Residency of white sharks, *Carcharodon carcharias*, at the Neptune Islands Group Marine Park (2016–17)

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Photo: Andrew Fox

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SOUTHERN SHARK ECOLOGY GROUP

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4. ACKNOWLEDGEMENTS

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5. EXECUTIVE SUMMARY

- This report provides estimates of residency of tagged white sharks (*Carcharodon carcharias*) and a summary of electronic logbook data describing cage-diving activities at the Neptune Islands Group (Ron and Valerie Taylor) Marine Park between July 2016 and June 2017.

- Twenty sharks ranging 2–4.5 m total length (TL) were tagged at the Neptune Islands Group Marine Park between July 2016 and June 2017.

- Mean residency from the 23 sharks detected within the 2016–17 monitoring period at the North and South Neptune Islands was 9.8 ± 2.5 days (median = 3.8) and 4.0 ± 1.3 days (median = 1.9), respectively. The grand mean residency of white sharks at North Neptune Islands was 11.6 ± 16.3 days (log^{10} = 0.50 ± 0.99) and is within the Target range (≤ 0.7).

- E-logbook recorded 590 entries between 1 September 2016 to 30 June 2016 for 226 days of operations at the Neptune Islands Group. Reported daily sightings ranged 0–12 white sharks (mean ± standard error = 4.31 ± 0.18), while no white sharks were sighted on 26 days (11.5% of the days at the Neptune Islands).

- The total amount of berley used per day of operation varied between 0–165 litres (mean ± standard error = 61.7 ± 2.07) and was 0–80 litres per operator (mean ± standard error = 32.2 ± 0.82). The total number of bait bins used per day of operation varied between 0–3.75 (mean ± standard error =0.74 ± 0.05) and was 0–3 per operator (mean ± standard error = 0.62 ± 0.04). The amount of berley and bait reported by the cage-diving operators should, however, be interpreted with caution due to confusion with the reporting system affecting the reliability of the information recorded.

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 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 2016–17 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

Twenty white sharks were tagged with V16-6H acoustic transmitters programmed to send signals at random interval of 70–150 seconds (VEMCO Ltd., Halifax, Canada). Tags were tethered to a Domieir 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

Tagged white sharks were considered 'present' in the array if detected at least twice within a 24-hour period. This eliminated the possibility of 'false detections' that can occur when there are multiple acoustic tags present within range of an array of receivers (Pincock 2008). 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 1 July 2016 and 13 May 2017 when receivers were downloaded and re-deployed.

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). In March 2017, fields for attractant used and other component of the daily logbooks were simplified to improve accuracy and reliability of records. Specifically, the main changes were:

- GPS position no longer required as approximate location has been used by the operators and is sufficient to know the area where boats are anchored;
- Berleying or sound start/stop time no longer required as arrival and departure time is already recorded;

- Sound and berley/bait characteristics have been simplified to avoid ambiguity;
- Number of baits taken by individual sharks have been removed; and
- List of ‘other species’ has been shortened to the species most likely to be seen at the Neptune Islands.

The e-logbook was used to collect data on daily activities and sighting frequency of white sharks between 1 September 2016 and 30 June 2017.

8. RESULTS

Twenty white sharks ranging 2–4.5 m total length (TL) were tagged at the Neptune Islands (19 at North and 1 at South Neptune Islands) between 24 September 2016 and 1 June 2017. Table 1 provides a summary of the deployment data for each tagged shark. Three white sharks were tagged after the receivers were downloaded and one white shark was never detected. One tag was prematurely shed on the day it was deployed and was not included in the analysis. Eight white sharks tagged in previous years were also detected: 2 from the 2013–14 period, 3 from the 2014–15 period, and 3 from the 2015–16 period. Combined, 23 white sharks were detected during the 2016–17 period (Fig. 1).

A total of 22,152 acoustic detections was recorded (mean ± standard error = 963 ± 212). Tagged white sharks were detected for periods ranging between 3 and 53 days (Table 1).

Table 1. Detection summary of white sharks (n=61) between July 2016 and May 2017 acoustically tagged at the Neptune Islands Marine Park (N = North, S = South). TL = total length (m).

