Residency of white sharks, *Carcharodon carcharias*, at the Neptune Islands Group Marine Park (2021–22)

Charlie Huveneers[1] and Yuri Niella[1,2]

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

[2] *Macquarie University, Sydney, New South Wales*

Photo: Andrew Fox

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4. ACKNOWLEDGEMENTS

This project was carried out under the Department for Environment and Water permit number Q26292. Tagging was undertaken under Flinders University ethics approval number E398, E464-17, and BIOL4991-2.

This project was funded by the Department for Environment and Water and Flinders University. The authors would like to thank Calypso Star and Rodney Fox Shark Expeditions for providing logbook data and logistical support during the deployment of acoustic tags and deployment and servicing of acoustic receivers. We also thank: Lauren Meyer, Thomas Clarke, Joshua Dennis, Chloe Roberts, Laura Holmes, Adrienne Gooden, and Taryn-Lee Perrior for helping with fieldwork.

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 2021 and 30 June 2022.

- Twenty-eight sharks ranging 2.8–4.2 m total length (TL) were tagged at the Neptune Islands Group Marine Park (*n* = 18), Dangerous Reef (*n* = 3), the Pages Islands (*n* = 5) and Liguanea Island (*n* = 2) between 5 July 2021 and 28 June 2022, 19 of which were detected within the array (18 tagged at the Neptune Islands and one of the sharks tagged at Liguanea Island). Fourteen sharks tagged in previous years (2 WA-tagged sharks, 12 Neptune Islands-tagged sharks) ─ including two sharks tagged in the 2017–18, one in 2018–19, nine in 2019–20, and three in 2020–21 ─ and one shark tagged in WA on 25 February 2022 were also detected during the last monitoring period.

- Grand mean residency from the 34 sharks detected within the 2021–22 monitoring period at the North and South Neptune Islands was 7.93 ± 11.60 days (median = 5.50) and 5.74 ± 5.05 days (median = 4.38), respectively. The $\log_{10}$ of the grand mean residency at North Neptune Islands was 0.53 ± 0.42 and is within the Target range (≤ 0.7).

- E-logbook recorded 390 entries between 1 July 2021 and 30 June 2022 for 250 days of operations at the Neptune Islands Group. Reported daily sightings ranged 0–12 white sharks (mean ± standard error = 2.8 ± 0.2), while no white sharks were sighted on 28.8% of the days when boats were present. This year represents a 2-fold increase in the average number of sharks sighted compared to the last monitoring period (mean ± standard error = 1.39 ± 0.1).

6. INTRODUCTION

The white shark (*Carcharodon carcharias*) occurs worldwide 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 worldwide concerns regarding their population status, has prompted their protection across many 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 (Ron and Valerie Taylor) Marine Park. 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, DEW 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 (currently three), number of days of operation (currently 12 per fortnight), and the amount of food-based attractant that can be used (currently 100 kg day^{-1}). 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.

This report provides residency estimates of white sharks at the Neptune Islands (Ron and Valerie Taylor) Marine Park for 2021–22 and compares 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.

