Residency of white sharks, *Carcharodon carcharias*, at the Neptune Islands Group Marine Park (2019–20)

C Huveneers[1] and V Udyawer[2]

[1] *College of Science and Engineering, Flinders University, Adelaide, South Australia*

[2] *Australian Institute of Marine Science, Darwin, Northern Territory*

Photo: Andrew Fox

SOUTHERN SHARK ECOLOGY GROUP

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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 2019 and 30 June 2020.

- Twenty-six sharks ranging 2.4–4.5 m total length (TL) were tagged at the Neptune Islands Group Marine Park between 1 July 2019 and 30 June 2020. All tagged animals from the 2019–20 financial, including nine individuals tagged in previous years were detected within the array. Three additional white sharks tagged in Western Australia were detected within the Neptune Islands array, one of which (ID 104) was tagged in the 2019–20 financial year.

- Grand mean residency from the 38 sharks detected within the 2019–20 monitoring period at the North and South Neptune Islands was 7.96 ± 9.26 days (median = 4.95) and 2.95 ± 3.23 days (median = 2.09), respectively. The $\log^{10}$ of the grand mean residency at North Neptune Islands was 0.46 ± 0.88 and is within the Target range (≤ 0.7).

- E-logbook recorded 433 entries between 1 July 2019 to 30 June 2020 for 222 days of operations at the Neptune Islands Group. Reported daily sightings ranged 0–6 white sharks (mean ± standard error = 2.2 ± 0.1), while no white sharks were sighted on 49 days (22.1% of the days at the Neptune Islands). This represents a marginal decrease in the number of days when no white sharks were sighted compared to the 2018–19 period.

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 2019–20 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.

