Acoustic monitoring of large fishes and predators in South Australia's Marine Parks


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SOUTHERN SHARK ECOLOGY GROUP

Disclaimer

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Acoustic receiver deployments and servicing was funded by the Department for Environment and Water (DEW) and Flinders University, with the contribution of the Victor Harbor City Council and Oceanic Victor Pty Ltd. We thank Matt Lloyd and divers for the deployment and servicing of the acoustic receivers.

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EXECUTIVE SUMMARY

Quantifying the use of Marine Parks by marine animals such as fishes and sharks is integral to understanding the protective capacity of spatial management. While the location and size of Marine Parks is considered to play an essential role in protecting highly mobile species (in addition to effective planning, management, and enforcement), identifying how and to what degree distinct areas are connected, a concept broadly known as connectivity, is also imperative. This study investigated the presence, movements, and connectivity of three highly mobile marine species, bronze whalers (n = 55 [52 detected]; *Carcharhinus brachyurus*), white sharks (n = 132 [74 detected]; *Carcharodon carcharias*), and yellowtail kingfish (n = 24 [14 detected]; *Seriola lalandi*), within the South Australian Marine Park Network between 2010 and 2020. Acoustic telemetry was used to track the movements of animals (tagged with transmitters) when they swam near moored underwater receivers deployed within six South Australian Marine Parks (n = 67), as well as receivers outside of Marine Parks (n = 43) and South Australia (n = 37). The overall aim of the study was to quantify the presence of animals within Marine Parks relative to other areas, and identify connectivity between Marine Parks based on occurrences of individuals moving between them. Both bronze whalers and white sharks were detected (on any receiver) 6% and 7% of days monitored, respectively, while yellowtail kingfish were more resident (detected on 47% of days monitored). Despite these long absences (which are to be expected given the relative size of areas not monitored), both species of sharks were detected at up to three different Marine Parks (in addition to areas outside of Marine Parks and South Australia), whereas yellowtail kingfish were only detected at Neptune Islands Group Marine Park. Seasonal detections were variable across individuals and species, but broadly bronze whaler data showed an increase in the number of days detected from August to December, whereas yellowtail kingfish data was cyclical with the number of days detected peaking in May. No clear seasonal pattern was observed for white sharks. Bronze whalers and white sharks were detected in Marine Parks 53% and 100% of days with detections in South Australia (based on the median across individuals). Given that more receivers were deployed within compared to outside Marine Parks in South Australia (i.e., 61% of receivers were within Marine Parks), white sharks showed a stronger affinity to Marine Parks compared to bronze whalers. Bronze whalers and white sharks spent the greatest number of days within the Upper Gulf St Vincent and the Neptune Islands Group Marine Park, respectively. Connectivity between Marine Parks was typically limited because most animals were only detected at one Marine Park (mean across individuals); although bronze whalers were highly connected between Upper Gulf St Vincent Marine Park and unprotected areas adjacent to it. Overall, the high residency of yellowtail kingfish within the Neptune Islands Group Marine Park highlights the ability of Marine Parks to protect species attracted to specific areas. Bronze whalers and white sharks were not as readily detected as yellowtail kingfish; but most individuals spent a relatively large amount of time

within Marine Parks during days they were detected, particularly white sharks. Furthermore, Marine Parks showed some degree of connectivity, the amount of which may be limited by the number and spatial configuration of receivers. Acoustic telemetry, both within and outside of Marine Parks, provided an effective way to monitor these highly mobile species.

1. INTRODUCTION

1.1. Value of Marine Parks

Marine Parks, also commonly known as Marine Protected Areas (MPAs), provide increasingly important restrictions against human activities to help conservation and rehabilitation efforts in sensitive or ecologically important areas (Leenhardt *et al.* 2015). With clear spatial delineation and prioritisation of long-term sustainability of natural ecosystems being fundamental to the establishment and enforcement of MPAs, they provide a powerful tool to protect the oceans. Only a small portion of the oceans are protected globally (<10%), occurring at varying levels of protection (e.g., some industrial activity, such as fishing, may be allowed). Australia has one of the highest levels of protection in the world with 36% of coastal waters designated as protected and 9.6% of which is at least highly protected (Marine Protection Atlas (2023). When planned and managed effectively, MPAs have been demonstrated to be highly effective at preventing habitat destruction, pollution, over-exploitation of marine resources such as fishes, and population declines of endangered species, among others (Leenhardt *et al.* 2015; Ban *et al.* 2017; Davidson and Dulvy 2017). In addition to environmental benefits, Marine Parks also provide social and economic value to humans that rely on the oceans and their resources for recreation, culture, and livelihood. Thus, understanding how Marine Parks are used by marine animals, such as fishes and sharks, is important for effective management of species that contribute not only to the wellbeing of ecosystems, but humans as well. For example, identifying how frequent animals are present within Marine Parks and whether multiple Marine Parks are used together (i.e., connectivity) provides key information about the role Marine Parks have in protecting and supporting animal populations long-term.

The South Australian Marine Park Network consists of 19 Marine Parks formed in 2009, covering over 26,000 km^2 of ocean. Seven key biophysical principles were used to design and establish the network (Department for Environment and Heritage 2008); the four main principles include *precautionary or anticipatory approach* (i.e., avoiding harm or risk is priority), *comprehensiveness* (i.e., full range of habitats and ecosystems included), *adequacy* (i.e., ongoing viability and support for natural processes), and *representativeness* (i.e., must reflect natural biodiversity and variability). Secondary principles include *connectivity and linkages* (i.e., importance of different sites), *resilience and vulnerability* (i.e., maintenance of natural state and processes), and *ecological importance* (i.e., inclusion of important areas and species). Additional priorities also exist, mainly pertaining to management and social, cultural, and economic goals (Department for Environment and Heritage 2008). These principles, developed and adapted from established national and international criteria, are integral for the success and long-term viability of the Marine Parks and the species and habitats they have been designed to protect.

1.2. Acoustic telemetry

Acoustic telemetry is a technological tool that uses acoustic signals to identify and track the movements of aquatic animals (Hussey *et al.* 2014). The technology is composed of two main parts: transmitter and receiver. The transmitter emits a coded frequency-specific signal that travels through the water. It is attached internally or externally to an animal. The receiver, usually moored stationary underwater close to the bottom, detects and stores the signals emitted by transmitters. Receivers are only able to detect transmitters when the tagged animal is within a certain distance of the receiver because the sound waves eventually attenuate and are undecipherable. The distance at which detections are possible, commonly known as the detection range, varies across systems (e.g., marine vs freshwater, depth, environmental profile; Kessel *et al.* 2014; Huveneers *et al.* 2016), but is usually between 100 – 1000 m. Tracking aquatic animals with acoustic telemetry is mainly limited by the number and location of receivers because data are only generated when receivers are deployed in areas used by tagged animals. Thus, space use is typically underestimated because receivers are typically not deployed throughout the home range of the animal. Nevertheless, acoustic telemetry offers many benefits for conducting research on the presence and movements of aquatic animals because once transmitters and receivers are deployed, they collect data autonomously, often collected millions of data points over long periods of time. As a result, acoustic telemetry research has investigated a broad range of topics pertinent to the management of freshwater and marine ecosystems (Matley *et al.* 2022).

1.3. Study species

Highly mobile species were the focus of this study, in part because the role of Marine Parks in adequately protecting species that travel large distances is not well known, but evidence suggests that large and well-connected MPAs can provide effective protection from threats such as illegal or unsustainable fishing (Dulvy *et al.* 2004; Knip *et al.* 2012; Dwyer *et al.* 2020). Studying connectivity of highly mobile species throughout the South Australian Marine Parks Network has been identified as a priority given the ecological role of mobile species such as sharks (Jones *et al.* 2018). Three mobile species were tracked for this study — bronze whalers (*Carcharhinus brachyurus*), white sharks (*Carcharodon carcharias*), and yellowtail kingfish (*Seriola lalandi*). Bronze whalers are found throughout most coastal temperate regions of the world in waters shallower than 100 m (Kellett 2021; Stephenson *et al.* 2023). Like most other sharks they are slow-growing and late-maturing (e.g., ~16 years), growing as large as 3.2 m (Drew *et al.* 2017). Their diet is diverse (e.g., bony fish, rays, squid, octopus) with foraging typically occurring towards the bottom of the water column. Bronze whalers undergo seasonal migrations largely associated with water temperature, in which animals move to lower latitudes during colder months and higher latitudes during warmer months

(Drew *et al.* 2019). White sharks are distributed throughout the world's oceans, only excluded from colder temperate and polar regions (Gubili *et al.* 2012). Females can grow to over 5 m and mature after 30 years of age; males are typically smaller and mature a few years earlier (Bruce 2008). White sharks feed primarily on large prey such as marine mammals, fish, seabirds, sea turtles and other sharks (Bruce 2008). Movements of white sharks near Australia are variable and difficult to predict, commonly moving along the coasts but also making migrations to New Zealand or other islands in the Pacific Ocean (Bradford *et al.* 2020; Duffy *et al.* 2012; Spaet *et al.* 2020). Generally, they make seasonal movements associated with water temperature (e.g., seeking cooler waters during warmer months; Bruce *et al.* 2019). Finally, yellowtail kingfish are a large (>1.5 m) schooling species in temperate and tropical waters between 13 – 26°C (Clarke *et al.* 2023). They prefer shallow depths (<50 m) in coastal areas feeding on pelagic prey such as baitfish (e.g., mackerel, prawn, squid), and are also a popular fisheries target. Broad-scale distribution of yellowtail kingfish is also influenced by water temperature; for example, becoming more abundant in south-eastern Australia during warm productive months (Champion *et al.* 2020; Niella *et al.* 2022).

1.4. Study aims

The overall aim of the study was to quantify space use of large highly mobile species within, and connectivity between, South Australian Marine Parks using acoustic telemetry. Doing so will contribute to the Government of South Australia's Marine Parks Monitoring, Evaluation, and Reporting Plan (Bryars *et al.* 2017) by providing research output to help evaluate the adequacy and role of South Australian Marine Parks in protecting valuable marine species.

2. METHODS

2.1. Study area and receiver deployments

The study was conducted in and around the South Australia Marine Park Network between 2010 and 2020. One hundred and ten acoustic receiver (67 and 43 stations with detections within and outside Marine Parks, respectively) were deployed throughout this area (Fig. 1). An additional 37 receiver stations outside of South Australia (managed by IMOS) were incorporated due to detections of study animals on these receivers. Receiver presence and deployment locations changed throughout the study period due to changes in resources across the study period. Receivers were deployed in seven South Australian Marine Parks: Investigator, Thorny Passage, Neptune Islands Group, Western Kangaroo Island, Upper Spencer Gulf, Upper Gulf St Vincent, and Encounter. Receiver arrays, which were located both within and outside of South Australian Marine Parks were deployed in the following regions: Pearson/Flinders Islands, Coffin

Bay, Neptune Islands, Upper Gulf St Vincent, Glenelg, Fleurieu Peninsula, Pages Islands, and Victor Harbour (Fig. 1). Receivers were deployed <1 m off the bottom either directly via scuba or snorkel by hammering a long steel post into the substratum and attaching the receiver to it (hydrophone upwards), or remotely by lowering from the surface a receiver anchored by chain and concrete blocks and floated upright (hydrophone upwards) with a rope-attached float. Detection data on receivers were downloaded intermittently throughout the study period, typically between 6 months and a year. Additional descriptions of the receiver arrays are provided elsewhere (Huveneers *et al.* 2014a; 2014b; Rogers *et al.* 2014; Rogers and Huveneers 2016; Huveneers and Lloyd 2017; Munroe and Huveneers 2019).

