Queensland Shark Control Program

Review of Alternative Approaches

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Cardno®

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Executive Summary

Background

Since 1962, Queensland has relied upon a Shark Control Program (SCP) that has used nets and drumlines to catch and kill large sharks to reduce the risk of shark bites in 10 coastal regions (**Table ES1**, **Figure ES1**). These regions incorporate the main areas where swimming and surfing occur within the state. Since the SCP commenced, only one human fatality has resulted from a shark bite on a protected beach however each year the methods also kill non-dangerous sharks and other types of fauna. Globally, there is a recognised preference to move away from the use of lethal methods to mitigate the risk of shark bite and use alternative non-lethal methods that promote better co-existence between people and sharks.

As part of its investigations into potential alternatives to the current operations of the SCP, the Queensland Department of Agriculture and Fisheries (DAF) commissioned Cardno to review alternative non-lethal methods of shark bite risk mitigation with the key objectives of:

> Delivering a comparative assessment of alternative shark control methods to those currently used in the SCP; and

> Delivering a trial implementation strategy.

Table ES1 Beaches, fishing apparatus and typical attributes of SCP regions.

					Key Features		
Group	SCP Region	Total No. Beaches	Drumlines (No. Beaches)	Nets (No. Beaches)	Typical Water Clarity	Typical Wave Energy	Land-based Elevation
North	Cairns	7	38 (7)	0	Poor	Low	Low
	Townsville	8	54 (8)	0	Poor	Low	Generally Low
	Mackay	6	45 (6)	2 (1)	Poor	Low	Generally Low
	Capricorn Coast	9	54 (9)	0	Fair to poor	Low	Generally Low
	Tannum Sands	1	12 (1)	0	Fair to poor	Low	Low
South	Woongarra Coast	4	20 (4)	0	Fair to good	Medium	Generally Low
	Rainbow Beach	1	12 (1)	3 (1)	Good	High	Low
	Sunshine Coast	23	78 (17)	11 (8)	Good	Mostly High; Medium (Woorim, Noosa)	Varies among SCP-protected beaches
	North Stradbroke	4	35 (4)	0	Good	Low (Amity Point); High (all others)	Good (Point Lookout, incl Main, Frenchmans, Deadmans & Cylinder Beaches). Low (others).
	Gold Coast	23	35 (12)	11 (11)	Good	High	Varies. Natural & man-made (highrises) vantage points
	Total	**86**	**383 (69)**	**27 (21)**			

Figure ES1 Overview of locations of SCP regions. NB: Bribie Island is part of the Sunshine Coast SCP region.

Key Findings

Non-lethal alternatives to the SCP's current approach of using nets and drum lines for mitigating the risk of shark bite can be divided into three broad categories: 'detection' of potentially dangerous sharks; 'deterrents' and 'barriers'.

Shark detection can include methods that: a) utilise aerial vistas over the beach, either through an aircraft (manned fixed wing, helicopter, or unmanned aerial vehicles or balloons) or personnel on land to detect and identify a potentially dangerous shark, b) are *in-situ* and aim to detect a previously tagged shark, and c) are *in-situ* and aim to detect all sharks (tagged and untagged) within a defined area.

Deterring sharks involves providing stimuli to a shark which results in a high probability of a shark not moving into an environment where water users are present. Shark deterrents can involve beach-wide approaches or personal devices that utilise electro-magnetic fields or visual, auditory or chemical stimuli.

Physical barriers are purpose-built barriers that do not aim to catch sharks, but rather exclude sharks from an area where water users are present (**Table ES2**).

The process used to identify the most fit for purpose alternative systems recognised that the SCP regions are highly variable in terms of habitat type, ranging from the surf beaches of the high energy Gold Coast and Sunshine Coast and other southern regions where the water clarity is generally good to the generally more sheltered beaches in the north where water clarity is often poor for much of the year (**Table ES1**). Alternative systems were evaluated for potential trial on the basis of: (a) whether they would be able to operate effectively in the prevailing conditions within a region; (b) were effective against the potentially dangerous bull, tiger or white sharks (as demonstrated through 'independent testing'); (c) were commercially ready; and (d) their comparative costs (where available). Importantly, community support was also considered to be a key factor that will need to be addressed in the final choice of alternative systems.

The review focused primarily on non-lethal shark detection and deterrent methods at the beach-scale. It also considered the effectiveness and potential role of personal deterrent devices, and included consultation with developers of alternative systems, researchers and shark control program managers from other jurisdictions.

The review found clear differences in the suitability of alternative systems among the SCP regions based on the differing environments between the north and the south. For example, even with the use of multi-spectral cameras used from aircraft, the prevailing poor water clarity in the north would limit detection of potentially dangerous sharks for a significant proportion of the year. Thus, visual observation systems are likely to be ineffective alternatives in the SCP regions of Cairns, Townsville, Mackay, Capricorn Coast and Tannum Sands. Further, although other commercially available shark detection systems (i.e. Cleverbuoy and detection of tagged animals) are not reliant on water clarity, these methods are among the least preferred ranked of the detection systems generally, meaning there are no ideal detection systems currently or potentially available for the north. The north regions are, however, suited to use the barrier systems because of a general lack of ocean swell, although any barrier would need to be able to be dismantled prior to a cyclone to avoid it being seriously damaged by such extreme weather events. Such barriers offer no protection to water users outside of them.

The prevailing good water clarity in southern Queensland lends itself to trialling of highly effective aerial detection systems in the SCP regions of Woongarra Coast, Rainbow Beach, Sunshine Coast, North Stradbroke and Gold Coast. To maximise the likelihood of detecting dangerous sharks, a system could include multispectral cameras, shark recognition software and real-time transmittal of information to beach users either via lifeguards or Smart devices. Further, given that the effectiveness (against potentially dangerous sharks) of an aerial detection system is directly related to operating time, sufficient temporal coverage necessitates that a system should include many flyovers of beaches each day. The high costs of such a system is potentially problematic where fixed wing or helicopter platforms are used, however, the lesser cost of drones may be acceptable, particularly if operated by lifeguards who are already working to protect water users at patrolled beaches within the SCP regions. If trialled, there needs to be understanding developed with respect to the minimum amount of time that drones need to be flown at a given location and the location-based factors that positively or negatively influence detection rates.

The Shark Spotter Program is another detection system that would perform well in the south, but only where the topography was adequate and where the water users were close to the spotter's position. It would be limited to areas where there is elevated land close to the water users (e.g. Point Lookout, North Stradbroke Island). The high labour costs of such a system and the effective visual range of observers also requires consideration. If a Shark Spotter Program were developed at Point Lookout the involvement of traditional owners through of the Quandamooka Yoolooburrabee Aboriginal Corporation should be considered. There still remains uncertainty as to the proportion of sharks that are spotted by drones and would be spotted by a Shark Spotters Program.

There are a few systems that they are not dependent on ocean swell or water clarity. These include the SMART (Shark Management Alert in Real Time) drumlines and some of the electric or magnetic deterrents. However, although it appears that SMART drumlines could effectively replace standard drumlines with a non-lethal shark bite risk mitigation system, there are some potential significant issues that would need close consideration, including the perceived or real impact of translocating potentially dangerous sharks to other areas, tidal variation and proximity of access points affecting servicing times and overall costs. These issues are not trivial issues and represent significant practical challenges. Queensland differs significantly from other areas where SMART drumlines have been trialled. Where the trials have been done in New South Wales and Western Australia, sharks can be translocated further offshore where there are no water users but in much of Queensland's north, particularly along the coast within the Great Barrier Reef, translocation is complicated because many offshore areas (e.g. continental islands or the Great Barrier Reef) are frequented by swimmers or other water users. The macrotidal environment in Queensland's north may also effect deployment and serviceability. Notwithstanding this, it may be possible to modify the operating procedure for SMART drumlines to require less servicing. Although this compromise may result in reduced survival of some sharks, it would reduce costs. We have concluded that there is merit in a limited trial of SMART drumlines but to consider the replacement of all current drumlines with SMART drumlines is impractical at this time.

The highest ranked of the beach-scale deterrents was the magnetic/visual Sharksafe barrier although it is understood that the Beach Barrier SRC1000 and Beach01 electrical deterrents are also currently being tested for effectiveness. Were either system trialled, they would require a means of monitoring for breakage or power failure (electrical only) so that water users could be notified about whether the system was not operating.

Table ES2 Summary of alternative shark bite risk mitigation systems including suitability to SCP regions, ranking within groups, commercial availability, proven effectiveness and cost.

System	Description	Most Suitable SCP Regions	Ranking within System Type	Commercial Readiness	Independently Tested to Determine Effectiveness		Cost	
					Against Dangerous Sharks	In Exposed Coast	Capital	Operational / Maintenance
Barriers								
Eco Shark Barrier Net	Small modules made of a nylon polymer joined to form an anchored, floating barrier that allows water to pass through 295 mm diameter squares.	North Group	1	Commercially available	Physical barrier to sharks. Effectiveness assumed when structural integrity is maintained.	Failure on the exposed north coast of NSW occurred when deployed.	High	Low
Bionic Barrier and Aquarius Barrier	The Bionic and Aquarius barrier differ from the Eco Shark Barrier in terms of material. The Aquarius barrier is made with heavy duty marine ropes with robust nylon struts and the Bionic Barrier, also made from nylon, has one-way hinges that allow it to adapt to sea height, or tidal fluctuations, swell and seabed movements.	North Group	1	Commercially available	Physical barrier to sharks. Effectiveness assumed when structural integrity is maintained.	Failure on the exposed north coast of NSW occurred when deployed.	High	Low
Temporary Barrier Net	Owned and maintained by the Kwazulu-Natal Sharks Board (KZNSB). KZNSB deploys a temporary net at Fish Hoek Bay. The net has a mesh size of 4 x 4 cm and is deployed (and retrieved) in calm seas in the swimming season.	North Group	1	Unavailable, but could be manufactured in Australia	Physical barrier to sharks. Effectiveness assumed when deployed and structural integrity is maintained.	Not designed to be deployed on exposed coastlines and not tested at such locations.	Low	Mod
Shark Detectors								
Drone	Detects sharks using unmanned aerial vehicles (UAVs, also known as 'drones'). Commercially available models are currently limited in their air-time due to battery constraints. Able to be used by lifeguards. Potential to use multispectral imaging to improve detection rate.	South Group	1	Commercially available	Can detect sharks, but limited by flight time and water clarity. Various factors influence detection rates. Further work required to determine visual rates of detection. Bull sharks and tiger sharks are less likely to be detected visually by human observers than whites due to being closer to the bottom with more cryptic colouration. Detection using multi-spectral cameras is high and largely independent of water clarity and sea conditions.	Tested off the exposed coast of Ballina. While sharks were detected, no estimates of the rate of detection were determined.	Mod	Low

System	Description	Most Suitable SCP Regions	Ranking within System Type	Commercial Readiness	Independently Tested to Determine Effectiveness		Cost	
					Against Dangerous Sharks	**In Exposed Coast**	**Capital**	**Operational / Maintenance**
Shark Spotters	An early warning initiative that uses a spotter in an elevated position to provide information in real time to beach goers about the presence or absence of dangerous shark species.	South Group	1	Commercially available	Yes for white sharks only. Unlikely to be highly effective for tiger or bull sharks.	Designed as solution for an exposed coastline.	Low	Mod
Manned Aircraft	Detects sharks from manned fixed-wing aircraft or helicopters with human spotters. Potential to use multispectral imaging to improve detection rate.	South Group	1	Commercially available	Can detect sharks, but limited by flight time and water clarity. Various factors influence detection rates. Detection rates of dangerous sharks present by human observers is low. Detection using multi-spectral cameras is high and largely independent of water clarity and sea conditions. Bull sharks and tiger sharks are less likely to be detected visually by human observers than whites due to being closer to the bottom with more cryptic colouration.	Detection rates of sharks known to be low using visual detection. Detection using multi-spectral cameras is high and largely independent of water clarity and sea conditions.	High	High
CleverBuoy	Detects sharks using sonar and identification software systems, transmitting information to lifeguards.	All	2	Commercially available	Limited independent trials of varying effectiveness. Some technical challenges for detection remain and are difficult to overcome in shallow areas where wave action suspends a large amount of sand and where air bubbles are prevalent.	Although gaps in independent testing remain, the challenges for appropriate levels of effectiveness are enhanced in areas of high wave activity where sand and air bubbles occur in the water column.	High	High
Acoustic and Satellite Tagging	Involves tagging sharks and deploying satellite-linked (VR4G) acoustic receivers, and data-recording acoustic receivers (VR2W) on the sea floor. Data from satellite-linked (VR4G) acoustic receivers can provide an early warning system of when a shark was close to popular beaches. Detections by VR2W receivers are not transmitted via satellite but are stored in the receiver's on-board memory.	All	3	Commercially available	Acoustic and satellite tagging can play a very important role in building knowledge of the movements and habitat use of dangerous shark species which can inform other mitigation and educational strategies, but it's effectiveness *per se* in mitigation is unproven. The method though is proven in terms of being able to effectively track the movements of sharks where detectors are deployed.	Yes	High	High

System	Description	Most Suitable SCP Regions	Ranking within System Type	Commercial Readiness	Independently Tested to Determine Effectiveness		Cost	
					Against Dangerous Sharks	In Exposed Coast	Capital	Operational / Maintenance
Area-based Deterrents								
Sharksafe Barrier	Components include grade C9 barium-ferrite permanent magnets and LDPE (Low-density polyethylene) piping to mimic kelp as visual barriers. The piping while anchored to the seafloor moves with waves and currents.	All	1	Prototype	Magnetic and visual deterrent to sharks. Some testing at a small scale on dangerous shark species	Independent testing has occurred on exposed coasts.	Mod	Low
Beach Barrier SRC1000 and Beach01	Ocean Guardian in partnership with ArmscorSOC Ltd purportedly use Shark Shield technology to create an electrical field along a line using linked buoys or cables.	All	2	Purportedly Prototype	No published results of testing undertaken.	No published results of testing undertaken.	Mod	Mod
Shark Repellent Cable	The KZNSB developed an electric cable anchored to the seabed with electrodes rising to the surface powered by a pack of large truck batteries and driven by the electronic controls housed in a small trailer on land. KZNSB	All	2	Prototype	No published results of testing undertaken.	No published results of testing undertaken.	Mod	Low
Shark Repelling System	Underwater gates produce an electromagnetic field and each unit of the gate is provided with a backup power supply and an alarm that provides notification of any power failures.	All	2	Prototype	Untested	Untested	Mod	Mod
Rubber Guard Electric Fencing	An electric cable which is heavy enough to stay on the seabed and a number of flexible vertical Rubber Fence wires which are distributed along the electric cable. The fence is energized with 100 to 200 Volt electric pulses, from a special water proof battery operated energizer designed for the purpose or with a combination of photovoltaic power or wave power modules.	All	3	Concept	Untested	Untested	Mod	Mod

System	Description	Most Suitable SCP Regions	Ranking within System Type	Commercial Readiness	Independently Tested to Determine Effectiveness		Cost	
					Against Dangerous Sharks	In Exposed Coast	Capital	Operational / Maintenance
Bubble Curtain	A bubble curtain works by generating air (e.g. through a compressor) along a submerged perforated hose which escapes from the perforations and rises to the surface resembling a curtain.	All	3	Concept	Untested	Untested	Mod	Mod
Other								
SMART Drumline	Fishing gear composed of classical material used for a standard drumline with hook and bait, however, the mooring buoy is designed to detect and relay a message to shore in real time when a shark or other animal has been hooked. There is then the opportunity for a shark contractor to immediately attend to the drumline and translocate and release the animal before it dies.	All	1	Commercially available	Proven	Yes	Mod	High

Implementation Strategy to Trial and Evaluate Alternatives

Trialling of alternatives needs to be informed by consultation and engagement at the local level and supported at the local level. Regardless of the alternatives trialled, it is critical that the community is informed of the exact nature and location of the trial being undertaken. It is worth noting that alternatives are likely to require environmental assessment and approval under relevant legislation. In Queensland this may include assessment, approval and permitting under the Commonwealth *Great Barrier Reef Marine Park Act 1975* and as an amendment to the current permit which allows existing SCP activities to operate within the marine park or a new permit. Relevant approvals under state marine park legislation (*Marine Parks Act 2004)* will also need to be considered if planned alternatives for trialling are within state marine parks (e.g. Moreton Bay Marine Park and the Great Sandy Marine Park). Referral to the Commonwealth for consideration as a controlled action under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* may also be required. Any approaches involving manned or unmanned aircraft will potentially need assessment and approval by the Civil Aviation Safety Authority (CASA).

Modify Existing SCP Fishing Gears and their Operation

There is scope to improve the current SCP and procedures to further minimise the impacts of the activity on marine fauna. For example, the SCP Scientific Working Group should identify where humpback whale and SCP shark net operations pose a higher risk to humpback whales and assess whether some nets should be replaced seasonally with drumlines. Bycatch reduction devices (e.g. pingers, LED lights etc.) used successfully for reducing interactions between protected species and commercial gillnet or line fisheries could also be considered.

Physical Barriers

Provided there is local support for such a structure it is recommended that at least one (1) temporary or permanent shark barrier be trialled in a region to protect bathers. It is recommended that the government offer a tender for provision of the service. If the structure is deployed within the Great Barrier Reef Marine Park, then assessment and approval by the Great Barrier Reef Marine Park Authority would be required. There is potential to spatially align a shark barrier with a stinger net. Physical barriers should not be considered in the Woongarra, Rainbow Beach, Gold Coast, Sunshine Coast or North Stradbroke SCP regions due to wave energy. Consultation with local councils and tourism operators should be undertaken to assist choosing an exact location within an SCP region. Deployment of a barrier will need to consider the presence and behaviour of estuarine crocodiles, particularly in the Cairns region. Deployment will need to ensure that no estuarine crocodiles are enclosed by a deployed barrier. Additionally, ongoing management will need to rapidly identify if an estuarine crocodile enters the area enclosed by a barrier and have detailed and effective protocols for its rapid and safe removal.

Further, because of the potential rates of biofouling in the tropics and how an adverse build-up of material could potentially lead to mechanical failure of a barrier, it is recommended that prior to deployment of an entire barrier, only small sections of the barrier material are initially deployed. The biofouling of these sections can be monitored and the results of this monitoring used to design the structure and determine a maintenance protocol. Anti-fouling options may also need to be considered pursuant to any policy or regulations.

Shark Spotters and Drones

The only SCP location where water clarity and suitable elevation occurs to make Shark Spotting activities similar to those employed at Cape Town, South Africa, is Point Lookout at North Stradbroke Island. Delivering the service could be potentially undertaken through the traditional owners who are experienced in service delivery. Consultation with the Quandamooka Yoolooburrabee Aboriginal Corporation to gauge their interest in undertaking a Shark Spotters Program and what it would entail should be undertaken.

While drones have some advantages over manned aerial flights, in terms of cost, to detect sharks at a locality, unless multi-spectral cameras are used, they will suffer from limitations due to poor water clarity and glare. Therefore, the use of drones for spotting sharks is not recommended at SCP locations north of Rainbow Beach but they could potentially be evaluated in the southern SCP regions. Moreover, given that many surfers prefer to surf early or late in the day, use of drones is likely to be even less efficient at such times. It is recommended that drones are only trialled in terms of gauging their potential to augment existing surf living saving activities at SCP locations. However, there is a need to test the ability of drones to spot sharks under various conditions. Any Civil Aviation Safety Authority requirements for flying drones will need to be complied with.

Education and Personal Choice

The Department should consider expanding educational material regarding sharks and personal protection with a clear onus on emphasising personal responsibility and adherence to signage and directives from life guards. Educational material should be tailored to the general public, tourism operators and/or tourism groups. Educational material can potentially extend to provide guidance to individuals or businesses about personal deterrents or other approaches that are commercially available and that have been scientifically tested independently with a demonstrated acceptable level of efficacy. In doing so, this would be advisory only rather than an endorsement of specific products with appropriate disclaimers required.

While the *Fisheries Act 1994* provides the legislative carriage for protecting bathers from sharks, other sectors of the state government (e.g. Department of Innovation and Tourism Industry Development) and local government are important stakeholders. Where relevant, these government entities could contribute financially and/or in-kind to relevant initiatives that they support and they should be involved in local consultation and engagement processes. For example, local councils in Western Australia are active in supporting locally relevant approaches to unprovoked shark bite.

SMART Drumlines

Trialling the effectiveness of SMART drumlines would represent a substantial cost to government. They should be installed only if there is local support to do so and provided a location for relocating tagged sharks does not pose a real or perceived risk to any water users elsewhere. Suitable SCP regions that have scope to relocate sharks captured by SMART drumlines include the Gold Coast, North Stradbroke Island, Sunshine Coast, Rainbow Beach, Woongarra and Tannum Sands. Rainbow Beach and Tannum Sands SCP regions currently deploy 12 standard drumlines. Based on this alone, they represent a good opportunity to conduct a relatively cost-effective trial at an appropriate scale. However, based on current servicing arrangements where the Rainbow Beach SCP is serviced from further south on the Sunshine Coast and Tannum Sands SCP is serviced from Yeppoon, the ability to appropriately service SMART drumlines would require consideration, particularly in relation to survival of hooked sharks or other biota.

In trialling SMART drumlines it is proposed that at an SCP location, some of the existing drumlines should be deployed as at present, while some are replaced with SMART drumlines. This would allow assessment of the relative fishing power of SMART drumlines compared with standard drumlines. This comparison may help to identify how many SMART drumlines would be required to deliver the same actual amount of fishing effort in an SCP region. The more efficient at catching sharks, the fewer SMART drumlines that would be needed should the trials proceed to implementation. Trials would provide information on the number of triggers per hour, information that is needed to determine service requirements.

Specific operational guidelines for the use of SMART drumlines should be developed if a trial proceeds. Existing guidelines were developed in NSW for SMART drumline trials and these have relevance for Queensland. These guidelines highlight procedures for potentially addressing issues such as: handling of dangerous sharks to maximise their likelihood of survival; understanding the likelihood that they will return to their site of capture; and prevention of injury to handlers. The existing operational guidelines can be amended to adapt a SMART drumline to the practical challenges of operating in Queensland. Amendments may include leaving the drumlines in place but unbaited overnight and adapting response time targets so that they are realistically achievable.

Further Innovation

Although a number of approaches show significant promise they require further development, including independent testing under Queensland conditions. Access to an appropriately targeted Innovation Challenge may assist in the further development of approaches that have clear promise. Approaches that have not reached the proof of concept stage or where there are *a priori* doubts about their efficacy should not be invested in by government at this time. Rather, only those approaches that have demonstrated potential to be adapted to Queensland environments and water users should be pursued through independent testing against specific performance criteria. There are three areas where targeted innovation funding could deliver effective results:

- The further development, assessment and tailoring of protective apparel (e.g. wetsuits) that is optimised for use by Queensland water users;
- The development of area-based deterrents or detection systems that are specifically tailored and independently tested in relevant Queensland environments; and
- Assessing the efficiency and effectiveness of drones including enhanced detection and recognition technologies for spotting sharks under Queensland conditions.

Evaluating the Performance of Trials

The key performance indicator would be measurement of the effectiveness against potentially dangerous sharks but other secondary indicators measuring other aspects of performance would assist with determining whether alternative approaches had met 'success criteria'. Reducing the risk of shark bite is the aim of any shark bite mitigation program and therefore the incidence of unprovoked shark bite should be measured. In this report we considered using the number of unprovoked shark bites as a key indicator, however, given that the incidence of shark bite is so low, particularly at SCP locations, it is unlikely to present results that can be analysed with any statistical certainty, even over a period of several years. Any shark bite at a trial location, however, should trigger an immediate review of the trial.

Indicators measuring other aspects of performance could include:

- Abundance of Potentially Dangerous Sharks - This information could be obtained during testing of SMART drumlines through analysis of catch rates but would be less readily obtained from trials of other alternative strategies or systems. The indicators may need to include a range of sources of information, including the frequency of reporting of interactions or sightings of sharks in SCP areas as recorded by lifeguards;
- Durability of Equipment - the durability of some systems may still need to be verified, particularly in relation to the potential for large tidal amplitudes or biofouling to alter effectiveness, or cause breaches or loss of power (where relevant);
- Detection Coverage (Time) - Some detection methods (e.g. drones) can detect sharks only when they are deployed at a given location. A key indicator is the amount of time a device is actively deployed so that it can detect a shark. A minimum amount of flight time per SCP region or SCP beach represents an appropriate indicator and will require deployment times to be logged and verified;
- Harm to Marine Fauna - the only alternative system with any potential to harm marine fauna would be SMART drumlines and under the prescribed operating procedure, the potential for harm to captured fauna is very minimal. Notwithstanding this, given customised operational guidelines for the use of SMART drumlines are proposed in order to meet the practical challenges of operating in Queensland, there could be potential for some captured species to be harmed if time until release is longer than the prescribed operating procedure; and
- Effectiveness of Education Strategies - The success of education could be measured through community sentiment surveys and user behaviour surveys that determined for example, whether there was an increasing trend for bathers to swim in protected areas and/or in the uptake of personal deterrent devices.

Non-SCP Areas

The recent incidents in Cid Harbour emphasize that there is risk to water users in areas outside of the SCP regions. This report focuses on reviewing alternative approaches that can be trialled within the existing SCP areas and included deterrents, detection and barrier approaches that can be deployed to collectively enhance the level of protection afforded to water users. However, it is not feasible for the entire Queensland east coast as well as the numerous reefs and islands that are frequently used for various water-based activities to be afforded collective protection. There are opportunities to facilitate further protection in SCP areas as well as protection outside these areas. This can be done by providing educational material to allow for more informed choices by water users or by encouraging the uptake of suitable personal deterrent devices or other methods (personal protective apparel) e.g. Government of Western Australia rebate scheme for personal deterrents.

However, it should be clearly recognised that shark deterrents and detection approaches are for human safety and as such there is a need to meet a minimum standard of performance, and for a responsible and evidenced based approach to marketing them that includes appropriate caveats. It is clearly not the role of DAF or the Queensland Shark Control Program Scientific Working Group to regulate shark deterrents or detectors to ensure that a minimum level of performance can be reached. However, when such approaches are viewed in the correct context of providing a commercial product for the purpose of enhancing human safety, the need for such regulation is justified. A long-term national approach to the issue of commercial deterrents and detection approaches, particularly personal deterrent devices, and their efficacy and marketing would be the development and implementation of an Australian Standard that products can be certified against. Such a standard would not stop innovation or ethically appropriate experimentation by entrepreneurs, but it would allow consumers to make an informed choice as to what does constitute an independently verified mitigation approach that is effective. The large array of personal deterrent devices, in particular all of which have manufacturer claims as to their effectiveness and reasons for effectiveness makes the choice for consumers difficult.

Consideration of Changes to Risk Levels

Notwithstanding the recommendations above, some consideration needs to be given to the potential change in risk associated with switching from a SCP based on lethal fishing for potentially dangerous sharks to one that would be based on non-lethal systems (i.e. co-existence). Clearly, if the Queensland SCP were to shift away from using nets or drumlines as its primary tool to reduce risk to water users there would be benefits to some threatened or protected species that are taken incidentally in the SCP. The risk to water users of an alternative arrangement to the SCP's current gear deployment is more difficult to evaluate. The SCP regions are focused on areas where there are concentrations of water users and it is clear from historical trends in total annual catches of all sharks and at least one of the potentially dangerous sharks, the bull shark, that the local abundances of those animals have been reduced through time. It is unclear to what extent the SCP contributed to that decline, but it is likely a contributing factor. White shark numbers caught in the SCP have also declined, but this pattern may be due to factors other than the SCP. Notwithstanding this, the corollary is that if the catch and kill component of the SCP were to be replaced by an alternative non-lethal system it is possible that this would result in greater abundances of sharks generally at beaches within the SCP regions, including potentially dangerous sharks.

Further, given standard nets or drumlines are likely to have contributed to localised depletions of shark species responsible for unprovoked shark bite, they may have also affected abundances further afield than the beaches where the SCP gear is deployed and beyond the limits of the SCP regions generally. It is not possible, however, to estimate the overall area over which the effects of local depletions have occurred. In comparison, none of the alternatives considered in this report would provide a level of protection to areas outside where they would be deployed. For example, an effective barrier would only provide protection to water users within the area it confined. It would provide no additional protection outside that area.

In terms of overlap of water users and potentially dangerous sharks, the weighting of human or shark presence in the potential for a shark bite is unclear. Notwithstanding this, there has been only one fatality and 27 unprovoked bites on an SCP protected beach since 1962. There were 19 fatalities and 36 bites in the whole of Queensland prior to 1962 and it is not unreasonable to conclude that local fish-downs have reduced the risk of shark bite to water users by reducing the potential for overlap between water users and potentially dangerous sharks. The choice of any non-lethal alternative system will need to consider closely how it monitors for, and potentially manages, a potential increase in the risk of shark bite due to increases in abundances of potentially dangerous sharks at SCP beaches, noting that there are also likely to be increases in the amount of water users in the future in line with general increases in the population of people in coastal areas.

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1 Introduction

1.1 Background

Globally, the frequency of unprovoked shark bite has been increasing but it remains very low (McPhee, 2014; Chapman and McPhee, 2016). Whilst an increase in the number of water users over time contributes to this trend, it does not explain it entirely with environmental factors which influence shark distribution and behaviour such as sea surface temperature, the distribution and abundance of prey, and habitat changes potentially having an influence (Amin, 2012; McPhee, 2014; Chapman and McPhee, 2016; Lagabrielle et al., 2018; Lee et al., 2018). While the probability of an unprovoked shark bite remains low, the vivid and graphic nature of a shark bite ensures a high degree of media reporting and public concern (Neff, 2012; McPhee, 2014; Bombieri et al., 2018; Simmons and Mehmet, 2018). The public may overestimate the risk of an unprovoked shark bite (Crossley et al., 2014) and this may be partly because the human fear of large predators, including sharks, has an evolutionary basis (Tooby and Cosmides, 1990; Mineka and Öhman, 2002). Further, although not quantified, unprovoked shark bites can potentially flow on to concerns about economic impacts on local businesses dependent on water-based tourism. This is particularly the case if a series of bites occurs at a single location in a short period of time. Actual incidents can ignite a lack of public confidence in beach-going and a lack of confidence in government response (Neff, 2012).

Hence, there remains a role for government in providing a level of direct protection from sharks and/or to support water users in making informed decisions about mitigating the risk of shark bite. This need is regardless of the probability of a bite occurring in locations where dangerous shark species and people regularly overlap. Government responses to unprovoked shark bite can involve public policies and management approaches that contend with the needs of public safety and the responsibility to protect threatened species (McPhee, 2014; Pepin-Neff and Wynter, 2018). Management agencies may implement measures that attempt to reduce bite risk, address public concern, or provide warning systems to identify the presence of sharks in real-time at a whole of beach or regional level or that educate individuals about safe behaviours.

Traditionally, the principal response to human wildlife interactions such as shark bite that cause fatalities or serious injuries to people consists of setting up a lethal population control program on the relevant species (Liu et al., 2001). The first response to shark bites historically, as seen in Australia, Hawaii and South Africa, has been to set up shark control programs that aim to mitigate risk by reducing the local numbers of sharks at popular swimming or surfing locations (Wetherbee et al., 1994; Dudley, 1997; Dudley and Simpfendorfer, 2006). More recently, a shift in human perception of human-wildlife interactions towards the philosophy of co-existence generally (Carter et al., 2012; Frank, 2016; Acuña-Marrero et al., 2018, Treves et al., 2006), has resulted in a collective push to move away from the use of lethal methods to control sharks to alternative methods that provide for enhanced safety and peace-of-mind for beach users, while reducing or eliminating significant environmental impact (Meeuwig and Ferreira, 2014; Gray and Gray, 2017; Simmons and Mehmet, 2018). This may be attributable to a realisation of the low risk to humans posed by the majority of sharks, the conservation status of some shark species, the role of many sharks as apex predators, the recognition of the need to reduce the overall anthropogenic mortality on shark species from various sources, and changes in public perception towards the intrinsic value and ecosystem benefits of sharks (Simpfendorfer et al., 2011; O'Connell and deJong, 2014; Gibbs and Warren, 2015; Pepin-Neff and Wynter, 2018). A recent review into *Shark mitigation and deterrent measures* by the Australian Senate Environment and Communications References Committee (Senate Committee 2017) has also recommended that the NSW and Queensland Governments replace lethal systems with non-lethal shark control programs.

Since 1962, Queensland has relied upon its 'Shark Control Program' (SCP) that has used nets and drumlines to target and catch large sharks. The SCP is a further purpose of the Queensland *Fisheries Act 1994*, which is to "reduce the possibility of shark attacks on humans in coastal waters of the State adjacent to coastal beaches used for bathing". Currently, the SCP operates in 10 regions along the Queensland mainland east coast and encompasses the main areas where swimming and surfing occur. Over time, the area of the SCP has changed as has the nature of the apparatus used and how and when this gear are deployed, including removing and replacing nets with drumlines within the Great Barrier Reef Marine Park. These changes have been in response to a variety of factors including a desire to reduce the impact of the SCP on non-target species such as marine reptiles and marine mammals as well as to shark populations (Sumpton et al., 2010; Erbe and McPherson, 2012).

1.2 Scope of Works

DAF is investigating whether there are any potential alternatives to lethal methods of shark bite risk mitigation that could be considered for the Queensland SCP. The SCP Research Strategy rates monitoring the development of non-lethal alternatives and trialling technologies considered suitable as the highest priority for research (DAF 2019).

To assist with these investigations, DAF has commissioned Cardno (NSW/ACT) Pty Ltd (Cardno) to review alternative non-lethal methods of shark bite risk mitigation, leveraging off any work previously conducted, and with the key objectives of:

- Delivering a comparative assessment of alternative shark control methods to those currently used in the SCP; and
- Delivering a trial implementation strategy.

2 Overview of Approach

Cardno's approach to identifying the most fit for purpose alternative systems to catch and kill for SCP regions was to use a four-step decision process:

1. ***Gather information about the environment*** – This required searching for the conditions that call for a decision on an appropriate risk mitigation measure. The review recognises that the SCP regions are highly variable in terms of habitat type, ranging from the surf beaches of the Gold Coast to the generally more sheltered beaches within the Great Barrier Reef (e.g. Cairns). The predominant conditions, as well as their ranges, needed to be identified for each of the SCP regions to determine whether they were within the effective operating conditions of the various types of alternative shark bite mitigation systems being considered. The catch in the existing SCP was also recognised in this process.

   Outcome: An understanding of the environmental characteristics of the regions that could potentially affect operations of alternative systems.

2. ***Gather information about alternative systems*** – This was done to understand the operating parameters of alternative systems (to catch and kill) to determine their effectiveness and efficiencies with regard to shark bite risk mitigation. A review of prospective alternative technologies (excluding aerial technologies) was prepared for the NSW Government in 2015 (Cardno, 2015). Since the review, prospective technologies have advanced significantly as has knowledge regarding the technologies and their applicability under certain scenarios. Consultation with manufacturers and scientists was undertaken to update knowledge of system characteristics in relation to key findings from the review in Step 1. Engagement with relevant managers was also undertaken to provide feedback on systems trialled in other jurisdictions.

   Outcome: An understanding of the various characteristics of the alternative systems, in relation to key findings from the review in Step 1.

3. ***Choice criteria*** – Evaluation criteria were developed for selecting a course of action among the possible alternative actions that allowed the various systems to be compared and contrasted. The approach involved developing a suite of 'fit for purpose' criteria that closely reflected the objectives of the SCP and that considered key findings in Steps 1 and 2.

   Outcome: A suite of fit for purpose criteria for evaluating alternative systems that matched the requirements of the SCP.

4. ***Analysis*** – This process adopted a selected course of action in a decision situation. The various alternative systems were evaluated against the relevant 'fit for purpose' criteria determined in the step above and the choices of the most optimal systems were justified by their compliance with the criteria as determined through consideration of the key findings in the information gathering process. The first pass was to determine whether the system could operate effectively in the given environment (i.e. to shortlist the various system types for a region, or groups of regions with similar characteristics). The result considered whether the system could operate effectively (yes, no or in limited circumstances) according to the prevailing environmental conditions. The next pass was to rank short-listed systems for trialling based on the following criteria, in order of importance: proven effectiveness against dangerous sharks (as demonstrated through 'independent testing') and commercial readiness.

   Outcome: In recognising the significant differences in habitats and the varying practical challenges across the SCP regions, the review aimed to rank each applicable (short-listed) approach in each of the SCP regions, or groups of regions with similar characteristics. Information about the occurrence and catches of potentially dangerous shark species in each SCP area would also be factored into considerations of alternative systems for regions.

NB: Where relevant we have identified significant challenges and/or information gaps and provide a blueprint for trialling. We recommend that community sentiment and costs are also to be included in decisions regarding what should be trialled, or what should not be trialled. This would need to be done through informed consultation that included information about the effectiveness and commercial readiness of the potential alternative systems.

3 Review of Existing Information

3.1 Current Management of Risk of Shark Bite

Catch and kill approaches to reducing shark bites have been reported in many countries including Australia, South Africa, New Zealand and Mexico. These shark control programs, including the current Queensland SCP (see below), have traditionally aimed to mitigate shark risk by reducing the coastal shark population, either through continuous fishing effort from mesh nets or baited drumline, or through short-term culls. Many shark control programs (including the Queensland SCP) have traditionally been supported by the efforts of lifeguards and also by aerial patrols (discussed later). Lifeguards are only effective at patrolled beaches during hours patrols are undertaken. Locating potentially dangerous sharks and issuing warnings (if necessary) is just one safety function undertaken by them, with the safety priority being to prevent drownings. In the early 1900s several Australian beaches erected shark spotting towers to assist life savers to protect bathers from shark interactions. Towers are still used in several locations globally, as surf life saver towers may improve detection by increasing the range over which a shark can be spotted. However, the height required for reliable spotting is well above that normally afforded by surf patrol towers.

3.1.1 Queensland Shark Control Program (SCP)

The aim of the Queensland SCP is to "*to reduce the chance of people being killed or seriously injured by sharks in Queensland*". Currently, it endeavours to achieve this by catching potentially dangerous sharks from swimming beaches with a dedicated fishing program. There were 36 shark bites in Queensland between 1916 and 1962, 19 of which resulted in fatalities. The Queensland SCP was established in 1962, after which time there has only been one fatality as a result of a shark bite at SCP protected beach (see **Section 3.2.2**).

3.1.1.1 Fishing Gear

The SCP currently employs two fishing gear-types to remove potentially dangerous sharks from swimming beaches: drumlines and mesh nets (nets). The drumline units each comprise a freshly-baited shark-fishing hook (usually about 14/0) suspended below a large plastic marker buoy (**Figure 3-1**). Bait are chosen on the basis of availability, as well as minimising scavenging by other animals such as dolphins (Sumpton et al., 2010). Mesh nets are 186 m long (3 x 62 m panels of 500 mm mesh netting) by 6 m deep and are suspended from the surface via a series of surface floats spanned between two or more large plastic marker buoys set adjacent to the shoreline (**Figure 3-2)**. Units of both gear-types are kept in position via heavy seabed anchors, with topographical features of the seabed, sea conditions and prevailing tides and currents associated with each protected beach determining precise position and distance from shore.

Weather permitting, each drumline and net is checked and serviced every second day by supervised independent contractors. Each unit is removed from the water for maintenance and replaced with a fresh unit at least once every 21 days.

