Residency of white sharks, *Carcharodon carcharias*, at the Neptune Islands Group Marine Park (2017–18)

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Photo: Andrew Fox

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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 2017 and 30 June 2018.

- Seventeen sharks ranging 2.8–4.4 m total length (TL) were tagged at the Neptune Islands Group Marine Park between 1 July 2017 and 30 June 2018. The target of tagging 20 sharks could not be achieved due to prolonged periods of low white shark abundance (93 days with 0–1 shark sighted).

- Grand mean residency from the 24 sharks detected within the 2017–18 monitoring period at the North and South Neptune Islands was 5.74 ± 9.32 days (median = 2.61) and 5.29 ± 4.55 days (median = 4.42), respectively. The $\log^{10}$ of the grand mean residency at North Neptune Islands was 0.38 ± 0.63 and is within the Target range (≤ 0.7).

- E-logbook recorded 541 entries between 1 July 2017 to 30 June 2017 for 278 days of operations at the Neptune Islands Group. Reported daily sightings ranged 0–12 white sharks (mean ± standard error = 2.94 ± 0.15), while no white sharks were sighted on 60 days (21.6% of the days at the Neptune Islands). This represents a near doubling in the number of days when no white sharks were sighted compared to the 2016–17 monitoring 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 each can operate to ten days per fortnight. The policy also sets a framework for the adaptive management of the cage-diving industry and trigger points 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 trigger points set in Smith and Page (2015).

The aim of this report is to provide residency estimates of white sharks at the Neptune Islands (Ron and Valerie Taylor) Marine Park for 2017–18 and compare them to previous years and to trigger points set in Smith and Page (2015). This report also summarise cage-diving activities and number of shark 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. 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.

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.

7.2.2. Tag deployments

Seventeen white sharks were tagged in the 2017–18 financial year with V16-6H acoustic transmitters, adding to the 69 sharks tagged during the previous four years of monitoring periods (2013–2017). 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, and combined regions.

The residency of white sharks is reported for the period between 1st July 2017 and 30th June 2018. Shark residency during previous periods was also recalculated using full datasets from 1st July to 30th June. This was required as previous estimates were sometimes calculated based on shorter datasets. For example, the 2016–17 estimate was previously calculated using acoustic data spanning 1 July to the 13 May due to receivers being downloaded on the 13th May. Residency for the 2001–02, 2009–11, and 2015–16 periods could not be recalculated due to unavailable data and were obtained from previous reports.

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 described in Rogers et al. (2014). No major changes to the fields in Fulcrum™ were made during the 2017–18 monitoring period. The e-logbook was used to collect data on daily activities and sighting frequency of white sharks between 1 July 2017 and 30 June 2018.

8. RESULTS

Seventeen white sharks ranging 2.8–4.4 m total length (TL) were tagged at North Neptune Island between 10 September 2017 and 26 May 2018. Two of the 17 sharks tagged during this monitoring period were sighted without their tags within days of being tagged and were removed from the analysis. Table 1 provides a detection summary for sharks that were detected in the 2017–18 monitoring period. Twenty-four white sharks were detected during the 2017–18 monitoring period. Ten sharks (42%) detected within the Neptune Islands in the 2017–18 monitoring period were tagged in previous years; eight of which (33%) were tagged in the 2016–17 period, and two (6%) from the 2015–16 period. The remaining 14 sharks (58%) were tagged during the 2017–18 monitoring period (Fig. 1). Shark 75, which was tagged in November 2017, was not detected by any receiver stations.

A total of 18,726 acoustic detections was recorded from 24 sharks in the 2017–18 monitoring period (mean ± standard error = 625 ± 264). Tagged white sharks were detected for periods ranging between 1 and 66 days (Table 1).

Table 1. Detection summary of acoustically tagged white sharks (n=86) between 1 July 2017 and 30 June 2018. TL = total length (m). Sharks are numbered based on tagging date, which differs from previous reports.

