Residency of white sharks, *Carcharodon carcharias*, at the Neptune Islands Group Marine Park (2018–19)

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Photo: Andrew Fox

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5. EXECUTIVE SUMMARY

- This report provides updated estimates of residency of tagged white sharks (*Carcharodon carcharias*) and a summary of electronic logbook data describing cage-diving activities at the Neptune Islands Group (Ron and Valerie Taylor) Marine Park between 1 July 2018 and 30 June 2019.

- Sixteen sharks ranging 2.6–4.2 m total length (TL) were tagged at the Neptune Islands Group Marine Park between 1 July 2018 and 30 June 2019. The target of tagging 20 sharks could not be achieved due to prolonged periods of low white shark abundance (112 days with 0–1 shark sighted).

- Grand mean residency from the 28 sharks detected within the 2018–19 monitoring period at the North and South Neptune Islands was 6.84 ± 15.69 days (median = 2.74) and 5.82 ± 5.12 days (median = 4.51), respectively. The $\log^{10}$ of the grand mean residency at North Neptune Islands was 0.40 ± 0.62 and is within the Target range (≤ 0.7).

- E-logbook recorded 568 entries between 1 July 2018 to 30 June 2019 for 272 days of operations at the Neptune Islands Group. Reported daily sightings ranged 0–7 white sharks (mean ± standard error = 2.0 ± 0.2), while no white sharks were sighted on 72 days (26.5% of the days at the Neptune Islands). This represents an increase in the number of days when no white sharks were sighted compared to the 2017–18 and more than doubled compared to 2016–17 (26.5 *vs.* 21.5 *vs*. 11.5% respectively).

6. INTRODUCTION

The white shark (*Carcharodon carcharias*) occurs world-wide in coastal temperate and subtropical regions (Klimley and Ainley 1996, Domeier 2012). White sharks are long-lived, relatively slow growing, late in maturing, and low in reproductive potential (Cailliet et al. 1985, Wintner and Cliff 1999). This combination of life history traits, and world-wide concerns regarding their population status, has prompted their protection across a number of jurisdictions. This includes listings under the International Union for the Conservation of Nature (IUCN – 'Vulnerable'), the Convention on International Trade in Endangered Species (CITES – Appendix I + II), and the Convention on Migratory Species (CMS – Appendix I + II), of which Australia is a signatory country. White sharks are listed as 'Vulnerable' under the Australian Commonwealth Government's *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* and are protected in all Australian and Commonwealth waters. However, as identified by the *National Recovery Plan for White Sharks*, the Australian white shark population is still threatened by interactions with commercial and recreational fishing, shark control activities, illegal trade in body parts, and the potential impacts of ecotourism and cage-diving operations (DEWHA 2010). Sites where white sharks aggregate can be targeted by wildlife tourism operators where industries have developed around cage-diving activities. These sites are also areas where white sharks can be exposed to a large amount of interactions and interference from human activities.

In Australia, the white-shark cage-diving industry began in the late 1970s in waters off the Eyre Peninsula in South Australia. The industry is now restricted in operations to the Neptune Islands Marine Park located 60–70 km south of Port Lincoln (Fig. 1), with most cage-diving activities focussed at the North Neptune Islands group. The locality is the only place where cage-diving with white sharks is permitted in Australia. After 2007, the industry expanded from two to three operators and the mean annual number of days when tours operated rose from 124 (2000–2006) to 265 (2008–2011) (Bruce and Bradford 2013). Studies showed that the residency of white sharks at the Neptune Islands changed between these periods and that the spatio-temporal distribution of white sharks is affected by the cage-diving industry (Bruce and Bradford 2013, Huveneers et al. 2013). As a result, DEWNR developed and implemented a new policy to improve management of white shark tourism at the site. The policy limits the number of commercial tour operator licences to three and number of days of tourism activity to five days per week. The policy also sets a framework for the adaptive management of the cage-diving industry and decision ranges when changes in licensing arrangements should be considered. Since 2013–14, the effects of the cage-diving industry on white sharks has been monitored annually using estimates of residency as

defined in Bruce and Bradford (2013) and compared to the decision ranges set in Annexure A to the South Australian White Shark Tour Licensing Policy.

The aim of this report is to provide residency estimates of white sharks at the Neptune Islands (Ron and Valerie Taylor) Marine Park for 2018–19 and compare them to previous years and to decision ranges set in Annexure A to the South Australian White Shark Tour Licensing Policy. This report also summarises cage-diving activities and number of sharks sighted reported via a daily electronic logbook to put residency estimates in context of cage-diving activities.

