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Results of the non-lethal SMART drumline trial in south-western Australia between 21 February 2019 and 20 February 2021

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1. Executive Summary

After a number of fatal and serious incidents involving white sharks (*Carcharodon carcharias*) in the south-west of Western Australia, the Government of Western Australia committed to undertaking a scientific trial of non-lethal Shark-Management-Alert-in-Real-Time (SMART) drumlines. The trial was initiated to provide the required evidence-based scientific data to inform the Government of Western Australia's shark mitigation strategy. This report evaluates and summarises the data derived from the Department of Primary Industries and Regional Development's (DPIRD) two-year trial (21 February 2019 to 20 February 2021).

The specific objective of the trial was to determine whether white sharks, which were relocated after capture on a SMART drumline and released at least 1 km from shore, remained off-shore (i.e. > 1 km) or whether they returned to nearshore coastal waters and beaches. To investigate white shark movements, captured sharks were tagged with an external acoustic tag, a conventional dart tag and a pop-up archival transmitting (PAT) tag. Acoustic receivers (VR2s) were deployed in six arrays, a primary array off Gracetown and five secondary arrays at adjacent surf locations in the Capes region. Seven near real-time acoustic receivers (VR4G), four within the arrays and three at nearby beaches in the Capes region (Meelup and Bunker Bay) complimented these arrays of VR2s.

A contractor was responsible for setting SMART drumlines daily at 10 fixed locations across 11.5 kilometres of coastline, about 500 m offshore from Hangmans surfbreak north of Gracetown through to Ellensbrook in the south. These drumlines were continuously monitored for 465 fishing days (63.6% of the 24-month period), with risk weather conditions preventing the use of fishing equipment on 266 days. DPIRD observers inspected fishing operations on-board the contractor's vessel for 163 days (35% of fishing days), and provided ongoing training to ensure high standards of animal welfare and data recording were maintained. Detailed information was recorded for every animal captured, including species, size, sex, hooking location, time spent on the hook, and release condition. Video footage from on-board and under-water cameras was used to monitor the process of animal handling and to verify the release condition of animals. In addition, third party observers (3POs) representing the Conservation Council of Western Australia and Sea Shepherd were on-board the vessel for eight fishing days (1.7% of fishing days), providing independent feedback on fishing operations. Finally, the DPIRD animal ethics committee continuously monitored and reviewed the procedures of the trial in order to maintain the highest practical animal welfare standards.

In total, 311 capture events occurred including two white sharks (target species), 266 non-target sharks, and 43 other non-target marine animals. Nine of these capture events were recaptures of animals originally caught and tagged as part of this trial, resulting in 302 unique animals being captured during the two-year trial. Non-target shark catch events comprised 168 tiger sharks (*Galeocerdo cuvier*), 48 bronze whaler sharks (*Carcharhinus brachyurus*), 37 shortfin makos (*Isurus oxyrinchus*), 10 dusky whaler sharks (*Carcharhinus obscurus*), two smooth hammerhead sharks (*Sphyrna zygaena*) and one scalloped hammerhead shark (*Sphyrna lewini*). The non-target species included 37 smooth stingrays (*Dasyatis brevicaudata*), four pink snapper (*Chrysophrys auratus*), and two samsonfish (*Seriola hippos*). Excluding the four pink snapper, all animals were released alive with 90% (n = 281) of all animals captured being subsequently released in good condition. This positive outcome for minimising negative animal welfare outcomes can be attributed to the constant patrolling while baits were deployed

and rapid response time. The contractor responded to 800 activations with an average response time to a SMART drumline of 11.1 minutes, and the average duration for which animals were on the hook was 27.7 minutes. Shark captures ranged in size from a 0.91m (Total Length, TL) dusky whaler shark to a 4.60 m TL white shark.

On 25 April 2019, a 4.6 m (TL) female white shark was captured off North Point, and was relocated offshore. Once released it was detected on three acoustic receivers on the offshore line before moving south. The estimated track shows that in the first 24 hours the shark continued to move offshore from the release site and then headed southwards, rounded Cape Leeuwin, moved further east and arrived in waters offshore of Esperance in May before the PAT tag released on 18 June 2019. This shark travelled approximately 1,304 km in the 54 days that the PAT tag was attached and was also subsequently recorded by the VR4 receiver at West Beach (Esperance) 235 days after its release from the SMART drumline.

The second white shark was a 3.3 m (TL) female, captured on 20 August 2019 south of Ellensbrook. It was relocated 1 km from shore and swam directly offshore being detected on three receivers on the offshore line before moving north-west to more offshore waters and then northwards along shelf edge waters to an area west of the Houtman Abrolhos Islands in early September. This shark then travelled along shelf waters to an area north of Bernier Island before beginning a return journey southward in early October. It was detected on acoustic receivers off Perth, and 76 days after release (6 November 2019) it was recorded on secondary arrays (Three Bears, Yallingup and Injidup) and subsequently the primary array at Gracetown where it was detected on the nearshore line of receivers. The SMART drumlines were not being fished at the time of this series of detections due to risk weather. This shark then continued moving south and east to the Recherche Archipelago area where the PAT tag released on 21 February 2020. It travelled an overall distance of approximately 5,156 km in the 182 days that the PAT tag was attached. This shark was also subsequently recorded by the VR4 receiver at Frenchmans Bay (Albany) on 16 March 2020. Its last detection occured on an acoustic receiver off Walpole on 13 July 2020, 328 days after its capture on the SMART drumline.

In addition to the two white sharks that were tagged and released as part of the SMART drumline trial, 36 other white sharks were detected within the Capes arrays during the two year period. There were 13 separate movements of white sharks through the Gracetown array when the SMART drumlines were actively being fished, which did not result in their capture. In contrast, DPIRD’s targeted shark tagging program, which supports the Shark Monitoring Network, yielded a much higher capture rate for white sharks, *i.e.* 51 white sharks from 143 fishing days during the same two-year trial.

The objective of this trial was to determine if a white shark that was relocated offshore remained offshore or returned to nearshore coastal waters relatively quickly, thereby continuing to pose a risk. That is, was the short-term risk posed by an individual white shark reduced or not. Athough the two white sharks captured in the trial did remain offshore immediately after relocation, based on the low white shark catch at Gracetown during this trial it is, however, not possible to statistically demonstrate the effectiveness of SMART drumlines as a shark mitigation measure in these Western Australian conditions. Furthermore, the detection of 24 non-SMART drumline tagged white sharks in the Gracetown array compared to only two captured on the SMART drumlines indicates that the deployment of 10 SMART drumlines 500 m from shore at fixed locations along the coast was not an effective method to

catch white sharks. It can therefore be concluded that this mitigation measure does not eliminate the risk to ocean users.

2. Background

Human encounters with sharks are uncommon and rarely result in injuries, however shark bites can have traumatic consequences for those involved, their families, friends and affected communities (Curtis *et al.*, 2012). Between 2000 and 2020 there were 82 shark bite incidents in coastal waters of Western Australia (WA) of which 18 were fatal (Australian Shark Attack File 2020). Of the 18 fatalities that took place over the 20-year period, 17 reportedly involved white sharks. Despite the annual frequency of such encounters in WA being highly variable and low since official records began, there has been an increasing trend since the 1970s (West, 2011; DoF, 2012; McPhee, 2014).

Consequently, during this recent period of increased frequency of white shark bites and encounters along the WA coast, the Government of Western Australia adopted various shark mitigation strategies, including the SharkSmart WA (app) and website to inform the public about shark safety information and these mitigation tools provided (see https://www.sharksmart.com.au/). The overall strategy was designed to reduce the likelihood of shark-human encounters and included the development and maintenance of the Shark Monitoring Network (SMN) and tagging of predominantly white sharks in WA waters in order to provide detailed information on when and where white sharks are detected in WA. When shark monitoring receivers in coastal waters detect a tagged shark, the public are alerted in near real-time through websites, mobile notifications and text messages, and in some coastal locations shark warning systems. This allows the public to make informed decisions on where they undertake water-based activities.

A range of studies have contributed to developing an enhanced understanding of the complex and dynamic interactions between shark and human abundance, distribution and behaviours that contribute to white shark bite incidents (e.g. DoF 2014; McPhee, 2014; Chapman and McPhee, 2016; McAuley *et al.*, 2017) and this knowledge is utilised within a framework of shark hazard mitigation strategies. Data derived from research aligned to this program has resulted in an improved understanding of the movement ecology of white sharks in coastal waters of WA (McAuley *et al.*, 2016; McAuley *et al.*, 2017) and their interactions with fisheries (Taylor *et al.*, 2016; Taylor *et al.*, 2018).

In Australia, there have been shark control programs in place in both New South Wales (NSW) and Queensland (QLD) for decades (McPhee, 2012) in response to public concerns about hazards posed by sharks. These programs use large mesh nets and baited hooks on drumlines (QLD only) close to popular beaches. There is also an ongoing program of shark mesh nets used along part of the east coast of South Africa. The drumline method was trialed off beaches in the Perth metropolitan, Geographe Bay and Capes region in Western Australia in 2014, but this was not continued as an ongoing method of shark hazard mitigation.

The effectiveness of mesh nets and drumlines in reducing shark bite incidents remains unclear from a statistically testable perspective, in part due to the rarity of occurrences. Nonetheless, in comparing long periods of before and after mesh-based shark control programs in QLD, NSW and South Africa, Dudley (1997) found that “the apparent successes of the programs in reducing total numbers of shark attacks at meshed beaches are impressive”. The reductions in catch rates of sharks led Dudley (1997) to suggest that the programs work by reducing the numbers of sharks in an area and then continually harvesting any new immigrants that come into an area to keep numbers down. In his review, McPhee (2012) concurs that if shark nets

and drumlines are effective it is through reducing numbers of sharks in an area as neither method actually forms a barrier between the coast and the open ocean. The basic premise is to reduce shark numbers, and thereby the probability of an encounter between a shark and a water user near a beach (Dudley, 1997). McPhee further noted that shark bite incidents have been recorded from beaches where shark nets are deployed, so while such programs reduce risk they do not eliminate it. Although these shark control programs are generally considered to have improved the safety of people in the water (McPhee, 2012), there are concerns with mortality of non-target (bycatch) species including iconic animals of high social value (i.e. whales, dolphins, turtles). There is also community concern with mortality of sharks caught in mesh nets and drumlines given the premise that effectiveness as a stand-alone mitigation method is based on reducing the numbers of potentially dangerous sharks.

One innovative response to the need for better environmental outcomes for target and non-target species in the context of shark hazard mitigation in oceanic waters is the SMART (Shark-Management-Alert-in-Real-Time) drumline, which is intended to be non-lethal. This method was first deployed as part of a shark mitigation strategy at Reunion in the southern Indian Ocean (Guyomard *et al*., 2019; Guyomard *et al*., 2020). The system uses a baited hook, as for traditional drumlines, but has an added communication buoy tethered to the drumline that detects when a bait is taken and immediately alerts personnel via phone. This initiates an immediate response with the aim to reach the drumline before the shark (or bycatch) dies. The State Government of NSW implemented a trial of a modified version of SMART drumlines in 2015, with target sharks tagged and relocated 1 km from shore (https://www.dpi.nsw.gov.au/fishing/sharks/management/smart-drumlines).

The Government of Western Australia instigated a trial of this technology in order to determine whether it could be integrated into the suite of ongoing shark hazard mitigation strategies in WA. Because the SMART drumline method is designed to be non-lethal, its application when combined with live-release of sharks after relocation offshore is not intended to reduce the local shark population over a long period as is the case with traditional drumline and beach mesh programs. Rather, the SMART drumline aims to provide a short-term reduction in shark numbers by removing them from nearby beaches, thereby decreasing the likelihood of encounters. That is, the goal is to achieve an immediate risk reduction. The challenge from a hazard mitigation perspective is demonstrating how long a relocated shark remains away from beaches and how does this translate into a change in risk levels to water users.

The objective of this study is to evaluate the efficacy of the non-lethal SMART drumline method for reducing risk to humans in south-western Australia while maximizing welfare outcomes for target and non-target species. At the independent recommendation of WA's Chief Scientist, the SMART drumline trial was extended beyond the first year to enable a more thorough assessment of the effectiveness of this technology. As a result, this report evaluates the data derived from the non-lethal SMART drumline trial in south-western Australia from 21 February 2019 to 20 February 2021, with specific reference to the movement patterns of white sharks (*Carcharodon carcharias*).

3. Methods

3.1 SMART Drumline Configuration

The scientific framework for the trial was decided following community consultation, including the configuration of the SMART drumlines in the Gracetown area. A SMART Drumline Trial Ministerial Reference Group was formed, with representatives from State and Local Government Agencies, the Conservation Council of Western Australia, Sea Shepherd, Surfing WA and Surf Life Saving Western Australia. The Reference Group assisted in many aspects of the trial, provided regular feedback on the process, and assisted in communicating the trial objectives and preliminary results to interested community members.

The configuration of the SMART drumline locations surrounding Gracetown was open to public consultation from 13 September 2018 until 10 October 2018. The preferred option was that 10 SMART drumlines be deployed evenly, about 500 m from shore, along 11.5 km of the coast.

3.2 SMART Drumline Operations

Weather permitting, the 10 SMART drumlines were deployed and retrieved daily by a commercial contractor to the Department of Primary Industries and Regional Development (DPIRD). Commencement of SMART drumline deployment occurred no later than one hour after sunrise and was completed no later than two and a half hours after sunrise. During periods of risk weather conditions in the morning or operational limitation to vessel launching (i.e. peak recreational boat launching), the delayed commencement of fishing operations was approved. Retrieval of SMART drumlines did not occur earlier than two hours before sunset, and was completed by sunset. When the weather conditions changed to become not conducive to the safe handling of animals, or the fishing operations staff, fishing gear was retrieved earlier (risk weather). The set and retrieval times of each SMART drumlines was recorded (Appendix 9 Gear sheet).