Shark	TL	Sex	Date tagged	Location tagged	North Neptune		South Neptune	
					N detections	N days detected	N detections	N days detected
25	4.2	Male	21/07/2014	North Neptune	7	1	*	*
45	3	Male	17/12/2015	South Australia	110	12	93	10
47	2.8	Male	17/12/2015	South Australia	538	30	*	*
53	3.3	Male	16/10/2016	North Neptune	251	4	604	23
56	3.7	Male	13/11/2016	North Neptune	66	2	*	*
57	3.1	Male	27/11/2016	North Neptune	93	2	*	*
62	3	Female	18/04/2017	North Neptune	95	3	*	*
63	2.8	Female	18/04/2017	North Neptune	54	3	1263	15
64	2.6	-	19/04/2017	North Neptune	25	1	13	2
68	3.8	Female	14/05/2017	North Neptune	937	14	272	10
70	3.3	Male	10/09/2017	North Neptune	1340	17	560	11
71	3.9	-	18/10/2017	North Neptune	124	1	*	*
72	3.3	-	20/10/2017	North Neptune	5868	69	120	11
73	3	Male	11/11/2017	North Neptune	60	4	*	*
74	2.9	Female	12/11/2017	North Neptune	135	4	*	*
76	3.4	Male	13/11/2017	North Neptune	87	6	79	2
77	4	Male	14/11/2017	North Neptune	2825	29	*	*
78	2.9	Male	08/01/2018	North Neptune	203	6	89	6
79	3.4	Male	08/01/2018	North Neptune	53	5	*	*
80	3.7	Male	09/01/2018	North Neptune	1360	23	376	5
81	2.8	Male	10/01/2018	North Neptune	92	3	*	*
82	3.4	Male	10/01/2018	North Neptune	48	4	237	6
83	3.2	Male	26/05/2018	North Neptune	313	5	*	*
84	4.4	Female	26/05/2018	North Neptune	270	5	*	*

* Indicates that shark was not detected during the report monitoring period (1 July 2017–30 June 2018).

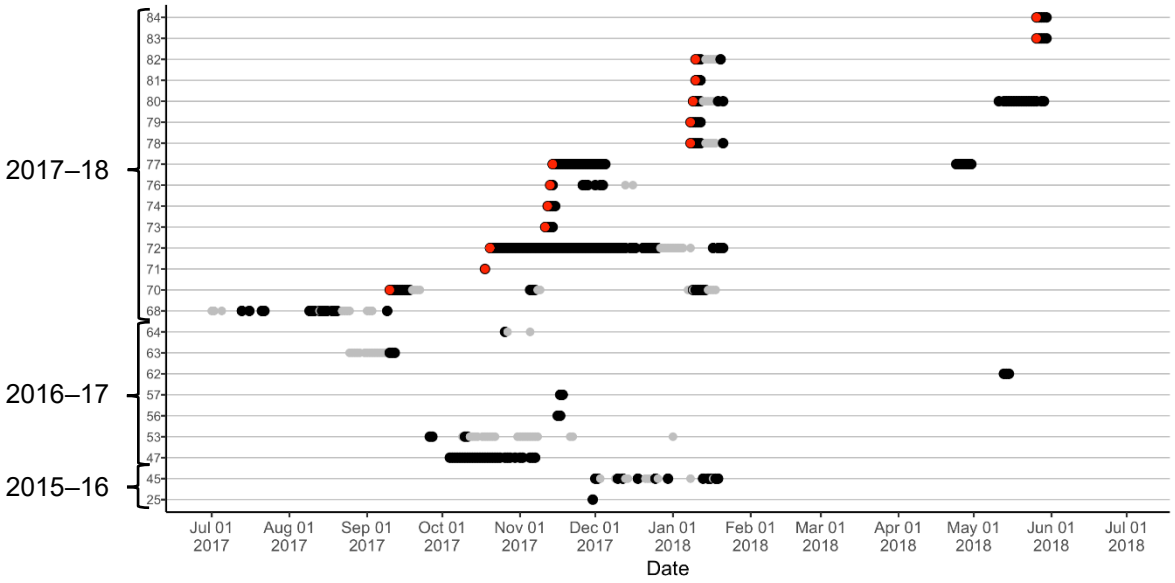

Figure 1. Daily detections for white sharks (n = 25) at the North (black symbols) and South (grey symbols) Neptune Islands between 1 July 2017 and 30 June 2018. Red symbols represent tagging date for sharks tagged in the 2017–2018 financial year. Numbers next to y-axis are monitoring years shark was tagged. Note: Sharks 45 and 47 were tagged outside the Neptune Islands Group, all other sharks were tagged at the North Neptune Islands Group. No detections were obtained from Shark 75 that was tagged in November 2017.

8.1 Residency

Residency periods exhibited by white sharks at the North and South Neptune Islands combined ranged from 1 to 34 days (Table 2). All but two sharks that were detected in the 2017–18 monitoring period were tagged at North Neptune Islands, the other two sharks (i.e. Shark ID 45 and 47) were tagged outside the Neptune Island Group Marine Park but in South Australia. The majority of detections were recorded at the North Neptune islands and the grand mean residency was 5.74 ± 9.32 days (grand median = 2.61). Most white sharks had a mean residency <5 days (64%), and only two individuals resided at North Neptune Islands for >20 days. Of the twenty-four sharks that were detected at North Neptune Islands, 11 were also detected at South Neptune Islands. Residency periods in these sharks were similar between the two islands, where the grand mean residency was 5.29 ± 4.55 days (grand median = 4.42) at South Neptune Islands. 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 63 was 15.38 days at South Neptune Islands and 2.02 days at North Neptune Islands.