7. METHODS

7.1 Geographical area

The Neptune Islands Group (Ron and Valerie Taylor) Marine Park (referred to as the Neptune Islands hereafter) is located near the approach to Spencer Gulf, ~30 nautical miles from Port Lincoln, South Australia and 14 nautical miles from the southern Australian mainland. This offshore island complex of limestone-capped granite mounds comprises the North and South Island groups, which are ~12 km apart (Figure 1). The Neptune Islands comprise a Sanctuary Zone (North Neptune Islands), Habitat Protection Zone (South Neptune Islands), and Restricted Access Zones (North and South Neptune Islands) (http://www.environment.sa.gov.au/marineparks/find-a-park/eyre-peninsula/neptune-islands). At the North Neptune Islands, cage-diving operators mostly anchor in the bay on the southeast side of the largest islands and on the northern side of the two islands. At the South Neptune Islands, operators mostly anchor on the eastern side of the northern island.

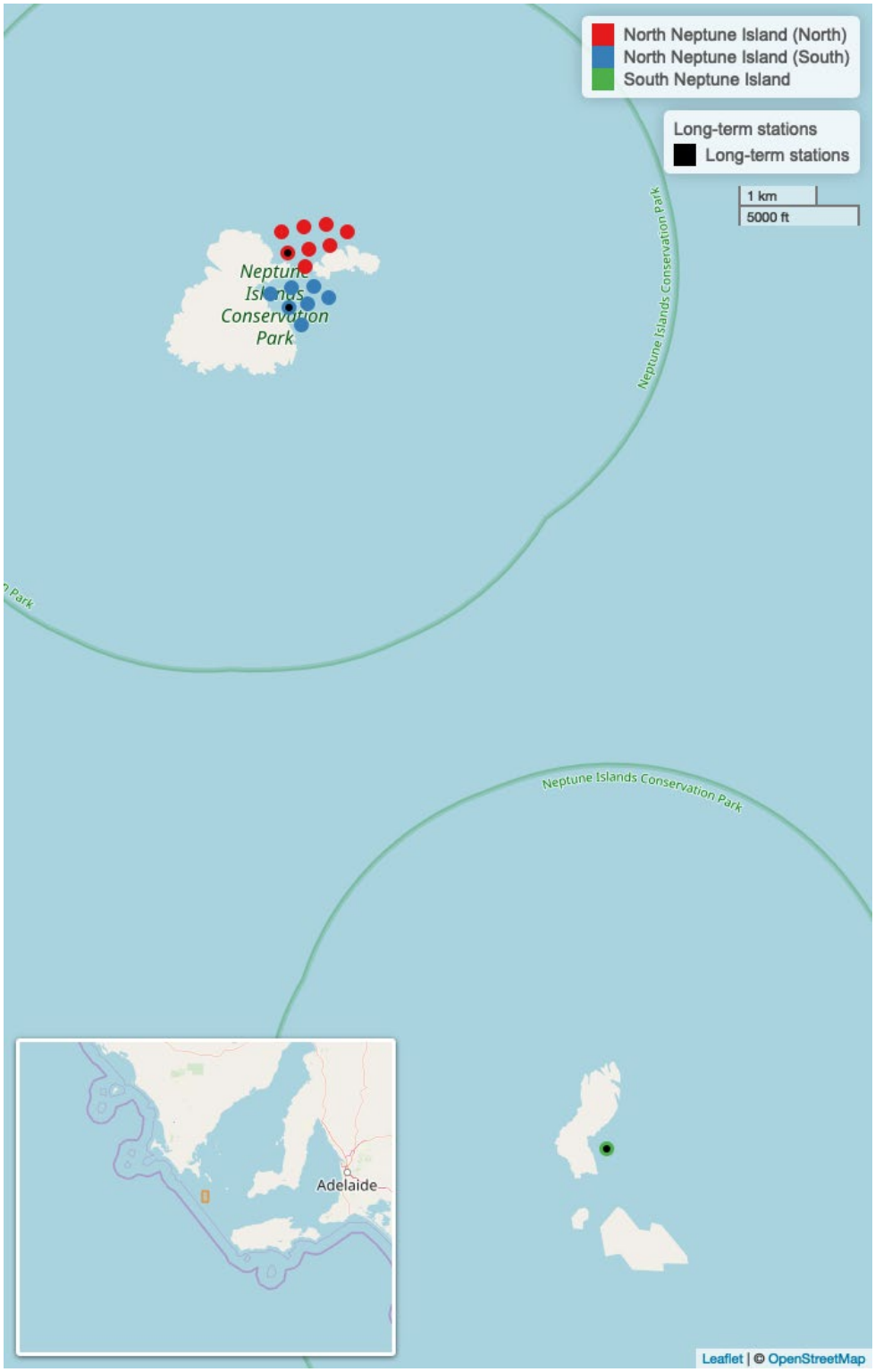

Figure 1. Map of the Neptune Islands Group (Ron and Valerie Taylor) Marine Park with deployment locations of acoustic receiver stations. Stations with a black point represent long-term stations that have been present since the start of the monitoring in 2013, with coloured positions denoting the fine-scale positioning system deployed in 2018.

