CSIRO PUBLISHING

SHORT COMMUNICATION
https://doi.org/10.1071/MF22039

MARINE & FRESHWATER RESEARCH

Are sharks attracted to caged fish and associated infrastructure?

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Handling Editor:
Colin Simpfendorfer

Received: 12 February 2022
Accepted: 23 June 2022
Published: 25 July 2022

Cite this:
Huveneers C *et al.* (2022)
Marine and Freshwater Research, **73**(11), 1405–1411.
doi:10.1071/MF22039

ABSTRACT

There are increasing concerns over the possible effects of aquaculture pens on the local abundance and residency of sharks, and its associated risk for shark bites at nearby beaches and surf breaks. We used acoustic tracking and a before–during–after–control–impact design to assess the residency and local abundance of 117 bronze whalers and 843 white sharks around a 45-m-diameter aquaculture pen installed in South Australia for tourism purposes. Only 14 bronze whalers (12.0% of individuals tagged) and nine white sharks (1.1% of individuals tagged) were detected throughout the 5-year monitoring period and there was no evidence of the pen affecting these sharks, in either the number of sharks detected or number of detections (proxy for length of time detected). The low amount of interactions with the pen was likely to be due to a combination of low fish biomass, pen installed in a shallow location, local shark species being migratory species, and good husbandry practices. Adequate planning and management, and good husbandry practices, such as removal of dead fish from pens and avoiding over-feeding to ensure the feed is entirely consumed, are key to reducing shark interactions with cage fish and associated infrastructure.

Keywords: acoustic tracking, aquaculture, bronze whaler, *Carcharhinus obscurus*, *Carcharodon carcharias*, fish farm, residency, white shark.

Introduction

Sharks possess an array of specialised sensory systems that have been shaped by over 400 million years of evolution (Grogan *et al.* 2012). Each sensory modality allows sharks to detect and respond to different stimuli, either within its immediate environment or over broad spatial scales (Gardiner *et al.* 2012, 2014). A shark's innate response to external stimuli will typically lead to the shark investigating or approaching the source of the stimuli, unless it is identified or perceived as a potential threat. This natural tendency of sharks to be attracted to external stimuli has been used by humans for extractive or tourism uses (e.g. the use of attractant in wildlife tourism; Meyer *et al.* 2021), with these actions contributing to concerns of increased risk (e.g. human–shark interactions such as shark-bite risk or catch depredation; Simpfendorfer *et al.* 2021).

Ocean fish farming, which can hold large concentrations of fish biomass, and its associated infrastructure can also be considered external stimuli that could affect shark behaviour by attracting sharks and increasing their residency in the vicinity of such aquaculture enclosures or pens (Papastamatiou *et al.* 2010; Rogers and Drew 2018). Such behavioural change in sharks may be linked to the olfactory, auditory, or visual cues produced by the large concentration of fish biomass and during regular feeding events. Aquaculture pens have also been used for wildlife tourism purposes, providing tourists with the opportunity to see and swim with species they would not normally be able to interact with in the wild. For example, a wildlife tourism opportunity for people to swim with a range of native fish species opened near Granite Island (Victor Harbor, South Australia, Australia) in July 2017. This swimming opportunity consisted of a 45-m-diameter aquaculture pen with up to 5 tonnes (Mg) of southern bluefin tuna (*Thunnus maccoyii*) and 0.5 Mg of other local fish species, which were fed a minimum of 5% bodyweight per day (weather permitting) to meet metabolic demands. Although the stocking or biomass was much less than standard commercial aquaculture operations (e.g. ~80 Mg in a southern bluefin tuna cages), the public expressed concerns about the potential for sharks to be attracted to these pens and the associated increased potential risk for shark bites at nearby beaches or surf breaks (https://www.adelaidenow.com.au/news/south-australia/hundreds-gather-at-victor-harbor-to-protest-against-tuna-pen-development-near-granite-island/news-story/6b66d4240e068be6762b5e69c225431a).

This study used acoustic tracking and a before–during–after–control–impact design over a 5-year period to assess the residency and abundance of bronze whalers (*Carcharhinus brachyurus*) and white sharks (*Carcharodon carcharias*) around the Granite Island pen. These species were selected because they are responsible for the most shark bites and concerns from the general public in South Australia (Riley *et al.* 2022; pir.sa.gov.au/fishing/sharks/shark_sightings_log). On the basis of findings from a previous study on the effects of caged fish on shark residency and movements showing that sandbar sharks (*Carcharhinus plumbeus*) aggregated around ocean-farming cages while tiger sharks (*Galeocerdo cuvier*) sporadically visited these cages (Papastamatiou *et al.* 2010), we hypothesised that bronze whaler will increase residency around the aquaculture pen, but that white sharks will not.