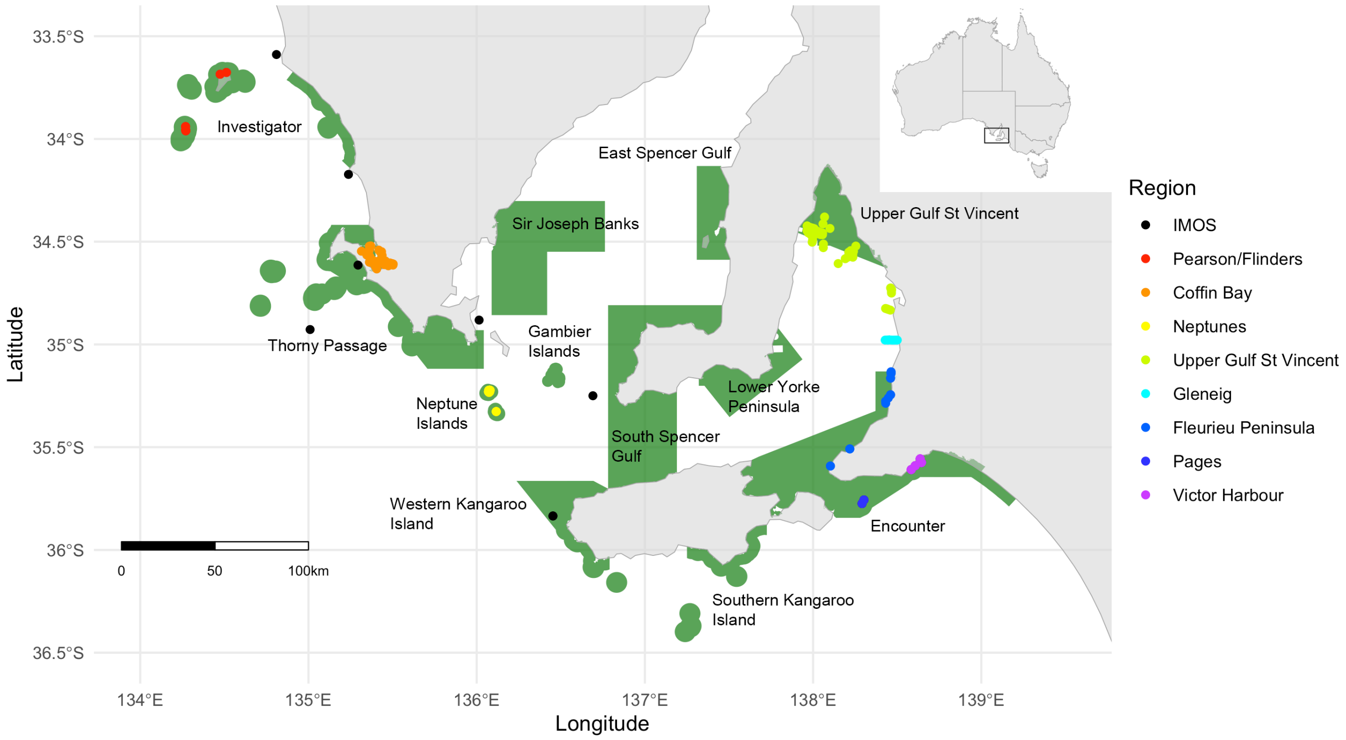

Figure 1: Receiver station locations (points coloured by general region) within and around the South Australia Marine Park Network (green areas delineating the different Marine Parks). Note Upper Spencer Gulf is not identified in the map due to the limited detections there (and for scaling). IMOS receivers outside of South Australia are not included.

2.2. Animal tagging

Animals were tagged with acoustic transmitters either internally or externally. Internal tagging consisted of catching the animal on hook and line, securing the animal ventral-side up, and surgically implanting a transmitter; the incision was then sutured closed. External tagging consisted of attaching a transmitter to the dorsal musculature with a modified speargun when the animal swam beside the vessel. Transmitter battery lives varied, but factory settings typically ranged between 2 – 10 years. Capture/release locations varied across species: bronze whalers (n = 55) were tagged at Upper Gulf St Vincent (Drew *et al.* 2019); white sharks (n = 132) were tagged at Neptune Islands (Niella *et al.* 2023); and yellowtail kingfish (n = 24) were tagged at Neptune Islands and Coffin Bay (Clarke *et al.* 2022).

2.3. Data analysis

Detection data from receivers were downloaded and examined to ensure quality assurance. Specifically, false detections (e.g., detections occurring for an animal at unrealistic locations or time periods due to incorrect acoustic signals being detected by a receiver) and dropped tags or dead animals within the detection range of receivers (e.g., resulting in falsely identifying a living animal present) were investigated and filtered when necessary. Both instances can be problematic in the proper interpretation of behaviour (Klinard and Matley 2020).

Various approaches were used to explore the presence of animals within and around the South Australian Marine Park Network. Most analyses were descriptive (i.e., reporting where and when animals were detected) given the scope of the study. Analyses also focused on daily occurrences of animals at different Marine Parks, as well as areas in South Australia outside of Marine Parks and areas outside of South Australia. The use of daily detection patterns (i.e., an animal was considered present if detected that day) was selected because it reduced biases associated with limited receiver coverage over shorter periods of time (e.g., hourly patterns might be confounded because the animal is not detected frequently despite being nearby). Animals that were detected for ≤15 days (between first and last detection; also known as their detection period) were not included in spatial estimates (e.g., presence within Marine Parks) to avoid inflating values from such limited number of detections. Note, animals with limited detections may have shed their tags, suffered a mortality event or transmitter malfunction, or not returned to a receiver station while their transmitter still had battery or prior to the end of the study.

3. RESULTS AND DISCUSSION

3.1. Detection summary

Detections from 52 (of the 55) tagged bronze whalers, 74 (of the 132) tagged white sharks, and 14 (of the 24) tagged yellowtail kingfish were tracked within the South Australian Marine Park Network between November 2010 and February 2020 (Fig. 2; Fig. 3; Fig. 4). Detection periods, defined here as the period between the first detection and last detection of each animal (by any receiver), excluding individuals with ≤15-day detection period, were between 1 – 2,132 days (mean ± SE: 762 ± 97 days), 1 – 1,349 days (376 ± 51 days) and 91 – 634 days (391 ± 46 days) for bronze whalers, white sharks, and yellowtail kingfish, respectively (Table 1; Table 2; Table 3). The number of unique days that bronze whalers, white sharks, and yellowtail kingfish were detected ranged between 1 – 705 days (57 ± 15 days), 1 – 140 days (31 ± 5 days), and 36 – 343 days (184 ± 24 days), respectively (Table 1; Table 2; Table 3). Based on these mean values, bronze whalers and white sharks were detected on any receiver ~7% and 8% of days monitored, respectively, while yellowtail kingfish was detected 47% of days monitored, all of which within the Neptune Islands Group Marine Park. Considering these animals are highly mobile pelagic predators and receiver coverage only incorporates a relatively small area in South Australia, it is not surprising to have low detection numbers for bronze whalers and white sharks. By contrast, yellowtail kingfish were highly resident to the Neptune Islands despite the capacity to make long-distance movements. For example, similar tracking work in this region found that a small number of yellowtail kingfish (8% of those tagged in South Australia) moved to New South Wales (Clarke *et al.* 2023). Variation in detection patterns across tagged individuals, as seen in this study, is also common, with some animals providing more detection data than others. Consequently, it is important to be cognisant of the strengths and limitations of acoustic telemetry at large scales. For instance, a lack of detections does not preclude animals being absent from areas near deployed receivers, nor can it be assumed animals are outside of a Marine Park because they are not detected there each day, particularly for Marine Parks with relatively limited receiver coverage (e.g., Thorny Passage).

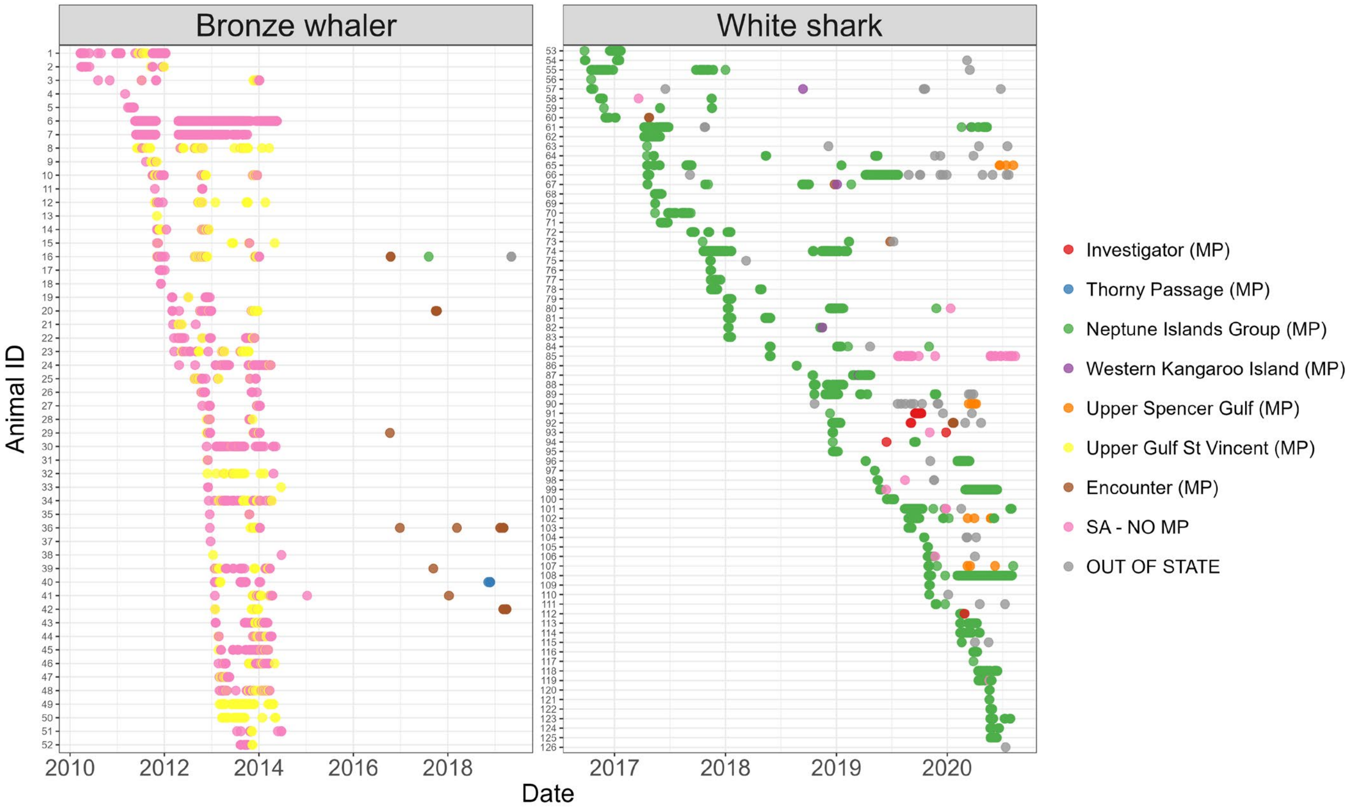

Figure 2: Daily presence of sharks at the different Marine Parks, as well as unprotected areas in South Australia and out of state receiver locations. Note, there may be some overlap in points from different areas detected on the same or proximate day and may not always be visible.

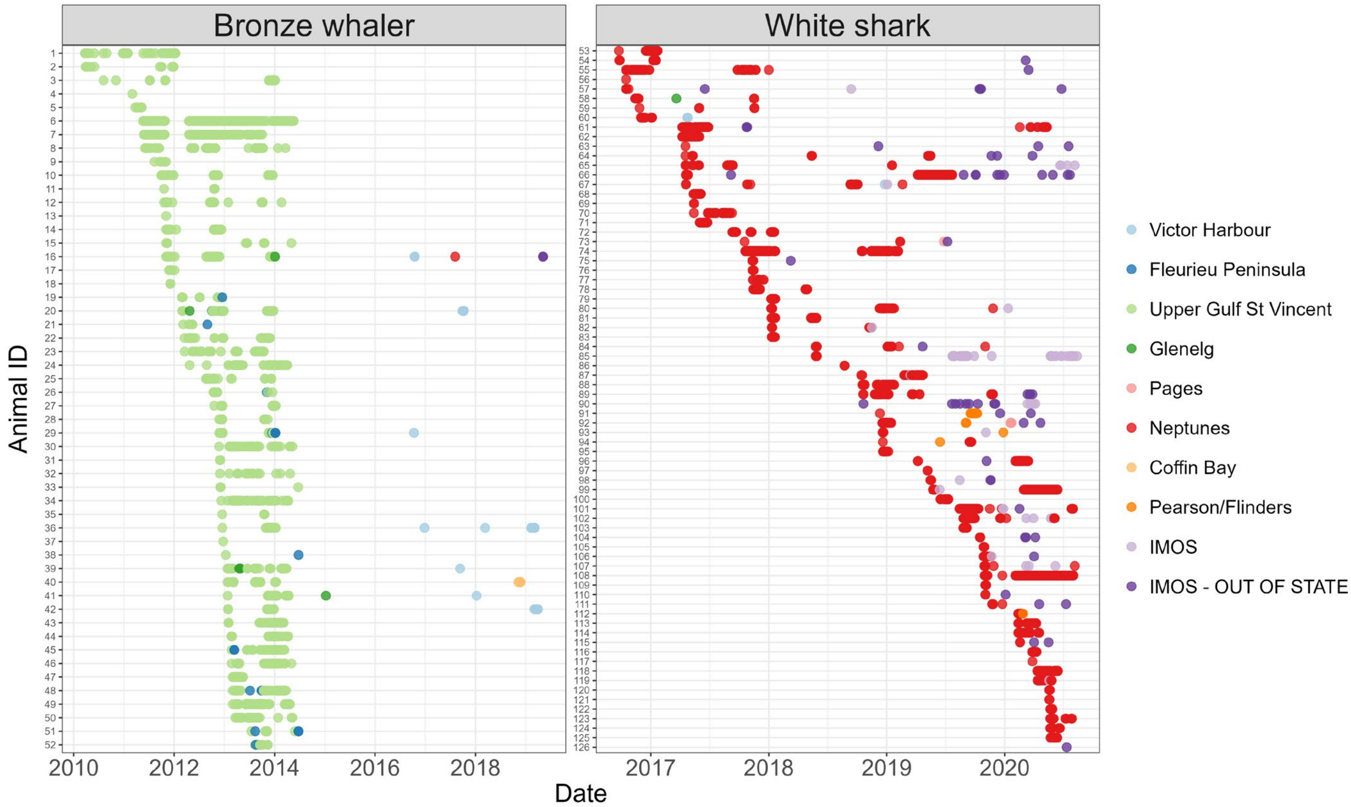

Figure 3: Daily presence of sharks at the different receiver array regions, as well as out of state receiver locations managed by IMOS. Note, there may be some overlap in points from different regions detected on the same or proximate day and may not always be visible.