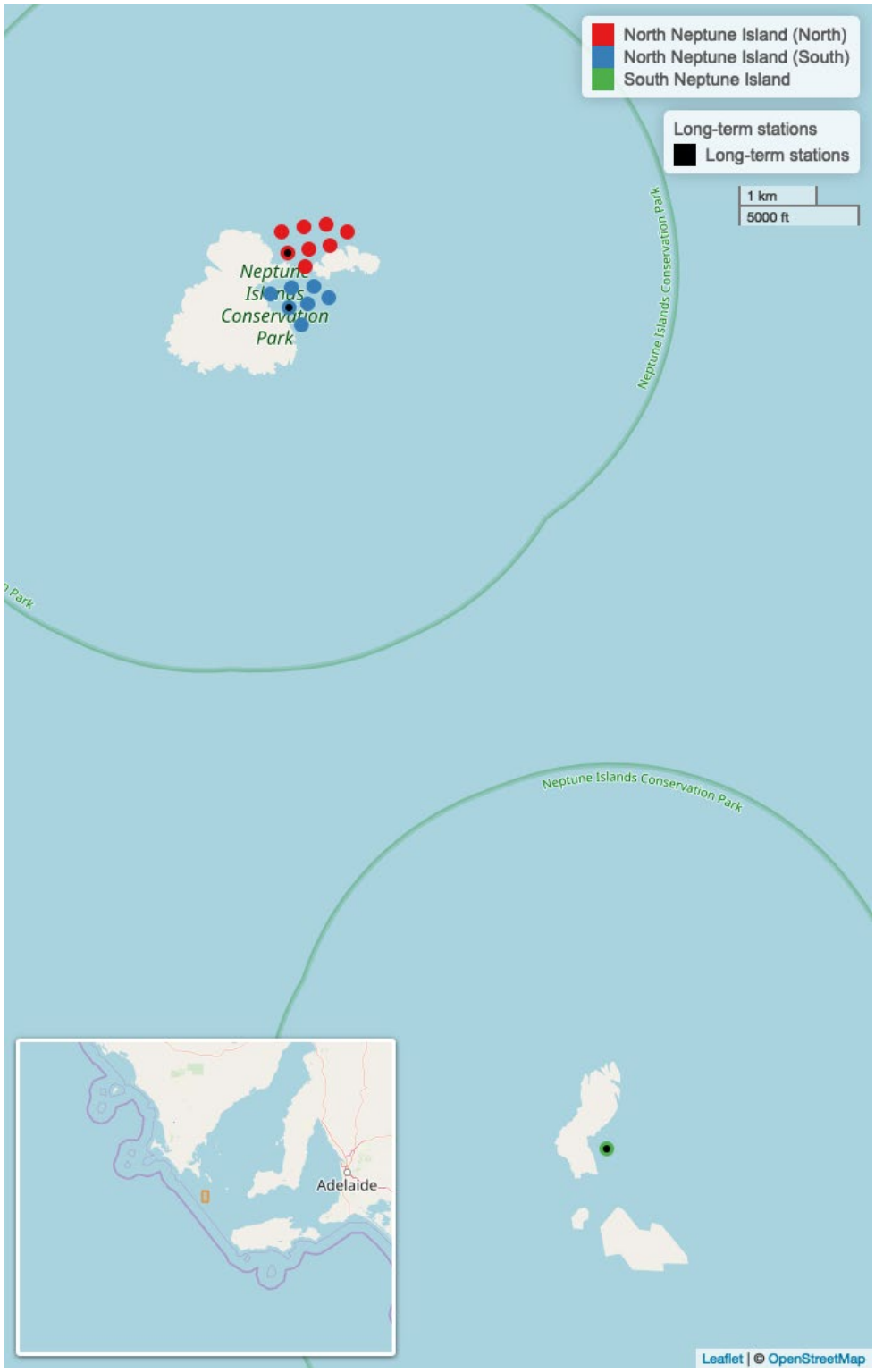

Figure 1. Map of the Neptune Islands Group (Ron and Valerie Taylor) Marine Park with deployment locations of acoustic receiver stations. Stations with a black point represent long-term stations that have been present since the start of the monitoring in 2013, with coloured positions denoting the fine-scale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

Twenty-six white sharks were tagged in the 2019–20 financial year with V16-6H acoustic transmitters, adding to the 102 sharks tagged during the previous six years of monitoring periods (2013–2019). In addition to the sharks tagged within the Neptune Islands, detections from three additional white sharks tagged in Western Australia were detected in the array, one of which (ID 104) was tagged in the 2019–20 financial year. 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 2019 and 30th June 2020.

7.3 Electronic logbooks

Cage-diving operators used the Fulcrum™ application to record daily electronic logbook (e-logbook) entries until 29/02/2020. From 01/03/2020, operators used a new custom-designed application developed to record operator activity (i.e. time of arrival at and departure from the Neptune Islands Group, quantity or type of attractant used, anchoring location), number of passengers, and number of shark sighted (with sex and estimated total length when known). The new application does not change the metrics collected by operators but provides a more streamlined and efficient way to record and report information. Data collected by operators since the new update is compatible with the older version. The e-logbook was used to collect data on daily activities and sighting frequency of white sharks between 1 July 2019 and 30 June 2020.

8. RESULTS

Twenty-six white sharks ranging 2.4–4.5 m total length (TL) were tagged at North Neptune Island between 14 August 2019 and 22 May 2020. Table 1 provides a detection summary for the thirty-eight white sharks that were detected at the Neptune Islands during the 2019–20 monitoring period. Nine sharks (23.6%) detected within the Neptune Islands in the 2019–20 monitoring period were tagged in previous years; six of which (15.8%) were tagged in the 2018–19 period, one shark (2.6%) from 2017–18, and two sharks (5.2%) tagged in the 2016–17 period (Figure 2). Three of the 38 sharks detected were tagged in Western Australia in August and November 2014, and August 2019.

A total of 42,115 acoustic detections was recorded from 38 sharks in the 2019–20 monitoring period (mean ± standard error = 1,108 ± 376 per shark). Tagged white sharks were detected for periods ranging between 1 and 140 days (Table 1).