Materials and methods

In total, 117 bronze whalers (57 in South Australia, SA, and 60 in Western Australia, WA) and 843 white sharks (128 in SA, 129 in WA, 586 in New South Wales, NSW) were tagged prior to or during the study period (March 2016–April 2021). These sharks were not tagged for the purpose of this study, but for various research projects (e.g. Barnes *et al.* 2016; McAuley *et al.* 2017; Braccini *et al.* 2017*a*, 2018; Drew *et al.* 2019; Spaet *et al.* 2020*a*, 2020*b*; Huveneers *et al.* 2021; Tate *et al.* 2021). All sharks were fitted with tags containing a battery life of up to 10 years, with more than 80% of the tags lasting across the entire study period. Bronze whalers were captured using a variety of standard fishing methods, including scientific and commercial longlines (WA and SA), single hook droplines (WA), and recreational game fishing (SA), and had an acoustic tag surgically implanted. White sharks were either externally tagged in the dorsal musculature by using a modified spear-gun applicator while free-swimming (in SA), or internally/externally tagged after being caught by targeted fishing or SMART drumlines as part of a bather protection research program (in WA and NSW). Details about fishing and tagging methods can be found in Drew *et al.* (2019) for SA, Braccini *et al.* (2017*b*, 2018) and McAuley *et al.* (2017) for WA, and Barnes *et al.* (2016) and Tate *et al.* (2021) for NSW.

Four acoustic receivers were deployed at key sites in the Victor Harbor region, including at two nearby comparative sites ~1.5 km apart (a seal colony (Seal Island) and 50 m from the pen near Granite Island (Granite Island)), and two strategic headlands likely to be migratory paths when sharks enter the Victor Harbor region (Kings Head and the Bluff) (Fig. 1). The Victor Harbor region is within the southern range of the Encounter Bay Marine Park and is home to a wide range of diverse habitats including reefs, high-energy dissipative beaches, and wetlands. Receivers were deployed in shallow waters (7–15 m) and close to shore or the pen (<400 m). Range testing within a similar habitat in Gulf St Vincent using a fixed tag attached to an anchored buoy-line and suspended in the water column at distances varying between 136 and 1100 m from multiple receiver locations indicated a maximum detection range of ~900 m and a 50% detection probability at ~500 m (Drew *et al.* 2019).

The receivers were deployed for a period of 61 months (5 years) from March 2016 to April 2021, encompassing periods before, during, and after one pen was installed with up to 5 Mg of southern bluefin tuna (*T. maccoyii*) and 0.5 Mg of other local fish species (e.g. *Chrysophrys auratus*). The pen was installed off Granite Island and stocked in July 2017 until April 2020, when all fishes were removed from the pen. The acoustic monitoring period, therefore, included 16 months prior to the pen being installed (i.e. before period), 33 months while the pen was present and holding up to 5.5 Mg of fishes (i.e. during period), and 12 months after all fishes were removed from the pen (i.e. after period). This provided a before–during–after–control–impact design, enabling us to assess the effects of the pen on shark abundance and residency patterns.

Because of the small number of detections overall, we limited our analysis to a description of the number of individuals, number of detections, and the number of days detected. The low number of detections for many individuals did not permit more statistical analysis (e.g. ANOVA, generalised linear mixed models) or comparison between sexes or across sizes. All analyses were undertaken using R software (ver. 4.2.0, R Foudnation for Statistical Computing, Vienna, Austria).

Ethics approvals and permits

All shark tagging was undertaken under the following animal ethics approvals and permits: Flinders University animal ethics approval #E360), New South Wales Department of Primary Industries (NSW DPI) Animal Care and Ethics 07/08, South Australian Department for Environment and Water permit Q26292, South Australian Department of Primary Industries and Regions (PIRSA) ministerial exemption