Shark	TL	Sex	Date	Location	N detections			N days detected		
					N+S	N	S	N+S	N	S
1	4.1	Female	14/09/2013	S	*	*	*	*	*	*
2	3.3	Male	15/09/2013	S	*	*	*	*	*	*
3	4.5	Male	28/09/2013	N	*	*	*	*	*	*
4	4.1	Male	9/10/2013	N	*	*	*	*	*	*
5	4.5	Male	14/10/2013	N	*	*	*	*	*	*
6	3.0	Male	26/10/2013	N	3	3	*	1	1	*
7	4.5	Male	26/10/2013	N	*	*	*	*	*	*
8	2.0	Male	15/11/2013	N	*	*	*	*	*	*
9	4.0	Male	29/01/2014	N	*	*	*	*	*	*
10	3.5	Male	29/01/2014	N	*	*	*	*	*	*
11	3.8	Male	29/01/2014	N	*	*	*	*	*	*
12	4.3	Male	23/02/2014	N	*	*	*	*	*	*
13	2.4	Male	24/02/2014	N	12	*	12	2	*	2
14	4.5	Female	26/02/2014	N	*	*	*	*	*	*
15	3.0	Male	28/02/2014	N	*	*	*	*	*	*
16	3.0	Male	18/07/2014	N	824	824	*	53	53	*
17	3.6	Male	19/07/2014	S	*	*	*	*	*	*
18	3.9	Female	19/07/2014	S	*	*	*	*	*	*
19	3.3	Male	20/07/2014	S	*	*	*	*	*	*
20	3.7	Female	20/07/2014	S	*	*	*	*	*	*
21	4.2	Male	21/07/2014	N	2849	2849	*	34	34	*
22	4.0	Male	18/10/2014	S	*	*	*	*	*	*
23	3.0	Female	19/10/2014	N	*	*	*	*	*	*
24	4.5	Male	19/10/2014	N	*	*	*	*	*	*
25	3.5	Male	15/11/2014	N	*	*	*	*	*	*
26	3.8	Male	15/11/2014	N	*	*	*	*	*	*
27	3.2	Male	16/11/2014	N	*	*	*	*	*	*
28	3.9	Male	24/01/2015	N	*	*	*	*	*	*
29	3.7	Male	24/01/2015	N	*	*	*	*	*	*
30	2.7	Male	24/01/2015	N	*	*	*	*	*	*
31	4.2	Female	2/05/2015	S	*	*	*	*	*	*
32	1.8	Female	6/05/2015	S	1197	1176	21	14	11	3
33	4.2	Female	6/05/2015	S	*	*	*	*	*	*
34	4.5	-	7/05/2015	S	*	*	*	*	*	*
35	2.6	-	7/05/2015	S	*	*	*	*	*	*
36	3.0	-	7/05/2015	S	*	*	*	*	*	*

37	3.4	-	7/05/2015	S	*	*	*	*	*	*
38	2.8	-	7/05/2015	S	*	*	*	*	*	*
39	3.9	Male	8/11/2015	N	1920	1908	12	24	24	1
40	3.2	Male	8/11/2015	N	*	*	*	*	*	*
41	3.0	Male	17/12/2015	N	*	*	*	*	*	*
42	3.0	Male	17/12/2015	N	3531	3481	50	33	31	3
43	2.8	Male	17/12/2015	N	1903	1901	2	41	40	1
44	4.2	Female	12/04/2016	S	*	*	*	*	*	*
45	4.0	Female	12/04/2016	S	*	*	*	*	*	*
46	2.0	Male	24/09/2016	N	999	430	569	32	10	24
47	2.4	Male	25/09/2016	N	359	357	2	12	10	2
48	3.3	Male	16/10/2016	N	2062	1813	249	41	26	17
49	4.4	Male	16/10/2016	N	41	41	*	1	1	*
50	3.3	Male	16/10/2016	N	17	14	3	4	3	1
51	3.7	Male	13/11/2016	N	642	642	*	12	12	*
52	3.1	Male	27/11/2016	N	45	45	*	1	1	*
53	3.3	Male	1/12/2016	N	377	349	28	15	11	4
54	2.8	Female	8/04/2017	N	1970	1821	149	27	23	4
55	3.2	Female	8/04/2017	N	1799	1141	658	33	19	14
56	3.8	Male	18/04/2017	N	97	97	*	1	1	*
57	3.0	Female	18/04/2017	N	298	76	222	4	1	3
58	2.8	Female	18/04/2017	N	140	138	2	6	5	1
59	2.6	-	19/04/2017	N	130	130	*	2	2	*
60	3.7	-	19/04/2017	N	937	937	*	8	8	*
61	4.5	Female	12/05/2017	S	*	*	*	*	*	*

* Indicates that shark was not detected during the monitoring period.