7.2 Acoustic telemetry

7.2.1. Receiver deployments

Three VR2AR acoustic receivers (Vemco Ltd., Halifax, Canada) were deployed within the Neptune Islands using a low-profile sub-surface mooring system that reduces interactions with operators anchors and chains, and white sharks. One VR2AR was deployed at each of the main berleying sites at the North Neptune Islands group and one at the South Neptune Islands group and have been maintained at those locations since 2013 (Figure 1; black points). In 2018, a fine-scale positioning system (VPS Vemco Positioning System, Vemco Ltd., Halifax, Canada) consisting of an additional array of 13 VR2AR receivers were deployed, and expanded the acoustic coverage at the North Neptune Island (Figure 1; coloured points). The deployment of these receivers will provide opportunities to investigate the positioning of sharks at the Neptune Islands in relation to cage-diving vessels, e.g. are white sharks mostly using Action Bay or the Main Bay; does white shark preferred location vary in relation to cage-diving vessels?

7.2.2. Tag deployments

Sixteen white sharks were tagged in the 2018–19 financial year with V16-6H acoustic transmitters, adding to the 86 sharks tagged during the previous five years of monitoring periods (2013–2018). Acoustic transmitters programmed to send signals at random interval of 70–150 seconds (VEMCO Ltd., Halifax, Canada). Tags were tethered to a Domeier umbrella dart-tag head using a 10- to 15-cm-long stainless wire trace (1.6 mm diameter). Tags were implanted in the dorsal musculature of sharks using a modified spear-gun applicator. Biases in residency estimates can be introduced by targeting specific sharks (e.g., sharks likely to remain in the Neptune Islands) or due to temporal variations in residency (e.g., sharks are more likely to remain within Neptune Islands during weaning of New Zealand fur seals). To minimise the potential impacts of these biases, tags were opportunistically deployed throughout the monitoring period.

7.2.3. Detection summary and residency periods

Daily detection summaries were plotted to examine the pattern of overall presence of tagged sharks during the study period. 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 period was estimated for each tagged shark and for each North and South Neptune Island Groups.

The residency of white sharks is reported for the period between 1st July 2018 and 30th June 2019.

7.3 Electronic logbooks

Cage-diving operators used the Fulcrum™ application to record daily electronic logbook (e-logbook) entries. Development of the structure and fields in the e-logbook is descried in Rogers et al. (2014). No major changes to the fields in Fulcrum™ were made during the 2018–19 monitoring period. The e-logbook was used to collect data on daily activities and sighting frequency of white sharks between 1 July 2018 and 30 June 2019.

8. RESULTS

Sixteen white sharks ranging 2.6–4.2 m total length (TL) were tagged at North Neptune Island between 22 August 2018 and 16 June 2019. Table 1 provides a detection summary for sharks that were detected in the 2018–19 monitoring period. Twenty-eight white sharks were detected during the 2018–19 monitoring period. Thirteen sharks (46.4%) detected within the Neptune Islands in the 2018–19 monitoring period were tagged in previous years; five of which (17.9%) were tagged in the 2017–18 period, four (14.3%) from the 2016–17 period, three sharks (10.7%) from 2014–15, and a single shark (4%) tagged in the 2013-14 period (Figure 2). Shark 86, which was tagged outside of the Neptune Island group in August 2018 was not detected at any receiver stations. Two of the 28 sharks detected were tagged in Western Australia in August and November 2014.

A total of 29,505 acoustic detections was recorded from 28 sharks in the 2018–19 monitoring period (mean ± standard error = 1,054 ± 376). Tagged white sharks were detected for periods ranging between 1 and 83 days (Table 1).

Table 1. Detection summary of white sharks (n=28) between July 2018 and June 2019 acoustically tagged at the Neptune Islands Marine Park. TL = total length (m).

Shark	TL	Sex	Date tagged	Location tagged	North Neptune		South Neptune	
					N detections	N days detected	N detections	N days detected
3	4.5	Male	28/9/2013	North Neptune	27	5	*	*
20	3.0	Male	18/7/2014	North Neptune	8	4	*	*
62	3.0	Female	18/4/2017	North Neptune	1079	8	52	1
63	2.8	Female	18/4/2017	North Neptune	107	2	*	*
64	2.6	-	19/4/2017	North Neptune	716	10	248	8
65	3.7	-	19/4/2017	North Neptune	9616	83	*	*
71	3.9	-	18/10/2017	North Neptune	*	*	5	2
72	3.3	-	20/10/2017	North Neptune	4388	46	169	16
79	3.4	Male	8/1/2018	North Neptune	1015	17	187	14
81	2.8	Male	10/1/2018	North Neptune	318	3	*	*
83	3.2	Male	26/5/2018	North Neptune	689	9	124	4
85	3.8	Male	22/8/2018	North Neptune	50	2	*	*
86	4.2	Male	23/8/2018	South Australia	*	*	*	*
87	3.3	Male	14/10/2018	North Neptune	912	16	2766	20
88	3.7	Male	18/10/2018	North Neptune	172	5	1269	29
89	2.6	Male	20/10/2018	North Neptune	440	19	221	8
90	3.8	Male	11/12/2018	North Neptune	10	1	*	*
91	3.6	Male	18/12/2018	North Neptune	999	19	222	5
92	3.7	Male	19/12/2018	North Neptune	105	3	*	*
93	2.8	Male	20/12/2018	North Neptune	42	1	*	*
94	3.9	Male	20/12/2018	North Neptune	672	12	9	1
95	3.8	Male	7/4/2019	North Neptune	85	2	*	*
96	3.1	Male	7/5/2019	North Neptune	119	2	*	*
97	3.1	Male	16/5/2019	North Neptune	326	4	*	*
98	2.8	Male	16/5/2019	North Neptune	392	5	*	*
99	3.4	Male	24/5/2019	North Neptune	1339	7	*	*
100	3.2	Male	16/6/2019	North Neptune	283	4	*	*
101	3.6**	Female	7/11/2014	Western Australia	4	1	*	*
102	2.4**	Male	27/8/2014	Western Australia	320	7	*	*