Each SMART drumline was baited with either Western Australian salmon (*Arripis truttaceus*) or sea mullet (*Mugil cephalus*) which was one kilogram in weight. Each SMART drumline was checked every three hours and empty hooks or those where part of the bait had been removed were re-baited. These regular checks were also designed to minimize harm to any animals that may not have triggered the alarm. The time and the bait present at each check was recorded (Appendix 9 Gear sheet). In the event of an alarm, the fisher was required to attend the triggered SMART drumlines within 30 minutes, and to determine whether an animal was on the hook or if it was a false alarm (Appendix 9 Gear sheet).

3.3 Capture, Tagging and Relocation of White Sharks

Animal ethics approval for the trial was granted through the DPIRD Animal Ethics Committee as projects AEC 18-5-14 and AEC 20-03-09 v1.0. This committee continuously monitored and reviewed the procedures of the trial in order to maintain the highest practical animal welfare standards.

On-board cameras were activated as soon as the crew confirmed that an animal was on a hook. When the animal was ready, it was secured to the vessel as per DPIRD targeted shark tagging program procedures such that pain and distress was minimised (e.g. shark's head and gills are submerged at all times). Once secured, the species identification of the animal was confirmed and a series of measurements were made (Appendix 10 Catch sheet).

For tag application, a pilot hole was made with a tagging applicator before inserting the tags. A yellow identification tag was inserted in all animals at the base of the dorsal fin. An acoustic tag and pop-up archival transmitting (PAT) tag was inserted into the base of the dorsal fin for all white sharks. The PAT and the acoustic tags were inserted on different sides of the fin.

Once all data collection and tagging was completed the animal was released. All white sharks and tiger sharks three metres or greater in total length (TL) were relocated at least one kilometre offshore and released, weather permitting. The relocation of the shark was only undertaken when both the health and safety of the crew and shark could be guaranteed. If the crew or shark welfare was in doubt, the relocation ceased and the shark was released as soon as possible, regardless of distance from shore. It was of paramount importance to this trial to avoid or minimise harm, including pain and distress.

3.4 Animal Welfare Metrics

A series of metrics related to animal welfare were generated and can be found in the appendices. These include;

- Response Time (9.3 Appendix 3)
- Hooked Time (9.4 Appendix 4)
- Hooking Location (9.5 Appendix 5)
- Release Condition (9.6 Appendix 6)

3.5 Acoustic Tracking

Acoustic tracking is used to determine the movement patterns by attaching an acoustic transmitter to the individual to be tracked. Acoustic receivers then detect the unique acoustic signal that is emitted by the transmitter. Acoustic receivers can provide near real-time notifications via shark monitoring receivers (VR4; Vemco) or store the data for subsequent retrieval and downloading (VR2; Vemco). This study externally attached an acoustic transmitter (V16-6H; Vemco) upon capture (3. Methods: 3.3 Capture, Tagging and Relocation of White Sharks), which permitted the detection of the shark on acoustic receivers in the SMN (https://www.sharksmart.com.au/research/shark-monitoring-network/), as well as acoustic receivers (VR2) deployed as part of this study (Figure 1a).

Prior to deployment of acoustic receivers, a series of range tests were conducted off Gracetown to determine the acoustic range of transmitters and hence inform the design of the arrays.

3.6 Acoustic Arrays

Acoustic receivers (*n*=240; VR2; Vemco) were deployed in six arrays in the Capes region and were complimented by seven near real-time shark monitoring receivers (VR4s), which are part of the SMN (Table 1; Figure 1a). The primary array of acoustic receivers was located off Gracetown and encompassed the 10 SMART drumlines (Figure 1a). The secondary arrays were located approximately 1 km offshore at other nearby beaches (Figure 2). Spacing of receivers in the primary and secondary arrays were based on the results of range testing, such that detection ranges from adjacent receivers should overlap under a range of conditions.

The Gracetown array was designed to determine the initial movements of relocated white sharks from the SMART drumlines. The array consisted of an inshore line of receivers from north of Hangmans to south of Ellensbrook approximately 500 m from the shore (Figure 1b). An associated offshore line complimented the inshore line, and was located approximately 2

km from shore. There were 10 cross-shore lines that joined the offshore and inshore lines creating the gated (Heupel *et al*., 2006) design (Figure 1b). Once a shark was captured on a SMART drumline and relocated 1 km offshore, its release would be between the inshore and offshore lines. Therefore, if it was detected on either of the offshore, or inshore lines its post-release movement could be established. It is possible to be detected on one of these lines and not pass through the line (see Heupel *et al*., 2006), hence the use of gates within the array to detect if it moved north or south through the array.

The secondary arrays (Figure 2) were designed to detect if a relocated shark moved to an adjacent surf break. Therefore, they consisted of a single line of receivers approximately 1 km from shore with receivers closer to shore at each end of the array to “box” out the area and permit detection of a white shark in the area (Figure 2).

Both the primary and secondary arrays as well as the associated VR4 receivers at Meelup and Bunker Bay permitted the detection of other acoustically tagged species. This report includes details of other acoustically tagged white sharks that were detected on acoustic receivers from Meelup to Prevelly (Figure 1a) from 21 February 2019 to 20 February 2021 inclusive.

The arrays were retrieved and replaced after the first 12 months of the trial (21 February 2019 to 20 February 2020) in order to download data and replace batteries. Given the challenging and dynamic operating environment of the south-west coast not all arrays were able to be re-established. This was because several locations continued to be problematic in terms of maintaining receivers *in situ* (i.e. receivers keep breaking free despite changes to mooring designs), in combination with insufficient replacement receivers being available and unforeseen delays in obtaining replacements.

Table 1 Number and type of acoustic receivers located in each of the arrays and the Meelup site in the Capes region.

Region	VR2	VR4G	Total
Meelup		3*	1
Windmills	14		14
Three Bears	10		10
Yallingup	19	1	20
Indjidup	27		27
Gracetown	132	3	135
Prevelly	38		38
TOTAL	**240**	**7**	**245**

* two additional VR4 receivers were installed during the SMART drumline trial in the Meelup region at Bunker Bay on 16 October 2020.

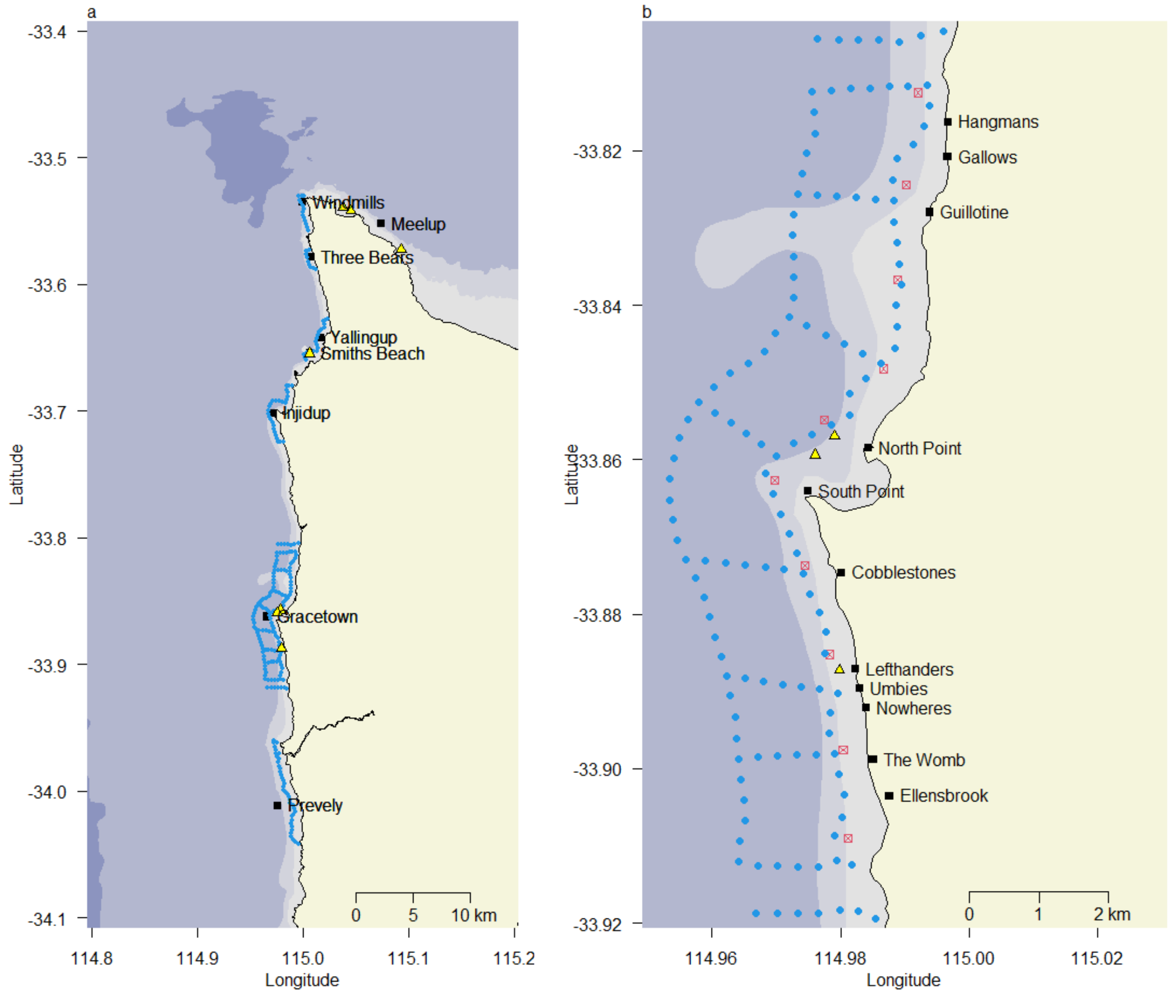

Figure 1 Location of VR2 (blue dots) and VR4 (yellow triangles) acoustic receivers a) in the Capes region, and b) off Gracetown with major surf breaks (black squares). SMART drumline locations (red crossed squares) and isobaths (0-10, 10-20, 20-50, 50-100, 100-200 >200 m; light to dark blue) also indicated.

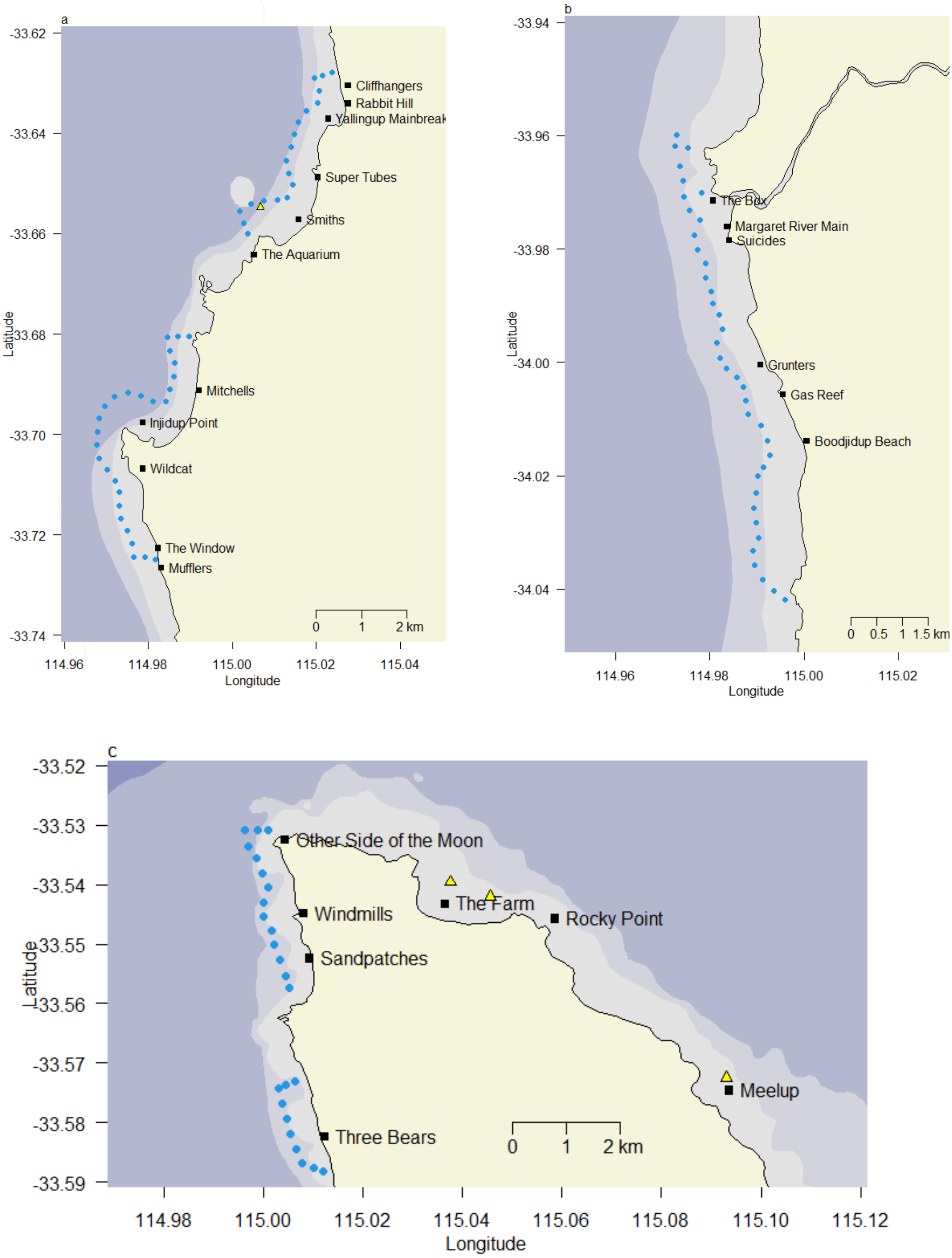

Figure 2 Location of VR2 (blue dots) and VR4 (yellow triangles) acoustic receivers a) off Yallingup and Injidup; b) off Prevelly and c) off Meelup, Windmills and Three Bears. Key as per Figure 1.