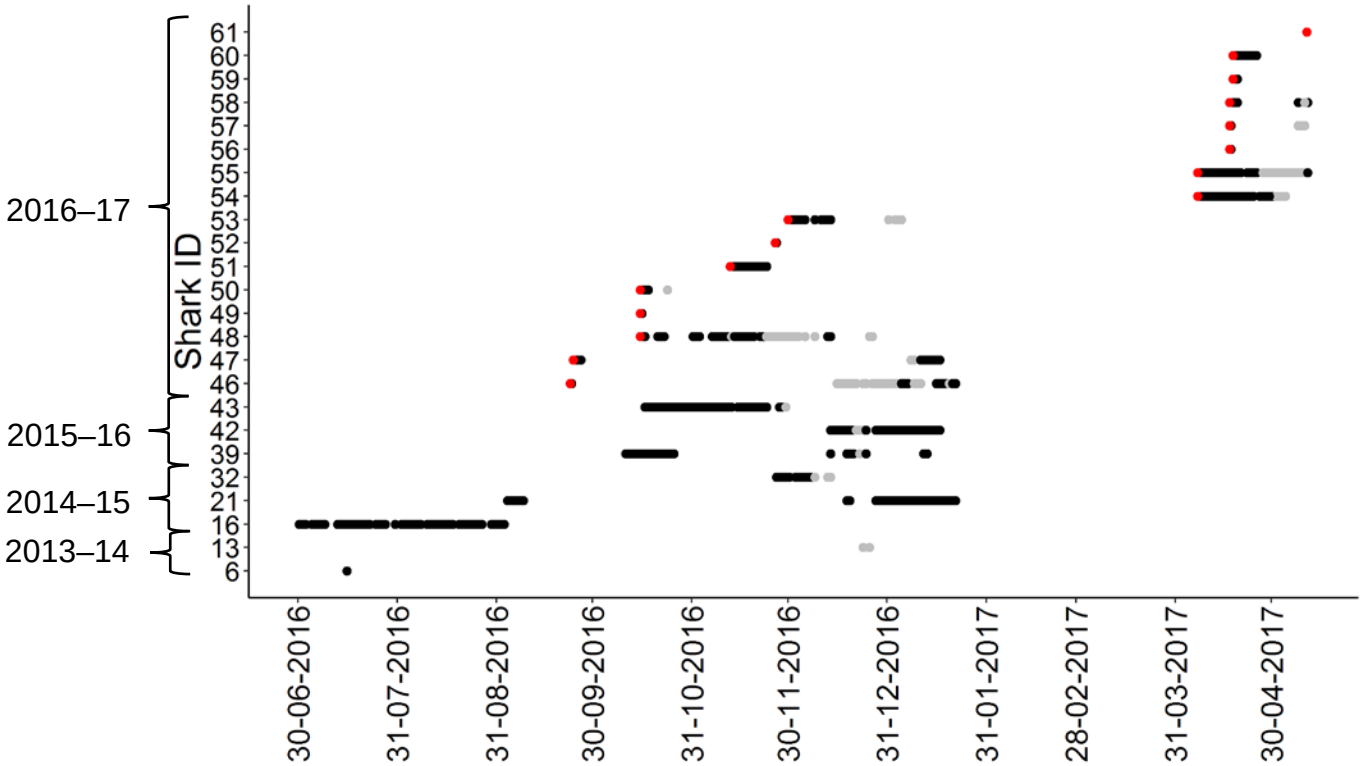

Figure 1. Daily detections for white sharks (n = 24) at the North (black symbols) and South (grey symbols) Neptune Islands between 1 July 2016 and 13 May 2017. Red symbol represents tagging date. Note: three sharks (Shark 62–65; not shown) were tagged after receivers were downloaded and Shark 61 was never detected.