* Indicates that shark was not detected during the report monitoring period (July 2018 – June 2019).

** Measurement from Western Australia are fork length

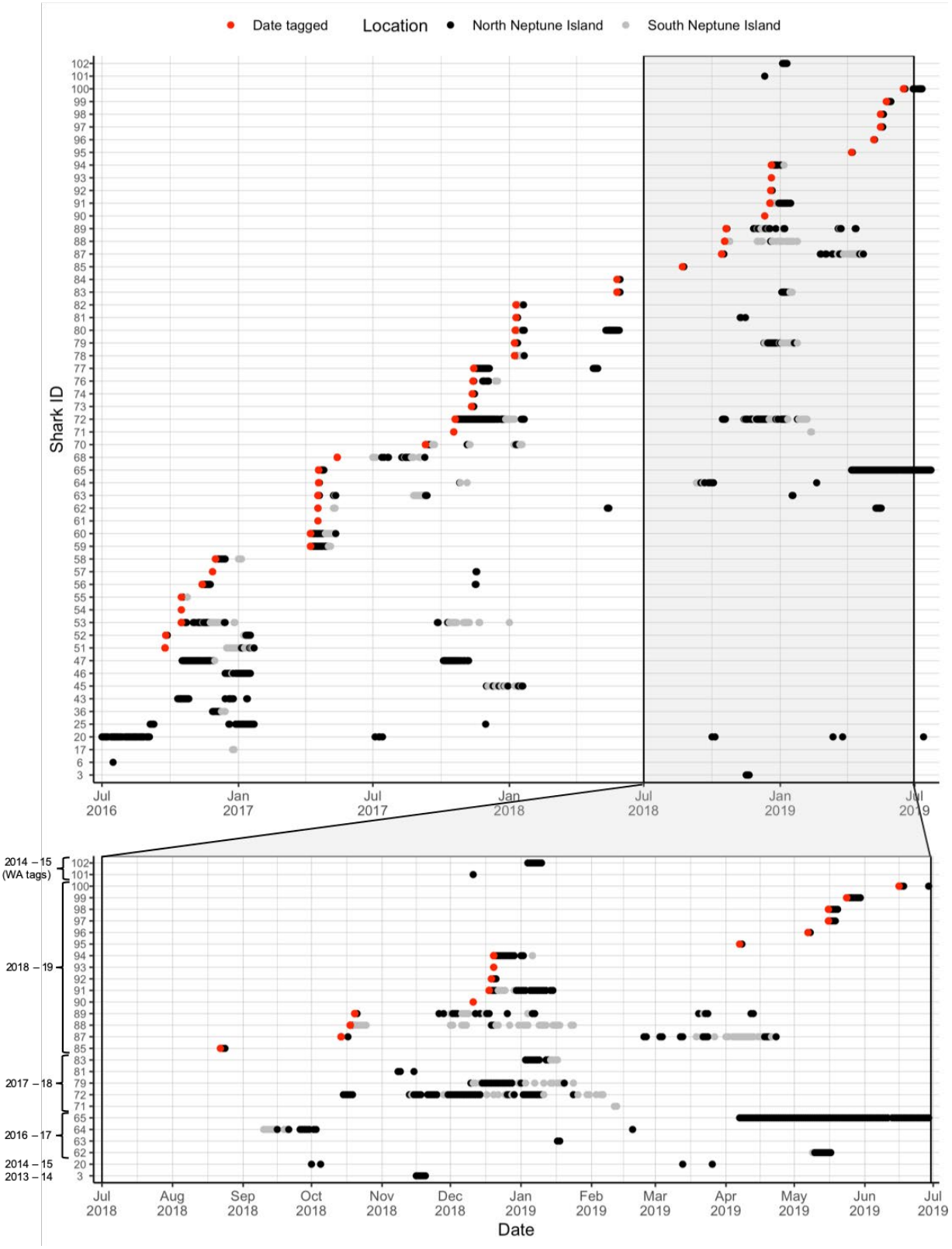

Figure 2. top panel: Daily detections for white sharks between 1 July 2016 – 30 July 2019 (n = 55) at the North (black symbols) and South (grey symbols) Neptune Islands. Red symbols represent dates when each shark was tagged. **Bottom panel:** Detection plot for white sharks detected at the Neptune Islands during the 2018-2019 financial year (n = 28). Numbers next to y-axis are monitoring years shark was tagged. Note: No detections were recorded from Shark 86 that was tagged in Oct 2018 outside the Neptune Islands Group.