3.7 PAT Tagging

Each white shark caught in the trial was fitted with a pop-up archival transmitting (PAT) tag (miniPAT 348; Wildlife Computers Ltd) to estimate broadscale patterns of movement post-capture. PAT tags, also referred to as pop-up satellite archival tags (PSATs), have been used frequently to track the movements of white sharks in various oceanic regions (e.g. Bruce *et al*., 2006; Francis *et al*., 2015; Skomal *et al*., 2017). They record and archive data on depth, temperature and light-level which, along with any additional positional data from acoustic tags, can be used to provide geo-locational data (Hill and Braun, 2001; Teo *et al*., 2004) as well as dive profiles and habitat utilization information. These data are stored in the tag, and should the tag be retrieved, full data sets can be downloaded. However, the primary mode of data retrieval is through satellite transmission of summary data sets (e.g. time-at-temperature and time-at-depth histograms as well as depth-temperature profile summaries and depth corrected dawn and dusk light level curves) through the Argos satellite system when the tag releases from the shark and floats to the surface. Release of the tag from the shark can be pre-programmed, but can also occur independently based on constant depth, rapid increase in temperature (tag ingestion) or when depth exceeds 1400 m. These features aid in tag recovery should a mortality occur resulting in the shark remaining on the sea floor, or sinking to depths which would result in crushing of the tag.

Each tag was programmed to collect ambient light levels, temperature and depth at 10-second intervals, with data pooled into 6-hour bins for histogram transmission. Daily geographical positions were estimated using Global Position Estimator (GPE3) software, which runs within the Wildlife Computers' Data Portal. The GPE3 software uses a Hidden Markov state-space model (time series) at a 0.25° grid resolution incorporating environmental variables, such as temperature, daylight and barriers to movement, and the maximum swimming speed of the study species (Bruce *et al*., 2006), which in this study was estimated at 3.6 km h^{-1}.

4. Results

4.1 Fishing Days

Weather permitting, the drumlines were deployed on 465 (63.6%) of the days between 21 February 2019, and 20 February 2021 (Table 2). There were more fishing days in the first 12-months (n=252 days), in comparison to the second year of the trial (n=213 days). A DPIRD observer was present on-board the vessel for 163 fishing days (35% of fishing days) over the two-year period. Observer coverage was higher in the first year (133 days) to ensure that all fishing and tagging operations adhered to the standard operating procedures.

Table 2 Days fished, not fished and the monthly proportion of days fished during the first two years of the SMART Drumline trial.

Year	Month	Days Fished	Days Not Fished	Proportion
2019	February	8	0	100
	March	23	8	74
	April	21	9	70
	May	24	7	77
	June	12	18	40
	July	18	13	58
	August	13	18	42
	September	17	13	57
	October	22	9	71
	November	25	5	83
	December	28	3	90
2020	January	24	7	77
	February	25	4	86
	March	21	10	68
	April	19	11	63
	May	12	19	39
	June	13	17	43
	July	8	23	26
	August	15	16	48
	September	11	19	37
	October	20	11	65
	November	21	9	70
	December	23	8	74
2021	January	28	3	90
	February	14	6	70

4.2 Catch Data

In total, 311 capture events occurred during the two year trial, including two white sharks, 266 other sharks, and 43 other animals (37 rays and six finfish; Table 3). Of these capture events, 11 were recaptures, with nine of the recaptures being animals that were initially tagged as part of the SMART drumline trial. Detailed capture information on the animals caught during year one of the trial is presented in FOP 139 (https://www.fish.wa.gov.au/Documents/occasional_publications/fop139.pdf). Detailed capture information for year two is presented in Appendix 1, with information pertaining to recaptured individuals presented in Appendix 8.

There were no white sharks captured during year two of the trial. Tiger sharks were the most common species caught in both years.

Table 3 Number of capture events by category and species during the two years of the SMART drumline trial.

Category	Species	Scientific name	Year 1	Year 2	**Total**
Target	White Shark	*Carcharodon carcharias*	2	0	**2**
Shark	Bronze Whaler	*Carcharhinus brachyurus*	36	12	**48**
	Dusky Whaler	*Carcharhinus obscurus*	10	0	**10**
	Scalloped Hammerhead	*Sphyrna lewini*	0	1	**1**
	Shortfin Mako	*Isurus oxyrinchus*	24	13	**37**
	Smooth Hammerhead	*Sphyrna zygaena*	1	1	**2**
	Tiger Shark	*Galeocerdo cuvier*	75	93	**168**
Ray	Smooth Stingray	*Dasyatis brevicaudata*	30	7	**37**
Finfish	Pink Snapper	*Chrysophrys auratus*	3	1	**4**
	Samsonfish	*Seriola hippos*	1	1	**2**
Total			182	129	**311**

4.3 White Shark Movements

Two white sharks were captured, relocated and released as part of the SMART drumline trial, both occurred in year 1, with no white sharks captured during the second year of operations (Table 3). Full details of these events are provided in DPIRD (2020), with a brief synopsis provided below.

4.3.1 White Shark SDL1

This 4.6 m (TL) female was captured, relocated and released on 25 April 2019. Upon release, WS SDL1 was detected on the offshore line of receivers moving in a southerly direction. This shark was not detected again on any of the receivers in the Capes region during the 12-month trial period (Figure 3). The PAT tag was deployed for 54 days, during which the shark travelled approximately 1,304 km (an average of 24 km/day). The estimated track shows that the shark moved offshore from the release site and subsequently south, rounded Cape Leeuwin, moving east and arrived at an area to the south-west of Esperance on 9 May 2019 (Figure 4). The shark remained in this offshore area until 9 June 2019, when it moved to an area south of Esperance before the PAT tag released from the animal 66 km south-east of Esperance on the pre-programmed date of 18 June 2019. This PAT tag was then retrieved by DPIRD staff.

Almost six months later (16 December 2019), WS SDL1 was detected on a VR4, which is part of the SMN off Esperance, indicating that the shark was still alive and the acoustic tag was active. From 09:47 to 10:02, it was detected seven times on the West Beach receiver (S33.88213, E121.8788).

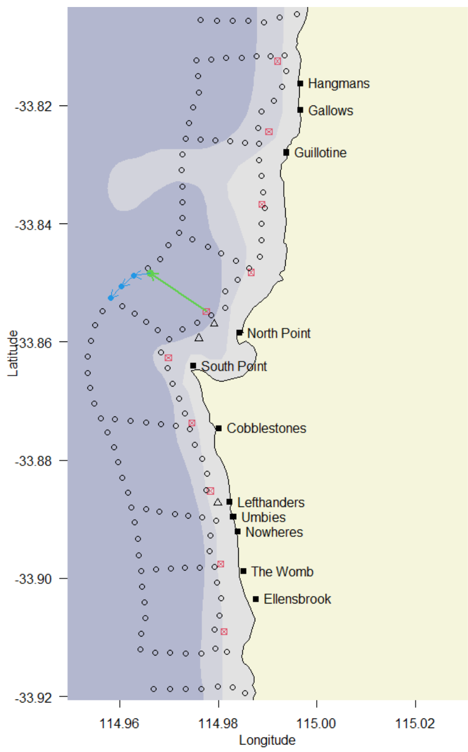

Figure 3 Acoustic detections (blue dots) and inferred straight line movements (blue arrows) of white shark (WS SDL 1) tagged on 25 April 2019. The relocation (green arrow) from SMART drumline (red crossed squares) to release location (green dot) is indicated in relation to the acoustic receivers. Key as per Figure 1.

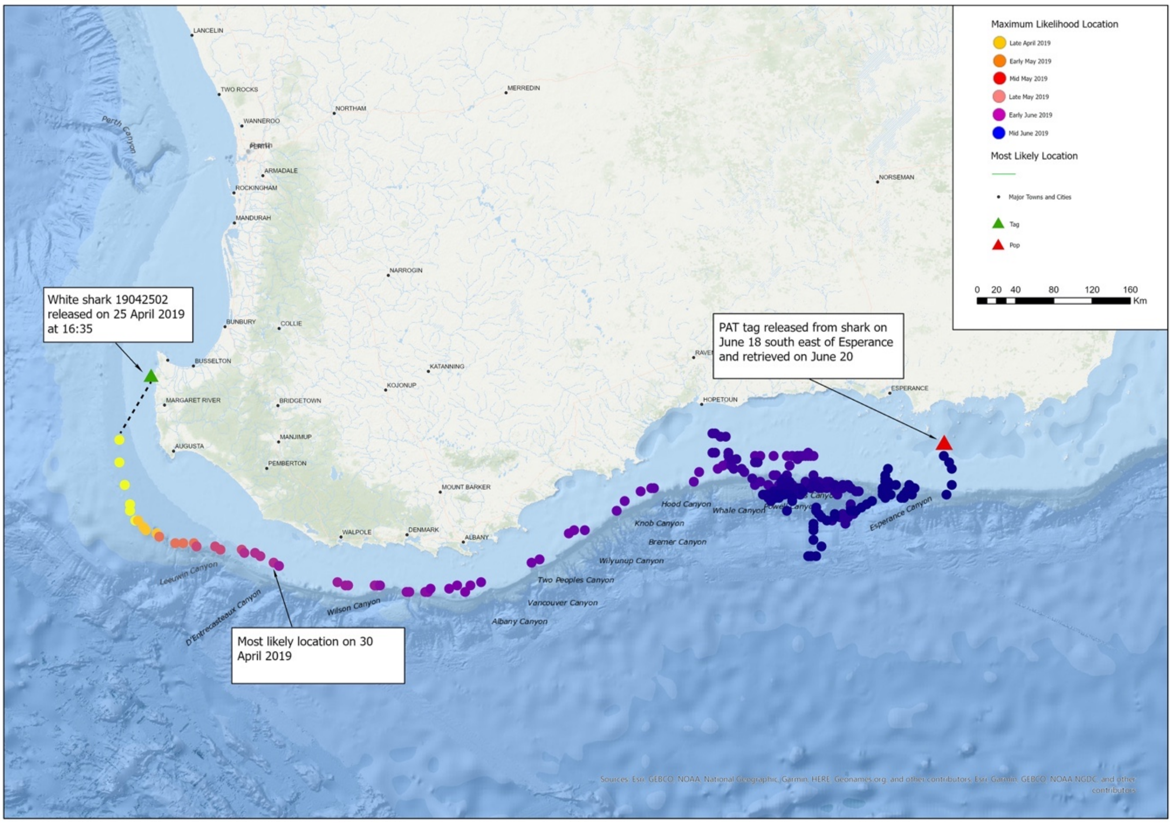

Figure 4 Estimated track of white shark (WS SDL 1) tagged on 25 April 2019 derived from PAT tag. Track is based on model-estimated daily locations using GPE3.

4.3.2 White Shark SDL2

The second white shark captured was a 3.3 m (TL) female that was captured, relocated and released on 20 August 2019. WS SDL2 was subsequently detected six times on three receivers offshore of its release location over a 9-minute period (Figure 5). Almost three months later (76 days) on 6 November 2019 WS SDL2 was detected moving through the acoustic arrays in the Capes region (Figure 6a). It moved south through the Three Bears, Yallingup, Injudup and Gracetown arrays (Figure 6b). Weather conditions on 6 November restricted the setting of SMART drumlines to a 6-hour period (from ~07:00 to 13:00). As a result, WS SDL2 moved through the study region when no fishing occurred.

A PAT tag was deployed on shark WS SDL2 for 182 days, during which the animal travelled approximately 5,156 km (an average of 28 km/day). The model-estimated daily positions show that subsequent to being tagged and relocated this shark initially moved in a north-west direction to more offshore waters and subsequently further northwards along the shelf edge to west of the Houtman Abrolhos Islands (Figure 7a). It then travelled along more inner shelf waters to an area north of Bernier Island. It then began a return journey southward remaining west of the Houtman Abrolhos Islands before travelling close to Rottnest and Garden Islands, where it was detected by acoustic receivers in the SMN (Figure 7b). The shark then moved south-west and progressed through the Gracetown array continuing to deeper, more offshore waters in the vicinity of the Leeuwin and D'Entrecasteaux Canyons. It then travelled eastward along the shelf edge waters before an extensive move southward into oceanic waters down to 38°S before heading north towards the coast in the vicinity of the Recherche Archipelago. The tag released from the animal on the pre-programmed date of 20 February 2020, 38 km from shore, in the waters of the Recherche Archipelago (Figure 7b).

WS SDL2 was detected again after the PAT tag had released from the animal, indicating that the shark was still alive and the tag was active. It was detected once on a VR4 receiver off Frenchman's Bay (S35.08678, E117.9459) on 16 March 2020 at 06:46. It was again detected moving south through the Gracetown array from midnight to 0200 on 23 June 2020 Initially it was detected on receivers offshore from Guillotines, it was then detected by an inshore receiver off South Point before moving offshore again and was last detected on offshore receivers out from Cobblestones (Figure 7b). Finally it was detected on an acoustic receiver off Walpole on 13 July 2020, 328 days after its capture on the SMART drumline.