Table 1. Detection summary of white sharks (n=28) between July 2019 and June 2020 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
59	2.8	Female	8/04/2017	NNI	319	12	101	5
65	3.7	-	19/04/2017	NNI	1592	23	*	*
83	3.2	Male	26/05/2018	NNI	11	1	*	*
89	2.6	Male	20/10/2018	SNI	*	*	123	5
93	2.8	Male	20/12/2018	NNI	499	6	*	*
95	3.8	Male	7/04/2019	NNI	665	32	21	2
98	2.8	Male	16/05/2019	NNI	901	18	*	*
99	3.4	Male	24/05/2019	NNI	8400	70	2166	32
100	3.2	Male	16/06/2019	NNI	252	8	*	*
101	2.42**	Male	27/08/2014	WA	6	1	1	1
103	3.41**	Female	6/10/2018	WA	2	1	*	*
104	2.78**	Male	20/08/2019	WA	100	6	11	2
105	2.9	-	16/06/2019	NNI	7110	60	*	*
106	3	Male	14/08/2019	NNI	3041	41	24	1
107	3.5	Male	26/08/2019	NNI	773	12	*	*
108	3.7	Female	16/10/2019	NNI	32	2	165	1
109	3.2	-	17/10/2019	NNI	122	3	*	*
110	3.7	Male	28/10/2019	NNI	451	12	*	*
111	3.2	Male	29/10/2019	NNI	106	5	*	*
112	2.8	Male	30/10/2019	NNI	7682	140	218	14
113	3.6	Male	28/10/2019	NNI	76	5	*	*
114	2.5	Male	2/11/2019	NNI	27	1	*	*
115	2.4	Male	23/11/2019	NNI	25	1	*	*
116	3.5	Male	23/11/2019	NNI	47	2	4	1
117	2.9	Female	12/02/2020	NNI	54	6	*	*
118	3	Male	12/02/2020	NNI	423	20	364	13
119	2.8	Male	12/02/2020	NNI	71	11	24	3
120	3	Male	14/02/2020	NNI	20	3	*	*
121	3.1	Female	26/03/2020	NNI	426	10	242	4
122	4.5	Female	26/03/2020	NNI	42	2	*	*
123	2.7	Female	11/04/2020	NNI	1337	29	42	4
124	4.5	Male	12/04/2020	NNI	421	12	51	5
125	2.85	Female	28/02/2014	NNI	168	4	*	*
126	3.7	Male	18/05/2020	NNI	35	2	*	*
127	2.65	Male	21/05/2020	SNI	*	*	328	8
128	2.8	Female	21/05/2020	NNI	174	6	308	4
129	4.1	Female	21/05/2020	NNI	564	5	822	9
130	3.8	Female	22/05/2020	NNI	1054	17	72	2

* Indicates that shark was not detected during the report monitoring period (July 2019 – June 2020).