8.1 Residency

Residency periods exhibited by white sharks at the North and South Neptune Islands combined ranged from 1 to 83 days (Table 2). All sharks that were detected in the 2018–19 monitoring period were tagged at North Neptune Islands, a single shark (Shark ID 86) was tagged outside the Neptune Island Group, however was not detected on the array within the Marine Park. Two additional sharks (Shark ID 101 and 102) originally tagged in Western Australia in 2014 were detected at the North Neptune Island in early 2019. The majority of detections were recorded at the North Neptune islands and the grand mean residency was 6.84 ± 15.69 days (grand median = 2.74). Most white sharks had a mean residency <5 days (69%), and only one individual resided at North Neptune Islands for >20 days. Of the 28 sharks that were detected at North Neptune Islands, 11 were also detected at South Neptune Islands. Residency periods in these sharks were similar at South Neptune Islands, where the grand mean residency was 5.82 ± 5.12 days (grand median = 4.51). Four of the 11 sharks that were detected at both islands displayed longer residency periods at South than North Neptune Islands. For example, mean residency period of Shark 79 was 14 days at South Neptune Islands and 6 days at North Neptune Islands.

Long-term detection patterns across the six monitoring periods (2013 – 2019) show sharks had elevated rates of detection at North Neptune Islands between October and February, with low detection rates in March–April and between June and September (Figure 3). At the South Neptune Islands, however, detection patterns indicated an elevated visitation of sharks in May, July–August, and December–January, with comparatively lower detection rates in March–April and September–November (Figure 3).

Table 2. Summary statistics showing residency estimates (mean; N = number of visits) for white sharks (n =28) at the Neptune Islands Group between 1 July 2018 and 30 June 2019. SD = standard deviation. Summary statistics were not provided when a shark only had a single residency period.

ID	Sex	North Neptune Island						South Neptune Island					
		N	Mean	Log_{10} (mean)	SD	Min	Max	N	Mean	Log_{10} (mean)	SD	Min	Max
3	Male	1	4.1	0.62									
20	Male	3	1.4	0.13	2.34	0.00	4.05						
62	Female	1	7.2	0.86				1	0.50	-0.30			
63	Female	1	1.1	0.06									
64	-	3	3.7	0.57	3.30	0.01	6.33	1	9.68	0.99			
65	-	1	83.1	1.92									
71	-							1	1.4	0.15			
72	-	4	12.9	1.11	13.61	0.52	31.07	5	4.51	0.65	5.55	0.03	10.79
79	Male	3	5.8	0.77	10.01	0.01	17.40	2	13.92	1.14	14.34	3.78	24.06
81	Male	2	0.4	-0.45	0.33	0.12	0.59						
83	Male	1	9.7	0.99				1	3.43	0.53			
85	Male	1	0.8	-0.12									
86	Male												
87	Male	6	2.2	0.34	1.96	0.50	5.61	2	14.38	1.16	16.36	2.82	25.95
88	Male	2	2.7	0.42	3.25	0.36	4.95	5	7.08	0.85	5.07	0.22	14.26
89	Male	7	2.7	0.44	3.11	0.02	7.83	4	1.90	0.28	3.69	0.01	7.44
90	Male	1	0.1	-1.12									
91	Male	2	9.2	0.97	9.18	2.74	15.73	1	7.23	0.86			
92	Male	1	2.0	0.29									
93	Male	1	0.5	-0.29									
94	Male	1	13.4	1.13				1	0.01	-1.88			
95	Male	1	1.1	0.02									
96	Male	1	1.2	0.07									
97	Male	1	3.2	0.51									
98	Male	1	3.6	0.56									
99	Male	1	5.7	0.76									
100	Male	2	1.3	0.11	1.12	0.49	2.07						
101	Female	1	0.3	-0.51									
102	Male	1	5.3	0.72									
Grand Mean			**6.84**	**0.40**					**5.82**	**0.40**			
Grand Median			**2.74**	**0.44**					**4.51**	**0.65**			
Grand SD			**15.69**	**0.62**					**5.12**	**0.88**			