3.1.1.2 Regions

For the purpose of data reporting, the SCP beaches and their associated gear-deployment locations have been partitioned into 10 discrete 'regions' (**Figure 3-3**). These regions include swimming beaches within the various parts of the coastline around populated areas. The regions vary in size with the Sunshine Coast and Gold Coast regions comprising the most beaches where gear is deployed (23 beaches in each), while the Tannum Sands and Rainbow Beach regions each have gear deployed at only one beach. Although the regions have a broad geographic spread along the Queensland coast, their entire area makes up a small proportion of the entire coast.

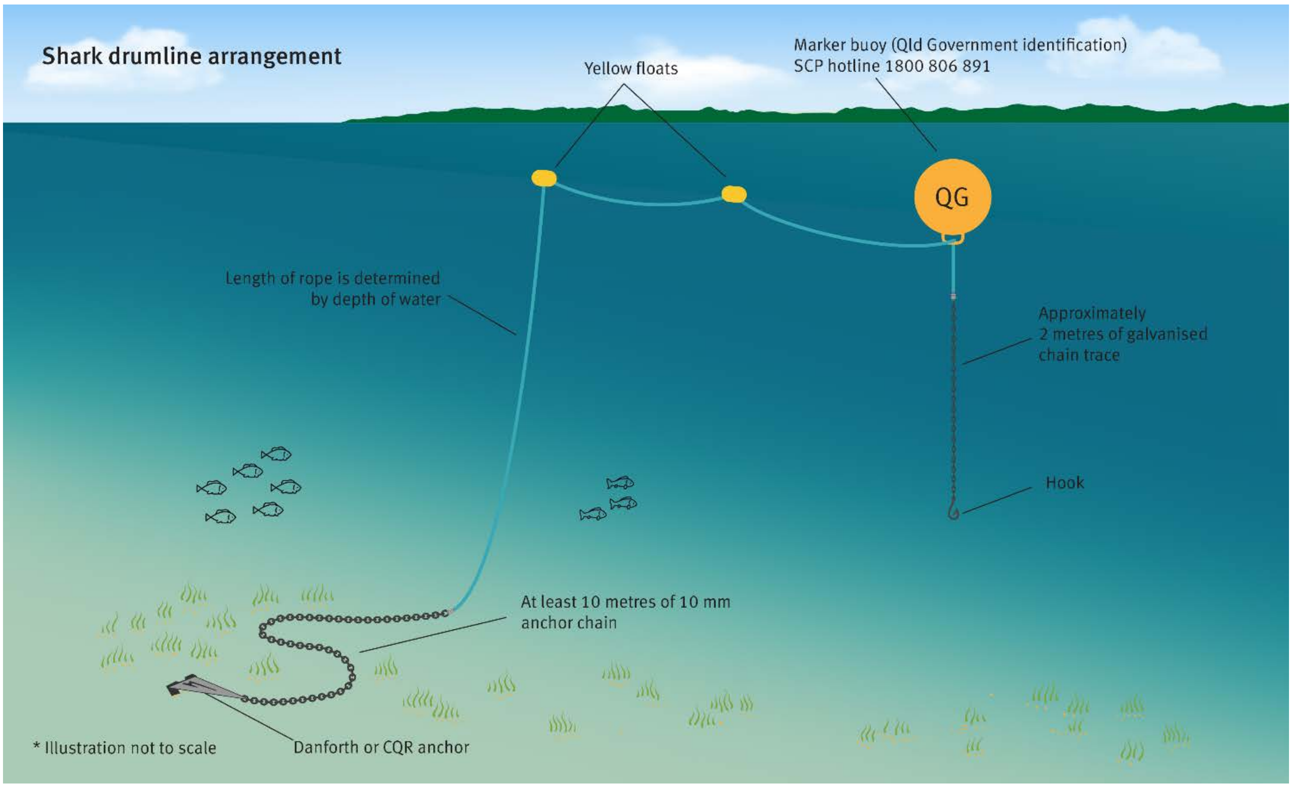


Figure 3-1 Shark Control Program drumline arrangement. Image identifies drumline components (floats, anchor and hook) and dimensions. (Source: Queensland Government)

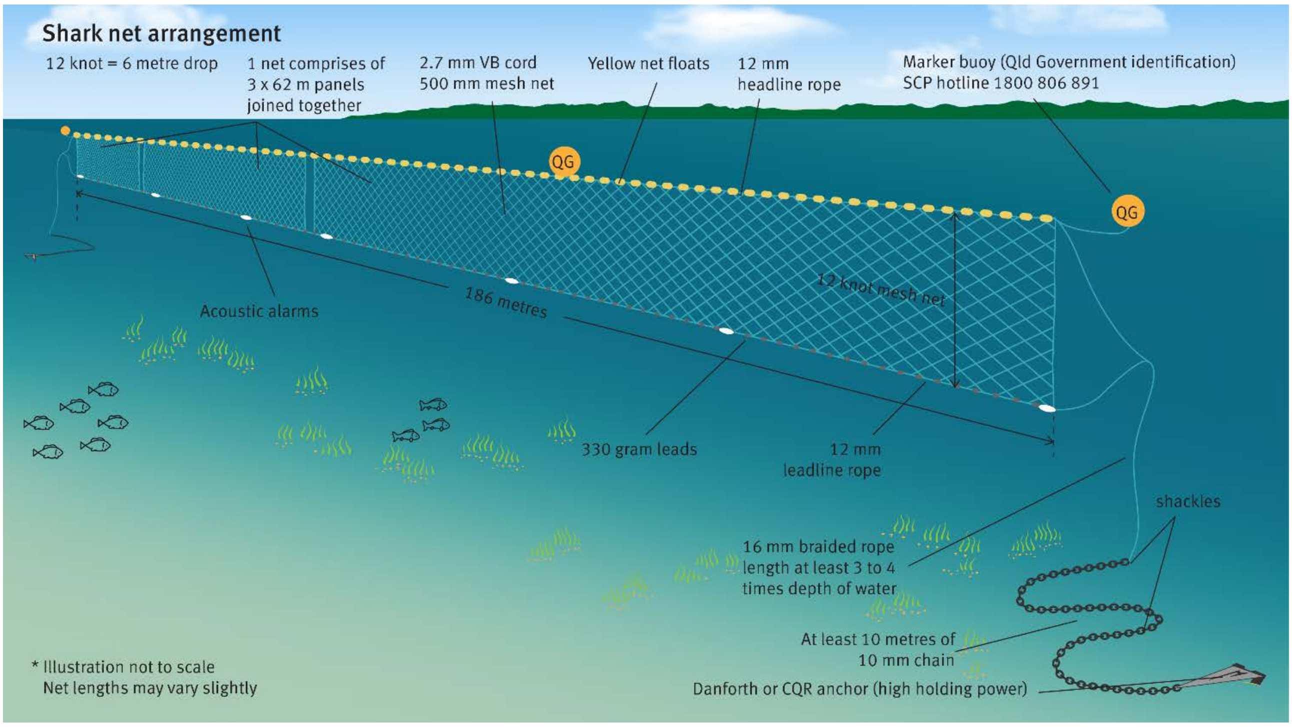


Figure 3-2 Shark Control Program mesh net arrangement. Image identifies net components (floats, shackles and acoustic alarms) and net dimensions. (Source: Queensland Government)

Figure 3-3 Overview of locations of Shark Control Program regions. NB: Bribie Island is part of the Sunshine Coast SCP region.

3.1.1.2.2 Gear Locations

Across the 10 regions, there is a total of 86 beaches, between Ellis Beach in the north and Rainbow Bay in the south, protected by drumlines (383 units at 69 beaches) and/or nets (27 units at 21 beaches), with four of those beaches protected by a combination of both gear-types (see **Appendix A** for the precise locations of gear within regions). The number of units in regions (drumlines + nets) ranges between 12 at Rainbow Beach and Tannum Sands, and up to 78 for Sunshine Coast, in which 17 of 23 beaches have only drumlines (**Table 3-1, Appendix A**). In contrast, nets are deployed only in Mackay (2 nets off 1 beach), Rainbow Beach (3 nets off 1 beach), Sunshine Coast (11 nets off 8 beaches) and Gold Coast (11 nets off 11 beaches) (**Table 3-1**). Nets were deployed in the Cairns region up until 2013, but have not been used in that region since that time.

At each beach the equipment actively fishes in adjacent offshore waters year-round according to a systematic large-scale spatial design. Initial deployment of gear has varied among the regions and there has been a gradual increase over time in the number of drumlines since the initial deployment. **Appendix B** shows when gear was initially deployed in each region and years where more gear was added or removed.

Stinger nets

In addition to the shark-targeting gears being deployed as part of the SCP, 'stinger net' enclosures designed to provide swimming areas safe from box jellyfish via an exclusionary fine-mesh barrier are also likely to contribute to providing protection from interactions with dangerous sharks and peace of mind for bathers. Each summer, stinger-net enclosures are installed in November and then dismantled the following May at a number of Queensland beaches, including many of the same beaches associated with SCP drumlines and/or nets (**Table 3-1**). For example, with the exception of one stinger-net located at Bramston Beach just to the south of Cairns, all of the remaining seven stinger-net enclosure locations in the Cairns area coincide with beaches at which drumlines are deployed. Similar spatial overlap occurs in Townsville (6 stinger-net locations) and, to a less coincidental extent in Tannum Sands (2 locations) and Gold Coast (6 locations) regions. Areas not associated with the ten regions covered by the SCP in which stinger-net enclosures are installed include Port Douglas (1 net), Mission Beach (4), Forrest Beach (1) and Airlie Beach (2).

Table 3-1 The number of beaches within SCP regions and apparatus at beaches. The number of stinger-nets at locations is also given.

Region	Total No. Beaches	Drumlines (No. Beaches)	Nets (No. Beaches)	Stinger-nets
Cairns	7	38 (7)	0 **	8
Townsville	8	54 (8)	0	6
Mackay	6	45 (6)	2 (1)	0
Capricorn Coast	9	54 (9)	0	0
Tannum Sands	1	12 (1)	0	2
Woongarra Coast	4	20 (4)	0	0
Rainbow Beach	1	12 (1)	3 (1)	0
Sunshine Coast	23	78 (17)	11 (8)	0
North Stradbroke	4	35 (4)	0	0
Gold Coast	23	35 (12)	11 (11)	0
Total	**86**	**383 (69)**	**27 (21)**	**16 (+ 8 elsewhere)**

** Nets have not been not deployed off beaches in the Cairns region since 2013.

3.1.1.2.3 Oceanographic and Topographic Features

Oceanographic and topographic features of beaches may influence the suitability of certain alternative systems for shark bite mitigation in a given area in terms of, for example, physical incompatibilities of gears or equipment with the environment, or impacts to catchability of dangerous sharks and/or non-target species.

Based on typical water clarity and wave energy of beaches, the five northern SCP regions of Cairns, Townsville, Mackay, Capricorn Coast and Tannum Sands are distinctly different from the five southern SCP regions of Woongarra Coast, Rainbow Beach, Sunshine Coast, North Stradbroke and Gold Coast (**Table 3-2**).

Water clarity, which is heavily influenced by terrestrial runoff, wind-wave action and tidal amplitude and currents, has the potential to impact visual shark detection systems. In general, the prevailing water clarity is considered fair to relatively poor at beaches in the north of Queensland, although there can be prolonged periods in winter and early spring where it can also be good. The prevailing water clarity in the south is considered to be generally good.

Typical wave energy at the Woongarra Coast is medium but further south to the NSW border it is considered high. To the north of Woongarra, the wave energy at beaches is generally low due to protection from the Great Barrier Reef, although cyclones can cause large waves in these areas. Strong wave energy is generally considered unsuitable for fixed barrier systems.

Land-based elevation nearby areas frequented by water users is also an important consideration due to the potential impact on the effectiveness of shark control strategies in terms of, for example, whether there would be elevated points on land for shark spotters. The only SCP regions where there is elevated land closeby SCP-protected beaches are the Sunshine Coast, North Stradbroke and Gold Coast.

Access points are an important consideration for gear that depends on rapid response times if sharks are caught, such as SMART drumlines. High tidal amplitude and its interaction with water depth, current speeds and water clarity could also provide limitations to the suitability of certain types of gear or accessibility by water-craft for servicing. Tidal amplitude is generally less in the five most southern regions compared to the northern group apart from Woongarra Coast.

Table 3-2 Oceanographic, topographic and boat access features of beaches in each SCP region

Region	Oceanographic Factors			Topographical Factors	
	Typical Water Clarity	Tidal Range (Amplitude)	Typical Wave Energy	Land-based Elevation	Main Access Points
Cairns	Poor	MHWS 2.62 MLWS 0.78 (1.84 m)	Low	Low	Yorkey's Knob Marina
Townsville	Poor	MHWS 3.11 MLWS 0.77 (2.34 m)	Low	Generally Low	Ross Creek Marina
Mackay	Poor	MHWS 5.29 MLWS 0.74 (4.55 m)	Low	Generally Low	Mackay Harbour
Capricorn Coast	Fair to poor	MHWS 4.23 MLWS 0.62 (3.61 m)	Low	Generally Low	Rosslyn Bay Marina
Tannum Sands	Fair to poor	MHWS 3.96 MLWS 0.72 (3.24 m)	Low	Low	Gladstone Harbour, Boyne River
Woongarra Coast	Fair good	MHWS 2.88 MLWS 0.56 (2.32 m)	Medium	Generally Low	Burnett Heads
Rainbow Beach	Good	MHWS 1.78 MLWS 0.38 (1.40 m)	High	Low	Beach launch or Bullock Creek boat ramp
Sunshine Coast	Good	MHWS 1.66 MLWS 0.26 (1.40 m)	High at most locations, except Woorim and Noosa (medium)	Varies among SCP-protected beaches	Mooloolah River and Spinnaker Sound Marina
North Stradbroke	Good	MHWS 1.78 MLWS 0.30 (1.48 m)	Low (Amity Point) High (all others)	Very good at Point Lookout (Main Beach, Frenchmans Beach, Deadmans Beach and Cylinder Beach). Low at other SCP-protected beaches.	Amity Point*, and beach launches for small vessels (<6 m)
Gold Coast	Good	MHWS 1.42 MLWS 0.11 (1.31 m)	High	Varies across SCP-protected beaches. Both natural (e.g. Burleigh Headland) and man-made (highrises) vantage points	Gold Coast Seaway

* Note: Amity has an enclosure (protects against sharks, boats and strong tidal currents);

3.1.1.2.4 Shark Catch

Although the SCP has been in operation since 1962 (see **Section 3.1.1**), gear was initially only installed in four regions. Gear was not installed in Tannum Sands, the last region to be included in the SCP, until 1983 (see **Appendix B**). In recent years (2001 until 2019), a total of 8,692 sharks were captured and killed by equipment deployed as part of the SCP (**Table 3-3**). While direct comparisons of numbers of sharks caught between drumline and nets for a given species or group of species cannot be made at a SCP-wide or regional spatial scales due to variable numbers of each gear-type in operation among regions and among years, some clear differences in the composition of catches are still apparent. Catches of potentially the most dangerous sharks (bull, tiger and white) in drumlines are almost 10-fold those in nets and this reflects the amount of drumlines deployed relative to nets (see **Section 3.1.1.1**). The potentially dangerous sharks make up a larger proportion of the total sharks caught in drumlines (57%) compared to nets (22%). Further, tiger and bull sharks make up much larger proportions of potentially dangerous sharks in both gear types compared to white sharks, which range between 1.1 and 5.8% respectively for drumlines and nets (**Table 3-3**).

Table 3-3 Total catch by Species grouping x Gear-type for QSCP between 2001 and 2019.

Taxa	Drumlines	% of all sharks (% of potentially dangerous sharks)	Nets	% of all sharks (% of dangerous potentially sharks)	Total catch
Dangerous sharks	3,691	57.3	495	22.0	4,186
Bull shark	(1,330)	(36.0)	(282)	(57.0)	(1,612)
Tiger shark	(2,320)	(62.9)	(184)	(37.2)	(2,504)
White shark	(41)	(1.1)	(29)	(5.8)	(70)
Other sharks	2,746	42.7	1,760	78.0	4,506
All sharks	6,437	100	2,255	100	8,692

For both gear types, the mean annual catches of the potentially most dangerous sharks varied according to latitude (**Figure 3-4**). In the case of bull sharks caught by drumline, Capricorn Coast recorded the highest mean annual catch (± SE; n = 19 years) of 29.5 (± 1.7) sharks.y^{-1}, which is more than twice the next highest value of 13.4 (± 1.2) sharks.y^{-1} recorded for the Townsville region (**Figure 3-4A**). The remaining three northern regions (i.e. Cairns, Mackay and Tannum Sands) recorded mean bull shark catches ranging between 5.7 and 7.6 sharks.y^{-1}. The five southern regions recorded the lowest mean annual bull shark catches, ranging between 0.5 (Gold Coast) and 2.4 (Sunshine Coast) sharks.y^{-1}. The general pattern for bull sharks caught by nets was consistent with that for drumlines, with the highest mean annual catch value recorded in the Mackay region (6.7 ± 1.4 sharks.y^{-1}), which is the only northern region that deploys nets (**Figure 3-4A**). The three southern regions that deploy nets (Rainbow Beach, Sunshine Coast and Gold Coast) recorded mean catches ranging between 1.7 and 4.1 sharks.y^{-1}.

The catches of tiger shark by drumlines appears to show a very general pattern of decline among regions from the north to the south, with the highest values recorded for Townsville and Mackay (20.6 ± 1.8 and 19.6 ± 2.2 sharks.y^{-1} respectively) and the lowest for North Stradbroke Island and Gold Coast (4.9 ± 0.6 and 2.3 ± 0.1 sharks.y^{-1} respectively) (**Figure 3-4B**). The mean annual tiger shark catches in nets is very similar to that for bull shark, with the highest value recorded in the Mackay region (8.1 ± 1.5 sharks.y^{-1}), while Rainbow Beach, Sunshine Coast and Gold Coast recorded values ranging between 0.1 and 0.7 sharks.y^{-1} (**Figure 3-4B**).

White shark has not been caught by drumline or by net in any of the five northern-most regions since 2000, and mean annual catches for drumlines or nets in the five southern regions have not exceeded 1.2 sharks.y^{-1} (**Figure 3-4C**). Among the southern regions, mean annual catches of white shark by drumlines and by nets were higher in the two southern-most regions (North Stradbroke Island and Gold Coast; > 0.6 sharks.y^{-1}) than in the three regions just to the north (Sunshine Coast, Rainbow Beach and Woongarra Coast; < 0.3 sharks.y^{-1}).

The general pattern in catches of other (potentially non-dangerous) sharks by drumline among regions indicated that, with the notable exception of Mackay (4.2 ± 0.5 sharks.y^{-1}), the highest mean catches were all in the northern half of SCP regions with values ranging between 22.1 ± 2.7 (Cairns) and 36.0 ± 3.3 (Townsville) sharks.y^{-1} (**Figure 3-4D**). The four southern-most regions recorded substantially lower mean annual drumline catches of other sharks, ranging between 2.4 ± 0.6 (Rainbow Beach) and 5.1 ± 0.9 sharks.y^{-1} (Sunshine Coast). As is the case for tiger sharks, it is apparent that catch rates of the other sharks have been highest in the regions in the middle of the geographical range of the SCP (i.e. Tannum Sands and Woongarra Coast) and well below average from Sunshine Coast southward. In contrast to drumlines, catches of other sharks by nets have been highest in the three southern regions, ranging between 19.0 ± 2.1 (Rainbow Beach) and 33.7 ± 3.9 (Sunshine Coast) sharks.y^{-1}, with Mackay recording a substantially lower value (6.2 ± 0.9 sharks.y^{-1}) (**Figure 3-4D**).

Drumlines and nets are both readily capable of catching bull, tiger and white sharks across a wide range of sizes (**Table 3-4**). Small, juvenile bull sharks (< 1 m long) were recorded as having been caught by drumline in the Cairns and Capricorn Coast regions, while a very small - likely neonatal - bull shark of 0.5 m in length was caught in a net off the Sunshine Coast. Similarly, small, juvenile tiger sharks <1 m in length have been caught by drumline in most, if not all SCP regions, while juvenile white sharks up to 2.1 m long have been recorded in all five of the more southern regions in which that species has been recorded.

Although a proportion of the catch of bull, tiger and white sharks in drumlines and nets are juveniles, the minimum mean length for any species was 1.37 m, and in the majority of regions generally above 1.6 m. (**Table 3-4**). This indicates that a large proportion of captured bull, tiger and white sharks in any region were of a potentially dangerous size.

It is also clear that some very large specimens of bull, tiger and white sharks do encroach into the vicinity of SCP-protected beaches in all regions. The length of the largest bull shark caught by drumline varied among regions, from 2.1 and 2.3 m for Gold Coast and Woongarra Coast respectively, up to 3.0 and 3.3 m for Cairns and North Stradbroke Island respectively (**Table 3-4**). Similarly large bull sharks were recorded in nets (largest >2.8 m across all netted regions). Very large tiger sharks were caught by drumline, with the largest varying by region between 3.8 m for the Gold and Sunshine coasts and 5.5 m for the Capricorn Coast. Large tiger sharks up to 5.2 m in length have also been caught in nets. Large white sharks have been captured by both drumline (up to 4.0 m long) and by net (up to 4.9 m long) across all the southern regions.

It is notable that in all but one (Cairns) of the five regions in which both gears are used, the mean length of bull sharks caught by drumline is slightly greater than that for bull sharks captured in nets (**Table 3-4**). This observation is also evident for tiger sharks across all five of those regions. In the case of white sharks, however, the mean length of sharks caught by drumline was greater than those captured by net in two of three regions in which both methods are used. This apparent difference among species may be due to behavioural factors or mechanical factors (i.e. size-related differences in ability to escape).

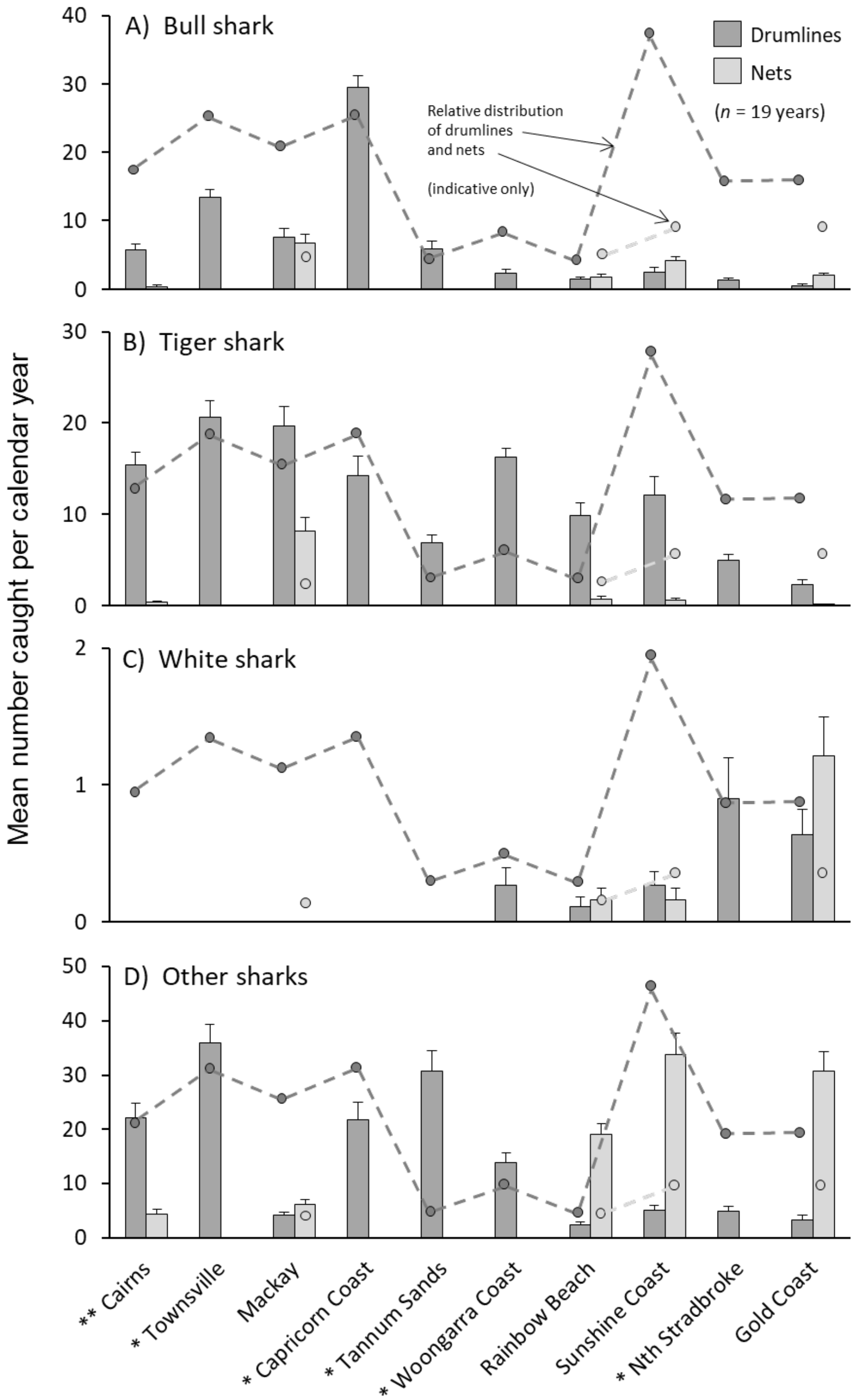


Figure 3-4 Mean number of A) bull sharks, B) tiger sharks, C) white sharks and D) all other sharks caught per calendar year (2001-2019, *n* = 19) by drumline (■) and by net (□) at each of the ten regions covered as part of the SPC. *, regions in which nets have not been used; **, nets used only up until 2013. Dashed lines and dots represent trendlines indicating the relative distribution of drumline and net units among the ten regions and are intended only as a visual aid for interpretation of catch data.

Table 3-4 Mean lengths and range in lengths of bull, tiger and white sharks caught from 2001-2019 by drumlines and nets in the SCP regions

Region		Bull Shark		Tiger Shark		White Shark	
		Drumline	Net	Drumline	Net	Drumline	Net
Cairns	n	94	5	198	4	n/a	n/a
	Mean	1.91 m	1.80 m	1.95 m	1.98 m		
	Range	0.7 – 3.0 m	1.1 – 2.9 m	0.7 – 4.4 m	1.3 – 2.6 m		
Townsville	n	211	n/a	281	n/a	n/a	n/a
	Mean	1.64 m		2.02 m			
	Range	up to 2.9 m		up to 4.2 m			
Mackay	n	102	53	210	60	n/a	n/a
	Mean	2.12 m	2.28 m	2.32 m	2.59 m		
	Range	1.4 – 2.9 m	1.7 – 3.0 m	1.0 – 5.3 m	1.9 – 3.9 m		
Capricorn Coast	n	379	n/a	198	n/a	n/a	n/a
	Mean	1.37 m		2.38 m			
	Range	0.6 – 2.5 m		0.4 – 5.5 m			
Tannum Sands	n	77	n/a	96	n/a	n/a	n/a
	Mean	1.43 m		2.23 m			
	Range	up to 2.5 m		1.0 – 5.3 m			
Woongarra Coast	n	36	n/a	198	n/a	5	n/a
	Mean	1.76 m		2.10 m		2.71 m	
	Range	up to 2.3 m		up to 4.0 m		2.0 – 3.4 m	
Rainbow Beach	n	26	24	110	11	2	3
	Mean	1.80 m	2.12 m	1.90 m	2.64 m	1.91 m	3.05 m
	Range	up to 2.8 m	1.4 – 3.2 m	0.8 – 4.8 m	1.4 – 5.2 m	1.6 – 2.2 m	1.8 – 4.9 m
Sunshine Coast	n	1001	168	1581	88	40	26
	Mean	1.77 m	2.01 m	1.80 m	2.33 m	3.22 m	3.07 m
	Range	1.0 – 2.8 m	0.5 – 3.1 m	0.6 – 3.8 m	1.9 – 3.3 m	2.6 – 3.8 m	2.1 – 4.0 m
North Stradbroke	n	24	n/a	70	n/a	16	n/a
	Mean	2.03 m		2.13 m		2.83 m	
	Range	1.4 – 3.3 m		up to 4.6 m		2.1 – 4.0 m	
Gold Coast	n	10	35	40	2	12	20

Mean	1.89 m	1.94 m	2.05 m	2.25 m	2.40 m	2.32 m
Range	1.6 – 2.1 m	1.3 – 2.8 m	1.0 – 3.8 m	2.2 – 2.3 m	1.8 – 2.9 m	1.6 – 3.4 m

The possibility of declines in local abundance of dangerous sharks or other species in areas where gear has been deployed (i.e. the potential for the SCP to have caused or contributed to 'fish-downs') was examined in plots of the historical catch in the only four SCP regions (i.e. Cairns, Townsville, Sunshine Coast and Gold Coast) where gear has been operating since the commencement of the SCP in 1962 (**Figure 3-5)**.

Temporal patterns in catches of bull shark varied considerably among the four regions (**Figure 3-5A**). Between 1963 and 1969 the total annual catch of bull shark in the Cairns region ranged between 5 and 64 sharks (for 1969 and 1965 respectively), while no more than two bull sharks were caught in any year from 1970 to 1992. In the Sunshine Coast region the highest annual catches of bull shark prior to 1993 were recorded in 1963 and 1986 (14 and 13 sharks respectively), with no other annual catch exceeding 7 individuals during that pre-1993 period. In contrast, in the Townsville and Gold Coast regions only one bull shark was recorded prior to 1993 (in 1992 and 1981 respectively).

In 1993 there was a dramatic increase in annual catch of bull shark in the Sunshine Coast region and, to a lesser extent the Gold Coast region, rising from < 2 up to 82 and 28 sharks respectively (**Figure 3-5A**). These spikes coincided with increases in the number of drumlines deployed in those regions in that or the preceding year (i.e. 25% and 20% respectively; **Appendix B**). These elevated catches persisted for ~3–5 years before swiftly decreasing to consistently lower levels from 1998 onwards (< 19 sharks per year for Sunshine Coast and < 6 sharks per year for Gold Coast). A similar spike in bull shark catch was recorded for Cairns in 1995 (from < 4 up to 21 sharks), before a decrease to mostly < 11 sharks per year since then – the exceptions being 13 and 14 sharks in 2011 and 2012 respectively. In general, annual catches of bull shark in Townsville gradually increased from negligible in 1993 to a peak of 21–24 sharks for the three-year period from 2010 to 2012. Since then, annual catches have ranged between 8 and 15 sharks per year. These two spikes in the northern regions could not, however, be linked to an increase in fishing effort and it is most likely that other gear-related changes and/or natural variability in shark populations were contributing factors. Although not presented graphically here, spikes in annual catches of bull shark similar in extent and timing to those shown in **Figure 3-5A** were also apparent for many of the other six regions.

In contrast to bull shark, temporal patterns in annual catches of tiger shark among the four regions presented were generally similar (**Figure 3-5B**). With the notable exception of relatively large catches of 67 and 68 tiger sharks for the Sunshine Coast and Gold Coast regions in 1963 (compared to 18 and 11 for Cairns and Townsville), catches among regions gradually increased through time from levels ranging between 4 and 28 sharks in 1964 up to highest-recorded levels in the 1980s and 1990s (Cairns – 55 sharks in 1980; Townsville – 64 sharks in 1994; Sunshine Coast – a spike of 79 sharks in 1987; Gold Coast – 57 sharks in 1986). From around 2000, annual catches of tiger sharks decreased at all four regions and have generally stabilised to levels ranging between 4 and 25 sharks for Cairns, 11 and 38 sharks for Townsville, 4 and 36 sharks for Sunshine Coast, and 0 and 10 sharks for Gold Coast. Notably, since 2005 annual catches of tiger shark have not exceeded 14 sharks in the Sunshine Coast region and 5 sharks in the Gold Coast region.

Catches of white shark via the SCP have been negligible in the Cairns and Townsville regions (0 and 3 sharks respectively since 1963). In the Sunshine Coast and Gold Coast regions there were gradual decreases in annual catches of white shark from around 10 – 25 sharks per year in 1963 and 1964 to < 10 sharks per year by the mid-1980s (**Figure 3-5C**). A further decrease in catch levels to < 5 sharks per year appears to have occurred around 2000 – a level that has persisted to the present.

A generally similar pattern of clear decline in annual catches through time is apparent for 'other sharks' (i.e. all shark species other than bull, tiger and white sharks, combined; **Figure 3-5D**). In the second full calendar year of SCP record keeping (1964) catches of other sharks across the four regions ranged from 183 to 315 sharks per year. In the cases of the Cairns, Townsville and Sunshine Coast regions, annual catches gradually declined to < 60 sharks by 2001, since which they have remained generally consistent. A similar long term decline occurred in the Gold Coast region, although the general trend was interrupted by a substantial spike from 161 in 1978 to 372 sharks in 1979, after which the gradual declining trend resumed such that catch levels had reached parity with the other three regions by the early 1990s.

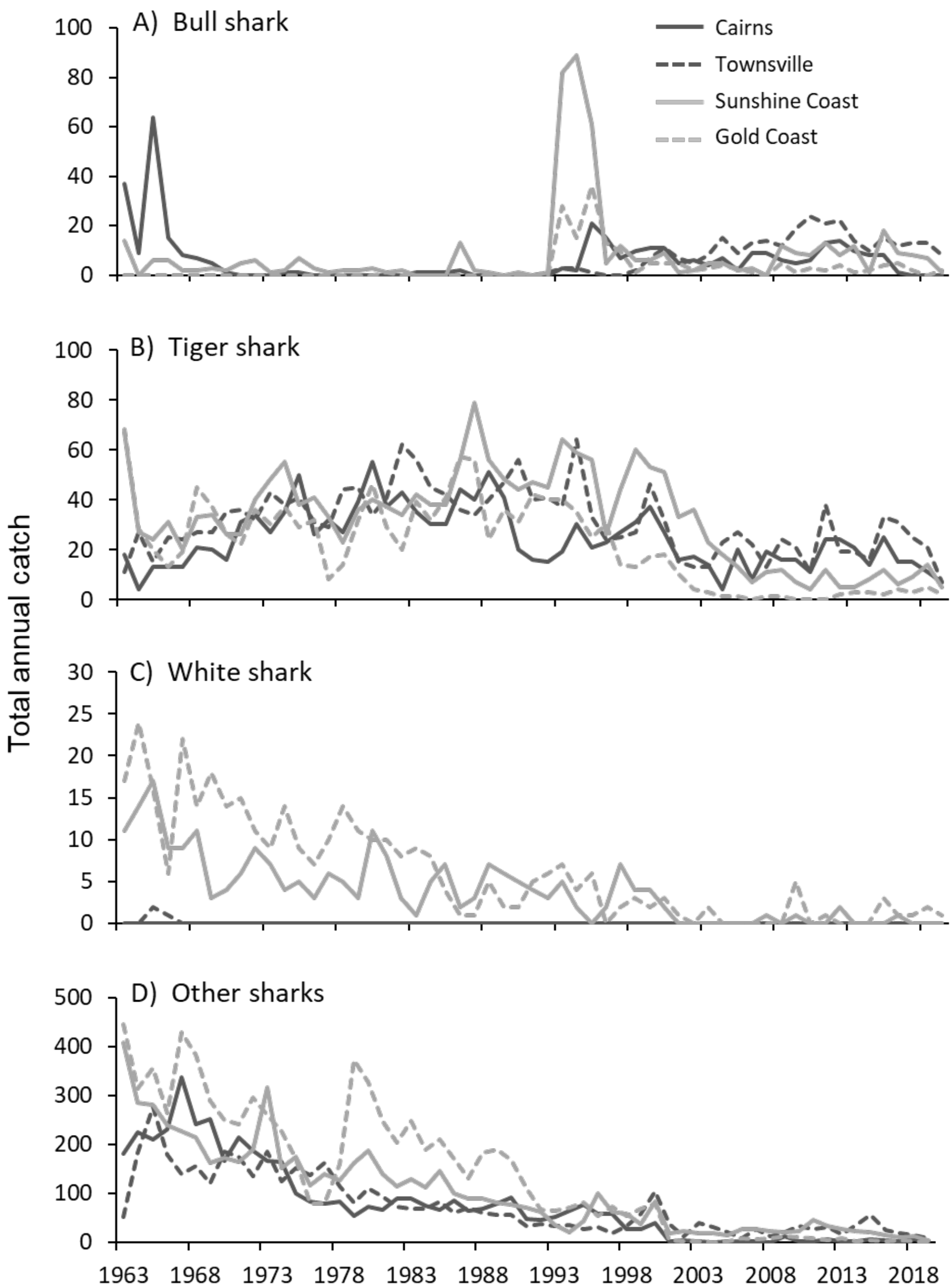


Figure 3-5 Temporal trends in annual total catch of A) bull shark, B) tiger shark, C) white shark and D) other shark species combined for the Cairns, Townsville, Sunshine Coast and Gold Coast regions since 1963.

3.1.1.2.5 Bycatch

A range of marine mammal (cetaceans) and marine reptiles have been fatally captured by SCP drumlines and/or nets since 2001. Confirmed species identifications have included whales (2 species), dolphins (5 species) and sea turtles (5 species) (**Table 3-5**). Totals of 259 dolphins, 82 sea turtles and 5 whales have been recorded.

The majority (64%) of the dolphins captured were common dolphins, followed by bottlenose (14%) and humpback (8%) dolphins (**Table 3-5**). Loggerhead and green turtles comprised the vast majority of sea turtles caught, each at just over 40% of the total.

Mean annual catches of marine mammals (whales and dolphins combined) varied according to latitude, with the highest values occurring for southern SCP regions (**Figure 3-6A**). Gold Coast recorded the highest mean annual catch of marine mammals (6.8 ± 0.8 cetaceans.y^{-1}), followed by Sunshine Coast (4.4 ± 0.6

cetaceans.y^{-1}) and Rainbow Beach (1.9 ± 0.4 cetaceans.y^{-1}). Mean annual catches in the northern regions did not exceed 0.4 cetaceans.y^{-1}. All five whales were caught in the Gold Coast region, while dolphins were caught in regions spanning the spatial extent of the SCP. The vast majority of common, bottlenose, humpback and spinner dolphins were caught in either Rainbow Beach, Sunshine Coast or Gold Coast regions. In contrast, all three snubfin dolphins were caught in northern regions (Cairns or Mackay).

There is no apparent latitudinal pattern in mean annual catches of sea turtles, with the highest value occurring for Gold Coast and Sunshine Coast (both 0.9 ± 0.2 turtles.y^{-1}), followed by Mackay (0.8 ± 0.4 turtles.y^{-1}) and Cairns (0.7 ± 0.3 turtles.y^{-1}) (**Figure 3-6B**). The mean annual catches of sea turtles across the other five regions were 0.2 turtles.y^{-1}or lower.

Table 3-5 Marine mammal and reptile species captured and killed by the SCP since 2001.