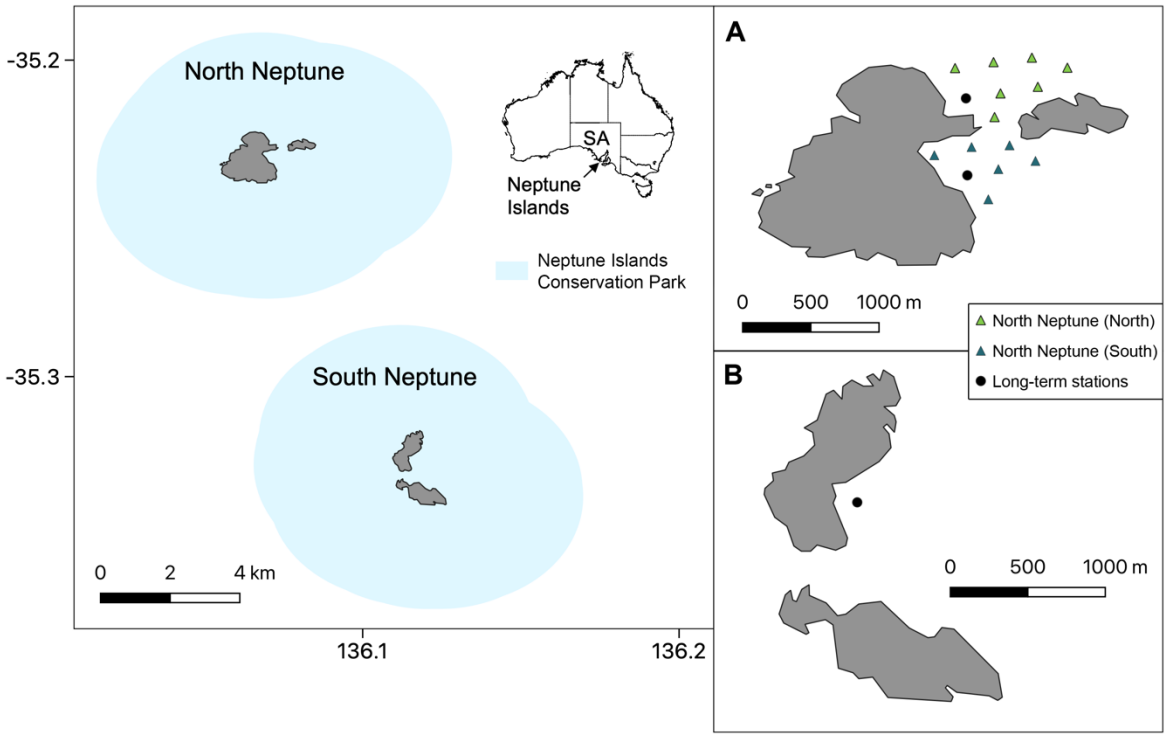

Figure 1. Map of the Neptune Islands Group (Ron and Valerie Taylor) Marine Park with deployment locations of acoustic receiver stations within (A) the North Neptune Islands and (B) the South Neptune Islands. Stations with a black point represent long-term stations that have been present since the start 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, Innovasea, 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-eight white sharks were tagged in the 2021–22 financial year with V16-6H acoustic transmitters, adding to the 140 sharks tagged during the previous eight years of monitoring periods (2013–2021). In addition to the sharks tagged within the Neptune Islands, detections from one white shark tagged in Western Australia (ID 154) was detected in the array, which was tagged off Daw Island (approximately 1,200 km away) on 25 February 2022 and got detected at the Neptune Islands on 16 March 2022 (19 days). Acoustic transmitters are programmed to send signals at random interval of 70–150 seconds (VEMCO Ltd., Halifax, Canada). Tags were tethered to a plastic umbrella dart 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 2021 and 30th June 2022.

7.3 Electronic logbooks

Since 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 2021 and 30 June 2022.

8. RESULTS

We tagged 28 white sharks ranging 2.8–4.2 m total length (TL) between 5 July 2021 and 28 June 2022 (North Neptune Island: *n* = 15; South Neptune Island: *n* = 3; Dangerous Reef: *n* = 3; Pages Islands: *n* = 5, Liguanea Island: *n* = 2), 19 of which were detected at the Neptune Islands (18 tagged at the Neptune Islands and one of the sharks tagged at Liguanea Island; Table 1). Table 1 provides a detection summary for the 34 white sharks that were detected at the Neptune Islands during the 2021–22 monitoring period. Fifteen sharks (44.1%) detected within the Neptune Islands in the 2021–22 monitoring period were tagged in previous years; two of which (5.9%) were tagged in the 2017–18 period, one (2.9%) in 2018–19, nine (26.5%) in 2019–20, and three (8.8%) in 2020–21 (Figure 2). A total of 71,010 acoustic detections was recorded from 34 sharks in the 2021–22 monitoring period (mean ± standard error = 2,088 ± 7,503 per shark). Tagged white sharks were detected for periods ranging between 1 and 120 days (mean = 14 days) (Table 1).

Table 1. Detection summary of white sharks (n = 34) between July 2021 and June 2022 acoustically tagged at the Neptune Islands Marine Park, Liguanea Island and Western Australia. TL = total length (m). NNI = North Neptune Islands; SNI = South Neptune Islands; LI = Liguanea Island; WA = Western Australia