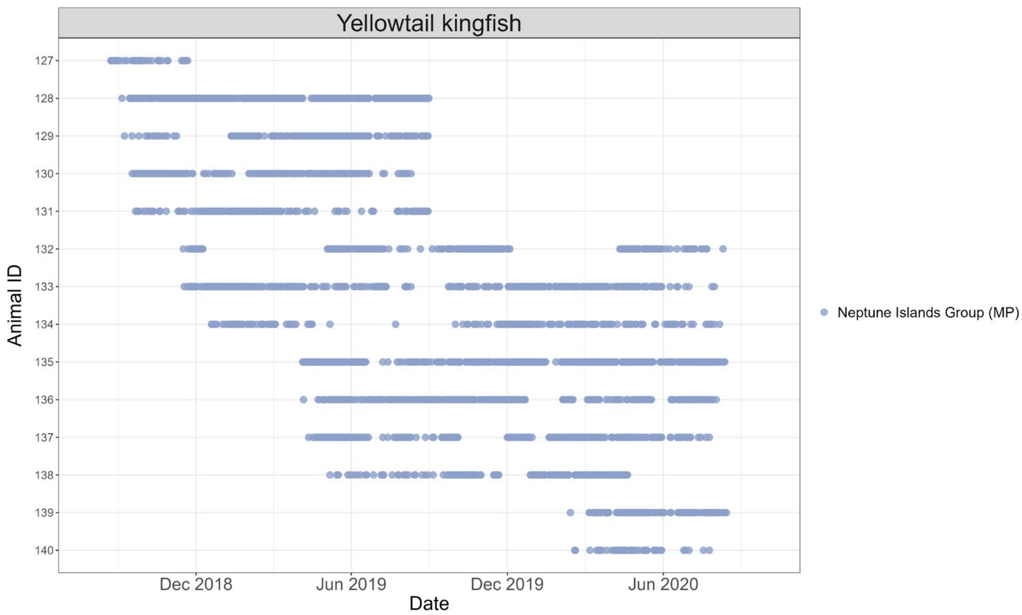

Figure 4: Daily presence of yellowtail kingfish at the different Marine Parks, noting that they were only detected at the Neptune Islands.

Table 1: Summary of detections of tagged bronze whalers including detections within South Australian Marine Parks. Rows highlighted in grey indicate animals that were detected for a period ≤15 days and were not included in mean calculations in the final two rows of the table. S.E. is standard error.

ID	First detection	Last detection	Sex	Size (cm)	Detection period (days)	Number of unique days detected	Number of detections	Number of Marine Parks visited	Percent detected in Marine Parks – relative only to days detected (%)	Percent detected in Marine Parks – relative to full detection period (%)
16	4/11/2011	8/05/2019	MALE	—	2743	99	3097	3	84	3
36	17/12/2012	7/03/2019	FEMALE	156	2272	32	848	2	88	1
42	27/01/2013	31/03/2019	FEMALE	119	2255	25	805	2	96	1
40	24/01/2013	25/11/2018	MALE	90	2132	33	1502	2	39	1
20	1/03/2012	8/10/2017	MALE	114	2048	60	3125	2	55	2
41	25/01/2013	9/01/2018	FEMALE	92	1811	41	2334	2	78	2
39	24/01/2013	11/09/2017	FEMALE	90	1692	69	5427	2	48	2
29	23/11/2012	10/10/2016	FEMALE	232	1418	29	498	2	34	1
3	6/08/2010	5/01/2014	FEMALE	123	1249	25	572	1	80	2
6	20/05/2011	20/05/2014	MALE	78	1097	705	207021	0	0	0
8	3/06/2011	21/03/2014	—	—	1023	66	1863	1	94	6
15	4/11/2011	3/05/2014	FEMALE	106	912	10	137	1	80	1
7	27/05/2011	3/10/2013	FEMALE	123	861	264	21276	0	0	0
12	19/10/2011	20/02/2014	MALE	95	856	43	1511	1	88	4
10	30/09/2011	19/12/2013	MALE	154	812	58	1185	1	60	4
24	23/04/2012	2/04/2014	—	—	710	73	1638	1	30	3
1	24/03/2010	11/01/2012	FEMALE	110	659	53	1422	1	13	1
2	28/03/2010	29/12/2011	FEMALE	106	642	15	167	1	13	0
22	16/03/2012	28/11/2013	FEMALE	103	623	34	864	1	24	1
23	17/03/2012	14/10/2013	MALE	104	577	70	2979	1	74	9
33	3/12/2012	21/06/2014	MALE	79	566	3	20	1	33	0
30	23/11/2012	10/05/2014	MALE	86	534	55	180	1	4	0
38	11/01/2013	24/06/2014	FEMALE	88	530	2	123	1	50	0
32	29/11/2012	23/04/2014	FEMALE	130	511	18	72	1	83	3

34	9/12/2012	10/04/2014	FEMALE	79	488	125	7486	1	66	17
25	20/08/2012	8/12/2013	FEMALE	115	476	44	4156	1	80	7
27	19/10/2012	9/01/2014	FEMALE	136	448	27	1283	1	56	3
46	23/02/2013	3/05/2014	MALE	85	435	68	2817	1	53	8
26	13/10/2012	16/12/2013	—	—	430	21	457	1	24	1
49	20/03/2013	10/05/2014	MALE	124	417	32	82	1	100	8
50	3/03/2013	23/04/2014	FEMALE	275	417	77	1044	1	100	18
44	21/02/2013	9/04/2014	MALE	115	413	28	1501	1	82	6
14	4/11/2011	10/12/2012	FEMALE	103	403	32	553	1	69	5
43	30/01/2013	8/03/2014	FEMALE	104	403	55	2862	1	62	8
48	2/03/2013	25/03/2014	FEMALE	101	389	83	3926	1	58	12
45	23/02/2013	13/03/2014	FEMALE	104	384	55	2530	1	24	3
11	19/10/2011	22/10/2012	MALE	137	370	6	78	1	17	0
28	23/11/2012	12/11/2013	FEMALE	173	355	14	330	1	43	2
51	15/07/2013	24/06/2014	FEMALE	103	345	11	282	1	18	1
35	16/12/2012	19/10/2013	FEMALE	122	308	4	305	1	25	0
19	27/02/2012	17/12/2012	MALE	99	295	23	715	1	9	1
21	7/03/2012	30/08/2012	MALE	95	177	6	125	1	33	1
52	12/08/2013	13/11/2013	—	—	94	17	316	1	18	3
9	12/08/2011	2/11/2011	FEMALE	92	83	5	136	1	60	4
47	2/03/2013	16/05/2013	FEMALE	82	76	58	4430	1	76	58
5	24/03/2011	11/05/2011	MALE	114	49	9	148	0	0	0
17	25/11/2011	4/01/2012	MALE	92	41	7	63	1	29	5
31	28/11/2012	2/12/2012	FEMALE	121	5	2	52	1	50	20
18	4/12/2011	5/12/2011	FEMALE	190	2	2	8	0	0	0
4	3/03/2011	3/03/2011	MALE	85	1	1	9	0	0	0
13	4/11/2011	4/11/2011	MALE	89	1	1	2	1	100	100
37	23/12/2012	23/12/2012	MALE	155	1	1	2	0	0	0
			Mean	**115**	**762**	**57**	**6262**	**1**	**50**	**5**
			S.E.	**6**	**97**	**15**	**4391**	**0**	**4**	**1**

Table 2: Summary of detections of tagged white sharks including detections within South Australian Marine Parks. The row highlighted in grey indicates the animal that was detected for a period ≤15 days and was not included in mean calculations in the final two rows of the table. S.E. is standard error.

ID	First detection	Last detection	Sex	Size (cm)	Detection period (days)	Number of unique days detected	Number of detections	Number of Marine Parks visited	Percent detected in Marine Parks – relative only to days detected (%)	Percent detected in Marine Parks – relative to full detection period (%)
57	16/10/2016	25/06/2020	MALE	330	1349	10	56	2	50	0
54	25/09/2016	6/03/2020	MALE	240	1259	13	362	1	92	1
55	16/10/2016	15/03/2020	MALE	330	1247	69	2916	1	99	5
65	18/04/2017	5/08/2020	FEMALE	280	1206	33	2049	2	100	3
66	19/04/2017	21/07/2020	—	370	1190	126	50290	1	91	10
63	18/04/2017	17/07/2020	MALE	380	1187	4	107	1	25	0
61	8/04/2017	11/05/2020	FEMALE	280	1130	84	14547	2	96	7
64	18/04/2017	27/03/2020	FEMALE	300	1075	20	5356	2	85	2
85	26/05/2018	12/08/2020	FEMALE	440	810	46	384	1	11	1
80	8/01/2018	12/01/2020	MALE	340	735	39	6917	1	97	5
67	19/04/2017	19/02/2019	FEMALE	260	672	25	779	3	100	4
73	18/10/2017	8/07/2019	—	390	629	5	137	2	80	1
90	21/10/2018	5/04/2020	MALE	420	533	13	119	1	31	1
84	26/05/2018	2/11/2019	MALE	320	526	21	3578	1	95	4
89	20/10/2018	27/03/2020	MALE	260	525	42	1645	1	90	7
92	18/12/2018	21/04/2020	MALE	360	491	33	5369	3	94	6
74	20/10/2017	6/02/2019	—	330	475	140	17783	1	100	29
91	11/12/2018	22/03/2020	MALE	375	468	24	4364	2	92	5
99	24/05/2019	13/06/2020	MALE	340	387	109	49164	1	99	28
93	19/12/2018	28/12/2019	MALE	370	375	6	783	2	83	1
58	13/11/2016	17/11/2017	MALE	370	370	15	690	1	93	4
59	27/11/2016	18/11/2017	MALE	310	357	5	191	1	100	1
101	14/08/2019	31/07/2020	—	290	353	71	36488	1	96	19
96	7/04/2019	14/03/2020	MALE	380	343	35	3994	1	97	10