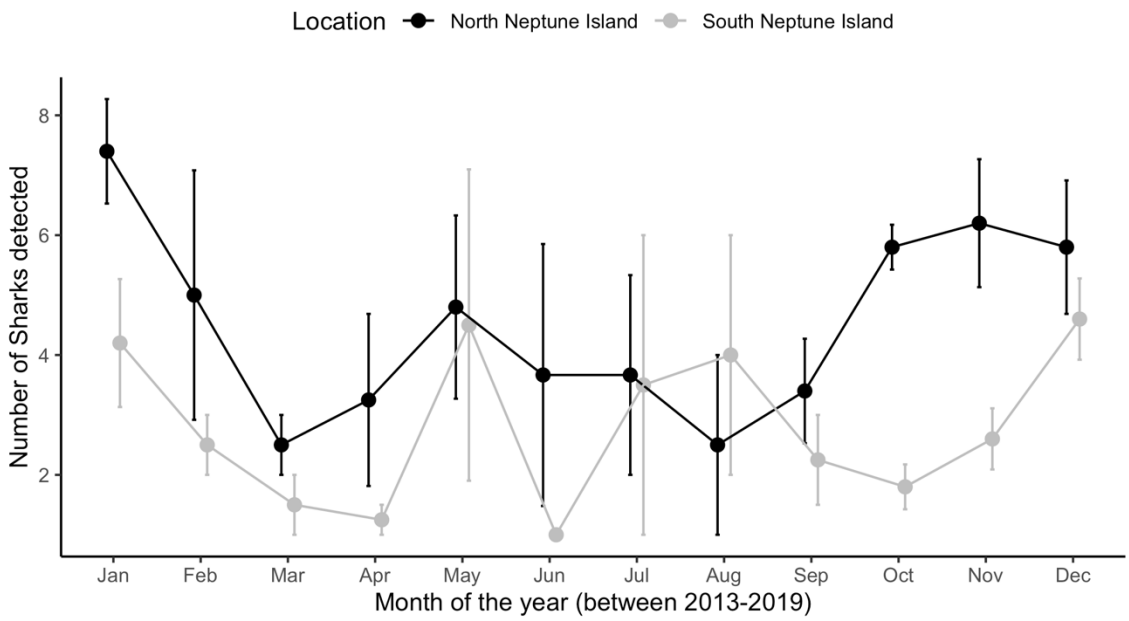

Figure 3. Seasonal pattern in shark detections between North and South Neptune Islands across the full monitoring period between 2013–2019. Points represent mean numbers of sharks detected per calendar month at North (black) and South Neptune Islands (grey), with bars representing standard error of the mean across six years.

8.2 Electronic logbook

Number of sharks sighted

E-logbook describing cage-diving industry activities comprised 568 records between 1 July 2018 to 30 June 2019. These records provided information about operator activities and shark numbers for 272 days out of the 364 days (74.7%). Reported daily sightings ranged 0–7 white sharks (mean ± standard error = 2.0 ± 0.1; Figure 4). No or only one white sharks were sighted on 72 and 40 days respectively (26.5 and 14.7% of the days at the Neptune Islands respectively). The number of sharks sighted peaked between April and May, with low numbers sighted in February–March, July–August, and November. Most of the shark sighted throughout the year were males with peaks in between September–January and April–June, while females were mostly sighted in April and May (Figure 4).