8.1 Residency

Residency periods exhibited by white sharks at the North and South Neptune Islands combined ranged from <1 to 64 (Table 2). Patterns differed between individuals and locations (Table 2). At the North Neptune Islands the grand mean residency was 11.6 ± 16.3 days (grand median = 6.3). Most white sharks had a mean residency <5 days (43%), and 17% resided at North Neptune Islands for >20 days. For most individuals, residency periods were shorter at the South Neptune Islands, where the grand mean residency was 3.2 ± 3.9 days (grand median = 2.0). However, residency periods of some individuals were greater at the South Neptune Islands. For example, mean residency period of Shark 46 was 7.8 days (n = 3) at the South Neptune Islands and 3.0 (n = 3) at the North Neptune Islands.

Table 2. Summary statistics showing residency estimates (mean; N = number of visits) for white sharks (n =23; Shark 61 was not detected) at the North (N) and South (S) Neptune Islands between 1 July 2016 and 13 May 2017. SD = standard deviation. Summary statistics were not provided when a shark only had a single residency period.

Shark ID	Tagging location	North Neptune Islands						South Neptune Islands					
		N	mean	Log(mean)	SD	min	max	N	mean	Log(mean)	SD	min	max
6	N	1	0.0	-2.55									
13	N							1	1.7	0.24			
16	N	1	64.3	1.81									
21	N	3	10.0	1.00	13.2	0.2	25.1						
32	S	1	11.1	1.04				1	5.1	0.71			
39	N	4	5.6	0.75	7.0	0.1	15.4	1	0.0	-1.57			
42	N	1	34.0	1.53				1	1.8	0.27			
43	N	1	43.0	1.63				1	0.0	-3.01			
46	N	3	3.0	0.47	3.0	0.0	6.0	3	7.8	0.89	9.2	2.0	18.5
47	N	2	4.0	0.60	3.2	1.7	6.3	1	0.7	-0.14			
48	N	3	10.2	1.01	10.6	1.3	21.9	3	5.5	0.74	8.2	0.5	14.9
49	N	1	0.2	-0.64									
50	N	1	1.3	0.11				1	0.0	-2.58			
51	N	1	10.9	1.04									
52	N	1	0.3	-0.57									
53	N	1	12.6	1.10				1	3.9	0.59			
54	N	1	23.2	1.37				1	2.9	0.46			
55	N	2	9.2	0.97	13.1	0.0	18.5	1	13.7	1.14			
56	N	1	0.3	-0.56									
57	N	1	0.5	-0.32				1	2.1	0.33			
58	N	2	2.2	0.35	0.7	1.8	2.7	1	0.0	-2.87			
59	N	1	1.2	0.07									
60	N	1	7.0	0.85									
Grand mean			11.6	0.50					3.2	-0.34			
Grand median			6.3	0.80					2.0	0.30			
Grand SD			16.3	0.99					3.9	1.49			

8.2 Electronic logbook

Number of shark sighted

E-logbook describing cage-diving industry activities comprised 590 records between 1 September 2016 to 30 June 2016. These records provided information about operator activities and shark numbers for 226 days out of the 303 days (74.6%). Reported daily sightings ranged 0–12 white sharks (mean ± standard error = 4.31 ± 0.18; Fig. 2). No white sharks were sighted on 26 days (11.5% of the days at the Neptune Islands). Mean sightings was 4–6 white sharks per day between September to January and April to June. The

number of shark sighted decreased to <2 in February and March. Most of the shark sighted in September–January were males, while females were mostly sighted in April and May (Fig.2).