** Measurement from Western Australia are fork length

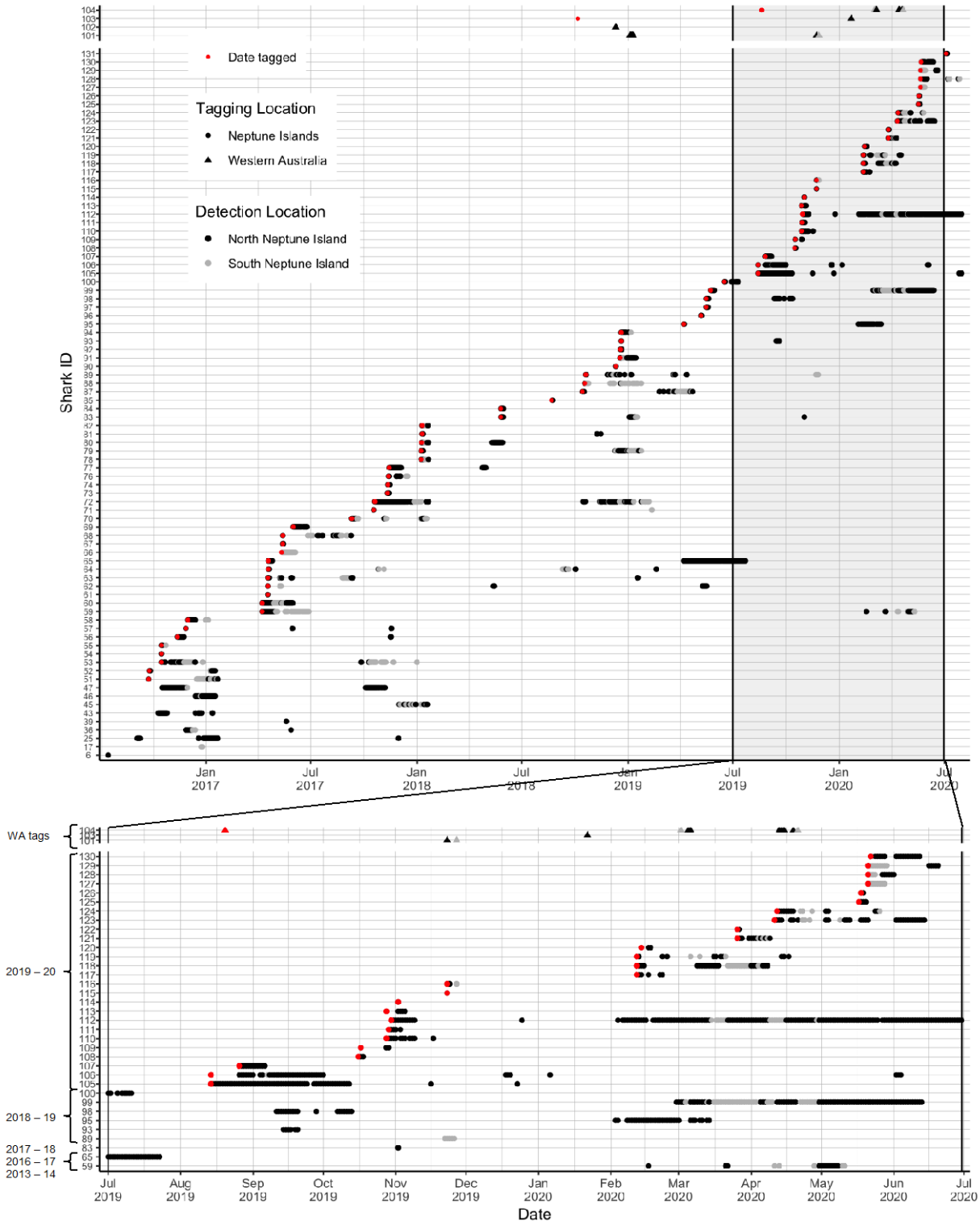

Figure 2. top panel: Daily detections for white sharks between 1 July 2016 – 30 July 2020 (n = 88) at the North (black symbols) and South (grey symbols) Neptune Islands. Red symbols represent dates when each shark was tagged. **Bottom panel:** Detection plot for white sharks detected at the Neptune Islands during the 2019–2020 financial year (n = 38). Numbers next to y-axis are monitoring years shark was tagged. Sharks tagged in WA are grouped at the top of both plots and are represented as triangles.

8.1 Residency

Residency periods exhibited by white sharks at the North and South Neptune Islands combined ranged from 1 to 76 days (Table 2). All but five sharks that were detected in the 2019–20 monitoring period were tagged at North Neptune Islands. Two of the five sharks tagged in the South Neptune Islands (Shark ID 89 and 127) were only detected at the South Neptune Islands in the 2019–20 monitoring period. Three additional sharks (Shark ID 101, 103 and 104) originally tagged in Western Australia in 2014 and 2019 were detected at the North Neptune Island, with Shark ID 101 and 104 also detected at the South Neptune Island during the 2019–20 monitoring period. Most detections were recorded at the North Neptune islands and the grand mean residency was 7.65 ± 9.3 days (grand median = 4.95). Most white sharks had a mean residency <10 days (66%), with two individuals resident at North Neptune Islands for >25 days. Of the 38 sharks that were detected at North Neptune Islands, 19 were also detected at South Neptune Islands, with two only detected there. Residency periods in these sharks were significantly lower at South Neptune Islands, where the grand mean residency was 2.95 ± 3.23 days (grand median = 2.09).