82	10/01/2018	16/11/2018	MALE	280	311	7	332	2	100	2
102	26/08/2019	4/06/2020	MALE	300	284	45	15422	2	100	16
107	30/10/2019	5/08/2020	MALE	320	281	10	540	2	100	4
108	31/10/2019	1/08/2020	MALE	280	276	190	64536	1	100	69
94	20/12/2018	20/09/2019	MALE	280	275	8	1844	2	100	3
111	23/11/2019	9/07/2020	MALE	350	230	6	196	1	67	2
87	14/10/2018	23/04/2019	MALE	330	192	36	6094	2	100	19
98	16/05/2019	19/11/2019	MALE	310	188	7	1628	1	57	2
104	16/10/2019	5/04/2020	FEMALE	370	173	6	371	1	50	2
78	14/11/2017	30/04/2018	MALE	400	168	29	2825	1	100	17
106	28/10/2019	1/04/2020	MALE	370	157	16	2847	1	88	9
60	1/12/2016	25/04/2017	MALE	330	146	17	388	2	100	12
81	9/01/2018	29/05/2018	MALE	370	141	28	1736	1	100	20
72	10/09/2017	18/01/2018	MALE	330	131	29	1936	1	100	22
53	24/09/2016	22/01/2017	MALE	200	121	32	999	1	100	26
75	11/11/2017	10/03/2018	MALE	300	120	5	65	1	80	3
70	14/05/2017	9/09/2017	FEMALE	380	119	28	1307	1	100	24
88	18/10/2018	24/01/2019	MALE	370	99	32	1292	1	100	32
115	17/02/2020	16/05/2020	MALE	300	90	4	121	1	50	2
123	21/05/2020	27/07/2020	FEMALE	280	68	16	1801	1	100	24
114	12/02/2020	17/04/2020	MALE	280	66	17	722	1	100	26
118	11/04/2020	14/06/2020	FEMALE	270	65	36	9077	1	100	55
110	2/11/2019	4/01/2020	MALE	250	64	3	167	1	67	3
113	12/02/2020	8/04/2020	MALE	300	57	32	3261	1	100	56
62	8/04/2017	31/05/2017	FEMALE	320	54	52	3319	1	100	96
119	12/04/2020	26/05/2020	MALE	450	45	17	2472	1	94	36
77	13/11/2017	16/12/2017	MALE	340	34	10	166	1	100	29
124	21/05/2020	20/06/2020	FEMALE	410	31	14	2622	1	100	45
100	16/06/2019	11/07/2019	MALE	320	26	13	3740	1	100	50
71	1/06/2017	25/06/2017	MALE	330	25	23	2952	1	100	92
68	13/05/2017	5/06/2017	FEMALE	440	24	23	1305	1	100	96
125	22/05/2020	12/06/2020	FEMALE	380	22	18	3664	1	100	82
95	20/12/2018	6/01/2019	MALE	390	18	13	3224	1	100	72

112	12/02/2020	27/02/2020	FEMALE	290	16	10	258	2	100	63
116	26/03/2020	9/04/2020	FEMALE	310	15	14	2731	1	100	93
79	8/01/2018	21/01/2018	MALE	290	14	12	292	1	100	86
103	26/08/2019	6/09/2019	MALE	350	12	12	3388	1	100	100
83	10/01/2018	20/01/2018	MALE	340	11	10	285	1	100	91
122	21/05/2020	28/05/2020	MALE	265	8	8	328	1	100	100
76	12/11/2017	15/11/2017	FEMALE	290	4	4	135	1	100	100
109	2/11/2019	5/11/2019	MALE	360	4	4	435	1	100	100
105	28/10/2019	30/10/2019	—	320	3	3	956	1	100	100
120	18/05/2020	20/05/2020	FEMALE	285	3	3	543	1	100	100
69	14/05/2017	15/05/2017	FEMALE	320	2	2	80	1	100	100
86	23/08/2018	24/08/2018	MALE	380	2	2	27	1	100	100
97	7/05/2019	8/05/2019	MALE	310	2	2	710	1	100	100
121	18/05/2020	19/05/2020	MALE	370	2	2	159	1	100	100
56	16/10/2016	16/10/2016	MALE	440	1	1	41	1	100	100
117	11/07/2020	11/07/2020	MALE	280	1	1	1	0	0	0
126	27/03/2020	27/03/2020	FEMALE	450	1	1	163	1	100	100
			Mean	**333**	**376**	**31**	**6057**	**1**	**89**	**22**
			S.E.	**7**	**51**	**5**	**1694**	**0**	**3**	**4**

Table 3: Summary of detections of tagged yellowtail kingfish including detections within South Australian Marine Parks. S.E. is standard error.

ID	First detection	Last detection	Sex	Size (cm)	Detection period (days)	Number of unique days detected	Number of detections	Number of Marine Parks visited	Percent detected in Marine Parks – relative only to days detected (%)	Percent detected in Marine Parks – relative to full detection period (%)
132	16/11/2018	10/08/2020	—	131	634	198	37679	1	100	31
133	17/11/2018	31/07/2020	—	108	623	313	13676	1	100	50
134	19/12/2018	6/08/2020	—	80	597	176	2710	1	100	29
135	5/04/2019	12/08/2020	—	113	496	343	58579	1	100	69
136	6/04/2019	2/08/2020	—	107	485	255	30771	1	100	53
137	12/04/2019	25/07/2020	—	136.5	471	216	17215	1	100	46
128	5/09/2018	31/08/2019	—	102	361	274	10076	1	100	76
129	8/09/2018	30/08/2019	—	115	357	169	9773	1	100	47
138	7/05/2019	20/04/2020	—	115	350	137	7727	1	100	39
131	21/09/2018	30/08/2019	—	87	344	139	2295	1	100	40
130	17/09/2018	10/08/2019	—	112	328	170	5976	1	100	52
139	13/02/2020	14/08/2020	—	122	184	105	3275	1	100	57
140	18/02/2020	25/07/2020	—	136	159	43	746	1	100	27
127	23/08/2018	21/11/2018	—	129	91	36	903	1	100	40
			Mean	**114**	**391**	**184**	**14386**	**1**	**100**	**47**
			S.E.	**5**	**46**	**24**	**4510**	**0**	**0**	**4**

Variability existed in the number of days individuals and species were detected throughout monthly and annual periods of the study (Fig. 5; Fig. 6). For example, bronze whalers were increasingly detected towards the end of the year (e.g., from August to December), while white shark detections (based on unique days) peaked in April and May. However, monthly detections, in addition to annual detections, can be confounded by technical aspects of the study such as the release period of tagged animals (e.g., greater likelihood of detections sooner after release), and require caution when interpreting. Still, consistent seasonal gaps in bronze whalers were apparent, particularly in the middle of 2012 and 2013 (Fig. 2), suggesting seasonal drivers affect the behaviour of this species. Bronze whalers have been shown to move into cooler waters at higher latitudes (e.g., South Australia) during warm months and returning to lower latitudes during colder periods (Drew *et al.* 2019); thus, the change in monthly detections is likely associated with seasonal migrations. Similarly, there was a seasonal pattern based on monthly detection days of yellowtail kingfish, peaking in May and reaching its lowest count in September, despite an equivalent number of individuals being detected throughout the study (Fig. 7). Yellowtail kingfish aggregate seasonally in this area with Clarke *et al.* (2022) finding the highest residency in December and January, and lowest during July and August. Still, many kingfish remain at the Neptune Islands year-round (Clarke *et al.* 2022) while others move to areas more in-line with thermal preferences such as Sydney Harbour (Niella *et al.* 2022). The findings in this study also support seasonal migrations.

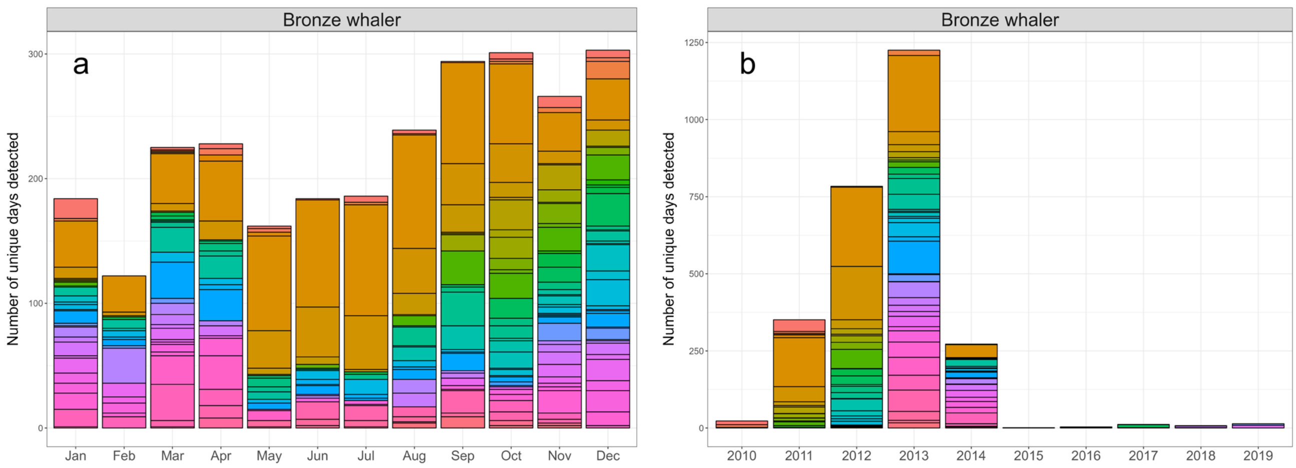

Figure 5: Number of days bronze whalers (coloured by individual) were detected within the South Australian Marine Park Network (including unprotected areas within South Australia) across months (a) and years (b) throughout the study period. Reduced detection of bronze whalers from 2014 is due to the receiver array in northern Gulf St Vincent being removed in early 2014.

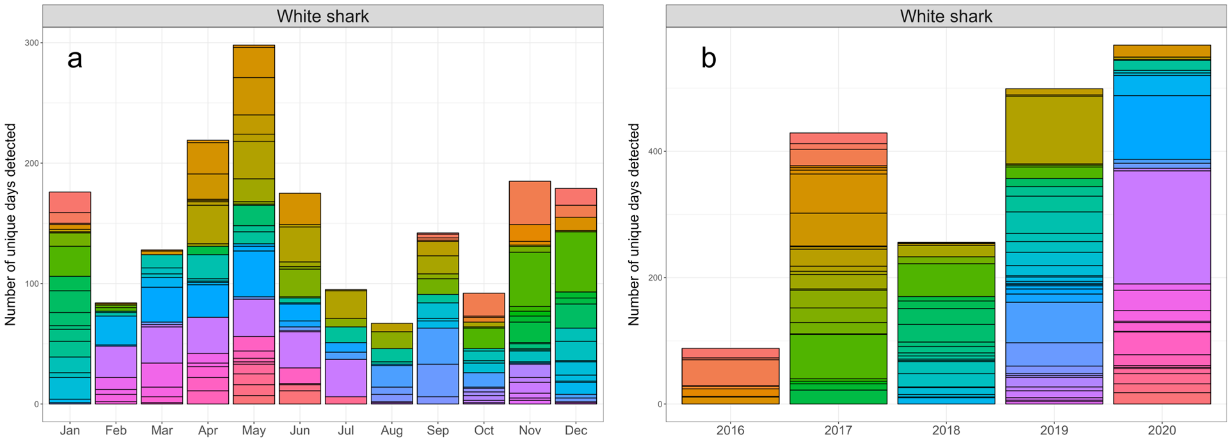

Figure 6: Number of days white sharks (coloured by individual) were detected within the South Australian Marine Park Network (including unprotected areas within South Australia) across months (a) and years (b) throughout the study period.

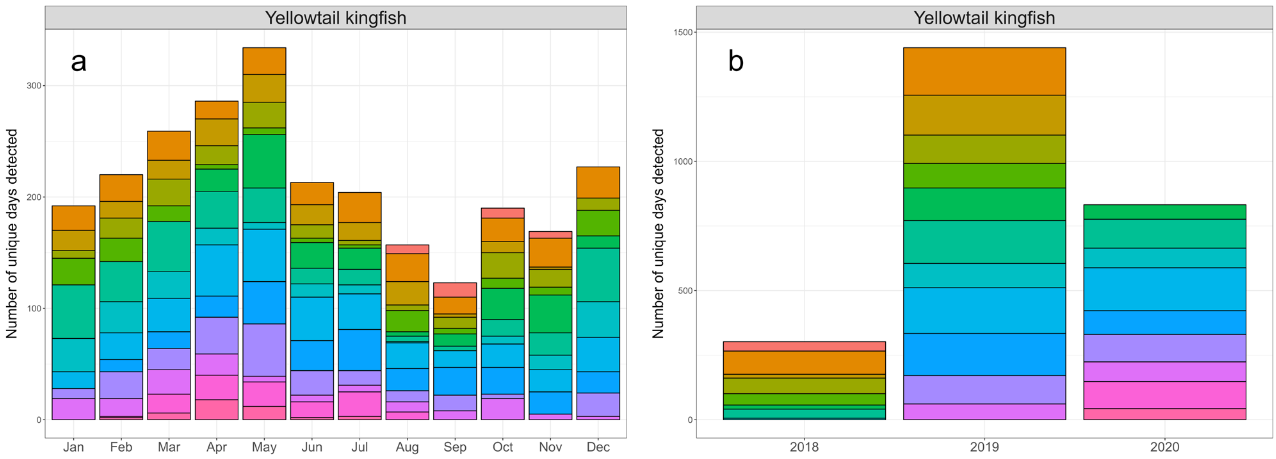

Figure 7: Number of days yellowtail kingfish (coloured by individual) were detected within the South Australian Marine Park Network (note, only Neptune Islands Group had detections) across months (a) and years (b) throughout the study period.