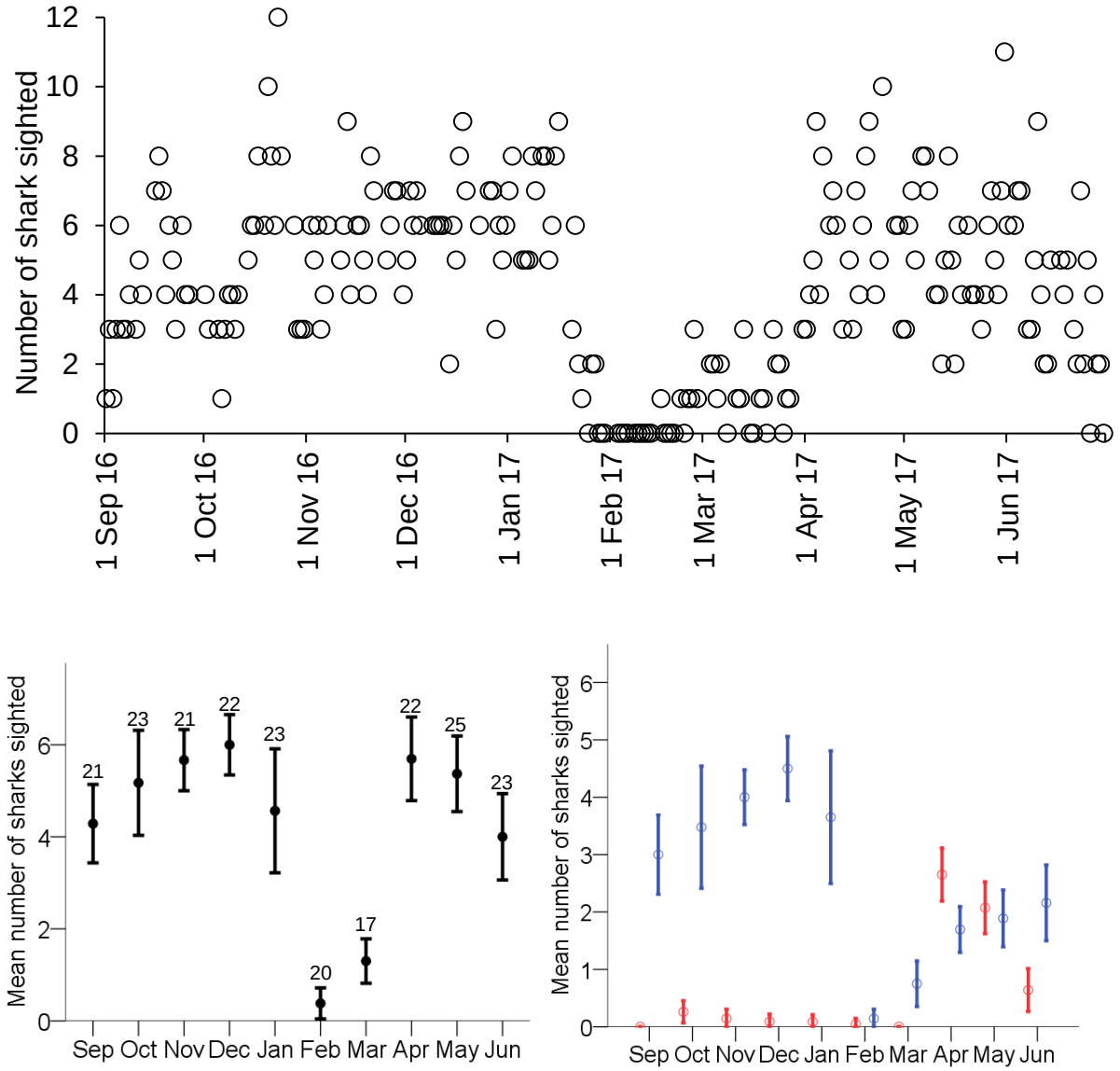

Figure 2. (Top) Number of shark sighted reported by the cage-diving operators through the Fulcrum™ e-logbook. (Bottom) Mean daily number of shark sighted for sex combined (left) and separated (right). Error bars represents 95% confidence intervals. Number next to each point shows the number of days operators were at the Neptune Islands each month.

Use of attractant

The total amount of berley used per day of operation varied between 0–165 litres (mean ± standard error = 61.7 ± 2.07) and was 0–80 litres per operator (mean ± standard error = 32.2 ± 0.82) (Fig 3a, b). The highest amount of berley used at the Neptunes was in late January (>120 litres per day). The amount of berley used was not significantly affected by the number of sharks sighted (Fig. 3c; linear regression not shown).

The total number of bait bins used per day of operation varied between 0–3.75 (mean ± standard error =0.74 ± 0.05) and was 0–3 per operator (mean ± standard error = 0.62 ± 0.04) (Fig. 4a, b). The increased amount of bait bins in late March 2017 was due to reporting confusion leading to the records from one operator not being reliable prior to late March 2017, and being excluded. The total amount of bait bins used prior to late March 2017 was therefore from one operator only and does not represent the total amount of bait used during that period. The number of bait bins used was not significantly affected by the number of sharks sighted (Fig. 4c; linear regression not shown).

Note: Some of the reported amount of berley and bait might have been affected by misinterpretation of the required reporting (see Discussion).