Long-term detection patterns across the five monitoring periods (2013–2018) show sharks had elevated rates of detection at North Neptune Islands between October and February, with low detection rates in March and between June and September (Fig. 2). At the South

Neptune Islands, however, detection patterns indicated an elevated visitation of sharks in May, with comparatively lower detection rates in March–April and September–November (Fig. 2).

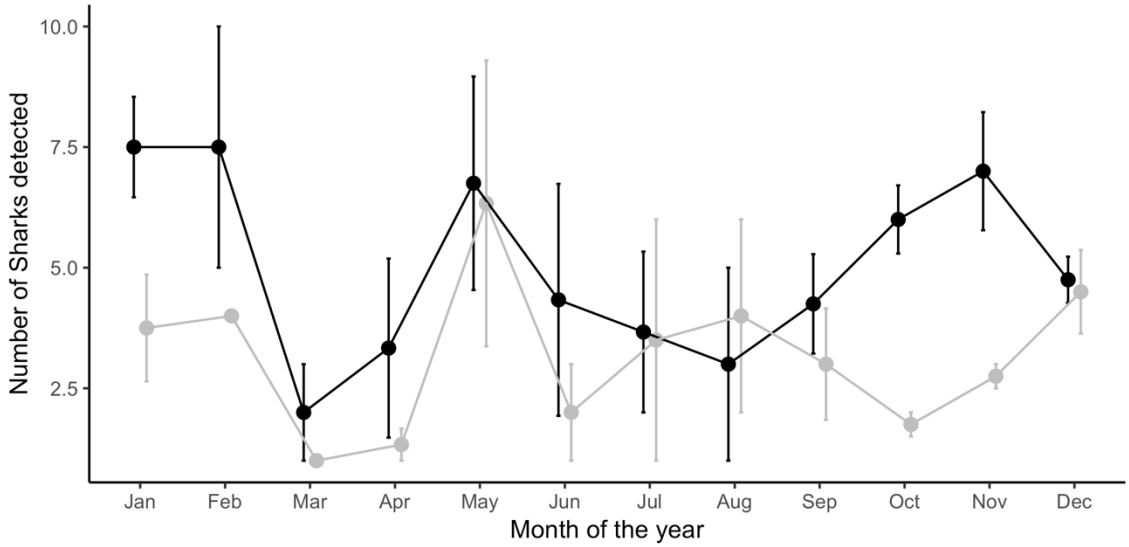

Figure 2. Yearly pattern in shark detections between North and South Neptune Islands across the full monitoring period between 2013–2018. Points represent mean numbers of sharks detected per calendar month at North (black) and South Neptune Islands (grey), with bars representing standard error of the mean across the five years.

Table 2. Summary statistics showing residency estimates (mean; N = number of visits) for white sharks (n =24) at the Neptune Islands Group between 1 July 2017 and 30 June 2018. 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
25	Male	1	0.07	-1.18									
45	Male	5	2.85	0.45	2.79	0.0	6.3	5	2.24	0.35	2.82	0.0	5.4
47	Male	1	34.00	1.53									
53	Male	2	1.05	0.02	0.51	0.7	1.4	4	5.24	0.72	6.24	0.0	13.2
56	Male	1	1.33	0.12									
57	Male	1	1.59	0.20									
62	Female	1	1.58	0.20									
63	Female	1	2.02	0.30				1	15.38	1.19			
64	Unknown	1	0.18	-0/75				2	0.01	-2.12	0.0	0.0	0.0
68	Female	3	6.65	0.82	5.67	0.1	10.3	4	2.48	0.39	1.72	0.0	3.9
70	Male	3	5.35	0.73	2.82	2.7	8.3	4	1.95	0.29	1.32	0.5	3.2
71	Unknown	1	0.3	-0.53									
72	Unknown	2	35.02	1.54	44.25	3.7	66.3	1	11.86	1.07			
73	Male	1	2.88	0.46									
74	Female	1	2.38	0.38									
76	Male	2	4.84	0.68	5.38	1.0	8.6	1	3.14	0.50			
77	Male	2	13.16	1.12	11.03	5.4	21.0						
78	Male	2	1.91	0.28	2.42	0.2	3.6	1	6.17	0.79			
79	Male	1	3.41	0.53									
80	Male	3	7.36	0.87	8.98	1.7	17.7	1	4.42	0.65			
81	Male	1	1.55	0.19									
82	Male	2	0.76	-0.12	1.05	0.0	1.5	1	5.33	0.73			
83	Male	1	3.76	0.57									
84	Female	1	3.70	0.57									
Grand Mean			**5.74**	**0.38**					**5.29**	**0.41**			
Grand Median			**2.61**	**0.42**					**4.42**	**0.65**			
Grand SD			**9.32**	**0.63**					**4.55**	**0.89**			