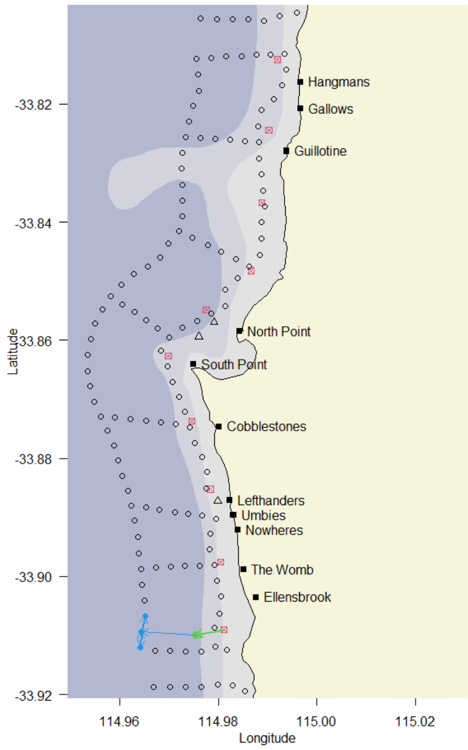

Figure 5 Acoustic detections (blue dots) and inferred straight line movements (blue arrows) of white shark (WS SDL 2) tagged on 20 August 2019. Key as per Figure 1.

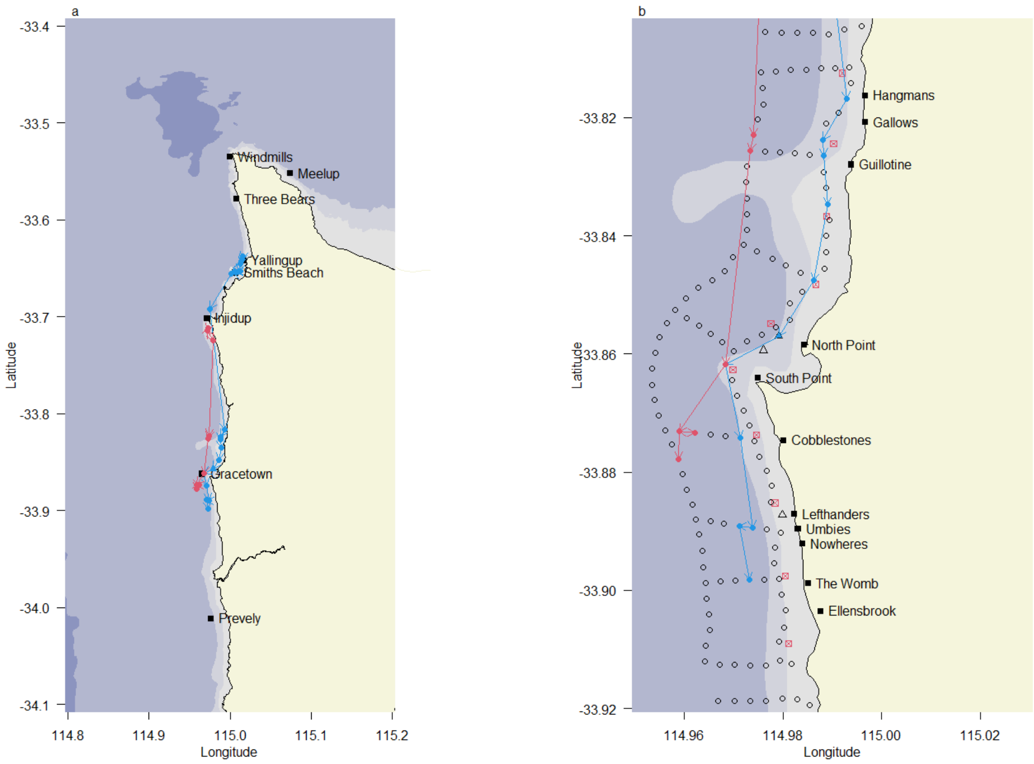

Figure 6 Detections (dots) of acoustically tagged white shark (WS SDL2) on 6 November 2019 (blue) and 23 June 2020 (red) a) in the Capes region and b) within the Gracetown array. Arrows are inferred straight-line movements between successive detection locations and represent an indicative path only. Key as per Figure 1.

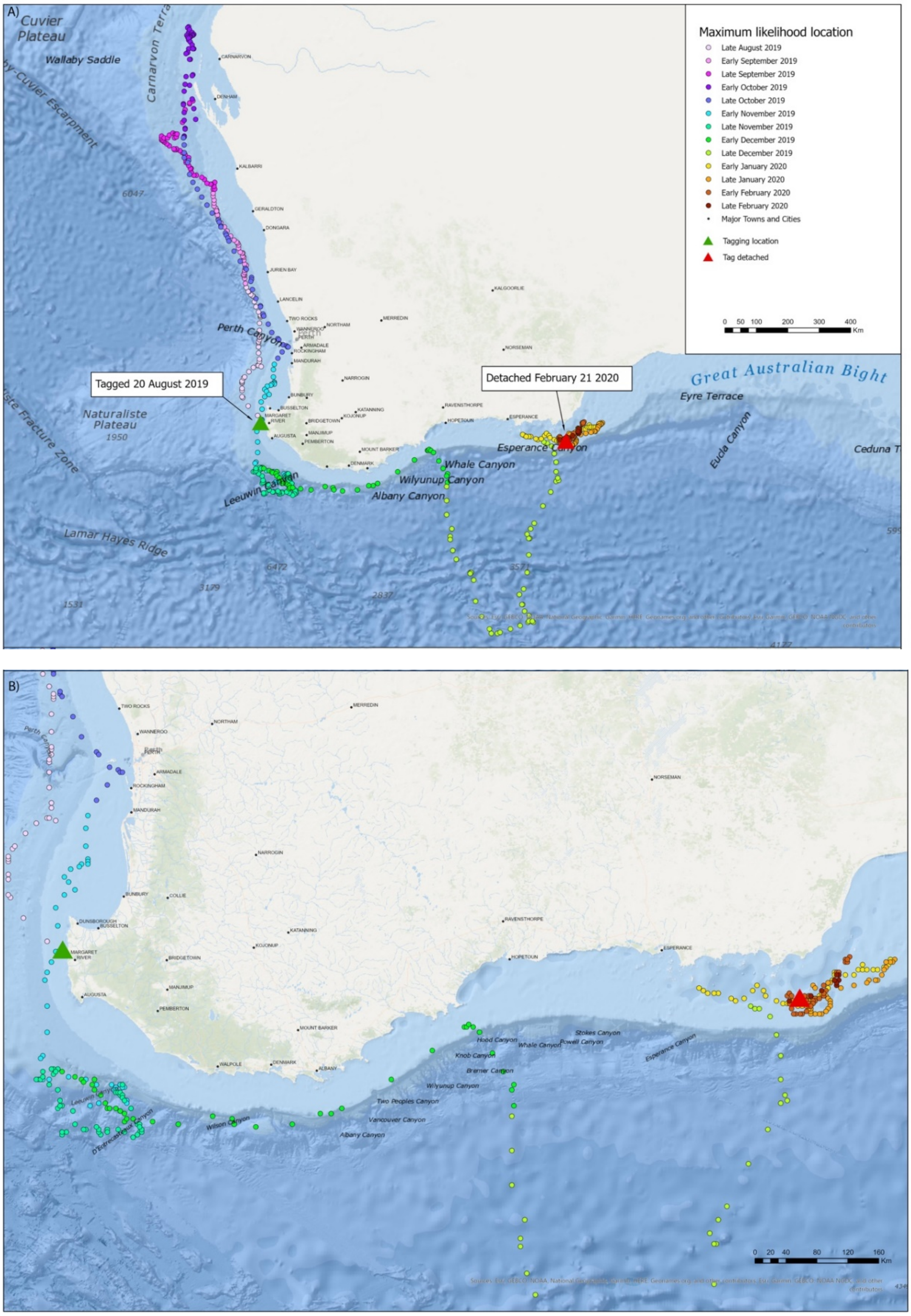

Figure 7 Estimated track of a) white shark (WS SDL2) tagged on August 20 2019 and b) zoomed extent of track in south-western waters. Track is based on model-estimated daily locations from PAT tag using GPE3.

4.3.3 Additional White Shark Detections

Thirty-six individual white sharks, which were tagged as part of other programs were detected within the Capes region during the two years of the SMART drumline trial. These included white sharks tagged as part of the DPIRDs Targeted White Shark Tagging Program (*n*=22), as well as white sharks tagged in New South Wales (*n*=2) and South Australia (*n*=12), with sharks ranging in size from 1.85 – 4.94 m fork length. One shark was tagged in 2013, though the majority of tagged sharks were released from 2018 – 2020 (*n*=26).

Separate "shark movement" events were defined as detections that occurred more than 48 hours since the last recorded detection for individual sharks on receivers in the Capes region. This resulted in 89 separate movements across the 36 white sharks detected in the Capes region during the two years of the SMART drumline trial. The majority of these movements (*n*=35) were detections at a single array / receiver in the Capes region, and as such determining directionality of movement was not possible. The remaining movements were in a southerly direction (*n*=26), northerly direction (*n*=18) or in "circular" movements[1](*n*=10). There is no evidence to support seasonality in the timing or direction of white shark movements through the Capes region (Figure 8).

Within the SMART drumline trial area off Gracetown, 24 individual white sharks were detected over the two years of the trial, comprising 46 shark movements through the array. Most sharks were only detected making a single shark movement, though one individual was detected making eight shark movements through the Gracetown array. Of these 46 shark movements however, only 13 shark movements from eight white sharks occurred when the SMART drumlines were being actively fished (Figure 9). Some white shark movements (Figure 9a; green, blue; Figure 9b; light green, yellow) were only detected on receivers away from SMART drumline locations while they were being actively fished. Others passed a SMART drumline, while other drumlines were active, though that specific location had just been removed (Figure 9b dark blue). The remaining trips passed by at least one SMART drumline location while being fished.

There was only one instance of a tagged shark being detected in the Gracetown array of receivers when a SMART drumline was activated. This was a single detection of a white shark on the offshore line (Figure 9b light green) at 08:56 on 20 November 2020, coinciding with the activation of the SMART drumline off South Point. Given the white shark was not detected on any of the midshore or nearshore VR2 or VR4 receivers adjacent to the SMART drumline, it is unlikely that this shark caused the drumline to activate.

[1] A multi-directional movement was defined as a "circular movement".

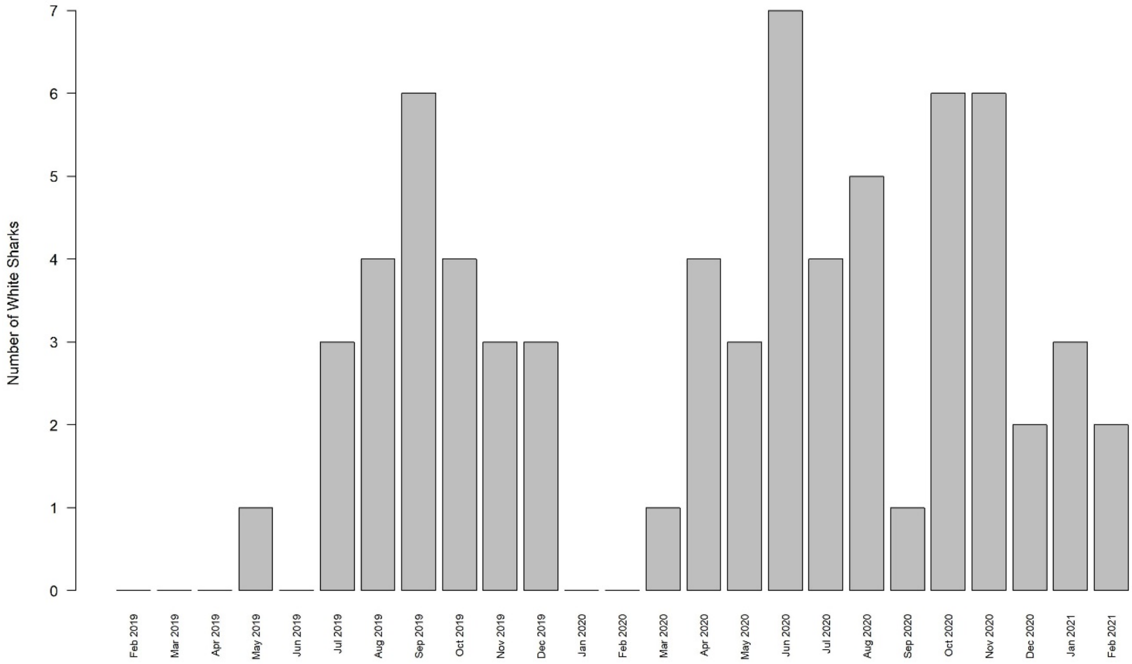

Figure 8 Number of individual tagged white sharks detected by month in the Capes region

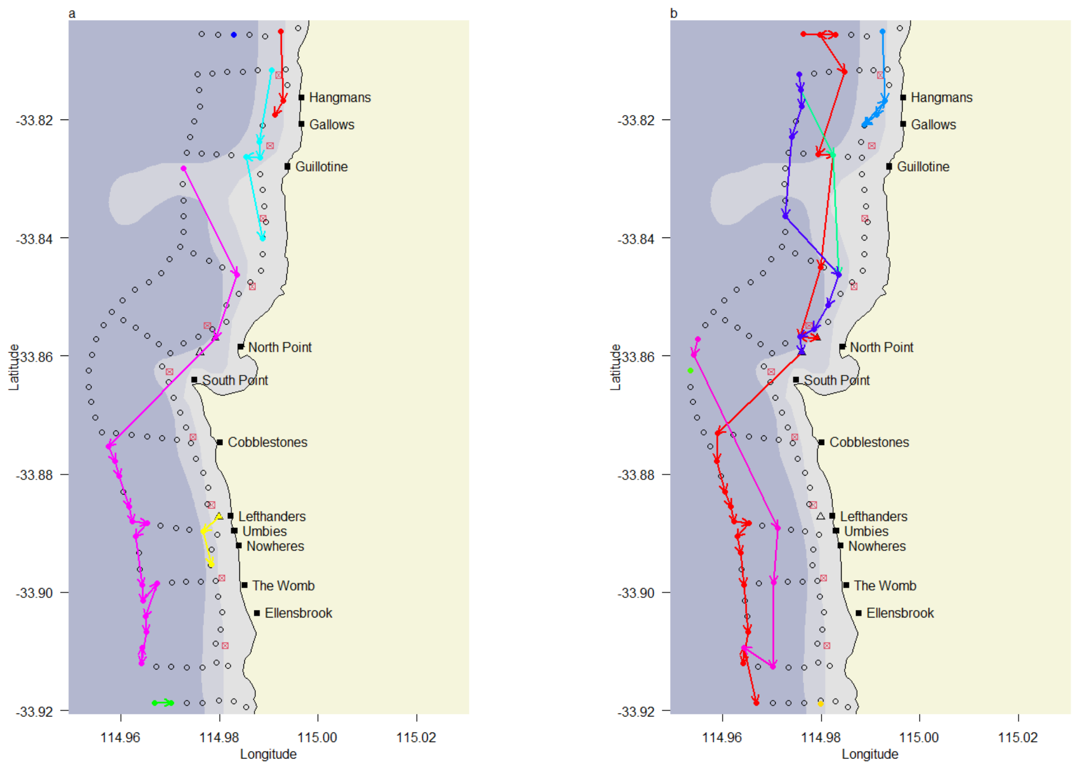

Figure 9 Detections (solid dots) of acoustically tagged white sharks that were detected within the Gracetown array while SMART drumlines were being actively fished. Arrows are inferred

straight-line movements for a shark between successive detection locations and represent an indicative path only. Key as per Figure 1.

