NSW Shark Management Strategy and Shark Program Review

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Prepared for

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Cardno®

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Conflict of Interest Statement

The individual authors of this report, and Cardno, have previously assisted manufacturers of shark bite mitigation systems but have no ongoing financial relationships with these entities. This includes manufacturers or distributors of area-based deterrents, detectors or personal deterrent devices.

Executive Summary

New South Wales (NSW) Department of Primary Industries (Fisheries) (DPIF), part of the Department of Regional NSW, commissioned Cardno (NSW/ACT) to undertake an independent evaluation of the five-year 2015/16-2019/20 Shark Management Strategy (SMS) and the Shark Programs of 2020/21 and 2021/22. The SMS and Shark Program were implemented to provide protection from target sharks to swimmers, surfers and other water users at NSW coastal beaches whilst minimising harm to other marine fauna. Target sharks include White Sharks (*Carcharodon carcharias*), Bull Sharks (*Carcharhinus leucas*) and Tiger Sharks (*Galeocerdo cuvier*) given these have most frequently been involved in serious shark bites in NSW.

The scope of works (SoW) included the following components:

1. Review and assessment of the performance of the NSW Shark Management Strategy including:

    a. Assessing the effectiveness of mitigation measures on the number of shark incidents; and

    b. Assessing the cost-effectiveness of mitigation measures against the economic impacts of shark interactions on the NSW community.

2. Review the new information (including social research) and technologies generated since a report was prepared by Cardno (2015) and summarise the implications of that new information on the future direction and approach of shark mitigation in NSW, and provide recommendations for their potential future use in mitigation of shark incidents in NSW:

3. Conduct an analysis of NSW, other Australian states and territories, and other international jurisdictions to compare and contrast:

    a. Shark mitigation approaches used across those jurisdictions and their efficacy for reducing shark interactions;

    b. The underpinning regulatory frameworks that support shark mitigation programs;

    c. Funding arrangements for shark mitigation approaches and programs; and

    d. To what extent community preferences inform shark mitigation approaches and programs.

4. The review is to inform consideration by the Government of ongoing funding for shark mitigation measures for 2022-23 and beyond, including any associated regulatory mechanisms to operationalise the program in NSW.

The Shark Programs of 2020/21 and 2021/22 include the Shark Meshing (Bather Protection) Program (SMP) in the Sydney, Newcastle and Wollongong ("Metro") area as well as a range of options for mitigating unprovoked shark bite identified in the five-year SMS trials and research program. Compared with historical circumstances, the program has adapted to changing circumstances with shark interactions and public perceptions and covers a larger geographic area including areas where no mitigation previously occurred: this was due to increasing incidence (since 2014) of shark bite (particularly from White Sharks) to surfers on the NSW Far North and Mid North coasts. This 'paradigm shift' is significant and has required a greater government investment using a broader range of approaches to address the risk of shark-human interactions. In 2021/22, the Shark Program has expanded state-wide, based on findings from the SMS and recent community consultation, conducted in early 2021.

Consistent with similar programs in other jurisdictions and with recommendations made by Cardno (2015) and by BMT (2018), DPIF has trialled and then adopted a range of approaches including education, research and mitigation via the SMS and Shark Programs. This approach is comparable to programs in Queensland and Western Australia, although investment, research and trialling of alternative (to catch and kill) shark bite mitigation gear by the NSW Government exceeds those other states. The SMS research program that underpins the current Shark Program is of a suitable standard as identified by bibliometric analysis of output.

It is sufficiently broad and multi-disciplinary, given the limitations inherent in mitigation of unprovoked shark bites. The research has directly informed uptake or discontinuation of some of the trialled mitigation options.

In addition to the SMP nets deployed at 51 beaches within the Metro area, the Shark Program for 2021/22 includes a significant state-wide expansion of the non-lethal area-based shark bite mitigation gear that has resulted from SMS trials and research (i.e. SMART drumlines, drones and VR4G listening stations). The gear is deployed in areas popular to water users and/or where significant shark bites have occurred and will include 170 SMART drumlines, 37 VR4G shark listening stations and drone surveillance (by Surf Life Saving NSW) at 50 beaches. The Shark Program for 2021/22 includes education and awareness strategies, including funding for Surfing NSW to provide the tools and training to increase protection for their boardrider clubs and surf schools, and it will continue to be supported by research, including tagging of target sharks.

Dudley (1997) analysed shark attack rates in the three areas of the world where shark nets have been deployed (QLD, NSW and South Africa) and indicated that, in the NSW SMP region, the annual number of shark attacks decreased substantially (from 0.35 to 0.04, i.e. ~90%) on a per year per beach basis between the period before (1900 – 1937) and after net deployments (1937 - 1997). Subsequent investigations of historical Australian shark attacks have increased the number of interactions within the SMP region during those early post-netting years. Since 2000, nine interactions in the Metro region have involved swimmers and 25 involved surfers. Twenty-nine (85%) of these occurred at netted beaches while five occurred at non-netted beaches. Notably, most of the interactions with swimmers were with Wobbegongs. Thirteen of 18 (72%) interactions with surfers involved target sharks or unidentified sharks at beaches which had nets deployed at the time of the incident. This highlights that shark nets do not eliminate the risk to surfers from target sharks, corroborating the NSW Government messaging that a suite of mitigation measures is required to minimise interactions. The ratio of bycatch to target sharks in SMP nets is high (~ 10:1) and community support for nets is limited. The findings of SMS net trials on the NSW north coast were similar.

At the beaches where drones have been trialled by Surf Life Saving NSW the data are compelling. There were no bites between sharks and water users on drone fly days at these beaches and there were numerous situations, particularly in the Far North and Mid North regions, where, after drones spotted a potentially dangerous shark (i.e. a target shark or large shark that could not be identified), that a warning was issued to water users (e.g. shark siren) and where life guards evacuated water users from the ocean. Given there were interactions (bites or other physical contact between sharks and humans or their surfboard) at many of these beaches, particularly in the Far North and Mid North regions, in a comparable period before the drone trials commenced and during the period of drone trials but on 'non-fly' days, the drones and the resultant warnings and evacuations have undoubtably been effective at reducing, if not 'eliminating', shark bite to water users. Drones are also very popular with the community as evidenced by stakeholder opinion surveys conducted by DPIF and independent researchers (e.g. Stokes et al., 2020).

Data for evaluating the effectiveness of SMART drumlines are also indicative of having an effect. At beaches in the Far North region where SMART drumlines have been deployed for approximately five years since December 2016, and in the eight other regions where SMART drumlines were trialled under the SMS, there have been no interactions when the gear was operating, compared with 11 interactions in the Far North region within a similar period prior to the initial deployment. Notwithstanding, there were three interactions at beaches in the Far North region that occurred either very early in the morning before SMART drumlines were deployed for the day, or on days where the operator considered conditions were too rough to deploy the gear. Those interactions are reflective of the primary limitation of SMART drumlines which is that they are unable to be deployed during all daylight hours and for all days of the year if conditions for their deployment, checking and retrieval are not suitable.

The effectiveness of VR4G tagged shark listening stations as a shark bite reduction system is not apparent. At most beaches where VR4G shark listening stations were deployed there were marginally fewer interactions compared with a similar period prior to their deployment, however in the South region there was actually an increase in interactions. The tracking data from the VR4Gs has however, been one of the most effective tools for communicating to the public that target sharks are not resident to a beach but in fact undertake annual movements covering hundreds to thousands of kilometres. They have also demonstrated that despite the 'north-south' and 'south-north' movements and the 'winter-spring' and 'summer-autumn' peak abundances of White Sharks, and Tiger and Bull sharks, respectively, these target species can occur anywhere on the NSW coast at any time of the year.

Although helicopter aerial surveillance is no longer part of the current Shark Program, it is also noted that during the SMS trials these resulted in evacuations of water users on the Mid to Far North regions of NSW and were popular with a large section of the community.

The cost effectiveness of the program should be measured in terms of human lives saved or injuries avoided although public confidence in beach safety is important as it contributes to the desirability of a location for tourism spend and shark bite mitigation can also have costs in terms of impact to marine wildlife (including threatened species). In life insurance terms, an intervention that costs less than $5.1 million per annum is cost effective in terms of saving a single life. This value does not suggest that an investment of $5.1 million or less per annum is sufficient or cost-effective. As discussed in this report, a case exists that the value of human life estimated by the Commonwealth Government is an underestimate. Further, although it is difficult to quantify the number of lives saved, it is plausible that more than one fatality per year is prevented in NSW by the Department's shark bite mitigation program. Additionally, it is highly plausible that shark bite mitigation activities in NSW prevent serious injuries that can have an additional economic cost. The program also contributes to public confidence in beach safety, including in regional coastal communities, and this can have economic benefit for tourism in coastal communities at the local and regional scale.

The NSW Government investment in the SMS was $16.1 million over five years, with a further $8 million on the Shark Program in 2020/21 and an increased investment of $21.4 million in 2021/22. Over its five-year life the NSW Government investment in shark bite mitigation through the SMS, the Far North Coast net trials and the SMP was about $27 million. These programs needed only to have prevented four or more fatalities and/or tens of people being severely injured to have been cost-effective. Given the results from the drone and SMART drumline trials, and the four fatalities in 2019/20 and 2020/21 at areas with little if any shark mitigation, it is highly plausible. Moreover, given the SMS focused only on mitigation systems that have little or no impact on target sharks and other marine life, it has caused no measurable harm or costs to the marine environment or wildlife (including threatened species). It also provided considerable potential benefit to the public in having the option for a closer relationship and understanding of sharks in NSW waters. Overall, the Shark Program has, and in its current form will continue to have, a considerable net benefit.

Given its effectiveness, the Shark Program for 2022/23 should continue to deploy area-based shark bite mitigation gear in areas popular to water users and/or well-known for shark bites as per the Shark Program for 2021/22, supported by research and the SharkSmart education and awareness program. Notwithstanding this, DPIF could consider rationalising some components of the program in the future based on past lessons learned and those that can be learned in the Shark Program for 2021/22 and 2022/23. A monitoring, evaluation and reporting (MER) framework with indicators suitable for measuring the performance of the Shark Program would provide the basis for rationalisation. Specific issues that may be limiting the effectiveness of VR4G tagged shark listening stations need to be resolved as soon as possible so that an informed decision can be made about whether to continue to include VR4Gs in the future Shark Program as a risk mitigation tool. The issues of immediate concern are the small number of VR4Gs deployed (noting the numbers are planned to increase from 21 to 37 across the coast in 2021/22), the level to which users of the SharkSmart app rely on the VR4G information in their decision making and whether the level of tagged sharks relative to untagged sharks may give users a false sense of security about the potential proximity of target sharks at or close to beaches where VR4Gs are deployed. The role of VR4Gs in contributing to shark research is acknowledged, but a proportion of this contribution is outside the direct role of mitigating unprovoked shark bite.

There is also strong community and local council sentiment in regard to removing the nets in the Metro region and replacing these with non-destructive shark mitigation gear, especially drones and SMART drumlines. The evidence indicates, albeit only over a period of about six years, that SMART drumlines maximise the catch of target sharks, maximise the survival of marine life that interacts with the gear, and minimises the catch of non-target animals. SMART drumlines have demonstrated that they are more effective than nets at intercepting target sharks before they can interact with beachgoers, which is the closest surrogate available for 'reducing the risk' to water users, which is all but impossible to quantify. The two six-month trials of nets alongside SMART drumlines on the Far North Coast determined that the catch per unit of effort on SMART drumlines was 15 and 32 times greater, respectively than nets. SMART drumlines also minimise harm to the environment, with survival-at-point-of-release at approximately 98.5% at beaches where the gear is deployed, providing additional benefits to the Critically Endangered east coast population of the Grey Nurse Shark (*Carcharias taurus*), endangered and vulnerable marine turtles and hammerhead sharks, and the Vulnerable White Shark. Notwithstanding the environmental advantages of, and community support for, replacing nets with non-destructive shark bite mitigation gear, and given that nets have been effective at reducing the frequency of shark bite in the Metro region since installation (Dudley, 1997), the Government would need to monitor factors contributing to potential increases in interactions in the SMP region if the nets were to be removed, and have adaptive processes in place to mitigate risk if it became a concern in the future.

Notwithstanding the success of the Shark Program at reducing incidents at beaches where area-based mitigation gear is deployed, a lesson learned from this review has been that a fair proportion of the total number of incidents in NSW occur to surfers at beaches where or when the gear is not deployed, particularly on the mid and north coasts of NSW. The NSW Government should consider greater focus on reducing interactions to this group of water users in remote areas, and potentially recognise surfers as a key stakeholder group for shark bite mitigation.

There are limitations to how far and wide area-based deterrent systems can be deployed. For example, Surf Life Saving Clubs, which are the current base for drone surveillance, occur at <30% of the beaches in regions outside of the Metro region and only at 10% of beaches in the South region. There are also logistical challenges to servicing SMART drumlines in many remote areas and/or those with limited port access. The social research showed that the community sentiment was that government has a responsibility to protect the public from the risk of unprovoked shark bite, but many people, particularly surfers, also considered that it was a collective responsibility by government and individuals in more remote locations. Given these sentiments, the NSW Government needs to be clear in how it conveys its messaging to the community about the limitations to its role (e.g. 'no silver bullet') and that irrespective of where and what measures the Government implements, there should always be a presumed collective responsibility when entering the ocean (e.g. to be SharkSmart).

A suitable approach would be to convey the concept of the Shark Program as a 'hierarchy of protection', similar to what is used in Reunion and already used in the Shark Program in an informal, stakeholder engagement level. A potential three-tiered concept for the NSW Shark Program, that incorporates the tools available to it, would be to consider mitigation as (see **Figure ES1**):

> ***Tier 1 - Perimeter.*** *Reduce spatial overlap between water users and target sharks.*
>
> This is currently done in the Shark Program using lethal (i.e. beach netting in the Metro region) or non-lethal approaches (e.g. VR4G shark listening stations, drones, SMART drumlines) and with research, community education and engagement that results in shark smart human behaviour.
>
> ***Tier 2 - Proximity.*** *Reduce likelihood of shark bite when beach-based overlap between water users and target sharks cannot be avoided.*
>
> This relies on product development, technology, education and community engagement resulting in greater uptake of existing, effective personal deterrent devices than is current.
>
> ***Tier 3 – Prevent bleeding.*** *Reduce the impacts of a shark bite when one has occurred.*
>
> This relies on people using puncture- or tear-proof wetsuits or being trained in suitable first aid to prevent death from bleeding.

This concept acknowledges that in Tier (1) it is impossible, even at beaches with drones, nets, SMART drumlines, or other gear, to reduce the spatial overlap between water users and target sharks by 100%, except if people stay out of the water or potentially by having barriers (which were proven in the SMS to be unfeasible on the exposed coastal beaches of NSW). Tier (2) is another layer of protection available to water users that becomes important when Tier (1) has not been 100% effective, or is not in operation (e.g. in remote areas). Modelling has also shown that across Australia, potentially more than 1,000 people by 2066 could avoid being bitten if all water-users wore effective personal shark deterrents. Tier (3) is a final layer of protection that comes into play if a shark bite was to occur. Tier (3) aims to reduce the impact of a shark bite injury by stopping uncontrolled bleeding from upper and lower torso injuries which is the common cause of fatalities. This can be done either by wearing puncture- and tear-proof wetsuits or by applying suitable first aid. Although not yet readily commercially available, trials of puncture- and tear-proof wetsuits show great promise with a number of products in development. Injuries may still occur due to the pressure of the bite, but the products reduce the chances of bleeding. In terms of improving access to adequate first aid, this would involve educating people about new techniques that can reliably completely stop or substantially reduce blood loss in severe limb injuries.

Although the Shark Program for 2021/22 already includes the components of Tiers (1) and (2) in its approach (i.e. drone, VR4G, SMART drumline deployments, beach meshing and some information about personal deterrents on the SharkSmart website and App), the hierarchical concept would simplify messaging to the public about the importance of Tiers (2) and (3), particularly where Tier (1) is not available. As it currently stands, the Shark Program focuses heavily on Tier (1) mitigation and provides only limited advice about personal deterrents that people could consider. Tier (1) is essential and must be retained but with some rationalisation (see below). We recommend that more resources are allocated to facilitating awareness of the importance of Tiers (2) and (3) mitigation measures, particularly to fill in the gaps left when Tier (1) is not present, or may never be available, at some beaches. We consider it likely based on the study by Huveneers et al., (2018) that had effective personal deterrents been used more often on the Mid and Far North coasts, then it follows that risk of bites by White Sharks to surfers that occurred in recent years might have been reduced substantially.

The role of education and awareness in mitigating the risk of shark bite cannot be overstated. Shark awareness is crucial to ensuring that people know how to reduce their personal risk through their behaviour (whether that be avoiding swimming/surfing at times of greatest risk or when to consider using a personal deterrent, or being able to respond to a shark bite in a timely manner with suitable first aid/trauma kit). It remains a key part of the Shark Program for 2021/22 as it would be under the hierarchal concept. There is a role for the educational and awareness component of the NSW Shark Program in the future to do this while balancing the perception of commercial endorsement of a specific product as well as communicating the need for individuals to take responsibility for their own safety in some areas. The education component already communicates the importance of independent trials of personal deterrent devices, that these trials were robust and that the results of testing provided meaningful reductions to risk (with appropriate caveats). Links to the studies that have undertaken independent testing can continue to be provided. This information can be provided in a fact sheet like that currently available on the SharkSmart webpage and may contribute to greater certainty for consumers and facilitate more effective evidence-based consumer choices. Notwithstanding this, it is apparent from the currently limited uptake by surfers that there are likely to be other challenges in promoting meaningful uptake of these devices among surfers that will need to be overcome, including: dispelling myths and disinformation; managing over-confidence when using a device (such as surfing in areas such as river mouths or when schools of baitfish are nearby); and promoting maintenance and regular servicing and testing of devices that will be critical to performance.

In terms of other (newer) technologies that could also be considered for the Shark Program, electric barriers based on Shark Shield® technology are understood to be close to commercial readiness and advances in multi- and hyper-spectral imagery may improve shark detection in aerial surveillance. It is clear from the social research that community groups, coastal Councils and other organisations want to have a say in the type (and amount) of mitigation deployed within their jurisdictions and in some cases this will inevitably lead to requests to Government for more or different gear and support in different locations that is beyond current budget. Understandably, since the cluster of shark bites in 2014/15 on the north coast, the NSW Government's approach to shark bite mitigation operations outside of the SMP area has been discretionary and evolving in response to lessons learned as well as incidences. Enacting the Shark Program in legislation would be advantageous to governance in terms of defining a minimum scope of activities, enhanced certainty regarding operational needs, funding needs to meet legislative requirements, reducing Government approvals and 'red tape', and enabling the program to be responsive to the economic, environmental and social needs of the community

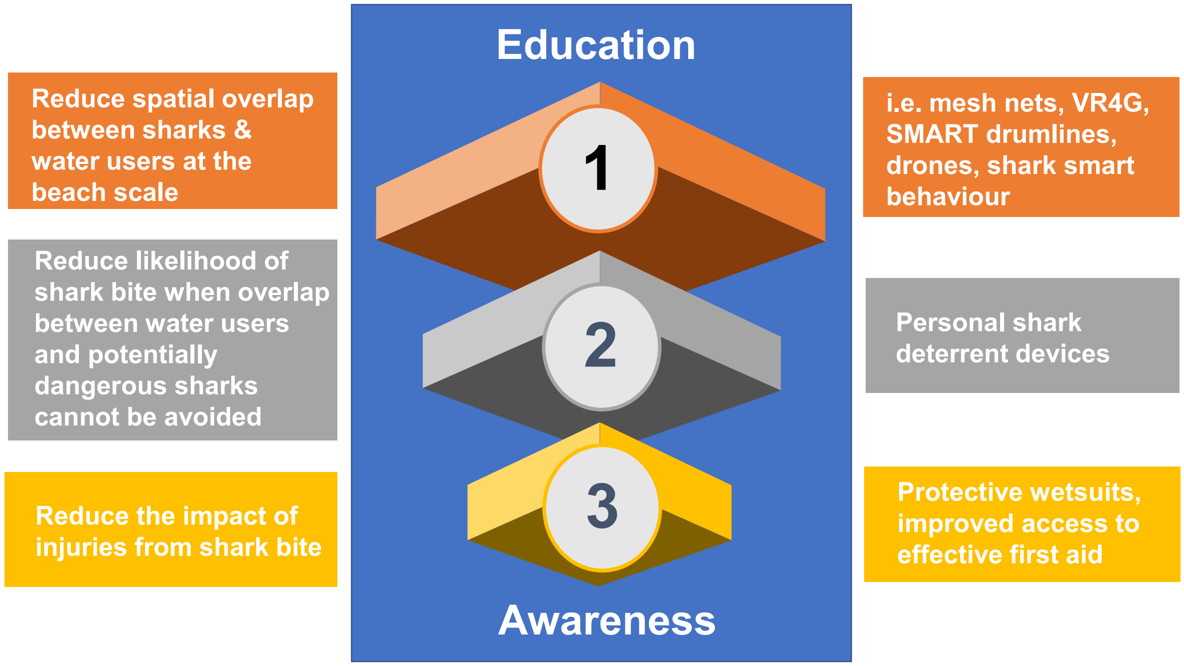

Figure ES1. A proposed hierarchical (three-tiered) concept for mitigating the risk of shark bite

Based on the review, recommendations are given below (numbering does not indicate priority).

Recommendation 1

The Shark Program for the future continues to deploy area-based shark bite mitigation gear in areas popular to water users and/or well-known for shark bite as per the Shark Program for 2021/22, supported by research and the SharkSmart education and awareness program, but considers rationalising some of its components (see Recommendations 3, 4, 7 and 8).

Recommendation 2

The SharkSmart campaign of the Shark Program should consider conveying the Government's approach as a three-tiered hierarchy of protection supported by education and awareness:

> ***Tier 1 - Perimeter.*** *Reduce spatial overlap between water users generally and target sharks.*
>
> This is currently done in the Shark Program using lethal (i.e. beach netting in the Metro region) or non-lethal beach protection gear (i.e. VR4G shark listening stations, drones, SMART drumlines) and with research, community education and engagement that results in shark smart human behaviour.
>
> ***Tier 2 - Proximity.*** *Reduce likelihood of shark bite when beach-based overlap between water users and target sharks cannot be avoided.*
>
> This relies on product development, technology, education and community engagement resulting in greater uptake of existing, effective personal deterrent devices than is current.
>
> ***Tier 3– Prevent bleeding.*** *Reduce the impacts of a shark bite when one has occurred.*
>
> This relies on people using puncture- or tear-proof wetsuits or being trained in suitable first aid to prevent death from bleeding.

Recommendation 3

The Shark Program continues to undertake, or supports, further research and monitoring (i.e. data gathering, analysis and reporting) of current area-based bite mitigation systems and trialling of emerging area-based bite mitigation systems and personal devices.

Recommendation 4

Issues that may be limiting the effectiveness of VR4G tagged shark listening stations at mitigating shark bite are resolved as soon as possible so that an informed decision can be made about whether to continue to include VR4Gs in the future Shark Program as a risk mitigation tool.

Recommendation 5

The Shark Program is enacted under NSW legislation and policy that incorporates the entirety of its shark bite mitigation and response strategy (i.e. the SMP, the Shark Incident Response Plan and other Shark Program activities) and to ensure long-term commitment by NSW Government to its operationalisation. The legislation should include specific aims and objectives for the Shark Program that convey to the community the roles of NSW Government and the personal responsibilities of the water users.

Recommendation 6

The Shark Program continues to provide information about the latest developments and suite of independently tested and verified personal deterrent devices and shark-bite resistant materials (if they become commercially available) and improved first aid and trauma treatment by surfers. NSW Government could consider providing a rebate for NSW residents when they purchase an approved personal deterrent or first aid/trauma kit/training and develop, or contribute to the development of, a minimum standard for effectiveness.

Recommendation 7

The Shark Program develops and implements a monitoring, evaluation and reporting (MER) framework that measures the performance of its key components and that can be used to drive adaptive management when needed. The following indicators are examples of those that could be developed, reported on and reviewed on a biennial basis to monitor the effectiveness of the program:

> The number of interactions at beaches where area-based mitigation systems are deployed and for a similar period prior to deployment;

> The number of interactions at beaches where area-based mitigation systems are not deployed;

and, the effectiveness of the 'education and awareness strategy':

> The uptake and use of personal deterrents, and potentially personal protective wetsuits and knowledge of improved first aid, by surfers;

> The uptake of the SharkSmart App; and

> Community sentiment within particular areas of the coast and towards particular aspects of the Shark Program.

A further indicator is proposed that will improve understanding of how the distribution and abundance of target sharks relates to potential incidents if they occur in the future:

> Trends in relative abundance and size of White Sharks, Bull Sharks and Tiger Sharks in nearshore coastal areas of NSW (i.e. as spotted by drones, caught by SMART drumlines or caught in SMP nets, standardised by effort).

Recommendation 8

The Shark Program continues to explore potential partnerships in relation to all three tiers in the hierarchy of protection, including co-funding models, with local Councils, community groups and other organisations that would improve shark bite mitigation at a local level.

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Glossary of Abbreviations

Term/Acronym	Description
BWT	Bull, White and Tiger sharks and records where the species involved in an interaction was unknown
DAF	Queensland Department of Agriculture and Fisheries
EPBC Act	Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*
DPIF	The NSW Department of Primary Industries (Fisheries)
FM Act	NSW *Fisheries Management Act 1994*
Interaction	A bite, bump or other physical contact (such as a bite to a surfboard) between shark and a human
KZNSB	KwaZulu-Natal Sharks Board (South Africa)
Lifeguard	Paid or volunteer Government, Council or SLSC supervisors of beach activities
Patrolled beach	Beach where there is an SLSC
SCP	Queensland Shark Control Program
Shark incident	An interaction between a human and a shark that results in a bite, bump or other physical contact (such as a bite to a surfboard)
SharkSmart	DPIF's repository of information and resources to help individuals reduce the risk of a close encounter with a shark at NSW beaches.
SLSC	Surf Life Saving Club
SMART drumline	Shark Management Alert in Real Time drumlines
SMP	The NSW Shark Meshing (Bather Protection) Program in metropolitan areas between Stockton and South Wollongong
Shark Program	The NSW Shark Program to mitigate risk from shark bite
SMS	The NSW Shark Management Strategy (2015/16 to 2019/20)
SoW	Scope of Works (of this review)
Target sharks	The three species of sharks (Bull Sharks, *Carcharhinus leucas;* White Shark, *Carcharodon carcharias;* and Tiger Sharks, *Galeocerdo cuvier*;) that have been implicated most in unprovoked shark bite in NSW
Unprovoked shark bite	Incidents in which a bite on a human occurs in the shark's natural habitat with no human provocation of the shark, as opposed to when a human initiates interaction with a shark in some way such as when a diver attempts to feed a shark or when a spearfisherman spears a fish
VSL	Value of statistical life
TEV	Total Economic Value
Water users	Includes, swimmers, surfers, spearfishers, and users of other water craft in nearshore areas of the coast
WA	Western Australia

1 Introduction

1.1 Project Scope and Required Services

New South Wales (NSW) Department of Primary Industries (Fisheries) (DPIF), part of the Department of Regional NSW, has commissioned Cardno (NSW/ACT) Pty Ltd to undertake an independent evaluation of the five-year 2015/16-2019/20 Shark Management Strategy (SMS) and the 2020/21 and 2021/22 Shark Programs. The SMS and Shark Programs were implemented to provide protection from target sharks to swimmers, surfers and other water users at NSW coastal beaches whilst minimising harm to marine fauna that may be affected by the program (e.g. sharks and rays, marine reptiles and marine mammals).