Long-term detection patterns across the seven monitoring periods (2013–2020) 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 =38) at the Neptune Islands Group between 1 July 2019 and 30 June 2020. 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
59	Female	3	3.10	0.49	4.65	0.00	8.45	3	1.03	0.01	0.97	0.01	1.94
65	-	1	22.86	1.36									
83	Male	1	0.03	-1.47									
89	Male							1	3.05	0.48			
93	Male	1	6.26	0.80									
95	Male	1	40.05	1.60				2	0.17	-0.76	0.12	0.09	0.25
98	Male	3	4.86	0.69	4.49	0.00	8.86						
99	Male	3	24.28	1.39	17.57	13.2	44.54	3	11.58	1.06	14.22	0.12	27.49
100	Male	1	10.62	1.03									
101	Male	1	0.15	-0.81				1	0.00	-5.00			
103	Female	1	0.00	-2.42									
104	Male	2	3.16	0.50	3.41	0.75	5.57	2	0.01	-2.28	0.00	0.00	0.01
105	-	3	20.09	1.30	33.85	0.28	59.19						
106	Male	5	8.11	0.91	15.37	0.00	35.54	1	0.56	-0.25			
107	Male	1	10.54	1.02									
108	Female	1	0.71	-0.15				1	0.37	-0.44			
109	-	2	0.59	-0.23	0.82	0.01	1.17						
110	Male	2	6.46	0.81	8.11	0.72	12.20						
111	Male	1	5.03	0.70									
112	Male	5	27.84	1.44	30.29	0.02	75.31	3	4.32	0.64	3.72	0.02	6.53
113	Male	1	7.97	0.90									
114	Male	1	0.18	-0.74									
115	Male	1	0.05	-1.27									
116	Male	1	1.14	0.06				1	0.01	-2.30			
117	Female	1	10.94	1.04									
118	Male	3	6.42	0.81	2.93	3.24	9.02	2	7.02	0.85	9.90	0.02	14.02
119	Male	4	2.67	0.43	1.21	1.02	3.85	2	2.09	0.32	2.95	0.01	4.18
120	Male	1	3.59	0.55									
121	Female	1	14.23	1.15				1	4.53	0.66			
122	Female	1	1.05	0.02									
123	Female	4	8.26	0.92	5.10	0.80	12.33	2	1.69	0.23	2.35	0.02	3.35
124	Male	3	3.19	0.50	3.29	1.21	6.98	2	2.84	0.45	3.33	0.49	5.19
125	Female	1	2.72	0.43									
126	Male	1	1.33	0.13									
127	Male							1	6.92	0.84			
128	Female	1	5.10	0.71				1	2.16	0.33			
129	Female	1	3.91	0.59				1	7.14	0.85			
130	Female	1	19.20	1.28				1	0.52	-0.28			
Grand Mean			**7.96**	**0.46**					**2.95**	**-0.24**			
Grand Median			**4.95**	**0.69**					**2.09**	**0.32**			
Grand SD			**9.26**	**0.88**					**3.23**	**1.49**			

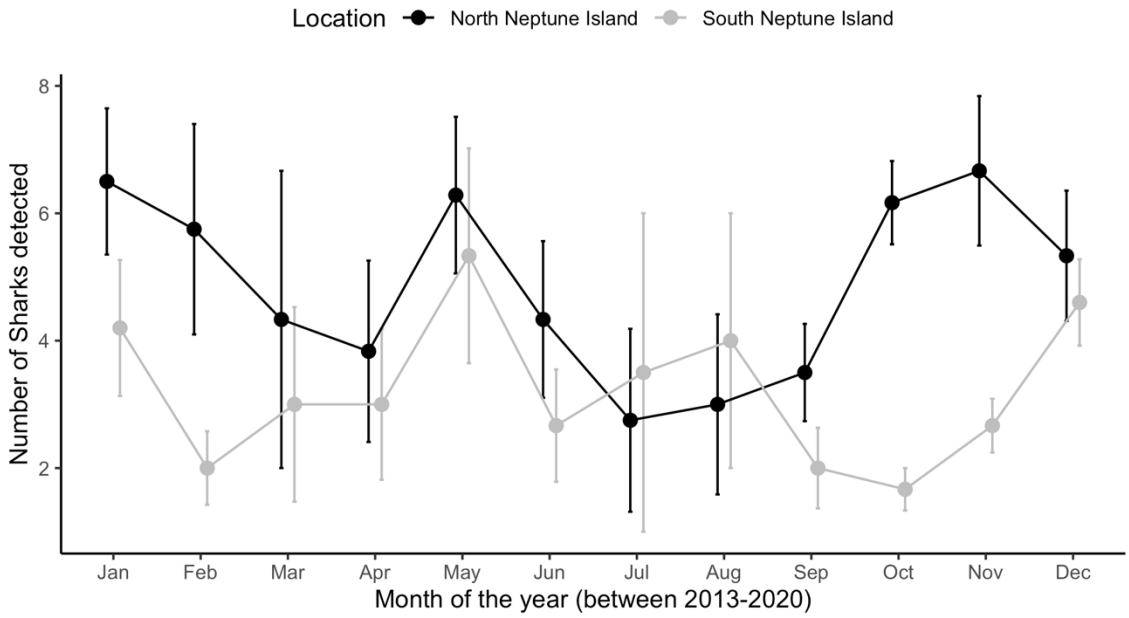

Figure 3. Seasonal pattern in shark detections between North and South Neptune Islands across the full monitoring period between 2013–2020. Points represent mean numbers of sharks detected per calendar month at North (black) and South Neptune Islands (grey), with bars representing standard error of the mean across seven years.