8.2 Electronic logbook

Number of sharks sighted

E-logbook describing cage-diving industry activities comprised 541 records between 1 July 2017 to 30 June 2018. These records provided information about operator activities and shark numbers for 278 days out of the 365 days (76.2%). Reported daily sightings ranged 0–12 white sharks (mean ± standard error = 2.94 ± 0.15; Fig. 3). No white sharks were sighted on 60 days (21.5% of the days at the Neptune Islands). The number of sharks sighted peaked between April and May, with low numbers sighted in February and June. Most of the shark sighted between September–January were males, while females were mostly sighted in April and May (Fig.3).

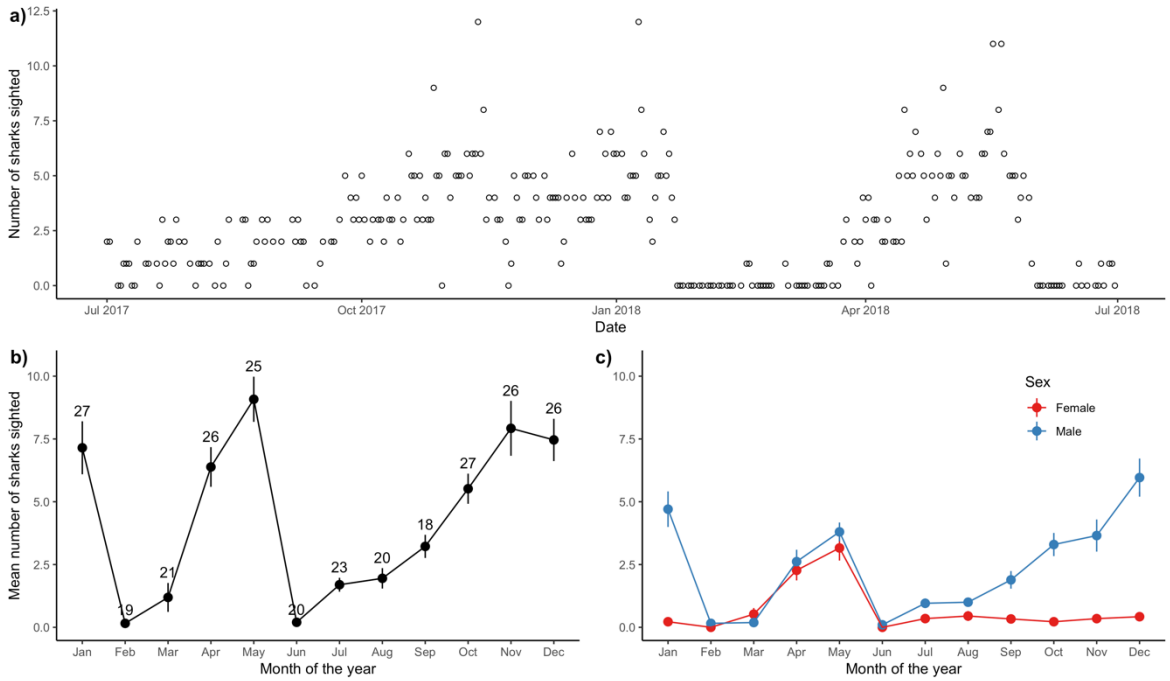

Figure 3. (a) Number of sharks sighted reported by the cage-diving operators through the FulcrumTM e-logbook in the 2017–18 financial year. **(b)** Mean daily number of sharks sighted at each calendar month and **(c)** separated by sex. Error bars represents standard error of the mean values. Number above to each point in **(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 (Bruce et al. 2005; Fig 4). Based on this study, Smith and Page (2016) developed decision points 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. 4).

In 2017–18, the grand mean residency of white sharks at North Neptune Islands was 5.74 days (log_{10} = 0.38) and is within the Target range.