3.2. Space use throughout all Marine Parks

All tagged sharks detected >15 days were detected in at least one Marine Park (except for three bronze whalers; Table 1; Table 2). Both species, on average, were detected in one Marine Park with some individuals being detected in as much as three (Table 1; Table 2). Bronze whalers were detected in Marine Parks between 0 – 100% of days (50 ± 4%; median: 53%; when individuals with ≤15-day detection period omitted) when only days with detections were considered (Table 1). White sharks were detected in Marine Parks between 11 – 100% of days (89 ± 3%; median: 100%) when only days with detections were considered (Table 2). On days when animals were not detected in Marine Parks, they were either detected at receivers adjacent to the South Australian Marine Park Network or in other states. The high residency of yellowtail kingfish within the Neptune Islands Group Marine Park highlights the ability of this area in protecting this species, which appears to be attracted to the area by shark cage-diving tourism operations (Clarke *et al.* 2022).

When comparing animal space use or presence patterns between different areas (i.e., inside vs outside Marine Parks) with acoustic telemetry, it is necessary to consider biases that may affect interpretation of results, such as where animals were tagged and released, as well as the configuration of the receiver array. Regarding receiver array configuration in this study, 67 of the 147 receiver stations that detected animals were deployed in Marine Parks, while 43 locations were within South Australia but outside of Marine Parks and 37 locations were outside of South Australia. Therefore, within South Australia, there is likely a bias resulting in greater likelihood of detecting animals within Marine Parks compared to outside (i.e., 61% of locations are within Marine Parks). Under the assumption that each receiver location functions equivalently (e.g., detection efficiency and range are similar) and the specific layout of receivers does not affect the possibility of detections (e.g., single vs linear vs gridded receiver arrays; Kessel *et al.* 2020), the relative use of areas (weighted against the possibility of detections within them) was elucidated (Matley *et al.* 2021). Broadly, if an animal was detected within Marine Parks for more than 61% of time while being detected in South Australia, it demonstrated a high propensity to be selecting for areas with Marine Parks. For bronze whalers, 18/47 individuals were detected >61% of days in Marine Parks (i.e., mean: 50%; median: 53%), whereas 51/58 white sharks were detected >61% of days in Marine Parks (i.e., mean: 89%; median: 100%; Fig. 8). Therefore, white sharks showed a higher affinity to be within Marine Parks than bronze whalers, which more than half had negative selection for Marine Parks. Nevertheless, and as stated prior, there are potential confounding factors that may affect interpretation of these findings, such as receiver configuration, release location, and species-specific behavioural differences (see section 3.3).

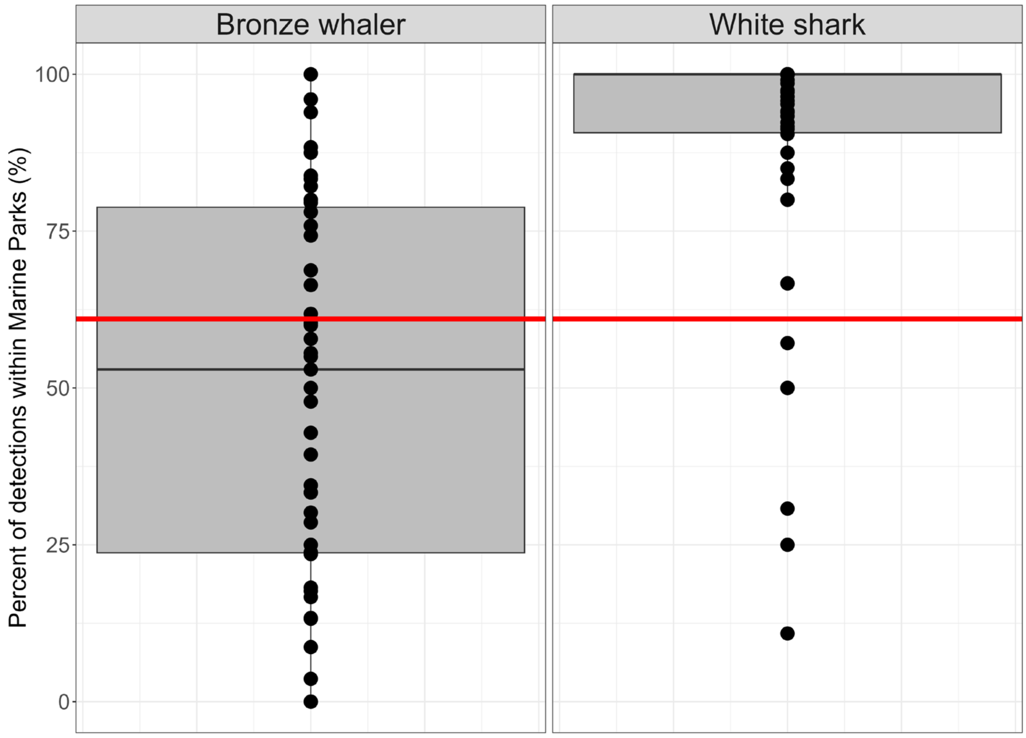

Figure 8: The percent of days individuals (black points) were detected within Marine Parks relative to days detected in unprotected areas of South Australia, summarized within-species using a boxplot (i.e., interior black line represents median values). The red horizontal line represents the percent of receivers within Marine Parks relative to the number of receivers in unprotected areas of South Australia (i.e., 61%). Estimates above this red line highlight a greater likelihood of positive selection for Marine Parks due to its higher relative use compared to availability, while estimates below the red line suggest negative selection due to the limited use despite availability. Note, there is some overlap in individual points.

3.3. Space use between Marine Parks

Bronze whalers were detected in Thorny Passage, Neptune Islands Group, Upper Gulf St Vincent, and Encounter but not Investigator or Western Kangaroo Island Marine Parks (Fig. 9; Fig. 10). Upper Gulf St Vincent was the primary Marine Park visited (all bronze whalers combined), but presence outside of Marine Parks was relatively common as well. Bronze whalers detected in Gulf St Vincent were also consistently detected at unprotected areas (Fig. 11), indicating a high degree of connectivity within the Gulf. Specifically, 49 individuals moved between Upper Gulf St Vincent and unprotected SA areas (i.e., within Gulf St Vincent; Fig. 12), with few movements between other areas (Fig. 12). Examining movements between receiver array areas, independent of Marine Parks, provided additional information on connectivity between regions (Fig. 1; Fig. 13). For example, 18 individuals moved from Upper Gulf St Vincent to adjacent areas including Glenelg (n = 4), Fleurieu Peninsula (n = 9), Victor Harbour (n = 4), and Coffin Bay (n = 1), with several returning directly from Glenelg (n = 2) and Fleurieu Peninsula (n = 6). One bronze whaler moved from Victor Harbour to the Neptune Islands, and one animal moved out of state from Neptune Islands (Fig. 13).

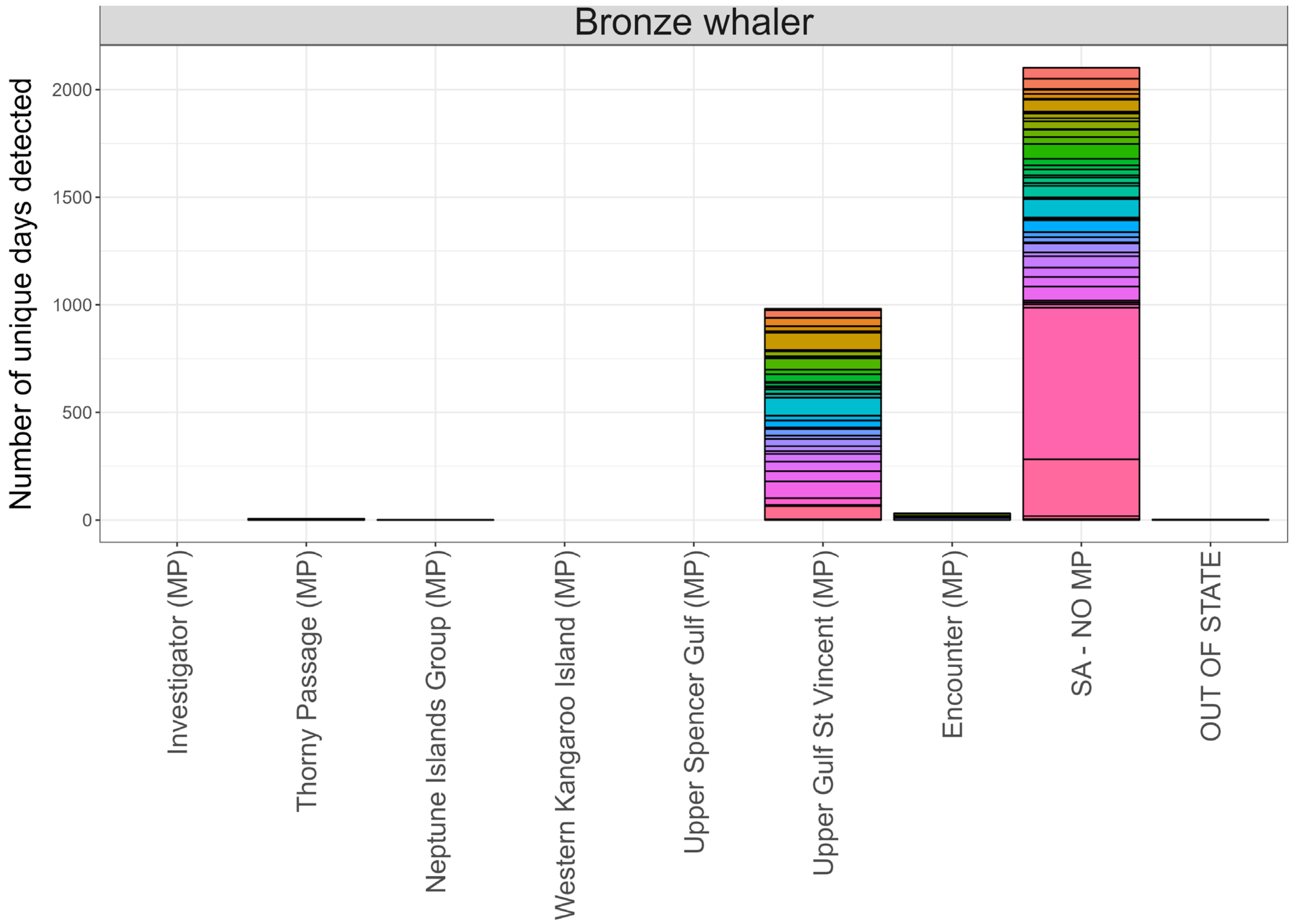

Figure 9: Number of days tagged bronze whalers were detected within each Marine Park (including unprotected South Australian areas and out of state detections) with emphasis on importance of different Marine Parks.

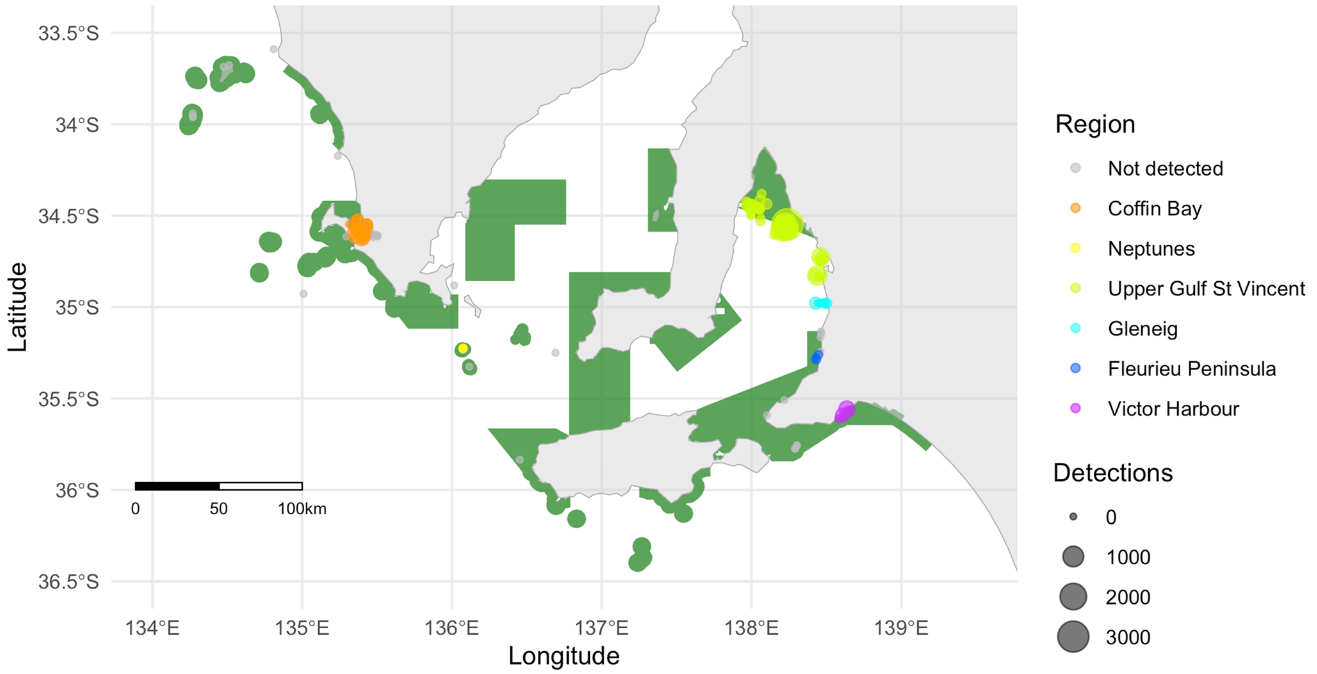

Figure 10: Detections of bronze whalers in the different regions (and receiver arrays) in South Australia throughout the study period. Note Upper Spencer Gulf is not identified in the map because there were no detections of bronze whalers.