Shark	TL	Sex	Date tagged	Location tagged	North Neptune		South Neptune	
					N detections	N days detected	N detections	N days detected
78	3.4	Male	08/01/2018	NNI	61	6	42	8
83	4.4	Female	26/05/2018	NNI	1	1	-	-
90	3.8	Male	11/12/2018	NNI	323	7	88	4
108	3.2	Male	30/10/2019	NNI	68	6	-	-
112	2.4	Male	23/11/2019	NNI	4	3	-	-
114	3.2	Male	23/11/2019	WA	309	16	27	5
115	2.9	Female	12/02/2020	NNI	407	33	290	23
116	3.0	Male	12/02/2020	NNI	392	24	154	7
117	2.8	Male	12/02/2020	NNI	230	22	413	23
121	2.7	Female	11/04/2020	NNI	72	11	7	1
123	2.9	Female	18/05/2020	NNI	4,200	51	79	3
125	2.6	Male	21/05/2020	SNI	326	16	139	16
135	3.1	Male	01/01/2021	SNI	175	10	14	2
136	3.9	Male	08/01/2021	NNI	-	-	152	5
139	2.4	Male	16/01/2021	WA	43	3	-	-
141	3.1	Male	05/07/2021	NNI	3,779	29	-	-
142	3.2	-	06/07/2021	NNI	5,377	92	-	-
144	4.2	Male	22/10/2021	NNI	742	17	1,318	8
145	4.2	-	22/10/2021	NNI	41,761	120	2,154	14
146	4.0	Female	30/10/2021	LI	8	1	-	-
147	4.2	Male	15/01/2022	NNI	11	2	-	-
148	3.4	Male	15/01/2022	NNI	46	3	-	-
149	3.1	Male	15/01/2022	NNI	520	19	1,052	21
150	3.3	Female	16/01/2022	NNI	103	2	-	-
151	3.8	Male	05/02/2022	SNI	7	4	154	7
152	3.4	Male	06/02/2022	SNI	346	19	429	13
153	3.0	Male	06/02/2022	SNI	-	-	122	5
154	3.5	Female	25/02/2022	WA	-	-	9	1
155	3.4	Female	07/06/2022	NNI	1,097	17	242	4
156	3.8	Female	07/06/2022	NNI	1,491	11	48	2
157	3.7	Female	08/06/2022	NNI	99	5	1,579	20
158	3.5	Female	08/06/2022	NNI	233	3	123	3
159	2.8	Female	28/06/2022	NNI	32	1	-	-
160	3.8	Female	28/06/2022	NNI	112	3	-	-