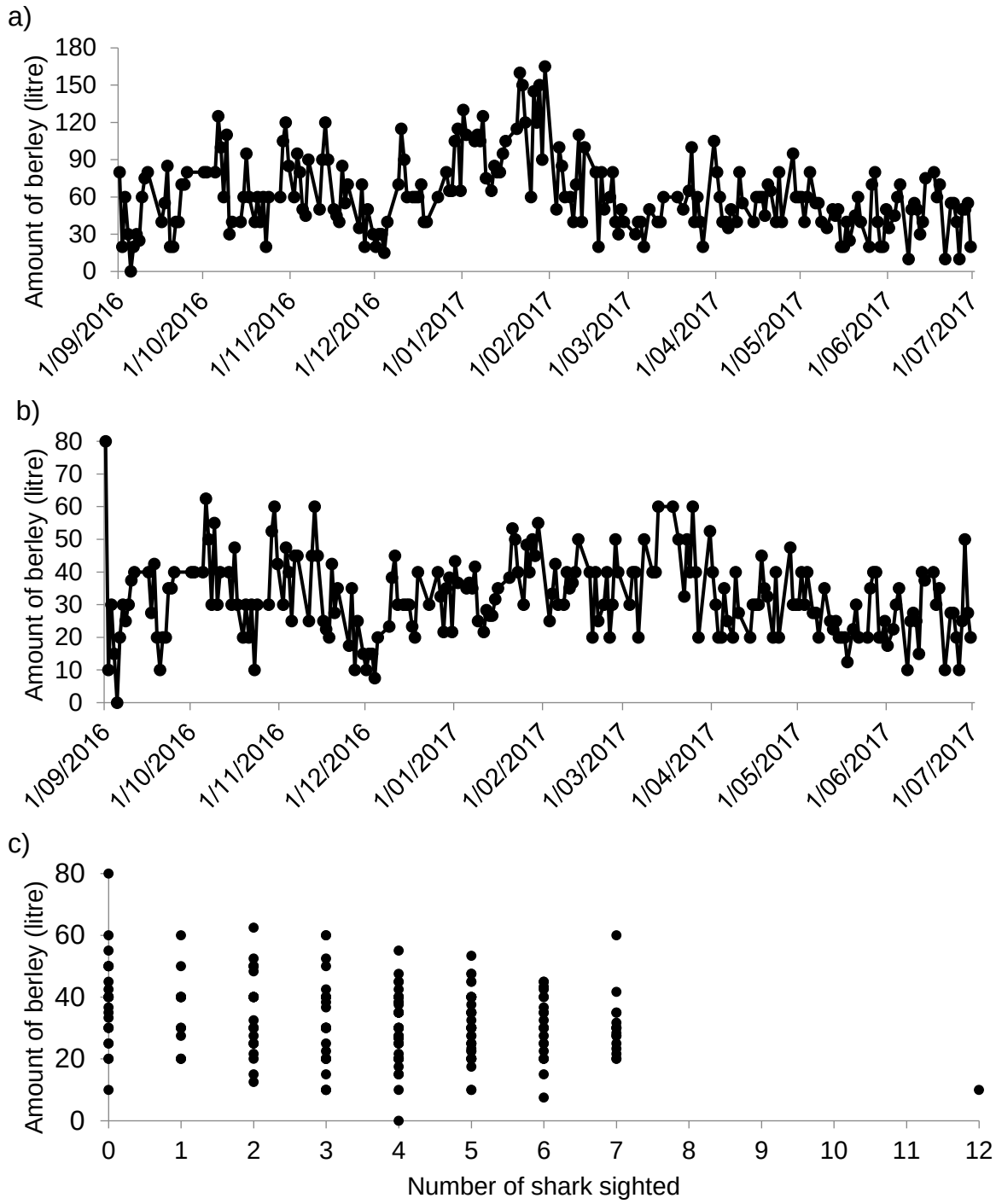

Figure 3. Amount of berley used between 1 September 2016 to 30 June 2017. (a) Total amount of berley used; (b) Amount of berley used per operators; and (c) Relationship between the number of shark sighted and amount of berley used.