The Scope of Works (SoW) included the following components:

1. Review and assessment of the performance of the NSW Shark Management Strategy including:

    a. Assessing the effectiveness of mitigation measures on the number of shark incidents; and

    b. Assessing the cost-effectiveness of mitigation measures against the economic impacts of shark interactions on the NSW community.

2. Review the new information (including social research) and technologies generated since a report was prepared by Cardno (2015) and summarise the implications of that new information on the future direction and approach of shark mitigation in NSW, and provide recommendations for their potential future use in mitigation of shark incidents in NSW:

3. Conduct an analysis of NSW, other Australian states and territories, and other international jurisdictions to compare and contrast:

    a. Shark mitigation approaches used across those jurisdictions and their efficacy for reducing shark interactions;

    b. The underpinning regulatory frameworks that support shark mitigation programs;

    c. Funding arrangements for shark mitigation approaches and programs; and

    d. To what extent community preferences inform shark mitigation approaches and programs.

4. The review is to inform consideration by the Government of ongoing funding for shark mitigation measures for 2022-23 and beyond, including any associated regulatory mechanisms to operationalise the program in NSW.

The SoW was to be addressed in a report, with a primary focus of reviewing the work and activities undertaken in shark mitigation in NSW since October 2015 to date and to provide detailed recommendations to inform the development of the 2022/23 NSW Shark Program. This was to involve, but would not be limited to, reviewing the relevant published literature and reports by DPIF and/or its consultants on the SMS sub-programs and more recent work identified as follow:

- Surveillance, detection and deterrents,
    - Aerial Surveillance,
    - Drones/Unmanned Aerial vehicles,
    - Shark Barriers,
    - SMART Buoys,
    - Clever Buoy,
    - Listening stations,
    - Seabed electric fencing;
- Science and Research
    - Tagging,

  - Doctoral projects,
  - Annual grants program,
  - Social research;

> Education and Community Awareness

  - SharkSmart App,
  - Community awareness program,
  - Enhance partnerships with lifesaving organisations,
  - Community engagement on the outcomes of the SMS;

> Regulatory mechanisms required for ongoing operationalisation of shark mitigation in NSW, informed by a review of other national and international jurisdictions; and

> Costing models used for Shark Mitigation in Australian and overseas jurisdictions.

Completion of the report was required by 8 October 2021. **Table 1-1** shows where in this report each item in the SoW was addressed.

Table 1-1 Scope of Works and relevant report section

Scope of Work Part	Where addressed in Report
1. Review and assess the performance of the NSW Shark Management Strategy including:	
a. Assessing the effectiveness of mitigation measures on the number of shark incidents; and.	3.3, 7, 8
b. Assessing the cost-effectiveness of mitigation measures against the economic impacts of shark interactions on the NSW community.	3.4, 7, 8
2. Review the new information (including social research) and technologies generated since a report was prepared by Cardno (2015) and summarise the implications of that new information on the future direction and approach of shark mitigation in NSW, and provide recommendations for their potential future use in mitigation of shark incidents in NSW.	4.1 - 4.4, 7, 8
3. Conduct an analysis of NSW, other Australian states and territories, and other international jurisdictions to compare and contrast:	
a. Shark mitigation approaches used across those jurisdictions and their efficacy for reducing shark interactions;	5.1 - 5.6
b. The underpinning regulatory frameworks that support shark mitigation programs;	5.1 - 5.6
c. Funding arrangements for shark mitigation approaches and programs;	5.1 - 5.6
d. To what extent community preferences inform shark mitigation approaches and programs.	5.1 - 5.6
4. The review is to inform consideration by the Government of ongoing funding for shark mitigation measures for 2022-23 and beyond, including any associated regulatory mechanisms to operationalise the program in NSW.	6, 7, 8

1.2 Review of Earlier Reports

Since the 1930s there has a been a range of measures used to protect water users in NSW from shark bite (Reid and Krogh 1992). Major approaches were the deployment of mesh nets at popular beaches from

Newcastle to Wollongong and surveillance by lifesavers, with bells rung to warn bathers when sharks are spotted. Lifeguards then often used surfboats, jet skis or inflatable boats to try to herd a shark away from the beach. Although beach meshing nets is considered effective for reducing bites (Dudley, 1997), recognition of the need to protect sharks and other marine animals captured in the beach meshing nets and the broadening usage of beaches along the NSW coast has prompted re-assessment of the earlier methods. Two recent reports commissioned by DPIF were used to inform the future direction of management and mitigation of potential shark bite. These are reviewed briefly below.

1.2.1 Review of Bather Protection Technologies (Cardno 2015)

Cardno (2015; see also McPhee et al., 2021) was commissioned by DPIF to provide an independent review of emerging technology for bather protection (swimmers and surfers) and create a short list of feasible technologies to trial at some NSW ocean beaches. The focus of the review was on technologies that might be effective at a whole-of-beach scale, although some consideration was also given to personal protection devices. Methods were evaluated in terms of the following:

> Shark detectors v deterrents

> Large-scale deterrents v personal deterrents.

Aerial survey methods were not considered as part of the 2015 review.

In ranking various methods eight criteria were developed:

1. Practicalities for implementation at a whole-of-beach scale
2. Potential for adverse effects on human health (e.g. people with pacemakers)
3. Ability to withstand local environmental conditions
4. Commercial availability
5. Effectiveness of method on white, tiger and bull sharks (these species discussed further below)
6. Verification of effectiveness via independent testing
7. Potential for adverse effects on wildlife
8. Potential to affect other water users.

The review made the following recommendations:

1. The short-listed technologies would not be likely to provide a single, simple solution that would apply to all NSW beaches, thus emerging technologies should be integrated to provide a suite of protective measures.
2. Shark deterrent methods operating at large scales have potential for whole-of-beach protection, but needed further refinement before being trialled in NSW.
3. The short-list of shark detectors identified for potential trial on NSW beaches was limited to a shark spotter trial, but the use of SMART (Shark Management Alert in Real Time) drumlines and Clever Buoy™ methods could be suitable with further refinement. These are described briefly as follows:
   a. Shark spotting requires the use of trained observers stationed at appropriate vantage points.
   b. SMART drumlines comprise a buoy with a baited hook and a transmitter that sends a message to shore once a shark is hooked. A vessel then travels to the captured shark fast enough to minimise the risk of mortality to the shark, tows the shark offshore well away from the beach, and releases it.
   c. Clever Buoy™ is a sonar detection method designed to detect sharks at beaches where a Clever Buoy™ buoy is deployed. The system uses multi-beam sonar to detect underwater

objects, in this case sharks. A modem transmits data to a computer which differentiates sharks from other marine animals[1].

4. Finally, Cardno (2015) recommended that the NSW Government consider including advice in its SharkSmart program regarding the types of personal deterrents that it would recommend as being suitable for bathers or surfers to use in remote locations and for surfers to use around headlands.

1.2.2 NSW SMS Mid-term Review (BMT 2018)

BMT was engaged by DPIF to conduct an independent, mid-term review of the SMS including the work and activities undertaken up to mid-2018, and to provide detailed recommendations for ongoing work on the SMS. The scope included the following components:

1. Review and assess the performance of each element of the SMS as described in the Business Case, and make recommendations where necessary to improve performance;
2. Review the new knowledge generated to date (including shark biology, technology, and community attitudes) and summarise the implications of new information on the future direction and approach of shark mitigation in NSW, where necessary identifying knowledge gaps that need addressing;
3. Briefly summarise any new technologies that have been developed and provide recommendations for their future use in shark mitigation or what further evaluation will be needed if they were to be considered for use in NSW;
4. Review the shark mitigation approaches in other Australian states and other countries and make recommendations to ensure the SMS remains world-class; and
5. Review the community engagement, education, and communications in the delivery of the Shark Management Strategy and make recommendations where necessary to improve their cost effectiveness.

As part of the BMT review as applied to NSW, approaches to mitigation of shark bite in other jurisdictions were reviewed; these included Western Australia (WA), USA, South Africa, Brazil, New Zealand, Reunion, the Caribbean and South Pacific.

The Business Case for the SMS was prepared by DPIF and included three program areas (BMT, 2018):

1. Surveillance, detection and deterrents program, with trials of the following:
   - Aerial Surveillance (primarily by helicopters)
   - Drones/Unmanned Aerial vehicles
   - Shark Barriers
   - SMART Drumlines
   - Clever Buoy™
   - Listening stations (VR4G as well as existing listening stations VR2s)
   - Seabed electric fencing/cable technology
2. Science and Research
   - Satellite and acoustic tagging of white, bull and tiger sharks
   - Funding for doctoral and post-doctoral projects
   - Annual grants program
3. Education and Community Awareness
   - Refinement and roll out of the SharkSmart App

[1] https://www.sharksmart.nsw.gov.au/__data/assets/pdf_file/0014/1237010/sms-factsheet-clever-buoy.pdf

- Community awareness programs
- Enhancing partnerships with lifesaving organisations

The review methodology included reviewing literature and reports and interviews with Departmental staff. Recommendations included the following:

1. Undertake an internal strategy session following the Mid-Term Review to better define and align "where to from here" with the SMS;
2. Track and deliver science and research activities including progressing promising new investigations and research;
3. Continue to invest in social research and targeted consultation with stakeholders about shark mitigation options;
4. Develop a more coherent and proactive communication and engagement strategy about the key findings of the SMS including what is being communicated, when it is intended to be communicated, and key platforms for delivery;
5. Develop a program for integrating the science into management including updating SharkSmart messages;
6. Keep a watching brief on other shark control programs and new commercial technology; and
7. Inform current and future Government policy on shark management.

The following sections review current knowledge of shark bite, biological data on shark species of most concern with respect to human safety and then discusses the current SMS and Shark Program for 2021/22.

1.3 Global Trends and Drivers in Unprovoked Shark Bite

Unprovoked shark bite is one of the most geographically dispersed and widely reported type of human-wildlife conflict (Hardiman et al., 2019). Unprovoked shark bite is increasing globally and while the geographic range of where bites have occurred is large, most occur in six "hotspots" – United States, Australia, Brazil, South Africa, Bahamas and Reunion (McPhee, 2014; Chapman and McPhee, 2016). Whilst an increase in the number of water users over time contributes to this trend of increasing bites, it does not explain it entirely (Amin, 2012; McPhee, 2014; Chapman and McPhee, 2016). Other factors influencing the increase can include changes in the abundance of relevant shark species and factors that may change the spatial distribution of relevant shark species relative to water users. The latter can be due to various potentially interacting factors including climate change, changes in the abundance and distribution of prey, changes in habitat, and other environmental changes (Hazin et al., 2008; Chapman and McPhee, 2016; Afonso et al., 2017; Lemahieu et al., 2017; Lagabrielle et al., 2018; Ryan et al., 2019).

Globally, there are records of bites to people from many species of shark, but three species (White Shark, *Carcharodon carcharias*; Tiger Sharks, *Galeocerdo cuvier*; and Bull Sharks, *Carcharhinus leucas*) have been implicated most in unprovoked shark bite (McPhee, 2014). These three species (referred to as "target sharks" under the NSW shark bite mitigation programs since 2015) are responsible for over 90% of fatal unprovoked bites (McPhee, 2014). While there is much public debate regarding trends in the population of these species, population size and trends are not well known and difficult to determine. Chapman and McPhee (2016) identified limitations to stock assessment including incomplete data sets, the wide-ranging movement of the species and great individual variation in movement, transient populations, small population size and capture heterogeneity. The known information about these species in NSW is given in **Appendix A**.

1.4 The NSW Shark Management Strategy (SMS) and the Shark Programs for 2020/21 and 2021/22

Shark bite mitigation in NSW has historically focussed on the use of shark nets at 51 beaches between Newcastle and Wollongong in the Greater Sydney region (i.e. the Shark Meshing (Bather Protection) Program - SMP) augmented by manned aerial patrols. These traditional intervention measures have become highly controversial due to mortality of target sharks, unintended capture of non-dangerous species

(Meeuwig and Ferreira, 2014; Gibbs and Warren, 2015). As a response to bites (serious and fatal) in northern NSW, there was an impetus to expand the geographic footprint of mitigation activities.

The Cardno (2015) report was assessed at a workshop by approximately 70 independent experts from around the world in September 2015 and was the basis for the NSW Government's $16 million Shark Management Strategy (SMS). The SMS was a five-year program (2015/16 to 2019/20) that trialled a suite of mitigation technologies and helped to increase knowledge about the movement and ecology of the three target White, Tiger, and Bull Sharks. The SMS complemented the NSW Government's other existing shark mitigation and awareness programs including the SMP. The SMS was a scientifically-driven, integrated strategy involving innovative trials and funding of continual projects over five years to determine the most effective shark bite mitigation measures at NSW beaches. The objective of the SMS was to increase protection for beachgoers from shark interactions, while minimising harm to sharks and other marine life.

Elements that were trialled included: aerial surveillance; satellite and acoustic tagging of White Sharks, Tiger Sharks and Bull Sharks; underwater listening stations to detect tagged sharks; SMART Drumlines (Shark Management Alert in Real Time); shark barriers; sonar technology; and unmanned aerial vehicles (drones). The SMS also included the enhancement of a suite of existing measures such as the SharkSmart app for mobile devices, partnerships with Surf Life Saving NSW and the Australian Professional Ocean Lifeguard Association, and the SharkSmart education campaign. Funding for research and development and post-graduate projects was provided for other shark detection systems and personal deterrents, and for understanding community opinions.

The NSW Shark Program in 2021/22 includes the existing SMP but also utilises popular, trialled components of the Shark Management Strategy, including drones (used by Surf Life Saving NSW at 50 beaches), 170 SMART drumlines, and 37 VR4G listening stations at beaches within and outside of the Metro region. The objective of the SMP is to reduce the chances of shark interactions within the area of operation of the program whilst minimising impacts on non-target species. It also includes community awareness and education programs such as SharkSmart (**Figure 1-1** and **Figure 1-2**). The Shark Program aims to increase protection for beachgoers whilst minimising harm to sharks and other marine life.

Figure 1-1 NSW Shark Program 2021-2022

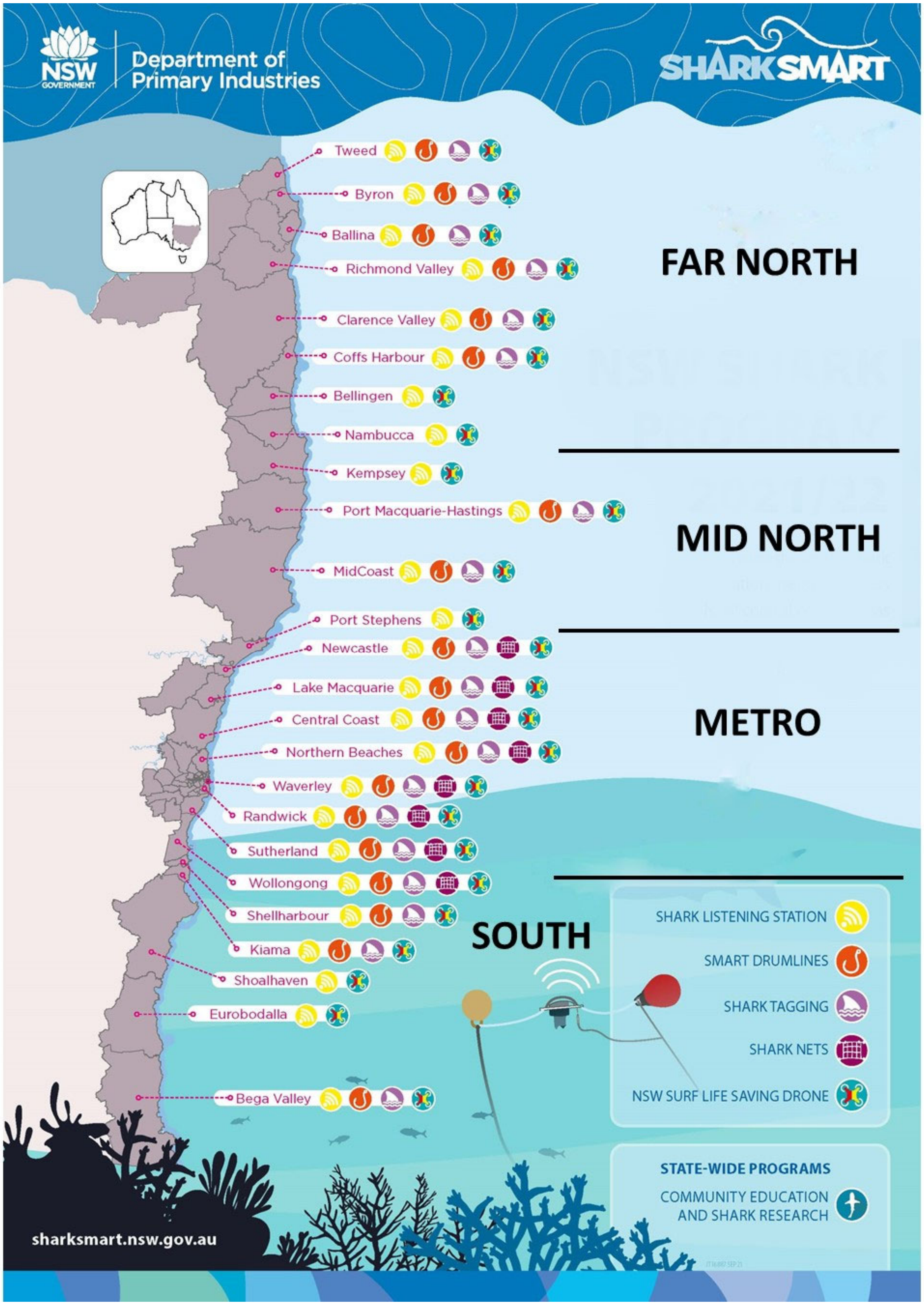


Figure 1-2 Locations of NSW Shark Program 2021-2022 gear. For the purposes of this report, the NSW coast was considered as four regions (Far North, Mid North, Metro and South).

2 Methodology

2.1 Key Sources of Information

Key sources of information for this report included:

> The NSW SharkSmart website - https://www.sharksmart.nsw.gov.au/Spatial information (i.e. beach, headland, coastal waterbody or offshore reef/island);

> SMS reports, research outputs and results of gear trials;

> Other relevant peer-reviewed literature and scientific reports;

> Consultation with shark scientists (NSW, nationally and internationally);

> The Australian Shark Attack File;

> Google Earth and the map function of Microsoft Bing, for a list of all the beaches along the coast of NSW ('beach list'); and

> Surf Life Saving Australia for the locations of all Surf Life Saving Clubs (SLSCs) along the NSW coast (https://sls.com.au).

2.2 Approach to SoW Task (1) - Reviewing & Assessing the Performance of the SMS

2.2.1 Task (1a). Assessing the effectiveness of mitigation measures on the number of shark incidents

The approach to this task was to evaluate all three of the SMS subprograms given they combine to reduce the number of interactions either directly (through the 'Surveillance, Detection and Deterrents' subprogram) or indirectly (through the 'Science and Research' and 'Education and Community Awareness' subprogram).

The effectiveness of the 'Science and Research' subprogram was evaluated by:

> A bibliometric analysis of the research outputs;

> Uptake of lesson learned from the trials.

The 'Education and Community Awareness' subprogram operates concurrently with the Surveillance, Detection and Deterrent subprogram. Although it could be considered to operate coast-wide, there are presently few metrics available to evaluate its contribution to risk mitigation.

The SoW specified that the 'number of shark incidents' was to be a key indicator in assessing the performance of the SMS. Here we have interpreted 'shark incident' as an interaction between a human and shark that results in a bite, bump or other physical contact (e.g. board bite). Cardno's approach was to compare the number and type of interactions occurring to different water user groups (swimmers, surfers and other users) in areas where the SMS Surveillance, Detection and Deterrent subprogram and Shark Programs for 2020/21 and 2021/22 were operating since 2015 with other areas for a similar number of years before these programs were operating. The period prior to implementation of the SMS was considered a *temporal baseline* and areas where the subprograms were not operating were considered as *spatial controls*. Comparisons were also made of the incidents within and outside the area of operation of the SMP and Shark Program. Further detail about the incident dataset, comparisons made and how data were grouped and presented is given in **Appendix B**.

In addition to the key indicator of shark incidents, the Surveillance, Detection and Deterrent subprogram provided the following additional indicator of the effectiveness of mitigation:

> Evacuations of water users after a potentially dangerous shark (i.e. a target shark or whaler shark (*Carcharhinus* spp.) or unidentified shark in excess of 2m), spotted through aerial surveillance (helicopter and/or drones), was within 100 m of water users and swimming towards them.

Possible limitations affecting how these indicators can be interpreted, include:

- The Surveillance, Detection and Deterrent subprogram was rolled out according to initial experience about the gear (i.e. trials) and consequently much of the gear for this subprogram was not deployed for the entire five years of the SMS or deployed in the Shark Programs for 2020/21 or 2021/22;
- There are some areas where the SMS gear was deployed concurrently with SMP gear and overlapped with traditional aerial surveillance (i.e. the Metro region);
- The random nature and clusters of shark bite in areas for some years (see **Section 1.3**) means that the five-year duration of the SMS and additional years of the Shark Programs 2020/21 and 2021/22 may not have been sufficient to provide enough data on interactions to allow for meaningful comparisons with a baseline or against controls.

2.2.2 Task (1b). Assessing the **cost-effectiveness of mitigation measures against the economic impacts of shark interactions on the NSW community**

The complexities of drivers and outcomes of unprovoked shark bite make a quantitative cost benefit analysis of mitigation approaches largely unachievable in the timeframe available for this review. Nonetheless, this review has considered as best as possible the question of the costs and benefits of the SMS and whether the program represents value for money.

Overall, there is a lack of relevant economic information to model cost-effectiveness and new empirical information cannot be obtained within the limited timeframe of this review. Methods focussed on identifying in economic terms the value of a human life in a policy context and discussion of the likelihood of the program saving lives over and above the cost of the program. Where available, peer reviewed information which demonstrates a change, or likely change in patterns of beach and water use by the public in response to unprovoked shark bite are discussed in the context of economic impacts. The value of wildlife in conceptual terms has also been discussed.

2.3 Approach to SoW Task (2) - Reviewing the new information and providing recommendations for future use in mitigation of shark incidents in NSW

McPhee et al. (2021) was utilised in order to provide an update on area-based mitigation approaches and augmented where necessary with additional literature and SMS publications.

2.4 Approach to SoW Task (3) - Reviewing approaches, regulatory frameworks, funding arrangements and community preferences in other places

While interventions are common in response to unprovoked shark bite, the focus of the review was on jurisdictions that had a programmatic response. In order for an appropriate comparison, only programs undertaken by governments were included. Publicly available information was sourced on funding arrangements, legislative and governance arrangements, and the components included in mitigation.

2.5 Approach to SoW Task (4) – Consideration of future funding including regulatory mechanisms

The approach to address this task was to draw together the key aspects from the previous three tasks and to use a weight of evidence approach to make considered and pragmatic recommendations.

3 Assessment of Performance

3.1 Assessment of Science and Research Outputs

3.1.1 Introduction

This section considers the SMS ‘Science and Research’ subprogram which has provided a diverse and substantial body of research work related to various aspects of understanding and mitigating unprovoked shark bite. Research is necessary to provide an evidenced-based foundation for the management of unprovoked shark bite.

3.1.2 Bibliometric Analysis

Bibliometric analysis assesses the quantity and quality of research outputs. DPIF provided a list of publications generated as part of the SMS, including completed peer-reviewed publications, peer-reviewed articles drafted but not currently available (e.g. articles in press, submitted, or in preparation), technical reports and presentations. The quartile ranking of journals in which the articles were published was used as a measure and this ranking information was accessed via Scimago[2]. As most published articles are very recent, an analysis of citations as a measure of research impact is premature as citations may take several years to accrue in any meaningful way following publication of an article.

Thirty-four published, peer-reviewed journal articles were identified by the authors of this report as having been supported by the SMS. A review of all publications identified that they were all linked to relevant aspects of unprovoked shark bite. All articles were published in journals from reputable academic publishing houses (e.g. Elsevier, Wiley) and none were in poor quality journals identified as predatory[3]. Of the 34 articles assessed, 31 were in the top quartile (Q1), two were in Q2 and one was not yet assigned a ranking as it was in a new journal. Authors of articles included DPIF scientists as well as highly respected scientists from universities. Overall, the pattern of publishing is exceptional in terms of quality. Information provided to the authors identified a further 13 publications in progress and at various stages of completion. These appear highly likely to have a similar high quality publication pattern as those already completed.

Research on shark bite mitigation is necessarily multi-disciplinary and requires addressing human dimensions, some key aspects of the biology and ecology of shark species directly related to understanding and mitigating the risk of a bite, the development and trialling of various technologies under different conditions and identifying and reducing environmental impacts of mitigation measures (where relevant). Overall, research undertaken under the SMS covers the breadth of disciplines of relevance to unprovoked shark bite.

Seventeen articles were associated with the trialling and implementing alternative technologies with the greatest single concentration of research effort focussed on drone technologies. Twelve articles focussed on shark biology with a focus on aspects relevant to understanding matters associated with unprovoked shark bite. These include publications on the movement and habitat use of target shark species and factors (e.g. presence of whale carcasses) that may increase the spatial overlap between water users and target shark species. Four articles focussed on human dimensions, with research including the psychological impacts on families, first responders and surviving victims.