Marine Mammals				Marine Reptiles	
Whales	No. individuals	Dolphins	No. individuals	Marine Turtles	No. individuals
Antarctic minke whale	1	Australian humpback dolphin	21	Flatback turtle	5
Humpback whale	4	Australian snubfin dolphin	3	Green turtle	34
		Bottlenose dolphin	36	Hawksbill turtle	3
		Common dolphin	167	Leatherback turtle	3
		Spinner dolphin	12	Loggerhead turtle	35
		Unidentified dolphin	20	Unidentified sea turtle	2
Total	**5**		**259**		**82**

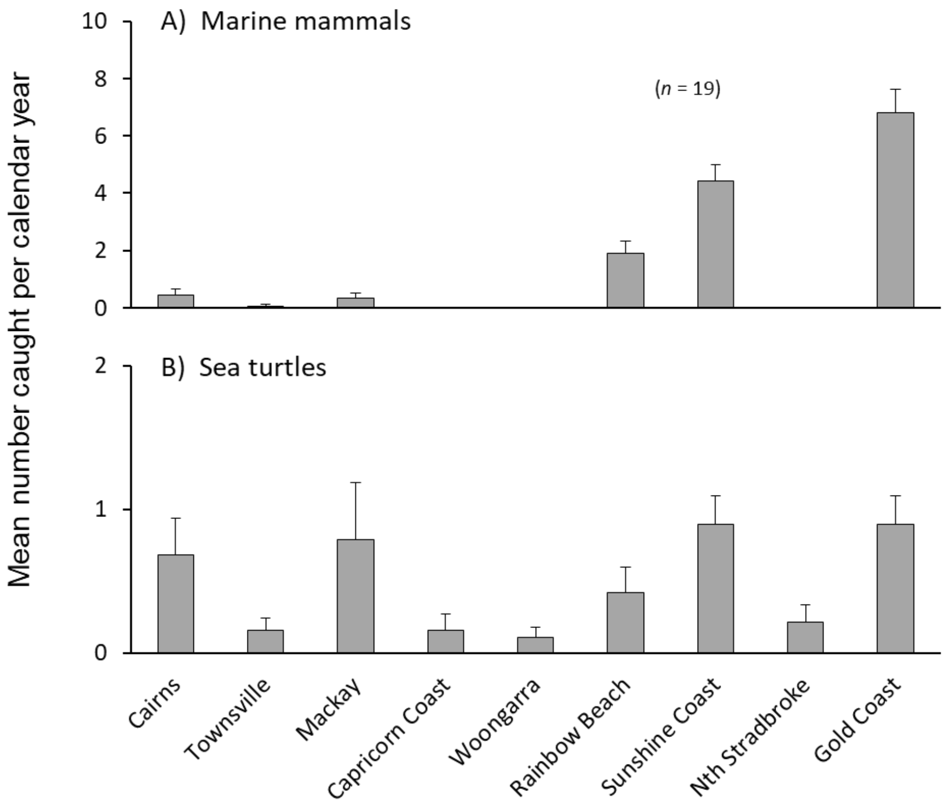


Figure 3-6 Mean number killed of A) marine mammals (whales & dolphins) and B) sea turtles caught per calendar year (2001-2019, n = 19) at each of nine regions covered as part of the SCP. Data for drumlines and nets have been combined.

3.1.2 Other Shark Bite Risk Mitigation Programs

There are various shark bite risk mitigation programs in other parts of Australia and in many parts of the world where shark bite is considered a risk. Many of these programs are long-running and have relied on catch and kill systems historically, however, based on the review below, many are now investigating the potential for co-existence of sharks and water users and are trialling many types of non-lethal systems.

3.1.2.1 The New South Wales Shark Management Strategy

Historically, for more than a century, the NSW Government has proactively initiated various strategies to mitigate the risk of shark–human interactions. Initial efforts, which also extend to present day include permanent swimming enclosures in some estuaries and at ocean beaches popular for swimming, fixed-location towers for lifeguards and, in recent decades, aerial surveillance to inform authorities about the proximity of sharks to bathers.

In 1937, bottom set gillnets or ‘mesh-nets’ (measuring 150 m long × 6 m deep and comprising 600 mm stretched mesh opening) were introduced off 18 Sydney beaches as a lethal measure to target virtually all local species of sharks. The nets currently are anchored off 51 beaches between Wollongong and Newcastle from 1 September to 30 April each year in what is collectively termed the ‘shark-meshing program’ (SMP). The SMP has been deemed an effective strategy by the NSW Government, measured by relatively fewer total shark-human interactions at netted than pre-netted or un-netted beaches, including a reduction from 13 fatalities in the three decades before meshing to a single fatality (in 1951) in the following eight decades.

The NSW Shark Management Strategy (SMS) complemented the existing Shark Meshing Bather Protection Program to increase protection for bathers from shark interaction as well minimising harm to sharks and other marine life. The NSW SMS is a scientifically driven investment of $16M since 2016 for projects over five years with focus on the north coast of NSW in response to the proportion of shark attacks. This includes the following components:

> Surveillance, detection and deterrents including:
  - Ongoing aerial surveillance.
  - Two new technology barrier nets to be initially trialled at north coast beaches, with a view to an additional four trials on other NSW beaches.
  - 20 VR4G shark listening stations, to provide real-time tracking data of tagged sharks. Ten listening stations deployed between Tweed Heads and Forster, with four earmarked for beaches off Evans Head, Ballina, Lennox Head and Byron Bay.
  - Partnership with Surf Life Saving NSW and professional lifeguard associations to refine procedures for shark observation and incident response.
  - In-water surveillance trials of sonar technology.
  - Trials of unmanned aerial devices.
  - Monitoring of emerging electric fences and other promising technology will continue, to determine their effectiveness and suitability.
> Science and research including through targeted a Shark Management Strategy Annual Competitive Grants Scheme.
> Education and community awareness and enhancement and maintenance of the popular SharkSmart Mobile App, to include real-time tracking of tagged sharks on a mobile phone/tablet.

3.1.2.2 Western Australia

The Western Australian Government has been developing a Shark Hazard Mitigation Strategy (SHMS) since 2008 to manage shark-human interactions at beaches (Department of the Premier and Cabinet, 2016). This involved aerial and beach patrols during SHMS's infancy in 2008. Since then over $40M have been injected into SHMS following fatalities between 2010 and 2013. This funding has been committed to research into methods and technologies to better manage the risks of shark-human interactions.

Following the fatality in 2013, the Western Australian Government deployed a number of standard baited drumlines at several swimming beaches and surf spots in the metropolitan and south-west regions during a three-month trial period between January and April 2014 aimed to provide added protection from the risk of shark-human interactions (Department of the Premier and Cabinet, 2016). A further three-year extension was proposed following the trial but was not recommended for implementation by the Western Australian Environmental Protection Authority due to a high degree of scientific uncertainty around impacts on the south-western White Shark population.

Since the Western Australian Government's withdrawal of the drumline proposal, additional beach enclosures (a barrier covering the full water column by a series of anchors and floats which prevents sharks from entering an area) and aerial patrols have been implemented along the south-west (Department of the Premier and Cabinet, 2016). The continued tagging of White Sharks and the maintenance of real-time satellite linked receivers was confirmed in 2016/17.

The SHMS has now evolved to include a range of complementary measures including (Government of Western Australia, 2019):

> Beach and aerial surveillance:
  - Helicopter and beach patrols over metropolitan and South West beaches.
  - Jet skis and event support to assist evacuations when a shark is sighted.
  - Drone patrols to monitor beaches and support events.
> Subsidising the cost of personal shark deterrents for surfers and divers.
> Additional beach enclosures. Five beach enclosures are currently in place at Old Dunsborough, Busselton, Middleton Beach (Albany), Sorrento Beach and Quinns Beach. Funding has also been offered to the City of Mandurah to install a beach enclosure at Falcon Beach.
> Surfing Western Australia (Surfing WA) partnership. A shark mitigation partnership with Surfing WA provides funding for jet skis and drones for event patrols, as well as free first-aid training that is tailored specifically for surfers.

> A specialised Shark Response Unit (SRU) has been developed within the State Government to respond to shark incidents and work with other first responders to improve warning notifications and responses, so they are continually improved.

> Beach Emergency Number (BEN) signs. BEN signs are being installed at key coastal locations across the State to improve response times to any emergency incidents.

> Legislative ban on shark cage diving for tourism and other activities which may change the behaviour of sharks.

> Whale carcass management. Collaboration across government departments and land managers to tow carcasses that are adrift, when conditions are suitable, and a program to trial additional towing options. Where possible, small whale carcasses will be towed, when removal by land is not practical.

> SharkSmart website provides the latest research, and safety information relating to sharks and includes a real-time shark activity map highlighting the latest sightings and tagged shark detections.

> A new SharkSmart App so water users can easily check for the latest shark information at their local beach.

> Integrated shark notification and response system provides ‘real-time’ information on shark sightings and tagged shark detections to land managers and the public, to assist people in making informed decisions about their water use.

> Sea Sense campaign to help improve safety by informing water users on Western Australia’s shark mitigation strategies, and how to use them to enjoy the beach with confidence, as well as how to check for the latest shark information, and how to report sightings.

3.1.2.3 KwaZulu Natal

In 1952, seven gill nets, each 130 m long, were laid along the Durban beachfront. By March 1966 there were fifteen beaches with protective nets. In 2007, drumlines replaced half of the nets at 17 of the 18 beaches along the Hibiscus Coast in an effort to reduce the entanglement of bycatch species. The South African shark attack records show an average of six incidents per year but with the deployment of shark nets and drumlines on KwaZulu-Natal beaches, this has now been reduced to less than one per year (KwaZulu-Natal Sharks Board, 2019).

Shark nets in KwaZulu-Natal are 214 m long and 6 m deep and secured at each end by two 35 kg anchors. The stretched mesh size is 51 cm and nets are laid in two parallel rows approximately 400 m offshore in water depths of 10-14 m (KwaZulu-Natal Sharks Board, 2019). Due to the prevalence of bycatch by shark nets, research in determining the efficacy of dolphin deterrent devices has been carried out.

This service is expensive and selected beaches were poorly utilised. Hence, the nets were recommended for removal in 1994 as the costs could not be justified. Furthermore, after a revision of the Australian programs (i.e. in NSW and Queensland) fewer nets were deployed per protected beach than in KwaZulu-Natal.

Drumlines in KwaZulu-Natal consist of a large, anchored float from which a single baited hood is suspended (KwaZulu-Natal Sharks Board, 2019). Drumlines were introduced at 17 beaches in 2007 to reduce bycatch of non-target species such as whales, dolphins and turtles.

Most beaches were or continue to be protected by a combination of these two pieces of equipment however, the quality of equipment varies from beach to beach (KwaZulu-Natal Sharks Board, 2019). The KwaZulu-Natal Sharks Board have also been investigating electrical shark repellent devices for some years. This includes personal shark deterrent devices but also a shark repellent cable. A trial of the shark repellent cable at Glencairn Beach since October 2014 was approved by the Department of Environmental Affairs. The cable emits a low frequency pulsed electronic signal without killing or harming sharks or other marine fauna.

3.1.2.3.1 Trials in Other South African Provinces

Scientists have been trialling non-lethal shark deterrent methods in the waters around Cape Town, to the south-west of the province of KwaZulu-Natal following several attacks since 2004 (Nature, 2015), including a two-year trial of a temporary shark-exclusion net at Fish Hoek Beach. The deployment of this net was designed to minimise bycatch with smaller mesh and removal and installation daily. While labour intensive, the deployment of the net was considered beneficial with public support however, the use of the net is limited to small, sheltered beaches and mainly protects swimmers, not surfers who venture out into deeper water and where there is more wave energy.

Following the net trial in Fish Hoek Beach, a six-month trial of an electromagnetic shark barrier was implemented (Nature, 2015). This was a 100 m long prototype barrier made of many devices similar to electromagnetic personal shark deterrent devices, anchored to the seafloor in two parallel lines near Glencairn. However, this trial did not produce any useful data due to inclement weather conditions which meant no sharks were encountered during the trial.

In response to a series of unprovoked shark bites in South African waters a Shark Spotters Program was developed and trialled in the Cape Town region (Oelofse and Kamp, 2006). The program is an early warning initiative that provides information in real time on the presence or absence of white sharks to beach goers. The programs commenced in 2004 and since that time over 1,700 shark sighting have been recorded. It is an advisory service only. The program operates throughout the year at four beaches and seasonally at another four (see **Section 3.3.1.2.2**).

3.1.2.4 Reunion Island

Following the first fatal attack on Reunion Island in early 2011, the rising risk of shark-human encounters resulted in the Island being coined a ‘shark attack hotspot’ (SurfSimply, 2015). The number of shark bites on Reunion Island matched that of South Africa, a country with almost 70 times the population. Hence, the government provisionally banned surfing and water sports outside of the lagoons in July 2013. The ban was renewed six times until 2015.

Since 2014, Reunion Island has used drumlines in conjunction with long lines to cull dangerous sharks along with shark barriers. They are also trialling other, alternative systems to catch and kill. An underwater lookout method was invented on Reunion Island (SurfSimply, 2015). However, this method relies on extensive visibility and minimal turbulence in the water. Lookouts worked five days a week for 2-6 hours at select locations on Reunion Island.

In recent years, a trial of a South African invention (the SharkSafe Barrier) has been implemented on Reunion Island (SurfSimply, 2015). The SharkSafe Barrier is made out of tubes containing strong magnets arranged similarly to a kelp forest with a 100% success rate at deterring highly motivated sharks (SharkSafe Barrier, 2019) (see more detailed information in **Section 3.3.1.2.3**). This technology doesn’t appear to affect other marine fauna with the flexibility to be installed in water depth between 0 and 12 m while resisting swells as high as 8 m.

3.2 Water Users and Occurrence of Unprovoked Shark Bite in Queensland

3.2.1 Water Users by Location

‘Swimming’ (as opposed to watercraft use) was by far the most popular activity undertaken by those beach visitors entering the water in 2018/19 (**Figure 3-7**). In the five northern-most regions between 82% and 95% of water users were swimmers, compared to slightly proportionally fewer (73–90%) water users in the five southern-most regions, indicating that watercraft use is proportionally more popular in the south than in the north.

Of the swimmers, the vast majority were recorded as entering the water to swim between the flags (**Figure 3-7**). With the exceptions of data from SCP-protected beaches in the Cairns (CV: 51%) and Gold Coast (PL: 58%) regions, more than 70% of swimmers at SCP-protected beaches swam between the flags.

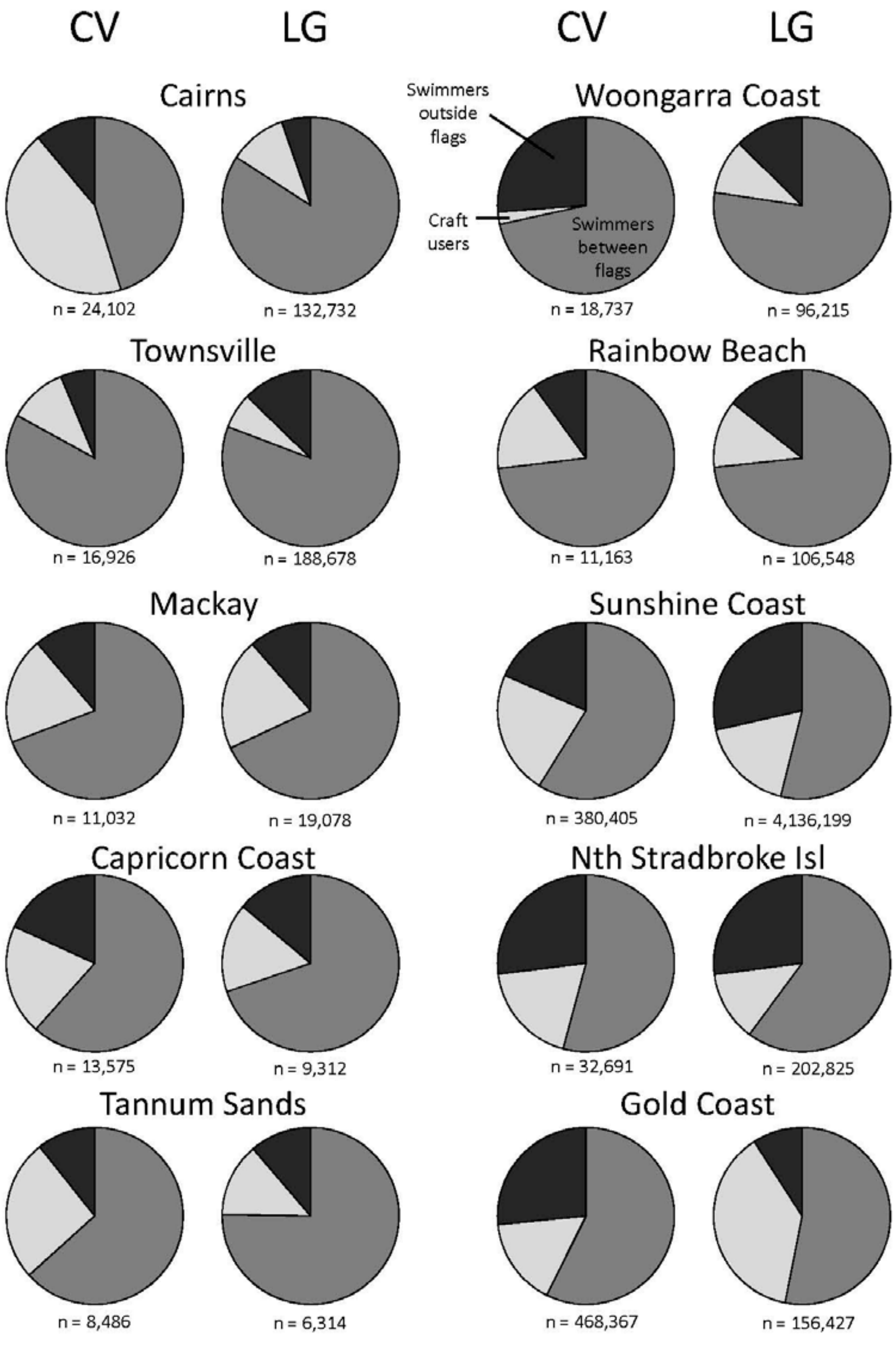


Figure 3-7 Water user type for SCP-protected beaches (by region), recorded during the 2018/19 fiscal year separately by Professional Lifeguards (LG) and Community Volunteers (CV) (Source: SLSC Queensland). NB: water craft type was not available but is likely to include surfboards, paddle boards, surf skis, kayaks, and other small craft.

3.2.2 Unprovoked Shark Bites by Location

The number and location of unprovoked shark bite on the Queensland east coast was examined using the Global Shark Attack File (https://www.sharkattackfile.net/) for the period 1962 to 2018. Consistent with McPhee (2014), the focus of the analysis was shark bites where victims had chosen to be in the water and where the bite was unprovoked. Bites where the victim may have perished due to drowning before being bitten by a shark were also excluded, as were interactions with water craft (e.g. kayaks) where no physical injury to a person occurred. Injuries that may have been from a marine animal that may not have been a shark (e.g. toadfish, barracuda, stingrays) were also excluded.

In undertaking the analysis for this report, unprovoked bites were considered on a regional basis with regions consisting of the SCP regions and other clearly identifiable regions (e.g. Hervey Bay) where SCP gear is not deployed. Further, within an SCP region (e.g. the Gold Coast) analyses made a distinction as to where SCP apparatus did not occur. An example of this are unprovoked bites in the Gold Coast canals.

Overall, 82 records in the Global Shark Attack File met the required criteria. The frequency of unprovoked shark bites was extremely low and geographically dispersed. The most bites recorded in a year was six in 1990 (**Figure 3-8**, **Table 3-6**). There is no clear trend over time in the frequency of bites. Eight bites resulted in fatalities with only one of those at a beach which had SCP apparatus in the water at the time.

Since 1962, the number of unprovoked shark bites at beaches protected by SCP fishing apparatus (27) has been about half of the number of bites in other areas of Queensland (55) (**Table 3-6**). For seven of the SCP regions at beaches protected by SCP fishing apparatus, there has been none or only one (1) unprovoked shark bite. The exception has been in the three most southern SCP regions where between four and 13 bites in total have been recorded at protected beaches. Of all the areas, bites were most frequent on offshore islands and reefs of the Great Barrier Reef. Within SCP protected beaches, surfers were the most frequently bitten, followed by swimmers. In non-SCP protected areas, swimmers were the most frequently bitten, followed by spearfishers and then snorkelers.

No attempt was made from the records to identify the shark species responsible because for the majority of records a species is not attributed or not attributed with suitable precision or accuracy.

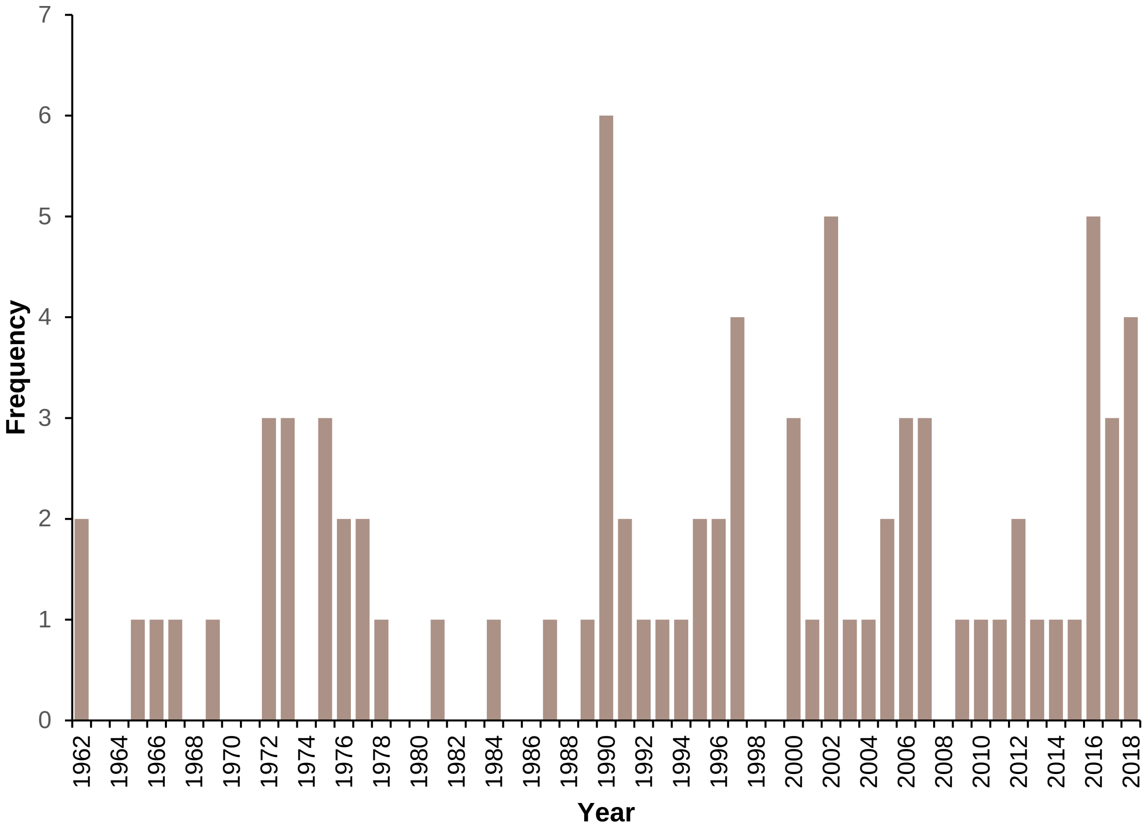


Figure 3-8 Frequency of unprovoked shark bites in total (i.e. SCP and non-SCP regions) in Queensland since the commencement of the SCP in 1962.

Table 3-6 Record of unprovoked shark bites by user group in SCP regions (bold) and non-SCP areas (non-bold) since the commencement of the SCP in 1962.

Location	Swimmer	Surfer	Snorkeler	Spear-fisher	Scuba Diver	Other	Unknown	TOTAL
Great Barrier Reef Offshore Islands and Reefs	3		6	9	2		2	22
Cairns SCP region							**1**	**1**
Hinchinbrook area				1				1
Townsville non-SCP area							1	1
Townsville SCP region			**1**					**1**
Whitsundays	3		2	1	1			7
Mackay SCP region								**0**
Clairview	1							1
Keppel Islands				1			1	2
Capricorn Coast SCP region								**0**
Gladstone		1						1
Tannum Sands SCP region								**0**
Woongarra non-SCP area		1						1
Woongarra SCP region	**1**							**1**
Hervey Bay	2						1	3
Rainbow Beach SCP region								**0**
Sunshine Coast SCP Area region	**2**	**8**				**1**	**2**	**13**
Moreton Bay/Brisbane River	3	1			1	1	1	7
North Stradbroke Island SCP region	**2**	**1**					**1**	**4**
Gold Coast SCP region	**2**	**2**					**3**	**7**
Gold Coast non-SCP Area (e.g. canals and rivers)	8						1	9
TOTAL (SCP regions)	**7**	**11**	**1**	**0**	**0**	**1**	**7**	**27**
TOTAL (non SCP areas)	20	3	8	12	4	1	7	55

3.2.2.2 Species Responsible

Three species of sharks (white sharks *Carcharodon carcharias*. tiger sharks *Galeocerdo cuvier*, and bull sharks *Carcharhinus leucas*) have been implicated most commonly in unprovoked shark bite and are probably responsible for the majority of fatalities and serious injuries (McPhee, 2014). Notwithstanding this, other species can occasionally bite people. There can be substantial inaccuracies in eyewitness or victim reports of the species responsible for an unprovoked bite, or a lack of species resolution (e.g. “a whaler”). This is unsurprising given the extremely traumatic nature of a shark bite event and the difficulty of positively identifying shark species unless a trained or experienced person is able to get a clear view of the shark. In Queensland, species identification is made even more challenging by the diversity of shark species present. Often the only reliable way of identifying the shark species present is by assessing the pattern of the bite wound or the presence of shark teeth or fragments on a victim or a watercraft such as a surfboard or kayak.

3.3 Alternative Responses to the Current SCP Systems to Unprovoked Shark Bite

3.3.1.1 Overview of Alternatives

The review assesses alternative shark control systems that can potentially be deployed or utilised in Queensland. It identifies those that are currently available commercially, those that are being trialled but not yet commercially available, and those that are beyond the proof of concept stage and are potentially of direct relevance. This information was obtained through consultation with manufacturers. Other potential alternative shark bite mitigation systems or devices with active international or Australian patents (see **Appendix H**) that did not appear to have progressed beyond concept were not considered in this review.

Alternatives to the SCP’s current approach of using mesh nets and drumlines for mitigating the risk of shark bite can be divided into two broad categories: ‘detection’ of potentially dangerous sharks; and ‘deterrents’. This section provides an overview of the main types of detection and deterrent methods and the main considerations for their deployment and efficacy. Detailed information on the specific systems is included in **Table 3-7** and **Appendices C-G**.

Shark detection can include methods that: a) utilise aerial vistas over the beach, either through an aircraft (manned fixed wing, helicopter, or unmanned aerial vehicles or balloon) or personnel on land to detect and identify a potentially dangerous shark, b) are in-situ and aim to detect a previously tagged shark, and c) are in-situ that aim to detect all sharks (tagged and untagged) within a defined area. Ideally to be effective as a direct protection method, any detection method needs to be able to transmit information regarding the presence of a large shark to water users in real time (or close to it).

Deterring sharks involves providing stimuli to a shark which results in a high probability of a shark not moving into an environment where water users are present. Shark deterrents can involve approaches that utilise electro-magnetic fields or visual, auditory or chemical stimuli, and such approaches are based on an understanding of the sensory biology of sharks. Physical barriers are purpose-built barriers that do not aim to catch sharks, but rather exclude sharks from an area where water users are present and thus create an environment where people can participate in water activities where sharks are absent. Barriers can be permanent or temporary. While visual deterrents may also have a physical component, this paper considers physical barriers as barriers that prevent a shark from accessing an area provided that the structural integrity of the barrier is maintained.

While some of the approaches (e.g. aerial surveys) discussed in this report have been already used in some shark control programs historically, we focus on recent modifications to these approaches, as well as discussing information on their efficacy.

3.3.1.2 Beach-scale Systems

3.3.1.2.1 Barriers

Physical barriers either wholly, or in part, aim to separate sharks from water users such as bathers. They do not aim to capture sharks or other marine life. Physical barriers principally aim to protect bathers, but there is no reason that a number of the products could not be placed at a specific location to provide protection for other water users, for example surfers, provided they did not alter the surf breaks or safe use of the surf break. For net-type barriers that wholly enclose an area, provided the net is intact it will effectively exclude sharks. As such, scientific trials to prove shark behavioural responses to barriers or exclusion are not required. However, engineering assessments are required as permanent physical barriers need to be designed to withstand the conditions at the location where they are deployed and trialled to ensure that in practice they do. This ability to withstand conditions must be tested over a relatively long period of time (e.g.

years). Biofouling is also a potential issue that can greatly limit the cost-effectiveness of the approach. The potential for biofouling will be geographically variable and transferability of information on biofouling from one location to another requires caution. Floating seagrass and seaweed that lodges on to barriers may also impact the structural integrity of a barrier.

While barriers are deemed permanent, with notice they must be able to be removed for cleaning and for extreme weather events such as cyclones. The issue of biofouling of physical barriers in the Queensland marine environment would need to be assessed and this would need to include impacts from it on the physical integrity of the structures. In the case of any physical failures, protocols would need to be implemented to ensure that components would be collected from the environment so that they do not contribute to marine debris or become a safety hazard. Some barriers can also be temporary and regularly deployed and retrieved which eliminates many of the engineering requirements, but this can also be labour intensive.

3.3.1.2.2 Detecting Sharks

Aerial Surveys and Land based Approaches.

Traditionally, aerial surveys have used manned fixed-wing aircraft or helicopters with human spotters. Aerial surveys using spotters have primarily been used to detect sharks that frequent the surface for feeding and courtship or form aggregations (Wilson, 2004, Motta et al., 2010, Cliff et al., 2007, Rowat et al., 2009; Kaijura and Tellman, 2016), allowing individuals, or groups, to be readily detected. The species most responsible for shark bite however, generally do not form aggregations, and spend much of their time below the surface of the water, often close to the seabed in the case of tiger sharks (Holland et al., 1999, Bonfil et al., 2005), or in the case of bull sharks in highly turbid water (Cliff and Dudley, 2011). Combined with variable water clarity, wind strength and sea chop, such species are a difficult target for aerial observers to reliably detect and identify and subsequently to assess the risk to beach users. Moreover, aircraft travelling along a coastline spend a very small amount of time over each beach (less than a minute) and thus limit the opportunity to locate a shark present off a given beach. Spotting sharks is often one function of aerial patrols with others including prevention of drownings or locating vessels in distress.

The efficacy of aerial surveys is obviously dependent on the ability to detect the target animal. Robbins et al., (2014) assessed the depths at which 2.5 m long shark analogues could be detected by fixed-wing and helicopter observers and, using this information, investigated the effects of aircraft distance and environmental variability on sighting rates under a mode of operation that was very similar to that of the shark aerial patrol program used in New South Wales, Australia. Even with water clarity of approximately 6 m, they found that observers in both fixed-wing and helicopters could only detect the shark analogues if they were shallower than 2.5 m and 2.7 m below the water surface, respectively (Robbins et al., 2014). During subsequent transects with analogues placed less than 2.5 m under the surface, observers still recorded sightings very infrequently, with overall sighting rates of only 12.5% and 17.1% for fixed-wing and helicopter observers, respectively. Although helicopter observers had consistently higher success rates of sighting analogues within 250 m of their flight path, neither aircraft observers sighted more than 9% of analogues deployed over 300 m from their flight paths. Overall, the low rates of detections found by Robbins et al., (2014) led them to express serious doubts on the efficacy of aerial beach patrols (using human observers) as an effective early-warning system to prevent shark bites. However, Dicken and Booth (2013) successfully used a helicopter to survey white sharks off bathing beaches in South Africa; implying that aerial surveys as a bather protection tool are likely dependent on the local environmental conditions within which they are flown. The public tend to significantly overestimate the probability of an aerial survey flight spotting a shark at a beach (Crossley et al., 2014). Therefore, the perceived precision of aerial patrols for shark bite mitigation by the public are well in excess of the actual precision.

There are however advances that constitute much more recent approaches to airborne shark surveillance. Unmanned Aerial Vehicles (UAVs, also known as ‘drones’) are cheaper to run than manned aircraft, but commercially available models are currently limited in their air-time due to battery-life or other logistical constraints. Several marine fauna studies have been published using UAVs (Koski et al., 2009; Hodgson et al., 2013; Kizka et al., 2013; Colefax et al., 2017, 2019; Keleher et al., 2019). Although these devices have potential to help lifeguards with surveillance at individual beaches, currently the same problems of detectability would apply as above and the operator would need to interpret video footage quickly to ensure there are no delays in sending warnings. Development of algorithms to automate accurate detection of potentially dangerous species in real time are possible and identified by Colefax et al., (2019) as a research need, but surface chop and reduced underwater visibility could still prove too complex for their reliance under the variable conditions usually experienced within one day at a beach. Although, civil aviation restrictions in many countries will limit the use of UAVs for large distance surveys, they will likely fill a niche for small area surveys. The use of tethered UAVs via helium filled balloons and/or kites may provide longer-term surveillance ability and should be considered for scientific testing of their abilities as a shark bite mitigation strategy in various environmental conditions.

Many of the Queensland SCP regions are characterised by naturally seasonally low water clarity and this mitigates against the widespread use of aerial surveys as an effective tool in a number of locations. However, this does not apply to the Rainbow Beach, Sunshine Coast, Gold Coast, North Stradbroke Island or Woongarra SCP areas. Emerging technology in the area of drones may address some of the limitations of using people to spot sharks reliably. In particular, multispectral imaging shows promise as a remote sensing tool in the marine environment (Chirayath and Earle, 2016) and has been trialled as a method for detecting sharks. Using shark analogues, Lopez et al. (2014) found detection rates averaging 84.8% when multispectral imaging was used, a substantial improvement on the estimates obtained by Robbins et al. (2014). Further testing of multi-spectral approaches is required on actual sharks rather than shark analogues and over a range of conditions including conditions present along ocean beaches.

Those who have a responsibility for general surf safety at beaches (e.g. surf life savers) may also contribute to mitigating the risk of unprovoked shark bite by keeping watch for large sharks, alerting water users when sharks are present, and directing them out of the water, but observers on suitable headlands can potentially overcome this inherent problem and reach horizontal observation coverage suitable for shark detection. The South African ‘Shark Spotters’ program developed and trialled in Cape Town in response to a series of unprovoked shark bites utilises such local mountain lookouts for their teams of shark spotters (Oelofse and Kamp, 2006). The Shark Spotters program is an early warning initiative that provides simple information in real time on the presence or absence of potentially dangerous shark species to beach goers (Engelbrecht et al., 2017).

Detecting Tagged Animals.

Although telemetry projects on sharks are now spread world-wide (e.g. Hammerschlag et al., 2011; Bradford et al., 2011; McAuley et al., 2016; Kock et al., 2018), their project design has seldom focused on shark bite mitigation. However, shark telemetry projects can provide an early warning system when a tagged shark moves close to popular beaches (McAuley et al., 2016). Kock et al. (2018) also demonstrates that such studies over time can provide significant information which identifies areas and times where overlap between sharks and humans is elevated. In the context of mitigating unprovoked shark bite, the predominant role of tagging is in the advancement of knowledge related to understanding shark movement and habitat use which in the long term can provide information on the temporal and spatial distribution of sharks relative to water usage by people.

However, acoustically-tagged sharks can be detected by arrays of fixed receivers that either log the presence of the tagged shark for future download by the receiver owners or send the record in near-real time to the owner. This latter option is a relatively new development (Bradford et al., 2011) but has the potential to provide real-time information to beach-goers and assist the public and authorities in decision-making. These alerts for tagged sharks can then be communicated to the public via social media, dedicated websites, and text messages to subscribers. However, sharks that are not tagged are still likely to be in the area and the lack of alerts may present a false sense of security for beachgoers.

The more tagged sharks that are utilising the coastal area the greater the likelihood of a detection at a beach where a receiver is present and it may be very difficult to tag a sufficient proportion of potentially dangerous sharks in a locality to be an ‘effective’ detection’ system. Maintaining receivers in position requires mooring designs informed by knowledge of longshore sand movement and regularity of scouring events, plus oceanographic conditions and severe weather events potentially encountered in the region. Placement of receivers should be such that they provide the detection swath relevant to the local site. Several studies have been conducted to determine effective range of detection for acoustic tags under varying environmental conditions (Huveneers et al., 2016), a critical component to consider when designing an acoustic receiver array for protection against unprovoked shark bite. As well as maintaining these receivers in place, an ongoing shark tagging program is required as new cohorts of sharks of a size potentially capable of biting a human will annually recruit into the population and be potentially present along coastlines. These factors subsequently can lead to an expensive ongoing shark tagging program for the management agency responsible for beach safety.

Tagging of sharks with tags suitable for real time telemetry require animal ethics approval and in Queensland, needs to undertaken by suitably qualified persons. Tagging using standard external attachment tags is frequently undertaken by sportfishers in Queensland provided the targeting and capture of animals is consistent with fisheries and marine parks legislation. Such tagging has contributed to knowledge of marine animals, including sharks (Pepperell, 1992; Dunlop et al., 2013).

Detecting Untagged Animals.

Detecting untagged sharks can be done either through deploying in-water observers (divers), capturing the 'image' of a shark via camera deployments or through sonar technologies, or by capturing the animals via fishing techniques. Divers have been used in Reunion where they enter the water and patrol the area (Lagabrielle et al., 2018). However, this effort is labour intensive, carries a safety risk, and relies on suitable water clarity and swell to be effective. Similarly, monitoring an area of water for shark activity using underwater cameras would be extremely reliant on suitable water clarity; however, the advent of cheap wireless data transfer will potentially allow cameras to stream video to land-based stations where observers or computer algorithms could be used to confirm shark presence.

Alternatively, sonar technologies using sonar arrays have the potential to detect sharks without the need for either visual or animal capture. There have been substantial advancements in sonar technologies in recent years, and some assessment of their potential for shark bite mitigation have been undertaken. Parsons et al. (2015) identified that for a given frequency and noise level, maximum detection and identification ranges are influenced by system source level, beam pattern, bathymetry, object target size and acoustic reflectivity. Areas adjacent to surf beaches prove particularly challenging for the detection of sharks by sonar approaches as air bubbles in the water column occur, negatively influence sonar beam propagation (Farmer et al., 2001; Vagle et al., 2005). In terms of the deployment of a vertical array of sonar units to cover an area, they identified that issues of interference where beams from more than one unit overlap is an important consideration. They concluded that a vertical array in shallow waters (<15 m) may not provide suitable benefits at ranges greater than 75 m. Despite the questionable efficacy and practicality of acoustic approaches as described by Parsons et al. (2015) they are judged favourably by the public as it is considered that further technological advancements will improve performance (Simmons and Mehmet, 2018).

As sonar units are relatively expensive, the number of units potentially needed to provide detection at a beach is an important consideration in terms of the cost effectiveness of the technology if applied in practice. As the beam width is also dependent on depth, shallower water locations which predominate at many current locations of the SCP would require more sonar units for a given area than deeper locations.

A final method of detecting presence of potentially dangerous sharks is via their capture using fishing gear. Although both the South African and NSW shark bite mitigation programs release all live sharks, generally these programs have high mortality rates for large 'target' sharks caught in the nets (84% Cliff and Dudley, 2011; 83% Dalton et al., 2017). The first 'green strategy' for mitigation of shark bites was initiated off Recife, Brazil, where target shark mortality was only 30% due to the use of hook-based fishing gear rather than mesh nets (Hazin and Afonso, 2013). This strategy also involved the careful relocation of target sharks well away from beaches in waters greater than 25 m deep.