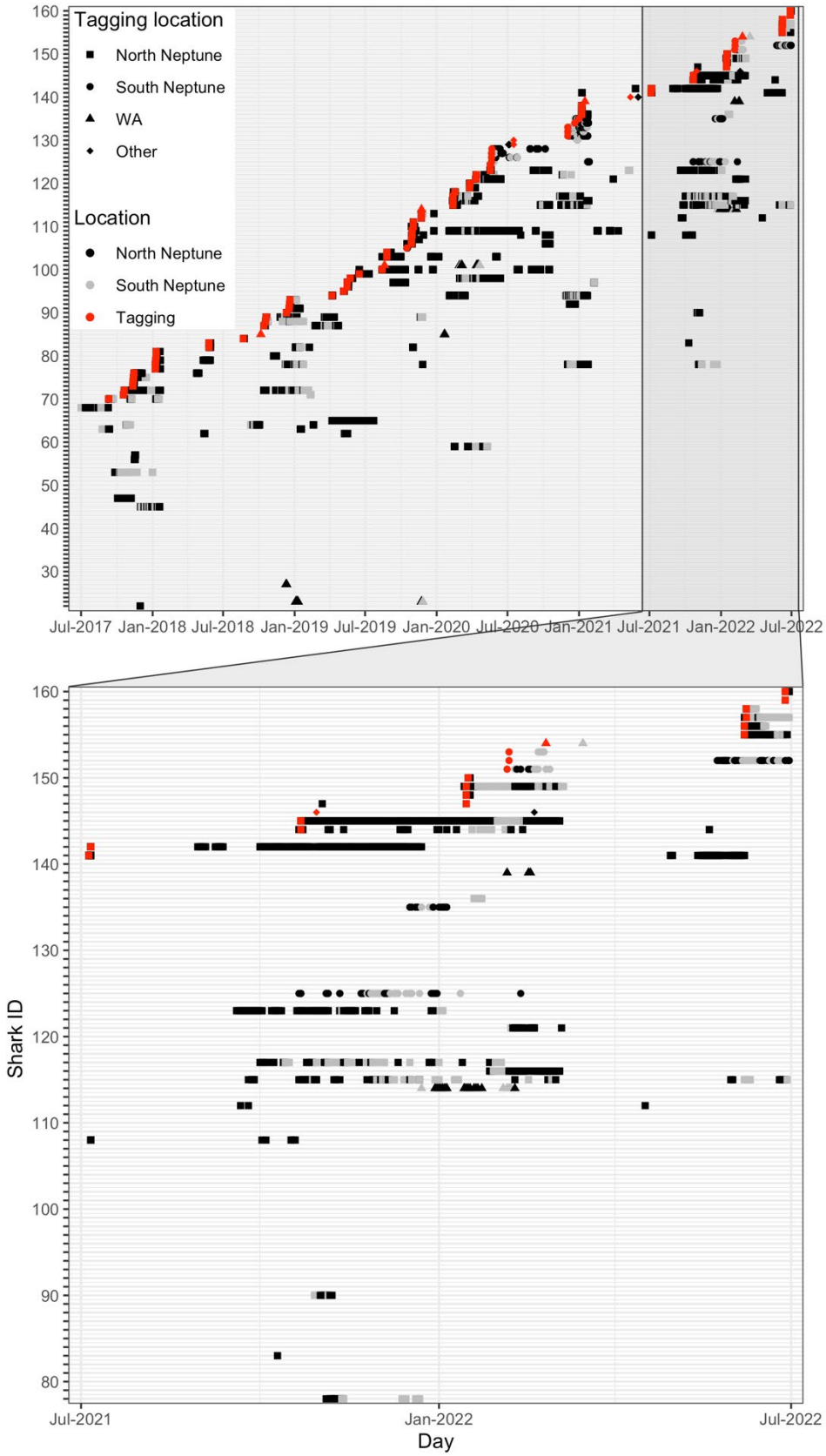

Figure 2. Top panel: Daily detections for white sharks between 1 July 2017 – 30 June 2022 at the North (black symbols) and South (grey symbols) Neptune Islands. Red symbols represent dates when each shark was tagged. **Bottom panel:** Detection plot for white sharks detected at the Neptune Islands during the 2021–22 financial year (n = 34).

8.1 Residency

Residency periods exhibited by white sharks at the North and South Neptune Islands combined ranged from 1 to 100 days (Table 2). Sharks had similar or longer residency at the North Neptune Islands than the South Neptune Islands (Table 2). Across all sharks detected in 2021–22, maximum residency at South Neptune Islands was shorter (27 days) than at North Neptune Islands (100 days) (Table 2). Most shark detections (87.8%) occurred at North Neptune Islands, where the grand mean residency was 7.93 ± 11.60 days (grand median = 5.50). Most white sharks had a mean residency <10 days (88.2%), with 20.6% of all sharks having maximum residency times between 20 and 40 days and two individuals (IDs 142 and 145) respectively being resident at the North Neptune Islands for 83 and 100 days (Table 2). Of the 31 sharks detected at North Neptune Islands, 19 (61.3%) were also detected at South Neptune Islands, with three sharks only detected there (Table 2). Residency periods of most these sharks were usually similar or longer at North Neptune Islands, except for sharks 117, 125, 144, 152 and 157, which had residency times up to 8 times longer at South Neptune Islands. The grand mean residency at South Neptune Islands was 5.74 ± 5.05 days (grand median = 4.38). Long-term detection patterns across the nine monitoring periods (2013–2022) show sharks had elevated rates of detection at North Neptune Islands between the October to February period and in May, 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 between November–January and May–August periods (Figure 3).