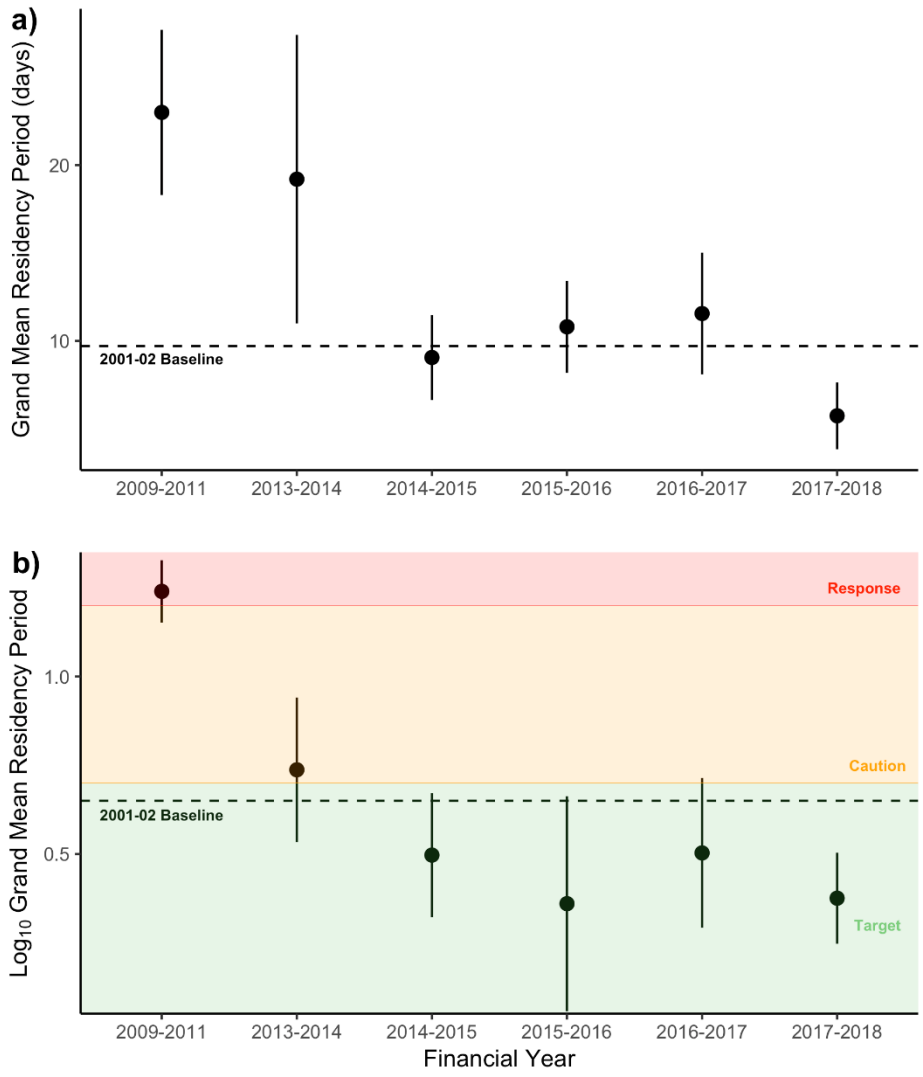

Figure 4. Change in **(a)** grand mean residency, and **(b)** log10 of grand mean residency of acoustically monitored white sharks at North Neptune Islands, across the six monitoring periods. Horizontal broken lines in plots represent the baseline values of grand mean residency and log^{10} transformed value calculated by Bruce et al. (2005) in 2001–2002. Shaded areas in panel **(b)** represent decision points developed for the cage-diving industry by Smith and Page (2016).

9.2 Cage-diving activities

The e-logbook is an important tool to record cage-diving activities and the number of white shark frequenting the Neptune Islands Group. The e-logbook revealed that the proportion of days without any shark sighted nearly doubled during this monitoring period compared to 2016–17 (21.5 *vs.* 11.5% respectively). Low abundance or lack of sharks occurred during similar months in 2016–17 and 2017–18. The magnitude and duration of these periods, however, increased in 2017–18, leading to the average number of sharks sighted per day decreasing from 4.3 to 2.9. The reason for the overall low abundance and prolonged periods with no sharks is unknown and warrants further investigation.

10. CONCLUSION

The 2017–18 residency of white sharks at North Neptune Islands (0.59) continues to be within the Target range. Individual variation, however, remains high with shark residency ranging from less than a day to 34 days. Residency estimates should, therefore, be interpreted with caution, especially when originating from a low number of individuals.

Number of shark sighted were reported by cage-diving operators throughout the monitoring period as required and showed a decreased number of shark sighted at the Neptune Islands Group. With the number of shark sighted having been recorded on each operator days since 1999, 20 years of daily shark sightings will soon be available 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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