Subsequently, a new shark fishing device known as the Shark-Management-Alert-in-Real-Time (SMART) drumline was invented in Reunion to maximize survival rate of captured animals (Guyomard et al., 2019). The SMART drumline includes a GPS satellite buoy and a 'Catch-A-Live'™ system alerting fishers when an animal is caught in near-real time. The alert is initiated when the bait is taken by an animal and the magnetic trigger is activated. The approach constitutes a meaningful compromise between the need to target potentially dangerous species, such as bull, tiger and white sharks near popular beaches and the requirement to release, and possibly tag captured animals (Guyomard et al., 2019). SMART drumline trials have been completed in NSW and are progressing in WA.

They also provide an opportunity to translocate and release further offshore any shark species caught, as per the strategy initiated in Brazil. Reducing mortalities of caught animals in any fishing operation requires extra labour expense, as fishers are required to be on standby to immediately respond to a communication informing of a caught animal. Although fishing is a method of detecting sharks, subsequent analysis of environmental factors associated with those captures may lead to understanding conditions affecting shark abundance and distribution in nearshore waters. Additionally, telemetry tagging of released animals can provide even more benefit for risk management through developing an understanding of how animal abundance and distribution relates to local environmental conditions, plus through their subsequent detection by acoustic receiver arrays especially if they relay such detections in real-time. Such catch and release programs may even lead to acting as a shark deterrent if released sharks move out of the area.

3.3.1.2.3 Beach-scale Deterrents

Sharks have specialised receptors (ampullae of Lorenzini) enabling them to detect extremely weak electrical potentials generated by other animals and inanimate objects; these are used principally for locating prey. The electrical receptors of sharks are highly sensitive at short distances (0.5 m), and a corollary of this high sensitivity is that it is easily saturated by intense stimulation such as that created by an artificial electrical field (Hart and Collin, 2015).

Although the use of electrical barriers to deter sharks were first assessed (and rejected) by the NSW Menace Committee in 1929 (Anon, 1935), and early attempts in South Africa appeared to fail (Cliff and Dudley, 1992), the use of electrical deterrents fixed in position to protect an area shows promise. This approach requires deployment of a series of electrodes spaced within an area and connected to a power source that generates an electric current. Personal electrical deterrents based on similar approaches have been found through field testing to successfully deter sharks (albeit not 100% of the time) (Smit and Peddemors, 2003; Huveneers et al., 2013). At this time though there no scientifically proven and commercially available electrical deterrents that can be used to protect an area of water beyond those used for personal protection. Research on developing practical and effective approaches is ongoing, but the results are yet to be published in the scientific literature. For example, Ocean Guardian have purportedly built prototype virtual nets with electrode lengths connected to buoys spaced apart every few metres either by a cable floating on the surface, where the ends or corners of the cable are anchored to the seabed using standard sea anchors (SRC1000), or where each buoy is anchored independently (Beach01). The proposed approach is a partnership between Ocean Guardian and the Kwa-Zulu Natal Sharks Board, and builds on the research and development work undertaken by the latter, including appropriately designed trials off Glencairn Beach (South Africa). A particular challenge with undertaking field evaluations of such deterrents is the need for testing locations to be located in water clear enough to record shark behaviour and with enough shark encounters to allow for statistically robust conclusions to be drawn. Alternatively, trials should be conducted in areas where long-term telemetry data on shark movements exist and where subsequent activity responses to electrical barriers can be analysed. While all sharks have ampullae of Lorenzini, the possibility of interspecific differences in responses to area-based electrical deterrents cannot be ruled out at this stage. Ideally, field tests should be on at least one of the three most potentially dangerous species to humans, and preferably all three. People with pacemakers are informed by manufacturers to avoid wearing an electric shark deterrent, and it would also be prudent for such people to be informed to stay a minimum distance (e.g. 5 m) from any electric deterrent employed in an area.

Deterrents have also been designed using a combination of permanent magnets and a visual component. The Sharksafe Barrier™ combines barium-ferrite permanent magnets and a PVC piping arrangement to mimic kelp as the piping moves with the waves and currents. Permanent magnets are thought to act on the electro-sensory system of sharks indirectly through electromagnetic induction which is thought to be the same physical mechanism that allows sharks to detect the Earth's magnetic field (O'Connell et al., 2014a). The actual sensory processes by which sharks detect magnetic fields are not yet determined with certainty. The visual component of the approach was based on observations that white sharks appear not to readily enter kelp forests (O'Connell et al., 2014b). The rationale of using both the visual and magnetic components in the barrier is that it may maximise the performance of the physical barrier across circumstances where turbidity may vary as it produces two distinct stimuli detectable by two of the shark's sensory systems. That said, from the trials undertaken to date the importance of the magnetic component of the barrier is still uncertain (O'Connell et al., 2014a, 2018). Overall trials of the Sharksafe Barrier™ have found to be effective at modifying the behaviour of both white and bull sharks with both being effectively excluded from the area where they are deployed (O'Connell et al. 2014a and b, 2018). However, although the system was found to be durable in a high energy coastline, the spatial scale (tens of metres) of experiments to date are small relative to the area that needs to be covered to provide practical and meaningful protection for water users.

Since the 1930s, bubble curtains have been proposed as a method for deterring sharks from entering an area by creating a visual barrier (Anon, 1935). A bubble curtain generates air (e.g. through a compressor) along a submerged, perforated hose which escapes from the perforations and rises to the surface, resembling a curtain. With respect to sharks, this approach showed early promise in tank trials, however subsequent trialling identified only very limited deterrent abilities as the animals habituated to the bubble curtains (Gilbert, 1968). While there is renewed interest in bubble curtains as a shark deterrent (Hart and Collin, 2015), no new independent assessments have provided evidence to support their effectiveness and specific systems have not been considered further in this review.

The development of chemical deterrents can be dated back to at least 1942 with the U.S military being an important driver of this research in response to the fear servicemen had of sharks (Baldridge Jr. 1990; Stroud et al., 2014; Hart and Collin 2015). In addition to actually deterring a shark, chemical deterrents need to be non-lethal to sharks and other marine animals, be able to be synthesised and stored without denaturing for a sufficient period of time, and be effective in relatively small volumes to allow for practical use. When these three factors are considered a number of chemicals which elicit avoidance responses in sharks are not suitable as a deterrent or repellent. Pardaxin and pavonin are naturally occurring toxins derived from certain soles (*Pardachirus* spp.) which can repel sharks, but are not suitable as a shark deterrent or repellent as they lose potency when freeze-dried for long periods of time (Hart and Collin, 2015). Chemicals such as sodium dodecyl sulphate (SDS) generally require the release of a volume of chemical that is too large for practical use in the field and may have broader environmental impacts (Baldridge, 1990). Surfactants such as sodium lauryl sulphate which is used in many common household goods (e.g. shampoos and laundry detergent) can elicit a response if delivered directly to the mouth of a shark (e.g. via a squirt gun), but is not effective as a repellent when released into the water at low concentrations (Smith Jr., 1991; Sisneros and Nelson, 2001). The more recent focus on chemical deterrents has been for personal use rather than for broader deployment and based on biologically relevant compounds (semiochemicals) rather than those that are an irritant to shark senses (Hart and Collin, 2015). Some of these are based on necromones in decomposing shark tissue which contains high concentrations of acetic acid in addition to a large array of amino acids, short chain and fatty carboxylic acids, amines and short chain lipid oxidations products (Stroud et al., 2014). The RepelSharks™ personal chemical deterrent uses such a compound and proved to disperse competitively feeding Caribbean reef sharks (*Carcharhinus perezi* and *C. acronotus*) (Stroud et al., 2014). However, trials on potentially dangerous sharks such as white and tiger sharks have not been published, and it is plausible that necromones may be a feeding stimulant for shark species that scavenge on other sharks which include white and tiger sharks. Further, applying RepelSharks™ which is deployed via a small canister is not feasible at a large spatial scale.

Acoustic deterrents have been proposed to mitigate shark bite and sharks are known to be sensitive to low-frequency sounds up to 2000 Hz and have a peak sensitivity at around 100 Hz (Hueter et al., 2004). There has been focus recording and playing back orca (*Orcinus orca*) calls as a deterrent since orcas include elasmobranchs in their diet (Reyes and García-Borboroglu, 2004, Engelbrecht et al., 2019). Chapuis et al. (2019) assessed the behavioural response of seven shark species to orca calls and novel sounds and identified that responses varied between shark species and individuals of a shark species. The presented acoustic stimuli alone were not an effective deterrent for white sharks, even though orca appear to displace white sharks following predation events (Pyle et al., 1999, Jorgensen et al., 2019). Ryan et al., (2018) also found that acoustic deterrents using novel sounds did not significantly reduce feeding in three shark species including the white shark. The efficacy of acoustic deterrents on bull or tiger sharks does not appear to have been investigated.

3.3.1.3 Personal Deterrents and Protective Apparel

Personal deterrents are designed to protect an individual who is using the deterrent rather than collective protection of a number of people at a location. Personal deterrent methods are diverse and include: electrical deterrents, magnetic deterrents (permanent magnets and electropositive metals), chemical deterrents, and visual deterrents. Individual deterrents come with relevant caveats from the manufacturers that they are not 100% effective all the time in all situations. Personal deterrents represent an approach that allows for individuals to take personal responsibility for their own safety, and an approach that is applicable to areas within and outside SCP activities. Tourist operators can potentially make personal deterrents available to clients thus providing an additional level of protection and peace of mind for them. No deterrent will ever be effective 100% of the time in all circumstances. There are a diverse range of potential personal deterrents and as evidenced by patent activity in Australia and overseas (particularly in the U.S.), the field remains highly attractive to entrepreneurs. Consumers should preferentially choose personal deterrents that have undergone independent scientific testing, and that are most applicable to the shark species likely to be encountered and the particular water activity that they are partaking in. Putting faith into a personal deterrent that is ineffective may lead to a person taking additional risks in the water in the belief that they are adequately protected.

Table 3-7 Summary of alternative shark bite risk mitigation systems including country of manufacture, commercial availability, proven effectiveness and cost.

System	Description	Country of Manufacture	Commercial Readiness	Independently Tested to Determine Effectiveness		Cost	
				Against Dangerous Sharks	In Exposed Coast	Capital	Operational / Maintenance
Barriers							
Eco Shark Barrier Net	Small modules made of a nylon polymer joined to form an anchored, floating barrier that allows water to pass through 295 mm diameter squares. http://www.ecosharkbarrier.com.au/	Australia	Commercially available	Physical barrier to sharks. Effectiveness assumed when structural integrity is maintained.	Failure on the exposed north coast of NSW occurred when deployed.	High	Low
Bionic Barrier and Aquarius Barrier	The Bionic and Aquarius barrier differ from the Eco Shark Barrie in terms of material. The Aquarius barrier is made with heavy duty marine ropes with robust nylon struts and the Bionic Barrier, also made from nylon, has one-way hinges that allow it to adapt to sea height, or tidal fluctuations, swell and seabed movements. https://www.globalmarineenclosures.com/	Australia	Commercially available	Physical barrier to sharks. Effectiveness assumed when structural integrity is maintained.	Failure on the exposed north coast of NSW occurred when deployed.	High	Low
Temporary Barrier Net	Owned and maintained by the Kwazulu-Natal Sharks Board (KZNSB). KZNSB deploys a temporary net at Fish Hoek Bay. The net has a mesh size of 4 x 4 cm and is deployed (and retrieved) in calm seas in the swimming season.	South Africa, but can be manufactured in Australia	Unavailable, but could be manufactured in Australia	Physical barrier to sharks. Effectiveness assumed when deployed and structural integrity is maintained.	Not designed to be deployed on exposed coastlines and not tested at such locations.	Low	Mod
Shark Detectors							
Drone	Detects sharks using unmanned aerial vehicles (UAVs, also known as'drones'). Commercially available models are currently limited in their air-time due to battery constraints. Able to be used by lifeguards. Potential to use multispectral imaging to improve detection rate.	Australia	Commercially available	Can detect sharks, but limited by flight time and water clarity. Various factors influence detection rates. Further work required to determine visual rates of detection. Bull sharks and tiger sharks are less likely to be detected visually by human observers than whites due to being closer to the bottom with more cryptic colouration. Detection using multi-spectral cameras is high and largely independent of water clarity and sea conditions.	Tested off the exposed coast of Ballina. While sharks were detected, no estimates of the rate of detection were determined.	Mod	Low
Manned Aircraft	Detects sharks from manned fixed-wing aircraft or helicopters with human spotters.	Australia	Commercially available	Can detect sharks, but limited by flight time and water clarity. Various factors influence detection rates. Detection rates of dangerous sharks present by human	Detection rates of sharks known to be low using visual detection. Detection using multi-spectral	High	High

System	Description	Country of Manufacture	Commercial Readiness	Independently Tested to Determine Effectiveness		Cost	
				Against Dangerous Sharks	In Exposed Coast	Capital	Operational / Maintenance
	Potential to use multispectral imaging to improve detection rate.			observers is low. Detection using multi-spectral cameras is high and largely independent of water clarity and sea conditions. Bull sharks and tiger sharks are less likely to be detected visually by human observers than whites due to being closer to the bottom with more cryptic colouration.	cameras is high and largely independent of water clarity and sea conditions.		
CleverBuoy	Detects sharks using sonar and identification software systems, transmitting information to lifeguards. https://www.smartmarinesystems.com/	Australia	Commercially available	Limited independent trials of varying effectiveness. Some technical challenges for detection remain and are difficult to overcome in shallow areas where wave action suspends a large amount of sand and where air bubbles are prevalent.	Although gaps in independent testing remain, the challenges for appropriate levels of effectiveness are enhanced in areas of high wave activity where sand and air bubbles occur in the water column.	High	High
Shark Spotters	An early warning initiative that users a spotter in an elevated position to provide information in real time to beach goers about the presence or absence of dangerous shark species. https://sharkspotters.org.za/	N/A	Commercially available	Yes for white sharks only. Unlikely to be highly effective for tiger or bull sharks.	Designed as solution for an exposed coastline.	Low	High
Acoustic and Satellite Tagging	Involves tagging sharks and deploying satellite-linked (VR4G) acoustic receivers, and data-recording acoustic receivers (VR2W) on the sea floor. Data from satellite-linked (VR4G) acoustic receivers can provide an early warning system of when a shark was close to popular beaches. Detections by VR2W receivers are not transmitted via satellite but are stored in the receiver's on-board memory.	Canada	Commercially available	Acoustic and satellite tagging can play a very important role in building knowledge of the movements and habitat use of dangerous shark species which can inform other mitigation and educational strategies, but it's effectiveness *per se* in mitigation is unproven. The method though is proven in terms of being able to effectively track the movements of sharks where detectors are deployed.	Yes	High	High
Area-based Deterrents							
Sharksafe Barrier	Components include grade C9 barium-ferrite permanent magnets and LDPE (Low-density polyethylene) piping to mimic kelp as visual	South Africa	Prototype	Magnetic and visual deterrent to sharks. Some testing at a small scale on dangerous shark species	Independent testing has occurred on exposed coasts.	Mod	Low

System	Description	Country of Manufacture	Commercial Readiness	Independently Tested to Determine Effectiveness		Cost	
				Against Dangerous Sharks	In Exposed Coast	Capital	Operational / Maintenance
	barriers. The piping while anchored to the seafloor moves with waves and currents. https://www.sharksafesolution.com/						
Shark Repellent Cable	The KZNSB developed an electric cable anchored to the seabed with electrodes rising to the surface powered by a pack of large truck batteries and driven by the electronic controls housed in a small trailer on land. KZNSB	South Africa	Prototype	No published results of testing undertaken.	No published results of testing undertaken.	Mod	Mod
Rubber Guard Electric Fencing	An electric cable which is heavy enough to stay on the seabed and a number of flexible vertical Rubber Fence wires which are distributed along the electric cable. The fence is energized with 100 to 200 Volt electric pulses, from a special water proof battery operated energizer designed for the purpose or with a combination of photovoltaic power or wave power modules.	Denmark	Concept	Untested	Untested	Mod	Mod
Shark Repelling System	Underwater gates produce an electromagnetic field and each unit of the gate is provided with a backup power supply and an alarm that provides notification of any power failures.	Belgium	Prototype	Untested	Untested	Mod	Mod
Beach Barrier SRC1000 and Beach01	Ocean Guardian in partnership with ArmscorSOC Ltd purportedly use Shark Shield technology to create an electrical field along a line using linked buoys or cables.	Australia partnering with South Africa	Purportedly Prototype	No published results of testing undertaken.	No published results of testing undertaken.	Mod	Mod
Bubble Curtain	A bubble curtain works by generating air (e.g. through a compressor) along a submerged perforated hose which escapes from the perforations and rises to the surface resembling a curtain.	N/A	Concept	Untested	Untested	Mod	Mod
Personal Deterrents							
Ocean Guardian (for divers,	Ocean Guardian's battery-powered products use Shark Shield technology which creates a three-dimensional, pulsing, electrical field. It is a water immersion-activated device fitted	Australia	Commercially available	Independently tested with statistically significant results.	Independently tested with statistically significant results.	Low (per product)	Low

System	Description	Country of Manufacture	Commercial Readiness	Independently Tested to Determine Effectiveness		Cost	
				Against Dangerous Sharks	In Exposed Coast	Capital	Operational / Maintenance
snorkellers and surfers)	to the tail pad and underside of a surfboard (for surfers) or a diver's or snorkeler's leg. https://sharkshield.com/technology/						
Rpela (for surfers)	A battery-powered device that produces an electric field around the surfer. It is a water immersion-activated device fitted to the underside of a surfboard. https://www.rpela.com/	Australia	Commercially available	Independently tested with statistically significant results.	Independently tested with statistically significant results.	Low (per product)	Low
No Shark (for divers, snorkelers, swimmers and surfers)	Previously ESDS, it is battery-powered device that produces an electric field around the user. It is a water immersion-activated device fitted to a limb of the user. http://www.noshark.com	USA	Commercially available	Independent testing revealed no statistically significant difference.	N/A	Low (per product)	Low
SharkBanz and Modom Shark Leash (for swimmers and surfers)	Uses magnets to produce a magnetic field around the user. SharkBanz is a device fitted to a limb of the user and Modom Shark Leash is fitted as per a legrope on a surfboard. http://www.sharkbanz.com.au	USA	Commercially available	Not independently tested.	Not independently tested.	Low (per product)	Low
RepelSharks	A chemical deterrent available in aerosol cans that when released covers a broad area, at least for a short period of time until it disperses. It is a manufactured chemical that is based on necromones of decomposing shark tissue that are considered to disperse some species of shark. https://repelsharks.com/	West Indies	Commercially available	Not independently tested for white, bull or tiger sharks.	Not independently tested for white, bull or tiger sharks	Low (per product)	Low
Shark Mitigation Systems (SMS) (for surfers)	Designs that break up the silhouette of surfboards to purportedly appear as separate objects and unlike normal shark prey. https://shop.sharkmitigation.com/	Australia	Commercially available	Not independently tested or results not currently available.	Not independently tested or results not currently available.	Low (per product)	Low
Sharkeyes (all water users)	Shark Eyes is purportedly a visual shark deterrent sticker that can be attached to the underside of a board. https://sharkeyes.com.au/	Australia	Commercially available	Not independently tested.	Not independently tested.	Low (per product)	Low

System	Description	Country of Manufacture	Commercial Readiness	Independently Tested to Determine Effectiveness		Cost	
				Against Dangerous Sharks	In Exposed Coast	Capital	Operational / Maintenance
Other							
SMART Drumline	Fishing gear composed of classical material used for a standard drumline with hook and bait, however, the mooring buoy is designed to detect and relay a message to shore in real time when a shark or other animal has been hooked. There is then the opportunity for a shark contractor to immediately attend to the drumline and translocate and release the animal before it dies.	Reunion Island	Commercially available	Demonstrated to catch sharks with high rates of survival provided detections can be effectively serviced.	Tested in exposed conditions at Ballina and Reunion. Exposed conditions are not an issue provided they do not prevent reaching the drumline should a detection occur.	Mod	High

4 Applicability of Alternative Systems for use in the Shark Control Program

To evaluate whether alternative approaches to the SCP's current approach of using mesh nets and drumlines for mitigating the risk of shark bite would be fit for purpose for trialling, a range of evaluation criteria were considered. Further details of these evaluation criteria are given in the section below. These were combined in a decision process to determine the most suitable systems for regions, or groups of regions with similar characteristics.

4.1 Evaluation Criteria

A range of factors could potentially be considered when choosing an alternative system for some or all of the SCP regions. We suggest that some factors have greater importance than others. For example, it would be pointless trialling a system in any of the southern regions if it could not cope with the prevailing sea conditions, or, the less often but larger swell events. Given the aim of the Queensland SCP is "*to reduce the chance of people being killed or seriously injured by sharks in Queensland*", another important factor is the performance of the systems against potentially dangerous sharks. Cost, commercial readiness and community sentiment are also important considerations.

Factors requiring less consideration are those that have potential to be more easily managed. For example, consider that some deterrents would presumably affect other species of marine fauna besides white, tiger and bull sharks and could potentially interact with the use of critical habitat (known aggregation sites) by the critically endangered grey nurse shark (*Carcharias taurus*). Grey nurse sharks are of very little concern to bathers but known aggregation sites for this species occur near Rainbow Beach (at Wolf Rock) and Stradbroke Island (at Flat Rock). Notwithstanding this, the potential risk of a deterrent affecting this species could be minimised if the deterrent was not used in areas close to the known aggregation sites.

Further information on the choice of evaluation criteria is given below:

4.1.1 Criteria Used to Rank Alternative Systems

Suitability to local environmental conditions

Many of the alternative systems only operate effectively within discreet environmental parameters whereas others are more versatile. The two parameters with the greatest potential to effect operations are water clarity and ocean swell.

Visual observation systems generally rely on clear water to spot sharks, although some systems can account for poorer water clarity at times, by using multispectral cameras, or in the case of the shark spotters by displaying flags that notify the water users of poor spotting conditions. Notwithstanding this, given that prevailing water clarity in the northern group of regions is poor for much of the year, visual observation systems would not be suitable there as a key tool for mitigation of risk.

Ocean swell can affect anchoring or cause breakage of in-water systems. To remain in place and intact, a system must be durable to the constant oscillations caused by prevailing swells. However, it is not just the prevailing swells that require consideration, but also the potential for extreme events. For example, although it would appear that barriers could be safely be deployed in the coastal SCP regions of Queensland where there is generally very little swell on the beaches, consideration is also needed as to how they would cope with the occasional cyclonic conditions (i.e. could they be easily extracted from the water for preservation prior to these extreme events).

Given the capital costs of some systems, *suitability to local environmental conditions* is the primary criteria to consider when evaluating the potential of alternative systems for trialling. This is particularly the case for in-water systems where the potential clean-up costs and environmental consequences of breakage and redistribution of debris could potentially be great.

Effectiveness against potentially dangerous sharks

The next most important factor to consider is the *effectiveness against potentially dangerous sharks.* Although this can be assumed for barriers it needs to be proven for all other systems given it is directly related to the aim of the Queensland SCP "*to reduce the chance of people being killed or seriously injured by sharks in Queensland*". We considered that 'independent testing' was required to demonstrate proof that an alternative system reduces the risk of bite. The weight of evidence indicates that catch and kill has been an effective form of mitigation against shark bite at the targeted beaches in the jurisdictions of Queensland and NSW, at least. There were 36 shark bites in Queensland between 1916 and 1962, 19 of which resulted in fatalities. The SCP was the responding mitigation in 1962 from which only one fatality has been the result of a shark bite on a protected beach (see **Sections 3.1.1** and **3.2.2**). In NSW, since the introduction of the shark meshing program in 1937 there has similarly been a reduction in fatalities at netted beaches.

Commercial readiness

Our review of the potential alternative systems for shark bite mitigation indicated the systems are in various states of readiness ranging from those that are only at a proof of concept stage, to those where the prototype has been tested or where there is current commercial readiness. The state of commercial readiness is important given it may directly affect when an alternative system can be made suitably ready for trial or when it could potentially be integrated into the SCP.

4.1.2 Criteria also requiring Consideration

Cost

Costs for alternative systems vary in terms of hardware, deployment and operational costs and maintenance. Given commercial sensitivities, we were not able to obtain comparable costs for all of the systems but we were able to make assumptions about the relative differences among systems in their costs.

Cost is not considered to be among the most important evaluation criteria, but it will be important for DAF to be able to discriminate among the alternative systems in terms of their setup and operational costs.

Community sentiment

A lesson learned from the roll out of the NSW Shark Management Strategy has been that community sentiment requires close consideration, including sentiment as to all types of shark bite mitigation systems that are preferred or, in the case of alternative systems to catch and kill, which of those the community would consider for trialling. From discussion with managers of the NSW Shark Management Strategy, it is understood that community sentiment can vary between water user groups and non-water users, among water user groups and among regions. Lessons learned from NSW government suggest that community buy-in would be important to support and in some respect, drive, decisions regarding the future of the Queensland SCP. Community sentiment would best be gauged by presenting the community with an informed list of options of potential alternatives against the status quo. This process would work best if the community were presented with only the few most highly ranked alternative systems for their region.

4.2 Decision Analysis

Decision support tools are a useful approach to solving complicated problems - i.e. best applied to unstructured or semi-structured problems. For this report, the process involved four steps to identify and rank the most fit for purpose alternative systems to the SCP's current approach of using nets and drumlines for mitigating the risk of shark bite in its ten regions.

The process initially requires information gathering steps (steps 1 and 2) to understand the operating conditions and the effective operating parameters of the alternative systems. The evaluation criteria (for ranking) were determined in step 3 and tested against in step 4.

The ranking process involved two passes. The first pass determined whether the prevailing conditions in the environment were within the effective operating parameters of systems (**Table 4-1**). The second pass ranked the various types of systems against each other according to weighted fit for purpose criteria **Table 4-2**.

Further detail on the four steps supporting decisions regarding alternative systems are given below:

1. ***Gather information about the environment*** – This required searching for the conditions that call for a decision on an appropriate risk mitigation measure. The review recognised that the SCP regions are highly variable in terms of habitat type, ranging from the surf beaches of the Gold Coast to the generally more sheltered beaches within the Great Barrier Reef (e.g. Cairns). The predominant conditions, as well as their ranges, needed to be identified for each of the SCP regions to determine whether they were within the effective operating conditions of the various types of alternative shark bite mitigation systems. The catch in the existing SCP was also recognised in this process.

   Outcome: An understanding of the environmental characteristics of the regions that could potentially affect operations of alternative systems.

2. ***Gather information about alternative systems*** – This was done to understand the operating parameters of alternative systems (to catch and kill) to determine their effectiveness and efficiencies

with regard to shark bite risk mitigation. Consultation with manufacturers and scientists was undertaken to confirm system characteristics in relation to key findings from the review in Step 1. Engagement with relevant managers was also undertaken to provide feedback on systems trialled in other jurisdictions.

Outcome: An understanding of the various characteristics of the alternative systems, in relation to key findings from the review in Step 1.

3. ***Choice criteria*** – Evaluation criteria were developed for selecting a course of action among the possible alternative actions that allowed the various systems to be compared and contrasted. The approach involved developing a suite of 'fit for purpose' criteria that closely reflected the objectives of the SCP and that considered key findings in Steps 1 and 2.

   Outcome: A suite of fit for purpose criteria for evaluating alternative systems that matched the requirements of the SCP.

4. ***Analysis*** – This process adopted a selected course of action in a decision situation. The various alternative systems were evaluated against the relevant 'fit for purpose' criteria determined in the step above and the choices of the most optimal systems were justified by their compliance with the criteria as determined through consideration of the key findings in the information gathering process. The first pass was to determine whether the system could operate effectively in the given environment (i.e. to shortlist the various system types for a region, or groups of regions with similar characteristics). The result considered whether the system could operate effectively (yes, no or in limited circumstances) according to the prevailing environmental conditions. The next pass was to rank short-listed systems for trialling based on the following criteria, in order of importance: proven effectiveness against dangerous sharks and commercial readiness.

   Outcome: In recognising the significant differences in habitats and the varying practical challenges across the SCP regions, the review aimed to rank each applicable (short-listed) approach in each of the SCP regions, or groups of regions with similar characteristics. Information about the occurrence and catches of potentially dangerous shark species in each SCP area was also factored into considerations of alternative systems for regions.

NB: Where relevant we have identified significant challenges and/or information gaps and provide a blueprint for trialling. Cost and community sentiment are also to be included in decisions regarding what should be trialled, or what should not be trialled. This would need to be done through informed consultation that included information about the effectiveness and commercial readiness of the potential alternative systems.

4.3 Rankings

The first pass (i.e. knockout process of the decision analysis) indicated visual observation systems would be ineffective for much of the time in the north group of SCP regions including Cairns, Townsville, Mackay, Capricorn Coast and Tannum Sands due to prevailing poor water clarity (**Table 4-1**). The first pass also indicated that permanent barrier systems would be impractical in the south group of regions of Woongarra, Rainbow Beach, Sunshine Coast, North Stradbroke and Gold Coast because of ocean swell. In the south group, however, the temporary barrier net could potentially be deployed on the western side of North Stradbroke Island. The Shark Spotter Program would also be unable to be used effectively in the south group apart from a very few locations where there was suitable elevation (e.g. North Stradbroke Island).

Rankings of specific barrier types, shark detection systems, area-based deterrents and other alternative systems are given in **Table 4-2**. Based on the *Effectiveness against potentially dangerous sharks* and *Commercial readiness* the various permanent barrier types and the temporary barrier net ranked equally. There were however differences in capital and operational costs between permanent barriers and the temporary net.

Drones, the Shark Spotter Program and manned aerial surveys also all ranked equally, although manned aerial surveys were expected to have greater capital and operational costs than the other two systems. If operational costs of drones could be subsidised by being integrated into the existing duties of lifeguards at patrolled beaches, then drones would potentially have less operational costs than the Shark Spotter Program. Of the other shark detection systems, Cleverbuoy^{TM} ranked higher than detection systems based on tagging sharks.

The Sharksafe^{TM} barrier ranked highest among the area-based deterrents. Although the electrical-based Beach Barrier SRC1000 and Beach01, Shark Repellent Cable and Shark Repelling System deterrents ranked next highest, these electrical systems have not yet demonstrated effectiveness against potentially dangerous sharks.

Table 4-1 First pass of decision analysis: suitability of alternative systems to conditions at north and south groups of SCP regions

					Detector Systems					Barrier Systems		Deterrent Systems		Other
Group	**SCP Regions**	**Typical Water Clarity**	**Land-based Elevation**	**Typical Wave Energy**	**Manned aircraft**	**Drone**	**Subsurface sonar**	**Tagged animals**	**Shark spotters**	**Permanent**	**Temporary net**	**Electric**	**Magnetic / visual**	**SMART Drumline**
North	Cairns Townsville Mackay Capricorn Coast Tannum Sands	Generally poor	Generally low lying	Low	Very limited season	Very limited season	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
South	Woongarra Rainbow Beach, Sunshine Coast North Stradbroke Gold Coast	Good	Some headlands	High Medium (Woongarra) Low (Amity Point, Nth Sradbroke)	Yes	Yes	Yes	Yes	Limited areas	No	Limited areas	Yes	Yes	Yes

Table 4-2 Second pass of decision analysis: rankings for each type of area-based system within broader groups based on fit for purpose criteria of proven effectiveness, commercial readiness and cost

System	Description	Ranking within System Type	Proven against Dangerous Sharks[1]	Commercial Readiness	Capital Cost	Operational / Maintenance Cost
Barriers						
Permanent	Eco Shark Barrier Net	1	Yes	Yes	Mod	Low
	Bionic Barrier and Aquarius Barrier	1	Yes	Yes	Mod	Low
Temporary	Temporary Barrier Net	1	Yes	Yes	Low	Mod
Shark Detectors						
Drone	Lifeguard manned	1	Yes	Yes	Mod	Low
Spotters	Shark Spotters	1	Yes	Yes	Low	Mod
Manned Aircraft	Plane or helicopter	1	Yes	Yes	High	High
Subsurface	Clever Buoy	2	Yes, but limited trialling and not in whitewater	Yes	High	High
Tagged animals	Acoustic Tags	3	No[2]	Yes	High	High
	Satellite Tags	3	No[2]	Yes	High	High
Area-based Deterrents						
Magnetic / visual	Sharksafe Barrier	1	Yes	Prototype	Mod	Low
Electric	Beach Barrier SRC1000 and Beach01	2	No	Prototype	Mod	Mod
	Shark Repellent Cable	2	No	Prototype	Mod	Mod
	Shark Repelling System	2	No	Prototype	Mod	Mod
	Rubber Guard Electric Fencing	3	No	Concept	Mod	Mod
Visual	Bubble Curtain	3	No	Concept	Mod	Mod
Other						
Catch and release	SMART Drumline	1	Yes	Yes	Mod	High

[1] As demonstrated by ‘independent testing’, apart from physical barriers where effectiveness has been assumed when structural integrity is maintained
[2] The method is only proven in terms of its ability to effectively track the movements of sharks where detectors are deployed.

5 Discussion and Key Findings

5.1 Consideration of Changes to Risk Levels

Although there will always be divergent interests and opinions about the way to mitigate human wildlife interactions such as interactions with sharks, the growing global awareness for biodiversity conservation that has arisen in the last few decades appears to be driving a progressive reduction of culling, which has been replaced increasingly by public education programs, awareness of shark hazard and development of alternative beach protection programs (Curtis et al., 2012). In effect, a range of strategies has been developed that can be described best as co-existence. Such a non-lethal approach is also consistent with recommendations made by the Australian Senate Environment and Communications References Committee in its recent review into *Shark mitigation and deterrent measures* (Senate Committee 2017). The first step in moving towards such a system of coexistence is to evaluate how such alternative approaches could reduce the levels of risk in the existing systems, if at all, and whether the consequent levels of risk would be acceptable.

Clearly, if the Queensland SCP were to shift away from using fishing apparatus as its primary tool to reduce risk to water users there would be benefits to some threatened or protected species that are taken incidentally in the SCP (see **Section 3.1.1.2.5** and Gribble et al.,1998). However, of the threatened marine mammals, marine reptiles and sharks with *Environment Protection and Biodiversity Conservation Act* 1999 ‘critically endangered’ or ‘endangered’ listings, where the loss of even small numbers of individuals are of potential concern, only the catches of the critically endangered grey nurse shark (*Carcharias taurus)* and endangered loggerhead turtles (*Caretta caretta*) since 2001 have been greater than one individual, on average, per year at ~1.2 individuals yr^{-1} and ~1.8 individuals yr^{-1} respectively. For both species, these average annual losses under the current SCP would be unlikely to be of a magnitude that would be large enough to threaten the viability of populations of either species. In effect, the SCP as it is currently operating is highly unlikely to be exerting any impact that is deleterious to the recovery of populations of listed threatened species.

The risk to water users of an alternative arrangement to the SCP’s current gear deployments is more difficult to evaluate. Lessons from Reunion Island, however, are that high and medium levels of overlap of tagged bull sharks and water users corresponded to areas historically involved in shark bites (Lemahieu et al., 2017). The SCP regions are focused on areas where there are concentrations of water users and it is clear from historical trends in total annual catches of all sharks and at least one of the potentially dangerous sharks, the bull shark, that the local abundances of those animals have been reduced through time (see **Section 3.1.1.2.4**). It is unclear to what extent the SCP contributed to that decline, but it is likely to have been a contributing factor. White shark numbers caught in the SCP have also declined, although this pattern is likely to have been due to factors other than an effect of the SCP. Notwithstanding this, the corollary is that if the catch and kill component of the SCP was to be replaced by an alternative non-lethal system it is possible that this would result in greater abundances of sharks generally at beaches within the SCP regions, including potentially dangerous sharks.

Further, given standard nets or drumlines are likely to have contributed to localised depletions of shark species responsible for unprovoked shark bite, they may have also affected abundances further afield than the beaches where the SCP gear is deployed and beyond the limits of the SCP regions generally. It is not possible, however, to estimate the overall area over which the effects of local depletion have occurred. In comparison, none of the alternatives considered in this report would provide a level of protection to areas outside where they would be deployed. For example, an effective barrier would only provide protection to water users within the area it confined. It would provide no additional protection outside that area.

While the risk of a shark bite is low in both relative and absolute terms, and will be likely to stay that way, there will remain heightened individual and community focus that is well over and above the quantified risk. This cannot be avoided and governments are likely to always take a certain level of responsibility for mitigating the risk of unprovoked shark bite.

In terms of overlap of water users and potentially dangerous sharks, the weighting of human or shark presence in the potential for a shark bite is unclear. Several authors have addressed the role of both variables in interactions, and the global increase of users in recreational areas has been proposed to rather be the driving force behind shark bite frequency (Schultz, 1967; Kock and Johnson, 2006). Notwithstanding this, there has been only one fatality and 27 unprovoked bites on an SCP protected beach since 1962. There were 19 fatalities and 36 bites in the whole of Queensland prior to 1962 (see **Sections 3.1.1** and **3.2.2**) and it is not unreasonable to conclude that local fish-downs have reduced the risk of shark bite to water users by reducing the potential for overlap between water users and potentially dangerous sharks. The choice of any non-lethal alternative system will need to consider closely how it monitors for, and potentially manages, a potential increase in the risk of shark bite were it to facilitate increases in abundances of potentially dangerous sharks at SCP beaches, noting that there are likely to also be increases in the amount of water users in the future in line with general increases in the population of people in coastal areas (see the Implementation Strategy, **Section 6.2**).

5.2 Alternative Beach-scale Systems for SCP Regions

The beach environments of the northern and southern groups of SCP regions are very different in terms of the key variables that govern the effective operating conditions of the various types of shark bite mitigation systems: ocean swell and water clarity. In terms of ocean swell, the south is exposed and the north has protection from the Great Barrier Reef. Based on the evaluation criteria, this results in clear differences in the suitability of alternative systems among the SCP regions.

Even with multi-spectral cameras, the prevailing poor water clarity for spotting for a significant proportion of the year in the north means visual observation systems would be ineffective for much of the time in the SCP regions of Cairns, Townsville, Mackay, Capricorn Coast and Tannum Sands. Further, although water clarity is not an issue for other commercially ready shark detection systems (i.e. Cleverbuoy™ and detection of tagged animals), these are among the least preferred ranked of the detection systems generally, meaning there are no suitable detection systems that could be relied upon for the entire year for the north.

The north, however, is suited to the barrier systems because of a general lack of ocean swell, although any barrier would need to be able to be removed prior to a cyclone to avoid it being seriously damaged by such extreme weather events. Notwithstanding this, given each barrier system unit can only cover a small area, most of the regions would require many units to provide equivalent coverage to the existing arrangements of drumlines and/or nets. Such barriers offer no flow-on protection to water users outside of them. Nonetheless they can provide a high level of peace-of-mind for bathers.

In contrast to the north, the prevailing good water clarity in the south of Queensland lends itself to trialling of highly ranked aerial detection systems. To maximise the chance of spotting sharks, a system would be best to include multispectral cameras, shark recognition software and real time transmittal of information to beach users either via lifeguards or Smart devices. Further, given the effectiveness (against potentially dangerous sharks) of an aerial detection system is directly related to the amount of time it is operating, sufficient temporal coverage necessitates that a system would need to include many flyovers of beaches within any given day. The high costs of such a system is potentially problematic were fixed wing or helicopter platforms to be used, however the lesser cost of drones may be acceptable, particularly if they were operated by lifeguards who are already working to protect water users at patrolled beaches within the SCP regions. Although it is unlikely that drones could be relied on as the only system of shark bite risk mitigation at beaches in the south because lifeguards would not practically be able to dedicate a large proportion of their daily duties to flying drones, they could provide a supplementary surveillance tool for the lifeguards. There needs to be an understanding developed with respect to the minimum amount of time that drones need to be flown at a given location and the location-based factors that positively or negatively influence detection rates.