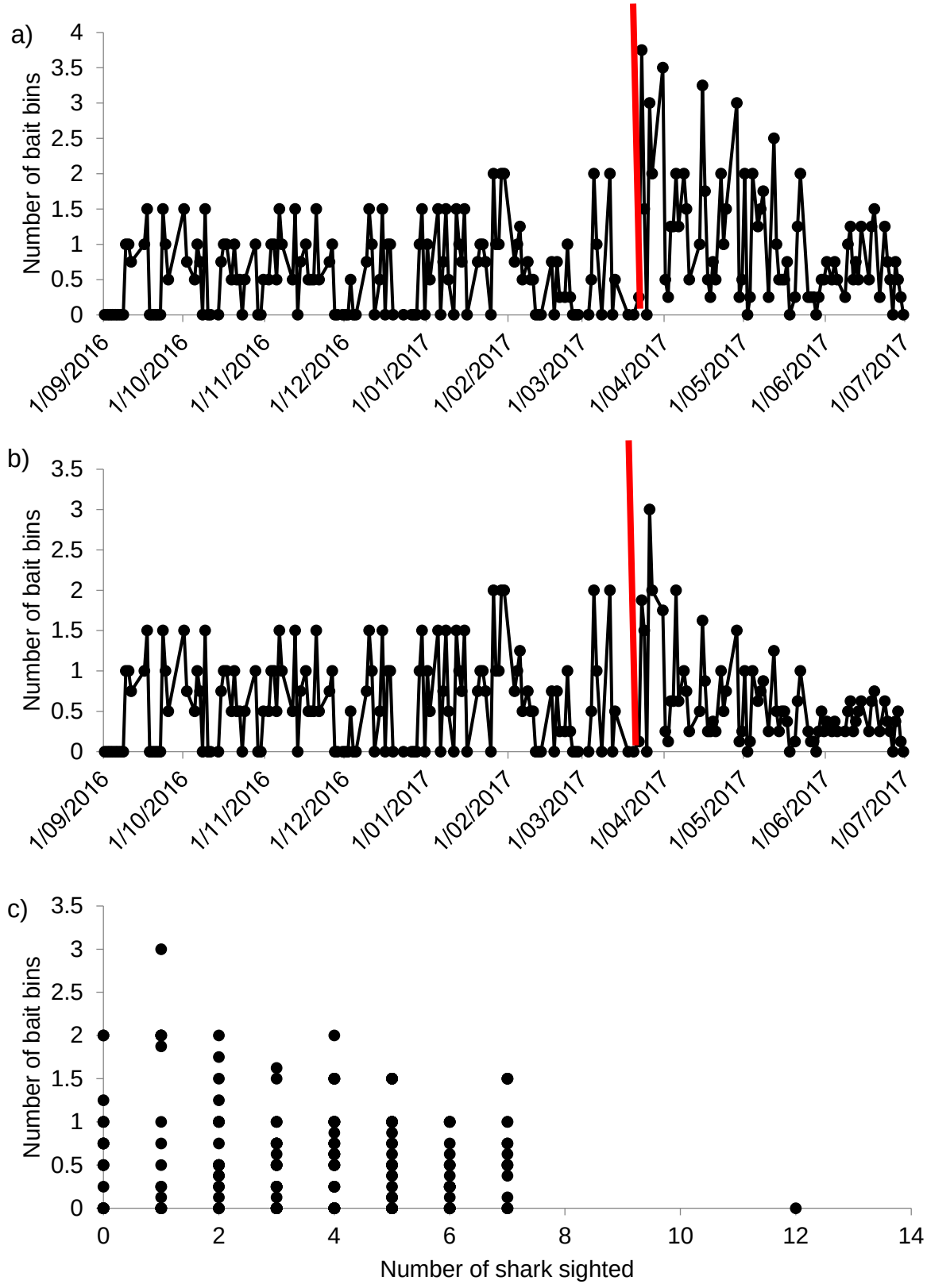

Figure 4. Number of bait bins used between 1 September 2016 to 30 June 2017. (a) Total number of bait bins; (b) Number of bait bins used per operators; and (c) Relationship between the number of shark sighted and number of bait bins used. The red line corresponds to the date when Fulcrum fields were modified to remove previous confusion with some fields. Records prior to that date includes one operator only;

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; Table 3). Based on this study, Smith and Paged (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. 5; Table 3).

In 2016–17, the grand mean residency of white sharks at North Neptune Islands was 11.6 days (log^{10} = 0.50) and is within the Target range.

Table 3. Estimates of overall mean log^{10} residency of whites sharks detected at North Neptune Islands.