Table 2. Summary statistics showing residency estimates (mean; N = number of visits) for white sharks (n = 34) at the Neptune Islands Group between 1 July 2021 and 30 June 2022. 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
78	Male	1	8.20	0.91	-	-	-	2	4.55	0.45	5.02	1.00	8.10
83	Female	1	1.00*	0.00	-	-	-	-	-	-	-	-	-
90	Male	1	6.30	0.80	-	-	-	1	6.90	0.84	-	-	-
108	Male	3	1.30	0.10	0.44	1.00	1.80	-	-	-	-	-	-
112	Male	2	2.50	0.30	2.12	1.00	4.00	-	-	-	-	-	-
114	Male	3	5.63	0.60	4.20	1.00	9.20	2	2.40	0.29	1.98	1.00	3.80
115	Female	9	4.10	0.49	3.22	1.00	10.20	8	4.03	0.30	7.02	1.00	21.30
116	Male	2	13.55	0.71	17.75	1.00	26.10	1	5.70	0.76	-	-	-
117	Male	10	2.50	0.20	3.50	1.00	12.10	7	4.47	0.41	5.11	1.00	14.00
121	Female	2	6.15	0.53	7.28	1.00	11.30	1	1.00*	0.00	-	-	-
123	Female	5	12.06	0.77	10.32	1.00	22.60	2	1.10	0.04	0.14	1.00	1.20
125	Male	7	1.60	0.15	0.15	1.01	3.70	2	14.05	0.72	18.46	1.00	27.10
135	Male	2	5.50	0.73	1.70	4.30	6.70	1	4.30	0.63	-	-	-
136	Male	-	-	-	-	-	-	1	4.30	0.63	-	-	-
139	Male	2	1.00	0.00	0.00	1.00	1.00	-	-	-	-	-	-
141	Male	3	8.67	0.49	13.11	1.00	23.80	-	-	-	-	-	-
142	-	3	32.27	1.01	44.41	1.00	83.10	-	-	-	-	-	-
144	Male	8	2.52	0.22	3.19	1.00	10.10	2	6.05	0.63	6.01	1.80	10.30
145	-	2	58.95	1.62	58.48	17.6	100.3	1	14.10	1.15	-	-	-
146	Female	1	1.00*	0.00	-	-	-	-	-	-	-	-	-
147	Male	2	1.00	0.00	0.00	1.00	1.00	-	-	-	-	-	-
148	Male	1	1.80	0.26	-	-	-	-	-	-	-	-	-
149	Male	3	7.40	0.86	1.66	6.20	9.30	3	7.77	0.72	7.18	1.50	15.60
150	Female	1	1.40	0.15	-	-	-	-	-	-	-	-	-
151	Male	1	6.50	0.81	-	-	-	2	5.80	0.74	2.69	3.90	7.70
152	Male	3	7.00	0.75	4.96	2.20	12.10	2	9.45	0.95	4.74	6.10	12.80
153	Male	-	-	-	-	-	-	2	1.75	0.20	1.06	1.00	2.50
154	Female	-	-	-	-	-	-	1	1.00*	0.00	-	-	-
155	Female	1	22.90	1.36	-	-	-	1	2.90	0.46	-	-	-
156	Female	1	9.90	1.00	-	-	-	1	1.00*	0.00	-	-	-
157	Female	1	7.30	0.86	-	-	-	1	21.00	1.32	-	-	-
158	Female	1	2.10	0.32	-	-	-	1	2.60	0.41	-	-	-
159	Female	1	1.00*	0.00	-	-	-	-	-	-	-	-	-
160	Female	1	2.60	0.41	-	-	-	-	-	-	-	-	-
Grand Mean			**7.93**	**0.53**					**5.74**	**0.53**			
Grand Median			**5.50**	**0.49**					**4.38**	**0.54**			
Grand SD			**11.60**	**0.42**					**5.05**	**0.37**			

(*) Sharks with a single visit of less than 24-hours residency were rounded up to 1 day.

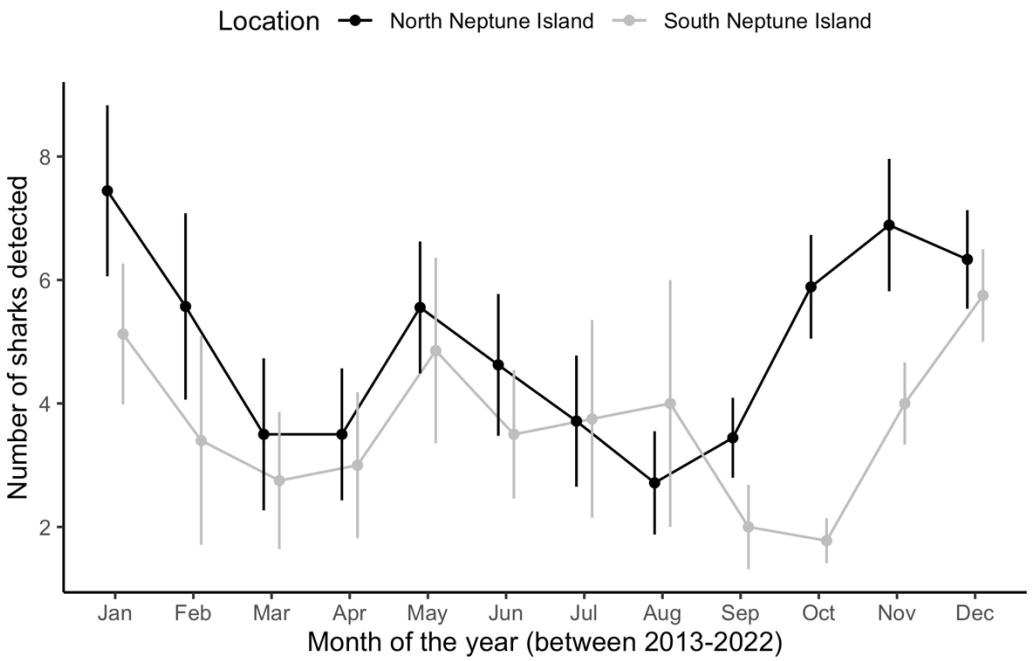

Figure 3. Seasonal pattern in shark detections between North and South Neptune Islands across the full monitoring period between July 2013 and June 2022. Points represent mean numbers of sharks detected per calendar month at North (black) and South (grey) Neptune Islands, with bars representing standard error of the mean across the nine financial years.