3.1.3 Results of Trials

The SMS trials have occurred along much of the NSW coastline with most occurring in the Far North and Mid North regions (**Table 3-1)**. All of the commercially available alternative (to catch and kill) area-based mitigation systems flagged for trial in the Cardno (2015) report were tested for their ability to detect, deter or intercept sharks. Barriers and mesh nets were also trialled in the Far North region and drones and helicopter surveillance was also trialled in other regions. The following sections consider how well the systems operated with respect to shark deterrence, detection or interception. This information is useful for inferring their efficacy, but the true test is whether they reduce the number of interactions between sharks and humans (see **Section 3.3)**, and whether they met the other component of the objective of the SMS, which was to 'minimise harm to sharks and other marine life'.

[2] https://www.scimagojr.com/
[3] See https://predatoryjournals.com/journals/ for a list of predatory journals

Table 3-1 Beaches and Surf Life Saving Clubs in regions, and percentages of beaches where SMS trials of bite mitigation systems was done.

Region	Total No. of Beaches	No. of SLSC (% of Total No. of Beaches)	Percentage of Beaches where SMS trials were done: Drones	SMART Drumlines	Helicopter Surveillance	Listening Stations (VR4G)	Mesh Nets	Barriers	Cleverbuoy
Far North	124	27 (22%)	17%	18%	67%	6%	4%	0%[3]	0%
Mid North	90	25 (28%)	14%	7%	91%	7%	0%	0%	1%
Metro	147	88 (60%)	7%	10%	0%[1]	1%	0%[2]	0%	0%
South	229	23 (10%)	3%	7%	64%	2%	0%	0%	0%
Total	590	163 (28%)	9%	10%	78%	4%	0%	0%	0%

[1] Helicopter surveillance has also been done on Metro beaches since 2009 as part of the SMP and are therefore not included under SMS trials

[2] The SMP has been operating on Metro beaches since 1937 – 51 beaches are currently netted

[3] Attempts to trial barriers on the coast were unsuccessful

3.1.3.2 Interception Systems

3.1.3.2.1 Mesh Nets on North Coast

Despite the timely implementation of the SMS in October 2015 following the expert workshop to assess the Cardno (2015) report, shark bites continued in the Ballina and Evans Head region and the NSW Government agreed to public requests to trial traditional shark nets on the North Coast. Shark mesh nets were trialled at five beach locations in northern NSW (Lennox Head, Ballina and Evans Head) in two six-month fishing trials between 8 December 2016 and 2 May 2018 (Broadhurst and Cullis, 2020). It was considered by DPIF important to conduct trials in different latitudes and faunal assemblages, as results may not be directly extrapolated from shark net deployments in the Metro region. Further, it is also possible that the longstanding nature of shark net deployments in the Metro region may have caused a “fish down effect” on some taxa that would not be evident in northern NSW.

Across both trials, a total of 11 target sharks were caught, comprised of five Bull Sharks (3 dead, 2 released alive), three White Sharks (2 dead, 1 released alive) and three Tiger Sharks (1 dead, 2 released alive).

Bycatch was significant: 409 non-target animals were caught across both trials, 210 of which were released alive. Numerically dominant bycatch species included Australian Cownose Ray *(Rhinoptera neglecta*), Pygmy Devil Ray (*Morbula eregoodoo*) and the White Spotted Eagle Ray (*Aetobatus ocellatus*). Listed threatened species were also captured – Great Hammerhead Shark (*Sphyrna mokarran*) (34 dead, 1 released alive), Loggerhead Turtle (*Caretta caretta*) (2 dead, 10 released alive), Green Turtle (*Chelonia mydas*) (5 dead), Grey Nurse Shark (*Carcharias taurus*) (1 dead, 1 released alive), Hawksbill Turtle (*Eretmochelys imbricata*) (1 dead), Leatherback Turtle (*Dermochelys coriacea*) (1 dead), and an unidentified turtle (released alive). In addition, seven Indo-Pacific Bottlenose Dolphins (*Tursiops aduncus*) and one Common Dolphin (*Delphinus delphis*) were also caught with none released alive.

Apart from some small differences, catches in the northern NSW of target sharks, other sharks and bycatch were generally comparable with captures in the SMP in the Metro region (Reid et al., 2011; SMP annual performance reports - https://www.sharksmart.nsw.gov.au/shark-nets). Given the north coast net trials were done within areas where SMART drumline trials were underway, comparisons can be made of the catches in each gear (see below).

3.1.3.2.2 SMART drumlines

SMART drumlines mitigate risk by capturing sharks at beaches and relocating them further offshore fr. SMART drumlines in NSW allow for the release of sharks alive and in good health (based on external visual assessments) (Tate et al., 2019). They have been trialled in the northern and mid north NSW coastline, Newcastle, Sydney, Kiama, Ulladulla, Tathra and Merimbula. Tate et al., (2021a) reported a total of 22,025 individual SMART drumline deployments on the northern and mid-north coast and south coast of NSW across 1,637 deployment days resulted in the capture of 500 animals of 16 species. Target shark species accounted for 70% of the total catch with White Sharks contributing 298 of the 350 sharks that were caught. Tate et al., (2021b) observed few non-target species on video beneath SMART drumlines and, relative to target species, bycatch numbers were small and numerically dominated by other non-target sharks including Dusky Whalers (*Carcharhinus obscurus*), Smooth Hammerhead Sharks (*Sphyrna zygaena*), Common Blacktip Whalers (*Carcharhinus limbatus*) and Grey Nurse Sharks (*Carcharias taurus*) (Tate et al., 2021a). In addition to the Grey Nurse Shark, the only other listed threatened species captured by the SMART drumlines was one Loggerhead Turtle (*Caretta caretta*).

Of the animals captured, only four (~1%) could not be released alive – one White Shark, one common Blacktip Whaler, one Smooth Hammerhead Shark and one Black Marlin (*Istiompax indica*). Catch rates were influenced by water temperature (Tate et al., 2021a). However, just because SMART drumlines are in the water, it does not mean they will intercept all sharks in the area. Guyomard et al., (2020) showed that baits do not attract sharks into nearshore waters, implying that sharks need to already be in close proximity to the SMART drumline baits and/or actively feeding to be enticed to take the bait. This could mean that sharks entering a beach area from its sides (see for example, Colefax et al., (2020a) drone tracking of white sharks) might not be intercepted as opposed to sharks entering a beach area from directly offshore which exhibit a much greater chance of taking bait and being caught (Tate et al 2021b). One of the questions around whether the removal of a shark to a location that is only one kilometre offshore from its capture point was an effective mitigation measure was answered through satellite tagging, whereby White Sharks were observed moving offshore after release (Butcher et al., in prep.).

It should also be noted that the catch of Bull Sharks in SMART drumlines was the least for the three target sharks, but it is not clear if this a reflection of their catchability or other factors .Tate et al. (2021a) only reported nine captured during all trials on the northern and mid-north coast and south coast of NSW despite helicopter surveys indicating Bull Sharks have a strong presence in at least the northern and mid-northern coasts (see NSW DPI, 2018b). As SMART drumlines are only actively fishing during the day (i.e. the time when people surf and swim at ocean beaches) – the species composition of the catch could differ if they were configured differently or were actively fishing at night, including the capture of more bull sharks (see Niella et al., 2021a). Bull sharks are known to utilise habitat differently and have different patterns of activity during the diel cycle (Snelson et al., 1984; Smoothey et al., 2019). Further, avid recreational anglers that target bull sharks in northern NSW and southern Queensland have a preference for fishing at night due to higher catch rates (D. McPhee, pers. obs.).

When the catches in SMART drumlines at Ballina and Evans Head were compared against catches in the net trials done in these areas (NSW DPI, 2018a) it was concluded that the fishing power of the 30 SMART drumlines in the area was greater than for five 150 m nets. In the first trial, nets caught a total of nine (0.002 per net per 24-h soak) versus 36 (0.03 per SMART drumline per 24-h soak) target sharks (i.e. SMART drumlines were 15 times more efficient), respectively, while in the second trial, two (0.0005 per net per 24-h soak) and 16 (0.016 per SMART drumline per 24-h soak) target sharks (i.e. 32 times more efficient) were netted and hooked (NSW DPI, 2018a). In terms of bycatch, there were 409 non-target animals caught in the nets (51% of which survived) versus 19 non-target animals in the SMART drumlines (one of which died).

Further, in the trials in the Metro region where SMART drumlines were deployed adjacent to SMP nets, the drumlines caught more White Sharks (12) and Tiger Sharks (5) than the SMP nets (8 and 0, respectively). This suggests that they are more efficient at catching those two target sharks than mesh nets. It is noted that no Bull Sharks were caught in either SMART drumlines or mesh nets during the trials in the Metro region or at any other trial location, except Evans Head and Ballina, highlighting the importance of learning more about habitat occupancy rates of Bull Sharks and how any shark mitigation gear is best used, including potentially in conjunction with other systems, to minimise the chances of an interaction with water users. Overall, the trials have indicated that given SMART drumlines intercept more target sharks than nets when standardised for fishing effort (NSW DPI,2018a), and that this gear has very little consequence to bycatch, it is an effective, non-lethal shark bite mitigation tool. Further analysis of the actual reduction of interactions at beaches where the trials were done is given in **Section 3.3.2**.

3.1.3.3 Detection Systems

3.1.3.3.1 Clever Buoy™

Clever Buoy™ was trialled at Hawks Nest Beach (Port Stephens). These trials identified that although White Sharks can be detected and identified, the range of a sonar unit in this trial was limited (maximum range 46 metres). Refinements and further field testing were identified by the initial trials as necessary but, as discussed in McPhee et al. (2021), effectively overcoming the challenges is difficult. Clever Buoy™ was also trialled in WA in 2017 at a cost of $462,000: these trials identified significant and unresolved difficulties and concluded that the system could not yet be adopted as a public safety tool.

3.1.3.3.2 Drones

Drones have been extensively trialled within the SMS for their potential to be used as a shark spotting tool (Butcher et al., 2019; Colefax et al., 2019, 2020a, 2020b, 2021; Kelaher et al., 2020) and are now used by lifeguards and volunteers at 50 NSW beaches in 2021/22 to detect sharks and facilitate evacuations in the event there is a target shark present. During 2018/19, approximately 9,000 drone flights were undertaken with approximately 2,000 hours of flying. During this period 350 sharks were spotted, resulting in 48 beach evacuations. Drone flights are restricted to normal patrol hours (9AM to 4PM). Several studies funded by the NSW SMS considered aspects associated with the implementation and efficacy of drone use for shark detection. As summarised in McPhee et al., (2021) and discussed by several other authors (e.g. Butcher et al., 2019) water depth and water clarity significantly impaired detection probabilities by drones and the greater precision achieved from post-hoc analysis of video footage. Kelaher et al. (2019, 2020) also noted the substantial improvement in precision achievable with such analysis. However, for shark bite mitigation the focus needs to be on detections in real-time.

Colefax et al., (2019) identified, from a potential 360 flights, approximately 12.2% of flights were cancelled with weather conditions the most common reason for this occurring. Separate fauna sightings totalled 386, with 17 (4.4%) being confirmed as sharks. Ten of these shark sightings were correctly identified in the field while a remaining seven were detected in post survey video analysis. These results highlight the prevalence of potential errors in sighting in real time and a potential role for artificial intelligence in improving sightability of target sharks using drones.

Several studies of drone deployments focussed on attempting to understand aspects of the biology and behaviour of target sharks to inform mitigation and education. Colefax et al. (2020a) successfully used drones to monitor the localised movement of White Sharks along NSW beaches and this provided important information to understand factors that may increase risk and how other mitigation measures (e.g. SMART drumlines) may be optimally deployed (see **Section 3.1.3.2.2)**.

Further analysis of evacuations and the actual reduction of interactions at beaches where the drones have been trialled by SLSCs is given in **Section 3.3.2**.

3.1.3.3.3 Tagging and VR4G listening stations

More than 700 target sharks were tagged (with acoustic tags) during the period under review to learn more about how these animals are using NSW coastal waters. These sharks have been subsequently detected by VR4G shark listening stations (i.e. devices that detect a nearby animal with an acoustic tag and relay detections in real-time to monitoring systems such as the NSW SharkSmart App, see also Bradford et al., 2011). Overall, the tagging and tracking program has showed that White Sharks travel significant distances, rather than staying close to one location; some tagged sharks travel as far as New Zealand or WA (Spaet et al., 2020a, 2020b). In summer, more Bull and Tiger sharks use NSW waters than at other times, as they move south with the East Australian Current (Heupel et al., 2015; Smoothey et al., 2019; Espinoza et al., 2021; Ledee et al., 2021). Analysis of data on tagged sharks shows that most juvenile White Sharks move north along the NSW coast during winter and spring, when the waters are cooler in northern NSW. They then head south over summer and autumn to track cooler waters in the southern states (Bruce et al., 2019; Spaet et al., 2020a, 2020b). That is not to say there are no White Sharks in NSW waters in summer or autumn – tagging results show they can be anywhere at any time along the coast (Bruce et al., 2019) with no clear environmental conditions enabling prediction of their occurrence off NSW coastal beaches (Spaet et al., 2020a).

VR4Gs shark listening stations have been deployed at 21 locations with a further 16 deployed in 2021/22 on the NSW Coast from Kingscliff to Eden, to provide real-time alerts of tagged sharks to beachgoers via the SharkSmart app. When a tagged shark swims within 500 metres of a listening station, an instant alert is sent to the SharkSmart App, website and Twitter feed @NSWSharkSmart providing real-time updates to the public and beach authorities. DPIF has provided more than 50,000 alerts from listening stations to the public to inform where and when tagged sharks are along our coast. Notwithstanding, there are concerns around their effectiveness being dependent on whether the number of tagged sharks represents a large proportion of the nearshore population of target sharks (see **Appendix A** for population estimates of White Sharks), and only being helpful for those at a beach with a listening station, which comprise a very small proportion (4%) of the total number of beaches in NSW (see **Table 3-1**), and where the user has a smart device that uses the SharkSmart App.

3.1.3.3.4 Helicopters

Helicopter surveillance has been used on Metro beaches since 2009 which were expanded through the SMS to include trials in other regions to cover ~67% of the NSW coastline (see DPI, 2018b). Although helicopters can cover large areas, their flyover time at each beach is short (minutes) and constitutes a very small proportion of each day. Nevertheless, if a target shark is identified close to swimmers or surfers, helicopters can communicate with water users through sirens and a loudspeaker and in some instances can herd the shark back out to sea. The trials showed that approximately 15% of all marine wildlife sighting events are of the three target sharks or other large but unidentified sharks. Approximately 10% of target species, or Whalers >2 m, sightings led to beach evacuations, where these sharks were within 100 m and swimming directly towards water-users. In all years of the trials most evacuations were in either the Far North or Mid North regions with few evacuations in the South region. In each year of the trials the Metro region had the least evacuations, including some years where there were no evacuations (**Table 3-2**).

Table 3-2 Evacuations of water users from helicopter loudspeaker due to proximity to a target shark or Whalers >2 m and where these sharks were within 100 m and swimming directly towards water-users

	Year			
Region	**2017**	**2018**	**2019**	**2020**
Far North	11	36	56	46
Mid North	73	19	86	19
Metro	8	-	-	3
South	9	8	38	16

3.1.3.4 Shark barriers

Shark barriers are a physical barrier that aim to separate sharks from beachgoers. Unlike the Shark Meshing Program nets, barriers form a fully enclosed swimming area, creating an ‘underwater fence’ which extends from the seabed to the surface. DPIF planned a trial of two shark barriers in 2016 to provide an enclosed shark-free area for beachgoers but the barriers could not be installed effectively and safely. The currently available shark barrier products are not designed for the dynamic surf coastline off NSW and long-shore sand movements. Occasional large swells and surf create extreme strain and drag on devices and this is exacerbated given some sides of the barriers must be installed perpendicular to these forces. Long-shore sand movements creates issues for reliable anchorage. Both trials were discontinued and currently available shark barrier products were considered to be only suitable for NSW estuaries or highly sheltered coastlines in other states.

3.1.3.5 Deterrents

3.1.3.5.1 Area-based deterrents

No area-based deterrents trialled given none were commercially available or trial ready.

3.1.3.5.2 Personal deterrents

There are different types of devices including electric, magnetic, chemical and visual deterrents designed to disrupt sharks' sensors to deter them from approaching. The SMS supported testing, by independent scientists, of five commercially available products for surfers (Huveneers et al., 2018). In contrast to all other trials these trials explicitly tested levels to which these devices could reduce the risk of bite. Some electrical devices show meaningful reductions to the risk of shark bite. Huveneers et al., (2018) tested Shark Shield® Pty Ltd [Ocean Guardian] Freedom+ Surf, Rpela, SharkBanz bracelet, SharkBanz surf leash, and Chillax Wax) by comparing the percentage of baits taken, distance to the bait, number of passes, and whether a shark reaction could be observed. The effectiveness of the deterrents tested was variable, with the Freedom+ Surf affecting shark behaviour the most and reducing the percentage of bait taken from 96% (relative to the control board) to 40%. The other deterrents had limited or no measurable effect on white shark behaviour. A subsequent study by Blount et al., (2021) found that a modified Rpela device (Rpela v2) did show a measurable effect on white shark behaviour, but there have been no further independent tests of the other three devices tested by Huveneers et al. (2018).

3.1.3.6 Personal Protective Wetsuits

The SMS supported the testing of novel wetsuit materials including those that utilise ultra-high molecular weight polyethylene (UHMWPE) fibre woven into neoprene (Whitmarsh et al.,2019). 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. To date, only one product has been independently tested by Whitmarsh et al., (2019) with positive results. If the protective apparel clearly proves to be effective and practical for use, it represents an advancement highly suitable for water users. 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. See **Section 4.3.2.1** for further information.

3.1.3.7 Social Studies and Education

Shark bite mitigation is primarily focussed on reducing the chances of an interaction, but mitigating the perception of risk is also an important consideration. Simmons and Mehmet (2018) identified that the fear of sharks is disproportionate to the risk of actual harm. Shark bite mitigation programs are a particularly challenging and problematic case for politicians and managers where conflicting views within a community are heightened by the sensitive topic of human life versus species protection (Cullen-Knox et al., 2017). The public views shark bite mitigation as a combination of personal accountability and government responsibility (Lucrezi et al., 2019), and some form of government response is generally required when an unprovoked shark bite occurs (Simmons et al., 2021a).

The SMS has funded work (e.g. Simmons and Mehmet, 2018; Mehmet and Simmons, 2019; Simmons et al., 2019, 2021a, 2021b; Stokes et al., 2020) which demonstrates that the public has a clear preference for mitigation measures that do not harm sharks or other marine life. This provides a strong evidence base for understanding public perceptions and preferences which needs to be incorporated with information on efficacy to address both risk and risk perception. A more detailed discussion of awareness and education with regard to shark bite is given in **Section 3.2**.

3.1.4 Synthesis and Conclusions

Through its three subprograms the SMS has undertaken or supported systematic trialling of all potentially feasible and commercially available shark bite mitigation systems, personal deterrents and protective wetsuits. The trialling has been robust, scientifically-based, and has incorporated community feedback to ensure that it is consistent with their priorities and expectations. As a result, the Shark Programs for 2020/21 and 2021/22 include deployment of generally the most potentially effective and popular area-based shark detection systems supported by community awareness programs. By having these area-based systems operating on the Mid to Far North Coast of NSW for the past five years in a larger geographic area including areas where mitigation activities were not previously undertaken and by strengthening awareness of shark smart behaviour, the SMS trials not only provided knowledge about the functioning of systems but they have also reduced the number of shark bites from a potentially greater total than what could have occurred at the beaches where they have been trialled (see further analysis of interactions in **Section 3.2**). Collecting evidence that continues to reinforce this link will be a key challenge for the Shark Program in the future. It will also provide further evidence to that already demonstrated through the SMS of whether alternative approaches to catch and kill can one day 'replace' the mesh nets used in the Metro region without reducing the catch of target sharks (see **Section 8**).

A further challenge for the Shark Program in the future will be how best to help increase the uptake of personal deterrents, and, potentially, personal protective wetsuits, given the evidence is building around the effectiveness of some devices (see further discussion in **Section 7 and 8**).

3.2 Assessment of Education and Awareness Strategies

3.2.1 Introduction

This section considers the SMS 'Education and Community Awareness' subprogram and the SharkSmart campaign which aims to educate the community about the shark awareness in order to reduce the risk of unprovoked shark bite.

3.2.2 Results of Social Studies

Beach goers grossly overestimate the number of fatal and non-fatal unprovoked shark bites (Simmons and Mehmet, 2018). In terms of fatal unprovoked shark bites, the public overestimates their occurrence by a factor of four (Crossley et al., 2014). Beach goers are more concerned about unprovoked shark bite than drowning at a beach despite the higher risk of the latter (Crossley et al., 2014; McPhee, 2014). Social science funded by the SMS has improved awareness of shark bite in the community and also awareness in management of community expectations and opinions.

Simmons et al., (2021a) found almost unanimous support for education and research as preferred response to managing risk from sharks in NSW, and little support for invasive strategies perceived to harm marine life, such as shark nets and drumlines. Support for shark management responses decreased as invasiveness of the response increased. The use of SMART drumlines was ranked 14th out of 20 potential management actions with only various lethal approaches ranked below it. Just 15% of respondents moderately agreed or strongly agreed with the use of SMART drumlines, and 56% moderately disagreed or strongly disagreed with their use. Simmons et al. (2021b) found that SMART drumlines were somewhat valued at all locations for their tagging function and potential to contribute to understanding of sharks through research, but they were not generally valued as a strategy for reducing the risk of harm from sharks and not considered a long-term solution. Community sentiment also suggested there must be better ways to tag sharks that reduce the risk of harm to sharks. Likewise, VR4G shark listening stations were considered to contribute to research and understanding of shark movements but ineffective for reducing harm from sharks because only a tiny proportion of target sharks are tagged (Simmons et al., 2021b).

EY Sweeney (2021) found that for surfers in NSW only 26% of survey respondents believed it was acceptable to kill sharks to reduce potential threats to humans. They also identified that following a serious or fatal shark bite, surfers generally expected government to increase surveillance and alerting the public to the incident, but only 14% of survey respondents expect the government to catch and kill sharks in the area where the bite occurred. In the Tweed and Clarence Valley LGAs the use of shark nets was the least popular of six management strategies among community members surveyed (McVeigh and Parker, 2021).

Simmons et al., (2021a) identified that the use of drones as the top-ranking non-invasive mitigation system (5th out of 20) with various education initiatives being the only actions that are more popular. Stokes et al.,

(2020) also found the use of drones on coastal beaches was accepted by the majority of people surveyed (88%) due to perceptions of reduced impact on sharks, and the relatively low cost. Stokes et al., (2020) found the highest level of awareness of the use of drones for shark surveillance was by surfers, but also indicated less confidence in their utility compared with other groups surveyed.

Specifically focussing on surfers, EY Sweeney (2021) surveyed their attitudes in relation to the risk of a shark encounter. The study found that surfers identified that zero risk did not exist. This is consistent with risk taking being a component of motivation and satisfaction with surfing as a sport (Stranger, 1999; Diehm and Armatas, 2004; Liao et al., 2007). EY Sweeney (2021) also found that whether a surfer enters the water is dependent on whether they perceive the risk to be acceptable and undertook their own risk assessment before entering the water. This risk assessment was informed by a range of observations and information sources as well as their own personal risk tolerance. Thus, while risk is inherent in the activity of surfing, surfers do not ignore the level of risk and make decisions in real time based on their assessment and tolerance of risk.

Public support for different mitigation methods is also influenced by demographics, personal exposure to various mitigation methods and media reporting that over or under-emphasises some systems. Gray and Gray (2017) found that older people (> 51 years) were more supportive of lethal methods in the Greater Sydney region than younger people. This is perhaps because older people have a greater fear of sharks than younger people as identified by a survey of residents of Rio De Janeiro (Ostravaski et al., 2021). The surfing community consists of different subgroups with different motivations and constraints (Sotomayor and Barbieri, 2016), and it follows that there will be differences in views regarding sharks between subgroups. In relation to sharks in NSW, EY Sweeney (2021) found that the perception of risk was higher in surfers that had surfed for more than 20 years. It is not unusual for the more avid participants in a leisure activity to have differing views than the less avid on a range of issues including attitudes to management (Bryan, 2000). More avid participants in a leisure activity often have more invested financially and psychological in the activity compared to those that are less avid (McPhee, 2008). This often means that there is a dichotomy for management where most participants have views that may differ from those with more invested in an activity who constitute a minority of participants.

EY Sweeney (2021) found that surfers in NSW considered that reducing the risk from unprovoked shark bite was a collective responsibility by government and individuals. Therefore, while government plays a role, individual surfers accept that they too have an active role in reducing risk. Importantly there is a geographic and demographic difference in the level of personal responsibility accepted. On less popular unpatrolled beaches and remote beaches, surfers think that the responsibility should be held by the individual and older surfers (aged over 55) also put greater emphasis on individual responsibility.

McVeigh and Parker (2021) identified that individuals taking personal responsibility was the second most popular shark bite mitigation response (behind drones) among survey participants and there was strong support (87%) for personal shark deterrents. Personal deterrents were considered advantageous as the only protection available to people using unpatrolled coastline, and for those seeking to take greater personal responsibility (Simmons et al., 2021b). However, a survey of NSW Coastal Councils and residents throughout NSW found that taking personal responsibility ranked only 4th out of 8 mitigation approaches and the use of personal shark deterrent ranked 6th (Mehmet et al., 2021).

To date, no social science survey work has been undertaken to assess barriers to uptake of personal shark deterrents. However, some relevant work exists on barriers to uptake of helmets to prevent concussion injuries among surfers. Taylor et al., (2005) found some of the main barriers to uptake were a perceived lack of need, discomfort, and potential negative impacts on surfing performance. Simmons et al., (2021b) identified that personal deterrents were considered expensive and cumbersome and not many people trusted them. They were considered to potentially lead water users to ignore danger signs and make poor decisions. Simmons et al., (2021a) also identified that there was limited knowledge of them among surfers and that many would not purchase them without proof of efficacy. The latter is understandable. Overall an education campaign on the use of personal deterrents that communicates efficacy of various products and based on an understanding of other barriers to uptake is warranted.