4.4 Shark Bite Incident

The only shark bite incident to occur within the trial area during the 2 year period occurred on 30 January 2021 in Cowaramup Bay. A swimmer sustained minor injuries to her left foot when she was bitten by a shark at ~10:00am while she was 15-20 m from shore in water < 2 m in depth within the bay. All SMART drumlines were operational at the time of the incident. DPIRD scientists confirmed that the tooth mark impressions on the foot were derived from either a small whaler shark (*Carcharhinus* spp.) or small white shark.

4.5 DPIRDs Targeted Shark Tagging Program

In order to support the SMN, DPIRD undertakes a targeted shark tagging program. Highly trained crews are deployed in advantageous situations to capture, tag and release white sharks. In the first year of the trial (21 February 2019 to 20 February 2020), 18 white sharks were caught from 51 days of fishing effort while in the second year of the trial (21 February 2020 to 20 February 2021) 33 white sharks were caught from 92 days of fishing effort. This resulted in a combined catch of 51 white sharks by targeted tagging over the two-year trial period.

5. Discussion

This SMART drumline trial has collected movement data from a limited number of white sharks (n = 2) captured in the first year of the trial, with no additional white sharks captured in the second year of the trial. During the trial period, 36 other acoustically tagged white sharks were detected by acoustic receivers. These white sharks were tagged previously by DPIRDs targeted shark tagging program and additional white shark tagging programs in NSW and South Australia. Twenty-four white sharks were detected by receivers within the Gracetown acoustic array where the SMART drumline fishing methods were trialled. Eight white sharks were detected during actual fishing operations. These data indicate that the SMART drumlines do not catch or interact with all white sharks present in an area. In addition, while a low number of white sharks were captured, the trial demonstrated that the SMART drumlines have the ability to capture large sharks (WS SDL1 – 4.6 m TL female) and relocate them at least 1 km offshore.

The SMART drumline trial resulted in a low capture rate of white sharks (n=2) for the 465 fishing days over the two years of operation. In contrast, DPIRDs targeted shark tagging program yielded a capture of 51 white sharks from 143 days of fishing effort over the same period. A key difference is that the DPIRD tagging is specifically targeted towards localities that have existing, elevated feeding opportunities for white sharks. In contrast the SMART drumline trial was located in an area known to have white sharks but not known to have consistent specific feeding attractants, notwithstanding the periodic presence of whale carcasses nearshore.

5.1 White Shark Movements

As discussed previously (DPIRD, 2020), the initial movements of the two white sharks captured during the first year of SMART drumline trial were directly offshore after relocation and release. As a shark hazard mitigation strategy, the direct offshore movement exhibited by the two SMART drumline white sharks would reduce the risk to coastal water users. WS SDL 1 has not been subsequently recorded within the Gracetown array but was detected back inshore in Esperance 235 days after release on a VR4 receiver. WS SDL 2 was detected in the Gracetown array 76 days since its release (DPIRD, 2020) and again 307 days since release. WS SDL 1 remained in more offshore waters throughout the period the PAT tag was attached while WS SDL 2 undertook subsequent movements within inshore waters since its release. However, WS SDL 2 was subsequently detected in nearshore waters again, first being detected by the Perth Metropolitan SMN array on 28 October, and then detected in the Capes region on the acoustic arrays 8 days later on 6 November 2019, 76 days after being released in Gracetown.

The direct offshore movement pattern exhibited immediately after release by the two SMART drumline caught white sharks was not generally exhibited by the other white sharks tagged from related programs that were detected within the Gracetown array. These other sharks, as well as the subsequent detection of WS SDL 2, 76 and 307 days later, demonstrated alongshore movements, detected on receivers either on the inshore, mid-shore or on the offshore lines.

The data derived from the PAT tags revealed that they detached on the dates specified for release and there was no mortality of these white sharks. The PAT tag data for each white shark shows that they travel large distances and that travel is not unidirectional. Movement occurred to areas as far north as near Bernier Island, with both sharks moving around the south coast of Western Australia before the tags released. White sharks move broadly through coastal and

offshore waters of Western Australia. There is currently an ongoing investigation of the movement patterns of white sharks in Western Australia through the deployment of PAT tags on white sharks as part of the DPIRD tagging programs.

There was no evidence of any consistent seasonal movement pattern from the white sharks detected in the Capes region. There was considerable variation in the direction of movement of white sharks in the Capes region. Some white sharks were detected moving north through the arrays, only to be detected moving in a southerly direction weeks later, with a pattern of alternating directions persisting over several months. These findings concur with a previous Departmental study that reported limited evidence of predictable return behavior, seasonal movement patterns or coordination to the direction or timing of individual white shark's movements (McAuley *et al*., 2017). At a finer scale, white sharks tagged as part of other DPIRD tagging programs were detected moving past actively fished SMART drumlines. Clearly, these white sharks did not consume the available baits and thus did not activate the SMART drumline. As these baits were present on the subsequent bait checks, it indicates that not every white shark is intercepted by the SMART drumlines.

5.2 Catch Composition and Release Condition

Due to the lack of long-term catch records on white sharks in Western Australia (McAuley and Simpfendorfer, 2003; Taylor *et al*., 2018), it cannot be reliably determined whether or not the observed white shark catch is 'typical' for the study region. Nevertheless, the results are broadly consistent with those observed in the previous lethal drumline trial, whereby no white sharks were caught in the Perth metropolitan, Geographe Bay or Capes region between 25 January and 30 April 2014, with up to 30 drumlines being used daily (DoF, 2014). During the previous trial, tiger sharks were the most commonly-caught species, a result which is replicated in this study.

Catches of white sharks in NSW SMART drumline trials varied considerably between locations in the North Coast, Newcastle, Sydney and Bega Valley region (https://www.sharksmart.nsw.gov.au/technology-trials-and-research/smart-drumlines). These catches ranged from zero white sharks (e.g. Sydney trial in February and May 2019) through to much higher numbers in the North Coast (434 white sharks, December 2016 to June 2020). The low white shark catches at some of these NSW locations is consistent with the results from the current study. However, the much higher catches of NSW are at odds with those from WA.

The two white sharks caught in the current trial were much larger animals than the majority of white sharks caught in NSW. Female white sharks are believed to mature at between 4.5 and 5.0m TL (Malcolm *et al*., 2001), suggesting that WS SDL1 (4.6 m TL, female) was an adult, while WS SDL2 (3.3 m TL, female) was a sub-adult. The sizes of these two sharks are consistent with those caught in Departmental tagging programs in Western Australia. The capture of these large sharks in addition to the lack of straightened hooks or damaged snoods indicate that the equipment used during the trial was appropriate for targeting large white sharks. Furthermore, the bait used in the trial (Australian salmon or sea mullet) has successfully been used to catch white sharks in Departmental tagging programs and in the NSW drumline program (https://www.sharksmart.nsw.gov.au/__data/assets/pdf_file/0005/871682/SMART-drumlines-faqs.pdf), and has been recorded in the stomach contents of juvenile white sharks caught off NSW (Grainger *et al*., 2020).

On average, animals spent only a short time on the hook (<30 minutes in most cases) which resulted in the majority of animals being released in good condition (90%, n = 281). The survival of the two white sharks following their release was also confirmed by the acoustic and satellite data. Blood samples taken from white sharks caught in the NSW SMART drumline program indicate that this capture method may be a relatively low-stress capture method if short response times are used, as was the case in the current trial (Madlinger, 2019; Tate *et al*., 2019). Therefore, the process of capturing and relocating white sharks is unlikely to cause population-level impacts for white sharks off Western Australia.

5.3 Stakeholder Engagement

A key elelement of this trial has been establishing and maintaining stakeholder engagement and involvement in the oversight of the program. Importantly, the Ministerial Reference Group has played a valuable role in liasing with the trial managers, ensuring that the Government maintained transparency throughout the process. Members of the Ministerial Reference Group supported the use of a non-lethal shark mitigation measure in the context that it was preferable to lethal methods such as gillnets or unattended drumlines. Overall, formal feedback from all third party observers that were placed on-board the contractor's vessel was very positive, indicating that the crew and DPIRD staff were competent and professional during fishing operations and that the processes and procedures developed and implemented for the SMART drumline trial were rigorous and robust. Feedback indicated that on-board processes were aligned to maximizing animal welfare by striving to release animals quickly and in good condition. It has been a key feature of the SMART drumline trial that animal welfare has been paramount and integral to the success of the program. Where appropriate, recommendations made by third party observers and the local community were incorporated into the standard operating procedures. For example, the suggestion to record underwater video footage of released animals was enacted in April 2019. The use of third party observers in this manner from external organisations such as the Conservation Council of WA and Sea Shepherd has been beneficial in regard to informing and educating their members on the trial, and providing feedback from the communities they represent on the design, implementation and progress of the SMART drumline trial. DPIRD's independent Animal Ethics Committee has also provided dilgent oversight of the program, ensuring sufficient data was being provided to allow independent assessment of how the animal welfare aspects of the project were tracking.

6. Conclusions

The SMART drumline trial was conducted in a challenging marine environment. The initial movements of the two white sharks captured during the SMART drumline trial were directly offshore after relocation and release. The type of direct offshore movement exhibited by the two SMART drumline caught white sharks provides some evidence of an immediate reduction in risk posed by the particular shark in each instance. However, it is important to note that the sample size is insufficient to compare the movement of SMART drumline caught white sharks with other white sharks tagged outside of the trial. Therefore, such evidence must be interpreted with caution.

The SMART drumline gear has proven to be capable of capturing large white sharks, but the trial only yielded two white sharks. The numbers of white sharks caught in this SMART drumline trial was much less than in northern NSW. This is a reflection of the different marine environments of each study, the different populations of white sharks that occur off WA and

NSW (Hillary *et al.*, 2018), and the fact that several of the NSW trials occurred in known white shark nursery grounds. Moreover, DPIRD's targeted shark tagging program yields a much higher white shark catch rate from the targeted days of active fishing.

During the two-year trial, eight acoustically tagged white sharks were detected in the vicinity of active SMART drumline gear but not captured. A further 16 tagged white sharks which were not tagged as part of the SMART drumline trial swam through the broader array of receivers that encompassed the drumlines at times they were not set

The trial has exemplified the need for animal welfare to be paramount. Consequently, animals spent only a short time on the hook (<30 minutes in most cases) which resulted in the majority of animals being released in good condition (90%) and no observed mortalities of any shark species.

Given the low number of SMART drumline captured white sharks it was not possible to obtain the necessary evidence-based data required to assess the efficacy of SMART drumlines as a shark hazard mitigation measure for white sharks in Western Australia.

7. Acknowledgements

The Department wishes to thank all personnel involved in undertaking this trial. We thank the professional work of Fairfield Ltd and acknowledge the assistance and support of the Shire of Augusta-Margaret River and the Department of Biodiversity, Conservation and Attractions. For allowing information on their respective tagged sharks to be shared we thank the Governments of South Australia and New South Wales. Assistance was also provided by VEMCO and Wildlife Computers in the design and management of shark tracking systems. We thank members of the Ministerial Reference Group which included participants from the Conservation Council of WA, Surfing WA, Surf Life Saving WA, Department of Biodiversity, Conservation and Attractions and Sea Shepherd for their support and for the assistance of the independent third party observers.

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9. Appendices

9.1 Appendix 1 – SMART Drumline Catch Details

For some catch events, not all information could be recorded. The majority of finfish species are unable to be sexed externally, hence were recorded as an unknown sex. Sex could not be determined for those species which released themselves from the hook (see Appendix 9.6) and as a result the lengths for these species are an estimate.