8.2 Electronic logbook

Number of sharks sighted

E-logbook describing cage-diving industry activities comprised records for 250 days out of the 364 days (68.7%) between 1 July 2021 to 30 June 2022. Reported daily sightings ranged 0–12 white sharks (mean ± standard error = 2.8 ± 2.5; Figure 4a). No or only one white shark was sighted on 72 and 15 days respectively (28.8 and 6.0% of the days at the Neptune Islands respectively). The number of sharks sighted peaked between December–February, with low numbers sighted between July–September and March–April periods (Figure 4b). Males were more frequent than females between October and March (Figure 4c).

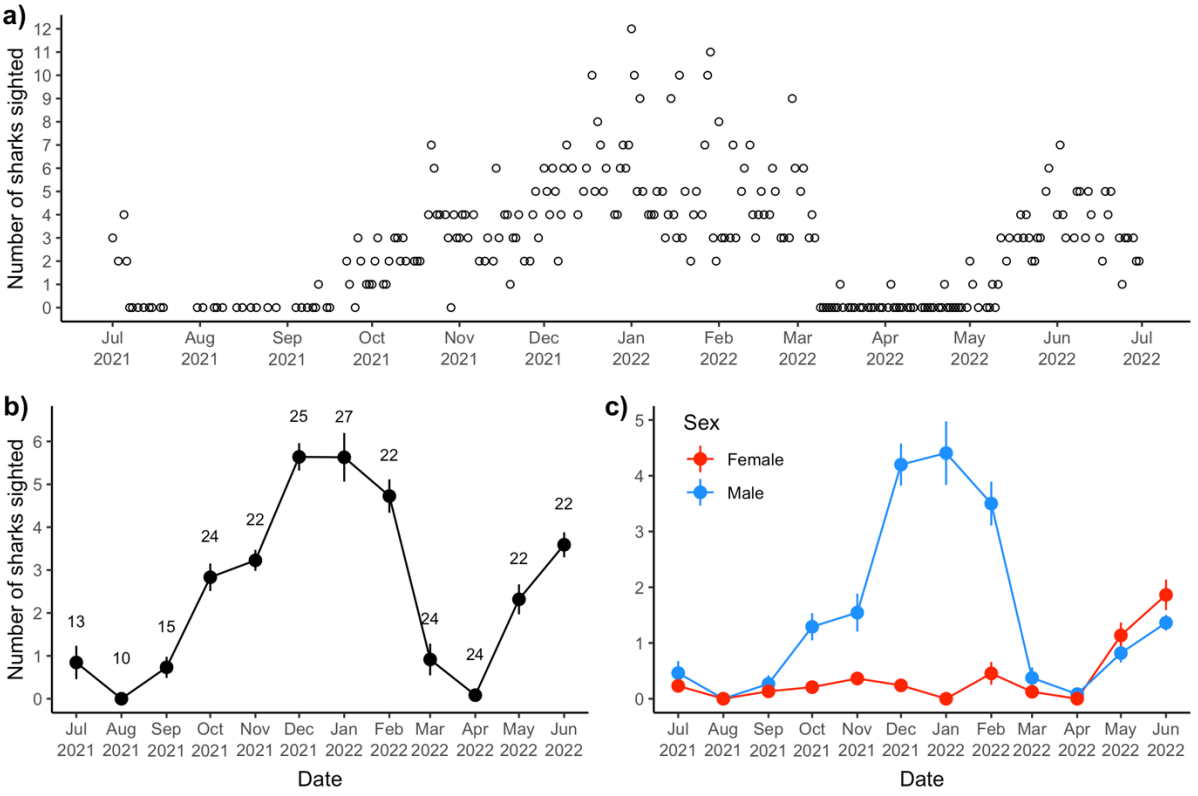

Figure 4. (a) Number of sharks sighted reported by the cage-diving operators through the e-logbook in the 2021–22 financial year. **(b)** Mean daily number of sharks sighted each month and **(c)** separated by sex for the 2021–22 financial year. Error bars represents standard error of the mean values. 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 allowed at the Neptune Islands (2009–2011), residency and $\log_{10}$ increased 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 (Figure 5; Table 3). Long-term trends since the 2015–16 financial year until present highlight a stabilisation of residency and $\log_{10}$ values to below 2001–02 baseline levels and within the Target range (Figure 5).