3.2.3 SharkSmart

SharkSmart is DPIF's repository of information and resources to help individuals reduce the risk of a close encounter with a shark at NSW beaches. It provides information about:

> Ecology and protection status of target sharks and other sharks in NSW;

> Smart behaviours for swimmers, surfers and other water user groups for reducing risk of shark bite;

> Information about the shark tagging and tracking program and the nets used in the Metro region;

> Key results of area-based mitigation and personal deterrent trials with links to further details for interested persons; and

> Beach goer information including how to download the SharkSmark app for useful tips on reducing the risk of a shark encounter and for the latest advice, alerts and information.

3.2.4 Synthesis and Conclusions

Surveys have provided the NSW Government with information on community sentiment about sharks, and shark bite mitigation preferences with non-invasive approaches such as aerial surveillance being supported and preferred over invasive and/or lethal approaches such as shark nets. Across several studies of community sentiment, drone surveillance was highly supported (and preferred over helicopters). While SMART drumlines and VR4G shark listening stations were generally valued by the community as a research tool, their suitability and efficacy for mitigating unprovoked shark bite was viewed as low by the community. Community education was seen as an important part of reducing the risk of shark bites to help people take personal responsibility for their own safety. Overall, community sentiment is that government has a role to protect the public from the risk of unprovoked shark bite, but many people, particularly surfers, also considered that it was a collective responsibility by government and individuals in more remote locations in NSW. In this regard, some studies showed strong support for personal deterrents as a solution in remote areas while others found that they weren't used because of a lack of understanding of efficacy, cost, a perceived lack of need, discomfort, and potential negative impacts on surfing performance.

The SMS has played a large part in determining what area-based mitigation systems have been deployed in the North, Mid North and South regions in the Shark Programs for 2020/21 and 2021/22 although notably the mesh netting has been retained in the Metro region. It is clear that a future expectation of the community is for research to resolve the long-standing question of whether the nets in the Metro region can be removed and replaced by a non-invasive system without an increase in risk to water users. From community surveys undertaken, negative community sentiment regarding shark netting is clear and consistent.

The SharkSmart App has been downloaded over 70,000 times. It is a well-organised repository of information that includes all of the information about the SMS and Shark Program for 2021/22 and the research that has driven its current status and it is a great resource for beach goers looking to determine their personal risk and potentially modify their behaviour based on their location, proximity to area-based mitigation, recent shark sightings and environmental conditions. It is noted however that under the 'My Risk' tab there is no reference to surfers potentially considering using a personal deterrent in certain situations despite these devices being able to reduce risk in more remote areas (see further discussion in **Section 7**). It has been identified that while there is a level of public support for the use of personal deterrents, an education campaign based on an understanding of the barriers to uptake of effective personal deterrents is warranted.

3.3 Assessment of Mitigation on Numbers of Shark Incidents

3.3.1 Introduction

This section focuses on determining the effectiveness of the SMS 'Surveillance, detection and deterrents' subprogram and the SMP by assessing patterns in interactions in NSW between water users and sharks. Incidents were investigated at the beach level with reference to specific deployments of SMS and SMP bite mitigation gear, but also at a regional to understand the broader context of bites.

3.3.2 Beach-scale Patterns in Interactions Since Implementing the SMS

This section focuses on the effectiveness of SMS gear that has been retained in the Shark Program for 2021/22 (drones, SMART drumlines and VR4G shark listening stations).

3.3.2.1 The Effect of Drones

There are 27 SLSC-patrolled ocean beaches at which SLSC-piloted drones have been operating since 2017, 2018 or 2019 - 13 in the Far North, six in the Mid North, three in the Metro and five in the South region (**Table 3-3**). The first beaches at which the SLSC-piloted drone program was implemented were Byron Main, Tallows, Lennox Head, Shelly (Ballina), Lighthouse (Ballina), Evans Head and Town (Port Macquarie) beaches, all in December 2017. The beaches that have most recently been included are South Kingscliff, Killick (Crescent Head), Forster and Mollymook, all during the second half of 2019.

Among the Far North beaches there have been 88 instances of a siren being activated as a direct result of a shark being spotted by a drone, with the vast majority resulting in a water evacuation order (**Table 3-3**). There has been around half that number of instances in the Mid North region and, given half the number of beaches are covered than in the Far North region, suggests a roughly similar proportion of sirens/evacuations. There were no instances of siren activation at the three Metro beaches where drones were trialled and only six instances at beaches in the South region. In terms of individual beaches, the highest number of siren/evacuation incidents was recorded for Lennox Head in the Far North (29), followed by Birubi (Mid North; 18), Lighthouse (Ballina, Far North; 17), Forster (Mid North; 15) and Byron Main (Far North; 13). Notably, two other beaches along the short stretch of coast between Lennox Head and Lighthouse beaches, Sharpes and Shelly beaches, have recorded a combined 16 siren/evacuation incidents.

In the case of Far North beaches at which the SLSC-piloted drone program has been operating, there was a total of 15 human-shark interactions (involving BWT species only) between the start of 2010 and the dates on which the first SLSC-piloted drone flights were flown (**Table 3-3**). A total of 60% of these occurred at beaches between Lennox Head and Lighthouse (Ballina) inclusive, and 20% at beaches around Byron Bay. Most notably, since SLSC-piloted drone flights commenced at each of the 13 Far North beaches there have been no interactions on days during which a drone had been flown. There have, however, been five interactions across the 13 beaches since SLSC-piloted drone flights commenced, but these all occurred on days during which a drone was not flown. Four of those five interactions occurred at beaches between Lennox Head and Lighthouse (Ballina) inclusive.

There have been fewer interactions at Mid North beaches at which the SLSC-piloted drone program has been operating than at the Far North beaches, with totals of only three prior to the dates on which the first SLSC-piloted drone flights were flown (two of which were at Crescent Head) and four since those first flights (**Table 3-3**). However, as was the case for Far North beaches, none of the latter four interactions across those six beaches occurred on days during which a drone had been flown. There have also been relatively few interactions at Metro and South region beaches at which the SLSC-piloted drone program has been operating since 2010 (five and four respectively), with only one per region occurring since the first SLSC-piloted drone flights were flown (**Table 3-3**). Those two interactions occurring since commencement of the SLSC-piloted drone program at Metro and South beaches were on days during which a drone had not been flown.

Table 3-3 Total no. instances of siren soundings / water evacuations, and human-shark interactions (BWT species) for beaches covered by SLSC-piloted drone operations. Interaction data are for three temporal categories: 2010 to the first flight, and flight days vs. non-flight days since the first flight.

				No. Interactions		
				Before drones	Since drones	
Beach	**SLSC**	**First SLSC drone flight**	**Total Sirens/Evacs**	**(from 2010 - 1st flight)**	**On flight days**	**On non-flight days**
Kingscliff	Cudgen Headland	4/11/2018	0	2	0	0
South Kingscliff	Salt	24/09/2019	5	0	0	1
Byron Main	Byron Bay	26/12/2017	13	0	0	0
Clarkes	Byron Bay	7/01/2018	0	1	0	0
Wategos	Byron Bay	7/01/2018	0	1	0	0
Tallow	Byron Bay	16/12/2017	0	1	0	0
Lennox Head	Lennox Head-Alstonville	27/12/2017	29	1	0	2
Sharpes	Ballina Lighthouse & Lismore	7/01/2018	9	3	0	1
Shelly	Ballina Lighthouse & Lismore	25/12/2017	7	2	0	1
Lighthouse	Ballina Lighthouse & Lismore	27/12/2017	17	3	0	0
Evans Head	Evans Head-Casino	25/12/2017	7	1	0	0
Yamba	Yamba	18/11/2018	1	0	0	0
Park	Coffs Harbour	20/12/2018	0	0	0	0
FAR NORTH total			**88**	**15**	**0**	**5**
Killick (south)	Kempsey-Crescent Head	17/11/2019	5	2	0	1
Town	Port Macquarie	18/12/2017	0	0	0	1
Flynns	Port Macquarie	8/12/2018	2	0	0	0
Lighthouse	Tacking Point	29/09/2018	0	1	0	1
Forster	Forster	23/11/2019	15	0	0	0
Birubi	Birubi Point	3/11/2018	18	0	0	1
MID NORTH total			**40**	**3**	**0**	**4**
Redhead	Redhead	3/11/2018	0	2	0	0
Blacksmiths	Swansea Belmont	22/11/2018	0	0	0	0
Avoca	Avoca	9/12/2018	0	2	0	1
METRO total			**0**	**4**	**0**	**1**
Kiama Surf	Kiama	2/02/2019	0	1	0	1
Mollymook	Mollymook	8/12/2019	2	1	0	0
Malua Bay	Batemans Bay	1/12/2018	1	0	0	0
Tathra	Tathra	20/12/2018	1	1	0	0
Pambula	Pambula	1/12/2018	2	0	0	0
SOUTH total			**6**	**3**	**0**	**1**

3.3.2.2 The Effect of SMART Drumlines

There are 50 ocean beaches where SMART drumlines have been deployed, either on an ongoing basis (i.e. north from Evans Head) or as part of temporary trials (south from Coffs Harbour) since December 2016 - 45 off 14 beaches in the Far North, 10 off five beaches in the Mid North, 30 off 15 beaches in the Metro, and 40 off 16 beaches in the South region (**0**). A total of 35 SMART Drumlines located off 10 beaches between Lennox Head and Evans Head beaches (inclusive) comprises the ongoing SMART drumline program, which has been operational for 58 months since December 2016. All SMART drumline deployments elsewhere along the coast have to date been short-term trials (< 7 months duration) and this limits the usefulness of the simple comparison of tallies of interactions occurring in the presence or absence of drumlines.

In the case of the Far North region beaches off which SMART drumlines have been deployed on an ongoing basis since December 2016, there have been 14 interactions since 2010, with three occurring since SMART drumlines were first deployed on 1/12/2016 – an almost five-year period (**0**). SMART drumlines are removed from the water in the evening and reinstalled in the morning and they are not deployed at all on days where ocean swell or seas are large. Importantly, all three interactions since 1/12/2016 at beaches in the Far North region occurred when SMART drumlines were not in the water (i.e. early in the morning or on a rough day).

This indicates that the overall effectiveness of SMART drumlines between Lennox and Evans Head was a 100% reduction in interactions compared to the seven-year period prior to their installation.

Table 3-4 Total no. human-shark interactions (BWT species) since 2010 for beaches currently or previously temporarily covered by SMART drumline operations. Interaction data are for two temporal categories: while SMART drumlines were deployed and operational, and while SMART drumlines were absent or non-operational. [a] – Includes one interaction since 1/12/2016 where SMART drumlines were either not set on the day or where the interaction took place in the morning prior to drumlines being set for the day.

Beach	No. SMART Drumlines	Period of deployment	Total months deployed	No. Interactions since 2010 (inclusive)	
				Drumlines operational	Drumlines absent
Lennox Head	5	1/12/2016-current	58	0	2[a]
Boulder	1	1/12/2016-current	58	0	0
Sharpes	4	1/12/2016-current	58	0	4[a]
Angels	2	1/12/2016-current	58	0	0
Shelly	3	1/12/2016-current	58	0	3[a]
Lighthouse	2	1/12/2016-current	58	0	3
South Ballina	3	1/12/2016-current	58	0	1
Airforce	4	1/12/2016-current	58	0	0
Evans Head	8	1/12/2016-current	58	0	1
Half Tide	3	1/12/2016-current	58	0	0
Diggers	2	1/08/2017-3/02/2018	7	0	0
Park	2	1/08/2017-3/02/2018	7	0	0
Boambee	4	1/08/2017-3/02/2018	7	0	0
Sawtell	2	1/08/2017-3/02/2018	7	0	0
FAR NORTH total	**45**			**0**	**14**
Tuncurry	3	1/08/2017-3/02/2018	7	0	1
Forster	1	1/08/2017-3/02/2018	7	0	0
Pebbly	1	1/08/2017-3/02/2018	7	0	0
One Mile	4	1/08/2017-3/02/2018	7	0	0
Burgess	1	1/08/2017-3/02/2018	7	0	0
MID NORTH total	**10**			**0**	**1**
Stockton	2	1/02/2019-30/04/2019, 30/08/2019-01/12/2019	6	0	0
Nobbys	2	1/02/2019-30/04/2019, 30/08/2019-01/12/2019	6	0	0
Newcastle	2	1/02/2019-30/04/2019, 30/08/2019-01/12/2019	6	0	0
Bar	2	1/02/2019-30/04/2019, 30/08/2019-01/12/2019	6	0	0
Merewether	2	1/02/2019-30/04/2019, 30/08/2019-01/12/2019	6	0	0
Palm	2	10/02/2019-12/05/2019, 30/08/2019-01/12/2019	6	0	0
Whale	2	10/02/2019-12/05/2019, 30/08/2019-01/12/2019	6	0	0
Avalon	3	10/02/2019-12/05/2019, 30/08/2019-01/12/2019	6	0	0
Bilgola	1	10/02/2019-12/05/2019, 30/08/2019-01/12/2019	6	0	0
Newport	2	10/02/2019-12/05/2019, 30/08/2019-01/12/2019	6	0	0
Dee Why	2	10/02/2019-12/05/2019, 30/08/2019-01/12/2019	6	0	1
North Curl Curl	2	10/02/2019-12/05/2019, 30/08/2019-01/12/2019	6	0	0
South Curl Curl	1	10/02/2019-12/05/2019, 30/08/2019-01/12/2019	6	0	0
Freshwater	2	10/02/2019-12/05/2019, 30/08/2019-01/12/2019	6	0	0
Manly	3	10/02/2019-12/05/2019, 30/08/2019-01/12/2019	6	0	0
METRO total	**30**			**0**	**1**
The Farm	1	1/11/2017-30/03/2018	5	0	1
Mystics	3	1/11/2017-30/03/2018	5	0	0
Jones	2	1/11/2017-30/03/2018	5	0	1
Bombo	2	1/11/2017-30/03/2018	5	0	1
Kendalls	1	1/11/2017-30/03/2018	5	0	0
East	1	1/11/2017-30/03/2018	5	0	0
Buckleys	1	1/11/2017-30/03/2018	5	0	0
Narrawallee	2	1/11/2017-30/03/2018	5	0	0
Mollymook	3	1/11/2017-30/03/2018	5	0	1
Collers	1	1/11/2017-30/03/2018	5	0	0
Rennies	1	1/11/2017-30/03/2018	5	0	0
Racecourse	2	1/11/2017-30/03/2018	5	0	0
Tathra	10	1/03/2019-20/04/2019	2	0	1
Short Point	3	1/03/2019-20/04/2019	2	0	0
Merimbula	3	1/03/2019-20/04/2019	2	0	1
Pambula	4	1/03/2019-20/04/2019	2	0	0
SOUTH total	**40**			**0**	**6**

3.3.2.3 The Effect of VR4G Shark Listening Stations

There are 21 ocean beaches where VR4G listening stations have been deployed and operational since May 2015 - eight beaches in the Far North, six beaches in the Mid North, two beaches in the Metro, and five beaches in the South region (**Table 3-5**). VR4Gs off Far North beaches have been operational for between 51 and 77 months, with those off beaches in other regions operational for similar periods of time (Mid North 59 to 68 months, Metro 59 months, and South 58 to 59 months). A further 16 VR4Gs are to be deployed, taking the total to 37 (one in every coastal local government area) in 2021/22.

There have been 14 interactions since 2010 at Far North beaches off which VR4Gs were positioned, with eight occurring prior to deployment of the VR4Gs and six occurring since VR4Gs were operational (**Table 3-5**). In the case of Mid North beaches, there were three interactions prior and one since VR4G deployment, while the opposite was the case for beaches in the South region at which VR4Gs were deployed. Two interactions were recorded at Redhead beach, in the Metro region, prior to VR4G deployment, with none after that time.

Table 3-5 Total no. human-shark interactions (BWT species) since 2010 for beaches off which VR4G listening stations were deployed as part of the SMS. Interaction data are for two temporal categories: prior to deployment of VR4Gs; and since deployment of VR4Gs.

Beach	Period of deployment	Total months deployed	No. Interactions since 2010 (inclusive)	
			VR4G operational	VR4G absent
Kingscliff	13/05/2016-current	65	2	0
Clarkes	16/12/2015-current	70	0	1
Lennox Head	4/03/2016-current	67	2	1
Sharpes	15/12/2015-current	70	1	3
Lighthouse	10/07/2017-current	51	0	3
Evans Head	6/05/2015-current	77	1	0
Yamba	3/03/2016-current	67	0	0
Park	15/02/2016-current	68	0	0
FAR NORTH total			**6**	**8**
Trial Bay Front, Horseshoe	16/02/2016-current	68	0	0
Killick (south)	19/10/2016-current	59	1	2
Lighthouse	23/02/2016-current	67	0	1
Old Bar	20/10/2016-current	59	0	0
Forster	22/02/2016-current	67	0	0
Bennetts	27/10/2016-current	59	0	0
MID NORTH total			**1**	**3**
Redhead	27/10/2016-current	59	0	2
Bondi	4/11/2016-current	59	0	0
METRO total			**0**	**2**
Kiama Surf	10/11/2016-current	59	2	0
Cudmirrah	11/11/2016-current	59	0	0
Mollymook	10/11/2016-current	59	0	1
Malua Bay	29/11/2016-current	58	0	0
Merimbula	30/11/2016-current	58	1	0
SOUTH total			**3**	**1**

3.3.3 Interactions within the Metro Region Before and After Implementation of the SMP

There have been 70 interactions at SMP beaches since 1900, with 36 (97% fatal) involving swimmers, 18 involving surfers and the remaining 16 involved in other or unknown activities. The mean of average annual frequency of interactions between swimmers and BWT species (including ‘unknown species’ records) per beach (*n* = 51 beaches) prior to first deployment of the SMP nets has decreased substantially (by ~90%) on a per year per beach basis (**Figure 3-1A**). The opposite appears to be the case for surfers involved in interactions with BWT sharks at SMP beaches, but this is not surprising given that surfing was not popular prior to SMS netting commencing. The rate of fatality or injury (combined) associated with those interactions with surfers (61%) has been substantially lower than for swimmers.

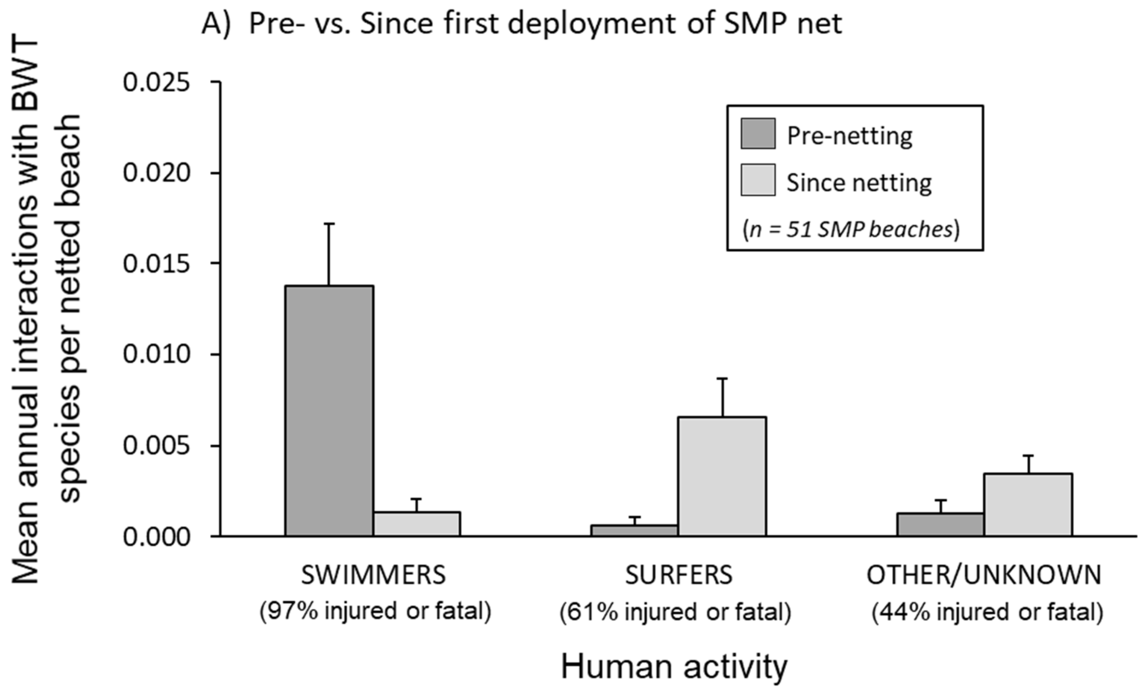
The 'other activities' represented within this SMP beach interactions dataset included surf ski, kayaking, sailboarding, SCUBA diving, snorkelling and spearfishing[4]. There were seven interactions for which the species was unknown. As has been the case for surfers, the mean of average annual frequency of interactions per beach increased since the first SMP net deployment, but differences were marginal. The rate of fatality versus non-fatal injury (combined) associated with those interactions (44%) has been lower than for swimmers and surfers (**Figure 3-1A**).

On a decade by decade basis, the frequency of interactions between swimmers and BWT species (including 'unknown' species records) increased from the 1910s through the 1920s, before decreasing almost as quickly through the 1930s and 1940s decades (**Figure 3-1B**). From the 1950s through to the 1970s there was a further gradual decrease to zero. Since then, there has been only one interaction across all SMP beaches involving a swimmer. There was a noticeable increase in the frequency of interactions between surfers and BWT species from 2000 onwards where it has remained fairly constant until the present (**Figure 3-1B**).

Looking at more recent patterns at the beach level, there have been 48 interactions in the Metro region since 2000, with nine involving swimmers and 25 involving surfers. Of those 34 interactions with swimmers and surfers, 29 (85%) occurred at netted beaches while five occurred at non-netted beaches with the Metro region. Eight of those nine swimmer interactions involved Wobbegongs or Grey Nurse Sharks, with one reportedly involving a Dusky Whaler (Australian Shark Attack File 2021).

A total of 18 (72%) of the 25 surfer interactions at Metro region beaches since 2000 involved BWT species (or unidentified species) – and predominantly White Sharks (12) – with the remaining seven involving Wobbegongs or Grey Nurse Sharks. Of the 18 surfer interactions involving BWT or unidentified species, only two occurred at non-netted beaches and another three occurred during the winter months at netted beaches when nets were not deployed. Given this, it can be summarised that 13 of 18 (72%) surfer interactions with BWT (or unidentified) species at Metro region beaches since 2000 occurred at beaches that had nets deployed at the time of the incident, indicating that shark nets in the Metro region do not eliminate the risk to surfers from BWT sharks.

[4] Spearfishing is prohibited except within 20 m of the ends of any beach. Most incidents would not be at beaches, but on rock reef north or south of beaches.



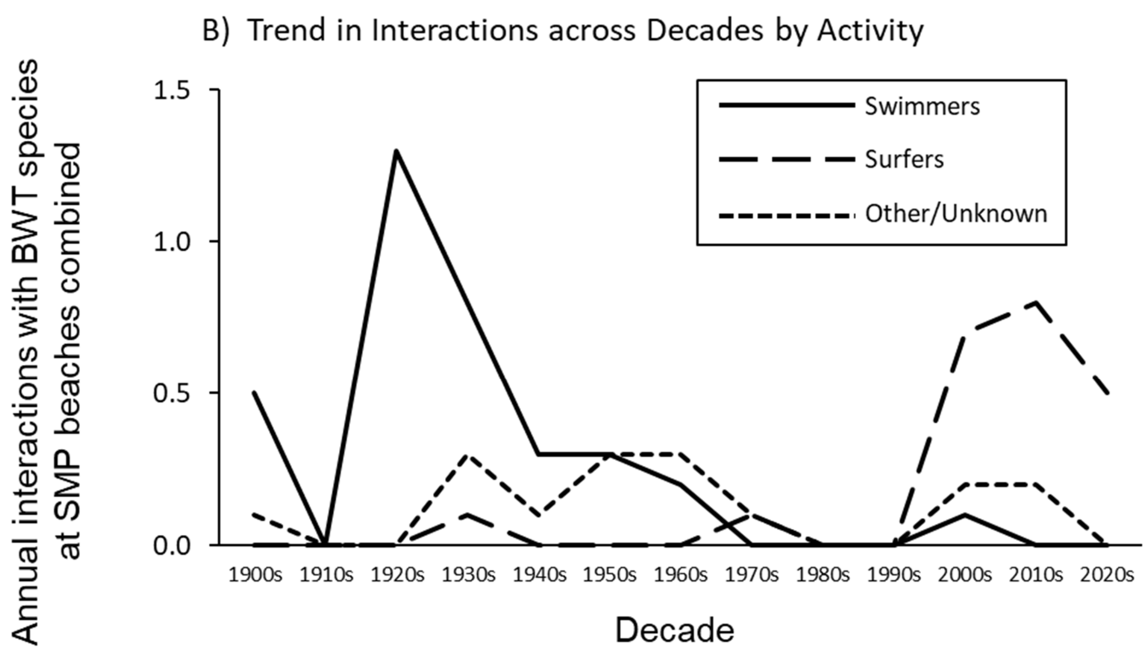


Figure 3-1 A) Mean of average annual rate of human-shark interactions involving BWT species (White, Whaler, Tiger and unidentified) per SMP beach (n = 51 beaches) for the periods prior to (Pre-net) and following (Since netting) first net deployment, with the durations of these periods determined separately for each beach. Data are presented separately for incidents involving swimmers, surfers and other/unknown categories, with the proportions of the total interactions either fatal or injured (combined) shown. B) Trends in annual rate of interactions involving BWT species through time (data compiled by decade) for all current SMP beaches combined. NB. Data do not distinguish between interactions that occurred in months when nets were not deployed.

3.3.4 Broad-scale Patterns in Interactions

This section summarises the main findings in patterns in interactions at all beaches in the Far North, Mid North, Metro and South regions. Further detail can be found in **Appendix B**. This information about the generality of interactions has been included for contextual purpose and to inform recommendations for potential adjustments to the Shark Program in the future.