The Shark Spotter Program is another detection system that may perform well in the south, but only in places where the topography was adequate and where the water users were close to the spotter's position. It would be limited to areas where there is elevated land close to the water users. The high labour costs of such a system and the effective range of the observer also requires consideration. There still remains uncertainty as to the proportion of sharks that are spotted by drones and would be spotted by a Shark Spotters Program. A challenge for using any visual detection method (with the exception of multi-spectral cameras) is that bull sharks often pose greater risk when water clarity is low (e.g. after rain) and hence when detection conditions are poor.

There are a few systems that are likely to perform well in all SCP regions. SMART drumlines and some of the electric or magnetic deterrents can function effectively in ocean swell and are not dependent on water clarity. Indeed, the Senate Committee review recommended that the NSW and Queensland Governments immediately replace lethal drumlines with SMART drumlines. On face value, although it appears that SMART drumlines could effectively replace standard drumlines with a non-lethal shark bite mitigation system, there are some potential issues that would need close consideration. For example, if SMART drumlines were to result in the translocation of potentially dangerous sharks to other areas, this could be perceived to impact water users outside of the SCP regions. Further, tidal variation at access points and travel times between access points and the locations of deployed gear may reduce the effectiveness of the gear's ability to reduce mortality to the more sensitive species caught. The costs of servicing a SMART drumline system are also very high given a contractor is required to be 'on-call' to unhook and translocate animals. Notwithstanding this, the operating procedure for SMART drumlines could potentially be modified so that less servicing was required and although this compromise would likely result in reduced survival of some of the catch, it would reduce costs. Consideration could also be given to retaining the ability to kill captured bull sharks as is done in Reunion Island. Overall, and despite the results of the Senate Committee review, we do not suggest that is feasible to replace all current drumlines with SMART drumlines. However, we do consider a trial of SMART drumlines as feasible. Such a trial may assist with addressing some of the practical challenges, but it may also further highlight the impracticality of the approach for the majority of SCP regions.

The highest ranked of the beach-scale deterrents was the magnetic/visual Sharksafe barrier and it is understood that the Beach Barrier SRC1000 and Beach01 electrical deterrents are also currently being tested. As per SMART drumlines, these systems are not affected by ocean swell or water clarity but have other potential issues, for example both systems require monitoring for breakage or power failure (electrical only) so that water users can be notified rapidly if the system were not operating.

Given the risks to the occurrence of shark bite identified in **Section 5.1** of partial or full replacement of currently deployed SCP catch and kill apparatus with non-lethal systems, it will be important to consider, for any of the above alternative systems, that adequate spatial and temporal coverage would be maintained. Any modification to the SCP would need to be supported by education and adequate stakeholder engagement and a monitoring process whereby the necessary information was collected that allowed the performance of key success criteria to be monitored (see **Section 6.2**).

5.3 Non-SCP Areas

In Reunion Island, emphasis has been placed on identifying priority areas for mitigating risk of shark bite by determining where there was high overlap between water users and sharks or where there was high occurrence of water users or sharks. Consistent with this, the SCP priority areas are based on high occurrence of water users on coastal beaches. However, some areas in Reunion Island where shark bite occurred were proven to correspond to areas of low overlap (Lemahieu et al. (2017), leading to the hypothesis that shark bites wouldn't always be correlated to the number of sharks or water users nor the time that sharks spent in a given area. The weighting of both human and shark presence variables is unclear. The recent incidents in Cid Harbour emphasize that there is a level of risk to water users in other areas outside of the SCP regions where there may be less overlap of water users and sharks than the more populated coastal beaches. Indeed, historical records of unprovoked shark bite since the inception of the SCP in 1962, indicate there has been double the incidence of bites in areas without SCP fishing apparatus compared to those with it in place, and most frequently on offshore islands and reefs of the Great Barrier Reef, including to spearfishers and snorkelers in addition to swimmers (see **Section 3.2.2**).

This report focused on reviewing alternative approaches that have potential to be trialled within the existing SCP areas and included deterrents, detection and barrier approaches that can be deployed to collectively enhance the level of protection afforded to water users. However, it is not feasible for the entire Queensland east coast as well as the numerous reefs and islands that are frequently used for various water-based activities to be afforded collective protection. There should be an onus on facilitating further protection in SCP areas as well as protection outside these areas. This can be through the provision of relevant educational material to allow for more informed choices by water users, or encouraging the uptake of suitable and effective devices as in done in Western Australia through a rebate scheme, that would facilitate greater use of personal deterrent devices and other methods (personal protective apparel). These approaches would also be consistent with recommendations by the Senate Committee (2017) with respect to personal deterrent devices. Rather than subsidies being available directly to individuals in the first instance, they could be made available to water-based tourist businesses for their clients.

While exceptions exist, the challenge with personal deterrent devices is that they are often marketed without the required independent assessment as to their efficacy overall, or their efficacy for certain shark species in certain circumstances. Thus consumers are often in a difficult circumstance when trying to choose a deterrent that works or is most applicable to their specific pattern of water use. This report includes a review of personal deterrent devices and proposes a way forward (see below and **Section 6.2**). As discussed in this report, there is substantial ongoing entrepreneurial activity associated with mitigating risk of unprovoked shark bite, particularly in the area of personal deterrent devices. Much of this activity does not initially occur in consultation with shark scientists or agencies with responsibilities for water user protection such as DAF. Given the potential for these devices to reduce risk to water users, the Queensland Shark Control Program Scientific Working Group should periodically keep up to date with new patents that are relevant. This is not onerous and both patent listings in Australia and the U.S. are relevant and easily sourced. This report has provided brief information on some current active patents. Patent activity in relation to mitigating unprovoked shark bite is likely to remain high due to the high-profile nature of the topic and the financial gain that could be obtained by widespread adoption of a new effective product.

A considerable number of personal deterrent devices and area-based deterrent or detection systems are marketed and promoted without independent testing of their efficacy. It should be clearly recognised that like seatbelts on a car or life jackets at sea, shark deterrents and detection approaches are for human safety and as such there is a need to meet a minimum standard of performance, and for a responsible and evidenced based approach to marketing them that includes appropriate caveats. The widespread use of a personal deterrent device that is ineffective may create a false sense of security and may see people putting themselves at additional risk (e.g. remaining in the ocean if a potentially dangerous shark is spotted) when leaving the water may be more prudent.

It is clearly not the role of DAF or the Queensland Shark Control Program Scientific Working Group to regulate shark deterrents or detectors to ensure that a minimum level of performance can be reached. However, when such approaches are viewed in the correct context of providing a commercial product for the purpose of enhancing human safety, the need for such regulation is justified. A long-term national approach to the issue of commercial deterrents and detection approaches, particularly personal deterrent devices, and their efficacy and marketing would be the development and implementation of an Australian Standard that products can be certified against. Such a standard would not stop innovation or ethically appropriate experimentation by entrepreneurs, but it would allow consumers to be able to make an informed choice as to what does constitute an independently verified mitigation approach that is effective. The large array of personal deterrent devices, all of which have manufacturer claims as to their effectiveness and reasons for effectiveness makes the choice for consumers difficult.

5.4 Approval Processes

In considering alternative systems, it is prudent to recognise that alternatives are likely to require environmental assessment and approval under relevant legislation. In Queensland this may include assessment, approval and permitting under the Commonwealth *Great Barrier Reef Marine Park Act 1975* and as an amendment to the current permit which allows existing SCP activities to operate within the marine park or a new permit. Such an assessment and approval process will need to consider specific relevant local issues, and issues specific to a particular deterrent or detection device proposed. Relevant approvals under state marine park legislation (*Marine Parks Act 2004)* will also need to be considered if planned alternatives for trialling are within state marine parks (e.g. Moreton Bay Marine Park and the Great Sandy Marine Park). Referral to the Commonwealth for consideration as a controlled action under the *Environment Protection and Biodiversity Conservation Ac 1999t* may also be required, again dependent on the exact alternative proposed for trialling and its locations. Any approaches involving manned or unmanned aircraft will potentially need assessment and approval by the Civil Aviation Safety Authority (CASA).

6 Implementation Strategy to Trial and Evaluate Alternatives

6.1 Components of Trials

In terms of implementing alternatives to current approaches used in the SCP, it needs to be recognised that physical conditions and patterns of water usage among the SCP regions are diverse. There is no single alternative to the current activities that can be deployed across all SCP regions. All alternatives have an additional cost for government associated with trialling their use. It is also recognised that many water users undertake activities outside the 86 beaches covered by the SCP including marine tourism focussed areas such as the Great Barrier Reef.

Implementation needs to be informed by consultation and engagement at the local level and alternatives need to be supported at the local level. An acceptable solution at one location may not be an acceptable solution at an adjacent location. That said, local support cannot supplant efficacy of an approach. Both Crossley et al. (2014) and Simmons and Mehmet (2018) identify that the public may have overly optimistic views of the efficacy of shark bite risk mitigation systems. We consider that engagement with local coastal councils is the priority. In Western Australia, engagement by the state government with local councils has led to the trialling of a range of mitigation approaches tailored to a region. Our consultations with NSW DPI staff for this project also emphasised the need for local engagement.

From the findings in this report we recommend the following be considered for trials:

Modify Existing SCP Fishing Gears and their Operation

There remains scope to continually improve the current SCP and procedures to further minimise the impacts of the activity on marine fauna. In particular, as the humpback whale population that utilises the east coast have increased, so has the interaction with SCP nets in the southern part of the state. All cetaceans are protected by state and federal legislation and such interactions are of community concern. Release of entangled whales requires investment of time to free them, and there are safety risks in doing so. DAF, in consultation with shark contractors should undertake an analysis of interactions and refer to the SCP Scientific Working Group for advice. The SCP Scientific Working Group should identify where humpback whale and SCP shark net operations pose a higher risk of entanglement of humpback whales and assess whether some nets could be replaced seasonally with drumlines. Drumlines could be trialled alongside nets for a season to ensure similar numbers, species and sizes of sharks are caught in both types of equipment. Bycatch reduction devices (e.g. pingers, LED lights etc.) used successfully for reducing interactions between protected species and commercial gillnet or line fisheries could also be considered

Physical Barrier

Provided there is local support for such a structure it is recommended that at least one (1) temporary or permanent shark barrier be trialled. The barriers would aim to protect bathers only. This report does not recommend one physical barrier type over another. Rather, it is recommended that the government offer a tender for provision of the service. If the structure is deployed within the Great Barrier Reef Marine Park, then assessment and approval by the Great Barrier Reef Marine Park Authority will be required. There is potential scope to spatially align a shark barrier with a stinger net. Physical barriers should not be considered in the Woongarra, Rainbow Beach, Gold Coast, Sunshine Coast or North Stradbroke SCP regions due to wave energy. Consultation with local councils and tourism operators should be undertaken to assist choosing an exact location within an SCP region.

Shark Spotters and Drones

The only SCP location where water clarity and suitable elevation occurs to make Shark Spotting activities similar to those employed at Cape Town feasible is Point Lookout at North Stradbroke Island. Point Lookout is used as a land-based location for monitoring the migration of humpback whales. Delivering the service could be potentially undertaken through the traditional owners who are experienced in service delivery. Consultation with the Quandamooka Yoolooburrabee Aboriginal Corporation to gauge their interest in undertaking a Shark Spotters Program and what it would entail could be undertaken.

While drones have some advantages over manned aerial flights to monitor sharks at a locality, unless multi-spectral cameras are used, they still suffer from limitations due to water clarity and glare. Given the water clarity, the use of drones for spotting sharks is not recommended at SCP locations north of Rainbow Beach as an alternative shark bite mitigation system to current systems. Given many surfers prefer to surf early in the morning or late in the afternoon, it should be recognised that this is a challenging time for reliably spotting sharks using drones, even if staff or volunteers are present to fly the drones at those hours. It is recommended that drones are only trialled in terms of gauging their potential to augment existing surf living saving activities at SCP locations. However, there is a need to test the ability of drones to spot sharks under various conditions and the efficacy at which they perform. Any Civil Aviation Safety Authority requirements for flying drones will need to be complied with, as well as any environmental requirements such as they need to avoid key bird nesting areas. It is understood that many SLSQ patrolled beaches are moving to the use of drones and this could provide a practical opportunity to also incorporate shark spotting capabilities alongside other uses of the drones (e.g. dropping flotation devices). Trials have been undertaken with Surf Life Saving NSW for shark monitoring and with SLSQ in north Queensland for crocodile spotting and could potentially be built upon in Queensland for shark monitoring at patrolled areas.

Education and Personal Choice

The Department should continue and expand where necessary educational material regarding sharks and personal protection with a clear onus on emphasising personal responsibility. For members of the public undertaking a leisure activity of their choosing, a clear emphasis on personal responsibility is justified. Education material should be tailored to the general public as well as to tourism operators and/or tourism groups. Education material can potentially extend to providing guidance to individuals or businesses about personal deterrents or other approaches that are commercially available and that have been independently scientifically tested with a demonstrated acceptable level of efficacy. In doing so, this would be advisory only rather than an endorsement of specific products with appropriate disclaimers required.

While the *Fisheries Act 1994* provides the legislative carriage for protecting bathers from sharks, other sectors of the state government (e.g. Department of Innovation and Tourism Industry Development) and local government are important stakeholders. Where relevant, these government entities could contribute financially and/or in-kind to relevant initiatives that they support and they should be involved in local consultation and engagement processes. Local councils in Western Australia are active in supporting locally relevant approaches to unprovoked shark bite.

Rebates for personal deterrents, or other ways of encouraging the uptake of suitable devices, could be considered by the government, similar to the subsidy provided in WA. This would particularly assist with surfers operating outside patrolled areas or times.

SMART Drumlines

A very limited trial of SMART drumlines could be considered in Queensland, however there are significant issues in Queensland compared to other areas where trials have been undertaken. Overall, the authors of this report are of the view that SMART drumlines are not a practical solution throughout the state.

In recommending a trial of SMART drumlines it is acknowledged that this potentially represents substantial cost to government. Currently the cost of an individual SMART drumline is approximately ($3,500). Based on this cost, the capital cost of replacing all standard drumlines currently in use with SMART drumlines is $1,340,500. However, there will be substantial additional operational costs for contractors that would need to be covered by the government. In Western Australia, the contractor was paid $6,000 per day to service SMART drumlines across approximately 11 km of coastline. The costs of tags for tagging captured and released sharks, were it also done, would be additional to the cost of the SMART drumline and is estimated at approximately $400 per tag. Animal ethics issues associated with having appropriately qualified staff to apply acoustic tags to sharks will need to be considered and costs are likely to be prohibitive.

It is also recognised that the circumstances in Queensland pose significant practical challenges relative to other locations where they have been trialled (Western Australia, northern NSW and Reunion). These challenges include the very large geographic coverage of the SCP, the difficulty of predictable all-tide and all-weather access in some locations, and in some instances the difficulty of identifying locations that captured sharks can be subsequently relocated too. This is because of the large number of offshore islands and reefs that are also utilised by water users and make it untenable to relocate captured sharks closer to such areas. There are also uncertainties regarding the proportion of “false alarms” which may result due to the shallow nature of a number of SCP beaches and the short wave action (chop) at them. If the baited hook of the SMART drumline is bouncing up and down vigorously, including bouncing up and down on the seabed, this may constantly result in false alarms rendering the apparatus impractical. This report was not able to identify the likelihood of this occurring or the individual SCP beaches where it would be a problem. However, it is potentially an important practical challenge that needs consideration in any trials undertaken.

SMART drumlines could be trialled if there is local support to do so and provided a location for relocating tagged sharks does not pose a real or perceived risk to any water users elsewhere. The trialling of SMART drumlines in NSW resulted in a significant proportion of sharks not returning to the beach they were captured at for a relevant period of time (e.g. months). It cannot be ruled out though that the sharks captured on the SMART drumlines never return to the beach where they were captured.

Unlike in northern NSW, a number of locations offshore of SCP locations have islands or reefs that are utilised by water users and support important tourist operations. In considering the locations for trials of SMART drumlines, the Mackay, Townsville, Capricorn Coast and Cairns region are problematic in terms of finding acceptable locations to relocate captured sharks to. In Mackay it would mean relocating sharks closer to the Whitsunday Islands and in the Capricorn Coast closer to the Keppel Islands which will not garner local support – particularly from tourism operators reliant on those areas. In Townsville and Cairns, it would also mean potentially locating sharks closer to islands and reefs that are utilised by water users such as divers, snorkelers or spearfishers and may pose a risk. Although with local input, it may be potentially feasible to identify acceptable locations, however these were not able to be identified in this report. Within the Great Barrier Reef Marine Park, consultation and engagement with tourism operators in the placement of SMART drumlines and the subsequent relocating of captured sharks would be critical.

In terms of SCP regions that have scope to relocate sharks captured by SMART drumlines offshore, they include the Gold Coast, North Stradbroke Island, Sunshine Coast, Rainbow Beach, Woongarra and Tannum Sands. A limitation of timely attendance to a SMART drumline being triggered is the distance from the launch location to the apparatus including the time taken to move between apparatus. In Western Australia it is clearly recognised that a limitation to timely servicing is when two alarms go off in a very short space of time. In most (if not all) instances it is unlikely that shark contractors can remain on land when SMART drumlines are baited and operational and instead may need to remain at sea in their general vicinity. This would represent a substantial change to SCP operations with an additional financial cost to the Department.

Both the Rainbow Beach and Tannum Sands SCP regions consist of 12 drumlines at a single beach. Based on this alone, they represent a good opportunity to conduct a relevant cost-effective trial at an appropriate scale. However, based on current servicing arrangements where the Rainbow Beach SCP is serviced from further south on the Sunshine Coast the ability to appropriately service SMART drumlines appears limited. Similarly, the Tannum Sands drumlines are serviced by contractors based at Yeppoon. The practicality of being able to service SMART drumlines in general across the SCP regions is a critical limitation, and one that is substantially more difficult in Queensland than at the other trialled locations (e.g. Western Australia, NSW and Robina) due to the much larger spatial scale of operations in Queensland SCP activities. New contract arrangements between contractors and the government would be required, and work health safety (WHS) issues addressed appropriately if SMART drumlines are to be trialled.

If trialling SMART drumlines, a number of traditional drumlines should remain in place while others are replaced with SMART drumlines. The exact numbers will depend on the specific location. This would allow assessment of the relative fishing power of SMART drumlines compared to standard drumlines which would inform how many SMART drumlines are required to deliver the same actual amount of fishing effort in an SCP region. The more efficient at catching sharks, the less SMART drumlines that will be needed should the trials proceed to ongoing implementation. Any trials would provide information on the number of triggers per hour that is need to determine service requirements.

If captured sharks on SMART drumlines are tagged with radio tags, then the position of listening stations to detect sharks should be optimised so that the direction of movement of sharks released can be identified. Trials may or may not include tagging animals at the same time. Tagging provides additional information on the movement of sharks but does not necessarily reduce the risk, which is primarily achieved by moving sharks further offshore.

Specific operational guidelines for the use of SMART drumlines should be developed and incorporated into the SCP activities if a trial proceeds. Existing guidelines were developed by NSW DPI for their SMART drumline trials and these have relevance for Queensland. These guidelines highlight procedures for potentially addressing (WHS) issues. The existing operational guidelines can be amended to adapt a SMART drumline to the practical challenges of operating in Queensland. Amendments may include leaving the drumlines in place but unbaited overnight and adapting response time targets so that they are realistically achievable.

Further Innovation

Although a number of approaches show significant promise they require further development, including independent testing under Queensland conditions. Access to an appropriately targeted Innovation Challenge may assist in the further development of approaches that have clear promise. Approaches that have not reached the proof of concept stage or where there are *a priori* doubts about their efficacy should not be invested in by government at this time. Rather, only those approaches that have demonstrated potential to be adapted to Queensland environments and water users should be pursued through independent testing against specific performance criteria. There are three areas where targeted innovation funding could deliver effective results:

- The further development, assessment and tailoring of protective apparel (e.g. wetsuits) that is optimised for use by Queensland water users;
- The development of area-based deterrents or detection systems that are specifically tailored and independently tested in relevant Queensland environments; and
- Assessing the efficiency and effectiveness of drones for spotting sharks under Queensland conditions and developing innovative new technologies like image recognition, multi-spectral cameras.

6.2 Evaluating the Performance of Trials

A means of evaluating the success or failure of trialling alternative strategies or systems will be important to determining which alternative strategies or systems could potentially be incorporated into the SCP in the longer term. The government has indicated that until an effective alternative is found, the Government will continue to support the SCP with its combination of shark nets and drumlines at 86 of Queensland's popular swimming beaches.

The key performance indicator would be measurement of the effectiveness against potentially dangerous sharks but other secondary indicators measuring other aspects of performance would assist with determining whether alternative approaches had met ‘success criteria’.

Reducing the risk of shark bite is the aim of any shark bite mitigation program and therefore the incidence of unprovoked shark bite should be measured. In this report we considered using the number of unprovoked shark bites as a key indicator, however, given that the incidence of shark bite is so low, particularly at SCP locations, it is unlikely to present results that can be analysed with any statistical certainty even over a period of several years. Any shark bite at a trial location, however, should trigger an immediate review of the trial.

Indicators measuring other aspects of performance could include:

Abundance of Potentially Dangerous Sharks

One potential risk of trialling non-lethal alternatives in the SCP is that the abundances of sharks generally, and of potentially dangerous sharks, may increase at local scales, thereby increasing the potential for interactions between water users and potentially dangerous sharks (**Section 5.1**). This information could be obtained in the proposed trial of SMART drumlines above (see **Section 6.1**) through analysis of catch rates but would be less readily obtained from trials of other alternative strategies or systems. The indicators may need to include a range of sources of information, including the frequency of reporting of interactions or sightings of sharks in SCP areas as recorded by lifeguards.

Durability of Equipment

Despite the review having considered the practicalities of alternative systems in relation to the operating conditions of Queensland environments, the durability of some systems may still need to be verified, particularly in relation to the potential for large tidal amplitudes or biofouling to alter effectiveness, or cause breaches or loss of power (where relevant) (e.g. heavily fouled floats or other parts of barriers may cause them to sink).

Detection Coverage (Time)

Some detection methods (e.g. drones) can only detect sharks when they are deployed at a given location. A key indicator is the amount of time a device is actively deployed so that it can detect a shark. A minimum amount of flight time per SCP region or SCP beach represents an appropriate indicator and will require deployment times to be logged and verified. The number of sharks detected over different periods of time could be compared and also compared with the number of sharks caught in traditional SCP gear.

Harm to Marine Fauna

The only alternative system with any potential to harm marine fauna would be SMART drumlines and under the prescribed operating procedure, the potential for harm to captured fauna is minimal and could be potentially addressed with continual improvement. Notwithstanding this, given customised operational guidelines for the use of SMART drumlines are proposed in order to meet the practical challenges of operating in Queensland (see **Section 6.1**), there could be potential for some captured species to be harmed if time until release is longer than the prescribed operating procedure. This information could be obtained in the proposed trial of SMART drumlines above. The key indicator for SMART drumlines is the time from the triggering of the device to when a contractor can arrive to remove the animal from the apparatus. There should be a review trigger if a certain number of non-target species are killed.

Effectiveness of Education Strategies

Education strategies are proposed that would promote shark safe behaviours, include the need for personal responsibility and may recommend users give consideration to the use of personal deterrent devices in particular situations (see **Section 6.1**). The success of education could be measured through community sentiment surveys and user behaviour surveys that determined for example, whether there was an increasing trend for bathers to swim in protected areas and/or in the uptake of personal deterrent devices.

7 References

Acuña-Marrero, D., de la Cruz-Modino, R., Smith, A. N., Salinas-de-León, P., Pawley, M. D., & Anderson, M. J. (2018). Understanding human attitudes towards sharks to promote sustainable coexistence. Marine Policy, 91, 122-128.

Amin, R., Ritter, E. and Kennedy, P. (2012). A geospatial analysis of shark attack rates for the east coast of Florida: 1994-2009. Marine and Freshwater Behaviour and Physiology. 45(3): 185-198.

Anon. Report of the Shark Menace Advisory Committee on suggested methods of protecting bathers from shark attack. Legislative Assembly, New South Wales. Government Printer, Sydney, 1935. 49pp.

Baldridge, H.D. Jr. (1990). Shark repellent: Not yet, maybe never. Military Medicine. 155: 358-361.

Bombieri, G., Nanni, V., Delgado, M. D. M., Fedriani, J. M., López-Bao, J. V., Pedrini, P., & Penteriani, V. (2018). Content analysis of media reports on predator attacks on humans: toward an understanding of human risk perception and predator acceptance. BioScience, 68(8), 577-584.

Bonfil, R., Mèyer, M., Scholl, M.C., Johnson, R., O'Brien, S., Oosthuizen, H., … Paterson, M. (2005). Transoceanic migration, spatial dynamics and population linkages of white sharks. Science. 2005 310, 100-103.

Bradford, R.W., Bruce, B.D., McAuley, R.B., and Robinson, G. (2011). An evaluation of passive acoustic monitoring using satellite communication technology for near real-time detection of tagged animals in a marine setting. The Open Fish Science Journal. 4, 10-20.

Broad, A., Knott, N., Turon, X. and Davis, A.R. (2010). Effects of a shark repulsion device on rocky reef fishes: no shocking outcomes. Marine Ecology Progress Series 408: 295-298.

Cardno (2015). Shark Deterrents and Detectors: Review of Bather Protection Technologies. Report prepared for NSW Dept. Primary Industries, 49 pp.

Carter, N. H., Shrestha, B. K., Karki, J. B., Pradhan, N. M. B., & Liu, J. (2012). Coexistence between wildlife and humans at fine spatial scales. Proceedings of the National Academy of Sciences, 109(38), 15360-15365.

Chapman, B.K. & McPhee. D.P. (2016). Global shark attack hotspots: Identifying the underlying factors behind increased unprovoked shark bite incidence. Ocean and Coastal Management 133, 72-84.

Chapuis, L., Collin, S. P., Yopak, K. E., McCauley, R. D., Kempster, R. M., Ryan, L. A., ... & Hart, N. S. (2019). The effect of underwater sounds on shark behaviour. Scientific Reports, 9(1), 6924.

Chirayath, V. & Earle, S.A. (2016). Drones that see through the waves – preliminary results from airborne fluid lensing for centimetre-scale aquatic conservation. Aquatic Conservation: Marine and Freshwater Ecosystems, 26 (Suppl. 2), 237-250.

Cliff, G., Anderson-Reade, M.D., Aitken, A.P., Charter, G.E., & Peddemors, V.M. (2007). Aerial census of whale sharks (Rhincodon typus) on the northern KwaZulu-Natal coast, South Africa. Fisheries Research, 84, 41-46.

Cliff, G. and Dudley, S.F.J. (2011). Reducing the environmental impact of shark-control programs: A case study from KWaZulu-Natal, South Africa. Marine and Freshwater Research 62: 700-709.

Colefax, A.P., Butcher, P.A. & Kelaher, B.P. (2017). The potential for unmanned aerial vehicles (UAVs) to conduct marine fauna surveys in place of manned aircraft. ICES Journal of Marine Science, doi:10.1093/icesjms/fsx100.

Collin, S.P. (2010). Electroreception in Vertebrates and Invertebrates. In: Breed, M.D. and Moore, J. (eds) Encyclopaedia of Animal Behaviour Volume 1, pp 611-620 Oxford Academic Press.

Crossley, R., Collins, C. M., Sutton, S. G., & Huveneers, C. (2014). Public perception and understanding of shark attack mitigation measures in Australia. Human dimensions of wildlife, 19(2), 154-165.

Curtis T.H., Bruce B.D., Cliff G., Dudley S.F.J., Klimley A.P., Kock A.A., Lea R.N., Lowe C.G., McCosker .E., Skomal G.B., Werryand J.M., West, J.G. (2012). Recommendations for governmental organizations responding to incidents of white shark attacks on humans. In M. L. Domeier (Ed.), Global perspectives on the biology and life history of the great white shark, Boca Raton, FL: CRC Press, pp. 477-510.

Dalton, S., Peddemors, V. and Green, M. (2017) Shark Meshing (Bather Protection) Program 2016-17 Annual Performance Report. NSW Department of Primary Industries.

Davison, A. & Kock, A. (2014). Fish Hoek Bay Exclusion Net Report. (http://sharkspotters.org.za/wp-content/uploads/2016/10/FINAL-Exclusion-net-report-24-06-14.pdf).

Department of Agriculture and Fisheries (DAF) (2019). Queensland Shark Control Program - Research Strategy, 7 pp. https://publications.qld.gov.au/dataset/queensland-shark-control-program-scientific-working-group-terms-of-reference/resource/3b1aacab-69aa-4569-a40e-fcaf3ef722c9.

Department of the Premier and Cabinet (2016) (WA). https://www.dpc.wa.gov.au/Publications/Documents/WA%20Gov%20SHMS_Updated180716_on%20website.pdf

Dicken, M.L. & Booth, A.J. (2013). Surveys of white sharks (Carcharodon carcharias) off bathing beaches in Algoa Bay, South Africa. Marine and Freshwater Research, 64, 530-539.

Dudley, S.F.J. (1997). A comparison of the shark control programs of New South Wales and Queensland (Australia) and KwaZulu-Natal (South Africa). Ocean and Coastal Management 34: 1-27.

Dudley, S. F., & Simpfendorfer, C. A. (2006). Population status of 14 shark species caught in the protective gillnets off KwaZulu–Natal beaches, South Africa, 1978–2003. Marine and Freshwater Research, 57(2), 225-240.

Dunlop, S. W., Mann, B. Q., & Van der Elst, R. P. (2013). A review of the Oceanographic Research Institute's Cooperative Fish Tagging Project: 27 years down the line. African Journal of Marine Science, 35(2), 209-221.Erbe, C., & McPherson, C. (2012). Acoustic characterisation of bycatch mitigation pingers on shark control nets in Queensland, Australia. Endangered Species Research, 19(2), 109-121.

Egeberg, C. A., Kempster, R. M., Hart, N. S., Ryan, L., Chapuis, L., Kerr, C. C., ... & Collin, S. P. (2019). Not all electric shark deterrents are made equal: Effects of a commercial electric anklet deterrent on white shark behaviour. PLoS one, 14(3), e0212851.

Engelbrecht, T., Kock, A., Waries, S., & O'Riain, M. J. (2017). Shark spotters: successfully reducing spatial overlap between white sharks (Carcharodon carcharias) and recreational water users in False Bay, South Africa. PloS one, 12(9), e0185335.

Engelbrecht, T., Kock, A., & O'Riain, M. J. (2019). Running scared: when predators become prey. Ecosphere 10(1): e02531. 10.1002/ecs2.2531

Erbe, C., & McPherson, C. (2012). Acoustic characterisation of bycatch mitigation pingers on shark control nets in Queensland, Australia. Endangered Species Research, 19(2), 109-121.

Frank, B. (2016). Human–wildlife conflicts and the need to include tolerance and coexistence: An introductory comment. Society & Natural Resources, 29(6), 738-743.

Gibbs, L. and Warren, A. (2015). Transforming shark hazard policy: Learning lessons from ocean-users and shark encounter in Western Australia. Marine Policy 58: 116-124.

Gilbert, P.W. (1968). The shark: Barbarian and benefactor. Bioscience, 18 (10), 946-950.

Government of Western Australia 2019). https://www.sharksmart.com.au/strategy/state-government/

Gray, G.M.E. & Gray, C.A. (2017). Beach-user attitudes to shark bite mitigation strategies on coastal beaches. Human Dimensions of Wildlife, 22(3), 282-290.

Gribble, N.A., McPherson, G. and Lane, B. (1998). Effect of the Queensland Shark Control Program on non-target species: Whale, dugong, turtle and dolphin: A review. Marine and Freshwater Research 49: 646-651.

Guyomard, D., Perry, C., Tournoux, P. U., Cliff, G., Peddemors, V., & Jaquemet, S. (2019). An innovative fishing gear to enhance the release of non-target species in coastal shark-control programs: The SMART (shark management alert in real-time) drumline. Fisheries Research, 216, 6-17.

Hammerschlag, N., Gallagher, A.J., & Lazarre, D.M. (2011). A review of shark satellite tagging studies. Journal of Experimental Marine Biology and Ecology, 398 (1-2), 1-8.

Hart, N.S. and Collin, S.P. (2015). Shark senses and shark repellents. Integrative Zoology 10: 38-64.

Hazin F.H.V., Afonso A.S. (2014). A green strategy for shark attack mitigation off Recife, Brazil. Animal Conservation, 17(4), pp. 287-296.

Hodgson, A., Kelly, N., & Peel, D. (2013). Unmanned aerial vehicles (UAVs) for surveying marine fauna: a dugong case study. PLoS One, 8 pp. e79556.

Holland, K.N., Wetherbee, B.M., Lowe, C.G., & Meyer, C.G. (1999). Movements of tiger sharks (Galeocerdo cuvier) in coastal Hawaiian waters. Marine Biology 134, 665-673.

Hueter R.E., Mann D.A., Maruska K.P., Sisneros J.A. & Demski, L.S. (2004). Sensory Biology of Elasmobranches. CRC Press, London.

Huveneers C, Rogers PJ, Semmens J, Beckmann C, Kock AA, et al. (2012). Effects of the Shark ShieldTM electric deterrent on the behaviour of white sharks (*Carcharodon carcharias*). Final Report to SafeWork South Australia. SARDI Publication No. F2012/000123–1. SARDI Research Report Series No. 632. Adelaide: SARDI - Aquatic Sciences.

Huveneers, C., Rogers, P., Semmens, J.M., Beckmann, C., Kock, A.A., Page, B. and Goldsworthy, S.D. (2013). Effects of an electric field on white sharks: In situ testing of an electric deterrent. PLoS One, 8(5) pp. e62730.

Huveneers, C.; Simpfendorfer, C.A.; Kim, S.; Semmens, J.M.; Hobday, A.J.; Pederson, H.; Stieglitz, T. … Harcourt, R.G. (2016). The influence of environmental parameters on the performance and detection range of acoustic receivers. Methods in Ecology and Evolution, doi:10.1111/2041-210X.12520.

Huveneers, C., Whitmarsh, S., Thiele, M., Meyer, L., Fox, A., & Bradshaw, C. J. (2018). Effectiveness of five personal shark-bite deterrents for surfers. PeerJ, 6, e5554.

Jewell, O.J.D., Gleiss, A.C., Jorgensen, S.J., Andrzejaczek, S., Moxley, J.H., Beatty, S.J., Wikelski, M., Block, B.A. & Chapple, T.K. (2019) Cryptic habitat use of white sharks in kelp forest revealed by animal-borne video. Biology Letters, 15(4)

Jorgenen, S.J., Anderson, S., Ferretti, F., Tietz, J.R., Chapple, T., Kanive, P., Bradley, R.W., Moxley, J.H. & Block, B.A. (2019). Killer whales redistribute white shark foraging pressure on seals. Scientific Reports, 9: 6153

Kajiura, S. & Tellman, S.L. (2016). Quantification of massive seasonal aggregations of blacktip sharks (Carcharhinus limbatus) in southeast Florida. PloS one, 8 (5) pp. e0150911.

Kelaher, B. P., Colefax, A. P., Tagliafico, A., Bishop, M. J., Giles, A., & Butcher, P. A. (2019). Assessing variation in assemblages of large marine fauna off ocean beaches using drones. Marine and Freshwater Research.

Kempster, R. M., Egeberg, C. A., Hart, N. S., Ryan, L., Chapuis, L., Kerr, C. C., ... & Meeuwig, J. J. (2016). How close is too close? The effect of a non-lethal electric shark deterrent on white shark behaviour. PLoS One, 11(7), e0157717.

Kiszka, J.J., Mourier, J., Gastrich, K., & Heithaus, M.R. (2016). Using unmanned aerial vehicles (UAVs) to investigate shark and ray densities in a shallow coral lagoon. Marine Ecology Progress Series, 560, 237-242.

Kock A., Johnson R. (2006). White shark abundance: not a causative factor in numbers of shark bite incidents. Finding a balance: White shark conservation and recreational safety in the inshore waters of Cape Town, South Africa, pp. 1-19.

Kock, A. A., Photopoulou, T., Durbach, I., Mauff, K., Meÿer, M., Kotze, D., ... & O'Riain, M. J. (2018). Summer at the beach: spatio-temporal patterns of white shark occurrence along the inshore areas of False Bay, South Africa. Movement Ecology, 6(1), 7

Koski, W. R.; Allen, T.; Ireland, D.; Buck, G.; Smith, P. R.; Macrander, A. M.; Halick, M. A.; Rushing, C.; Sliwa, D.J.; McDonald, T.L. Evaluation of an unmanned airborne system for monitoring marine mammals. Aquatic Mammals, 2009 35, 347–357

KwaZulu-Natal Sharks Board (2019). https://www.shark.co.za/Pages/ProtectionSharks-History

Lagabrielle, E., Allibert, A., Kiszka, J. J., Loiseau, N., Kilfoil, J. P. & Lemahieu, A. (2018). Environmental and anthropogenic factors affecting the increasing occurrence of shark-human interactions around a fast-developing Indian Ocean island. Scientific Reports, 8(1), 3676-3688.

Lee, K. A., Roughan, M., Harcourt, R. G., & Peddemors, V. M. (2018). Environmental correlates of relative abundance of potentially dangerous sharks in nearshore areas, southeastern Australia. Marine Ecology Progress Series, 599, 157-179.

Lemahieu, A., Blaison, A., Crochelet, E., Bertrand, G., Pennober, G., & Soria, M. (2017). Human-shark interactions: the case study of Reunion Island in the south-west Indian Ocean. Ocean & coastal management, 136, 73-82.

Liu J., Linderman M., Ouyang Z., An L., Yang J., Zhang H. (2001). Ecological degradation in protected areas: the case of Wolong Nature Reserve for giant pandas. Science, 292(5514), pp. 98-101.

McAuley, R., Bruce, B., Keay, I., Mountford, S, & Pinnell, T. (2016). Evaluation of Passive Acoustic Telemetry for Monitoring and Mitigating Shark Hazards off the Coast of Western Australia. Western Australia Department of Fisheries Report No. 273, 2016. http://www.fish.wa.gov.au/Documents/research_reports/frr273.pdf

McPhee, D.P. (2014). Unprovoked shark bites: Are they becoming more prevalent? Coastal Management 42(5): 478-492.

Meeuwig, J.J. and Ferreira, L.C. (2014). Moving beyond lethal programs for shark hazard mitigation. Animal Conservation 17(4): 297-298.

Mineka, S., & Öhman, A. (2002). Phobias and preparedness: The selective, automatic, and encapsulated nature of fear. Biological Psychiatry, 52(10), 927-937.

Motta, P.J., Malanka, M., Hueter, R.E., Davis, R.L., de la Parra, R., Mulvaney, S.L. ... Zeigler, L.D. (2010). Feeding anatomy, filter-feeding, and diet of whale sharks Rhincodon typus during surface ram filter feeding off Yucatan Peninsula, Mexico. Zoology 113, 199-212

Nature (2015). South African scientists trial humane shark deterrents: Orca-patterned wetsuits and shark-friendly nets among proliferation of research trials. doi:10.1038/nature.2015.18346

Neff, C. (2012). Australian beach safety and the politics of shark attacks. Coastal Management, 40(1), 88-106.