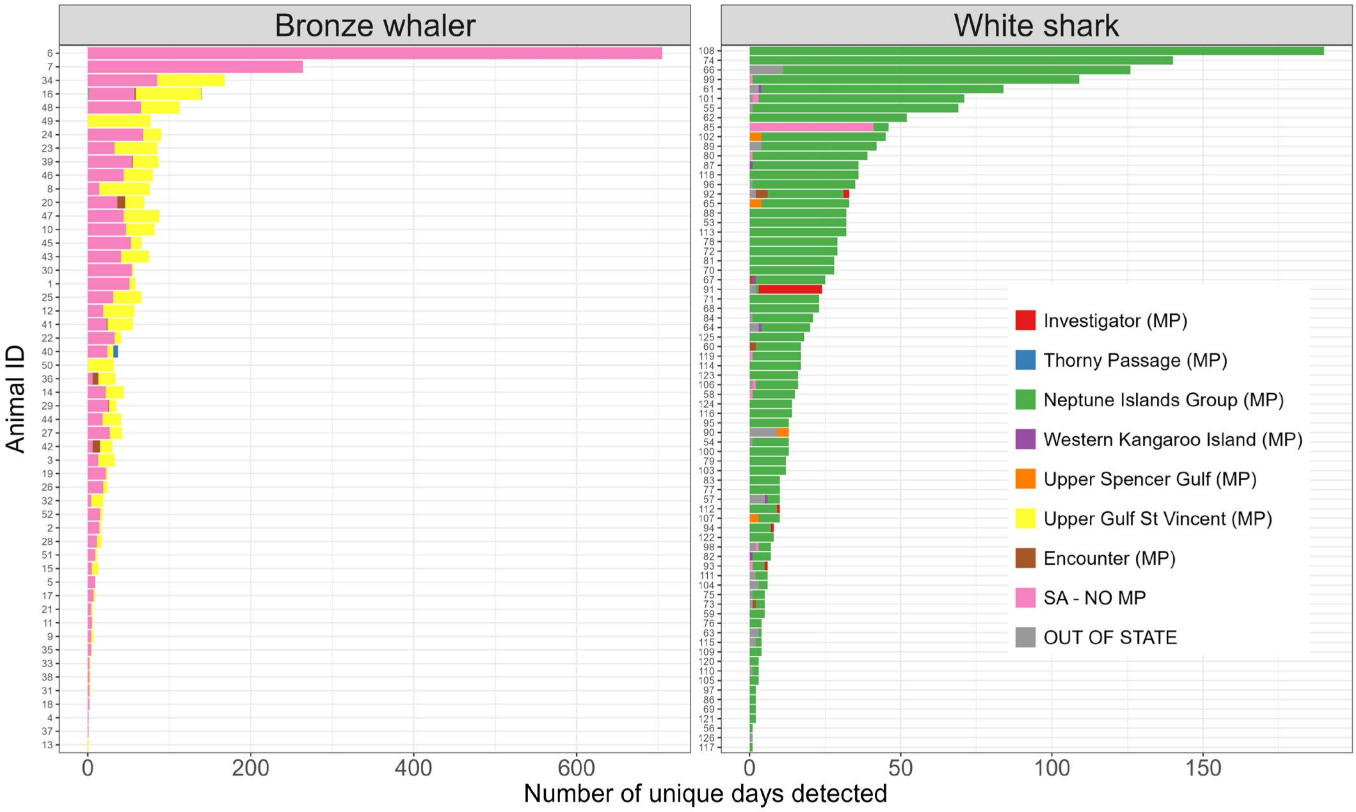

Figure 11: Number of days tagged bronze whalers were detected within each Marine Park (including unprotected South Australian areas and out of state detections) with emphasis on individual variability across species.

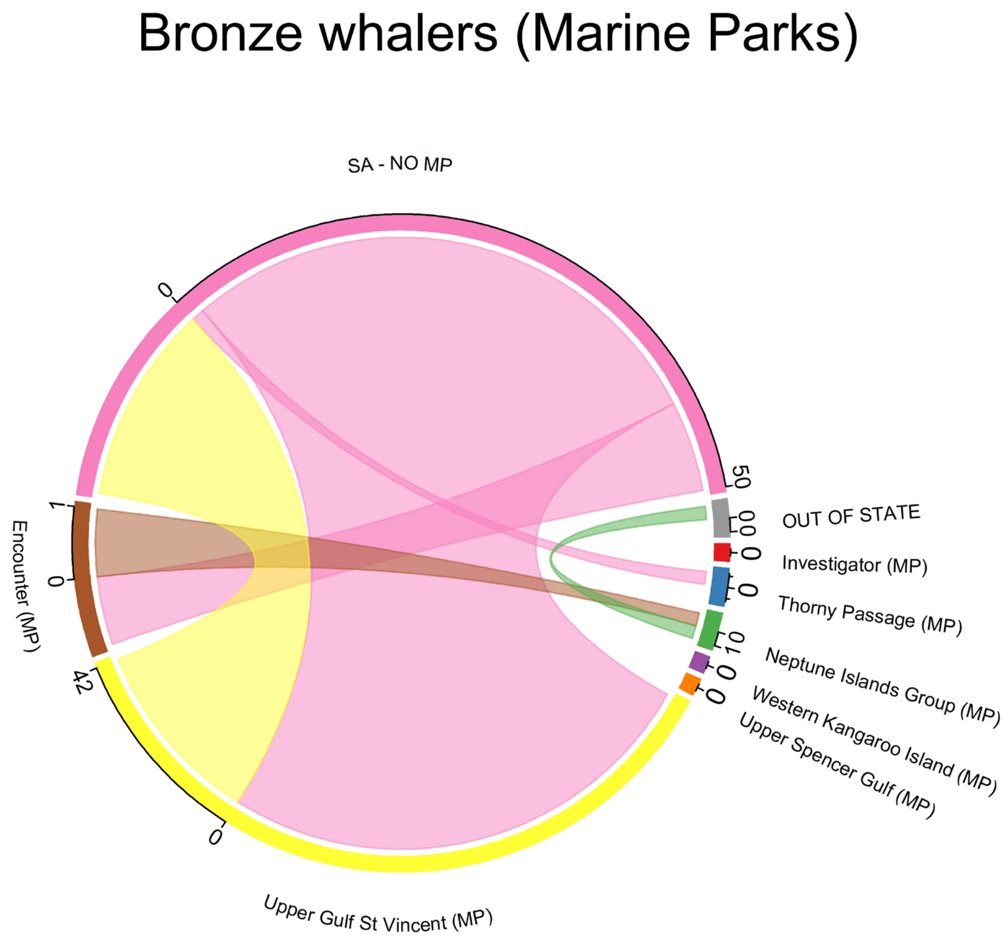

Figure 12: Connectivity of bronze whalers between Marine Parks (including unprotected South Australian areas and out of state detections). Each Marine Park is colour coordinated. Matching coloured lines and outer sectors indicate individuals moving from that area to another area (of different colour). The thickness of lines is weighted by the number of individuals making that movement.

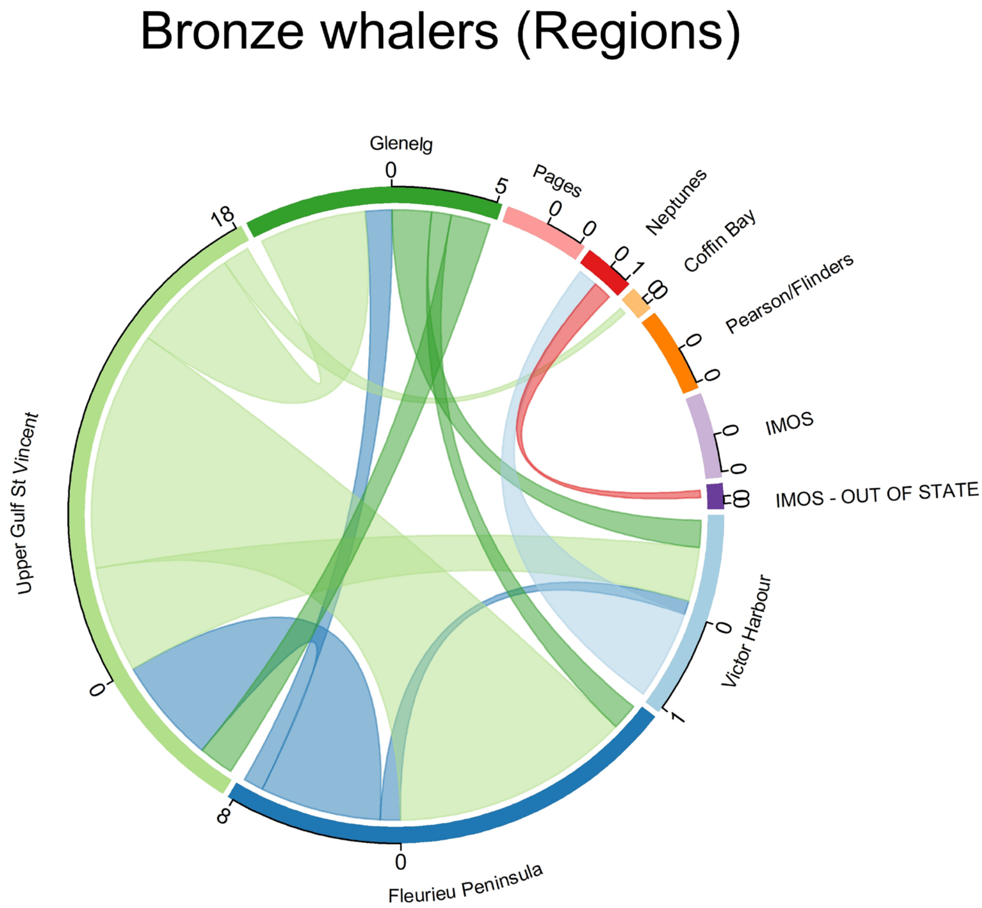

Figure 13: Connectivity of bronze whalers between receiver array regions (including unprotected South Australian areas and out of state detections). Each region colour coordinated. Matching coloured lines and outer sectors indicate individuals moving from that region to another region (of different colour). The thickness of lines is weighted by the number of individuals making that movement.

White sharks were detected in Investigator, Neptune Islands Group, Western Kangaroo Island, Upper Spencer Gulf, and Encounter Marine Parks, but not Thorny Passage or Upper Gulf St Vincent (Fig. 14; Fig. 15). Neptune Islands Group was visited on the most days (all white sharks combined), with detections in other Marine Parks, unprotected areas, or out of state relatively uncommon. Tagging primarily took place at the Neptune Islands, a known hotspot for white sharks (and co-located with shark cage-diving operations), which likely accounts for the high numbers of detections at Neptune Islands Group Marine Park. Individuals detected in areas outside of the Neptune Islands Group were often detected in multiple other Marine Parks (in addition to Neptune Islands Group), as well as out of state or at unprotected sites (Fig. 11). Only one animal detected more than a week was not detected at Neptune Islands Group; it was primarily detected in Upper Spencer Gulf and out of state, again, highlighting the importance of the Neptune

Islands to white sharks. The Neptune Islands Group showed the most connectivity with other Marine Parks (Fig. 16) with 38 individuals moving to other areas. Departures and arrivals from/to Neptune Islands Group were associated with six different areas (Encounter, Western Kangaroo Island, Upper Spencer Gulf, Investigator, unprotected SA areas, and out of state; Fig. 16). Movements between receiver array regions, independent of Marine Parks, also showed high connectivity centred around the Neptune Islands (Fig. 17).