3.3.4.1 Interactions Prior to and After Implementing the SMS

Since 1980 there have been 194 recorded instances of human-shark interactions, with 136 of these involving target sharks and records where the species responsible was unknown. Of all interactions between humans and BWT, surfers were involved in ~75% of the total and ~46% of these occurred in the Far North region. Very few incidences to swimmers have occurred in the Far North and Mid North regions since 1980. The annual rate of interactions (i.e. total no. interactions (beaches pooled) divided by no. years) between humans and BWT has, in general, been substantially higher during the six-year period Since-SMS (2016-2021) than during the 36-year Pre-SMS period for all four regions, (**Figure 3-2**). This trend is most prominent for surfers. Given the SMS trials were ramped up during the course of the five-year program and were not done at all beaches within regions, these data do not imply that SMS area-based shark bite risk mitigation deployments have been ineffective. Indeed, analysis at the individual beaches where the gear was deployed shows the opposite (see **Section 3.3.2**). Rather, it highlights the challenges faced in using area-based protection systems to reduce the state-wide level of interactions.

For swimmers, there have been few interactions with BWT since 1980 at beaches in the Far North and Mid North regions, while annual interaction rates for swimmers rose slightly from the Pre- to the Since SMS period in the Metro and South regions. There were also rises in rates of interaction for the ‘Other activities’ category for the Far North and Metro, with SCUBA diving, snorkelling, spearfishing and kayaking prominently represented among those records.

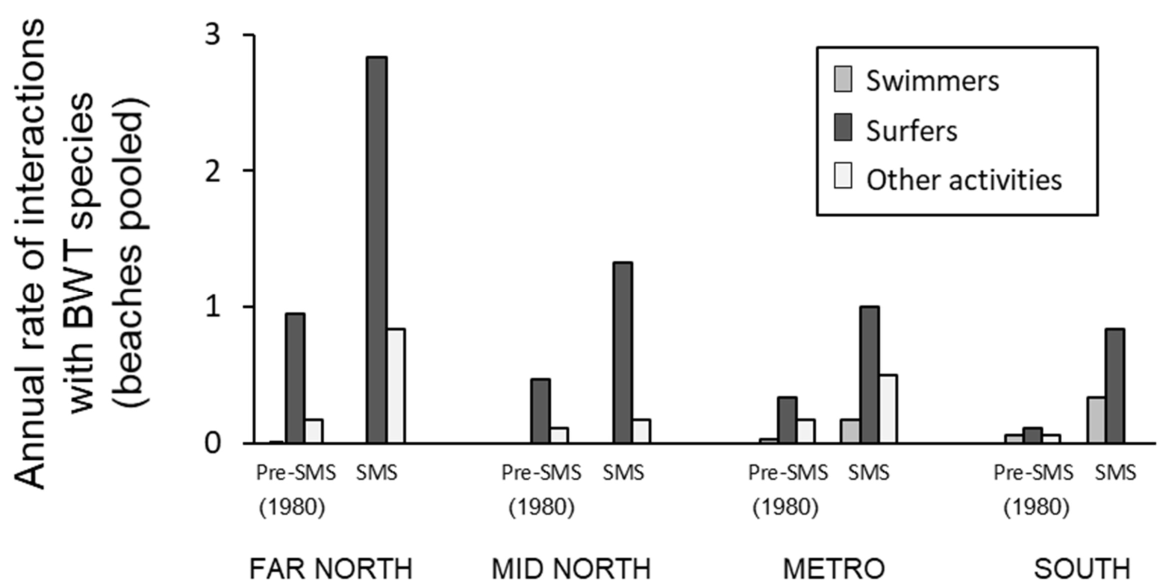


Figure 3-2 Annual rate of human-shark interactions (no. per year) involving BWT sharks in the Far North, Mid North, Metro and South regions (beaches pooled) during Pre-SMS (1980-2015, 36 years) and Since SMS (2016-2021, 6 years) periods. Data are presented separately for incidents involving swimmers, surfers and other activities.

A more detailed examination of annual rates of interactions between humans and BWT indicated that, despite there being substantially fewer patrolled than unpatrolled beaches in the Far North, Mid North and South regions, interactions since 1980 generally occurred most often to surfers at patrolled beaches (**Figure 3-3**). However, following implementation of the SMS in the Far North and Mid North regions, the rate of interactions with surfers at non-SLSC beaches has been only marginally less than for beaches with SLSCs. The same pattern in spatial distribution of interactions was apparent for the Metro region, although there are more patrolled than unpatrolled Metro beaches.

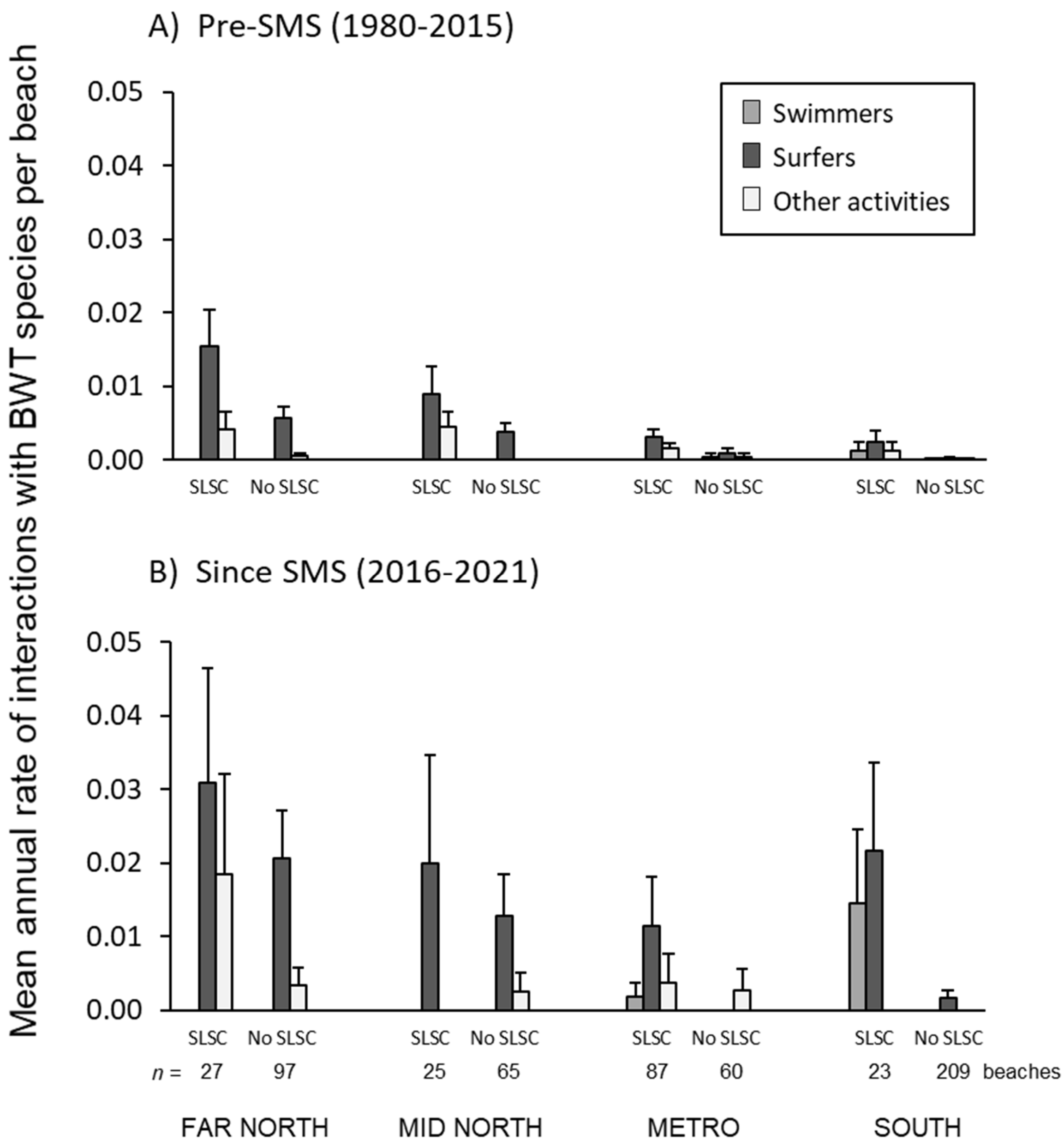


Figure 3-3 Mean annual rate (no. per year) of human-shark interactions (BWT species) per beach during the: A) Pre-SMS period (1980-2015); and B) period since commencement of implementation of the SMS (2016-2021); for patrolled (SLSC) and unpatrolled (No SLSC) beaches in the Far North, Mid North, Metro and South regions. Data are presented separately for incidents involving swimmers, surfers and other/unknown categories.

3.3.4.2 Outcomes of Interactions

Most interactions between a shark and humans generally result in an injury, but generally less than 10% of injuries are fatal. The exception was in the Metro region where fatalities accounted for 23.3% of Pre-SMS interactions. The patterns in relative proportions of victims that were either uninjured, injured or died as a consequence of an interaction were generally similar between the Pre-SMS and Since-SMS periods for each of the four regions.

3.3.4.3 Species Responsible

Since 1900, across NSW, White Sharks have been responsible for 13 of the 72 interactions involving swimmers (18.1%), with the vast majority (84.6%) resulting in a fatality. A relatively large proportion (30.1%) of all swimmer interactions involved Wobbegongs or Grey Nurse Sharks, with all resulting in non-fatal injury and it is noted that neither the SMS nor SMP are designed to reduce interactions with these non-target species. An even greater proportion (40.3%) involved unknown species, with 27.6% fatalities and 72.4% of victims injured, and it must be assumed that many of these would also have been from BWT. Whaler Sharks were generally unable to be classified to species, but probably included mostly Bull Sharks. Whalers were attributed to six (8.3%) of the interactions involving swimmers, resulting in a high proportion of fatalities (66.7%). Only two swimmer interactions were attributed to Tiger Sharks, with both resulting in a non-fatal injury. Only one of the 72 swimmer interactions resulted in no injury to the victim.

In contrast to swimmers, White Sharks were attributed to almost half (48.5%) of the 136 interactions involving surfers, with Whalers (16.2%), Tigers (2.9%) and Wobbegongs or Grey Nurse Sharks (19.1%) deemed responsible for far fewer interactions. The fatality rate across the 136 interactions involving surfers has been relatively low when compared to swimmers, with patterns in outcomes for White (45.5% uninjured, 48.5% injured and 6.1% fatal) and Whaler (36.4% uninjured, 54.6% injured and 9.1% fatal) shark interactions very similar. As with swimmers, confirmed surfer interactions with Tiger Sharks have been rare relative to White and Whaler sharks, with one fatality, two victims non-fatally injured and one instance of no injury. Interactions between surfers and Wobbegongs or Grey Nurse Sharks, have almost always resulted in injury (92.3%) but none were fatal. A loosely similar pattern is evident in the cases of surfer interactions for which the responsible shark species is unknown, with 72.2% resulting in injury and none in fatalities.

For other activities not falling into the swimming or surfing categories, White Sharks were attributed to 26.2% of the 61 interactions in this category, with Whalers (16.4%), Tigers (6.6%), Wobbegongs or Grey Nurse Sharks (19.7%) and unknown species (31.1%) attributed to the remainder. Most interactions with White (81.3%) and Whaler (80.0%) sharks did not result in any injury, with non-fatal injuries resulting in the cases of all remaining White and Whaler Shark interactions, bar one (a fatal White Shark interaction with a SCUBA diver). Two of the four Tiger Shark interactions resulted in no injury, while the other two sustained non-fatal injuries.

Overall, the annual rate of interactions (i.e. total no. interactions (beaches pooled) divided by no. years) for the six-year Since-SMS period was at least double than for a 36-year Pre-SMS period from 1980 for all but one of the three species category / region combinations (**Figure 3-4**).

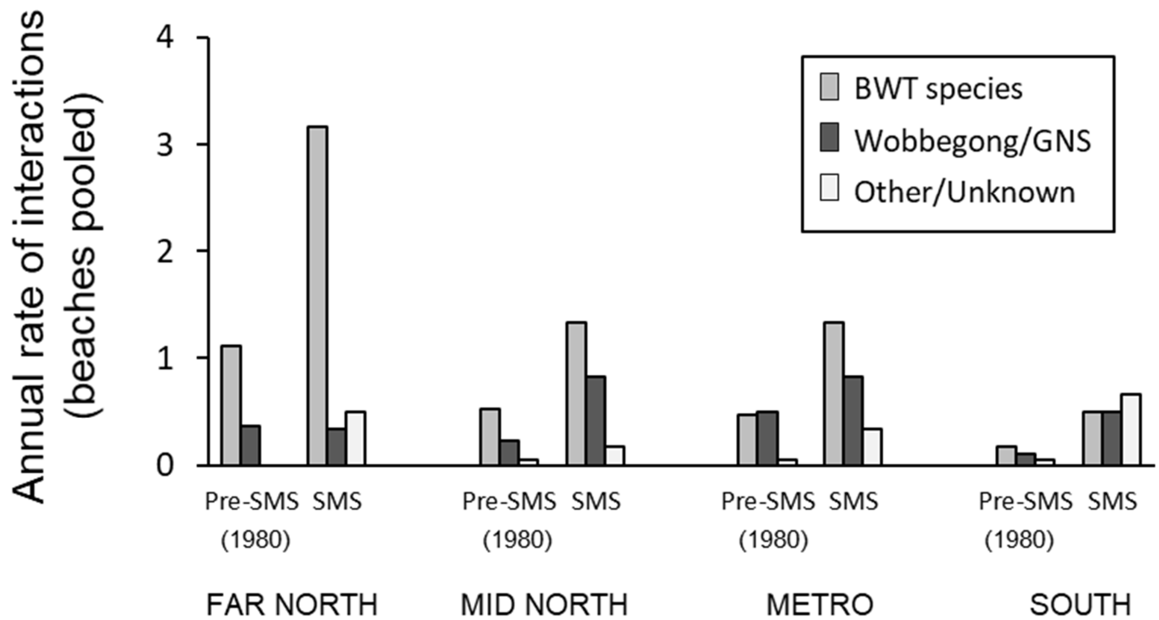


Figure 3-4 Annual rate of human-shark interactions for three separate species groupings (BWT species, Wobbegong/GNS and Other/Unknown) in the Far North, Mid North, Metro and South regions (beaches pooled) during the Pre-SMS (1980-2015, 36 years) and Since SMS (2016-2021, 6 years) periods, irrespective of activity and outcome.

3.3.5 Synthesis and Conclusions

At the many beaches where SLSCs have been trialling drones, there has been no bites on drone fly days and there have been numerous situations, particularly in the Far North and Mid North regions, where drones have spotted a potentially dangerous shark (i.e. a target shark or large shark that could not be identified) that has resulted in a warning to water users (e.g. shark siren) or an evacuation of the water. Given there were interactions at many of these beaches, particularly in the Far North and Mid North regions, in a similar period of years before the drone trials and during the period of drone trials but on 'non-fly' days, the drones and the resultant warnings or evacuations have undoubtably been effective at reducing, if not 'eliminating' interactions between sharks and water users.

SMART drumline deployments have also been similarly effective at reducing interactions between sharks and humans at beaches between Lennox and Evans Head in the Far North region and where this gear has been deployed for almost six years there have been no interactions (i.e. 100% effectiveness) while the gear is operational. At these beaches, however, given that all 11 of the pre-drumline interactions occurred in a cluster between January 2015 and October 2016 (i.e. a very small window of the pre-deployment test period), conclusions regarding effectiveness must be viewed with some caution. There were also three interactions at these beaches either early in the morning before SMART drumlines were deployed for the day or on a day where the ocean swell or seas were too large to deploy the gear safely. This highlights a limitation of the gear with regard to protecting surfers who may be in the water very early or late in the day or in large swells.

The effectiveness of VR4G shark listening stations is not apparent with generally only a marginally less number of interactions at beaches where they have been deployed compared to a similar period prior to their deployment. Indeed, in the South region there have been more interactions at beaches since their deployment.

In the Metro region, the mean rate of interactions between swimmers and BWT species (including 'unknown species' records) decreased substantially (by ~90%) from the period comprising years prior to first SMP net deployment to the period since the year of net deployment to today. The opposite has been the case for surfers, with the mean rate of interaction ten-times higher for the period comprising years since the year of net deployment. The incidence of interactions between surfers and BWT species in the Metro region generally increased steeply in the 2000s and has remained elevated, while there has been no concomitant trend of increase in swimmer interactions. At a beach level since 2000, of the 34 interactions with swimmers and surfers, 29 (85%) occurred at netted beaches while five occurred at non-netted beaches with the Metro region. Eight of those nine swimmer interactions involved Wobbegongs or Grey Nurse Sharks, with one reportedly involving a Dusky Whaler. Thirteen of 18 (72%) surfer interactions with BWT (or unidentified) species at Metro region beaches since 2000 occurred at beaches that had nets deployed at the time of the incident. These observations indicate that the SMP has been effective at reducing interaction with swimmers but is less effective for surfers. At a state-wide-scale, most interactions between sharks and humans since 1980 have occurred in the Far North region of NSW followed by the Mid North region and were mostly to surfers. Although most interactions result in an injury generally less than 10% of injuries are fatal. White Sharks were attributed to almost half of the interactions involving surfers, more than for swimmers. Historically, rates of interactions with BWT have been greater at patrolled (i.e. SLSC present) than at unpatrolled beaches, generally irrespective of activity (swimmer, surfer, other) but a fair proportion of the total also occur at unpatrolled beaches. This may reflect that patrolled beaches tend to be in more populated areas, historically were the primary location for all swimming and surfing, and therefore had and will have larger numbers of water users than unpatrolled beaches.

Since the SMS commenced in 2016 the rate of interactions between humans and target sharks has increased in the broad regions where SMS trials were done, but given it has also increased in the Metro region, which is netted and until recently had helicopter surveillance, the general increase is likely to be related to a global increase in unprovoked shark bite (McPhee, 2014; Chapman and McPhee, 2016). Other than SMART drumlining at Ballina and Evans Head which has been ongoing since the trial began in December 2016, the SMS was a series of trials of relatively limited spatial and temporal extent and magnitude, so it is not unsurprising that at a regional level the increase in interactions continued relatively unabated. As demonstrated by the zero bites at beaches while the SMART drumlines and drones were active, there may have been even more interactions if the SMS had not been introduced.

Overall, it can be concluded that drones and SMART drumlines have been effective at mitigating risk of shark bite at the beaches at which they are deployed. The available data demonstrates that drones and SMART drumlines have been 100% effective at reducing bites, but it is not clear if VR4Gs reduce interactions or not. It is noteworthy that because shark mitigation gear is only likely to mitigate the risk of shark bite at the individual beaches at which gear is deployed, interactions at a state-wide level outside of those areas with mitigation are generally increasing. If the Shark Program is to reduce the overall incidence of shark bite, then more area-based gear will be required than is currently deployed, or an alternative approach is needed (see further discussion in **Section 7)**.

3.4 Assessment of Mitigation in Terms of Cost Effectiveness

While the economic impacts on coastal communities are often identified as one of the reasons for Governments to intervene to mitigate the real or perceived risk of unprovoked shark bite (Couper and Walters, 2020), there is limited research on the exact nature of economic impacts following a shark bite or a series of shark bites. The nature of human visitation following an unprovoked bite is complex, with one PhD study from the United States (Stair, 2018, pp.53-56) finding that overall, there were net negative economic consequences for coastal counties:

- In the short term (within 3 days). in county hotels nights increased (424 nights) as people were attracted to the event (e.g. to see what happened, or to respond to or report on the emergency for example) but these positive impacts were more than offset by out of county loss of visitor nights (550) and
- Over a longer period (within 30 days of attack) there was a loss of hotel visitor nights (415) as beach goers adjusted their trips to avoid the in-county location of a bite.

Plausibly similar economic impacts could have occurred in NSW, particularly after a series of bites at a location over a short period of time, but the existence of economic impacts have not been empirically tested in NSW.[5] Changes in the participation in leisure activities following a shark bite may have localised and broader coastal economic impacts as found in the United States by Stair (2018). Although not empirically tested in NSW, these impacts may be a greater in a smaller coastal community with a heavy reliance on tourism compared to a metropolitan area with a large and diverse range of economic activities. Businesses that are almost wholly dependent on an activity such as surfing may be more prone to an economic impact after a local shark bite or bites than a business such as a retail food service outlet that services a broader clientele.

It is also plausible that participants who reduce their participation in a water-based leisure activity such as surfing may participate in alternative leisure activities. If this is a common response to an unprovoked shark bite it may wholly or partly offset local economic activity by redistributing activity among different businesses. It may also lead to a redistribution of economic activity between regions if spending occurs in businesses in different regions. Lemahieu et al., (2017) documented local changes to beach visitation in response to two unprovoked shark bites. Couper and Walters (2020) provided anecdotal evidence of surfers surfing less or ceasing surfing activities in response to unprovoked shark bites. However, Neff (2012) noted that visitation at Bondi Beach showed an immediate decline following a bite in 2009 but then a rapid return to pre-bite levels in the following weeks. Gibbs (2020) qualitatively identified a range of responses from individuals after a series of bites, including surfing and snorkelling less often in remote areas. While this may result in economic impacts in, or adjacent to, remote areas, the magnitude and type of economic impacts are not known.

[5] There is a range of literature that points to the adverse economic consequences (e.g. see Curtis et al., 2012, Hazin et al. 2008, Dudley, 2006) but these are not empirical tests of impact, undertaken by those with economic expertise. The empirical testing of adverse economic impact following an event/s is a suggested area for future research by the Department to support recurring funding requirements in NSW.

The priority of a shark bite mitigation program should be to reduce fatalities or serious injury from shark bites. Reducing the perception of risk should be secondary – but should not be ignored as both can contribute to the desirability of coastal tourism for international and interstate visitors. However, the main benefit of the program should be measured in terms of human lives saved or injuries avoided. This is not a limitation specific to the SMS, but simply a product of not being able to measure with any degree of certainty events that could, but do not occur with management interventions in place. Notwithstanding this, the results of drone trials by the SLSCs and SMART drumline deployments (see **Section 3.3.2**) indicate that these systems have reduced interactions substantially at beaches where this gear is deployed and it is more than likely that this has reduced injury (even death) to many people.

An economic value can be assigned to a human life for various purposes including in the context of hazard mitigation and the cost benefit of health programs (Landfeld and Seskin, 1982; Viscusi, 2008). Conceptual estimates of the value of a human life are contentious and varying estimates of the value of statistical life (VSL) are available and influenced by context and methodology (Viscusi and Aldy, 2003; Ashenfelter, 2006). Typically, the VSL declines during a person's life and generally in a non-linear fashion (Viscusi and Aldy, 2003). In 1995 US dollars, Miller (2000) identified that the best estimate of VSL for Australia was $2.68 million. Converting that value to 2021 Australian dollars equates to $6.77 million[6]. In their systematic review, Ananthapavan et al., (2021), using 2017 data, calculated that the median Australian VSL was AU$7.3 million. They noted that this value was higher than that being recommended by the Australian government at the time of $4.3 million. This figure has since risen to $5.1 million, according to the Australian Government Office of Best Practice Regulation[7]. Some commentators[8] suggest that the VSL used by the Australian Government is a substantial underestimate based on comparisons with other countries. The possibility of an underestimate is also borne out in the systematic review of Ananthapavan et al., (2021) and the extrapolation in this report from Miller (2000). Nonetheless, for the current purpose the recognised Australian Government value of $5.1 million will be used.

In addition to potential costs due to loss of life, other costs need to be considered. Serious injuries require substantial costs incurred by the health care system (including paramedics) and the victim, as well as foregone (and possibly permanent) earning opportunities for the victim in many cases. Additional costs may also be associated with the treatment of PTSD for victims, first responders, the victim's families/friends and witnesses. There are substantial complexities in terms of assessing the economic impact of, for example, a lost limb and it needs to be considered on a case-by-case basis.

Public confidence in beach safety is important as it contributes to the desirability of a location for tourism which has positive economic impacts. Neff (2012) identified that there was a perception of a decline in public confidence of the then NSW Government's beach safety program focussed on sharks. Providing a range of approaches to shark bite mitigation, reducing environmental impacts, understanding human perceptions, and expanding the area over which mitigation is applied have all contributed to building greater public confidence in shark bite mitigation in NSW since the findings of Neff (2012). Importantly to provide a level of public confidence in beach safety, mitigation measures need to be spatially comprehensive and include areas such as the north and mid-north NSW coasts where interactions are high and coastal tourism is important.

Wildlife has a total economic value (TEV) which may include a commercial (use) value and non-commercial values including existence values and bequest values (Richardson and Loomis, 2009; Teh et al., 2018; Sangha et al., 2019). Use values can include harvest activities (e.g. fisheries) as well non-harvest activities (e.g. whale watching). TEV assigned by communities and individuals to an animal is highly variable between taxa with animals bearing more anthropomorphic traits generally having higher value (Colléony et al., 2017). The TEV assigned by a community are often not strongly correlated with conservation status (Colléony et al., 2017; Bellon, 2019). The TEV for types of wildlife can change over time (Mazzoldi et al., 2019).

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[6] This value was calculated first by converting $US to $AU using the average 1995 conversion rate between the two currencies and then correcting for inflation from 1995 to the present using https://www.inflationtool.com/australian-dollar/1995-to-present-value?amount=3632914

[7] https://obpr.pmc.gov.au/resources/guidance-assessing-impacts/value-statistical-life

[8] https://www.crikey.com.au/2020/06/05/is-the-government-putting-the-wrong-dollar-value-on-the-cost-of-human-life/

Shark bite mitigation can have costs in terms of impact to marine wildlife (including threatened species). These impacts are highly dependent on the methods of mitigation used. For example, shark meshing results in the mortality of sharks and other marine animals. Dangerous shark species such as white and tiger sharks themselves have high non-consumptive use values (Gallagher and Hammerschlag, 2011; Cisneros-Montemayor et al., 2013). These values are likely to increase over time as positive community sentiments towards sharks in developed countries continues to increase (Pepin-Neff and Wynter, 2018). SMART drumlines can have low levels of mortality of captured animals and surviving animals can be impacted by short-term disruption to feeding and habitat use and some injuries because of capture and tagging. The use of drones may have no ecologically meaningful impacts on marine fauna.

The economic impacts of an activity, such as shark meshing, from the removal of fauna is dependent on the species lost and the relative and absolute mortality rate at the population level. The relative component is relative to other sources of mortality (e.g. commercial and recreational fishing). Absolute mortality rate is of concern if it is sufficient to induce a population decline to the extent where the species would become, or projected to become a listed threatened species or where recovery of a threatened species is inhibited.