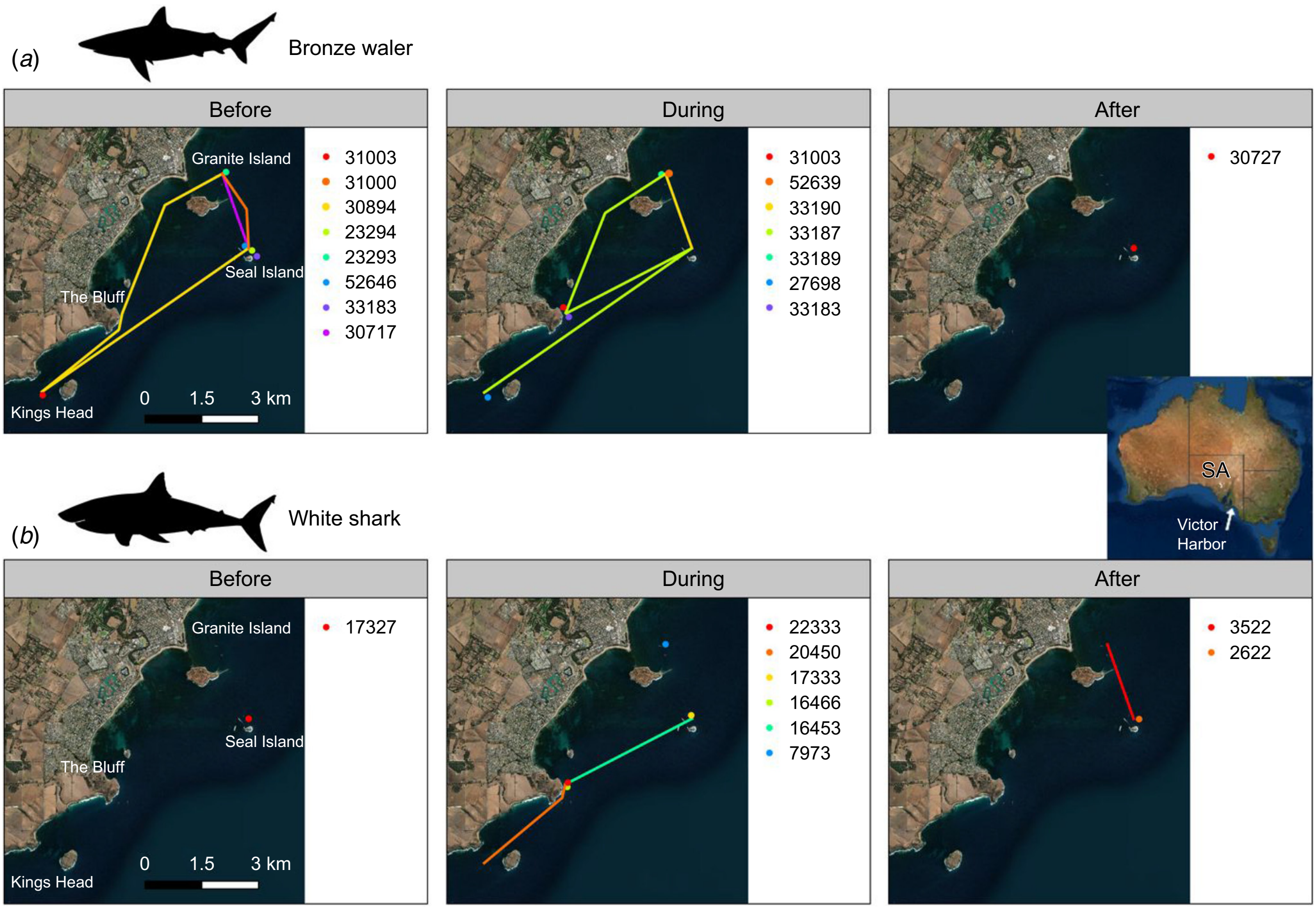

Fig. 1. Study site (Victor Harbor, Encounter Marine Park) with locations of four receivers and the detection of (*a*; top panels) bronze whaler, *Carcharhinus brachyurus*; and (*b*; bottom panels) white sharks, *Carcharodon carcharias*, with coloured circles and lines representing different individuals. Left panels show detections prior, middle panels show detections during, and right panels show detection after the aquaculture pen was deployed at the Granite Island location. Note that the Kings Head and The Bluff receivers were lost during the 'After' period.