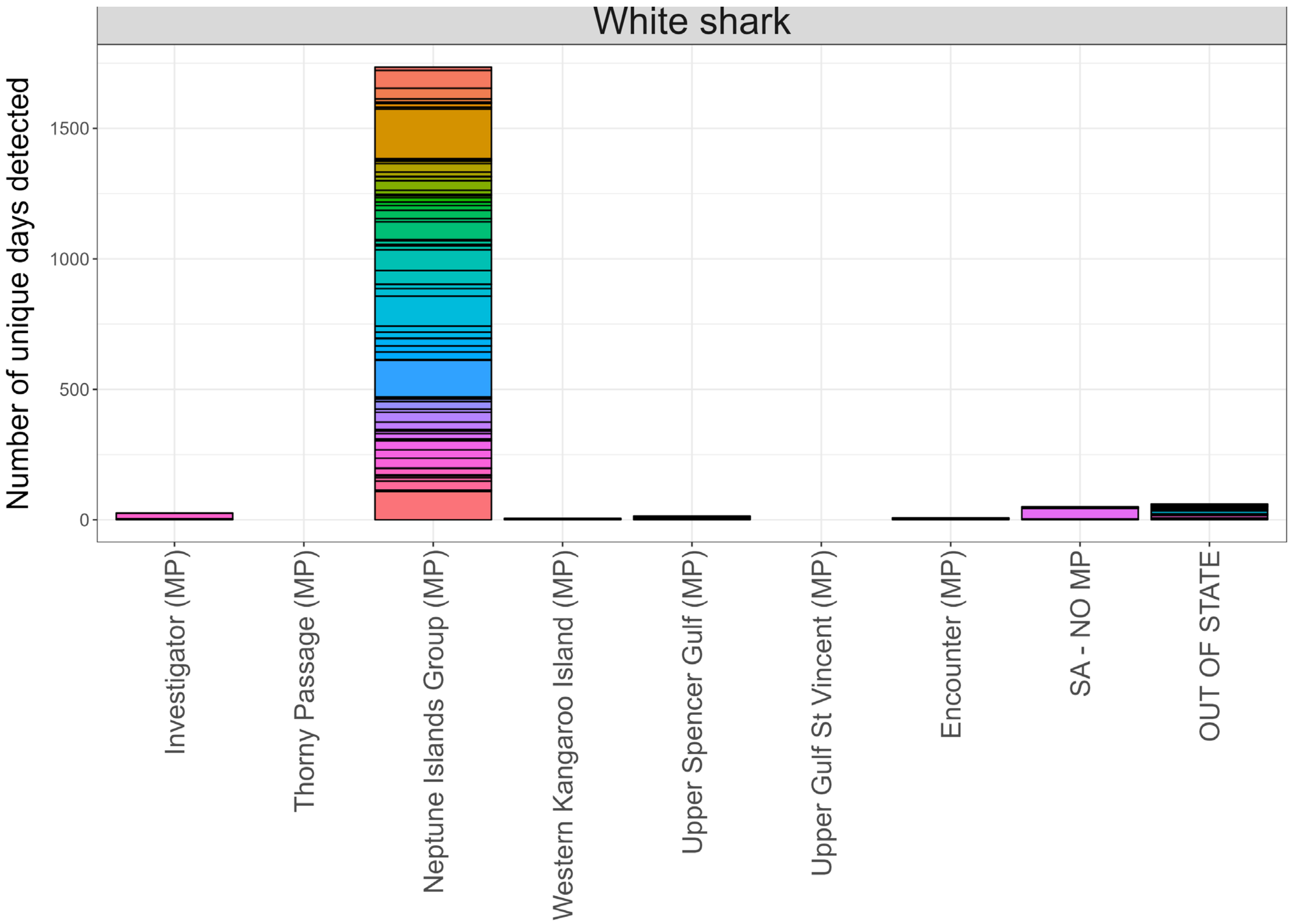

Figure 14: Number of days tagged white sharks were detected within each Marine Park (including unprotected South Australian areas and out of state detections) with emphasis on importance of different Marine Parks.

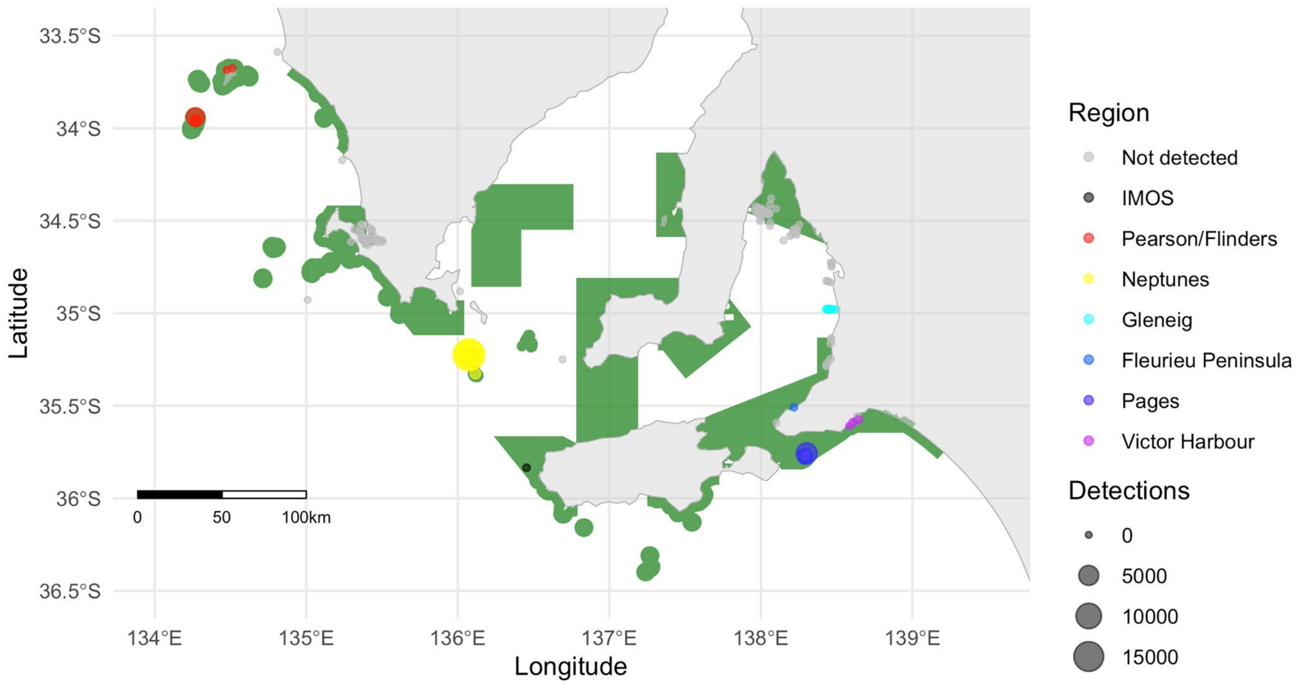

Figure 15: Detections of white sharks in the different regions (and receiver arrays) in South Australia throughout the study period. Note Upper Spencer Gulf is not identified in the map due to limited white shark detections (<0.01%).

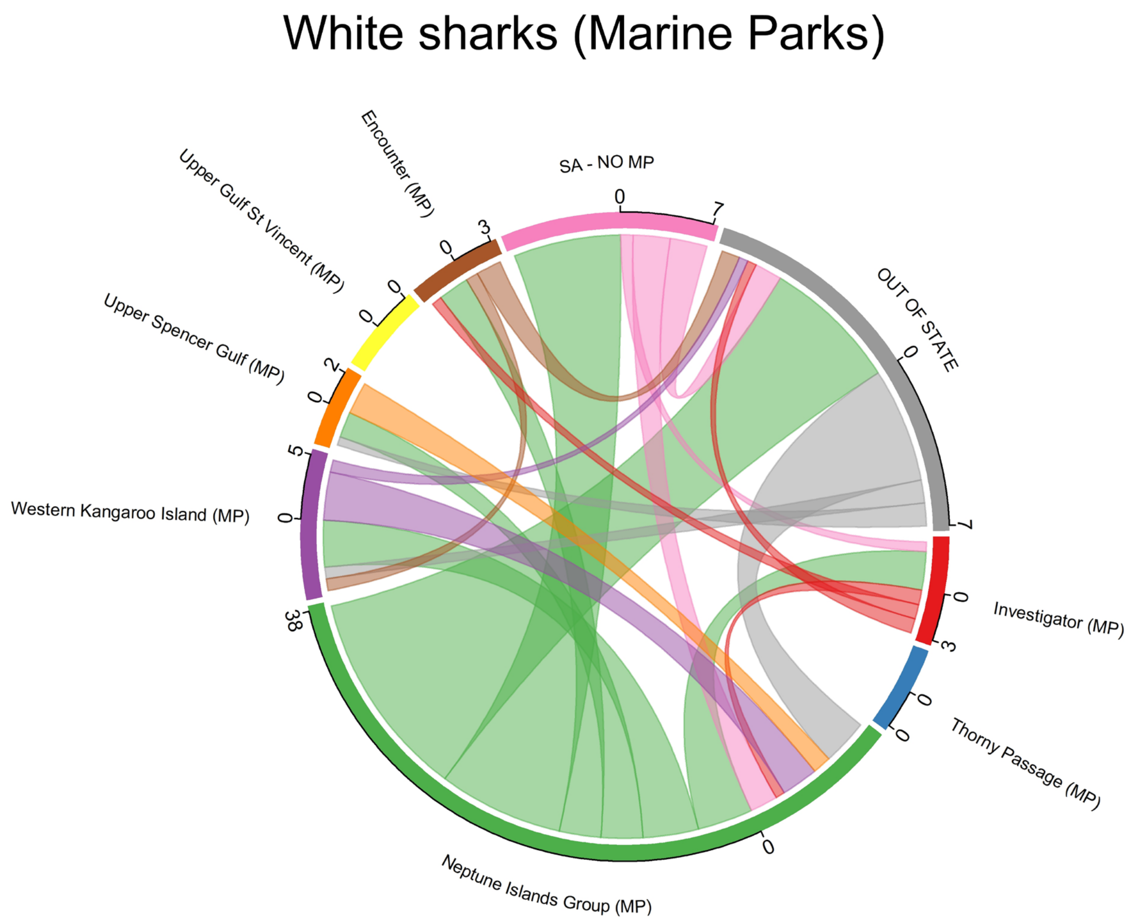

Figure 16: Connectivity of white sharks between Marine Parks (including unprotected South Australian areas and out of state detections). Each Marine Park is colour coordinated. Matching coloured lines and outer sectors indicate individuals moving from that area to another area (of different colour). The thickness of lines is weighted by the number of individuals making that movement.