Currently, there is no estimate of the value in economic terms for marine wildlife in NSW including species such as White Sharks, various cetaceans, other shark species and marine turtles. There are estimates of the value to non-consumptive tourism from various taxa in other locations. For example, Tisdell and Wilson (2002) found that tourists to Mons Repos Conservation Park (Queensland) would collectively be willing to pay $250,000 per year to protect marine turtles. This however is not directly transferable to NSW as the state lacks locations where turtles predictably nest in high densities such as Mon Repos. The economic value in this case is tied significantly to the ability of tourists to interact with the animals on land during their nesting and hatching (Tisdell and Wilson, 2001). Gallagher and Hammerschlag (2011) reviewed the economic value attributed to shark tourism globally and found highly variable contributions ranging from $2.3 million in the Maldives and $78 million per year in the Bahamas with the later associated with various reef shark species. A number of shark ecotourism activities are focussed on species that rarely occur in NSW (e.g. Whale Sharks *Rhincodon typus*) or in habitats that do not occur (e.g. coral reefs). Huveneers et al. (2017) estimated the economic value of shark cage diving focussed on white sharks to Australia was $25.5 million annually, but cage diving with white sharks is not an activity that occurs in NSW. The economic value of cetaceans such as whales associated with tourism has been the focus of a number of studies including in Scotland (Parsons et al., 2003), Queensland and WA (Wilson and Tisdell, 2003; Stoeckl et al., 2005), Iceland (Cook et al., 2020) and the Pacific Islands (Orams, 2002). Combined the various estimates are highly variable based on methodology and also context and the latter highlights the difficultly in transferring results with precision and accuracy from one location to another.

The determination of total economic value for wildlife potentially impacted by shark mitigation activities in NSW is a substantial research undertaking involving the collection of empirical information that is outside the scope of this report. Arguably it was also beyond the scope of the SMS to undertake such research and may have little influence on the strategic and day to day decisions made by DPIF with respect to shark bite mitigation.

3.4.1 Synthesis and Conclusions

In simple terms, an intervention that costs less than $5.1 million per annum is cost effective in terms of saving a single life. This value does not suggest that an investment of $5.1 million or less per annum is sufficient or cost-effective. As discussed in this report, a case exists that the value of human life estimated by the Commonwealth Government is an underestimate. Further, although it is difficult to quantify the number of lives saved, it is plausible that more than one fatality per year is prevented in NSW by the Department's shark bite mitigation program. Additionally, it is highly plausible that shark bite mitigation activities in NSW prevent serious injuries that can have an additional economic cost. The program also contributes to public confidence in beach safety – including in regional coastal communities and this can have economic benefit for tourism in coastal communities at the local and regional scale.

The NSW Government investment in the SMS was $16.1 million over five years, with a further $8 million on the Shark Program in 2020/21 and an increased investment of $21.4 million in 2021/22. Over its five-year life the NSW Government investment in shark bite mitigation through the SMS and SMP and aerial surveillance was about $27 million. These programs needed only to have prevented four or more fatalities and/or 10s of people being severely injured to have been cost-effective. Given the results from the drone and SMART drumline trials, and the four fatalities in 2019/20 and 2020/21 at areas with little if any shark mitigation, it is highly plausible. Moreover, given the SMS focused only on mitigation systems that have no or very little bycatch, it has caused no measurable harm or costs to the marine environment or wildlife (including threatened species) but considerable potential benefit to the public in having the option for a closer relationship and understanding of sharks in NSW waters. Overall, the Shark Program has, and in its current form will continue to have, a considerable net benefit.

4 Review of New Information

4.1 Introduction

Cardno (2015) reviewed alternative methods that were available at the time and which were subsequently used to inform the development of the SMS. Neither manned aircraft nor drones were included in that review, nor were personal deterrents. Technologies have emerged following that review. Some technologies identified in Cardno (2015) have not progressed to being commercially ready while trials of others found they were not effective for NSW conditions.

4.2 Area-Based Approaches

Historically, shark bite mitigation in NSW focussed on the use of shark nets in the Sydney/Wollongong/Newcastle (Metro) region (i.e. the SMP) augmented by manned aerial patrols. Nets have become highly controversial (Meeuwig and Ferreira, 2014; Gibbs and Warren, 2015). In response to bites including fatalities on the northern NSW coast, the geographic footprint of mitigation activities was expanded. This resulted in the expansion in area and focus of what was the SMP to the SMS, and more recently the Shark Program.

Table 4-1 summarises the status of alternative (to catch and kill) area-based technologies (see also McPhee et al., 2021) and describes the suitability of the various approaches to specific NSW conditions. Overall, since Cardno's (2015) review, the number of technologies suitable for NSW conditions have been reduced. In the case of barrier nets and sonar technologies, barrier net trials were abandoned following inability to deploy them due to local sea conditions, whilst aquarium and field trials of sonar technologies demonstrated a lack of suitable efficacy (see **Section 3.1.3**).

Overall, there are no completely new technologies that have been developed, or are known by the authors to be in development. However, drone technology and electric barriers continue to advance. As discussed in McPhee et al. (2021) and Colefax et al. (2021), multi-spectral and hyper-spectral cameras for drones represent new technologies which can improve efficacy under the full range of ambient conditions. However, they may not be currently suitable for widespread use given higher costs and the need for specialist operators. The trialling of hyper-spectral and multi-spectral cameras, artificial intelligence, with a focus on efficacy and the cost effective and practical deployment under NSW conditions, is the only new area-based approach that offers the potential to substantially advance shark bite mitigation. Other approaches such as the use of standard drones will also continue to evolve. As shark mitigation continues to be an active area of technological advancement and entrepreneurship, the Shark Program needs to be flexible to adapt to and utilise new technologies and approaches that do arise.

In terms of electric barriers, Ocean Guardian has used its Shark Shield® Technology to develop the LR1000 virtual barrier which Ocean Guardian indicates has been commercialised and is purportedly ready for large-scale trials. The virtual nets include horizontal and/or vertical 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 or where each buoy is anchored independently. Ocean Guardian expects installations can be hundreds of metres long and up to a maximum length of around 1000 m (0.62 mi) with a maximum depth of 12 m (39') but the system will still need to prove it can overcome challenges associated with installation and large swells and rough seas that plagued installation of barriers (see **Section 3.1.3**).

Table 4-1 Summary of the status of alternative (to catch and kill) technologies and McPhee et al., (2021) describe the suitability (or otherwise) of the various approaches to specific circumstances.

Technology	Comment
Barrier Nets	Trials of two available technologies were attempted in northern NSW but technologies were not suitable for the sea conditions experienced or the mobile seabed encountered. While barrier technology has advanced, it has not advanced suitably to overcome the practical challenges encountered in the active NSW coastline. Barrier nets remain a viable option to protect and give peace of mind to bathers in calm environments such as Sydney Harbour.
SMART drumlines	SMART drumlines have been trialled in NSW, WA and at Reunion and further trials are planned in Queensland. They can now be considered mature technology with trials answering some key questions related to their deployment including the movement of sharks on release, mortality on release, and practical implementation. This has included their effectiveness at catching target shark species (Tate et al., 2021a), physiological impact on White Sharks (Tate et al., 2019), bycatch levels in northern NSW (Tate et al., 2021a and b), whether their deployment attracts sharks (Guyomard et al., 2020). SMART drumlines also represent a key catching apparatus for the tagging of sharks for subsequent monitoring. Research investment from the NSW SMS has been critical in the further development of the technology and the assessment of efficacy and impacts. Community attitudes to SMART drumlines in northern NSW identified that they were valued for their contribution to research but not valued for making waters safer (Simmons et al., 2019). Elsewhere along the NSW coast, SMART drumlines receive little support amongst communities surveyed (Mehmet et al., 2021)
Drone technologies	Although not assessed as part of Cardno (2015), a substantial body of work, largely funded by the NSW SMS, has been undertaken to trial drone technologies and assess the practicality and community support of the approach. Drones that operate in the visual spectra can be considered mature technology. The next phase of drone development involves craft fitted with multi-spectral or hyper-spectral cameras (Colefax et al., 2021), in conjunction with artificial intelligence to improve detection rates under a full range of ambient conditions (McPhee et al., 2021). Gorkin et al., (2020) report on the Smart Eye detection systems using a blimp coupled with artificial intelligence to automatically detect the presence of sharks and the relaying of this information via smart technology has progressed to proof of concept for augmenting other approaches, but further research to understand and improve precision and accuracy are required.
Sonar Technologies	Trials of sonar technologies have not demonstrated a sufficiently high level of efficacy using existing technologies with some substantial practical challenges being difficult to overcome (McPhee et al., 2021).
Electric Barriers	Cardno (2015) identified three electric barriers that were in development. Two (Aquatek and Resen Energy) electric barrier products do not appear to have been further developed or trialled. The third product, initially developed by the KwaZulu-Natal Sharks Board has undergone further trials in South Africa. Ocean Guardian, a partner in this product, has implied that the electric barrier is ready for trials in Australia.
Sharksafe (Magnetic) Barrier	The Sharksafe Barrier has undergone further development and trialling overseas but at a relatively small spatial scale relative to what would be needed in NSW. Further research is necessary into the cost-effectiveness of the approach at a meaningful scale as well as research into effectiveness in high energy beach environments. Local trials would be necessary to address a range of significant practical challenges that will be geographically variable (e.g. biofouling) (McPhee et al., 2021).
Bubble Curtains	Although discussed in Cardno (2015), this approach was largely dismissed because of significant efficacy and practical concerns. No new information suggests that circumstances have changed.
Manned Aerial Surveys	Manned aerial surveys (e.g. via helicopters) made a contribution to beach safety including shark bite mitigation and although they were a component of the NSW Shark Program 2020/21, they have been discontinued. No technical advancements in their deployment or efficacy was identified.

4.3 Personal Approaches

4.3.1 Personal Deterrents

Personal deterrents play an important role in shark bite mitigation in some jurisdictions (**Section 5**) and these allow individuals to make personal choices for the type of device that suits their needs and circumstances. There is a diverse range of personal deterrents that employ different approaches to deterring a shark. As with any personal safety approach there is a need for it to be effective with the level of effectiveness communicated to the public with veracity. Personal deterrents will not be 100% in all circumstances (nor, by analogy, would seatbelts be 100% effective in all car accidents), and efficacy needs to be determined through independent assessment. Since Cardno (2015), several independent tests of personal deterrents available in Australia have been undertaken with varying outcomes (Kempster et al., 2016; Huveneers et al., 2018; Egeberg et al., 2020; Gautier et al., 2020; Thiele et al., 2020; Blount et al., 2021). Overall, electric deterrents represent the most effective type of deterrent although there is variation in performance of the various products (Huveneers et al., 2018). Bradshaw et al. (2021) mathematically modelled the reduction in bites if everyone used electric deterrents. They predicted that up to 1063 people (range: 185–2118) could potentially avoid being bitten across Australia by 2066 if all water users used the devices. Even at the lower confidence level of 185 humans avoiding being bitten, this represents a very substantial impact on risk. There is no equivalent modelling done for area-based shark bite mitigation systems for comparison.

Investigation of new personal deterrent approaches continues to attract ideas, investment and entrepreneurial activity. **Table 4-2** provides an updated list of personal deterrents and the testing undertaken.

Table 4-2 Summary of the status of personal deterrents.

Deterrent Type	Comment
Electric	
Ocean Guardian *based on* Shark Shield® Technology	New models have emerged, but all use the same Shark Shield® Technology to create an electric field around the user. The deterrent has been tested several times in different circumstances with a focus on testing on White Sharks (Huveneers et al. 2012, 2018), although testing on Black Tip Reef Sharks (Thiele et al., 2020) and Bull Sharks (Gauthier et al., 2020) has also been done. Overall, the device significantly reduces the risk of a bite occurring under experimental field conditions.
Electric Shark Deterrent System (ESDS)	The ESDS has been independently tested on White Sharks by Egeberg et al., (2020). Overall, it was demonstrated the device would not significantly reduce the risk of a negative interaction with a shark because of a very short effective range and an unreliable deterrent effect.
Rpela v2	Rpela v1 was tested by Huveneers et al. (2018) and that study showed it was less effective than the Ocean Guardian product. Further testing of a modified device (Rpela v2) was undertaken on White Sharks in WA and an improved and significant deterrent effect was confirmed (Blount et al., 2021). From fieldwork in New Caledonia, Gauthier et al. (2020) also demonstrated that Rpela v2 had a significant deterrent effect against Bull Sharks although the magnitude of bite reduction was less than for Ocean Guardian products.
Magnetic	
Shark Banz	Although popular and the focus of extensive marketing, independent testing by Huveneers et al, (2018) did not identify a change in White Shark behaviour or feeding in response to the presence of the Shark Banz product.
Electric	
Repel Sharks	RepelSharks is a chemical deterrent based on a necromone synthesized from decaying shark flesh. As identified in Cardno (2015) its efficacy was tested on Caribbean Reef Sharks with positive short-term results (Stroud et al., 2014). However, Cardno (2015) questioned its applicability to protect people against White or Tiger sharks which are known to scavenge dead sharks. Broadhurst and Tolhurst (2021) tested the efficacy of decaying shark flesh as a deterrent at Evans Head, NSW and concluded that it had no repellent effect against Tiger Sharks within the limitations of their experimental design. While this was not a direct test of RepelSharks, it was a valid test for the potential use of necromones as a shark deterrent under NSW conditions.
Chillax Surf Wax	Chillax Surf Wax is a homemade wax product that emerged after the Cardno (2015) report. Ingredients include organic bees wax and chilli. Huveneers et al., (2018) detected no change in White Shark behaviour or feeding in response to the presence of the Chillax Surf Wax. *A priori* there is no reason to expect a plant based olfactory product would influence shark behaviour as their ability to detect such substances that are novel to them is likely limited. Further, a wax is not designed to disperse into the water column.
Visual	
SAMS Cryptic Wetsuits	Cryptic wetsuits were discussed in Cardno (2015). Although they are commercially available, there appears to have been no further published independent testing of their efficacy for reducing the risk of an unprovoked shark bite.
Shark Eyes	Shark Eyes is a visual deterrent that emerged following Cardno (2015). It consists of a pair of eyes that can be mounted on the underside of a surfboard. The deterrent has not been independently tested and relies on anecdotes to support efficacy. However, in a similar approach, cows with eyes painted on their backsides avoided predation by lions compared with unpainted cows[9]. Collin (2018) reported that vision in sharks is complex and variable between species, so protection may not be efficacious across different species of sharks.

[9] https://www.australiangeographic.com.au/news/2016/07/new-eye-opening-solution-to-scare-off-predators/

4.3.2 Other Approaches

4.3.2.1 Shark Bite Resistant Fabric

Wetsuit materials have been developed and tested that are strong enough to substantially reduce the risk of a bite resulting in a serious injury, or fatality occurring from external bleeding, while remaining fit for purpose. These wetsuits incorporate ultra-high molecular weight polyethylene fibre into the neoprene wetsuit material. Although not yet commercially available initial independent testing of purpose designed shark bite proof material for wetsuits by Whitmarsh et al., (2019), Fiedler and Verstegen (2020) and Thiele et al., (2020) showed substantial promise. If the protective apparel clearly proves to be effective and practical for use, it represents an advancement highly suitable for all water users. The advantage of using a wetsuit made from shark bite resistant fabric is that for most water users it does not represent the need to purchase an additional piece of equipment, but rather than an alternative piece.

Injuries may still occur due to the pressure of the bite, but if a reduction in serious injuries or fatalities occurs it is a significant positive outcome. While personal shark deterrents focus on attempting to reduce the likelihood of a bite occurring, shark bite resistant wetsuits focus on reducing the consequence should a bite occur. The approach of reducing the consequence rather than likelihood of a bite occurring has the advantage of being more independent of shark behaviour and equally applicable throughout a jurisdiction.

Should shark resistant wetsuits become commercially available, they would be another tool available to water users to improve safety. Like all approaches, it should not be expected that they are 100% effective, however if a fatality did occur to someone wearing one, it can be assumed that the bite would still have been fatal if the person was wearing a standard wetsuit which offered less resistant to a bite.

4.3.2.2 Improving First Aid

Uncontrolled bleeding from upper and lower torso injuries is prevalent in shark bite and is the common cause of fatalities, yet access to tourniquet/trauma kits on beaches is not always available bystanders and many are likely to have suitable training in appropriate first aid. Taylor and Lamond (2021) have shown that manual inguinal compression provided by a single bystander is an easily taught first aid technique that can reliably completely stop or substantially reduce blood loss in the setting of a lower limb injury and is superior to an improvised tourniquet. Those authors proposed simple public instructional signage for the method.

4.4 Synthesis and Conclusions

4.4.1 Area based Systems

DPIF has considered and trialled a diversity of area-based approaches to shark bite mitigation that it considers to be the most suitable for use in the Shark Program in 2020/21 and 2021/22 (**Section** 3.1). The decision to discontinue trials of barrier nets on exposed coastlines and sonar technologies both appear to be warranted. The trial of barrier nets found that the exposed shoreline of NSW with its shifting sand was unsuitable for this approach and it was also not supported by local surfers. As outlined in McPhee et al., (2021), there are substantial technical constraints in the surf zone for effectively using sonar technologies and these constraints are difficult to overcome. The use of SMART drumlines was demonstrated to be a feasible method to capture large sharks in close proximity to NSW coastal beaches. Rather than euthanising the sharks, as per the Reunion Island program, NSW DPIF translocates the sharks offshore before releasing them. The high post-release detection rate of these tagged sharks, plus physiological data indicating minimal stress to these animals (Tate et al., 2019), highlights the minimal impact endured by the sharks whilst being moved away from populated beaches. The tagging of these sharks has led to the world's largest shark telemetry program and has provided benefit in enabling an array of 21 VR4G listening stations to relay tagged shark presence off beaches in real time to potential water users. Albeit that the number of tagged sharks is likely a small proportion of the overall population for each of the three species, the program has also spawned numerous educational opportunities, especially through posting of animal movements on social media platforms. Research activity in the SMS had a large focus on testing drone technologies and the research has substantially enhanced this approach to shark bite mitigation. While drone technology as a shark bite mitigation tool is popular (Stokes et al., 2020), it is only practical for use by SLSC's or where organised surf activities are held and when drones can be deployed. In addition, there are limitations in terms of sea state and visibility (Colefax et al., 2020; McPhee et al., 2021). It is noteworthy that drones on the NSW north coast failed to detect large sharks that were present in the area, as evidenced by capture on SMART drumlines or detection by acoustic receivers (Colefax et al., 2020).

As described in this report, shark bite in NSW has changed from predominantly affecting swimmers in the Metro region, especially within estuaries, to impacting surfers on ocean beaches in northern NSW (**Section 3.3.4**). This necessitates an approach that addresses risk to surfers in that region in addition to bathers at popular beaches. A significant proportion of bites occur at unpatrolled beaches. Therefore, the ability of drones (as currently operated by Surf Life Saving NSW) to mitigate risk to surfers in the region is limited under current flight legislation. While multi-spectral and hyper-spectral cameras on drones and AI can overcome some of the practical challenges of looking through seawater to detect the presence of a shark, they are unlikely to be practical for use by SLSCs and other community groups in the short term (~ five years). The costs of these camera modifications to drones will likely reduce public uptake, again potentially limiting them to times of organised surf events and/or deployment by organisations such as SLSCs which will be limited to flying over their patrolled areas.

A challenge for a shark bite mitigation program is balancing the actual efficacy of approaches with community perceptions. For example, from their surveys in NSW, Simmons et al., (2021a) found that the community had a preference for prioritising beaches that are popular with tourists. However, as discussed in this report in NSW such beaches may not be where risk is currently greatest. The public may also not have a good understanding of what mitigation methods are employed or the efficacy of methods with the latter typically overestimated. Crossley et al., (2014) found that 40% of residents in South Australia incorrectly believed that shark nets were used as a mitigation measure in that state. For South Australia, manned aerial patrols using light planes were a standard approach as an early warning system for the presence of sharks. However, Robbins et al., (2014) identified their ability to detect sharks was very low and cast doubt on their effectiveness as an early warning system to prevent unprovoked shark bite. Crossley et al., (2015) demonstrated that the public significantly overestimated their efficacy. The use of manned helicopters has similar limitations yet a relatively high level of public support (Simmons and Mehmet, 2018). Simmons and Mehmet (2018) also found a level of public support in NSW for newer technologies (e.g. sonar technologies) despite a lack of independent testing or testing that also demonstrated a lack of effectiveness (McPhee et. al., 2021).

4.4.2 Personal Protection and Improved First Aid

Personal deterrents can somewhat reduce the likelihood of a shark bite occurring, while improved first aid and more protective wetsuit materials can reduce the consequence from a bite. The research investment by the Department on developing shark bite resistant wetsuit materials has yielded promising results in experimental tests and form a foundation for commercialisation of shark-bite resistant wetsuits that can reduce the consequences of a bite. The focus on personal deterrents in the NSW Shark Program for 2021/22 is substantially less than other area-based mitigation approaches such as the use of drones. Until now, the main role of the SMS with respect to personal deterrents has been to fund trials, through the SMS, into the efficacy of some of the commercially available products. This is an appropriate first step as independent assessment of efficacy is critical. The results to date are highly variable across the various deterrents. No personal deterrent will be 100% effective, and this is an unachievable and unreasonable benchmark. However, a personal deterrent should result in a statistically significant and meaningful reduction in the risk of a bite occurring and this should be determined through independent testing using appropriate and ethical experimental design and analysis of data (see Huveneers et al., 2018 and Blount et al., 2021 for examples).

A challenge with personal deterrents is that choice for consumers is a difficult one. All personal deterrent manufacturers make claims regarding efficacy with these claims based on a continuum from independently tested trials using robust experimental design, to using scientific work of varying relevance to extrapolate efficacy, to anecdotal claims with no independent assessment. Using a deterrent that has little or no deterrent effect may result in people undertaking riskier activities (e.g. remaining in the water when notified of large sharks being present) under the belief that they have appropriate protection. Typically, for personal safety devices (e.g. life jackets and car seat belts) there is an Australian Standard in place which provides consumers certainty on efficacy when purchasing. Although a national standard is lacking for personal shark deterrent devices, independent testing of products and these results being made easily available is central to ensuring public are able to choose wisely and potentially enhance uptake of effective products.

Overall, testing efficacy and strongly encouraging greater use of effective personal deterrents is an area where future coordinated responses to shark bite mitigation can be improved. Providing information and encouraging the greater use of effective personal deterrents directly facilitates individuals making personal decisions about how they can reduce their own level of risk. While there will also be a role for government in shark bite mitigation, greater emphasis on personal decision-making is warranted. The same would apply for protective wetsuits if they become widely available to the public.

Finally, there is a need to integrate simple instructional information for shark bite first aid into the awareness and educational component of the Shark Program. Inclusion of this information might also be encouraged in registered training first aid courses, such as those required for workplace safety.

5 NSW, Australia-wide and International Comparisons

5.1 Introduction

Shark bite mitigation programs are a particularly challenging and problematic case for decision makers and managers where conflicting views within a community are heightened by the sensitive topic of human life versus species protection (Cullen-Knox et al., 2017). While the probability of an unprovoked shark bite remains low, the vivid nature of a shark bite ensures a high degree of media reporting and public concern (Neff, 2012; McPhee, 2014). The public views shark bite mitigation as a combination of personal accountability and government responsibility (Lucrezi et al., 2017), although some form of government response (or additional response) is generally required when an unprovoked shark bite occurs (Simmons et al., 2021a). This is particularly relevant with respect to a fatal, unprovoked shark bite or a series of bites causing serious injuries at one location or region over a short period of time. Responses to unprovoked shark bite involve public policies and management approaches that contend with the needs of public safety, the responsibility to protect threatened species and the increasing recognition of the role of large shark species in the marine environment (Simpfendorfer et al., 2011; O'Connell and de Jonge, 2014; McPhee, 2014; Gibbs and Warren, 2015; Pepin-Neff and Wynter, 2018b).

Government agencies may implement measures that attempt to reduce the chances of shark bite, address public concern, or provide warning systems to identify the presence of sharks at a beach in real-time. Governments can use lethal or non-lethal methods. Lethal methods include shark nets and traditional drumlines that aim to catch and usually kill potentially dangerous shark species adjacent to beaches. Non-lethal methods include manned or unmanned aerial surveillance, surveillance from land, capture and relocation of potentially dangerous species from an area, or barriers that separate people from sharks (McPhee et al., 2021). There are various methods that an individual (Hart and Collin, 2015; Huveneers et al., 2018) or government (McPhee et al., 2021) can implement to reduce the already low chance of an unprovoked shark bite.

There are five jurisdictions that have implemented an ongoing programmatic approach using diverse methods for shark bite mitigation – three in Australia (NSW, Queensland and WA) and one each at Reunion and South Africa. There are other locations where a single approach was implemented and subsequently scaled back or terminated. These include Recife Beach (Brazil) which has relied on the capture and relocation of sharks (Hazin and Afonso, 2014), Hawaii which had shark control programs using longlines between 1959 and 1976 (Weatherbee et al., 1994), and Hong Kong which used beach enclosures (McPhee, 2012). There is also increasing impetus around Cape Cod (Massachusetts) for a shark mitigation program in response to the increasing local prevalence of white sharks, with investigations[10] of mitigation methods but none are currently implemented systematically. Other mitigation activities (e.g. Shark Spotters Program at Cape Town) may also be implemented by NGOs but these are not discussed here, which focuses on the five government programs.

5.2 Queensland

The current Queensland Shark Control Program (SCP) has recently expanded from the initial use of lethal fishing gears to catch and kill sharks adjacent to popular beaches to include other non-lethal shark mitigation initiatives. The requirement for shark bite mitigation is contained in the the objectives of the Queensland *Fisheries Act 1994* with objective three stating: "*a further purpose of this Act is to reduce the possibility of shark attacks on humans in coastal waters of the State adjacent to coastal beaches used for bathing.*" Shark control activities in the Great Barrier Reef Marine Park also require a permit from the Great Barrier Reef Marine Park Authority, which includes a condition that DAF establish a Scientific Working Group to determine appropriate research into non-lethal alternatives and non-target species reduction strategies. The Queensland Department of Agriculture and Fisheries (DAF) administers the SCP.

Since 2019, as well as the deployment of traditional shark nets and drumlines, the Queensland SCP includes a dedicated education component "*Do Your Part. Be Shark Smart*"[11] and a Shark Control Program Research Strategy[12]. The responsibility for shark bite mitigation rests with DAF as it is a legislative requirement. The Queensland Shark Control Program Scientific Working Group provides expert advice to DAF in relation to the research strategy, scientific matters relevant to the program and non-lethal shark bite mitigation. NSW DPIF has an observer attending the working group, which facilitates the exchange of ideas and information across jurisdictions. The main role of the Group is to advise DAF in relation to:

> (a) development of a research strategy including research priorities relevant to shark control activities in the Marine Parks;
>
> (b) equipment configurations with the aim of improving program effectiveness and reducing impacts on non-target species in the Marine Parks;
>
> (c) published research and reports relevant to shark control activities in the Marine Parks; and
>
> (d) development of alternative technologies including non-lethal methods.