8.2 Electronic logbook

Number of sharks sighted

E-logbook describing cage-diving industry activities comprised 433 records between 1 July 2019 to 30 June 2020. These records provided information about operator activities and shark numbers for 222 days out of the 364 days (61%). Reported daily sightings ranged 0–6 white sharks (mean ± standard error = 2.2 ± 0.1; Figure 4). No or only one white shark was sighted on 49 and 33 days respectively (22.1 and 14.9% of the days at the Neptune Islands respectively). The number of sharks sighted peaked between September–October and in May–June, with low numbers sighted in July–August and between November–January. Most of the shark sighted throughout the year were males with peaks in between September–October and February, while females were mostly sighted in May and June (Figure 4). Operations were shut down between 24th March and 3rd May 2020 due to COVID-19 related lockdowns, reducing the total number of days of operation at the Neptune Islands by 50 days compared to the previous 2018–2019 financial year.

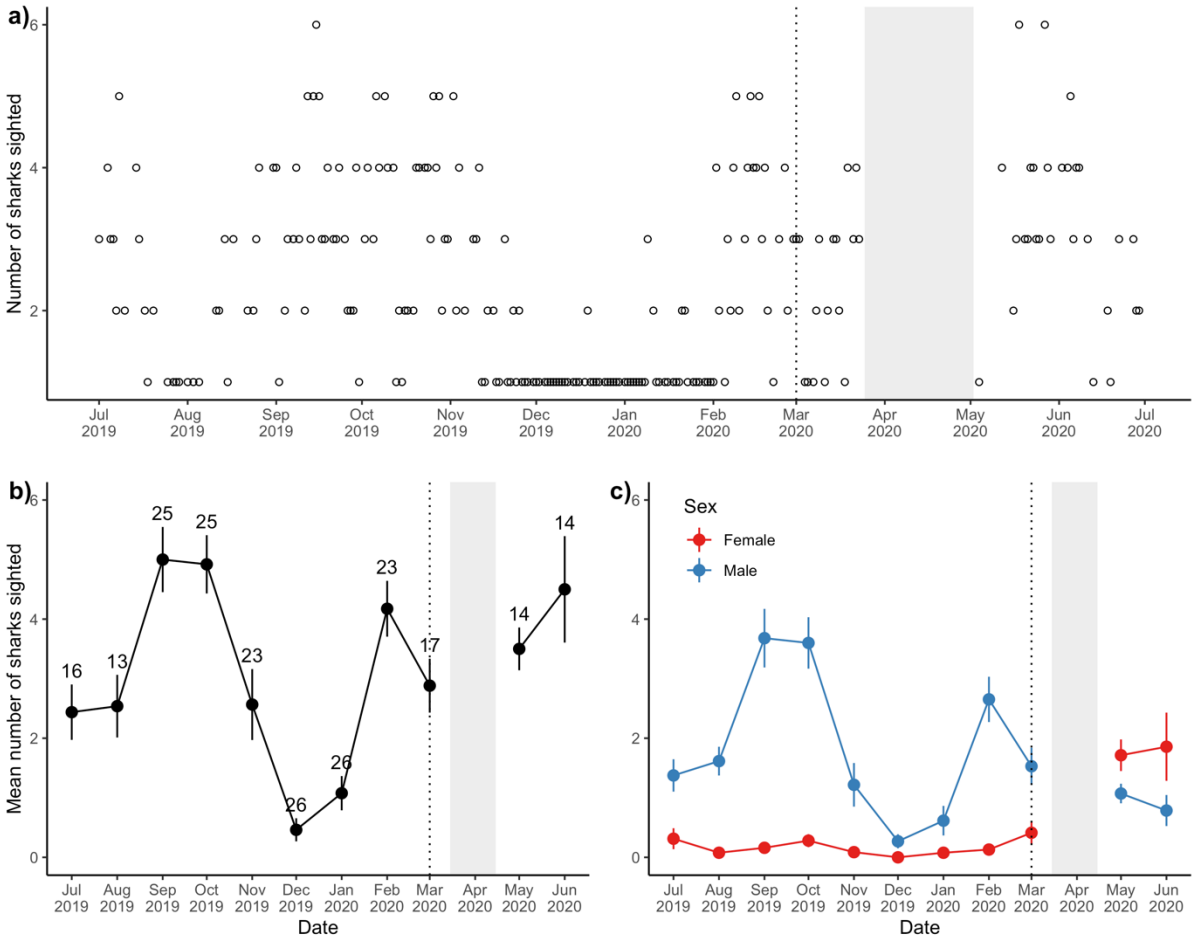

Figure 4. (a) Number of sharks sighted reported by the cage-diving operators through the e-logbook in the 2019–20 financial year. Broken line indicates the date from which log-book records were moved to a new format. Grey areas in plots indicate the period during COVID-19 related lockdown where no operations were conducted at Neptune Islands **(b)** Mean daily number of sharks sighted at each month and **(c)** separated by sex for the 2019–20 financial year. 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). Long-term trends since the 2015–16 financial year till present highlight a stabilisation of residency and $\log^{10}$ values to below 2001-02 baseline levels and within the Target range (Fig. 5).