NSW Department of Primary Industries (DPI). 2019. https://www.sharksmart.nsw.gov.au/technology-trials-and-research/smart-drumlines

O'Connell, C.P. and de Jonge, V.N. (2014). Integrating the findings from this special issue and suggestions for future conservation efforts – A brief synopsis. Ocean and Coastal Management 97: 58-60.

O'Connell, C.P., Hyun, S., Gruber, S.H., O'Connell, T.J., Johnson, G., Grudecki, K. and He, P. (2014a). The use of permanent magnets to reduce elasmobranch encounter with a simulated beach net. 1. The bull shark (Carcharhinus leucas). Ocean and Coastal Management 97: 12-19.

O'Connell, C.P., Andreotti, S., Rutzen, M., Meÿer, M., Matthee, C.A. and He, P. (2014b). Effects of the Sharksafe barrier on white shark (Carcharodon carcharias). Journal of Experimental Marine Biology and Ecology. 460: 37-46.

O'Connell, C. P., Andreotti, S., Rutzen, M., Meÿer, M., & Matthee, C. A. (2018). Testing the exclusion capabilities and durability of the Sharksafe Barrier to determine its viability as an eco-friendly alternative to current shark culling methodologies. Aquatic Conservation: Marine and Freshwater Ecosystems, 28(1), 252-258.

O'Connell, C. P., Andreotti, S., Rutzen, M., Meÿer, M., & Matthee, C. A. (2019). The influence of kelp density on white shark presence within the Dyer Island nature reserve, South Africa. Ocean & Coastal Management, 179, 104819.

Oelofse, G., and Kamp, Y. (2006). Shark spotting as a water safety program in Cape Town. In: Finding a Balance: White Shark Conservation and Recreational Safety in the Inshore Waters of Cape Town, South Africa, ed.. D.C. Nel and T.P. Peschak, 121-129.

Pepin-Neff, C.L. & Wynter, T. (2018). Reducing fear to influence policy preferences: An experiment with sharks and beach safety policy options. Marine Policy, 88, 222-229.

Pepperell, J. G. (1992). Trends in the distribution, species composition and size of sharks caught by gamefish anglers off south-eastern Australia, 1961-90. Marine and Freshwater Research, 43(1), 213-225.

Parsons, M.J.G., Parnum, I.M., Allen, K., McCauley, R. and Erbe, C. (2014). Detection of sharks with the Gemini imaging sonar. Acoustics Australia 42(3): 185-189.

Pyle, P., Schramm, M.J., Keiper, C., & Anderson S.D. (1999). Predation on a white shark (Carcharodon carcharias) by a killer whale (Orcinus orca) and a possible case of competitive displacement. Marine Mammal Science, 15(2): 563-568

Reyes, L.M. & García-Borboroglu, P. (2004). Killer whale (Orcinus orca) predation on sharks in Patagonia, Argentina: A first report. Aquatic Mammals, 30(3): 376-379.

Robbins, W.D., Peddemors, V.M., Kennelly, S.J. & Ives, M.C. (2014). Experimental evaluation of shark detection rates by aerial observers. PLoS one., 9 (2) pp. e83456.

Rowat, D., Gore, M., Meekan, M.G., Lawler, I.R. & Bradshaw, C.J.A. (2009). Aerial survey as a tool to estimate whale shark abundance trends. Journal of Experimental Marine Biology and Ecology, 368 (1): 1-8.

Ryan, L. A., Chapuis, L., Hemmi, J. M., Collin, S. P., McCauley, R. D., Yopak, K. E., ... & Schmidt, C. (2018). Effects of auditory and visual stimuli on shark feeding behaviour: the disco effect. Marine biology, 165(1), 11.

Schultz L.P. (1967). Predation of sharks on man. Chesapeake Science, 8(1), pp. 52-62.

Senate Committee (2017). Shark mitigation and deterrent measures. Report prepared by the Environment and Communications References Committee, Senate Printing Unit, Parliament House, Canberra. 224 pp.

Simmons, P., & Mehmet, M. I. (2018). Shark management strategy policy considerations: Community preferences, reasoning and speculations. Marine Policy, 96, 111-119.

Simpfendorfer, C.A.; Heupel, M.R.; White, W.T.; Dulvy, N.K. (2011). The importance of research and public opinion to conservation management of sharks and rays: a synthesis. Marine and Freshwater Research, 62 (6), 518-527.

Sisneros, J.A. & Nelson, D.R. (2011). Surfactants as chemical shark repellents: Past, present, and future. Environmental Biology and Fishes, 60, 117-130.

Smit, C.F. and Peddemors, V. (2003). Estimating the probability of a shark attack when using an electric repellent. *South African Statistical Journal.* 37: 59-78.

Smith, L.J. Jr. (1991). The effectiveness of sodium lauryl sulphate as a shark repellent in a laboratory test situation. *Journal of Fish Biology* 38(1): 105-113.

Stroud, E.M., O'Connell, C.P., Rice, P.H., Snow, N.H., Barnes, B.B., Elshaer, M.R. and Hanson, J.E. (2014) Chemical shark repellent: Myth or fact? The effect of a shark necromone on shark feeding behaviour. *Ocean and Coastal Management* 97: 50-57.

Sumpton, W., Lane, B., & Ham, A. (2010). Gear modifications and alternative baits that reduce bait scavenging and minimize by-catch on baited drum-lines used in the Queensland Shark Control Program. Proceedings of the Royal Society of Queensland, 116, 23.

Sumpton, W. D., Taylor, S. M., Gribble, N. A., McPherson, G., & Ham, T. (2011). Gear selectivity of large-mesh nets and drumlines used to catch sharks in the Queensland Shark Control Program. African Journal of Marine Science, 33(1), 37-43.

SurfSimply (2015). https://surfsimply.com/interviews/a-reunion-of-sharks/

Tooby, J., & Cosmides, L. (1990). The past explains the present: Emotional adaptations and the structure of ancestral environments. Ethology and sociobiology, 11(4-5), 375-424.

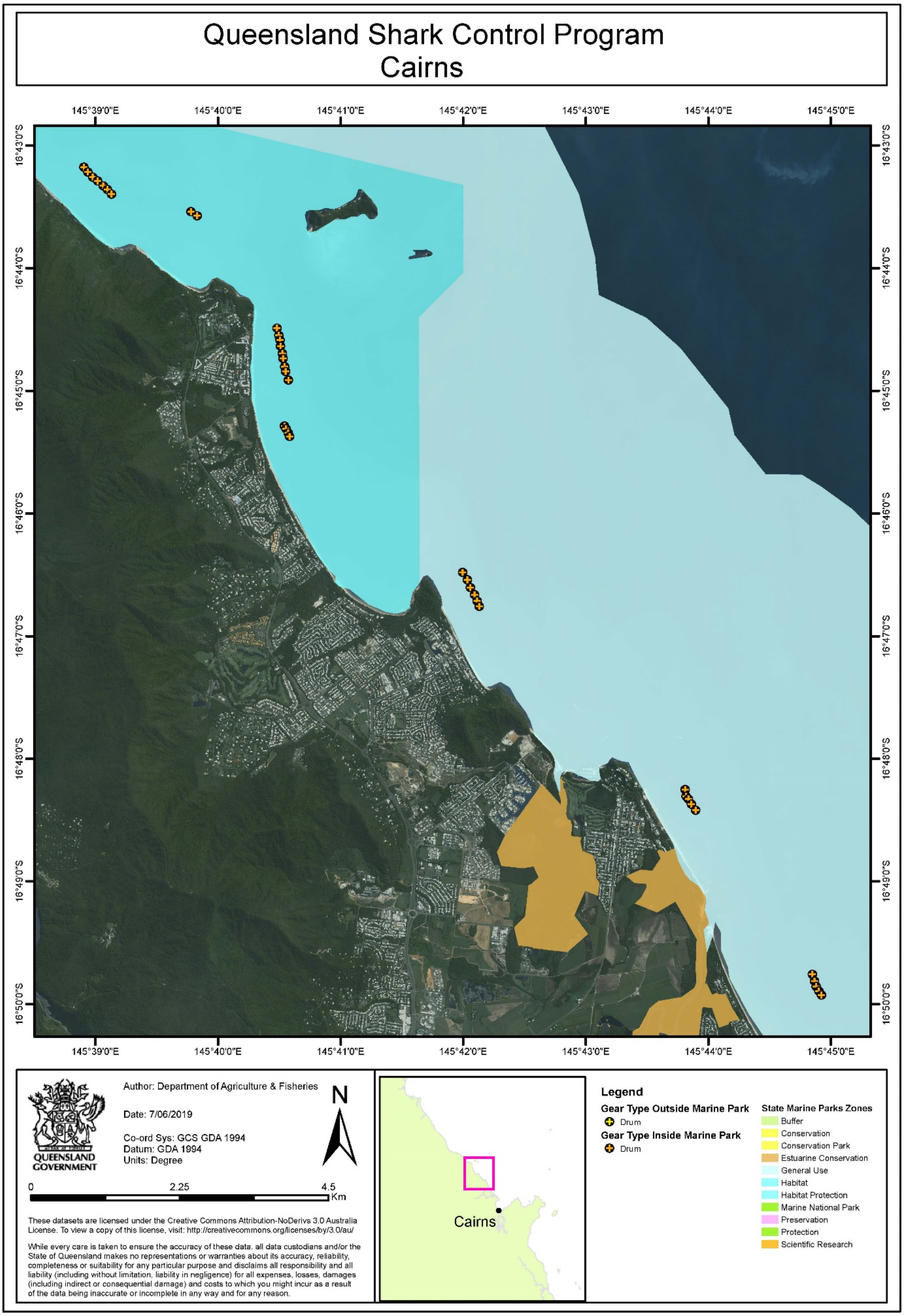
Treves A., Wallace R.B., Naughton-Treves L., Morales A. (2006). Co-managing human–wildlife conflicts: a review. Human Dimensions of Wildlife,11(6), pp. 383-396.

Wetherbee B.M., Lowe C.G., Crow G.L. (1994). A review of shark control in Hawaii with recommendations for future research. Pacific Science, 48(2),pp. 95-115.

Wilson, S.G. (2004). Basking sharks (*Cetorhinus maximus*) schooling in the southern Gulf of Maine. Fisheries Oceanography, 13 (4), 283-286.

APPENDIX A

CURRENT GEAR LOCATIONS WITHIN SCP REGIONS



Queensland Shark Control Program
Cairns
145°39'0"E
145°40'0"E
145°41'0"E
145°42'0"E
145°43'0"E
145°44'0"E
145°45'0"E
16°43'0"S
16°44'0"S
16°45'0"S
16°46'0"S
16°47'0"S
16°48'0"S
16°49'0"S
16°50'0"S
QUEENSLAND GOVERNMENT
Author: Department of Agriculture & Fisheries
Date: 7/06/2019
Co-ord Sys: GCS GDA 1994
Datum: GDA 1994
Units: Degree
N
0
2.25
4.5
Km
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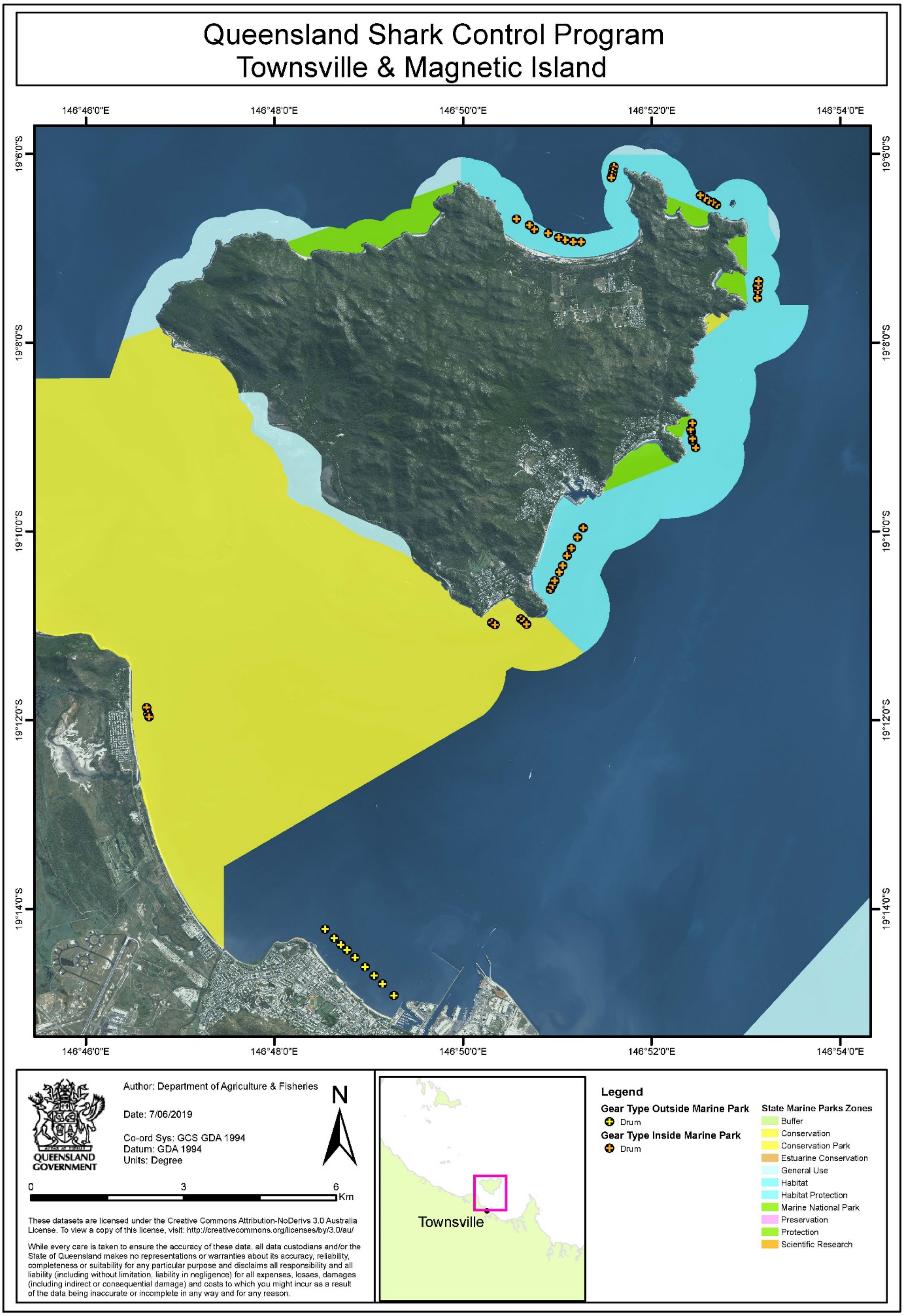
Cairns
Legend
Gear Type Outside Marine Park
Drum
Gear Type Inside Marine Park
Drum
State Marine Parks Zones
Buffer
Conservation
Conservation Park
Estuarine Conservation
General Use
Habitat
Habitat Protection
Marine National Park
Preservation
Protection
Scientific Research


Queensland Shark Control Program
Townsville & Magnetic Island
146°46'0"E
146°48'0"E
146°50'0"E
146°52'0"E
146°54'0"E
19°6'0"S
19°8'0"S
19°10'0"S
19°12'0"S
19°14'0"S
QUEENSLAND GOVERNMENT
Author: Department of Agriculture & Fisheries
Date: 7/06/2019
Co-ord Sys: GCS GDA 1994
Datum: GDA 1994
Units: Degree
N
0
3
6
Km
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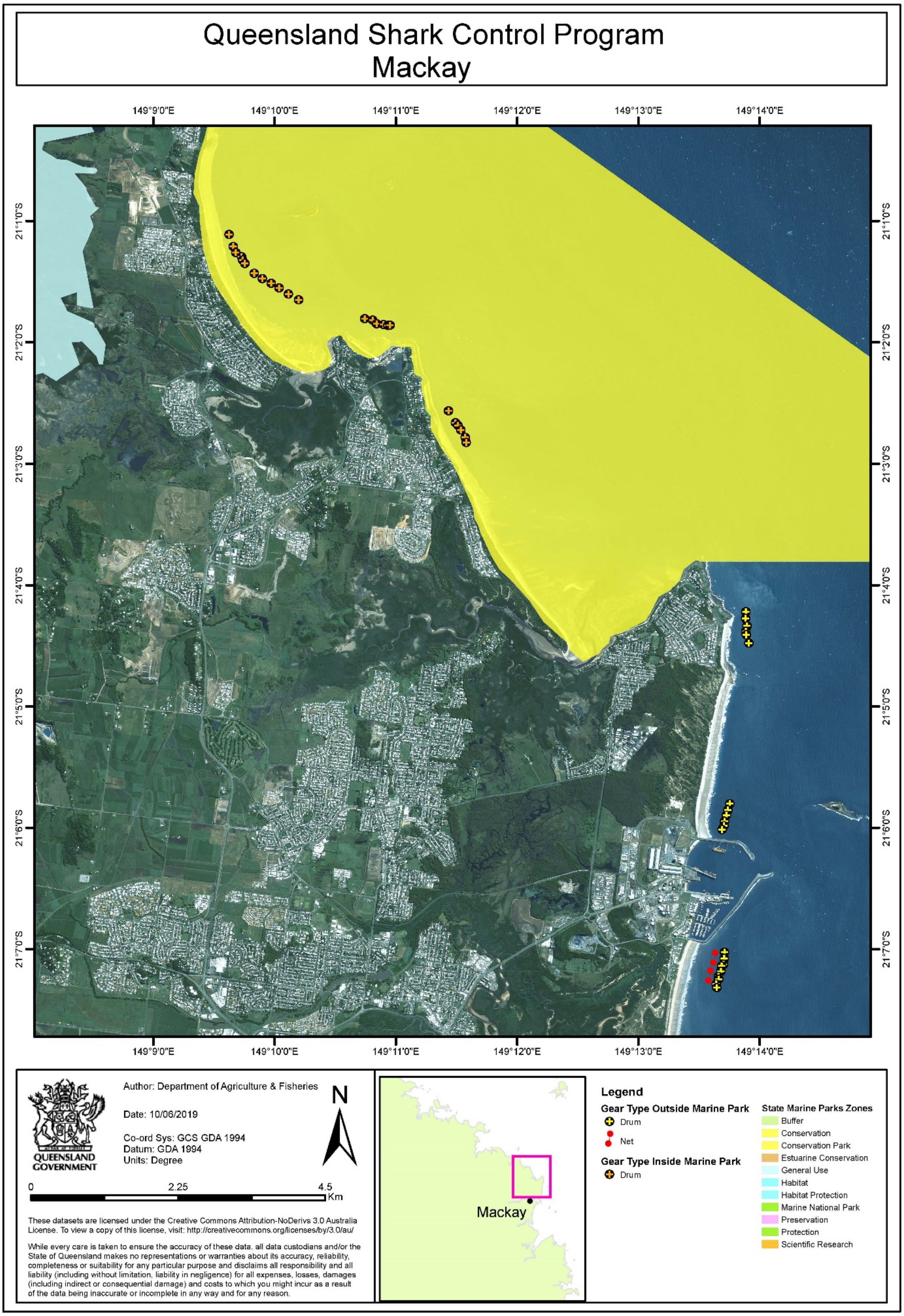
Townsville
Legend
Gear Type Outside Marine Park
Drum
Gear Type Inside Marine Park
Drum
State Marine Parks Zones
Buffer
Conservation
Conservation Park
Estuarine Conservation
General Use
Habitat
Habitat Protection
Marine National Park
Preservation
Protection
Scientific Research


Queensland Shark Control Program
Mackay
149°9'0"E
149°10'0"E
149°11'0"E
149°12'0"E
149°13'0"E
149°14'0"E
21°1'0"S
21°2'0"S
21°3'0"S
21°4'0"S
21°5'0"S
21°6'0"S
21°7'0"S
QUEENSLAND GOVERNMENT
Author: Department of Agriculture & Fisheries
Date: 10/06/2019
Co-ord Sys: GCS GDA 1994
Datum: GDA 1994
Units: Degree
N
0
2.25
4.5
Km
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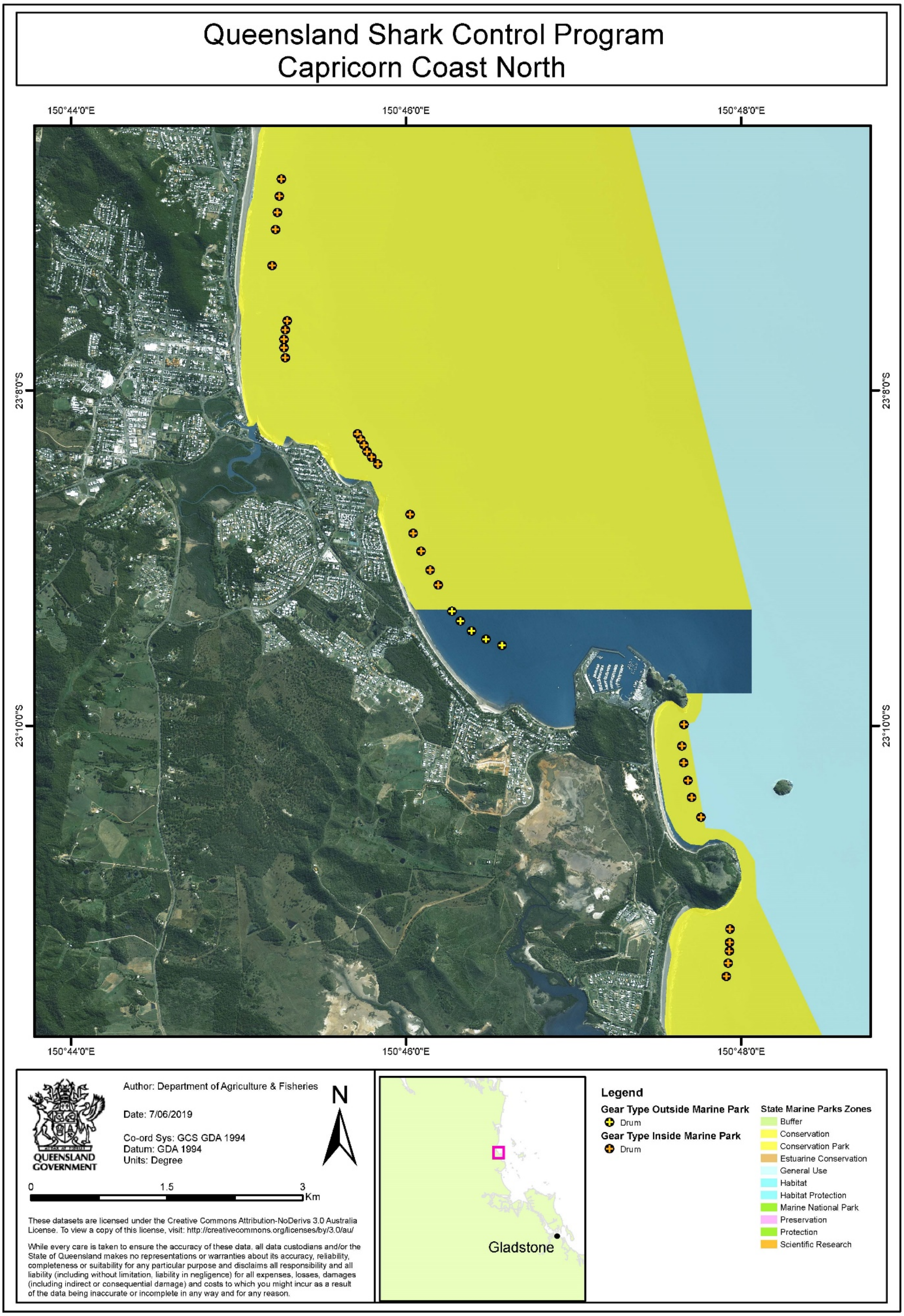
Mackay
Legend
Gear Type Outside Marine Park
Drum
Net
Gear Type Inside Marine Park
Drum
State Marine Parks Zones
Buffer
Conservation
Conservation Park
Estuarine Conservation
General Use
Habitat
Habitat Protection
Marine National Park
Preservation
Protection
Scientific Research


Queensland Shark Control Program
Capricorn Coast North
150°44'0"E
150°46'0"E
150°48'0"E
23°8'0"S
23°10'0"S
Author: Department of Agriculture & Fisheries
Date: 7/06/2019
Co-ord Sys: GCS GDA 1994
Datum: GDA 1994
Units: Degree
QUEENSLAND GOVERNMENT
N
0
1.5
3
Km
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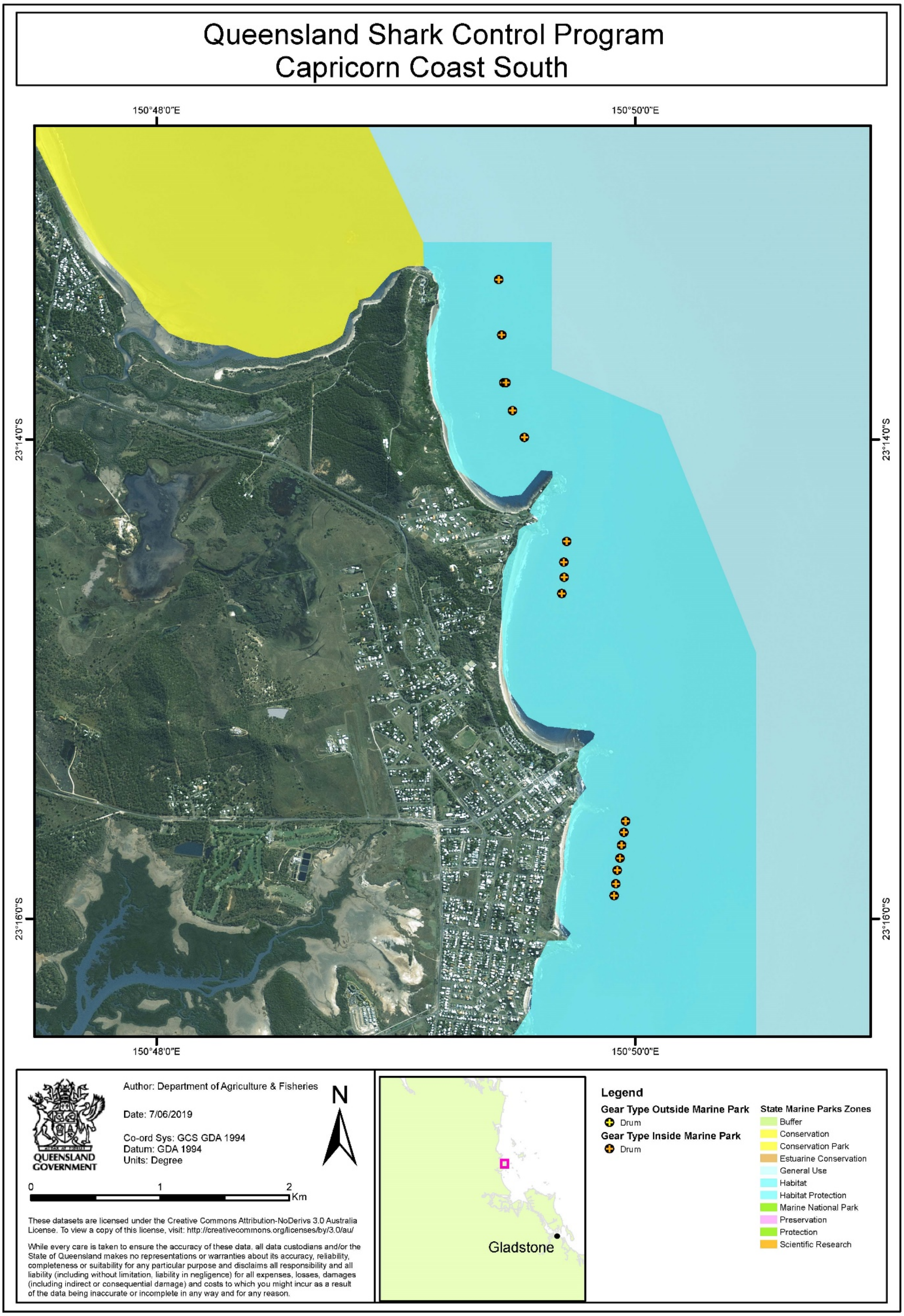
Gladstone
Legend
Gear Type Outside Marine Park
Drum
Gear Type Inside Marine Park
Drum
State Marine Parks Zones
Buffer
Conservation
Conservation Park
Estuarine Conservation
General Use
Habitat
Habitat Protection
Marine National Park
Preservation
Protection
Scientific Research


Queensland Shark Control Program
Capricorn Coast South
150°48'0"E
150°50'0"E
23°14'0"S
23°16'0"S
Author: Department of Agriculture & Fisheries
Date: 7/06/2019
Co-ord Sys: GCS GDA 1994
Datum: GDA 1994
Units: Degree
N
0
1
2
Km
QUEENSLAND GOVERNMENT
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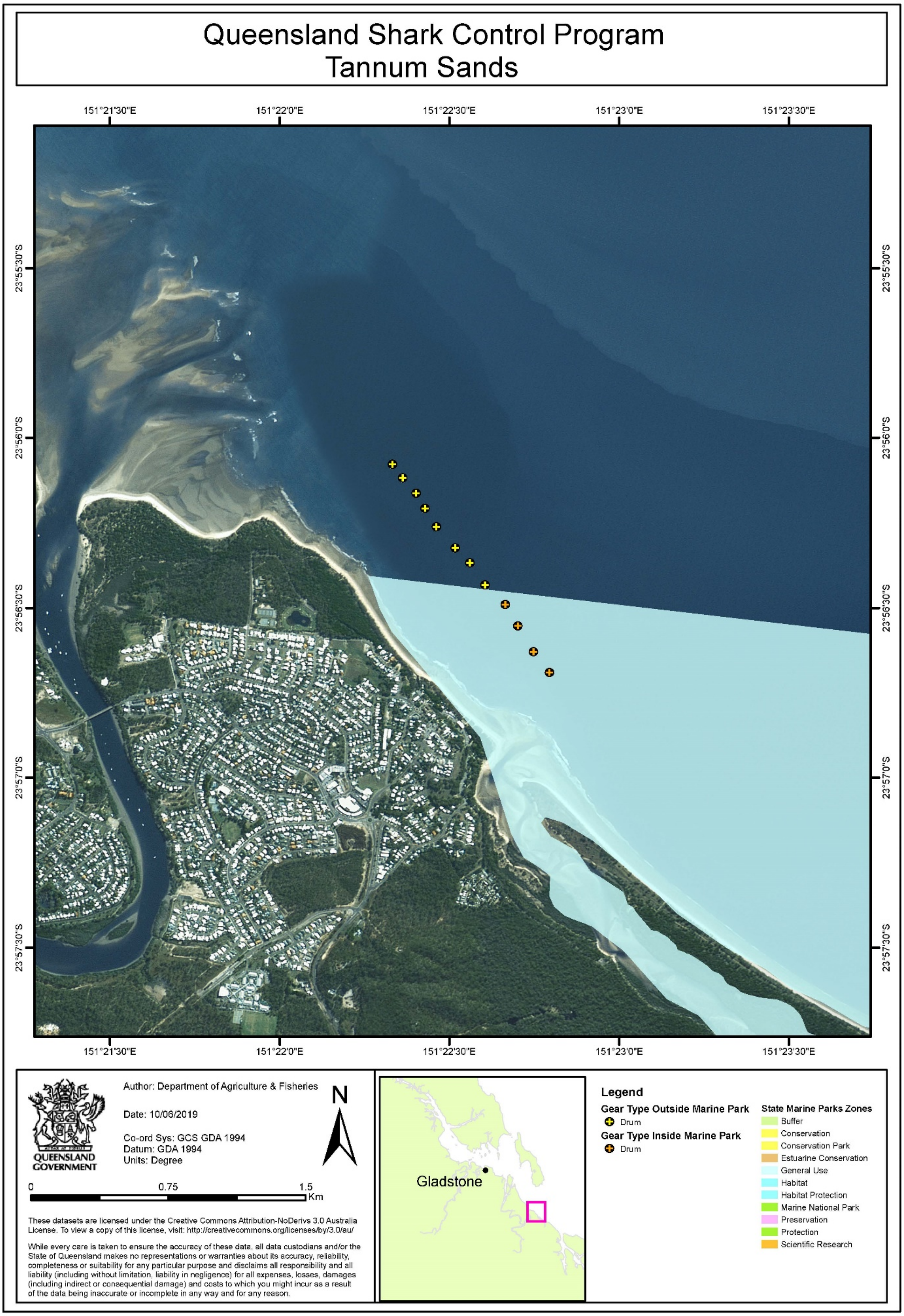
Gladstone
Legend
Gear Type Outside Marine Park
Drum
Gear Type Inside Marine Park
Drum
State Marine Parks Zones
Buffer
Conservation
Conservation Park
Estuarine Conservation
General Use
Habitat
Habitat Protection
Marine National Park
Preservation
Protection
Scientific Research


Queensland Shark Control Program
Tannum Sands
151°21'30"E
151°22'0"E
151°22'30"E
151°23'0"E
151°23'30"E
23°55'30"S
23°56'0"S
23°56'30"S
23°57'0"S
23°57'30"S
Author: Department of Agriculture & Fisheries
Date: 10/06/2019
Co-ord Sys: GCS GDA 1994
Datum: GDA 1994
Units: Degree
N
QUEENSLAND GOVERNMENT
0
0.75
1.5
Km
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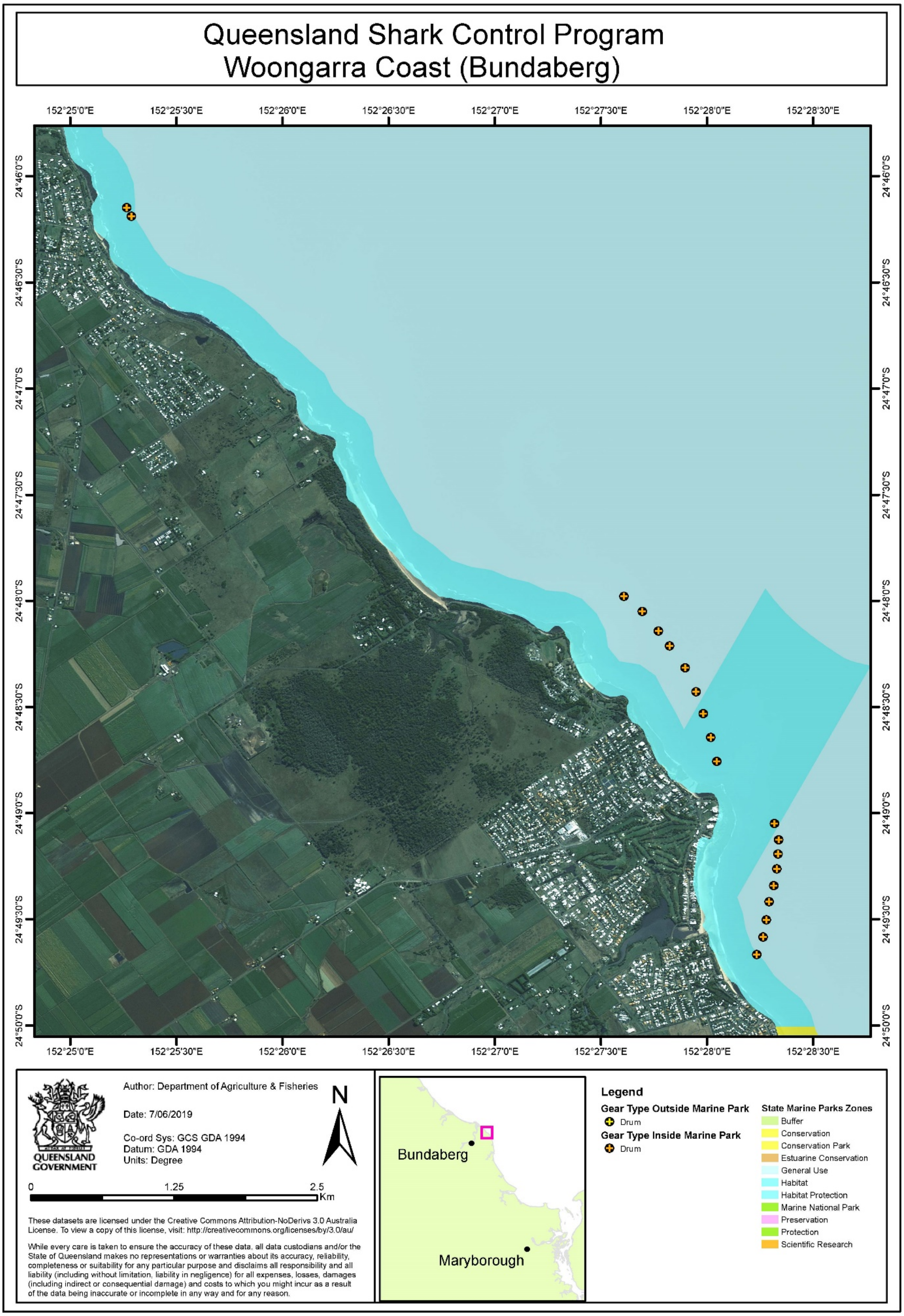
Gladstone
Legend
Gear Type Outside Marine Park
Drum
Gear Type Inside Marine Park
Drum
State Marine Parks Zones
Buffer
Conservation
Conservation Park
Estuarine Conservation
General Use
Habitat
Habitat Protection
Marine National Park
Preservation
Protection
Scientific Research


Queensland Shark Control Program
Woongarra Coast (Bundaberg)
152°25'0"E
152°25'30"E
152°26'0"E
152°26'30"E
152°27'0"E
152°27'30"E
152°28'0"E
152°28'30"E
24°46'0"S
24°46'30"S
24°47'0"S
24°47'30"S
24°48'0"S
24°48'30"S
24°49'0"S
24°49'30"S
24°50'0"S
Author: Department of Agriculture & Fisheries
Date: 7/06/2019
Co-ord Sys: GCS GDA 1994
Datum: GDA 1994
Units: Degree
QUEENSLAND GOVERNMENT
N
0
1.25
2.5
Km
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Bundaberg
Maryborough
Legend
Gear Type Outside Marine Park
Drum
Gear Type Inside Marine Park
Drum
State Marine Parks Zones
Buffer
Conservation
Conservation Park
Estuarine Conservation
General Use
Habitat
Habitat Protection
Marine National Park
Preservation
Protection
Scientific Research