The development and implementation of alternative technologies included a review by Cardno (2019) of approaches suitable for the diverse habitats and circumstances across the regions where the program occurs. Key technologies that have progressed or are progressing to trialling include drone deployments and the use of SMART drumlines.

After a series of shark bites in 2018 at Cid Harbour (Whitsundays), a five-point response plan[13] was developed which included education components and an investment of $250,000 towards scientific research focussed on understanding shark abundance and behaviour in that locality. Cid Harbour is not a location within the Queensland SCP, but a response was implemented by the Minister for Fisheries given the series of bites that occurred. The public pressure applied to the Minister for a local response at Cid Harbour following the bites is analogous to that applied to the then NSW Premier to respond to the series of bites that occurred in northern NSW in 2014 and 2015. While not formally a component of the NSW Shark Program, the DPI responds to individual shark interactions in accordance with its Shark Incident Response Plan (SIRP), which is a memorandum of understanding with NSW Police and Surf Life Saving NSW for responding to shark incidents. It outlines the roles and responsibilities of each agency using three tiers of incident: Level 1 shark sightings that are generally addressed at beach by Surf Life Saving NSW; Level 2

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[10] https://parkplanning.nps.gov/projectHome.cfm?projectId=91210
[11] https://www.daf.qld.gov.au/sharksmart
[12] https://www.daf.qld.gov.au/business-priorities/fisheries/shark-control-program/science-and-research
[13] https://www.daf.qld.gov.au/business-priorities/fisheries/shark-control-program/whitsundays-plan

interactions involving a bite to person or watercraft and generally addressed by DPIF; Level 3 serious or fatal bites that are responded to by all agencies. The SIRP is authorised by a permit under the *Fisheries Management Act 1994*. Legislative provisions like those in the *Queensland Fisheries Act 1994* could negate the need for such permits and relatively *ad hoc* incident management.

The Queensland Government funds shark bite mitigation activities with current funding being $17.1 million for four years commencing in 2019/20[14].

5.3 Western Australia

Unlike NSW and Queensland, WA has historically had no pre-existing program of shark capture for mitigating the risk to water users from unprovoked shark bite. Since 2008, the WA Government progressively developed a multifaceted shark hazard mitigation strategy. Commencing with aerial (helicopters and fixed-wing aircraft) and beach patrols in 2008, the strategy was significantly expanded following a series of fatal bites from 2010 to 2013. WA has subsequently established a Shark Response Unit to research shark populations and movements, improve responses and provide advice and information to ocean users. Between 2014 and 2020, $33 million was provided by the State Government for shark bite mitigation activities. The WA Government recently announced that the program would receive $17 million over the four years from 2021/22 to 2024/25 for the following activities:

- Aerial and beach surveillance;
- Jet ski integrated response team;
- Deployment of shark barrier nets;
- Shark tagging and monitoring, notification systems and awareness; and
- A rebate to consumers for the purchase of approved individual deterrents.

An approved personal shark deterrent device is one which has been independently tested scientifically and proven to be effective at reducing the likelihood of an interaction with a White Shark. Personal shark deterrent devices that meet these criteria can be approved by the Department of Primary Industries and Regional Development. Currently, rebates are available when purchasing an Ocean Guardian FREEDOM 7™ and/or an Ocean Guardian FREEDOM+ Surf™ (Bundle). Additional devices may be added to the scheme once tested scientifically, verified and approved by the Department of Primary Industries and Regional Development. There is a limit of one rebate per person per device. Thus, if a person has received the $200 rebate for the Ocean Guardian FREEDOM 7™, they will also be eligible to receive the $200 rebate for the Ocean Guardian FREEDOM+ Surf™ (Bundle).

5.4 Reunion

Reunion has a history of unprovoked shark bite including many bites with a high fatality rate since the 1990s (McPhee, 2014, Chapman and McPhee, 2016).

The Reunion Island Shark Risk Strategy was developed in 2016. Prior to this strategy, shark culling using standard fishing apparatus and bans on beach use were utilised. The strategy is coordinated by the *Centre de Ressources et d'Appui à la Gestion du Risque Requin* (CRA), which assists municipalities and local administrations with the implementation of projects that aims to reduce risk from sharks and is overseen by a Board of Directors. The strategy consists of several components including targeted fishing of Bull and Tiger Sharks, use of barrier nets, education and public awareness, promotion of scientifically proven personal deterrents and various research activities including those focussed on shark behaviour (Lemahieu et al., 2017). Under the strategy there have been extensive investment and trialling of alternative approaches and emerging technologies including the invention of SMART drumlines (Guyomard et al., 2019; Guyomard et al., 2020) and trials thereof (Niella et al., 2021a), deployment of barrier nets, drone trials, and trials of the Shark Safe Barrier. The strategy also has substantial components focussed on public awareness and

[14] https://statements.qld.gov.au/statements/87559

education, and research focussed on shark behaviour and the environmental drivers of shark distribution that is documented in various peer-reviewed publications (e.g. Lemahieu et al., 2017; Lagabrielle et al., 2018; Mourier et al., 2021; Niella et al., 2021a).

Reunion has recently begun trials of an experimental risk reduction strategy at one its key surfing locations - Saint-Leu. The strategy involves a first tier of protection that includes SMART drumlines (called PAVAC SPOT) with additional jet ski water patrol levels according to environmental conditions (mainly the turbidity). The last line of protection provided is that the surfers must wear a personal shark deterrent to enter the experimental area (to ensure the insurance will cover in case of a shark attack). Around 75% of the surfers (from around 300 registered surfers in Reunion) use shark deterrent devices (Michael Hoarau, pers. comm).

5.5 South Africa

There are two initiatives within South Africa focussed on shark bite mitigation. The first is the long-standing activities of the KwaZulu-Natal Sharks Board (KZNSB). The second is the City of Cape Town Shark Spotters Program. The KZNSB program is the most relevant for discussion in this report given its geographic scale and breadth of activities. The KZNSB was established by the Provincial Government and its legal mandate is the *KwaZulu-Natal Sharks Board Act 2008*. KZNSB activities are coordinated under a five-year Strategic Plan. The KZNSB historically focussed on the use of shark nets and drumlines to target and capture potentially dangerous shark species. While these mitigation measures continue with modification overtime, the activities have expanded into education, tourism, and development of alternative methods such as an electric cable deterrent and the development of an initial personal electric deterrent (SharkPOD) (Smit and Peddemors, 2003) which is now the basis of several electric deterrent models that are commercially available.

5.6 Synthesis and Conclusions

Table 5-1 summarises the attributes of the NSW Shark Program relative to the other jurisdictions discussed. Similar to Queensland and KwaZulu Natal, the development of the NSW Shark Program has evolved and expanded from long standing programs specifically focussed on catching target shark species adjacent to popular metropolitan beaches. The expansion of the scope of the programs has included trialling alternative mitigation methods and education campaigns. The WA and Reunion programs commenced more recently in response to an increase in unprovoked shark bites and lack the historical focus on the use of nets and drumlines to catch sharks near popular locations.

The NSW Shark Program shares several key characteristics with programs in other jurisdictions. Most noteworthy, it includes an educational component, undertakes biological and ecological research on shark species directly relevant to unprovoked shark bite, and identifies and evaluates emerging technologies. Compared with the Queensland and WA programs, where costs were available, the investment by the NSW Government is marginally greater. Even if funding levels were available for KwaZulu Natal and Reunion, the different costs of labour in those jurisdictions would make a meaningful comparison difficult. All programs are solely or substantially funded by state governments (or equivalents). Consistent with other jurisdictions, NSW through the Shark Program has demonstrated the ability to respond and adapt to changing circumstances such as a series of bites occurring in a location with little contemporary precedent.

There is variation in whether shark bite mitigation programs are legislated. Both Queensland and KwaZulu-Natal have programs that are explicitly legislated. NSW enables the head of the Fisheries agency to engage officers or contractors to use a specific 'beach safety meshing net' for the purposes of shark mitigation, and the WA and Reunion programs have no legislative basis. The Shark Meshing component of the program is also authorised by and managed in accordance with a Joint Management Agreement under the *Fisheries Management Act 1994*, which includes annual reporting and annual review by the NSW Fisheries Scientific Committee.

Using Queensland as an example, legislating the Queensland Shark Control Program has the general purpose of reducing shark bites adjacent to coastal beaches used for bathing, however, it also includes provisions that enable the Chief Executive of the Fisheries agency to apply the shark control program as and when necessary, e.g. s.20(2)(d). Such provisions ensure flexibility and adaptability to respond to the dynamic and unpredictable nature of shark bites in Queensland at locations that do not constitute coastal beaches used for bathing (e.g. Cid Harbour, Whitsundays). The greatest advantage of legislating a program is that there would be an ongoing requirement from Government to provide the necessary funds for meeting program objectives, rather than this being a discretionary decision. The disadvantages of legislating are that a program could have potential limitations in how, when and where it responds to shark bite but this can be overcome with well-drafted legislation (see above).

There are two governance models in use in the jurisdictions reviewed. The first is shared by Queensland, Reunion and KwaZulu-Natal where a level of external oversight and input exists for the shark mitigation programs. In Reunion and Kwa-Zulu the Board of Directors oversees the program. In Queensland, the Scientific Working Group provides substantial input into shark mitigation activities. The programs in NSW and WA have no formalised external oversight, although both are subject to the usual government reporting policies and procedures, e.g. Budget Estimates. On balance no specific legislative and/or governance model is superior and there are no significant deficiencies in the NSW SMS and 2020/21 and 2021/22 Shark Programs identified in this report, although it is recommended that NSW formalise and strengthen the program whilst improving public transparency and accountability by developing legislative and governance models similar to those of the Queensland SCP.

All five jurisdictions have trialled a different mix of alternative approaches, and some approaches have been trialled in multiple jurisdictions. As there is no single universally appropriate mitigation method and methods differ in their effectiveness under different circumstances, trialling an approach in more than one jurisdiction is warranted (McPhee et al., 2021). NSW differs from other jurisdictions in providing a targeted competitive grants program and this is discussed in more detail in **Section 3.1**.

Table 5-1 Summary of operations and funding in NSW and other jurisdictions

	Australia			International	
	NSW	**QLD**	**WA**	**Reunion**	**South Africa**
Funding source	State government	State government	State government	State govt equivalent and local authorities	State government and local authorities
Funding amount	$16 million over five years for the SMS (2015/16-2019/20); $1.3 million/year for SMP and aerial surveillance in recent years; $8 million for 2020/21 Shark Program $21.4 million for 2021/22 Shark Program	$17.1 million over four years (2019/20-2022/23)	$17 million over four years (2021/22 to 2024/25) for beach and aerial patrols, integrated communication systems and jet ski response team, tagging Incl. rebate for personal deterrents (~$70,00/yr)	Unknown	Unknown
In legislation	No	Yes	No	No	Yes
Oversight	Primarily Internal SMP external	Scientific Working Group	Internal	Board of Directors	Board of Directors
Education component	Yes	Yes	Yes	Yes	Yes
Use of shark nets and/or standard drumlines	Yes (nets)	Yes	No	No	Yes

Manned aerial surveillance	Yes	No	Yes	No	Limited [1]
Permanent shark barrier used on exposed coastline	Trial attempted	No	Yes	Yes	No
Involvement of Surf Life Saving Groups	Yes	Yes	Yes	No	No
Competitive and targeted grant program	Yes	No	No	No	No
Drone trials	Yes	Yes	Yes	Yes	No
Sonar trials	Yes	No	Yes	No	No
Electric barrier trials	No	No	No	Planned	Yes
SMART drumline trials	Yes	Planned	Yes	Completed	No
Rebate for individual deterrents	No	No	Yes	No	No
Research on shark biology and behaviour (including tagging and detection)	Yes	Yes	Yes	Yes	Yes
Demonstrated ability to respond to a serious event	Yes	Yes	Yes	Yes	Yes

[1] occurs opportunistically as part of other programs

6 Implications for Future Funding

The research funded by the SMS on the perceptions of various mitigation measures is valuable for informing strategies. While it is important to understand public perceptions, in the context of public safety policy, it is not the case that the most popular approaches are always the best. Efficacy at reducing actual risk is an important consideration. SMART drumlines, drones and VR4G shark listening stations are the basis for area-based mitigation in the Shark Program but as indicated in **Section 4.4**, although drones and SMART drumlines are effective, VR4G shark listening stations are yet to provide unequivocal proof as to whether they actually reduce the level of incidence of shark bite and if so, by how much. As indicated above, both Stokes et al., (2020) and Simmons et al., (2021a, 2021b) identified the use of drones as a highly popular approach by most beachgoing sectors and there are indications that drones are reducing shark incidents at trial beaches. Public opinion, however, can be highly reactive and can change more rapidly than an agency's ability to adapt a mitigation program. Public opinion could therefore change rapidly if a shark bite occurs at a beach when drones are in use, and like any public policy it will be important that whatever measures are implemented in future, that they be implemented for specific timeframes with measurable goals, objectives and performance indicators.

Stokes et al., (2020) identified that there is less support from NSW surfers for drones as a mitigation method compared with other groups surveyed. The operating times and locations for the use of drones are limited compared with the preferred locations and times for many surfers. Currently, the use of Surf Life Saving NSW drones limits their capacity to cover all areas and times utilised by surfers. There are also technical limitations which influence the precision and accuracy of real time detection of sharks by drones (see McPhee et al., 2021). Investment in drones in shark mitigation for surfers (particularly avid surfers) in NSW is likely to result in no change to actual risk experienced by them unless they are adjacent to patrolled beaches at times when the Surf Life Saving NSW drones are operating. The potential solution would be for surfing groups to undertake drone surveillance when they were surfing, especially in remote locations, and DPIF may look to support groups already undertaking or planning such an approach**3.3.2**.

Going forward, the NSW Government needs to balance its investment on reducing actual risk with a focus on surfers as the most at-risk group with risk perception and an ongoing research important for compiling knowledge that supports the efficacy of mitigation approaches to this group. Risk reduction perception should not be the justification for deployment of an approach, and consideration should be given by the DPIF to reassess such approaches and activities. VR4G shark listening stations for example, are a good study tool for understanding shark movement but they are not yet proven to reduce the rate of shark bites at beaches adjacent to the VR4G.

The SMS research subprogram measured the level of bite reduction to water users explicitly if they were to wear a personal deterrent (**Section 4.3**). The research will be critical in enabling consumers (particularly surfers) to assess efficacy of the devices being promoted online. Given entrepreneurs developing new products can struggle to find funding to conduct scientific testing, it may be beneficial for the current and future Shark Program or some other funding arm of Government to maintain a funding/grant component to enable suitable testing of new or prototype devices. This is particularly important given these devices, and behaviour, are the only form of mitigation in many areas of NSW where there are currently no, or will ever be, area-based deterrents and/or detection measures (see further discussion below).

7 Conclusions

> Part (1) of the Scope of Works required:
>
> Review and assessment of the performance of the NSW Shark Management Strategy including:
>
> a. Assessing the effectiveness of mitigation measures on the number of shark incidents; and
>
> b. Assessing the cost-effectiveness of mitigation measures against the economic impacts of shark interactions on the NSW community.

Addressing the effectiveness of mitigating unprovoked shark bite requires reducing the actual risk of a bite occurring and the perception of risk (McPhee, 2014). The need to address both actual and perceived risk is complex and made more so by the inherent nature of shark-human interactions. Some of the additional complexities in NSW that require consideration when assessing effectiveness include:

> the highly uncertain and dynamic nature of the marine environment;
> the long stretches of coastline that are used for recreation and the biophysical diversity of this coastline;
> the low frequency of unprovoked shark bites;
> the current practical inability to predict the likelihood of a bite occurring at a scale meaningful for deploying mitigation hardware;
> the diversity of mitigation tools available and the different modes of their operation (e.g. detection versus deterrent);
> the diversity of community views that extend across the full spectrum from extremely anthropocentric to extremely ecocentric;
> individual decisions of water users; and
> the practical and ethical challenges to undertake manipulative experiments to better quantify the effectiveness of a mitigation approach.

It is clear that the rate of shark bite in NSW has increased since 2000 and despite the nets of the SMP and the trials and research of the SMS, since 2015 the rate has generally increased from pre-2015 levels. This has been a result of a rise in shark bite (apparently almost exclusively by White Sharks) to surfers which mostly occurred on the Mid to Far North Coast of NSW and could be considered the new paradigm of shark bite (in terms of the location and water user group affected). The SMS has responded well to the situation through its three subprograms by undertaking robust testing and evaluation of potentially feasible shark bite mitigation systems and personal deterrents, thus the Shark Program for 2021/22 includes deployments of potentially effective area-based shark detection systems backed up by community awareness programs. This suite of protective measures is consistent with the Cardno (2015) report. By having these area-based systems operating on the Mid to Far North Coast of NSW during this period and by strengthening awareness of shark smart behaviour, the SMS has been adequate protection for swimmers and has likely reduced the overall number of shark bites at a state-wide scale (to all water user groups) from a potentially greater total than what could have occurred. It is also important to recognise that the SMS was a series of temporary trials of new and emerging shark mitigation measures and not an ongoing and sustained program, although in all likelihood those measures found to be effective are likely to underpin future shark programs in NSW.

At the actual beaches where some SMS gear has been deployed the data are compelling for drone and SMART drumlines. At the many beaches where SLSCs have been trialling drones, there has been ‘zero’ bites or other interactions on drone fly days and there have been numerous situations, particularly in the Far North and Mid North regions, where drones have spotted a potentially dangerous shark (i.e. a target shark or large shark that could not be identified) that has resulted in a warning to water users (e.g. shark siren) or an evacuation of the water. Given there were interactions at many of these beaches, particularly in the Far North and Mid North regions, in a similar period of years before the drone trials and during the period of drone trials but on 'non-fly' days, the drones and the resultant warnings or evacuations have undoubtably been effective at reducing, if not 'eliminating' interactions between sharks and water users.

At beaches in the Far North region where SMART drumlines have been deployed for roughly five years now, the number of interactions has been reduced by 100% when gear is in the water, although it is noted that one surfer was bitten prior to the daily deployment of SMART drumlines and there were two interactions on days where the gear was not deployed because of rough weather. Further, given that all 11 of the pre-drumline interactions occurred in a cluster between January 2015 and October 2016, this may have skewed the data towards a greater effect and suggests that further monitoring of this gear is required to be certain of its effect.

At beaches where VR4G shark listening stations were deployed there was only a marginally less number of interactions compared with a similar period prior to their deployment and in the South region there was actually an increase in interactions.

Although helicopter aerial surveillance is no longer part of the current Shark Program, it is also noted that during the SMS trials these resulted in a large amount of evacuations of water users on the Mid and Far North regions of NSW.

It may be unpalatable to many but it is important to put a dollar value on human life or major injury (e.g. loss of limb), and the after effects of shark bite to a victim, first responders and bystanders. Also, there are considerations associated with shark bite that have broader economic impacts, such as the cost of emergency response and hospital treatment of victims or potential impacts to business if tourists are deterred from visiting towns where there had been, or are at risk of, a shark bite. In this context, the budgets of the SMS at $16 million over five years, $8 million the Shark Program for 2020/21 and $21.4 million for 2021/22 are small compared with the potential costs of not having them, and there are good indications that at beaches where drones or SMART drumlines were deployed, the number of interactions between water users and sharks have been reduced by 100%. Moreover, these programs are designed to have no increased impacts on the environment (e.g. harm to non-target species), which means they also have a positive social impact, unlike the environmental and social effects of the SMP in the Metro region. Overall, the Shark Program has, and in its current form will continue to have, a considerable net benefit.

Notwithstanding this, given the potential differences in effectiveness among the mitigation gear used and that interactions to surfers also occur at beaches where the gear is not deployed, DPIF may want to consider rationalising the program (see **Section 8**) and greater focus than current on reducing interactions in remote areas (see below).

> Part (2) of the Scope of Works required:
>
> Review the new information (including social research) and technologies generated since a report was prepared by Cardno (2015) and summarise the implications of that new information on the future direction and approach of shark mitigation in NSW, and provide recommendations for their potential future use in mitigation of shark incidents in NSW.

Much has been done in the field of shark bite mitigation since Cardno (2015), particularly as a result of the SMS, which not only tested alternatives (to catch and kill) area-based risk mitigation technologies but also provided support to universities to collaborate on trials of area-based systems or for undertaking independent research on personal risk mitigation devices or community opinions. This new knowledge formed the basis for designing the Shark Program for 2020/21 and 2021/22, which incorporated a range of popular components of the SMS (others were discounted after trials) in addition to the SMP and NSW SharkSmart program. Analysis indicated that when drones or SMART drumlines were operating, there were no incidences of shark bite. Drones were also the most popular technology with the public. It is not yet clear whether VR4G shark listening stations have any measurable effect on the number of interactions.

The SMS trials present evidence that, for at least drones and SMART drumlines, alternative (to catch and kill) technologies can reduce shark bite at specific beaches. However, the rare occurrence of shark bite and occasional clusters means managers of the Shark Program need to be aware of the following issues to avoid potentially underestimating the risk of shark bite that could occur when relying on these technologies:

> Drones used by lifeguards are currently limited to 'line of sight' (~500 m) from the landing site, meaning that water users at unpatrolled beaches, or within a patrolled beach but potentially >500 m from a surf club building, may not be covered. Moreover, drone use and efficiency may be affected by adverse weather such as strong winds and turbid water. Temporal coverage by drones depends on the availability of pilots and it must be recognised that lifesavers and lifeguards have other duties, particularly during busy periods, and so it will be important to train and mobilise 'drone-only' lifesavers and lifeguards;

> SMART drumlines may not always catch the majority of target sharks at a beach (Guyomard et al., 2020). In trials in WA, for example, very few White Sharks of the known total at a beach were caught (DPRIRD, 2021). Evidence from Queensland suggests that Bull and Tiger sharks are not as readily caught by traditional drumlines as nets at some beaches (Sumpton et al., 2011), and Bull Sharks are more likely to be caught at night (Niella et al., 2021a), when most people are not surfing or swimming at ocean beaches. Notwithstanding this, and despite differences in latitudinal distribution and fishing effort (quantity and season), it is noted that the SMP nets fishing day and night have only caught 35 Bull Sharks since 1991 compared to 19 in nearly five years of SMART drumlining on the Far North Coast. There is also an issue of SMART drumlines not fishing very early in the morning or near dusk when surfers are often in the water or on days where the operator considers conditions are too rough for safe deployment. For example, one surfer was bitten prior to the daily deployment of SMART drumlines and there were two interactions on days where the gear was not deployed because of rough weather.

> VR4G shark listening stations only detect tagged sharks and, although DPIF has tagged (and will continue to tag) many sharks in the current Shark Program, it is not clear what proportion of the total of target sharks has been, or will be, tagged. The current catches of juvenile White Shark (~650) relative to the CSIRO estimate of the eastern Australasian population (~4,700) suggest that DPIF has caught approximately 14% of the juvenile population, however there are no such estimates for Tiger or Bull sharks. Even though listening stations are deployed at many popular beaches, there are still very few listening stations relative to the total amount of beaches in NSW and it is not clear how many water users (particularly surfers) are using the information or have a smart watch that would convey information to them in real time. Some of these uncertainties could lead to avid users having a false sense of security about the effectiveness of VR4Gs as a risk mitigation tool.

The multifaceted nature of the current Shark Program means there will be some resilience to such issues but there are also other issues to consider. Like any shark bite mitigation program, the Shark Program's area-based mitigation systems will not be able to reduce interactions between water users and target sharks by 100% at all times at the beaches where they are deployed, and there are still many surfing beaches without any specific area-based mitigation systems in place. Furthermore, SLSCs, where drones could potentially be based in the future, occur at <30% of the beaches in regions outside of the Metro region and only at 10% of beaches in the South region. The social research showed that the community sentiment is that government has a role in protecting the public from the risk of unprovoked shark bite, but many people, particularly surfers, also considered that it was a collective responsibility by government and individuals in more remote locations. Given these sentiments, the NSW Government will need to consider, and convey, not only whether its role extends to greater protection at specified nominated popular beaches or whether it also extends to other beaches currently with no gear (see further discussion below and **Section 8**).

Regardless of the decisions above, in addition to new learnings about the effectiveness of area-based technologies (this report), testing supported by the SMS has provided unequivocal proof of the ability of some personal deterrents to reduce the risk of shark bite, or in the case of protective wetsuits, at reducing the potential for a bleeding injury (but not necessarily a crush injury). This knowledge could be leveraged to improve the overall effectiveness of the future Shark Program (i.e. support drone and SMART drumline deployments, the SMP and education strategy) if there were greater understanding, acceptance and uptake of personal devices by NSW water users.

The approach might be to convey the future Shark Program as a 'hierarchy' of risk reduction (as proposed by Dr Huveneers across various public presentations). Hierarchal frameworks are well known tools for controlling risks in the workplace[15]. Indeed, successful mitigation of shark bite at some surfing places in Reunion is based on a multi-layered hierarchy of risk control. A suitable hierarchal concept for the NSW Shark Program, that incorporates the tools available to it, would be to consider mitigation in terms of three hierarchical tiers of protection (see **Figure 7-1**):

1) *Reduce spatial overlap between water users generally and target sharks.*

   This is currently done in the Shark Program using lethal (i.e. beach meshing in the Metro region) or non-lethal approaches (e.g. VR4G shark listening stations, aerial surveillance (drones) and SMART drumlines) but can also be done through human behaviour (e.g. if water users don't go in the water at dawn or dusk or when large schools of baitfish are present).

2) *Reduce likelihood of shark bite when overlap between water users and target sharks cannot be avoided.*

   This relies on people using effective personal deterrent devices.

3) *Reduce the impacts of a shark bite when one has occurred.*

   This relies on people using puncture- or tear-proof wetsuits or being able to get access to suitable first aid to prevent death from bleeding.