ME9903138, NSW DPI scientific permit P01/0059(A), and NSW Marine Parks permit P16/0145-1.1

Results

In total, 14 bronze whalers (12.0% of individuals tagged) and 9 white sharks (1.1% of individuals tagged) were detected throughout the monitoring period for up to 20 days (mean ± s.e.: 3.6 ± 1.0 days; Table 1). There was no clear evidence of the pen attracting bronze whalers or white sharks, in either the number of sharks detected, number of detections, or number of days detected. For bronze whalers, the number of sharks detected at the pen (four sharks) was similar to that at the nearby Seal Island (two sharks) and at other close-by receivers (e.g. three sharks at the Bluff; Fig. 1*a*). Whereas the number of bronze whaler detections (Fig. 2*a*) was slightly higher around the pen than at other locations when the pen was deployed, this receiver also detected bronze whalers more frequently than did the Kings Head and Seal Island receivers prior to the pen being installed (Fig. 2). The largest number of detections (253 detections) was by a bronze whaler at the pen when it was installed (10-day residency), with the other three sharks also being detected at Granite Island during this same period on a single day only, and with fewer detections (Fig. 2*a*). Similar multi-day residency was observed at other receivers when the pen was installed (e.g. bronze whaler detected in the region for 11 days with only 7% of detections around the pen; white shark detected for 15 days at the Bluff and Seal Island, but not detected at the pen).

The number of white sharks detected at the pen (one shark) when it was deployed (i.e. during period) was also similar to that at Kings Head (one), Seal Island (two sharks), and Bluff (four). Five of the six white sharks detected in the region while the pen was deployed were not detected by the receiver near the pen (Fig. 1). In addition, the white shark detected near the pen (detected by the Granite Island

Table 1. Summary of sharks detected in the Victor Harbor region between March 2016 and April 2021.

Tag ID	Total length (cm)	Sex	Date tagged	State tagged	Days detected	Number of detections
Carcharhinus brachyurus						
30717	115	Male	3/11/2011	South Australia	3	33
30727	190	Female	3/11/2011	South Australia	1	2
52639	114	Male	15/02/2012	South Australia	10	253
52646	232	Female	23/11/2012	South Australia	1	4
33183	156	Female	6/12/2012	South Australia	7	69
33187	119	Female	24/01/2013	South Australia	12	22
33189	90	Female	24/01/2013	South Australia	1	9
33190	92	Female	24/01/2013	South Australia	2	7
23293	175[A]	Female	7/02/2015	South Australia	1	91
23294	240[A]	Male	7/02/2015	South Australia	1	5
31000	275[A]	Female	18/10/2012	Western Australia	3	34
31003	272[A]	Female	17/10/2012	Western Australia	2	11
27698	311[A]	Female	17/10/2013	Western Australia	1	3
30894	248[A]	Female	2/10/2014	Western Australia	20	193
Carcharodon carcharias						
17327	330	Male	24/04/2017	South Australia	2	11
17333	260	Female	19/04/2017	South Australia	1	6
3522	320	Unknown	17/07/2020	South Australia	2	74
22333	320[A]	Female	8/09/2016	Western Australia	1	3
20450	306	Male	5/07/2016	New South Wales	2	6
16453	230	Female	1/12/2016	New South Wales	5	42
16466	245	Female	01/12/2016	New South Wales	1	9
7973	250	Male	5/09/2019	New South Wales	1	16
2622	231	Male	16/06/2020	New South Wales	2	13

[A]Lengths are converted fork lengths, using regressions from Cliff and Dudley (1992) for bronze whalers (*Carcharhinus brachyurus*) and Tanaka *et al.* (2011) for white sharks (*Carcharhinus carcharias*).

receiver on 1 day, with <20 detections; Fig. 2*b*) was not detected for longer than were white sharks detected at other receivers (1–4 days) within the period, indicating that white sharks were not attracted to the pen even when in its vicinity, nor resided around the pen for long periods. A white shark was also detected by the receiver pen (three detections) after the southern bluefin tuna were removed from the pen, suggesting that the presence of southern bluefin tuna in the pens did not correlate with white shark presence.

Discussion

Although aquaculture pens can produce stimulus and cues that can attract sharks, for example, large fish biomass, fish mortality, or feeding events, we found no clear evidence of white sharks or bronze whalers being preferentially attracted to or spending extended time around the pen. Our findings are similar to those of a previous study in Spencer Gulf (South Australia), showing that commercial aquaculture pens had limited effects on sharks (Rogers and Drew 2018). However, both this study and that of Rogers and Drew (2018) contrast with our hypothesis and with Papastamatiou *et al.* (2010), which found that fish farms in Hawaii can attract marine predators, such as sandbar sharks. Globally, there has also been extensive reports of sharks interacting with aquaculture, including in the Pacific Northwest (Nash *et al.* 2005), Puerto Rico (Alston *et al.* 2005), The Bahamas (Benetti *et al.* 2006), Latin America (Rojas and Wadsworth 2007), Reunion Island (Loiseau *et al.* 2016), the Mediterranean Sea (Barash *et al.* 2018), and Australia (Murray-Jones 2005). The discrepancy among these studies is likely to be due to a combination of the fish biomass in the pens and amount of feed used, location and habitat where the pens are deployed, the shark species occurring in the region, and husbandry practices.