Queensland Shark Control Program
Rainbow Beach

QUEENSLAND GOVERNMENT

Author: Department of Agriculture & Fisheries

Date: 7/06/2019

Co-ord Sys: GCS GDA 1994
Datum: GDA 1994
Units: Degree

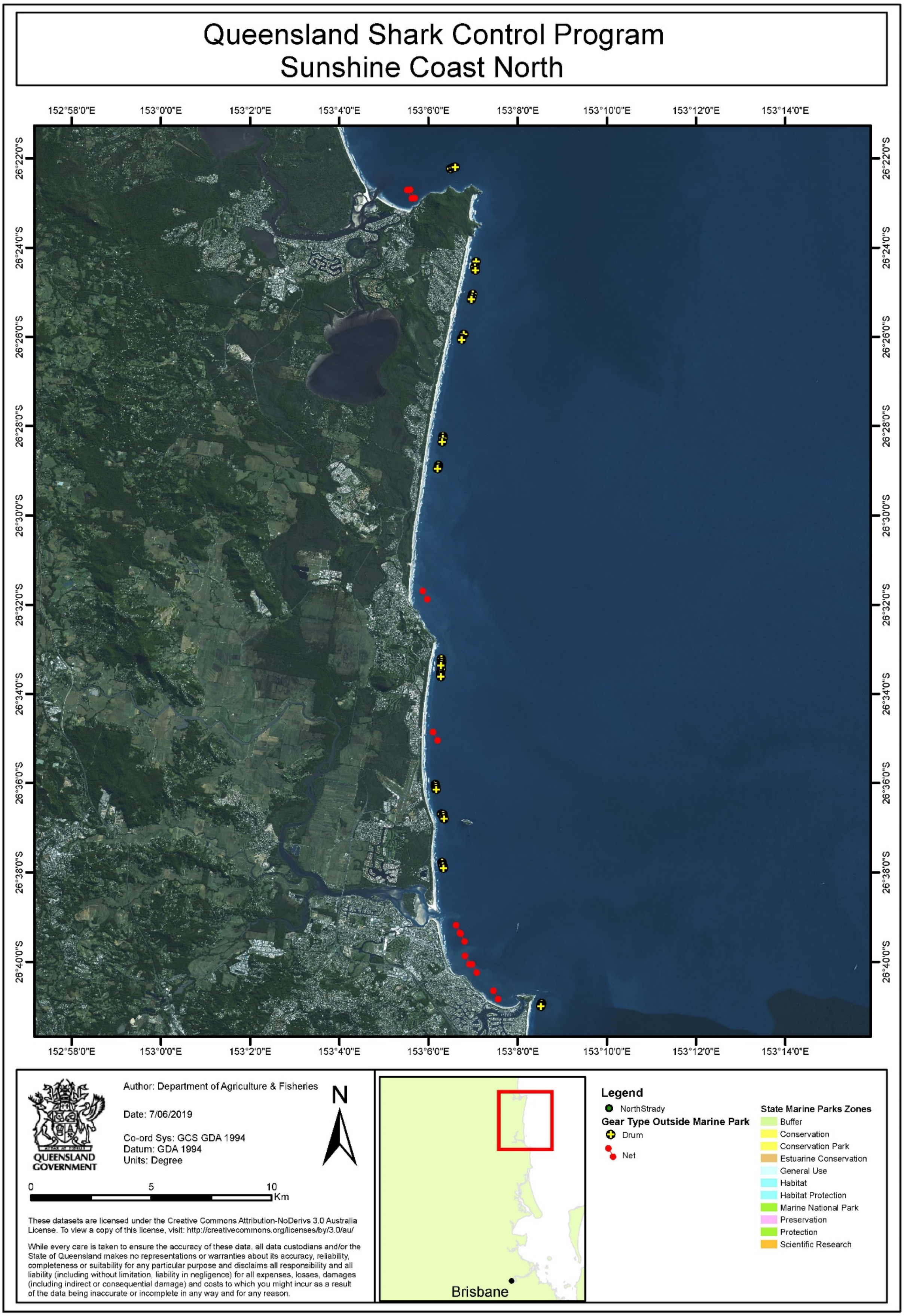
N

0 0.5 1 Km

Legend

Gear Type Inside Marine Park
- Drum
- Net

State Marine Parks Zones
- Buffer
- Conservation
- Conservation Park
- Estuarine Conservation
- General Use
- Habitat
- Habitat Protection
- Marine National Park
- Preservation
- Protection
- Scientific Research



Queensland Shark Control Program
Sunshine Coast North
152°58'0"E
153°0'0"E
153°2'0"E
153°4'0"E
153°6'0"E
153°8'0"E
153°10'0"E
153°12'0"E
153°14'0"E
26°22'0"S
26°24'0"S
26°26'0"S
26°28'0"S
26°30'0"S
26°32'0"S
26°34'0"S
26°36'0"S
26°38'0"S
26°40'0"S
QUEENSLAND GOVERNMENT
Author: Department of Agriculture & Fisheries
Date: 7/06/2019
Co-ord Sys: GCS GDA 1994
Datum: GDA 1994
Units: Degree
N
0
5
10
Km
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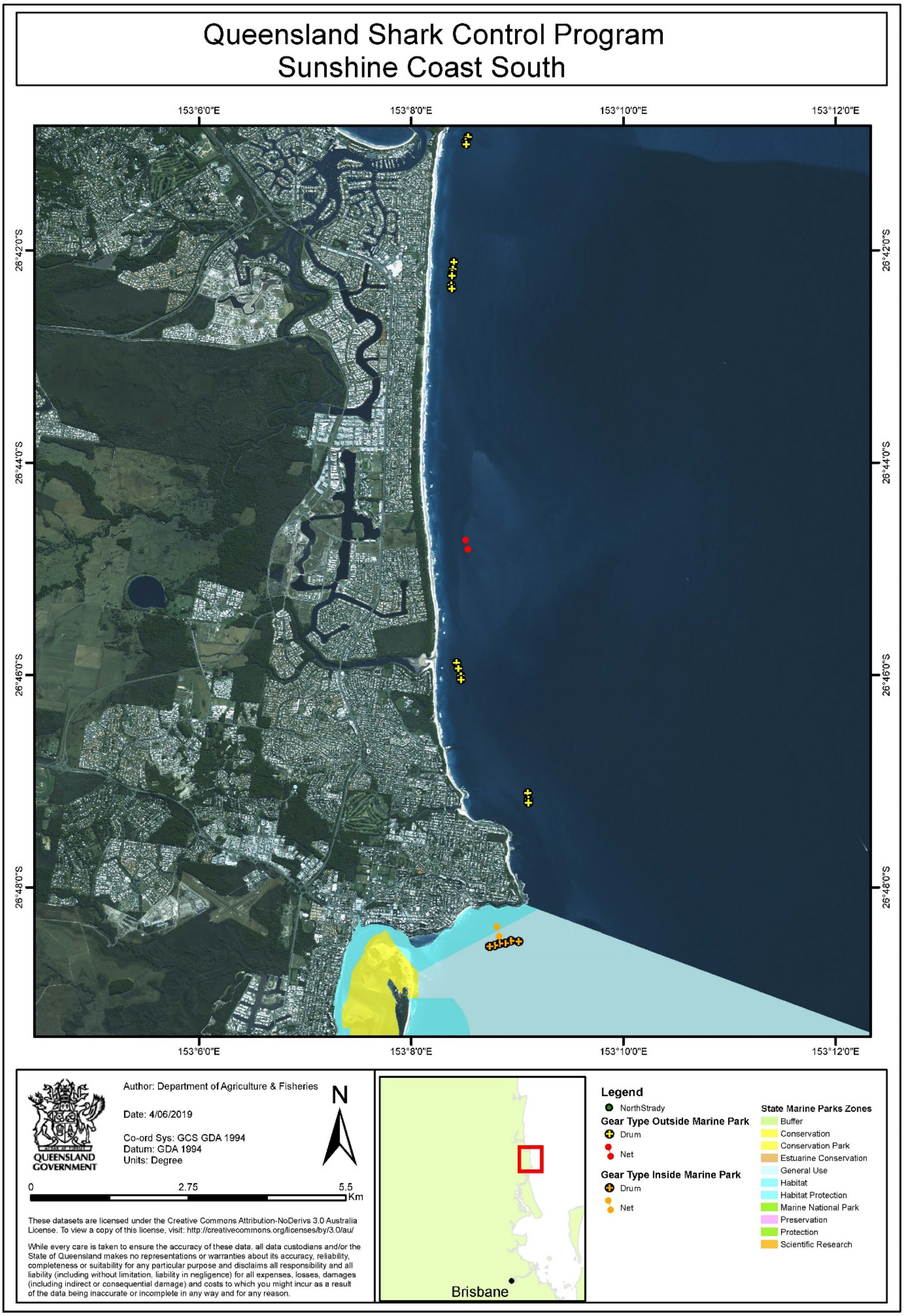
Brisbane
Legend
NorthStrady
Gear Type Outside Marine Park
Drum
Net
State Marine Parks Zones
Buffer
Conservation
Conservation Park
Estuarine Conservation
General Use
Habitat
Habitat Protection
Marine National Park
Preservation
Protection
Scientific Research


Queensland Shark Control Program
Sunshine Coast South
153°6'0"E
153°8'0"E
153°10'0"E
153°12'0"E
26°42'0"S
26°44'0"S
26°46'0"S
26°48'0"S
Author: Department of Agriculture & Fisheries
Date: 4/06/2019
Co-ord Sys: GCS GDA 1994
Datum: GDA 1994
Units: Degree
N
QUEENSLAND GOVERNMENT
0
2.75
5.5
Km
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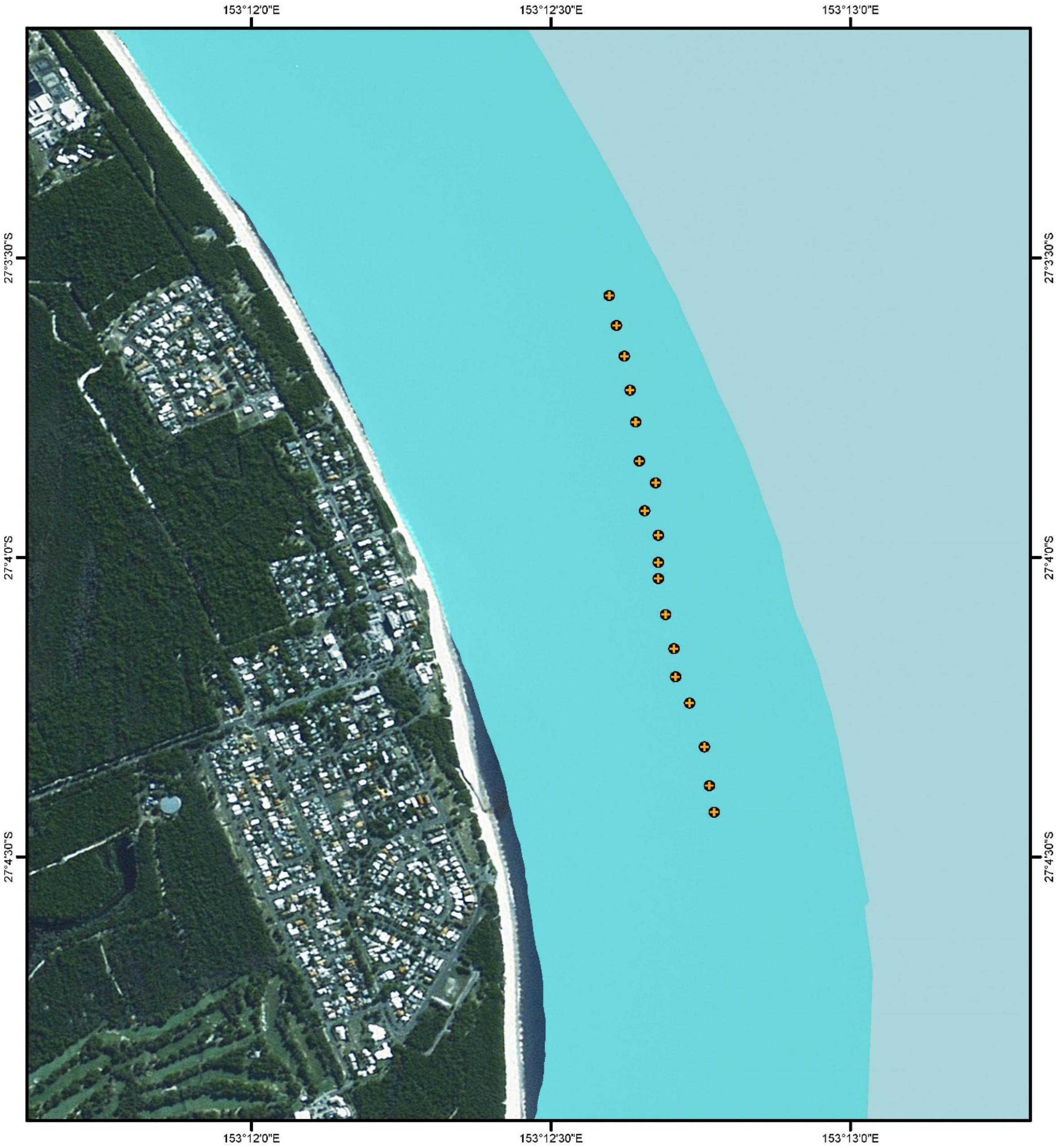
Brisbane
Legend
NorthStrady
Gear Type Outside Marine Park
Drum
Net
Gear Type Inside Marine Park
Drum
Net
State Marine Parks Zones
Buffer
Conservation
Conservation Park
Estuarine Conservation
General Use
Habitat
Habitat Protection
Marine National Park
Preservation
Protection
Scientific Research

Queensland Shark Control Program
Sunshine Coast - Bribie Island



Author: Department of Agriculture & Fisheries

Date: 7/06/2019

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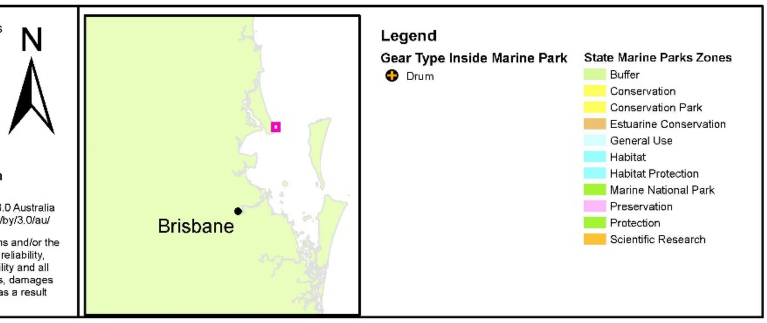
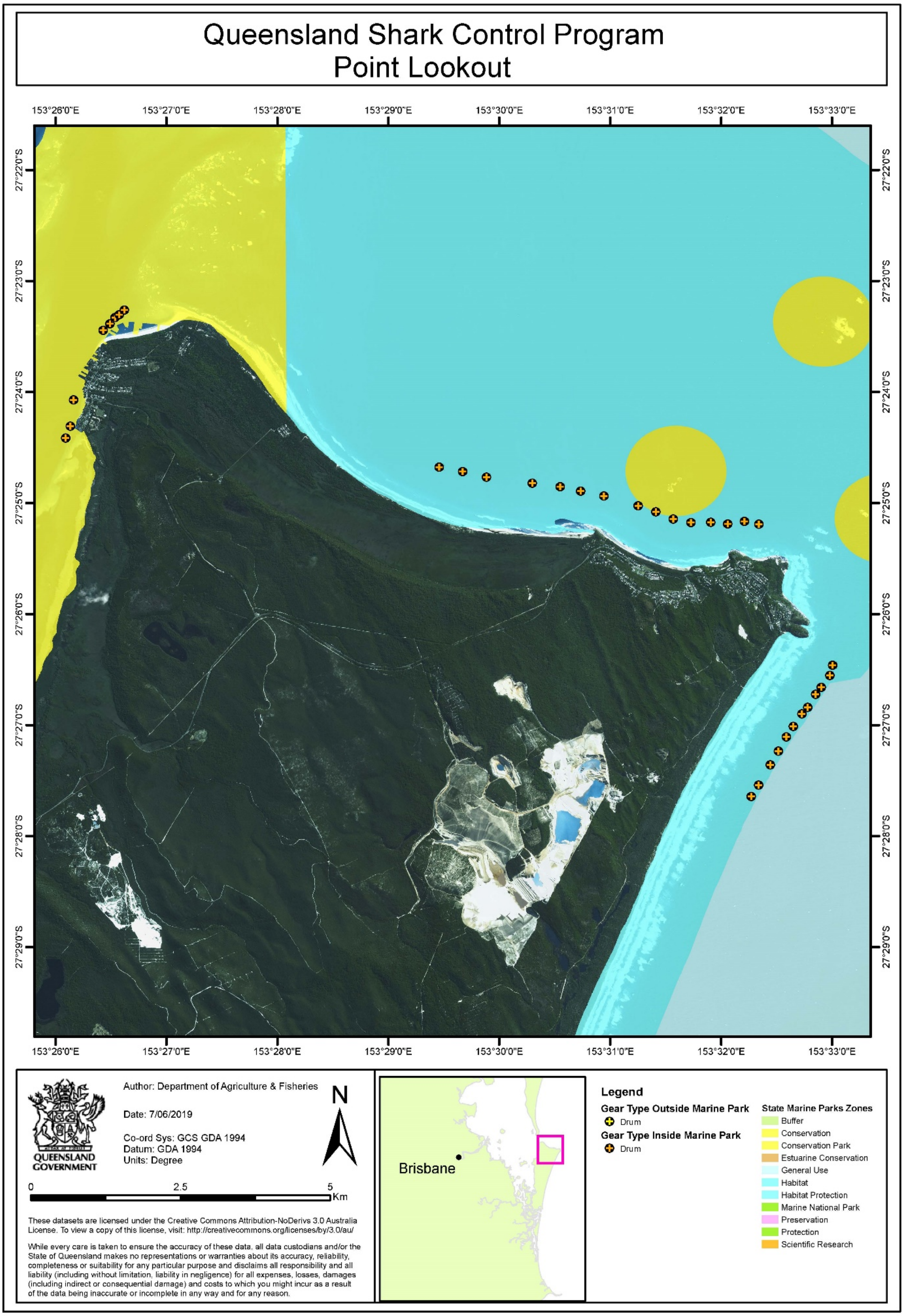
Units: Degree




Queensland Shark Control Program
Point Lookout
153°26'0"E
153°27'0"E
153°28'0"E
153°29'0"E
153°30'0"E
153°31'0"E
153°32'0"E
153°33'0"E
27°22'0"S
27°23'0"S
27°24'0"S
27°25'0"S
27°26'0"S
27°27'0"S
27°28'0"S
27°29'0"S
Author: Department of Agriculture & Fisheries
Date: 7/06/2019
Co-ord Sys: GCS GDA 1994
Datum: GDA 1994
Units: Degree
N
0
2.5
5
Km
QUEENSLAND GOVERNMENT
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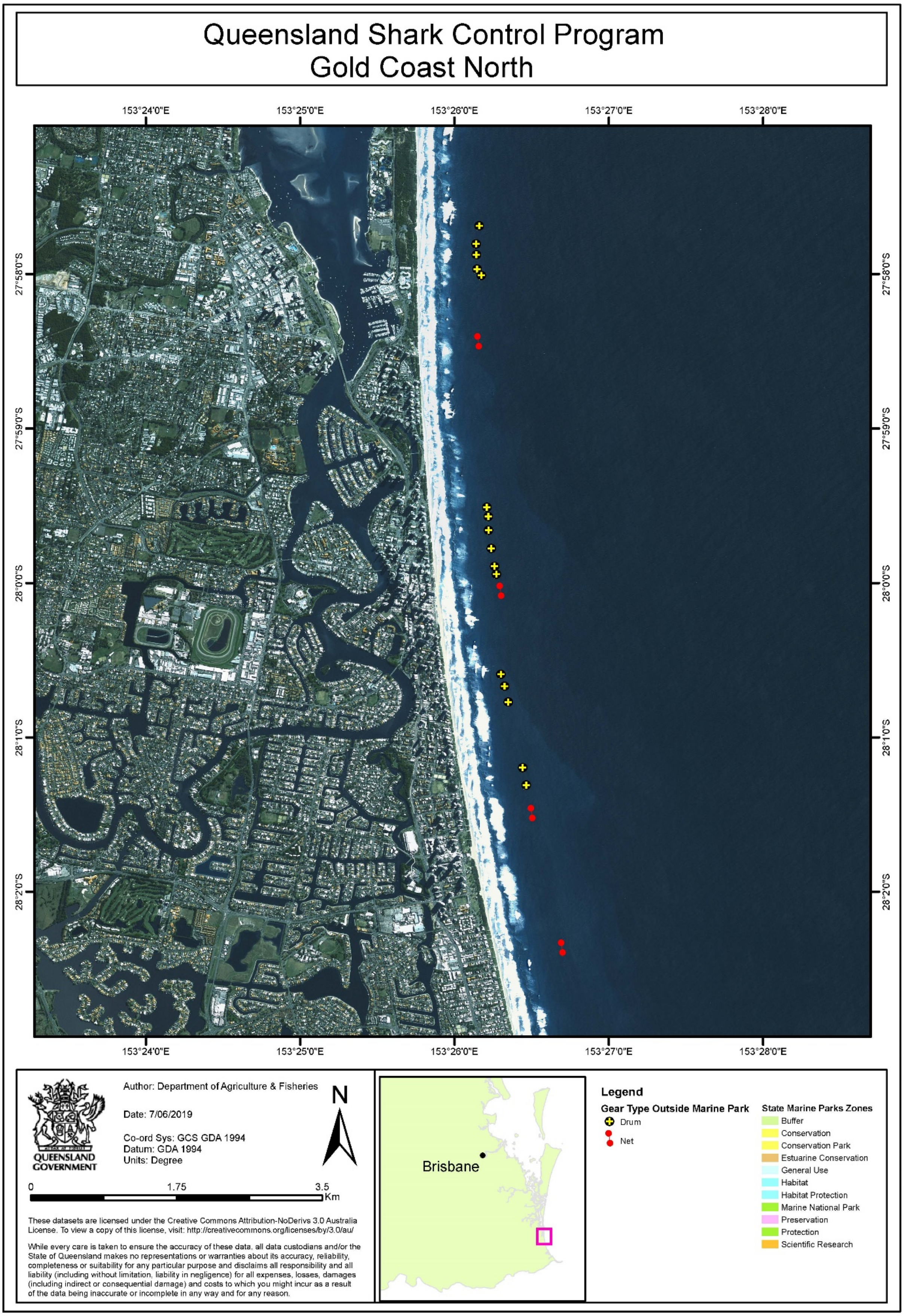
Brisbane
Legend
Gear Type Outside Marine Park
Drum
Gear Type Inside Marine Park
Drum
State Marine Parks Zones
Buffer
Conservation
Conservation Park
Estuarine Conservation
General Use
Habitat
Habitat Protection
Marine National Park
Preservation
Protection
Scientific Research


Queensland Shark Control Program
Gold Coast North
153°24'0"E
153°25'0"E
153°26'0"E
153°27'0"E
153°28'0"E
27°58'0"S
27°59'0"S
28°0'0"S
28°1'0"S
28°2'0"S
QUEENSLAND GOVERNMENT
Author: Department of Agriculture & Fisheries
Date: 7/06/2019
Co-ord Sys: GCS GDA 1994
Datum: GDA 1994
Units: Degree
N
0
1.75
3.5
Km
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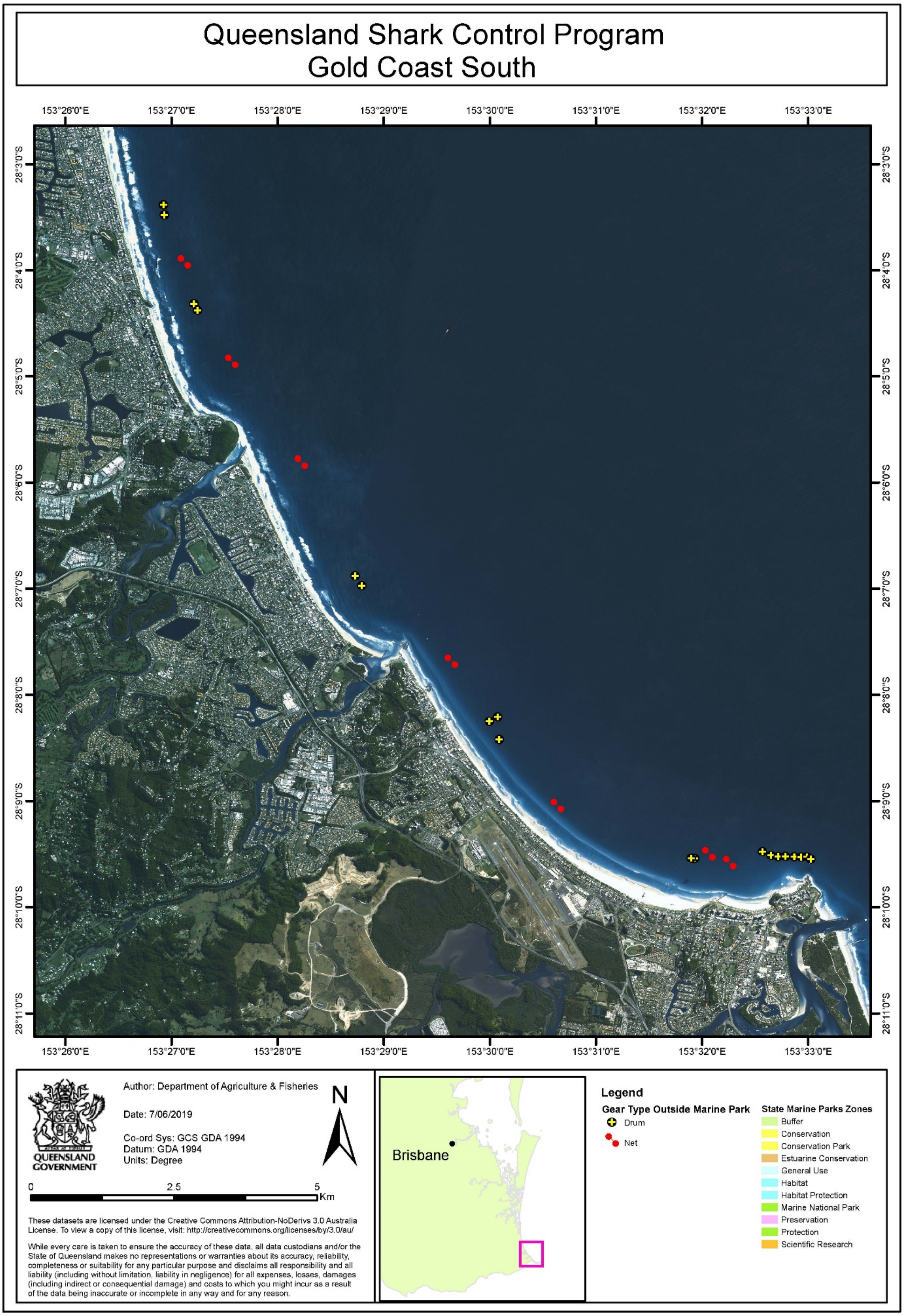
Brisbane
Legend
Gear Type Outside Marine Park
Drum
Net
State Marine Parks Zones
Buffer
Conservation
Conservation Park
Estuarine Conservation
General Use
Habitat
Habitat Protection
Marine National Park
Preservation
Protection
Scientific Research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Brisbane
Legend
Gear Type Outside Marine Park
Drum
Net
State Marine Parks Zones
Buffer
Conservation
Conservation Park
Estuarine Conservation
General Use
Habitat
Habitat Protection
Marine National Park
Preservation
Protection
Scientific Research

APPENDIX B
HISTORICAL CHANGES TO GEAR LOCATIONS WITHIN SCP REGIONS

Cardno
Shaping the Future

REGION	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1981	1982	1983	1984	1987	1989	1990	1991	1992	1993	1996	1998	2005	2006	2008	2013	2018	2019 (Current
Cairns	12D/3N	16D / 4N (+4D/+1N)		20D/4N (+4D)						10D/3N (-10D/-1N)	8D / 2N (-2D/-1N)		18D/5N (+10D/+3N)				24D/5N (+6D)																	38D (+14D/-5N)		38D
Townsville	24D/6N								18D/7N (-6D/+1N)		18D/5N (-2N)									23D/4N (+5D/-1N)					29D/3N (+6D/-1N)		42D / 2N (+13D/-1N)				54D (+12D/-2N)					54D
Mackay	No gear	16D/4N	20D / 4N (+4D)		24D/5N (+4D/+1N)	24D / 6N (+1N)			18D/6N (-6D)									18D/5N (-1N)									30D/4N (+12D/-1N)			27D/5N (-3D/+1N)					45D/2N (+18D/-3N)	45D/2N
Capricorn Coast				No gear				24D/6N			18D/6N (-6D)			24D/5N (+6D/-1N)													54D (+30D/-5N)									54D
Tannum Sands				No gear																	9D	12D (+3D)														12D
Woongarra Coast				No gear								9D			9D/1N (+1N)	15D (+6D/-1N)											20D (+5D)									20D
Rainbow Beach				No gear									12D/3N																							12D/3N
Sunshine Beach	17D/8N	17D/9N (+1N)							19D/11N (+2D/+2N)		18D/11N (-1D)			27D / 13N (+9D / +2N)			18D/11N (-9D/-2N)		24D/10N (+6D/-1N)	30D/11N (+6D/+1N)				36D/10N (+6D /-1N)	42D/9N (+6D /-1N)			62D/9N (+20D)						78D/11N (+18D/+2N)		78D/11N
North Stradbroke Island				No gear									2D/2N					24D (+22D/-2N)											28D (+4D)			32D (+4D)			35D (+3D)	35D
Gold Coast	24D/10N						18D/12N (-6D/+2N)																24D/11N (+6D/-1N)		36D/9N (12D/-2N)	24D/11N (-12D/2N)	30D/10N (6D/-1N)	30D/11N (+1N)					35D/11N (+5D)			35D/11N

APPENDIX C
SHARK DETECTION SYSTEMS

Shark Spotters Program

In response to a series of unprovoked shark bites in South African waters a Shark Spotters Program was developed and trialled in the Cape Town region (Oelofse and Kamp 2006). The program is an early warning initiative that provides information in real time on the presence or absence of white sharks to beach goers. The information can allow beach goers to make a more informed decision regarding entering or remaining in the water, and when a dangerous species of shark is spotted a clear directive that beach goers should leave the water is provided. The guiding principles of the program are:

1. Find a balance between people's safety & white shark conservation;
2. Reduce the spatial overlap between people & sharks; and
3. Take into account socio-economics, public safety and environment/ wildlife.

The program relies on a series of flags to communicate to beach goers the presence or absence of sharks and the reliability of spotting given the conditions at the time (**Figure C1**). There are four flags:

- Green flag: Spotting conditions good, no sharks seen;
- Black flag: Spotting conditions poor, no sharks seen;
- Red flag: Either a shark has been seen in the last two hours, or there is an increased risk of a shark being in the area; and
- White flag (with black shark): Shark has been spotted – siren will sound. Leave water immediately.

The programs commenced in 2004 and since that time over 1,700 shark sighting have been recorded. It is an Advisory service only. The program operates throughout the year at four beaches and seasonally at another four. Shark Spotters are positioned at strategic points along the Cape Peninsula, primarily along the False Bay coastline. Shark spotters are trained to recognise white sharks and differentiate them from other marine animals that do not pose a threat to water users. A spotter is placed on the mountain with polarised sunglasses and binoculars. This spotter is in radio contact with another spotter on the beach. If a shark is seen the beach spotter sounds a siren and raises a white flag with a black shark. When the siren sounds the water users are requested to leave the water and only return when the appropriate all clear signal is given. Shark sightings are also provided in real time via Facebook and Twitter. The program has been successful in restoring a significant degree of public confidence, however it has not completely eliminated shark bites occurring at beaches where the program has been operating. The program is not a volunteer program with shark spotters being paid a wage.

For effective operation, vantage points with substantial elevation are required (between 50 and 110 metres). The elevation needed is well above that normally afforded by surf patrol towers. The program is obviously only effective when spotters are in place (8:00AM to 6:00PM in South Africa). While sea state and weather condition impact the likelihood of sighting a shark that is present, this limitation is in effect incorporated into the warning system by virtue of the black flag which identifies that spotting conditions are poor. A difficulty encountered by the program in South Africa is ensuring that all people clear the water when a shark is sighted. This is no different to the challenge that surf life savers have in clearing the waters at patrolled beaches in Australia.

Recent developments in the Shark Spotters program include trialling the use of fixed cameras to augment (but not replace) the human observers, and continued expansion of targeted education activities with the aim of enhancing community understanding of the ecology of sharks.

With support from the Byron Bay Council, Sea Shepherd briefly trialled a Shark Spotters program based on volunteers at Wategos Beach. There was no uptake of the trial.

Figure C1 Shark Spotters in South Africa . Left: spotter checking beach, Right: flag indicating potential shark risk. Source: Alison Kock.

Acoustic and Satellite Tagging

The use of acoustic and satellite tagging for assessing movement patterns and habitat use of a range of marine animals (including sharks) is well established (**Figure C2**). The contemporary approach involves the use of arrays of fixed receivers to detect tagged animals. There is an Ocean Tracking Network (OTN) which is a $168-million ocean research and technology development platform headquartered at Dalhousie University (Nova Scotia). The OTN has receivers stationed in Western Australia and off Tasmania. There is also a series of receivers on the Australian east coast that are part of the Animal Tracking and Monitoring System (AATAMS), part of a much broader national marine monitoring initiative: the Integrated Marine Observing System (IMOS)[1].

Tagging of sharks on its own, does not provide a direct approach to mitigating unprovoked shark bite. Tagged sharks must be able to be detected at spatially relevant scales and this information communicated to water users.

Acoustic and satellite tagging of sharks is used in Western Australia to provide an early warning system of when a shark was close to popular beaches. The information collected from tagged sharks is also augmented with sightings by the public that are reported via a dedicated phone number. Information on tagged sharks that are detected by the receivers are communicated to the public via Twitter and a dedicated website[2]. Potentially a text message could be sent to a lifeguard to alert them to the presence of a shark. Information on the activity of tagged sharks; together with sightings by the public, the capture of a relatively large number of sharks in a short period of time for tagging, or other factors which are known to attract sharks to a specific region (e.g. the presence of a whale carcass) is integrated into shark alerts and warnings. The approach in Western Australia involves the deployment of satellite-linked (VR4G) acoustic receivers, and data-recording acoustic receivers (VR2W) on the sea floor. Detections by VR2W receivers are not transmitted via satellite but are stored in the receiver's on-board memory.

The ability of acoustic and satellite tagging to identify the presence of dangerous shark species at beaches where acoustic receivers are in place is a function of the number of sharks that have been captured tagged and released. The more sharks that are utilising the coastal area that have been tagged the greater the likelihood that a shark occurring at a beach where a receiver is present will be detected. There may also be location specific factors which influence the spatial range the performance of the tag and the ability of the receiver to detect it. Mitigating this may require the placement of receivers closer together in the array to ensure a continuous line of detection. Satellite-linked (VR4G) receivers need fresh batteries and a major service of their buoys and moorings. Data-recording (VR2W) receivers need to be recovered annually by divers so that the stored data can be downloaded and receivers serviced.

[1] http://www.imos.org.au/
[2] http://www.sharksmart.com.au/shark-activity/

The application of tags suitable for real-time telemetry requires approval by an appropriate Animal Ethics committee

Figure C2 Shark tagging. Left: A captured white shark in preparation for being fitted with an acoustic tag, Right: a satellite tag in a shark's dorsal fin. Source: NSW Fisheries.

Cleverbuoy

Cleverbuoy is an acoustic detection method designed to detect sharks at beaches where an array of buoys are deployed (**Figure C3**). Cleverbuoy uses a multi-beam sonar unit (Tritech Gemini Unit) to identify underwater objects. Multi-beam sonar technology was previously only used by the navy and the oil and gas industry but is now in more general use in environmental monitoring and assessment as costs have fallen. It is widely used to map seabeds (Brown and Blondel, 2009).

Sonar data from Cleverbuoy is transmitted via a closed system (i.e. CPU on buoy with modem connected to Optus 3G network with redundancy back to dedicated Optus satellite) to a server where software (made by Tritek) aims to distinguish sharks from other objects (i.e. sharks are identified as objects > 2 m that are self-propelled). The software has a set level of probability to provide a shark alert to an end user who can be located anywhere. Potentially a text message could be sent to a lifeguard to alert them to the presence of a shark. The alert will tell the end user which buoy has a shark nearby and specifies the GPS location of the buoy. A Cleverbuoy unit consists of a buoy anchored to the seabed. The sonar transducer is attached to the base mounting on the seabed (an anchor system) and there is an antenna on the surface of the buoy which transmits the sonar data. The transducer is reported by the manufacturer to emit sonar to a maximum distance of 85 m in a wedge that covers 120 degrees. The effective width of the beam though will be highly dependent on water depth.

Parsons et al. (2015) assessed the ability of the Tritech Gemini imaging sonar to detect sharks. They specifically assessed the ability of the technology to observe sharks of 1.4 to 2.7 m in length at ranges from 1 to 50 m. They found that within 5 m range shark shape, length and swimming action were readily discernible; however beyond this range, and unless swimming pattern could be clearly discerned, reliable identification of a shark was problematic. They identified that for a given frequency and noise level, maximum detection and identification ranges are reliant on system source level, beam pattern, bathymetry, object target size and acoustic reflectivity. In terms of the deployment of a vertical array of sonars to cover an area, Parsons et al. (2015) identified that issues of interference where beams from more than one-unit overlap is an important consideration. Overall, they concluded that a vertical array in shallow waters (< 15 m) may not provide suitable benefits at ranges greater than 75 m.

Some early trials of Cleverbuoy were undertaken by the company at the Abrolhos Islands (Western Australia) and trialled for a single day at both Bronte and Bondi beaches. The results from these trials are not publicly available. The University of Technology Sydney (UTS) undertook limited trials[3] on white sharks at Hawks Nest Beach (Port Stephens, NSW) as part of the NSW Shark Smart Strategy. This work identified that the approach had some promise but with substantial further research needing to be undertaken including assessing in beach environments that have wave and wind conditions representative of more

[3] https://www.sharksmart.nsw.gov.au/__data/assets/pdf_file/0007/815866/evaluation-of-clever-buoy-shark-detection-system-summary.pdf

ocean-exposed beaches in NSW. The NSW DPI did not undertake a roll-out of Cleverbuoy as part of the their Shark Smart Strategy.

Cleverbuoy won several high profile awards for the marketing of the product[4], but it is important to identify that these awards were not for the efficacy of the product itself. The evolution and marketing of the Cleverbuoy product is now de-emphasising sharks to a degree with a broader focus on environmental monitoring and communication uses. The company has identified that they have turned their efforts to potential overseas markets (particularly in the U.S.) due to inertia in the three tiers of Australian government[5].

Figure C3 A Cleverbuoy unit deployed for testing at Bondi Beach, NSW. Source: Craig Anderson.

Shark Alert

Shark Alert Pty Ltd., a WA company, in collaboration with Advanced Coherent Systems (ACS) has developed a multispectral camera system that can provide real-time spectral image processing to facilitate the automatic detection of sharks from an airborne platform. The cameras are spectrally filtered to enhance the contrast between the shark and the ocean background and real time image processing is used to automatically detect sharks even when there are such things as sun glints, surface clutter, and kelp that often substantially reduce performance of human observers or standard video cameras.

The system can be easily mounted onto small airplanes, helicopters and unmanned air vehicles. The four smaller apertures in the turret are the spectral cameras used for shark detection, and the larger aperture is for a video camera to operate the turret and for orientation (**Figure C4**). The Shark Alert system exploits a process that calibrates all images to enable accurate image processing, and then apply spectral, spatial and temporal processing to identify sharks in real time. The general process used is:

- Collect four spectral images simultaneously
- Apply flat field corrections to the images to remove lens effects
- Apply radiometric calibration to each image to get each in quantitative reflectivity units
- Spatially register all bands into an image cube with four layers
- Apply spectral and spatial algorithms to automatically detect sharks
- Create image verification of detected targets for sensor operator

[4] https://www.marketingmag.com.au/news-c/optus-clever-buoy-wins-cannes-gold-lion/
https://www.bandt.com.au/marketing/mc-saatchis-optus-clever-buoy-wins-even-more-global-recognition
[5] https://www.aph.gov.au/DocumentStore.ashx?id=d79e82cc-03f5-404f-bbf2-c9a8bcb382da.