Table A 1 SMART drumline (SDL) catch event details in chronological order from 21 February 2020 to 20 February 2021

Date	Time	SDL Number	Species	Total* Length (cm)	Sex	Release Condition
22 Feb 2020	14:47	9	Smooth Stingray	103	Male	1
24 Feb 2020	12:55	9	Tiger Shark	210	Female	1
24 Feb 2020	14:17	5	Tiger Shark	245	Male	1
25 Feb 2020	09:22	2	Pink Snapper	72	Female	4
25 Feb 2020	10:03	7	Tiger Shark	255	Male	1
26 Feb 2020	13:40	7	Tiger Shark	325	Female	1
26 Feb 2020	15:14	8	Tiger Shark	350	Male	1
28 Feb 2020	11:07	3	Tiger Shark	420	Female	1
28 Feb 2020	11:47	5	Tiger Shark	185	Female	1
02 Mar 2020	16:51	8	Tiger Shark	260	Female	1
03 Mar 2020	15:20	4	Tiger Shark	270	Female	1
08 Mar 2020	14:32	8	Tiger Shark	380	Female	1
09 Mar 2020	15:22	5	Tiger Shark	320	Female	1
11 Mar 2020	12:44	4	Bronze Whaler	250	Male	1
15 Mar 2020	16:10	7	Tiger Shark	430	Female	1
16 Mar 2020	10:18	6	Tiger Shark	250	Female	1
19 Mar 2020	10:29	7	Tiger Shark	230	Female	1
21 Mar 2020	11:58	4	Tiger Shark	280	Female	1
22 Mar 2020	10:09	4	Tiger Shark	380	Female	1
23 Mar 2020	16:06	3	Tiger Shark	265	Male	1
24 Mar 2020	12:02	6	Bronze Whaler	260	Male	1
24 Mar 2020	15:05	6	Shortfin Mako	130	Male	1
25 Mar 2020	14:38	3	Bronze Whaler	250	Male	1
04 Apr 2020	14:17	8	Tiger Shark	290	Male	1
06 Apr 2020	11:20	6	Shortfin Mako	250	Male	1
09 Apr 2020	10:11	5	Tiger Shark	230	Female	1
14 Apr 2020	09:21	10	Bronze Whaler	280	Male	1

Date	Time	SDL Number	Species	Total* Length (cm)	Sex	Release Condition
14 Apr 2020	13:22	8	Tiger Shark	350	Female	2
18 Apr 2020	08:08	10	Tiger Shark	240	Male	1
29 Apr 2020	13:33	1	Tiger Shark	390	Female	1
30 Apr 2020	11:46	7	Tiger Shark	250	Female	2
02 May 2020	13:34	7	Bronze Whaler	260	Male	1
13 May 2020	12:04	7	Shortfin Mako	260	Male	1
13 May 2020	13:14	10	Bronze Whaler	260	Male	1
13 May 2020	14:21	3	Tiger Shark	280	Female	1
19 May 2020	11:23	10	Tiger Shark	185	Female	1
07 Jun 2020	14:42	7	Shortfin Mako	190	Female	1
07 Jun 2020	15:17	4	Bronze Whaler	255	Male	1
08 Jun 2020	11:28	4	Samsonfish	145	Unknown	1
04 Jul 2020	13:24	10	Smooth Stingray	170	Unknown	1
26 Aug 2020	14:15	2	Shortfin Mako	250	Unknown	1
26 Aug 2020	15:20	2	Shortfin Mako	250	Unknown	1
14 Sep 2020	10:05	6	Shortfin Mako	150	Male	1
17 Sep 2020	10:57	10	Tiger Shark	335	Female	1
25 Sep 2020	15:44	2	Tiger Shark	340	Female	2
13 Oct 2020	08:34	10	Tiger Shark	290	Female	1
13 Oct 2020	14:59	4	Tiger Shark	250	Female	1
14 Oct 2020	09:07	8	Tiger Shark	240	Male	2
18 Oct 2020	09:29	1	Tiger Shark	410	Female	1
23 Oct 2020	10:12	7	Bronze Whaler	232	Male	1
23 Oct 2020	10:37	1	Tiger Shark	312	Female	1
24 Oct 2020	12:28	2	Tiger Shark	333	Male	1
25 Oct 2020	12:55	4	Tiger Shark	310	Male	1
11 Nov 2020	18:15	2	Shortfin Mako	NA	Unknown	NA
12 Nov 2020	11:43	2	Tiger Shark	342	Male	1
21 Nov 2020	06:54	10	Bronze Whaler	275	Male	1
21 Nov 2020	12:56	2	Tiger Shark	325	Female	1
23 Nov 2020	09:44	2	Tiger Shark	295	Male	1
24 Nov 2020	07:23	4	Smooth Stingray	172	Female	1
27 Nov 2020	12:20	2	Shortfin Mako	330	Female	1
29 Nov 2020	11:06	5	Shortfin Mako	190	Female	1
07 Dec 2020	12:08	10	Tiger Shark	283	Female	1
16 Dec 2020	11:51	10	Smooth Stingray	176	Female	1
19 Dec 2020	08:45	1	Tiger Shark	248	Female	1
21 Dec 2020	09:02	3	Shortfin Mako	260	Male	1
21 Dec 2020	11:41	3	Tiger Shark	295	Female	1
22 Dec 2020	06:36	10	Bronze Whaler	187	Male	1
22 Dec 2020	07:14	2	Tiger Shark	270	Female	1
22 Dec 2020	10:04	2	Tiger Shark	249	Female	1
22 Dec 2020	13:02	5	Tiger Shark	235	Female	2
24 Dec 2020	13:36	1	Tiger Shark	290	Female	1
24 Dec 2020	17:01	1	Tiger Shark	271	Male	1
25 Dec 2020	09:25	3	Scalloped Hammerhead	330	Female	2
28 Dec 2020	11:00	10	Tiger Shark	260	Male	1

Date	Time	SDL Number	Species	Total* Length (cm)	Sex	Release Condition
02 Jan 2021	08:16	7	Tiger Shark	299	Female	1
02 Jan 2021	17:57	5	Shortfin Mako	185	Female	1
03 Jan 2021	10:30	4	Tiger Shark	309	Female	1
03 Jan 2021	15:38	3	Tiger Shark	296	Female	1
04 Jan 2021	13:32	4	Tiger Shark	261	Female	1
05 Jan 2021	07:31	8	Tiger Shark	288	Male	1
05 Jan 2021	08:06	7	Tiger Shark	205	Male	1
05 Jan 2021	08:33	4	Smooth Stingray	80	Male	1
05 Jan 2021	13:37	4	Tiger Shark	250	Male	1
05 Jan 2021	15:20	7	Tiger Shark	252	Female	1
06 Jan 2021	07:18	5	Tiger Shark	252	Male	1
06 Jan 2021	09:52	1	Tiger Shark	425	Male	1
06 Jan 2021	15:27	4	Tiger Shark	240	Female	1
06 Jan 2021	17:57	4	Tiger Shark	350	Male	1
07 Jan 2021	11:16	5	Tiger Shark	235	Male	1
07 Jan 2021	12:13	4	Tiger Shark	230	Unknown	1
07 Jan 2021	12:44	7	Tiger Shark	274	Female	1
07 Jan 2021	14:34	10	Tiger Shark	225	Male	1
07 Jan 2021	16:50	1	Tiger Shark	230	Unknown	1
08 Jan 2021	13:18	13	Smooth Stingray	157	Female	1
09 Jan 2021	07:49	4	Tiger Shark	278	Male	1
09 Jan 2021	08:17	1	Tiger Shark	395	Male	1
09 Jan 2021	10:27	10	Tiger Shark	270	Female	1
09 Jan 2021	14:54	4	Tiger Shark	150	Female	1
09 Jan 2021	16:27	2	Tiger Shark	231	Female	1
11 Jan 2021	08:43	7	Smooth Stingray	130	Female	1
11 Jan 2021	09:54	5	Tiger Shark	264	Male	1
13 Jan 2021	08:11	3	Tiger Shark	310	Male	1
13 Jan 2021	09:56	5	Smooth Hammerhead	288	Female	1
13 Jan 2021	12:42	5	Tiger Shark	260	Female	1
15 Jan 2021	10:45	1	Tiger Shark	200	Female	1
15 Jan 2021	16:05	3	Tiger Shark	218	Female	1
16 Jan 2021	12:11	7	Tiger Shark	397	Female	1
16 Jan 2021	15:17	10	Shortfin Mako	270	Female	1
16 Jan 2021	17:39	3	Tiger Shark	251	Female	1
17 Jan 2021	13:13	3	Tiger Shark	277	Female	1
19 Jan 2021	07:17	5	Tiger Shark	200	Unknown	NA
19 Jan 2021	08:17	1	Tiger Shark	279	Male	1
19 Jan 2021	09:57	7	Tiger Shark	267	Female	1
19 Jan 2021	13:57	1	Tiger Shark	347	Female	1
19 Jan 2021	18:04	9	Tiger Shark	221	Female	1
23 Jan 2021	10:23	5	Tiger Shark	225	Female	1
24 Jan 2021	10:49	10	Tiger Shark	295	Female	1
24 Jan 2021	12:21	4	Bronze Whaler	295	Male	1
26 Jan 2021	13:40	3	Tiger Shark	430	Female	2
26 Jan 2021	14:31	2	Tiger Shark	195	Female	1
26 Jan 2021	15:11	4	Tiger Shark	248	Male	1

Date	Time	SDL Number	Species	Total* Length (cm)	Sex	Release Condition
26 Jan 2021	15:54	8	Tiger Shark	355	Female	1
27 Jan 2021	10:33	1	Tiger Shark	316	Female	1
31 Jan 2021	09:55	7	Tiger Shark	244	Male	1
06 Feb 2021	12:49	9	Tiger Shark	275	Male	1
06 Feb 2021	13:50	10	Bronze Whaler	234	Male	1
07 Feb 2021	10:57	4	Tiger Shark	207	Male	1
13 Feb 2021	09:23	9	Tiger Shark	393	Female	1
14 Feb 2021	14:11	2	Tiger Shark	298	Female	1

* smooth stingrays were measured as disc width

9.2 Appendix 2 - Non-target Species Capture Information

Tiger sharks dominated the catch of non-target species with 168 of the 309 captures (54%). Other commonly-caught species were bronze whaler sharks (*n* = 48; 16%), smooth stingrays (*n* = 37; 12%) and shortfin makos (*n* = 37; 12%) (Table A 2).

Animals of a range of sizes were captured on the SMART drumlines (Figure A 1). Shark captures ranged from a 91 cm TL dusky whaler shark to a 4.3 m tiger shark. Smaller species such as a 62 cm pink snapper were also captured (Figure A 1).

Table A 2 Number of non-target species capture events and their minimum, median and maximum total lengths (cm) captured during the two years of the SMART drumline trial.

Category	Species	Number	Min	Median	Max
Non-target sharks	Bronze Whaler	48	187	260.0	310
	Dusky Whaler	10	91	112.0	300
	Scalloped Hammerhead	1	330	330.0	330
	Shortfin Mako	37	120	220.0	367
	Smooth Hammerhead	2	155	221.5	288
	Tiger Shark	168	150	269.0	430
Ray	Smooth Stingray	37	80	130.0	180
Finfish	Pink Snapper	4	62	78.5	95
	Samsonfish	2	145	150.0	155

* smooth stingrays were measured as disc width

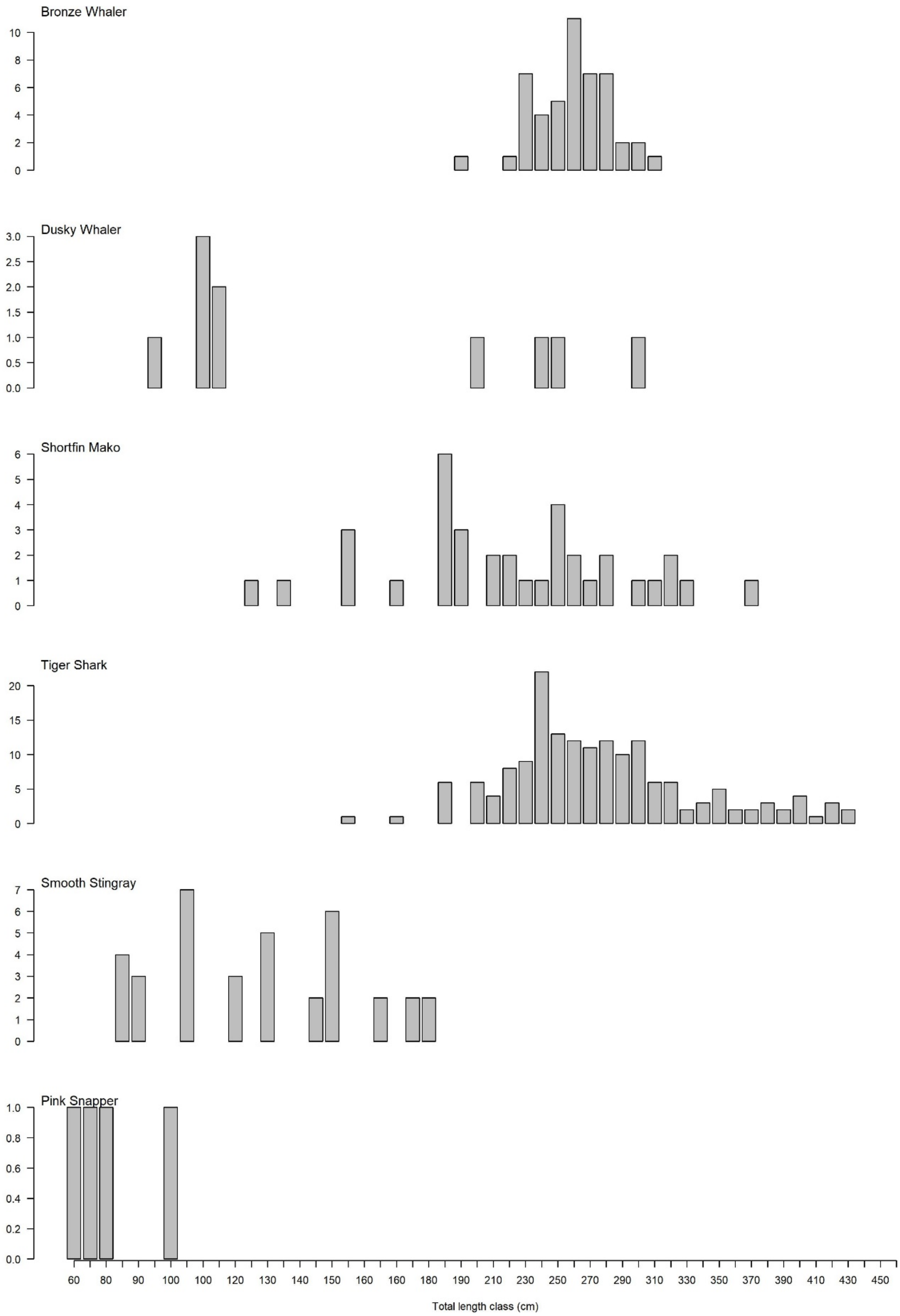

Figure A 1 Length frequency plot by species captured during the SMART drumline trial.