In 2019–20, the grand mean residency of white sharks at North Neptune Islands was 7.96 days (log_{10} = 0.46) and is within the Target range.

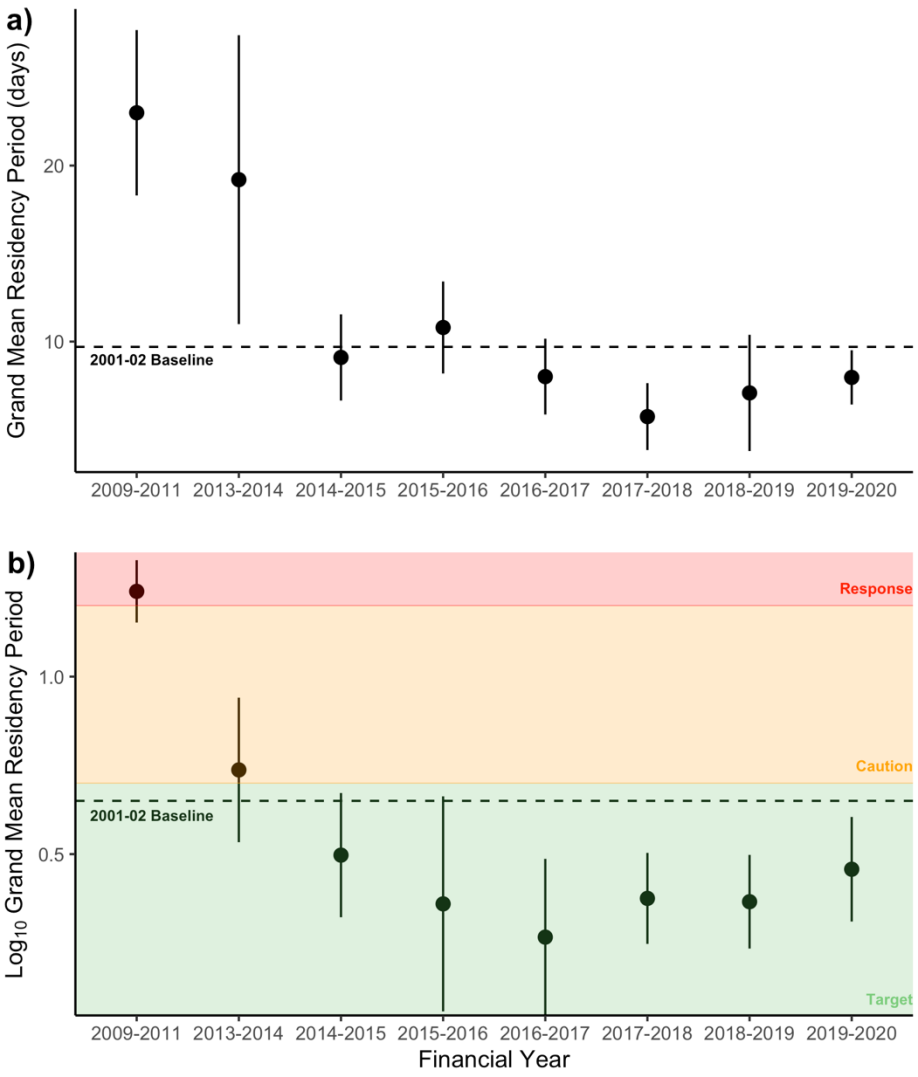

Figure 5. Change in **(a)** grand mean residency, and **(b)** $\log^{10}$ of grand mean residency of acoustically monitored white sharks at North Neptune Islands, across the eight monitoring periods. Horizontal broken lines in plots represent the baseline values of grand mean residency and $\log^{10}$ 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 2020. Slight discrepancies with previous reports are due to annual reassessment of potentially shed tag.