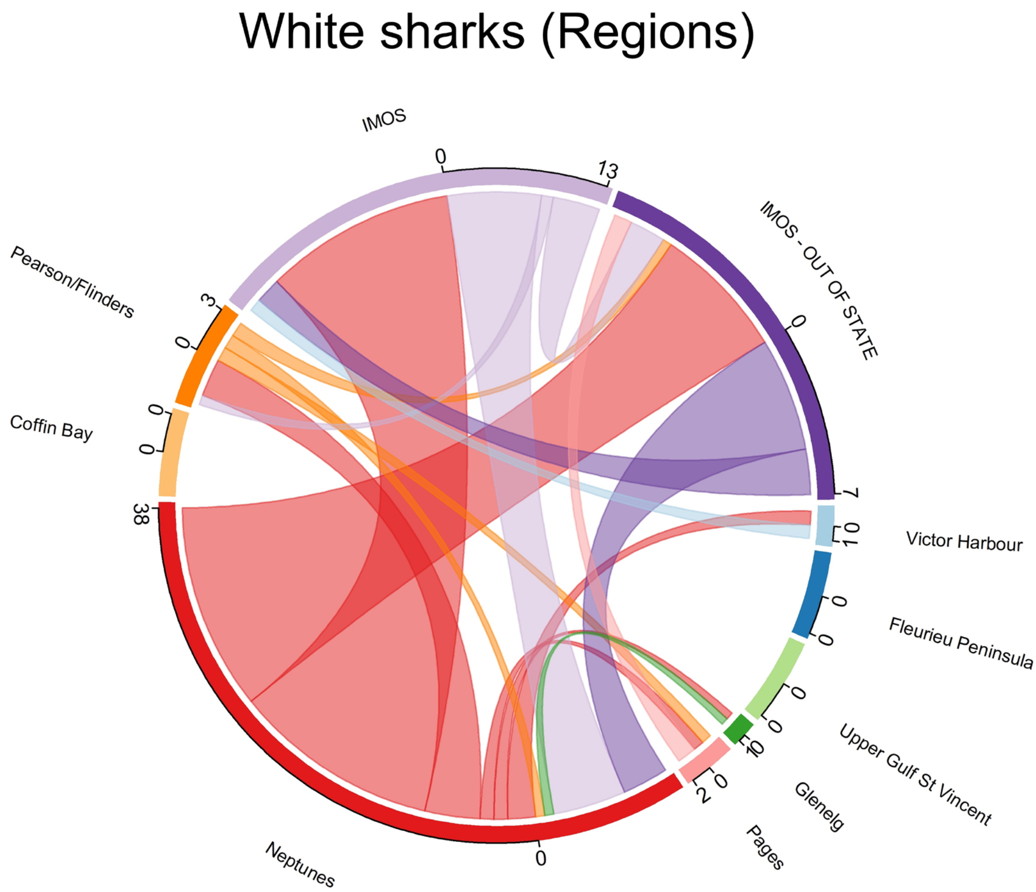

Figure 17: Connectivity of white sharks between receiver array regions (including unprotected South Australian areas and out of state detections). Each region colour coordinated. Matching coloured lines and outer sectors indicate individuals moving from that region to another region (of different colour). The thickness of lines is weighted by the number of individuals making that movement.

Overall, corridors of movement between bronze whalers and white sharks were considerably different, but this was pre-empted by the different Marine Parks used by the two species (Fig. 9; Fig. 14). For example, bronze whalers were not detected at Investigator or Western Kangaroo Island and rarely at the Neptune Islands Group, whereas white sharks were. Alternatively, white sharks were not detected at Thorny Passage and Upper Gulf St Vincent, whereas bronze whalers were. Whether these patterns are associated with tagging location, habitat preferences, competitive exclusion, or predator avoidance is not clear, warranting further investigation. The use of acoustic telemetry was effective in detecting all three species of large mobile predators with relatively high efficacy given the size of the study area and roaming capacities of the animals. For bronze whalers, acoustic telemetry showed high levels of connectivity within Upper Gulf St Vincent and between Marine Parks and unprotected areas of the gulf, raising potential concerns of these sharks spending significant time in unprotected South Australian waters. For white sharks, the importance of the Neptune Islands was shown; by contrast, acoustic telemetry highlighted that other areas are used with minimal frequency across most individuals. Future acoustic telemetry research could explore whether white sharks tagged in different states use South Australian Marine Parks similarly to those tagged locally. Finally, yellowtail kingfish in this study were exclusively detected at the Neptune Islands showing seasonal fluctuations in residency.

4. REFERENCES

Ban, N. C., Davies, T. E., Aguilera, S. E., Brooks, C., Cox, M., Epstein, G., ... & Nenadovic, M. (2017). Social and ecological effectiveness of large marine protected areas. *Global Environmental Change*, *43*, 82-91.

Braccini, J. M., McAuley, R., Harry, A. (2017). Spatial and temporal dynamics of Western Australia's commercially important sharks. FRDC Project No 2010/003. Perth, Australia.

Bradford, R., Patterson, T. A., Rogers, P. J., McAuley, R., Mountford, S., Huveneers, C., ... & Bruce, B. D. (2020). Evidence of diverse movement strategies and habitat use by white sharks, *Carcharodon carcharias*, off southern Australia. *Marine Biology*, *167*, 1-12.

Bruce, B. D. (2008). The biology and ecology of the white shark, *Carcharodon carcharias*. *Sharks of the open ocean: Biology, fisheries and conservation*, 69-81.

Bruce, B. D., Harasti, D., Lee, K., Gallen, C., & Bradford, R. (2019). Broad-scale movements of juvenile white sharks *Carcharodon carcharias* in eastern Australia from acoustic and satellite telemetry. *Marine Ecology Progress Series*, *619*, 1-15.

Bryars, S., Page, B., Waycott, M., Brock, D. & Wright, A. (2017). South Australian Marine Parks Monitoring, Evaluation and Reporting Plan, DEWNR Technical report 2017/05, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide

Champion, C., Hobday, A. J., Pecl, G. T., & Tracey, S. R. (2020). Oceanographic habitat suitability is positively correlated with the body condition of a coastal-pelagic fish. *Fisheries Oceanography*, *29*(1), 100-110.

Clarke, T. M., Whitmarsh, S. K., Dwyer, R. G., Udyawer, V., Pederson, H., & Huveneers, C. (2022). Effects of shark tourism on the daily residency and movements of a non-focal pelagic teleost. *Marine Ecology Progress Series*, *687*, 133-146.

Clarke, T. M., Whitmarsh, S. K., Jaine, F. R., Taylor, M. D., Brodie, S., Payne, N. L., ... & Huveneers, C. (2023). Environmental drivers of yellowtail kingfish, *Seriola lalandi*, activity inferred through a continental acoustic tracking network. *Aquatic Conservation: Marine and Freshwater Ecosystems*.

Davidson, L. N., & Dulvy, N. K. (2017). Global marine protected areas to prevent extinctions. *Nature ecology & evolution*, *1*(2), 0040.

Department for Environment and Heritage. (2008). Design principles guiding the development of South Australia's marine park boundaries. Coast and Marine Conservation Branch, Department for Environment and Heritage, South Australia.

Drew, M., Rogers, P., & Huveneers, C. (2016). Slow life-history traits of a neritic predator, the bronze whaler (*Carcharhinus brachyurus*). *Marine and Freshwater Research*, *68*(3), 461-472.

Drew, M., Rogers, P., Lloyd, M., & Huveneers, C. (2019). Seasonal occurrence and site fidelity of juvenile bronze whalers (*Carcharhinus brachyurus*) in a temperate inverse estuary. *Marine Biology*, *166*(5), 56.

Duffy, C. A., Francis, M. P., Manning, M. J., & Bonfil, R. (2012). Regional population connectivity, oceanic habitat, and return migration revealed by satellite tagging of white sharks, *Carcharodon carcharias*, at New Zealand aggregation sites. *Global perspectives on the biology and life history of the white shark*, 301-318.

Dulvy, N. K. (2006). Conservation biology: strict marine protected areas prevent reef shark declines. *Current biology*, *16*(23), R989-R991.

Dwyer, R. G., Krueck, N. C., Udyawer, V., Heupel, M. R., Chapman, D., Pratt, H. L., ... & Simpfendorfer, C. A. (2020). Individual and population benefits of marine reserves for reef sharks. *Current Biology*, *30*(3), 480-489.

Gubili, C., Duffy, C. A., Cliff, G., Wintner, S. P., Shivji, M., Chapman, D., ... & Noble, L. R. (2012). Application of molecular genetics for conservation of the white shark, *Carcharodon carcharias*, L. 1758. *Global Perspectives on the Biology and Life History of the White Shark*, 357-380.

Hussey, N. E., Kessel, S. T., Aarestrup, K., Cooke, S. J., Cowley, P. D., Fisk, A. T., ... & Whoriskey, F. G. (2015). Aquatic animal telemetry: a panoramic window into the underwater world. *Science*, *348*(6240), 1255642.

Huveneers, C., Rogers, P., & Drew, M. (2014a). Monitoring shark species of conservation concern within the Adelaide metropolitan and Gulf St Vincent regions. Final Report to the Adelaide and Mount Lofty Ranges Natural Resources Management Board. SARDI Publication No. F2013/000716-1. SARDI Research Report Series No. 754. Adelaide, Australia.

Huveneers, C., Rogers, P., & Drew, M. (2014b). Monitoring shark species of conservation concern within the Adelaide metropolitan and Gulf St Vincent regions. Update: May 2013 to May 2014. Report to the Adelaide and Mount Lofty Ranges Natural Resources Management Board.

Huveneers, C., Simpfendorfer, C. A., Kim, S., Semmens, J. M., Hobday, A. J., Pederson, H., ... & Harcourt, R. G. (2016). The influence of environmental parameters on the performance and detection range of acoustic receivers. *Methods in Ecology and Evolution*, *7*(7), 825-835.

Huveneers, C. & Lloyd, M. (2017). Residency of white sharks, *Carcharodon carcharias*, at the Neptune Islands Group Marine Park (2016–17). Report to the Department of the Environment, Water and Natural Resources. Adelaide, South Australia.

Jones, A., Waycott, M., Bryars, S., Wright, A., & Gillanders, B. (2018). Assessing connectivity in South Australia's Marine Parks Network. Report prepared for the Department of Environment, Water, and Natural Resources. University of Adelaide and DEWNR publication. Adelaide, Australia.

Kellett, M. D. (2021). Habitat use and trophic ecology of bronze whaler sharks (*Carcharhinus brachyurus*) in New Zealand (Doctoral dissertation, The University of Waikato).

Kessel, S. T., Cooke, S. J., Heupel, M. R., Hussey, N. E., Simpfendorfer, C. A., Vagle, S., & Fisk, A. T. (2014). A review of detection range testing in aquatic passive acoustic telemetry studies. *Reviews in Fish Biology and Fisheries*, *24*, 199-218.

Knip, D. M., Heupel, M. R., & Simpfendorfer, C. A. (2012). Evaluating marine protected areas for the conservation of tropical coastal sharks. *Biological conservation*, *148*(1), 200-209.

Klinard, N. V., & Matley, J. K. (2020). Living until proven dead: addressing mortality in acoustic telemetry research. *Reviews in Fish Biology and Fisheries*, *30*(3), 485-499.

Leenhardt, P., Low, N., Pascal, N., Micheli, F., & Claudet, J. (2015). The role of marine protected areas in providing ecosystem services. In *Aquatic functional biodiversity* (pp. 211-239). Academic Press.

Marine Protection Atlas (2023). Marine Conservation Institute. https://mpatlas.org/countries/AUS*/mpas/. Accessed on 08/02/2024.

Matley, J. K., Johansen, L. K., Klinard, N. V., Eanes, S. T., & Jobsis, P. D. (2021). Habitat selection and 3D space use partitioning of resident juvenile hawksbill sea turtles in a small Caribbean bay. *Marine Biology*, *168*, 1-15.

Matley, J. K., Klinard, N. V., Martins, A. P. B., Aarestrup, K., Aspillaga, E., Cooke, S. J., ... & Fisk, A. T. (2022). Global trends in aquatic animal tracking with acoustic telemetry. *Trends in Ecology & Evolution*, *37*(1), 79-94.

McAuley, R. B., Bruce, B. D., Keay, I. S., Mountford, S., Pinnell, T., & Whoriskey, F. G. (2017). Broad-scale coastal movements of white sharks off Western Australia described by passive acoustic telemetry data. *Marine and Freshwater Research*, *68*(8), 1518-1531.

Munroe, S. E. & Huveneers, C. (2019). Monitoring the presence and residency of sharks at key locations off Victor Harbor (Encounter Marine Park). Report to the Department of the Environment, Water and Natural Resources. Adelaide, South Australia.

Niella, Y., Smoothey, A. F., Taylor, M. D., Peddemors, V. M., & Harcourt, R. (2022). Environmental drivers of fine-scale predator and prey spatial dynamics in Sydney harbour, Australia, and adjacent coastal waters. *Estuaries and Coasts*, *45*(5), 1465-1479.

Niella, Y., Udyawer, V., Drew, M., Simes, B., Pederson, H., & Huveneers, C. (2023). Multi-year effects of wildlife tourism on shark residency and implications for management. *Marine Policy*, *147*, 105362.

Rogers, P. J., Huveneers, C., & Beckmann, C. (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.

Rogers, P. & Huveneers, C. (2016). Residency and photographic identification of white sharks *Carcharodon carcharias* in the Neptune Islands Group Marine Park between 2013 and 2015. SARDI Publication No. F2015/000825-1. SARDI Research Report Series No. 893. Adelaide.

Spaet, J. L., Patterson, T. A., Bradford, R. W., & Butcher, P. A. (2020). Spatiotemporal distribution patterns of immature Australasian white sharks (*Carcharodon carcharias*). *Scientific reports*, *10*(1), 10169.

Stephenson, F., Hamilton, O. N., Torres, L. G., Kozmian-Ledward, L., Pinkerton, M. H., & Constantine, R. (2023). Fine-scale spatial and temporal distribution patterns of large marine predators in a biodiversity hotspot. *Diversity and Distributions*.