Catch events for all animals peaked during the austral summer, with catch rates considerably lower during autumn – spring period (Figure A 2a). This pattern persisted across both years of the trial. It was likely driven by the tiger shark catch rates (Figure A 2) which is the dominant species captured on the SMART drumlines (Table 3). There was a strong seasonal pattern in the catch rate of tiger sharks which was at annual minima during winter before increasing through spring and peaking in summer, with this pattern also persistent between years (Figure A 2). By contrast, bronze whalers showed peaks in catch rates that occurred at different times throughout the two years, with peaks in June – July and November – December during year one while year 2 peaked in March and May before remaining at low levels until the end of the second year of the trial (Figure A 2).

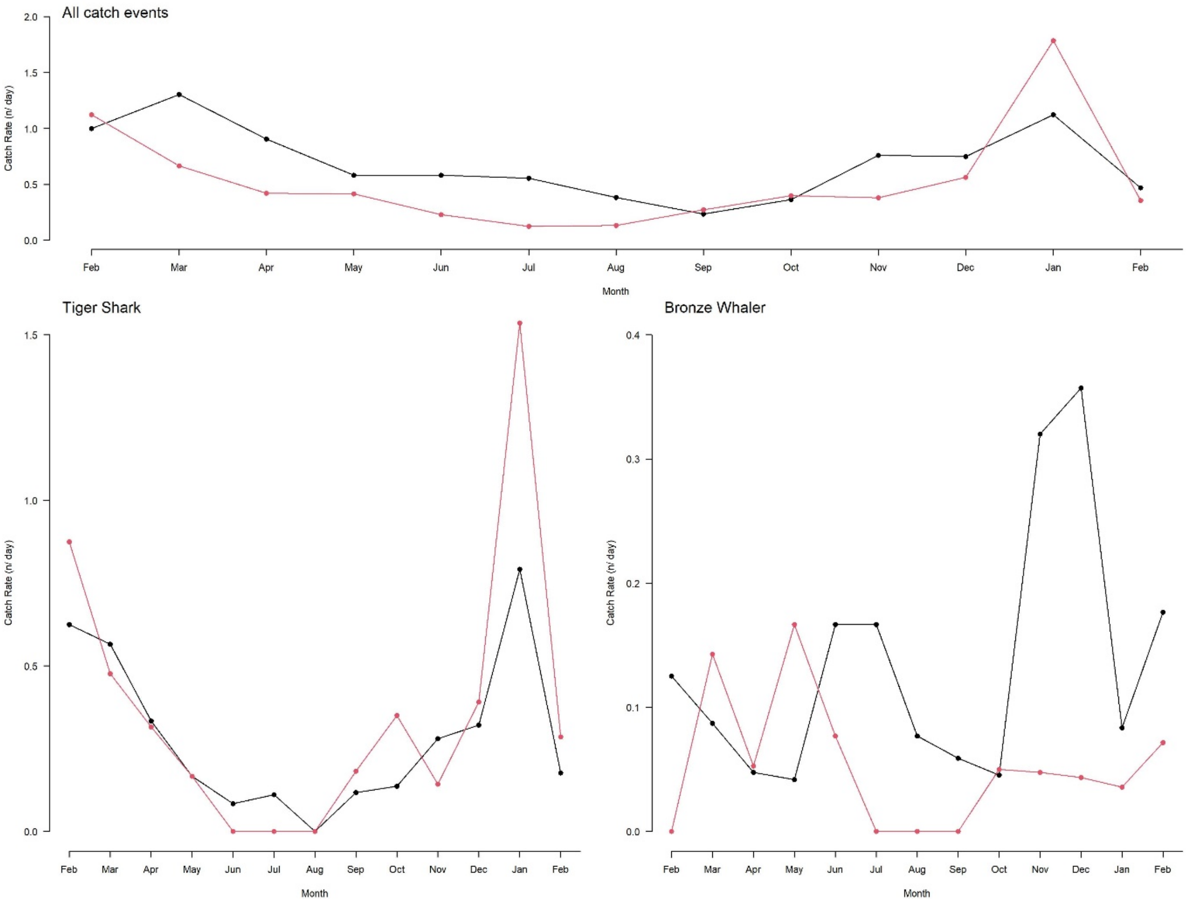

Figure A 2 Monthly catch rate (n/fishing day) overall, and by dominant species for year 1 (black) and year 2 (red) of the SMART drumline trial.

9.3 Appendix 3 - Response Time

The response time was determined differently depending on if an animal is present on the line or not. For alerts resulting in catch, the response time was from when the SMART drumline was activated until the boat arrived. For false alarms (no catch) the response time was taken from the SMART drumline alert until the bait was back in the water as recorded on the gear sheet.

The SMART drumline buoys were activated 800 times, with an average response time of 11.1 minutes (± 0.3 min SE). Response times for alerts, which resulted in catch, were on average 10.2 minutes (± 0.3 min SE) compared with 11.6 minutes (± 0.4 min SE) when it was a false alarm. False alarm response times were, as expected, longer than those resulting in catch as they were calculated from alert until when the bait was back, not just when the vessel arrived at the SMART drumline.

There were only two occasions when the maximum response time of 30 minutes was exceeded when an individual was caught (Figure A 3). Both occurred during the first year of the trial with details on each event in FOP 139.

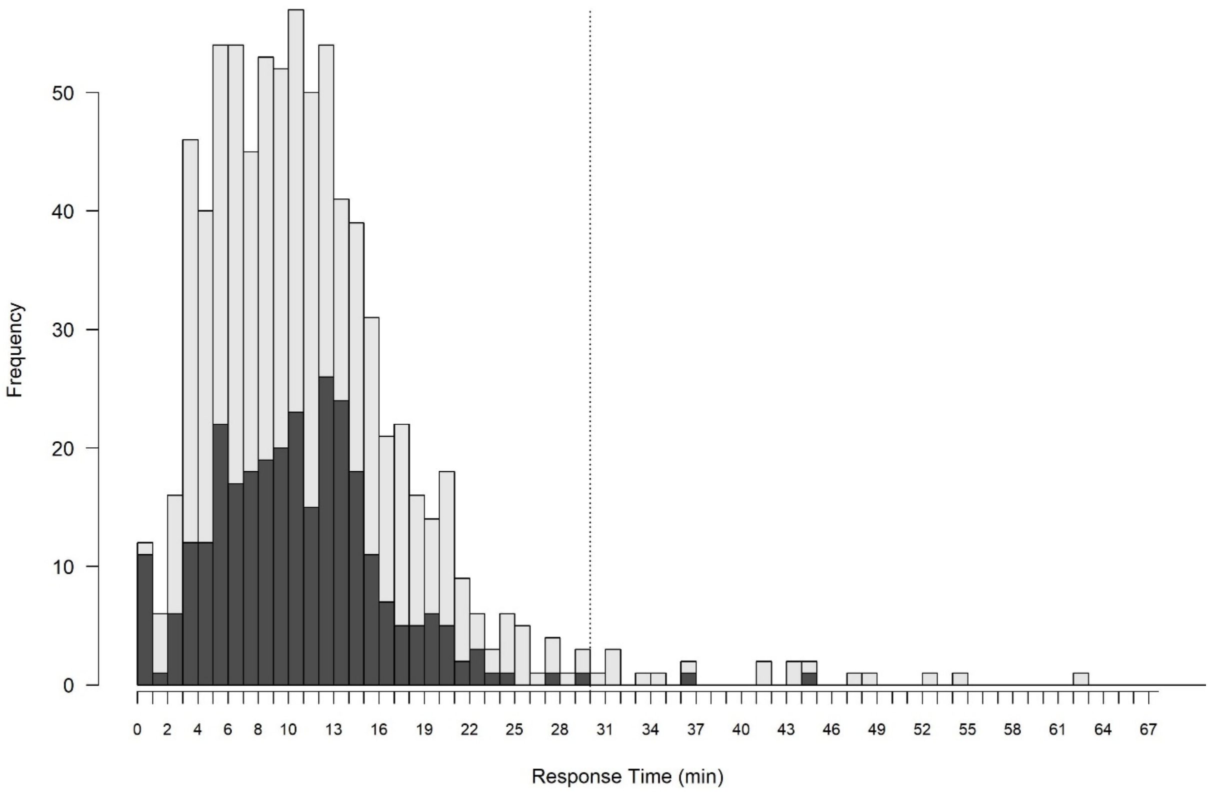

Figure A 3 Frequency of response times (minutes) to alerts from the SMART drumline buoys resulting from catch (dark grey) or false alarms (light grey). Vertical dotted line indicates the maximum allowable response time (30 minutes).

9.4 Appendix 4 - Hooked Time

The hooked time was determined for each animal as the time the animal triggered the alarm (capture), until the time of release. For animals that were relocated, this included the time of that relocation. A number of animals did not trigger the alarm and were found during the regular three-hour bait checks. Therefore, it was not possible to estimate hooked times in these 17 cases. Smooth stingrays and dusky whaler sharks comprised the majority of these no-alert captures with three shortfin makos, a tiger shark and two pink snapper being the other species which did not trigger the alarm.

For the remaining 294 individuals, they were on the hook for an average time of 27.7 minutes (range 5 – 143 min). The summary statistics by species are presented in Table A 3.

Table A 3 Summary statistics and number of no alert captures by species.

Species	Number	Mean Hook Time (mins)	Median Hook Time (mins)	Minimum Hook Time (mins)	Maximum Hook Time (mins)	Number of No Alert Captures
White Shark	2	55	55	38	72	0
Bronze Whaler	48	30	27.5	16	143	0
Dusky Whaler	10	18.4	19	14	23	5
Scalloped Hammerhead	1	25				0
Shortfin Mako	37	23	24	5	45	3
Smooth Hammerhead	2	22	22	20	24	0
Tiger Shark	168	30.2	28	10	73	1
Smooth Stingray	37	16.8	17	6	32	6
Pink Snapper	4	39	39	38	40	2
Samsonfish	2	10.5	10.5	9	12	0

9.5 Appendix 5 - Hooking Location

A Mustad Giant Circle Hook 20/0 (39937NP-DT) was used during the SMART drumline trial. Circle hooks are designed to hook the animal in the corner of the mouth to reduce injury from capture. The hooking location was recorded for all capture events and categorized as either:

- Corner: Hook is in the corner of the jaws;
- Mouth: Hook is inside the mouth. May be visible or not but can be determined by the length of trace protruding from the mouth;
- Swallowed: Hook has been swallowed and may be lodged in the gills or stomach. Hook will likely not be visible, with only a short length of trace protruding from the mouth; and
- Foul Hooked: The animal is foul hooked somewhere outside of the mouth or jaws. This includes, but is not limited to, outside of the gills, pectoral fins, flank etc.

For the 311 capture events, five shortfin mako and two tiger sharks "spat" the hook adjacent to the boat and hence the hooking location could not be determined. Of the remaining 304 catches, 213 (70%) animals were hooked in the corner of their mouth (Figure A 4). In the case of the 28 instances of foul hooking, 24 (85%) were smooth stingrays. Tiger sharks (n = 31) comprised the vast majority of swallowed hookings, with the remainder being shortfin makos (n = 3) and a bronze whaler. Twenty-eight catch events were hooked in the mouth and were a mix of tiger sharks (n = 14), dusky whalers (n = 3) smooth stingrays (n = 5), shortfin mako (n = 4) and one each of a bronze whaler and scalloped hammerhead.

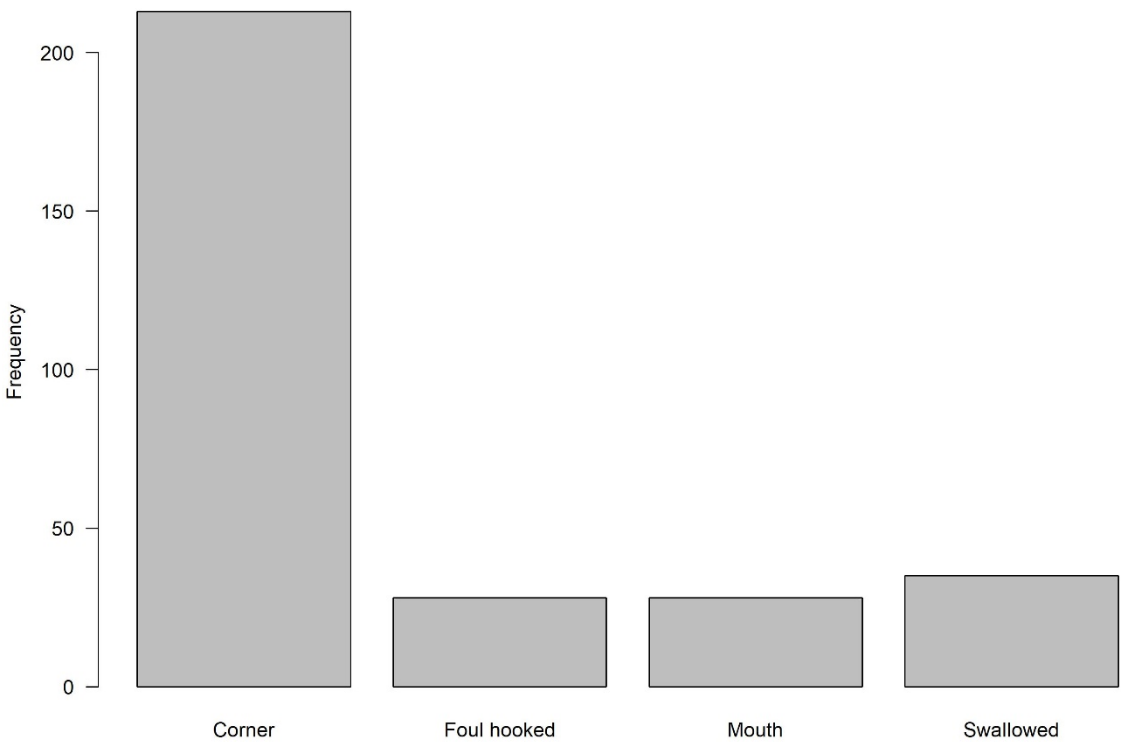

Figure A 4 Frequency of hooking location for individuals captured on SMART drumlines during the two-year trial.