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	8.01	11.0	0.27	1.12
2017–2018	5.7	9.3	0.38	0.63
2018–2019	7.08	16.5	0.37	0.66
2019–2020	7.96	9.26	0.46	0.88

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 decreased during this monitoring period compared to the previous 2018–19 period (22.1 *vs.* 26.5%). Low abundance or lack of sharks occurred during similar months across monitoring periods, i.e. July–August, but the 2019–20 monitoring period also had low number of sharks between November and January. The decreased number of days where sharks were not sighted led to a marginal increase in the average number of sharks sighted per day from 2 in the 2018–19 period to 2.2 in 2019–20 (Fig. 6).

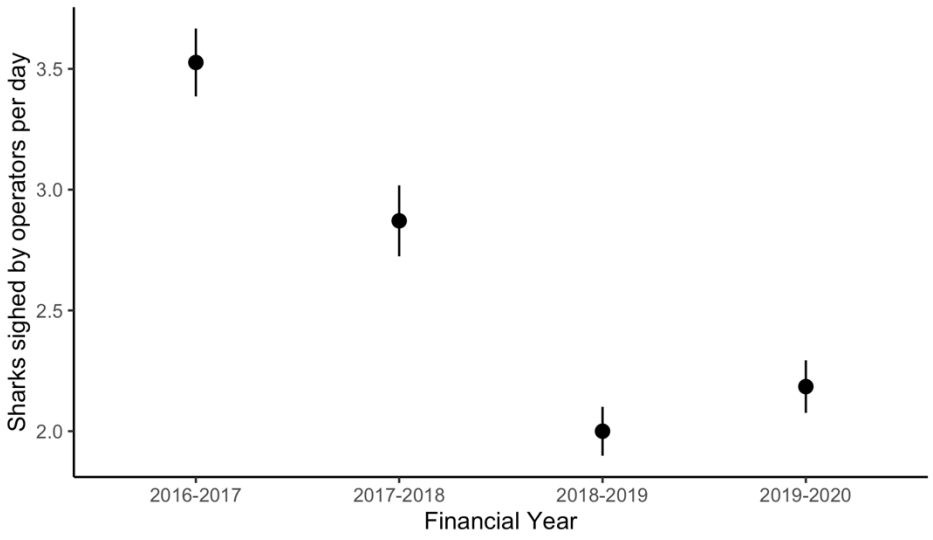

Figure 6. Trend in annual sighting rate recorded by operators using the e-logbook tool over the last three financial years (2016–2020).

10. CONCLUSION

The 2019–20 residency of white sharks at North Neptune Islands (log^{10} residence of 0.46) continues to be within the Target range for the sixth consecutive year. Individual variation, however, remains high with shark residency ranging from less than a day to 76 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. Some months with previously high shark abundance have also had low shark numbers in this monitoring period, i.e. November–December. 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.

11. REFERENCES

Bruce, B. D., and R. W. Bradford. 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.

Bruce, B. D., J. D. Stevens, and R. W. Bradford. 2005. Site fidelity, residence times and home range patterns of white sharks around pinniped colonies. Australian Government Department of Environment and Heritage, Hobart, Tasmania.

Cailliet, G. M., L. J. Natanson, B. A. Welden, and D. A. p. Ebert. 1985. Preliminary studies on the age and growth of the white shark, *Carcharodon carcharias*, using vertebral bands. Pages 49-60 *in* G. Sibley, editor. Biology of the White Shark, a Symposium. Memoirs of the Southern California Academy of Sciences, Volume 9. Southern California Academy of Sciences, Los Angeles.

DEWHA. 2010. Draft recovery plan for the conservation and management of White Sharks (*Carcharodon carcharias*).

Domeier, M. L. 2012. Global perspectives on the biology and life history of the white shark. CRC Press, Boca Raton.

Huveneers, C., P. J. Rogers, C. Beckmann, J. Semmens, B. Bruce, and L. Seuront. 2013. The effects of cage-diving activities on the fine-scale swimming behaviour and space use of white sharks. Marine Biology **160**:2863–2875

Klimley, A. P., and D. G. Ainley. 1996. Great white sharks: The biology of *Carcharodon carcharias*. Academic Press, London.

Rogers, P. J., C. Huveneers, and C. Beckmann. 2014. 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. SARDI Aquatic Sciences.

Wintner, S. P., and G. Cliff. 1999. Age and growth determinations of the white shark *Carcharodon carcharias*, from the east coast of South Africa. Fisheries Bulletin **153**:153-169.