Figure C4 Shark Alert multispectral camera mounted on turret

The Shark Alert system was trialled by Cardno on shark analogues off the coast of San Diego. The shark analogue was detected 100% of the time to depths below the water surface of 3.66 m and 91% detection was achieved when it was placed at 4.57 m below the surface. This was much deeper than had been achieved in another study using human observers with a similar sized shark analogue. Given the benthic habit of many sharks, it is important that aerial surveys are able to detect sharks swimming several metres below the surface, rather on or just under the surface. In the current trial, detection rates were very good with distance from the aircraft, with 88% detectability achieved as far as 350 m from the flight path (the limit of the test). This distance is much further than had been achieved previously using human observers.

The system is yet to be trialled on real sharks in Australia.

Little Ripper Drones

Westpac have worked with the University of Technology Sydney (UTS) to equip their Little Ripper Drones with artificial intelligence to improve the accuracy of detecting sharks with high accuracy in real-time. Information is sent to a control station on the beach where a human responder will have final say on what action to take. While this is a potential significant advancement it is unlikely to improve detection in all circumstances with poor water clarity remaining a significant challenge to overcome. No published independent assessment of the performance of Little Ripper Drones appears to have been undertaken or made available.

Drone Shark App.

The Drone Shark App is available via iTunes and provides drone footage to beach users. It has a free service which provides previous day’s footage as well as identifying when and where the drones are operating, and a paid subscription service. At this stage the beach coverage of the Drone Shark App is limited to Bondi, Tamarama and Bronte beaches from dawn to 8:00 but with expectations that this will expand. Ultimately the designers of the Drone Shark App hope to use the revenue to build wave pool parks and assist with youth mental health.

APPENDIX D
SHARK BARRIERS

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Eco Shark Barrier Net

The Eco Shark Barrier Net was designed in Western Australia. It consists of thousands of small modules made of the polymer nylon 6 or polycaprolactam (used to make cable ties) to form a barrier that allows water to pass through 295 mm diameter squares (**0 D1**). The modular design has a 450 kg breaking strain, or 12 tonne breaking strain when the support ropes are attached. It is held upright by floats on a surface rope spaced 100 mm apart. Chain and anchors hold the bottom of the barrier to the seabed and it can be setup with pylons on the corners or along its length. The Eco Shark Barrier Net has been successfully deployed at Coogee Beach (Western Australia), which is a beach largely protected from oceanic swells by Garden and Rottnest Islands. The initial trial was for four months (December 2013 - March 2014), and following that trial the design was improved and it was redeployed for an ongoing three year trial which commenced in November 2014[6] It has been reported by the manufacturer to have withstood waves of 1.5 metres. Cleaning of marine growth is possibly required every couple of years, although this may vary depending on the location where it is deployed as the potentially for biofouling will differ geographically as mentioned previously. At Coogee Beach, no entanglements of fauna have been recorded, although it does act as a fish aggregating device. It is reported that the manufacturers clean the currently deployed barrier themselves.

An installation of an Eco Shark Barrier Net was attempted at Lennox Head in NSW. It met with community opposition from surfers and physically failed due to the prevailing sea conditions there. The former highlights the importance of local community engagement for trialling a mitigation method, while the latter highlights the limitations of permanent barriers on high energy beaches. The failure led to community concerns about marine debris and the possibility of impacts on wildlife[7]. The trial was discontinued by NSW DPI.

Figure D1 Eco Shark Barrier Net. Left: long view of Barrier at Coogee Beach, WA. Right: floats and barrier material. Source: Eco Shark Barrier Pty Ltd

Bionic Barrier and Aquarius Barrier Nets

The Bionic Barrier and Aquarius Nets are also designed in Western Australia. They both evolved from the Eco Shark Barrier Net but are designed and manufactured by a different company (Global Marine Enclosures). The advancements are aimed at providing a barrier that is better able to withstand more wave energy and drag, and also to reduce the costs. In the event of an extreme weather event, the floats are easily removed from the barrier which will allow the frame panels to fold and drop down and rest on the seabed. In the event that part of the barrier gets damaged, the barrier features an ability to be repaired quickly in situ. The unique connection method allows damaged frame panels to be easily removed and replaced with new panels (**Figure D2).**

[6] http://www.ecosharkbarrier.com.au/about-us/ (Accessed 23/9/15)
[7] https://www.ballinaadvocate.com.au/news/concerns-failed-shark-eco-barriers-could-kill-mari/3091875/

An installation of an Aquarius Barrier was attempted at Lennox Head in NSW and similar to the eco-barrier net described in the previous section, it met with community opposition from surfers and physically failed due to the prevailing sea conditions there.

There are currently two installations of the Aquarius Barrier in WA. One at Quinn's Beach (Wanneroo) extends 85m offshore and 300m along the beach and one at Middleton Beach (Albany).

The latest product is the Aquarius Gen 2 Barrier which has aimed to overcome some of the physical limitations in earlier designs. Notwithstanding this, it remains highly unlikely that such a barrier will prove effective on exposed beaches on the Australian east coast (**Figure D3**).

Figure D2 Barrier and Aquarius Barrier Net material and float. Source. D.McPhee.

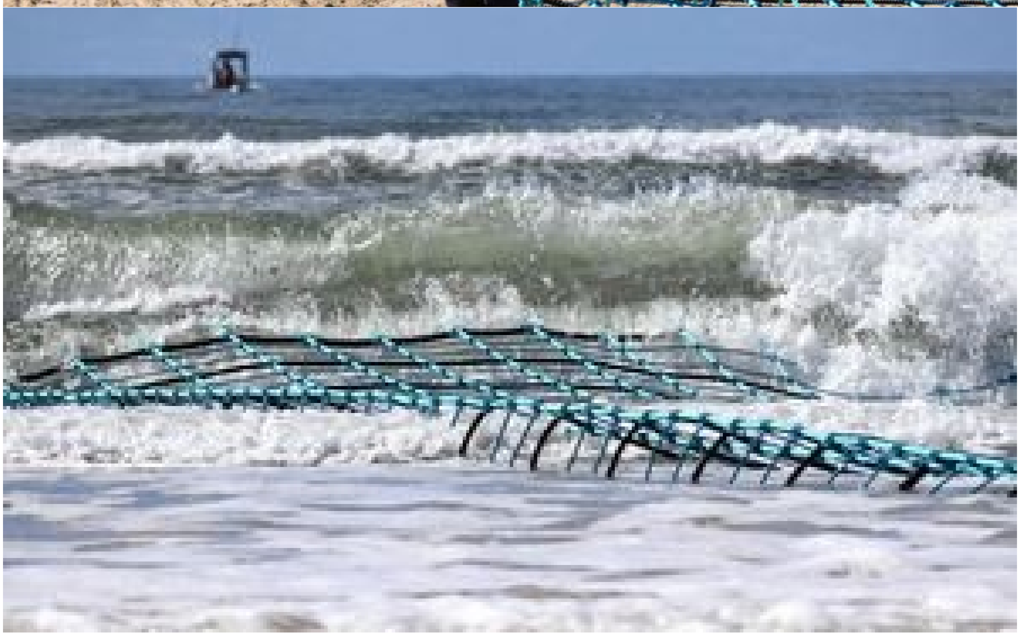

Figure D3 A bionic barrier being installed at Lennox Head and the aftermath during heavy weather

Temporary Barrier Net

At Fish Hoek Bay in South Africa, a temporary net (4 x 4 cm mesh size) is deployed to act as a physical shark barrier at one part of the beach (Davison and Kock (2014). The deployed net is suitable for protecting bathers only due to it being deployed at a relatively protected part of the beach (**Figure D4**). Deploying the net is a labour intensive operation, and the net has been modified a number of times (e.g. adding additional floats to increase buoyancy and vertical positioning in water column and improving the fastening system). These modifications have improved the efficiency of the daily operations and further reduced any risk of entanglements of any animals. Even with these modifications the deployment and retrieval of the temporary net remains difficult and labour intensive.

The advantage of using a temporary net is that the need for it to be designed to withstand all surf conditions is eliminated. However, it is of course only effective when it is deployed and this will depend on the limitations in surf of the vessels required to deploy it. Despite the best design efforts, the potential for the net to entangle wildlife exists, in particular fish. However, in practice this has not been an issue with only three Cape cormorants (*Phalacrocorax capensis*) entangled (S.Waries pers. comm). Nonetheless, the possibility of entanglements would need to be considered in any Queensland deployments.

Figure D4 Temporary Barrier Net deployed at a beach in South Africa. Source: Alison Kock.

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APPENDIX E

AREA-BASED DETERRENTS

Shark Repellent Cable (KwaZulu Natal Sharks Board and Ocean Guardian)

Research on electric deterrents for beach protection was first initiated in South Africa in the 1960s.

In 2010, research in South Africa led by the KwaZulu Natal Sharks Board resumed on overcoming the practical challenges encountered previously with deployment (see Cliff and Dudley 1992 for a discussion of the challenges). The South African National Space Agency (SANSA) undertook consolidation of available knowledge and modelling of electrical field distribution in seawater under different environmental conditions. In 2012, the South African Institute of Maritime Safety was commissioned to confirm the modelling, develop a prototype cable and then construct a full cable. The full cable was installed at Glencairn Beach in October 2014. Glencairn Beach is a small beach between two headlands and is exposed to prevailing wind and waves. Fish Hoek was the preferred location for testing as it was calmer, but concerns were raised there about the impacts of the physical structures on the commercial trek net (beach seine) fishery.

The recent deployment consisted of a large chain weighing down the cable with wave action covering the cable with sand (G. Cliff, pers. comm.). Electrodes vertically rose towards the surface from a depth of approximately six metres (**Figure E1**). The cable was powered by a pack of large truck batteries and driven by the electronic controls housed in a small trailer which was driven on site and connected each day. While there were some teething problems, once these were solved, the cable was reported to function well in terms of maintain its position on the seabed with no damage to the cable occurring. While the cable was successfully deployed, no white sharks were recorded approaching it – either by the resident Shark Spotters or by dedicated automated photography (a photo of the cable area taken every 7 seconds). Therefore, the ability of the barrier to effectively deter white sharks could not be determined, despite substantial efforts.

Further redesign, trialling and monitoring of the shark repellent cable is proposed by the KwaZulu-Natal Sharks Board (G. Cliff, pers. comm.). The redesigning includes development of a cable that is floating with electrodes dropping down, as opposed to the previously trialled approach of having the cable on the seabed with electrodes rising up. This new approach will potentially have the advantage of being able to be deployed on a temporary basis and can this can potentially alleviate interactions with commercial net fisheries.

Building on the research work in South Africa, Ocean Guardian have developed in conjunction with Kwa-Zulu Natal Sharks Board an electric virtual net that they are planning to trial at Busselton (WA) with the support of the local council. The proposed Ocean Guardian Marine Safety Zone approaches create a virtual net with electrode lengths connected to buoys spaced every few metres either by a cable floating on the surface, where the ends or corners of the cable are anchored to the seabed using standard sea anchors (SRC1000) (**Figure E2**), or where each buoy is anchored independently (Beach01) (**Figure E3**). The proposed approach is a partnership between Ocean Guardian and the Kwa-Zulu Natal Sharks Board, and builds on the research and development work undertaken by the latter, including appropriately designed trials off Glencairn Beach (South Africa).

Figure E1 Shark Repellent Cable. Left: cable leaving shoreline, Right: cable floats and controls. Source: Geremy Cliff.

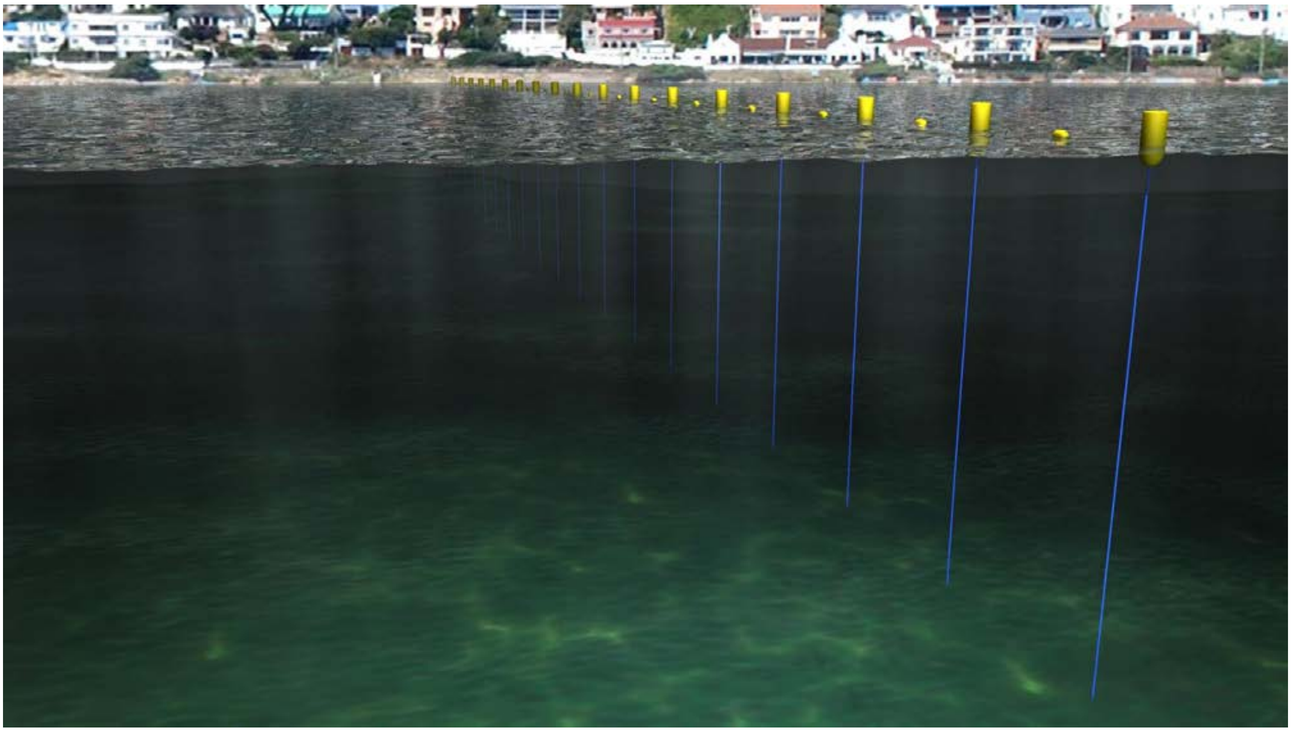

Figure E2 Ocean Guardian SRC1000 virtual net indicative arrangement. Source: Ocean Guardian

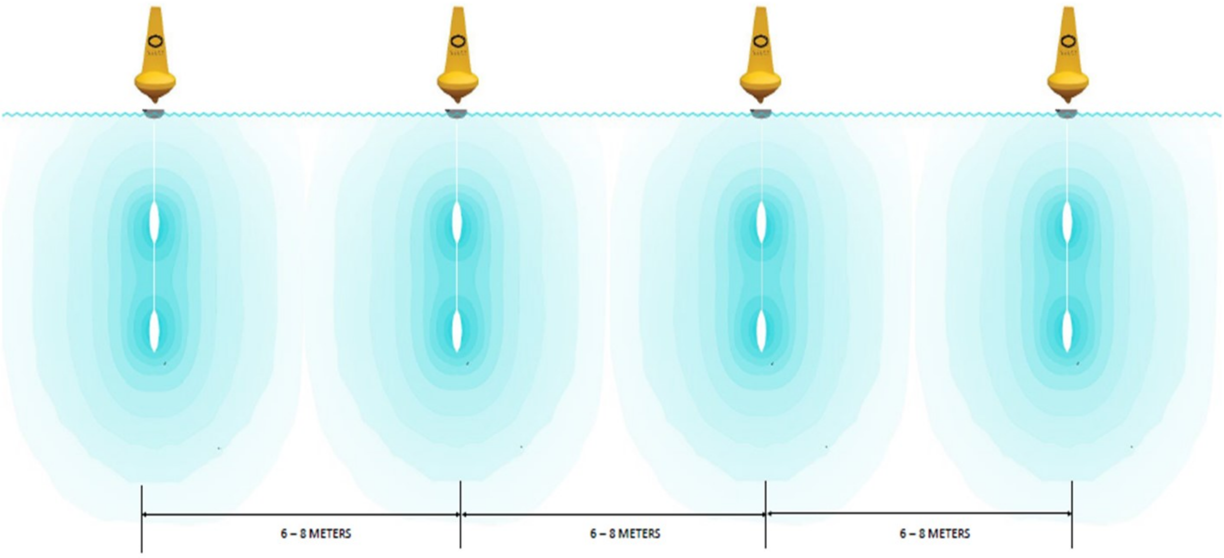

Figure E3 Ocean Guardian Beach01 virtual net virtual net indicative arrangement. Source: Ocean Guardian

Shark Repelling System (Aquatek Technology)

Following the series of unprovoked shark bites in Egypt in 2009, the Belgian company Aquatek Technology was formed to focus on developing an electric shark barrier. Underwater gates produce an electromagnetic field and each unit of the gate is provided with a backup power supply and an alarm that provides notification of any power failures. The approach has been reportedly trialled on various shark species (including bull sharks, white sharks and tiger sharks) in tanks and in the field (reef environment rather than surf beaches), but these trials do not at this stage constitute rigorous scientific experiments. They do however demonstrate proof of concept. The practicality and durability of the Shark Repelling System does not appear to have been tested yet in relevant sea conditions.

Bubble Curtains

Bubble curtains create a visual barrier and this approach showed early promise in tank trials (McCormick 1963), however subsequent trialling identified only very limited deterrent abilities. A bubble curtain works by generating air (e.g. through a compressor) along a submerged perforated hose which escapes from the perforations and rises to the surface resembling a curtain. There are practical challenges in efficiently generating enough air over a length of hose necessary to provide a suitably large barrier, and challenge in maintaining the hose in position in the surf zone. Additionally, the surf zone itself already can contain a large number of air bubbles due to turbulence, and this includes areas that sharks utilise as habitat, so the type stimuli is generally not novel, although the pattern of its delivery will be. No commercially available bubble curtains to mitigate the risk of unprovoked shark bites were identified. As well as being a visual barrier, they may create hydrodynamic cues that sharks respond to through their auditory or lateral line systems. Bubble curtains are also used to mask anthropogenic underwater noise such as from pile drivers and their potential impacts on dolphins (Würsig et al. 2000). The deployment of bubble curtains at a location over an extended period of time may potentially interrupt dolphin communication and affect habitat use by these animals, although as previously identified, bubbles are a natural feature of the surf zone water column. The impact may not be ecologically meaningful but it is still an impact that needs to be considered.

Additional recent work on the potential of bubble curtains as a shark barrier have been undertaken at the University of Western Australia, and while the publication of the results are imminent, they were not available at the time for inclusion in this report.

Sharksafe Barrier

The Sharksafe barrier consists of two key stimuli: grade C9 barium-ferrite permanent magnets and PVC piping to mimic kelp as visual barriers. The piping while anchored to the seafloor moves with waves and currents. The rationale of using both the visual and magnetic components in the barrier is that it may maximise the performance of the barrier across circumstances where turbidity may vary as it produces two distinct stimuli detected by two of the sharks sensory systems. That said, from the trials undertaken the importance of the magnetic component of the barrier is uncertain at best (O'Connell et al. 2014a, 2018) although it may be more important in more turbid waters. Overall, trials of the Sharksafe Barrier have been undertaken using a rigorous experimental design and the findings published in the scientific literature. The size of the barrier constructed and trialled to date was 13 m x 13 m. The results of these trials identified that the Sharksafe barrier is effective at modifying the behaviour of both white and bull sharks with the animals being effectively excluded from the area where they are deployed (O'Connell et al. 2014a and b; 2018). The Sharksafe barrier that incorporated kelp as a visual barrier additionally provided artificial habitat for a range of invertebrates and the Cape fur seal (*Arctocephalus pusillus pusillus*). The barrier proved structurally resilient over a time period of relevant to management (~ 300 days). Rapid biofuling with algae was noted but it was concluded that this does not affect the structural integrity.

The potential for habituation to the stimuli by potentially dangerous sharks still needs to be assessed, especially considering the recent discovery that white sharks enter dense kelp forests when foraging for seals (Jewell et al., 2019). O'Connell et al. (2019) in contrast identify that the density of white sharks is inversely related to kelp density, with white sharks not entering dense kelp beds, but utilising moderately dense beds. In Queensland extensive kelp beds do not naturally occur, and as such a Sharksafe Barrier will represent completely novel habitat that does not have a natural analogy. That along with the high diversity of shark species present means that results from other locations are unlikely to be directly transferable to Queensland. It also needs to be taken into consideration that tiger sharks are known to forage in association with vegetated habitats and are a species of concern in terms of unprovoked shark bites in Queensland.

APPENDIX F
PERSONAL DETERRENT DEVICES AND PROTECTIVE APPAREL

Cardno®
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Shark Shield Range of Devices

The company Ocean Guardian (formerly Shark Shield) makes a range of personal deterrents with models designed for diving, swimming, fishing and surfing (**Figure F1**). A specific model for spearfishers will be available soon. The deterrents produce an electrical field around a person in the water that sharks can detect and potentially respond to by moving away. Current models include the following:

- Scuba7 model for divers.
- Freedom 7 model for divers/snorkelers.
- Freedom + Surf and Surf Mini for surfboards.
- Fish01 for boatbased fishing to deter sharks from biting hooked fish.
- Boat01 for swimmers swimming from the back of a boat.

There have been four studies that have focussed on the shark shield technology and the predecessor of the current devices - the shark PoD. Smit and Peddemors (2003) compared the probability of an attack on a bait fitted with a shark PoD in both the power -on and power-off mode. They concluded that the probability of an attack in at most five minutes was reduced from 0.70 in power-off mode to about 0.08 in power-on mode and in a period of at most 10 minutes from 0.90 to 0.16. Huveneers et al. (2012) undertook independent testing of the Shark Shield Freedom7TM on white sharks using trials to determine its effectiveness on static baits and towed seal decoys. They found that the deterrent increased the time it took to take a static bait and the number of interactions per approach. On average sharks did not approach as close when the deterrent was activated. Tows of a seal decoy showed that the deterrent reduced the number of breaches, surface interactions, and the total number of interactions. Importantly, there was individual variation in behavioural responses to the deterrent. While the results of Huveneers et al. (2012) showed that the deterrent had an effect on white shark behaviour, it did not repel or deter them in all situations and for all individual sharks. This is an important point because although Smit and Peddemors (2003) and Huveneers et al. (2012) document statistically significant changes in shark behaviour which can be interpreted as reducing the risk of a bite on a person wearing a device when it is switched on, it does not translate into 100% protection.

Kempster et al. (2012) found that the Shark Shield Freedom 7™ can reduce white shark interactions with a static bait (under test conditions). Their study also provides evidence that white sharks show habituation to low voltage electric fields, at least over short time scales. However, despite this, sharks continued to be deterred by the Shark Shield™ for the duration of each trial. Importantly, and contrary to the opinion of some members of the surfing community in particular, there is no evidence that the Shark Shield attracts sharks (Collin, 2010; Kempster et al., 2016). Huveneers et al. (2018) identified that Shark Shield Freedom Surf+ under experimental conditions reduced the percentage of baits taken by white sharks from 96% to 40% and was this was the largest reduction of the five approaches designed specifically for surfing they trialled under similar experimental conditions.

In terms of impacts on fish assemblages from the Shark Shield, substantial effects of the electrical field on shallow-reef fish assemblages were not detected (Broad et al., 2010).

Figure F1 Shark Shield devices. Left: surfboard device fitted to rear of the board. Right: attached around the leg of a snorkeler. Source: Lindsay Lyon.

Rpela

The Rpela is a battery-powered electrical deterrent device for surfboards that produces an electric field around the surfer. It is a water-activated device fitted to a socket on the rear underside of a surfboard with a cable imbedded in the core leading forward by one metre to a positive output electrode. Huveneers et al. (2018) tested an earlier version of the Rpela (Rpela v1). Of the five deterrents tested by Huveneers et al. (2018) the Rpela was the only deterrent (along with the Surf +) which sharks reacted to more than the control board, although this difference was not statistically significant.

Following the trials undertaken by Huveneers et al. (2018), the device (Rpela v2) was modified in an effort to improve performance. Modifications were in terms of its electrode size, field propagation, pulse type, duration and frequency. With an electrode size of 50 cm and a frequency of discharge frequency of 14.5Hz, the ability of the Rpela v1 to recharge between pulses was limited and potentially affected the strength of the electric field. By reducing the size of the electrodes and reducing the frequency of discharge in Rpela v2, the strength of the electric field has effectively doubled, as determined by the voltage measured at 1 m from the device.

Testing of the Rpela v2 was undertaken by Cardno at Salisbury Island, Western Australia demonstrated that its current configuration significantly reduced the probability of a bite or interaction, and, when it did occur, the time to bite (inferred from the number of passes). Sharks also kept a greater distance from the bait when Rpela v2 was active. Like the Shark Shield group of products, Rpela v2 did not completely remove the risk of shark bite in the trials undertaken.

Electronic Shark Deterrent System

The Electronic Shark Defense System (ESDS). The ESDS is a portable electronic device which emits an electric field and is used by recreational water users to repel sharks. The device is designed to wrap around the ankle, and consists of a small electronic control unit connected to two square electrodes separated by 10 cm. The device is automatically activated when the electrodes are submerged in seawater, completing the electric circuit, which results in the generation of an electric field thought to be repellent to sharks.

Egeberg et al. (2019) tested the ESDS on white sharks in South Africa. They found that the ESDS had limited meaningful effect on the behaviour of *C*. *carcharias*, with no significant reduction in the proportion of sharks interacting with the bait in the presence of the active device. At close proximity (< 15.5 cm), the active ESDS did show a significant reduction in the number of sharks biting the bait, but this was countered by an increase in other, less aggressive, interactions.

The ESDS is now rebranded as “No Shark” and the manufacturer reports that they have improved the device. There is no independent testing of the modified device.

Sharkbanz

Sharkbanz incorporate strong magnets (Grade C8 barium ferrite; BaFe2O4) in a wrist or ankle band-personal device. The manufacturer identifies that the device is likely to be effective at deterring “hit and run” bites in murky water from sharks such as bull sharks, but this is of only limited effectiveness at deterring an ambush predator such as the white shark. Sharkbanz are actively promoted on social media and user driven content.

Huveneers et al. (2018) tested the efficacy of both the SharkBanz bracelet and the leash and found that neither affected the behaviour of white sharks or reduced the percentage of baits taken. This suggests that magnets are unlikely to be effective at deterring sharks because they will only protect close to the magnet, limiting their applicability as personal deterrents. Magnetic flux declines rapidly with distance from a magnet and Huveneers et al. (2018) identified that sharks would need to be less than 30cm away from a magnet contained in a Sharkbanz to act as a real deterrent. Given the limitations of magnets as a shark deterrent is related to the physics of magnetism, opportunities to enhance the device was still making it practical and safe to use appear limited. Further independent field testing using appropriate controls could be trialled on other species, however, the limited area of the magnetic field generated by Sharkbanz still appears to negate its efficacy.

RepelSharks

RepelSharks is a personal chemical deterrent available in aerosol cans that when released covers a broad area, at least for a short period of time until it disperses. The small aerosol can be worn by a diver, snorkeler, diver or spearfisher and the chemical released if they are being threatened by a shark. It is a manufactured chemical that is based on necromones in decomposing shark tissue which contains high concentrations of acetic acid in addition to a large array of amino acids, short chain and fatty carboxylic acids, amines and short chain lipid oxidations products (Stroud et al., 2014). The chemical deterrent has been trialled and shown to disperse competitively feeding Caribbean reef sharks (*Carcharhinus perezi* and *C. acronotus*). It is plausible that for shark species that scavenge on conspecifics, necromones may be a feeding stimulant. Given this potentially includes white and tiger sharks, further testing would be required before it could be considered in Queensland.

BCB Shark Repellent Survival Kit

The BCB Shark Repellent Survival Kit is a chemical deterrent releases an acetate solution and a cloud of black dye when the foil packet is squeezed in the water and is purported to be recommended for use by NATO. It appears to be identical to the 'Shark Chaser" which was shown to be ineffective at repelling sharks, although it may have been useful as a "psychological crutch" (Baldridge Jr. 1990; Smith Jr. 1991).

Chillax Wax

Chillax Wax made by the Common Sense Surf Company is a combination of eucalyptus, chilli, cloves, cayenne pepper, neem, tea tree oil, citronella, coconut, and beeswax is placed on the deck of surfboards, and the odour is allegedly dispersed as surfers paddle or sit on their board. Chillax Wax purports to mask the odour of surfers by overwhelming the shark's olfactory organs with odour atypical of their natural prey. None of the ingredients represent stimuli that are biologically relevant to sharks, and there is no specific rationale as to why the ingredients have been chosen for use. Huveneers et al. (2018) determined that Chillax Wax was not enough to dissuade an approaching shark to take the bait. While there are some potentially confounding factors in the work of Huveneers et al. (2018) for assessing the efficacy of Chillax Wax in relation to providing olfactory cues (tuna) to attract white sharks to the test apparatus, without further data there remains little *a priori* reason to expect Chillax Wax to be effective.

SAMS Warning TM and SAMS Cryptic TM Wetsuits

There are two wetsuit patterns currently marketed by Shark Attack Mitigation Systems (SAMS) - the SAMS Warning TM and the SAMS Cryptic TM (**Figure F2**). These designs are also utilised in products other than wetsuits including surfboard stickers and underlays, and swimwear. The SAMS Cryptic design is purported to make it difficult for the shark to see the wearer in the water column by using disruptive coloration and shaping from the visual perspective of a shark. The pattern is not only purported to be difficult for the shark to see, but is also designed to blend in with the background colours. The SAMS warning design is intended to overtly present the wearer as unlike any shark prey, or even as an unpalatable or dangerous food option.

While the wetsuit designs are based on knowledge of the shark visual system, the patterns designed to hide humans from sharks' view may reduce contrast, it is unlikely that a silhouette would disappear completely. Further the importance of visual cues and how sharks perceive such cues is likely to vary based on turbidity and in areas where turbidity is relatively high bull sharks can occur. Overall, both wetsuits designs have not been subjected to rigorous published experimental trials that can support their efficacy as a deterrent. In terms of the SAMS Warning TM design wetsuit designs based on the concept of animals considered to be dangerous to sharks are also questionable. A black and white banding pattern, meant to mimic a venomous sea snake, would only be useful to predators that are in some way affected by the potentially dangerous prey. The venom and venom apparatus of sea snakes is designed to capture prey and not deter predators (the animal is venomous not poisonous). In fact, sea snakes were the most commonly represented prey item in stomach content analysis of tiger sharks in Shark Bay, Western Australia (Heithaus 2001). Any deterrent effect is unlikely to be a result of biomimicry.

Figure F2 The SAMS Warning TM (left) and the SAMS Cryptic TM (right) wetsuits. Source: Craig Anderson.

Shark Eyes

Shark eyes is a visual deterrent for surfboards, and as the name suggests it consists of two pairs of eyes on the bottom of the surfboard (**Figure F3**). According to the manufacturer, it is designed to mimic human eye contact, making the shark feel like it has been spotted, thus taking away their element of surprise. Shark eyes have not been the subject of independent scientific assessment.

Figure F3 Figure caption Shark eye product on a surfboard (source https://sharkeyes.com.au/our-story/)

Protective Apparel

Unlike other approaches discussed, protective apparel does not reduce the probability of a bite occurring, rather they reduce the consequences should a bite occur. Currently there are a number of products in development but none that are commercially available. At least one product has been independently tested by Flinders University with positive results reported to date, although with further work required (C. Huveneers pers. comm). If the protective apparel clearly proves to be effective and practical for use, it represents an advancement highly suitable for divers, spearfishers and snorkelers. For the dive tourism industry, the provision of such wetsuits to customers potentially represents an additional safety measure that doesn't require a customer to wear any additional gear over and above wetsuits which are currently worn.

APPENDIX G
OTHER ALTERNATIVE SYSTEMS

Smart Drumlines

An additional method to mitigate the risk of unprovoked shark bite is deployment of the SMART Drumline in an area. This approach differs from those discussed elsewhere in this report in that it is not a deterrent or a barrier, but rather it is a method of capture with the aim of relocating the shark through a system designed specifically to substantially reduce the mortality of animals captured by a drumline. The fishing gear is composed of classical material used for a standard drumline, however the mooring buoy itself is designed to detect when an animal such as a shark has been captured on the drumline and relay a message to shore that a capture has occurred in real time. A triggering magnet is attached to the communications unit. When a shark takes the bait and puts pressure on the line, the magnet is released alerting a relevant personnel that there is an animal on the line. Once alerted, the team responds immediately (within 30 minutes in NSW and WA) to tag and release the shark or other marine animal. The mooring buoy is solar powered. Data recorders (VR2W) can also be deployed with buoys and therefore simultaneously collect information on the presence of tagged sharks that are not captured.

Smart Drumlines have been trialled at Reunion in depths of 10 to 30 metres including directly behind the surf break. A constraint with the approach is that it can only be effective if sea conditions do not prevent a contractor immediately attending the drumline to deal with the captured animal. There may also be practical challenges of requiring a contractor to be on standby and able to rapidly tend the drumline when a capture occurs. While the number of animals currently captured by Smart Drumline is relatively low, **Table C1** identifies that the survival of captured animals is considerably higher than that recorded in Queensland using standard drumlines.

SMART drumlines have been trialled in NSW and Western Australia. In NSW trials have been undertaken on the NSW north coast, Newcastle, Sydney and the Bega Valley region. Data on the trials are freely available with data from the NSW north coast being the most comprehensive. For the north coast trial between December 2016 and April 2019 up to 35 SMART drumlines were deployed and a total of 359 animals were caught with the most frequent species caught being the white shark. Survival rates of captured animals was high with only two white sharks that did not survive and a single mortality of a captured common blacktip shark and a black marlin. Sharks that are tagged and relocated move away from the coast for an average of 74 days before they are again detected on a VR4G. Post-release, the distance of the shark from the tagged location to the location of the VR4G was an average of 165 km (NSW DPI, 2018).

In Western Australia, ten SMART drumlines are deployed evenly across 11.5 kilometres of coastline in the State's South West, about 500 metres offshore from Hangman's surfbreak north of Gracetown to Ellensbrook in the south. The trial met with community concerns and protests initially although there were also protests urging their implementation[8]. The final scientific framework of the trial was decided following community consultation. The trial commenced on 21 February 2019 and is expected to run for 15 months. Weather permitting, SMART drumlines are deployed and retrieved each day, during day light hours. The drumlines are continuously monitored while in the water and positioned to allow a vessel to attend within 30 minutes of an alert being received. While the trial has not been completed, the monthly reports provide relevant information[9]. A total of 177 alarm activations occurred and resulted in 78 sharks and rays caught (44% success rate) between February and June 2019 with all released alive. A response time of under 30 minutes was not always achievable with the main reason being multiple alarms being activated within a short period of time. The cost of the trial is reported to be $3.84 million with the contractor being paid more than $6,000 per day[10].

SMART drumlines have higher "fishing power" than standard drumlines. This is because the ability of a standard drumline to catch a shark requires the presence of a bait and that bait remaining in a suitable condition that attracts a large shark. A contractor has no way of knowing in real time whether a bait remains present and suitable and as such a standard drumline may spend an amount of time not actually fishing. In the case of SMART drumlines this problem is largely eliminated and allows greater fishing efficiency. What

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[8] Examples include: https://www.watoday.com.au/national/western-australia/hundreds-protest-for-smart-drumlines-to-protect-wa-from-sharks-20180509-p4ze8t.html and https://www.busseltonmail.com.au/story/5779204/was-smart-drumlines-under-attack-from-shark-group/

[9] https://www.sharksmart.com.au/research/smart-drumline-trial/

[10] https://www.perthnow.com.au/news/sharks/smart-drum-lines-contractor-to-be-paid-6000-a-day-to-catch-sharks-in-was-south-west-ng-b881085866z

this means is that relative to standard drumlines, a smaller number of SMART drumlines can be deployed to obtain more or less the same catch.

Table G1 A comparison of survival rates of animals caught on Smart Drumline in Reunion with those caught by standard drumlines in Queensland. Source: David Guyomard (Reunion Island Regional Committee for Sea Fisheries and Aquaculture).

Species	Number of individuals caught		Survival rate (% of individuals found alive on the hook when retrieved)	
	Queensland (Sumpton et al. 2011)	Reunion – Smart Drumline	Queensland (Sumpton et al. 2011)	Reunion - Smart Drumline
Bull shark *(Carcharhinus leucas)*	79	9	25.9 %	100 %
Sandbar shark *(Carcharhinus plumbeus)*	28	2	10.7 %	50 %
Tiger shark *(Galeocerdo cuvier)*	485	16	31.0 %	100 %
Scalloped hammerhead *(Sphyrna lewini)*	11	4	0.0 %	50 %
Stingray (*Dasyatis sp.)*	-	15	-	100 %
Other unidentified rays	8	-	50.0 %	-

APPENDIX H
ACTIVE PATENTS

Cardno
Shaping the Future

Australian Patents (Active)				
Name	Date	Company/Contact	Type	Patent No
Shark Resistant Composite Fabric	10/4/19	Haydon Burford	Personal protection	2019901237
Shark Proof Swimming Enclosure	9/4/19	Gregory Webber	Area Barrier (physical)	2019901221
A Shark Barrier	24/3/17	Stellenbosch University	Area Barrier (physical)	2017243768
A Shark Self Defence Tool	8/9/17	Eduardo Marquez	Personal protection	2017225122
Radio Transmission Based Shark Alert System	19/12/17	David Cave et al.	Shark Detection	2017101768
Image Generating Shark Deterrent for watercraft	30/11/17	Robert Carraro	Personal (visual) deterrent	2017101672
Shark Deterrence Safety Modification	17/11/17	Scott Beith	Personal (visual) deterrent	2017101617
Marine predator repellent apparatus and system	16/6/16	Ignatius Hartzenberg	Area Barrier (electric)	2016281201
Shark Detection System, Apparatus, and Method	26/10/16	Allen Bennetto	Shark Detection	2016250364
Puncture and cut resistant material	3/5/12	John Sundnes	Protective apparel	20063407892

International Patents (Active)				
Name	Date	Company/Contact	Type	Patent No
Wave-riding vehicle with shark locating and repelling system	8/6/10	Guerry L. Grune	Personal (electric) deterrent	US7731554B2
Personal water activity apparatus with variable light display for protection against sharks and other water-borne predators	3/7/07	Mark A. Brodsky	Personal (visual) deterrent	US7238075B2

Shark repellent and preparation method thereof	23/6/17	Unknown	Personal and area (chemical) deterrent	CN106879612A
Swimming suit	4/12/18	Unknown	Personal (visual) deterrent	CN201820321984
Shark repellent system	18/8/15	Anantha Pradeep	Personal (visual) deterrent	US9108707B2
Shark repellent	31/3/11	Kim Joo Sik	Personal (electric and chemical)	WO2011037328A2
Wearabel (sic) shark repellent	17/2/16	Unknown	Personal (electric) deterrent	KR101594527B1
Shark repellent	28/2/19	Shree K. Kurup	Personal (chemical) deterrent	US20190059391A1
Anti-shark net for bathing beach	4/9/13	Unknown	Area Barrier (physical)	CN203172878U