In this study, the pen was deployed to provide people with the opportunity to swim with a range of native fish species,

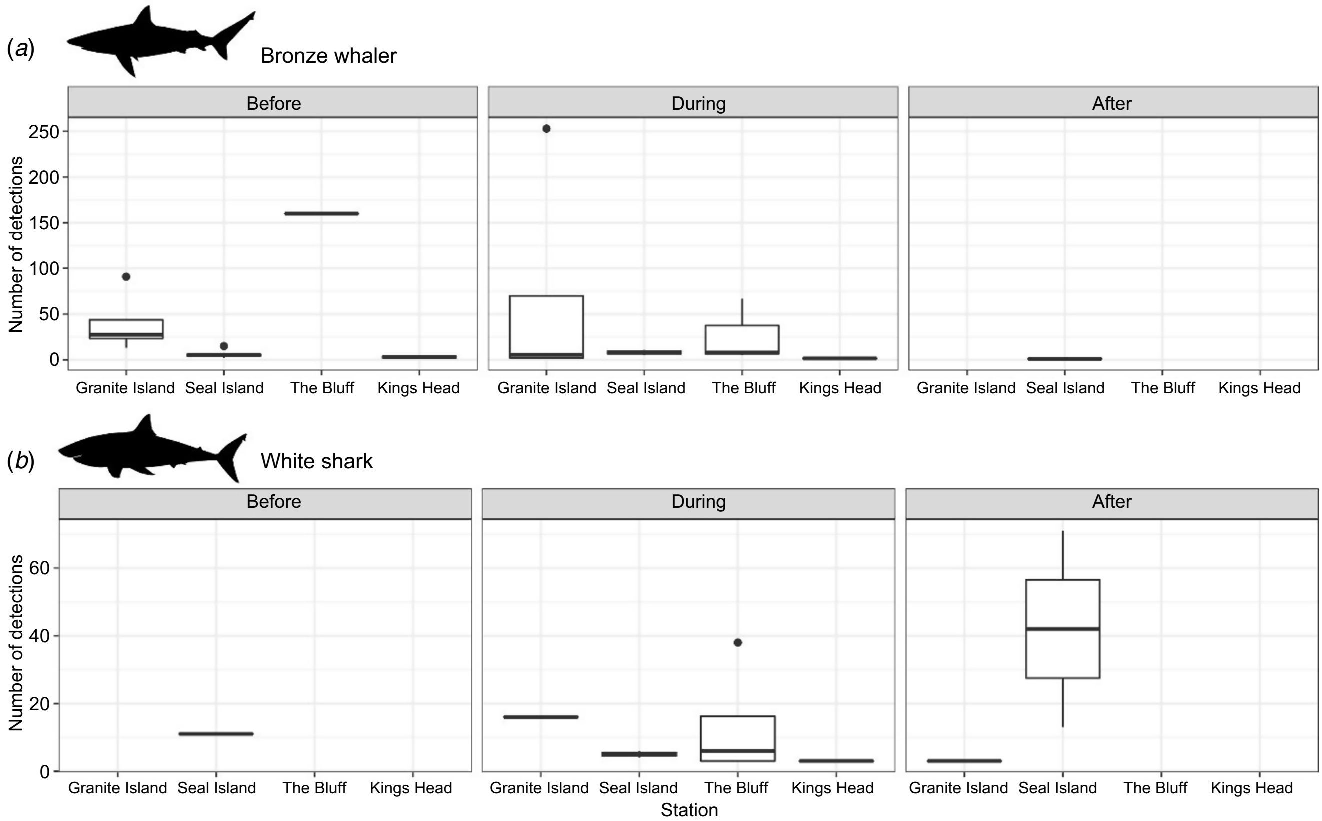

Fig. 2. Number of detections for (*a*; top panels) bronze whaler, *Carcharhinus brachyurus*; and (*b*; bottom panels) white sharks, *Carcharodon carcharias*. Left panels show detections prior, middle panels show detections during, and right panels show detection after the aquaculture pen was deployed at the Granite Island location. Note that the Kings Head and The Bluff receivers were lost during the 'After' period.

not for aquaculture purposes. The stocking density in the pen (max of 5 Mg of southern bluefin tuna and 0.5 Mg of other fish species) and, therefore, the amount of feed used was substantially lower than that of commercial aquaculture operations, potentially reducing its likelihood of attracting predators. However, the pens monitored by Rogers and Drew (2018) were standard commercial pens with ~130 Mg of yellowtail kingfish in each pen. Therefore, the low biomass in the pen off Granite Island might not be the sole reason for the lack of an attraction effect.