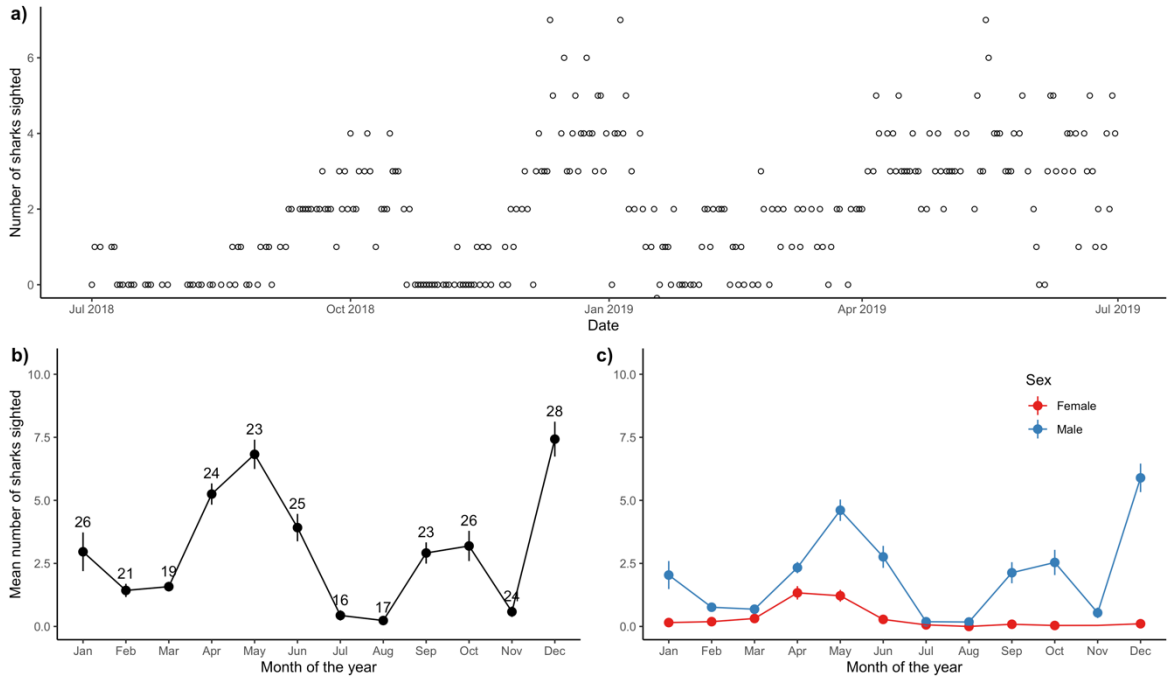

Figure 4. (a) Number of sharks sighted reported by the cage-diving operators through the Fulcrum^{TM} e-logbook in the 2018-19 financial year. **(b)** Mean daily number of sharks sighted at each calendar month and **(c)** separated by sex. Error bars represents standard error of the mean values. Number above to each point in plot b shows the number of days operators conducted diving activities at the Neptune Islands each month.

9. DISCUSSION

9.1 Residency

In 2001–02, prior to the cage-diving industry expanding, the grand mean residency of white sharks at North Neptune Islands was 9.7 ± 13.7 days (Bruce et al. 2005; Fig 5). Based on this study, Annexure A to the South Australian White Shark Tour Licensing Policy was developed which includes decision ranges for the cage-diving industry:

- Target range: ≤0 70 log^{10} days
- Caution range: 0.70–1.20 log^{10} days
- Response range: ≥1.20 log^{10} days

Prior to the new policy and limits on number of days operators are allowed at the Neptune Islands (2009–2011), residency and log^{10} increase to well-above the target range and within the response range. In the first year of the monitoring period (2013–14), residency and log^{10} decreased but was still within the caution range. Since then, residency and log^{10} has decreased further and has remained within the Target range (Fig. 5; Table 3).

In 2018–19, the grand mean residency of white sharks at North Neptune Islands was 6.84 days (log_{10} = 0.40) and is within the Target range.

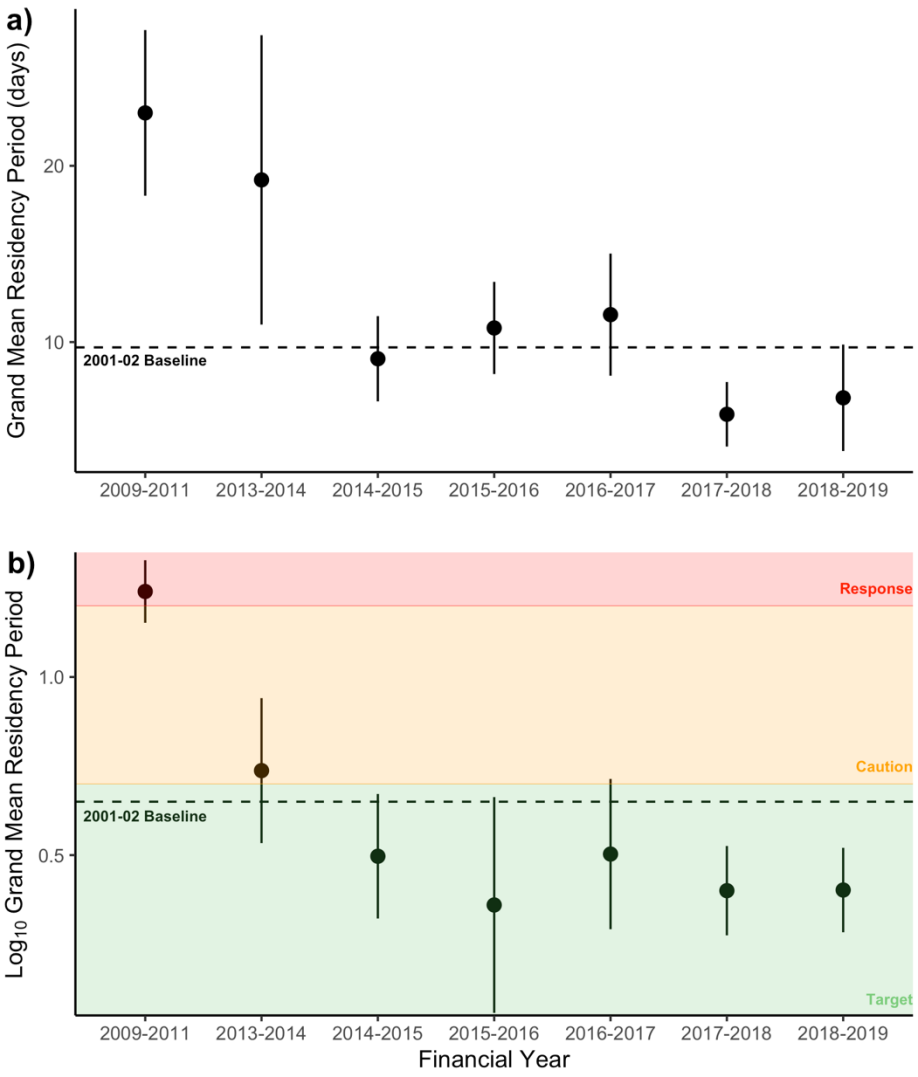

Figure 5. Change in **(a)** grand mean residency, and **(b)** $\log^{10}$ of grand mean residency of acoustically monitored white sharks at North Neptune Islands, across the seven monitoring periods. Horizontal broken lines in plots represent the baseline values of grand mean residency and $\log^{10}$ transformed value calculated by Bruce et al. (2005) in 2001–2002. Shaded areas in panel **(b)** represent decision ranges developed for the cage-diving industry and described in Annexure A to the South Australian White Shark Tour Licensing Policy.