In 2021–22, the grand mean residency of white sharks at North Neptune Islands was 7.9 days (log_{10} = 0.53) and is within the Target range.

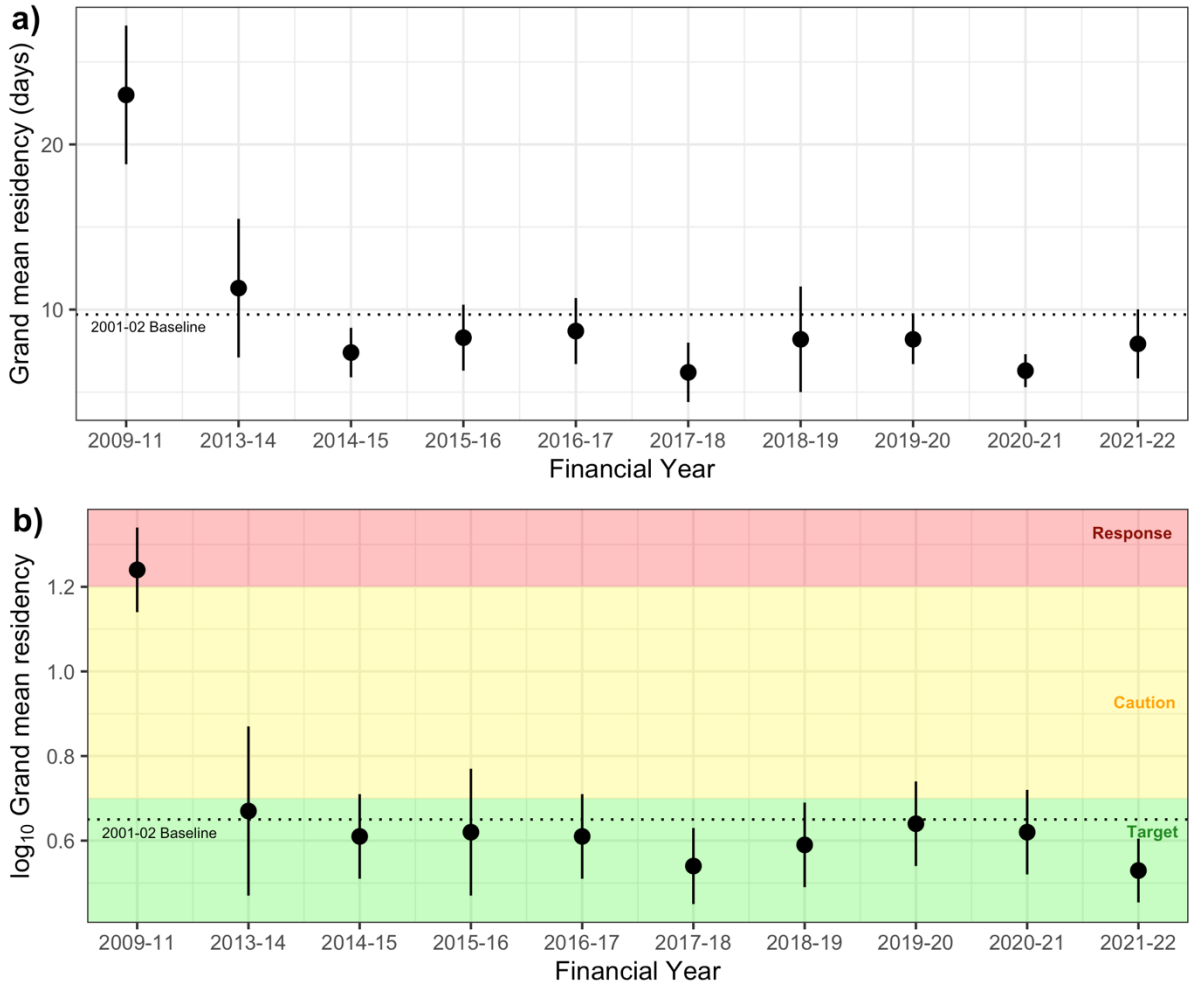

Figure 5. Change in **(a)** grand mean residency, and **(b)** $\log_{10}$ of grand mean residency of acoustically monitored white sharks at North Neptune Islands, across the 10 monitoring periods. Error bars represent standard error. Horizontal broken lines in plots represent the baseline values of grand 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. Discrepancies with previous reports are due to annual reassessment of potentially shed tag and refinement of the methods with residencies less than one day now rounded up to one day.

