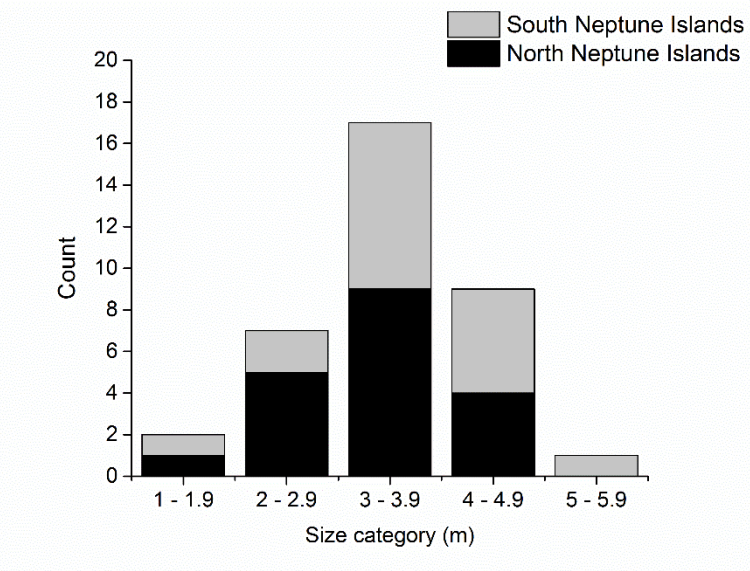

Figure 3. Size categories of white sharks for which residency was estimated at the North and South Neptune Islands.

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).

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

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.

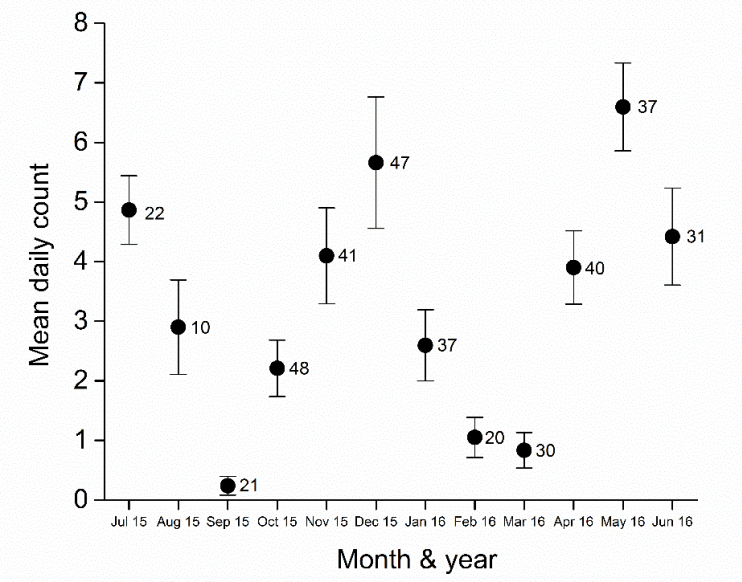

Figure 4. Mean daily sightings of white sharks in the Neptune Islands Group Marine Park in 2015–16. Error bars represent 95% confidence intervals for mean daily count data. Numbers next to each point show the sample size of reported sightings during each month.

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.

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.

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