Table 3. Estimates of overall mean log^{10} residency of white sharks detected at North Neptune Islands between 2001 and 2019.

Period	Grand mean residency (days)	SD	Log^{10} of residency	SD
2001-02 (baseline)	9.7	13.7	0.65	0.56
2009-2011	23.0	18.2	1.24	0.34
2013-2014	18.9	31.7	0.73	0.78
2014-2015	9.1	12.3	0.50	0.87
2015-2016	10.8	11.4	0.36	0.32
2016-2017	11.6	16.3	0.50	0.99
2017-2018	5.7	9.3	0.38	0.63
2018-2019	6.84	15.7	0.40	0.62

9.2 Cage-diving activities

The e-logbook is an important tool to record cage-diving activities and the number of white sharks frequenting the Neptune Islands Group. The e-logbook revealed that the proportion of days without any shark sighted marginally increased during this monitoring period compared to 2017–18 (26.5 *vs.* 21.5%) and more than doubled compared to 2016–17 (26.5 *vs.* 11.5%). Low abundance or lack of sharks occurred during similar months across monitoring periods, i.e. February–March and July–August, but the 2018–19 monitoring period also had low number of sharks in November leading to three periods of low shark abundance during 2018–19. The increased number and magnitude of days where sharks were not sighted led to the decrease in the average number of sharks sighted per day from 2.9 in the 2017-18 period to 2 in 2018-19 (Fig. 6).

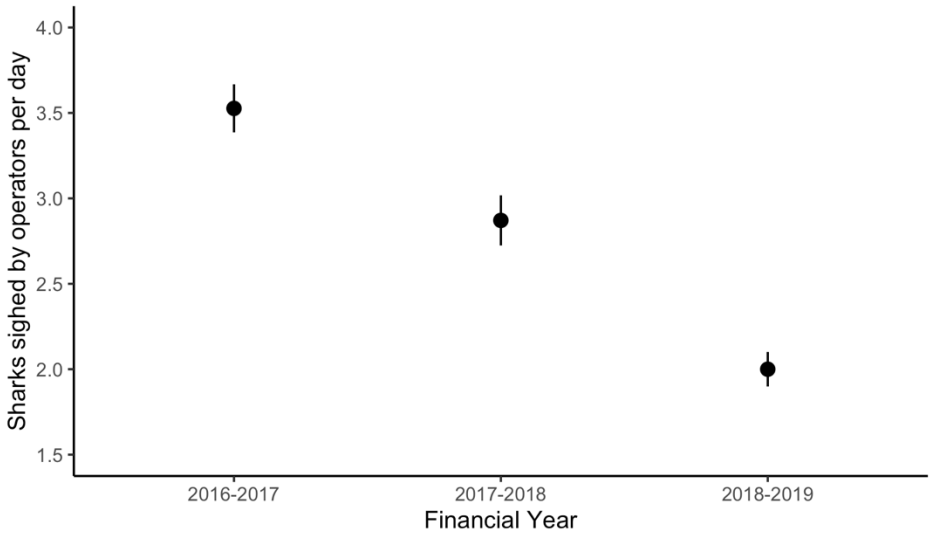

Figure 6. Trend in annual sighting rate recorded by operators using the e-logbook tool over the last three financial years (2016–2019).

10. CONCLUSION

The 2018–19 residency of white sharks at North Neptune Islands (log^{10} residence of 0.40) continues to be within the Target range for the fifth consecutive year. Individual variation, however, remains high with shark residency ranging from less than a day to 83 days. Residency estimates should, therefore, be interpreted with caution, especially when originating from a low number of individuals.

Number of sharks sighted were reported by cage-diving operators throughout the monitoring period as required and showed periods of consistently low shark abundance since 2014 (i.e. February–March). However, a large number of white sharks were previously sighted during some of these months, e.g. February 2013. Other months with previously high shark abundance have also had low shark numbers in this monitoring period, i.e. November. The inter-annual variability in shark abundance highlights the complexity of understanding what drives white sharks to visit and reside at the Neptune Islands Group. With the number of sharks sighted having been recorded on each operator days since 1999, we now have 20 years of daily shark sightings to assess the factors that might influence shark abundance at the Neptune Islands Group Marine Park. Such analysis will enable to better understand the processes affecting shark numbers at the Neptune Islands Group and will help predicting shark abundance, allowing cage-diving operators to plan their activities accordingly.

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