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	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	1.32
2016-2017	11.6	16.3	0.50	0.99

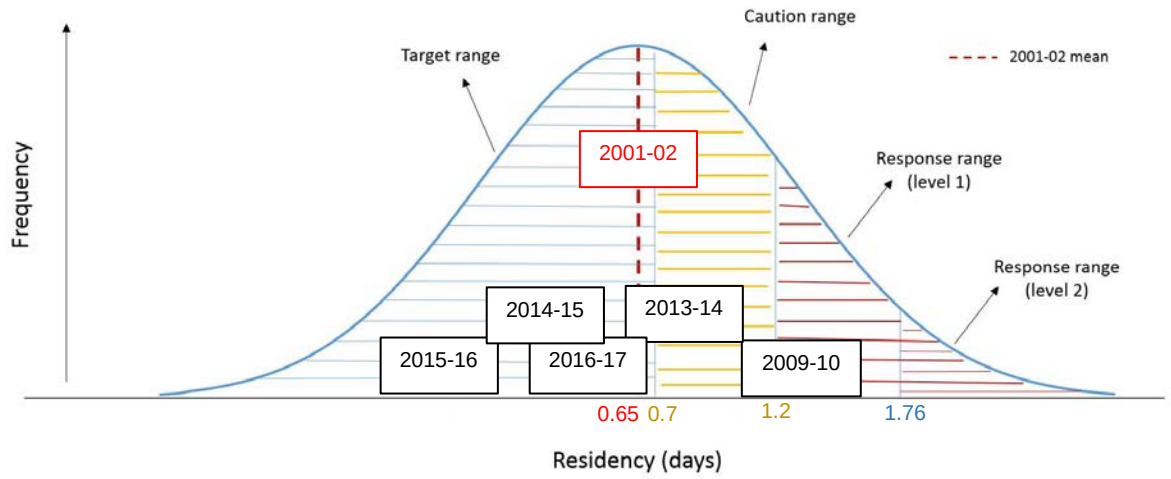

Figure 5. Schematic representation of the $\log^{10}$ of white shark residency at North Neptune Islands from 2001–02 until 2016–17. Position of the monitoring period date reflects the mean $\log^{10}$ value for that period.

9.2 Cage-diving activities

The e-logbook is an important tool to record cage-diving activities and the use of bait and berley. The e-logbook identified the largest amount of olfactory attractant used in late January, which coincided with the period of increased operator activity during days with long daylight hours. The number of bait bins decreased in late May–June, which corresponded to the period when a new 10-year license policy was discussed and put in place by DEWNR. This reduction in the amount of bait used by the operators shows an improvement in the practice of bait handling and that operators were less likely to lose bait to sharks. It is also possible that this reflects a change of reporting behaviour as a result of the new policy rather than an actual decrease in the number of baits consumed by white sharks.

The amount of berley and bait reported by the cage-diving operators should, however, be interpreted with caution due to confusion with the reporting system until March 2017 affecting the reliability of the information recorded, as seen with the sudden increased in the total number of bait bins after March 2017. Although we asked operators to only report baits that were consumed by white sharks or other organisms (e.g. when the tether breaks and the bait sinks to the seabed), some records might have also included recovered bait that were brought back to Port Lincoln. This might occur when the bait is not consumed for a period of time, leading operators to replace it with a new bait. When this occur, the old bait that is returned to Port Lincoln should not have been considered as ‘used’. The large number of bait used when no shark was sighted suggests that some records also included baits that

were returned to Port Lincoln. Combined, these factors likely affected the accuracy of the amount of bait used by the cage-diving industry.

10. CONCLUSION

The 2016–17 residency of white sharks at North Neptune Islands (0.50) continues to be within the Target range for a third consecutive year. Individual variation, however, remains high with shark residency ranging from less than a day to 64 days. Residency estimates should, therefore, be interpreted with caution, especially when originating from a low number of individuals.

Number of shark sighted and daily amounts of bait and berley used were reported by cage-diving operators throughout the monitoring period as required. However, potential confusion with the reporting system might have biased amounts recorded. Fields used to report attractant should be regularly reviewed in consultation with the cage-diving operators to ensure that the daily e-logbook is completed accurately. Operators should also ensure that new staff are adequately trained in the e-logbook and fields recording the amount of attractant used. The new industry policy and bait and berley limitations implemented in July 2017 might require the development of a new attractant reporting system to incorporate the need for compliance checks and avoid recording information multiple times.

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