In our study and that of Rogers and Drew (2018), the location of the pens was in a shallow water (~10 m off Granite Island; ~15 m in Spencer Gulf) and away from core movement paths and depth ranges preferred by white sharks (Bruce *et al.* 2006; Bradford *et al.* 2020) and bronze whalers (Drew 2017). This might have limited the number of interactions between white sharks and the pens. However, in this study, sharks were also detected by the Granite Island receiver prior to the pen being installed, whereas other sharks were not detected around the pen even when they were detected by nearby receivers in similar depths, thus supporting that the lack of attraction or aggregating effect might not necessarily be due to the pen location.

The ecology of the species occurring in the region and their propensity to aggregate for extended periods around infrastructure might be a driver of the species likelihood to be attracted to, and to remain within the vicinity of aquaculture pens. This was well illustrated in a Hawaiian study showing that ocean fish cages aggregated sandbar sharks, but not tiger sharks (Papastamatiou *et al.* 2010). White sharks have similar ecology to that of tiger sharks in that they are considered pelagic species that often migrate large distances (McAuley *et al.* 2017; Bradford *et al.* 2020; Spaet *et al.* 2020*b*). Bronze whalers also undertake large migrations (Huveneers *et al.* 2021), but can remain within an area for prolonged periods (Drew *et al.* 2019). White sharks have also been documented to remain around aquaculture pens in Port Stephens (NSW; P. Butcher, unpubl. data) and also get inside pens in Spencer Gulf (SA) and Mexico (Anonymous, pers. comm.) and in the Mediterranean Sea (Galaz and De Maddalena 2004). Species ecology alone might therefore not explain the low number of detections of bronze whalers and white sharks around Granite Island or the commercial pens, as evidenced by Rogers and Drew (2018).

The complexity of understanding the influence of aquaculture pens on shark abundance and residency highlights that the likelihood of aquaculture pens attracting sharks is dependent on a combination of factors and highly context-dependent. However, discussions with the aquaculture industry suggest that adequate planning and management (Lauer *et al.* 2015), and good husbandry practices, for example, removal of dead fish from pens and avoiding over-feeding to ensure the feed is entirely consumed, might be the key to reducing shark interactions with aquaculture infrastructure (Murray-Jones 2005; Rogers and Drew 2018). The low amount of interactions with the pen off Granite Island was likely to be due to a combination of factors, including low fish biomass, pen installed in a shallow location, local shark species being migratory species, and good husbandry practices.

Overall, although previous studies and reports have indicated that the aquaculture industry can affect shark behaviour and residency patterns (Murray-Jones 2005; Papastamatiou *et al.* 2010; Barash *et al.* 2018), this study showed that the aquaculture pen used for tourism off Granite Island did not lead to an increased number of sharks nor increased residency of sharks in its vicinity. Understanding the factors leading to changes in shark behaviour and movement patterns is complex and will require further studies across several aquaculture industries, ideally using a before–after–control–impact design similar to that used in this study.

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Data availability. Data were sourced from Australia's Integrated Marine Observing System (IMOS) – IMOS is enabled by the National Collaborative Research Infrastructure Strategy (NCRIS), and can be accessed from the IMOS Animal Acoustic Telemetry Database (animaltracking.aodn.org.au) or upon request from the lead author.

Conflicts of interest. The authors declare that they have no conflicts of interest.

Declaration of funding. Funding was provided through an Australian Research Council Linkage Project grant (LP120100652), the South Australian Department for Environment and Water, the Australian Fisheries Research and Development Corporation (FRDC grant number 2010/003 and 2012/020), the Adelaide and Mount Lofty Ranges Natural Resources Management Board, the Neiser Foundation, the Nature Foundation of South Australia Inc, the Department of Primary Industries and Regional Development, Government of Western Australia, Tracking Research for Animal Conservation Society (TRACS), and NSW Government through the Shark Management Strategy.

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