9.6 Appendix 6 - Release Condition

The condition of an individual at release was categorized numerically as;

1. Swam away strongly in good health
2. Swam away slowly
3. Failed to swim away and sunk, chances of survival appear low
4. Individual died
5. Individual was euthanized because of injuries

The vast majority (90%; *n* = 281) of capture events saw animals released in a good condition where they swam away strongly in good health (release condition 1). Of the remaining 30 captures, 24 swam away slowly (release condition 2). The two animals that were released in condition 3, were a 2.4m Tiger Shark and a 1.8m Shortfin Mako. Both sharks were corner hooked in the mouth, and had rapid response times (3 and 0 minutes, respectively) and were on the hook for less than 30 minutes (25 and 20 minutes respectively). The shortfin mako had minor lacerations from a bite mark of the left dorsal side.

Three pink snappers were found dead on the hook when the vessel arrived at the SMART drumline. One of these was found 22 minutes after triggering the alarm while the other two didn't set off the alarm and were found during a bait check. Finally, a fourth pink snapper was euthanised due to barotrauma.

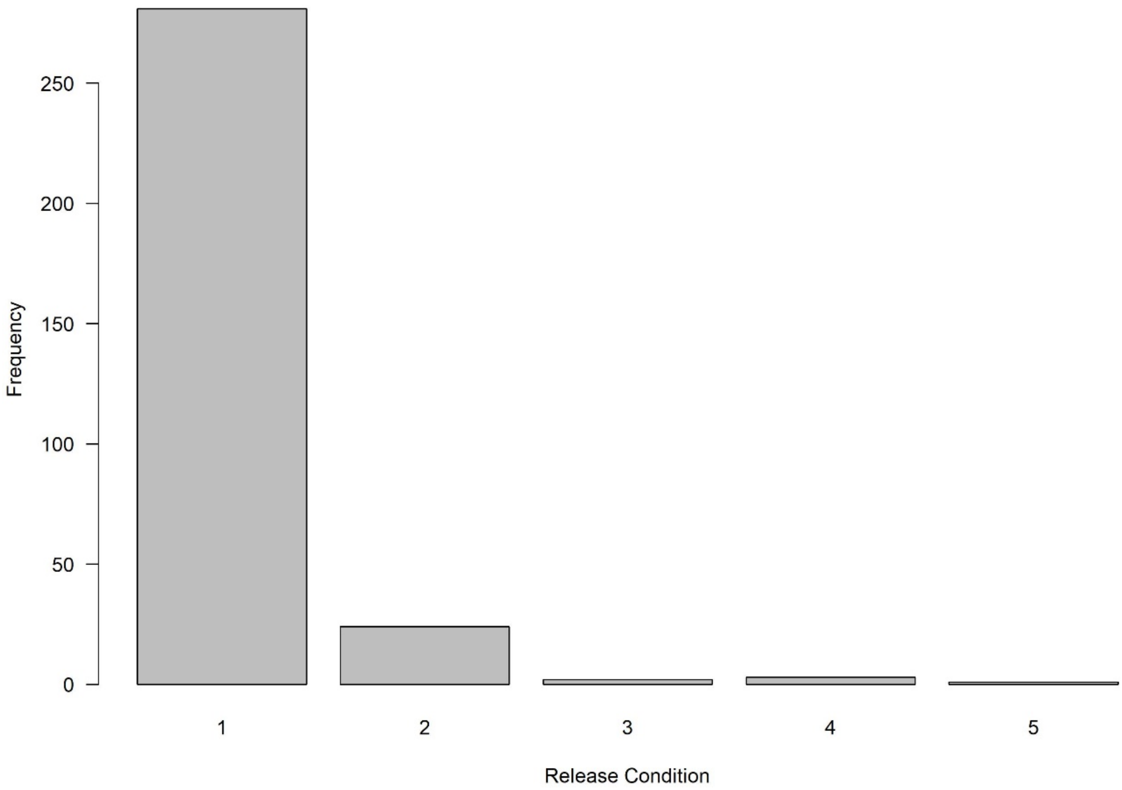

Figure A 5 Frequency of release condition for individuals captured on SMART drumlines.

9.7 Appendix 7 - Recaptures

During the two-year trial, there were 11 recaptures of animals on the SMART drumlines that had previously been tagged. Two of these recaptures were tiger sharks which had previously been tagged as part of a separate program, while the remaining nine were recaptures of animals originally captured and tagged as part of the SMART drumline trial (Table A4).

Four different species were recaptured after initially being tagged and released on the SMART drumlines. All were released in good condition (release condition 1) and all showed an increase in size during their time at liberty (Table A4).

A smooth stingray was recaptured on the 22 February 2020 with a SMART drumline tag. However, this ray was quickly released before the tag number could be accurately recorded. Due to this, it was not possible to determine the original capture information for this animal.

The two tiger sharks which were not tagged as part of the SMART drumline trial were tagged as part of the NSW Department of Primary Industries Gamefish Tagging Program. The first tiger shark (S270222) was tagged off Dunsborough while the second tiger shark (S254206) was tagged at Rosemary Island off Dampier.

Table A 4 Capture and recapture information of animals that were recaptured on SMART drumlines during the two year trial. Length (cm) is total length unless indicated (see below). For release condition see above.

Tag #	Species	Capture				Release				Liberty (days)	Growth (mm)
		Date	SDL No.	Length	Release Cond	Date	SDL No.	Length	Release Cond		
SDL071	Tiger Shark	2019-03-06	3	240	1	2020-01-08	1	245	2	308	5
SDL084	Shortfin Mako	2019-03-13	4	309	1	2019-12-24	8	315	2	286	6
SDL086	Bronze Whaler	2019-03-18	6	280	1	2019-12-18	3	295	1	275	15
SDL089	Smooth Stingray	2019-03-25	4	120^	1	2019-08-02	10	130^	1	130	10
SDL172	Bronze Whaler	2019-07-12	3	250	1	2019-12-27	4	270	1	168	20
SDL193	Shortfin Mako	2019-05-24	8	220	1	2020-05-13	7	260	1	355	40
SDL211	Smooth Stingray	2020-01-01	2	80^	1	2020-01-07	2	100^	1	6	20
SDL224	Tiger Shark	2020-01-08	4	295	1	2020-01-31	6	299	1	23	4
	Smooth Stingray					2020-02-22	9	103^	1		
S270222	Tiger Shark	2019-11-23		247		2020-01-01	1	230	1	39	-17
S254206	Tiger Shark	2016-09-29		185*		2020-12-07	10	235*	1	1892	50

* denotes fork length; ^ denotes disc width

9.8 Appendix 8 – Release of Other Acoustically & PAT tagged Sharks

During year two of the trial 20 tiger sharks and four shortfin makos were tagged with additional tags, in line with advice from the Chief Scientist. All sharks below (Table A 5) received an external acoustic and PAT tag. Their capture and release information is provided below. The short and long-term movement patterns will be examined and published when the full dataset is available.

Table A 5 Capture, tagging and release condition information of non-target sharks that were fitted with acoustic and PAT tags

Species Name	Date	Total Length (cm)	Release Condition	Acoustic	PAT
Shortfin Mako	2021-01-02	185	1	Y	Y
Shortfin Mako	2020-12-21	260	1	Y	Y
Shortfin Mako	2020-11-27	330	1	Y	Y
Shortfin Mako	2021-01-16	270	1	Y	Y
Tiger Shark	2020-12-24	271	1	Y	Y
Tiger Shark	2020-12-22	249	1	Y	Y
Tiger Shark	2020-12-24	290	1	Y	Y
Tiger Shark	2021-01-09	395	1	Y	Y
Tiger Shark	2020-12-19	248	1	Y	Y
Tiger Shark	2021-01-13	310	1	Y	Y
Tiger Shark	2021-01-06	350	1	Y	Y
Tiger Shark	2021-01-06	425	1	Y	Y
Tiger Shark	2020-11-12	342	1	Y	Y
Tiger Shark	2020-11-21	325	1	Y	Y
Tiger Shark	2021-01-03	309	1	Y	Y
Tiger Shark	2020-11-23	295	1	Y	Y
Tiger Shark	2020-10-18	410	1	Y	Y
Tiger Shark	2020-12-07	283	1	Y	Y
Tiger Shark	2020-12-21	295	1	Y	Y
Tiger Shark	2020-09-17	335	1	Y	Y
Tiger Shark	2020-10-23	312	1	Y	Y
Tiger Shark	2020-10-13	290	1	Y	Y
Tiger Shark	2020-12-22	270	1	Y	Y
Tiger Shark	2020-12-22	235	2	Y	Y

9.9 Appendix 9 - Gear sheet

Contractor Crew Names			
Fished today?	Y or N	DPIRD Observer	

Observed Environmental Conditions	At Gear Setting	At Gear Retrieval
Wind Speed (kts)		
Wind Direction		
Sea State (0-9)		
Cloud Cover (%)		
Water Visibility (m)	0-2 or 3-5 or 6-10 or 11-20 or >20	0-2 or 3-5 or 6-10 or 11-20 or >20
Swell (m)		
Sea (m)		

Row #	SMART Buoy #	**Set** Time (24hr)	Water Temp (°C)	Water Depth (m)	Lat/Long or Map Mark #	Bait Type	**Retrieval** Time (24hrs)	Water Temp (°C)	Bait Remaining at end of day (%)
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									

Row #	SMART Buoy #	Event Type (Alert or Check)	Start Time (24hr) (Alert or Check)	Bait Remaining on arrival (%)	Animal No or 'False Alarm' (FA)	Comments	Bait Type	End Time (24hr)
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								

Comments

9.10 Appendix 10 - Catch sheet

<table>
<tr><td>Date</td><td></td></tr>
<tr><td colspan="2">Fishing Gear</td></tr>
<tr><td>Smart buoy #</td><td></td></tr>
<tr><td>Time hooked (24 h)</td><td></td></tr>
<tr><td>Time boat arrived (24 h)</td><td></td></tr>
<tr><td>Time secured at boat (24 h) START GOPRO</td><td></td></tr>
<tr><td colspan="2">Catch Details / Inspection</td></tr>
<tr><td>Animal Number</td><td></td></tr>
<tr><td>Species Common Name</td><td></td></tr>
<tr><td>Alive or Dead upon first inspection</td><td>A or D</td></tr>
<tr><td>Hooking location</td><td>C | M | SW | FH</td></tr>
<tr><td>Sex</td><td>M or F or U</td></tr>
<tr><td>Total Length (cm)</td><td></td></tr>
<tr><td>Fork Length (cm)</td><td></td></tr>
<tr><td>Pre Caudal Length (cm)</td><td></td></tr>
<tr><td>Jaw width (cm)</td><td></td></tr>
<tr><td>Recapture</td><td>Y or N</td></tr>
<tr><td>Recapture Number</td><td></td></tr>
<tr><td>Conventional tag (check no)</td><td></td></tr>
<tr><td>Colour</td><td></td></tr>
<tr><td>Tagger name</td><td></td></tr>
<tr><td>Side of shark</td><td>L or R</td></tr>
</table>

Other Comments:

<table>
<tr><td>Acoustic tag (check no) ID</td><td></td></tr>
<tr><td>Tagger name</td><td></td></tr>
<tr><td>Side of shark</td><td>L or R</td></tr>
<tr><td>PSAT 1: Tag</td><td>Serial:</td></tr>
<tr><td>PSAT 2: Tag</td><td>Serial:</td></tr>
<tr><td>Tagger name</td><td></td></tr>
<tr><td>Side of shark</td><td>L or R</td></tr>
<tr><td>Genetic fin clips
CHECK LABELS</td><td>0 or 1 or 2</td></tr>
<tr><td>Photo (5 locations)</td><td>Y or N</td></tr>
<tr><td>Photo (Full-body & Head)
OTHER ANIMALS</td><td>Y or N</td></tr>
<tr><td>Release video</td><td>Y or N</td></tr>
<tr><td colspan="2">Relocation and release</td></tr>
<tr><td>Relocation start time (24hr)</td><td></td></tr>
<tr><td>Relocation end time (24hr)</td><td></td></tr>
<tr><td>Release time (24hr)</td><td></td></tr>
<tr><td>Latitude (Decimal Degree)</td><td></td></tr>
<tr><td>Longitude (Decimal Degree)</td><td></td></tr>
<tr><td>Distance offshore (m)</td><td></td></tr>
<tr><td>Water depth (m)</td><td></td></tr>
<tr><td>Hook removed</td><td>Y or N</td></tr>
<tr><td>If N, was hook or trace cut?</td><td>H or T or N</td></tr>
<tr><td>Release condition (1-5)</td><td></td></tr>
<tr><td colspan="2">Comments on Release:</td></tr>
<tr><td>Damage to fishing gear</td><td>Y or N</td></tr>
<tr><td colspan="2">If Y, describe here:</td></tr>
</table>