Table 3. Estimates of overall mean log_{10} residency of white sharks detected at North Neptune Islands between 2001 and 2022. Discrepancies with previous reports are due to annual reassessment of potentially shed tag and refinement of the methods with residencies less than one day now rounded up to one day.

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	11.3	16.5	0.67	0.59
2014–2015	7.4	8.0	0.61	0.50
2015–2016	8.3	9.5	0.62	0.54
2016–2017	8.7	10.9	0.61	0.55
2017–2018	6.2	9.3	0.54	0.42
2018–2019	8.2	16.7	0.59	0.46
2019–2020	8.2	9.3	0.64	0.51
2020–2021	6.3	5.1	0.62	0.44
2021–2022	7.9	11.6	0.53	0.42

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 decreased during this monitoring period compared to the previous 2020–21 period (42.7 *vs.* 28.8%). Low abundance or lack of sharks occurred during similar months as observed in the previous monitoring periods, i.e. July–August (2019–20) and February–April (2020–21). In addition, peak in shark sighting in 2021–22 occurred in similar months as in the last monitoring period 2020–21, i.e. December and January. The decreased number of days when sharks were not sighted led to an increase in the average number of sharks sighted per day from 1.4 in 2020–21 to 2.8 in 2021–22, and is similar to that observed in 2017–18 (Figure 6).

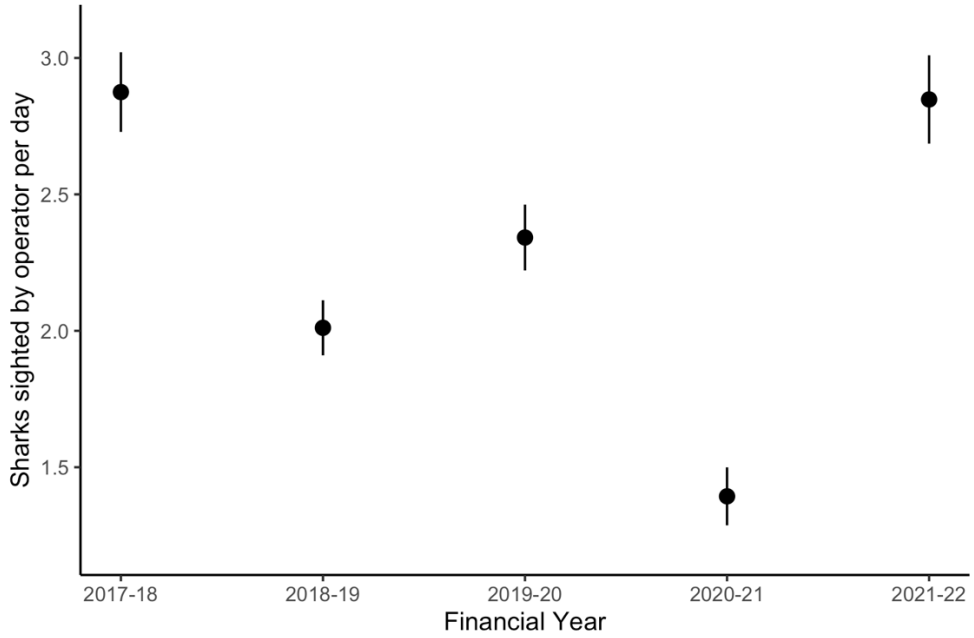

Figure 6. Trend in annual sighting rate recorded by operators using the e-logbook tool over the last five financial years (2017–2022). Error bars represent standard errors.

10. CONCLUSION

The 2021–22 residency of white sharks at North Neptune Islands (log^{10} residence of 0.53) continues to be within the Target range for the nineth consecutive year. Individual variation, however, remains high with shark residency ranging from less than a day to 100 days. Residency estimates should, therefore, be interpreted with caution, especially if originating from a low number of individuals.

Number of sharks sighted were reported by cage-diving operators throughout the monitoring period and showed periods of consistently low shark abundance since 2014 (i.e. February–April). However, a large number of white sharks were previously sighted during some of these months, e.g., February 2013, and again during the 2021–22 monitoring period. 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, there is > 22 years of daily shark sightings to assess the factors that might influence shark abundance at the Neptune Islands Group Marine Park. Future opportunities to analyse this data 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.