Such a tiered approach acknowledges the importance of Tier (1) but also that it is impossible, even at beaches with drones, nets, SMART drumlines, or other gear, to reduce the spatial overlap between water users and target sharks by 100% all the time except if people stay out of the water or potentially by having barriers, but these are not feasible to install on the exposed coastal beaches of NSW (McPhee et al., 2021). Tier (2) is an additional layer of protection to water users that becomes important when Tier (1) has not been 100% effective or is not in operation. Modelling has also shown that across Australia, potentially more than 1,000 people by 2066 could potentially avoid being bitten if all water-users wore effective personal shark deterrents (Bradshaw et al., 2021). Tier (3) is a final layer of protection that comes into play if a shark bite was to occur. Tier (3) aims to reduce the impact of a shark bite injury by stopping uncontrolled bleeding from upper and lower torso injuries which is the common cause of fatalities. This can be done either by wearing puncture- and tear-proof wetsuits or by applying suitable first aid. Although not yet readily commercially available, trials of puncture- and tear-proof wetsuits show great promise with a number of products in development. Injuries may still occur due to the pressure of the bite, but the products reduce the chances of bleeding. In terms of improving access to adequate first aid, this would involve educating people about new techniques that can reliably completely stop or substantially reduce blood loss in severe limb injuries.

Although the Shark Program for 2021/22 already includes the components of Tiers (1) and (2) in its approach (i.e. drone, VR4G, SMART drumline deployments, beach meshing and some information about personal deterrents on the SharkSmart website and App), the hierarchical concept may simplify messaging to the public about the importance of Tiers (2) and (3), particularly where Tier (1) is not available. As it currently stands, the Shark Program focuses heavily on Tier (1) mitigation and provides only limited advice about personal deterrents that people could consider. Tier (1) is essential and must be retained but with some rationalisation (see below). We recommend that more resources are allocated to facilitating awareness of the importance of Tiers (2) and (3) mitigation measures, particularly to fill in the gaps left when Tier (1) is not present, or may never be available, at some beaches.

Analysis of locations where shark bite incidents have occurred over the last two to three decades in NSW has shown that many interactions occur remote from populated areas (and surf lifesaving clubs), where there is currently no or limited potential to provide multi-faceted Tier (1) support because of logistical reasons (e.g. servicing SMART drumlines, building a surf club). Further, even if Tier (1) support could be provided in areas where it is currently not, the actual level of risk reduction provided by SMART drumlines may not be known with certainty for many years due to the small numbers or clustering nature of shark bite. We consider it likely based on the study by Huveneers et al., (2018) that had effective personal deterrents been used more often

[15] https://www.safework.nsw.gov.au/__data/assets/pdf_file/0006/446028/hierarchy-of-controls-SW09182.pdf

on the Mid and Far North coasts, then it follows that risk of bites by white sharks to surfers that occurred in recent years might have been reduced substantially.

The role of education in mitigating the risk of shark bite cannot be overstated. Shark awareness is crucial to ensuring that people know how to reduce their personal risk through their behaviour (whether that be avoiding swimming/surfing at times of greatest risk or when to consider using a personal deterrent). It remains a key part of the Shark Program for 2021/22 as it would be under the hierarchal framework. In the absence of a national (or even a legislated) standard, an information and educational gap exists in communicating to consumers which devices are effective at reducing risk. There is a role for the educational and awareness component of the NSW Shark Program in the future to do this while balancing the perception of commercial endorsement of a specific product as well as communicating the need for individuals to take responsibility for their own safety in some areas. The education component already communicates the importance of independent trials, that these trials were robust and that the results of testing provided meaningful reductions to risk (with appropriate caveats). Links to the studies that have undertaken independent testing can continue to be provided. This information can be provided in a fact sheet like that currently available on the SharkSmart webpage and may contribute to greater certainty for consumers and facilitate more effective evidence-based consumer choices. Notwithstanding this, it is apparent from the currently limited uptake by surfers that there are likely to be other challenges in promoting meaningful uptake of these devices among surfers that will need to be overcome, including:

- High costs of some proven effective devices (see further discussion below);
- Dispelling myths and disinformation (such as they attract sharks, or increase the vulnerability of non-wearers in the water);
- Managing over-confidence when using a device (such as surfing in areas such as river mouths or when schools of baitfish are nearby); and
- That maintenance and regular servicing and testing of devices is critical to performance.

Finally, the future of the Shark Program should to be adaptive to new knowledge about the effectiveness of currently deployed systems, community expectations and of new systems/devices that become available. Some technologies such as electric barriers based on Shark Shield® technology are understood to be close to commercial readiness and advances in multi- and hyper-spectral imagery may improve shark detection in aerial surveillance. There is also strong community and local council sentiment in regard to removing the nets in the Metro region and replacing these with non-destructive shark mitigation gear, especially drones and SMART drumlines. The evidence strongly indicates, albeit only over a period of about six years, that SMART drumlines maximise the catch of target sharks, maximise the survival of marine life that interacts with the gear, and minimises the catch of non-target animals. SMART drumlines have demonstrated that they are more effective than nets at intercepting target sharks before they can interact with beachgoers, which is the closest surrogate there is for ‘reducing the risk’ to water users, which is all but impossible to quantify. The two six-month trials of nets alongside SMART drumlines on the Far North Coast determined that the catch per unit of effort on SMART drumlines was 15 and 32 times greater, respectively. SMART drumlines also minimise harm to the environment, with survival-at-point-of-release at approximately 98.5 per cent at beaches where the gear is deployed, providing additional benefits to the Critically Endangered east coast population of Grey Nurse Shark, endangered and vulnerable marine turtles and hammerhead sharks, and the Vulnerable White Shark Notwithstanding the environmental advantages of, and community support for, replacing nets with non-destructive shark bite mitigation gear, and given that nets have been effective at reducing the frequency of shark bite in the Metro region since installation (Dudley, 1997), the Government would need to monitor factors contributing to potential increases in interactions in the Metro region if the nets were removed, and have adaptive processes in place to mitigate risk if it became a concern in the future.

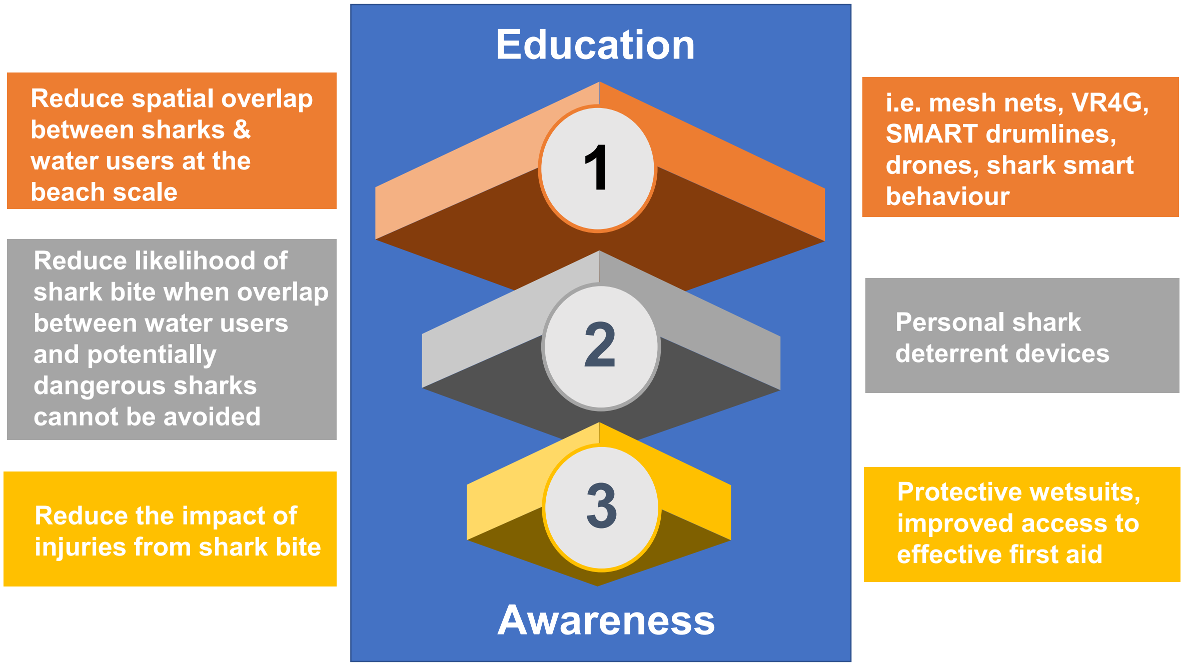

Figure 7-1 A proposed hierarchical (three-tiered) concept for mitigating the risk of shark bite

Part (3) of the Scope of Works required:

Conduct an analysis of NSW, other Australian states and territories, and other international jurisdictions to compare and contrast:

a. Shark mitigation approaches used across those jurisdictions and their efficacy for reducing shark interactions;

b. The underpinning regulatory frameworks that support shark mitigation programs;

c. Funding arrangements for shark mitigation approaches and programs;

d. To what extent community preferences inform shark mitigation approaches and programs.

Overall, the NSW Shark Program is consistent with other jurisdictions in terms of funding source and amounts (where this is known). The type of programs undertaken are also consistent and where differences exist they are justified on the need to tailor potential mitigation approaches to local conditions and local communities. It is clear from the social research that communities and coastal Councils want to have a say in the type (and amount) of mitigation deployed within their jurisdictions and in some cases this will inevitably lead to requests to Government for more gear and support in different locations that is beyond current budget. It is recommended that DPIF reviews its legislative and governance model to ensure it is optimal for accommodating these requests. Governance would also benefit if specific aims and objectives and performance indicators were developed that defined the following in the Shark Program:

> Roles of NSW Government;
> Responsibilities of water user groups;
> Locations (i.e. beaches where mitigation gear is deployed, or otherwise);
> Seasons (i.e. when mitigation gear is deployed);
> Partnerships (e.g. Surf Life Saving NSW, local councils, Surfing NSW); and
> Standards for personal deterrents.

Legislation is a formal set of rules which society uses to define how people and organisations are expected to behave. When enacting legislation, it needs to provide an overriding benefit compared to not doing so. The benefits of legislation include providing provisions that are legally enforceable as well as providing certainty in the scope and actions. A number of potential impacts from shark bite mitigation activities are already affected to varying degrees by other pieces of legislation such as the NSW *Biodiversity Conservation Act 2016*, NSW *Fisheries Management Act 1994*, Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* and the NSW *Animal Research Act 1985,* however there is no regulatory framework to ensure consistent decision-making, accountability and public confidence in the program and its processes. There is an advantage in legislating shark mitigation activities in NSW as it provides certainty in terms of a minimum scope of activities, enhanced certainty regarding operational needs, funding needs to meet legislative requirements, and enabling the program to be responsive to the economic, environmental and social needs of the community. As shark mitigation approaches continue to evolve and the need for mitigation at a location can change through time, flexibility in response is a key element for any program of shark bite mitigation. As the Queensland example shows, legislation does not have to limit the flexibility to respond to changing circumstances but gives certainty to ongoing operationalisation for both Government and the public, as opposed to the current arrangements in NSW which are generally discretionary, poorly understood by, and create uncertainty for the community.

Recognition of a tiered mitigation hierarchy is consistent with WA and Reunion. The hierarchy and associated regulatory framework need to encompass and unify all facets of the current shark mitigation program in NSW into one overarching program with defined sub-programs/pillars, e.g. Shark Incident Response, Shark Mitigation, Shark Incident Community Support. As indicated above, the tiered hierarchy concept would work best if there is recognition of the importance of all tiers, particularly if higher tier support is lacking. Given the Tiers (2) and (3) (personal protection) rely equally as much on individuals taking responsibility for using deterrents or wearing protective wetsuits as much as the Government promoting their use, this will require great effort to get the public on board at a meaningful level. DPIF could consider an alternate funding approach in this instance (see below)

> Part (4) of the Scope of Works indicated that:
>
> The review is to inform consideration by the Government of ongoing funding for shark mitigation measures for 2022-23 and beyond, including any associated regulatory mechanisms to operationalise the program in NSW.

As indicated above, there is potential variation in effectiveness among the area-based systems that are currently deployed at popular areas outside the Metro region, with the data indicating that drones and SMART drumlines were 100% effective when deployed and VR4G shark listening stations currently providing little, if any, benefit to immediate shark mitigation, but noting the contribution they make to understanding the movements and relative abundance of target sharks in the longer term. However, the period of learning about effectiveness has been small relative to the rare and infrequent nature of shark bite and it will be important to continue to learn more about these systems for many years to confirm these initial findings. As such, the Shark Program of the future must include a sufficiently funded research and monitoring program to continue to not only monitor these systems, including any proposed improvements, and also scientifically test any new systems that become available. Notwithstanding this, considering that VR4Gs are not demonstrably effective for mitigating short term risk and that the cost of tagging to support VR4Gs is large, it would be appropriate to resolve issues that may be limiting their effectiveness as soon as possible so that an informed decision can be made about whether to continue to include VR4Gs in the future Shark Program. The issues of immediate concern are the small number of VR4Gs deployed, the level to which users of the SharkSmart app rely on the VR4G information in their decision making, and whether the level of tagged sharks relative to untagged sharks gives users a false sense of security about the potential proximity of target sharks at or close to beaches where VR4Gs are deployed. The role of VR4Gs in contributing to marine research is acknowledged, but a proportion of this contribution is outside the direct role of mitigating unprovoked shark bite.

With an absence of a national standard, the Shark Program for the future may want to consider supporting development of specified standards for personal deterrents or protective gear and subsidising uptake of these devices that meet a standard or criteria, as is done in WA and Reunion. In WA, the government provides a $200 rebate for WA residents when they purchase an approved personal deterrent. This approach not only lessens the cost to a user of a personal deterrent but also provides clear direction to consumers as to which devices have met a specified standard of risk reduction and are endorsed by government, in theory promoting uptake of only effective devices. If it were to provide a rebate, NSW Government should get legal advice to ensure there would be no implications to Government in the event a surfer suffers an injury from shark bite whilst wearing a device.

While WA chose a flat rebate amount, another option is to choose a percentage discount (e.g. 20%) from the recommended retail price. This would allow for equal treatment of effective devices when they differed in price. In Reunion, shark deterrents (Tier (2)) are promoted as the last line of defence and the government has a protocol whereby surfers have to wear a device in an experimental surf area where the hierarchy of mitigation is being tested. The government promotes devices based on the results of scientific testing and in some areas of Reunion there are anecdotal reports of uptake by surfers in the order of 75% (Michael Hoarau, pers. comm.).

In WA, since the implementation of the rebate program in 2018, there have been 1,049 rebates issued for shark deterrent surfboard products at a total cost of ~$210,000 or roughly $70,000/yr (L. Lyon pers. comm.). Notably the rebate only resulted in a 20-30% increase in Ocean Guardian's sales in WA compared to the period prior to the rebate, but Ocean Guardian considers that was partly because its brand knowledge was already very high in WA. Given Surfing Australia considers there are 250,000 surfers WA, the sales suggest that roughly 0.4% of surfers have taken up the rebate. In NSW, surfers most likely to take up a rebate would be those living in, or regularly visiting, the non-Metro regions y (i.e. where the risk to surfers is greatest) and this group is likely to comprise a small proportion of the overall total number of surfers in NSW. Surfing Australia considers that there are up to 1 million surfers in NSW/ACT combined and if the uptake was proportionally similar to WA (and at $200/device) the rebate cost to NSW Government would be about $280,000 per year. If the proportional uptake were greater than this, the cost to NSW Government (at $200/device) would be $2 million per percent of the total number of surfers in NSW.

8 Recommendations

Based on the review, recommendations are given below (numbering does not indicate priority).

Recommendation 1

The Shark Program for the future continues to deploy area-based shark bite mitigation gear in areas popular to water users and/or well-known for shark bite as per the Shark Program for 2021/22, supported by research and the SharkSmart education and awareness program, but considers rationalising some of its components (see Recommendations 3, 4, 7 and 8).

Recommendation 2

The SharkSmart campaign of the Shark Program should consider conveying the Government's approach as a three-tiered hierarchy of protection supported by education and awareness:

Tier 1 - Perimeter. *Reduce spatial overlap between water users generally and target sharks.*

This is currently done in the Shark Program using lethal (i.e. beach netting in the Metro region) or non-lethal beach protection gear (i.e. VR4G shark listening stations, drones, SMART drumlines) and with research, community education and engagement that results in shark smart human behaviour.

Tier 2 - Proximity. *Reduce likelihood of shark bite when beach-based overlap between water users and target sharks cannot be avoided.*

This relies on product development, technology, education and community engagement resulting in greater uptake of existing, effective personal deterrent devices than is current.

Tier 3– Prevent bleeding. *Reduce the impacts of a shark bite when one has occurred.*

This relies on people using puncture- or tear-proof wetsuits or being trained in suitable first aid to prevent death from bleeding.

Recommendation 3

The Shark Program continues to undertake, or supports, further research and monitoring (i.e. data gathering, analysis and reporting) of current area-based bite mitigation systems and trialling of emerging area-based bite mitigation systems and personal devices.

Recommendation 4

issues that may be limiting the effectiveness of VR4G tagged shark listening stations at mitigating shark bite are resolved as soon as possible so that an informed decision can be made about whether to continue to include VR4Gs in the future Shark Program as a risk mitigation tool.

Recommendation 5

The Shark Program is enacted under NSW legislation and policy that incorporates the entirety of its shark bite mitigation and response strategy (i.e. the SMP, the Shark Incident Response Plan and other Shark Program activities) and to ensure long-term commitment by NSW Government to its operationalisation. The legislation should include specific aims and objectives for the Shark Program that convey to the community the roles of NSW Government and the personal responsibilities of the water users.

Recommendation 6

The Shark Program continues to provide information about the latest developments and suite of independently tested and verified personal deterrent devices and shark-bite resistant materials (if they become commercially available) and improved first aid knowledge by surfers. NSW Government could consider providing a rebate for NSW residents when they purchase an approved personal deterrent or first aid/trauma kit/training and develop, or contribute to the development of, a minimum standard for effectiveness.

Recommendation 7

The Shark Program develops and implements a monitoring, evaluation and reporting (MER) framework that measures the performance of its key components and that can be used to drive adaptive management when needed. The following indicators are examples of those that could be developed, reported on and reviewed on a biennial basis to monitor the effectiveness of the program:

> The number of interactions at beaches where area-based mitigation systems are deployed and for a similar period prior to deployment;
> The number of interactions at beaches where area-based mitigation systems are not deployed;

and, the effectiveness of the 'education and awareness strategy':

> The uptake and use of personal deterrents, and potentially personal protective wetsuits and knowledge of improved first aid, by surfers;
> The uptake of the SharkSmart App; and
> Community sentiment within particular areas of the coast and towards particular aspects of the Shark Program.

A further indicator is proposed that will improve understanding of how the distribution and abundance of target sharks relates to potential incidents if they occur in the future:

> Trends in relative abundance and size of White Sharks, Bull Sharks and Tiger Sharks in nearshore coastal areas of NSW (i.e. as spotted by drones, caught by SMART drumlines or caught in SMP nets, standardised by effort).

Recommendation 8

The Shark Program continues to explore potential partnerships in relation to all three tiers in the hierarchy of protection, including co-funding models, with local Councils, community groups and other organisations that would improve shark bite mitigation at a local level.

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APPENDIX

A

WHITE, TIGER AND BULL SHARKS

White Shark

The White Shark (*Carcharodon carcharias*) is known to occur in Australian coastal waters including in NSW, although it ranges into oceanic waters to depths of approximately 350 metres on the continental shelf (Bruce, 1992; Bruce et al., 2006; Lee et al., 2021). On the east coast of Australia, White Sharks occur in all regions south of Rockhampton in Queensland (Lee et al., 2021) but are more abundant in NSW during spring and summer (Lee et al., 2018; Bruce et al., 2019). In NSW, they have been captured regularly in recent times by the Shark Meshing Program (Reid et al., 2011; Lee et al.,2018) and in SMS trials (see **Section 3.1.3**) and there is a high degree of certainty that they were correctly identified.

This species is well known to cause bites resulting in serious injury or fatalities in Australia and overseas (Ritter and Levine, 2004; West, 2011; McPhee, 2014; Ricci et al., 2016; Lippmann, 2018). Bites which cause serious injuries or fatalities from White Sharks are relatively common compared with other species (McPhee, 2014; Chapman and McPhee, 2016; Lippmann, 2018). Between 1982 and 2011 in Australia, 41 unprovoked shark bites are attributed to White Sharks with about half of these being fatal (McPhee, 2014). In NSW, recent fatalities attributed with certainty to White Sharks were recorded at Kingscliff and Wooli in 2020 and Tuncurry Beach and Emerald Beach in 2021.

The White Shark is listed as “Vulnerable” under the NSW *Fisheries Management Act 1994* (FM Act), Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and internationally by the IUCN. When the White Shark was afforded legislative protection population size was not known hence there is no baseline upon which to assess population recovery. For eastern Australia and New Zealand, Hillary et al. (2018) using genetic methods estimated that the number of adults was small (approximately 280 to 650 individuals) and the overall population size in the region was between 2,500 and 6,750. Bruce et al., (2018) (an update of the Hillary study) suggested the total population size in 2017 was 5,460 (uncertainty range 2,909 – 12,802). The large ranges for these estimates are noteworthy and further add to the difficulty of detecting population trends through time.

One source of information that indicates the relative abundance of White Sharks (and also Tiger and Bull Sharks) in nearshore areas is the SMP catch. Given mesh nets have generally been used at the same beaches in the Metro region for the same time of year over many years, they may be considered a standardised tool for sampling sharks occurring between Stockton and South Wollongong. White Shark catch in the SMP was high initially but declined between 1950 and 1980 and then stayed very low for the next few decades (Reid and Krogh 1992; Reid et al., 2011; Lee et al., 2018). Between the 1999/2000 and 2014/2015 seasons, White Shark catches in the SMP rarely exceeded a total of 10 and were generally less than this, but since the 2015/2016 season catches have increased to be consistently in the order of three or five times greater than this (**Figure A1Error! Reference source not found.**). It is not known if this recent trend also applies to other areas of NSW to the north or south of the SMP but given that immature White Sharks are known to range throughout the NSW coastline (Spaet et al., 2020) it is plausible.

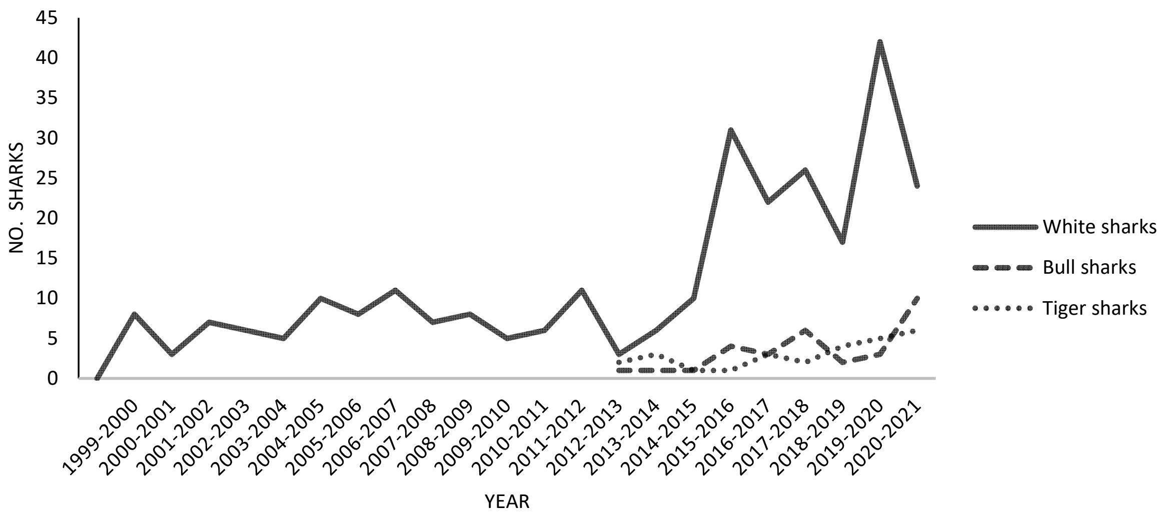

Figure A1. Catch of White, Tiger and Bull Sharks in the SMP since 1999-2000. Source: SMP annual reports and Reid.et al., (2011). Data not given for Bull and Tiger Sharks prior to 2012/13.

Tiger Shark

Tiger Sharks occur widely in subtropical and tropical waters and along the entire length of the Queensland east coast; their range extends into NSW (Last and Stephens, 2009; Holmes et al., 2012). They can occur in shallow nearshore areas and in the open ocean to depths exceeding 1,000 metres (Holmes et al., 2014; Lipscombe et al., 2020). They are captured infrequently in the NSW SMP, with a few beaches exhibiting deep water close to the nets significantly contributing to the catch (Reid et al., 2011; Lee et al., 2018).

Tiger Sharks can cause bites that result in serious injury or fatality in Australia and overseas (Lowry et al., 2009; West, 2011; Clua et al., 2014; McPhee, 2014; Ricci et al., 2016). Serious or fatal bites from Tiger Sharks are relatively common compared with other shark species (West, 2011; McPhee, 2014; Chapman and McPhee, 2016). At least ten fatal, unprovoked bites can be attributed to Tiger Sharks in Australia and further fatalities have occurred on spearfishers. The latest fatality from a Tiger Shark in Australia was in 2020 at Cable Beach (WA). Bites resulting in serious injuries occurred in the Whitsundays (Queensland) in 2019.

Tiger Sharks are identified internationally by the IUCN as “Near Threatened”, but the species are not listed as threatened species under Commonwealth or State legislation. Modelling by Roff et al. (2018) and Brown and Roff (2019) has identified that the Tiger Shark population on the Australian east coast has declined but the initial population size and the current population size has not been estimated. Since the 2012/2013 season catches of this species have been small, generally totalling <5 sharks per season, and much less than for White Sharks (**Figure A1**).

Bull Shark

Bull Sharks (*Carcharhinus leucas*) occur widely in subtropical and tropical waters, occurring along the entire east coast of Queensland and down to beyond Sydney in NSW (Last and Stephens, 2009; Smoothey et al, 2016). It occurs in coastal and nearshore waters and is the only very large shark species that occurs consistently in rivers and estuaries, including both natural and man-made waterways (e.g. residential canals and lakes) (Thorburn and Rowland, 2008; Werry et al., 2011, 2012a, 2012b; Smoothey et al., 2019). They can reside for periods of time in freshwater habitats (Gausmann, 2008). Surprisingly, Bull Sharks are infrequently caught in the NSW SMP (Reid et al., 2011; Lee et al., 2018) as they annually move from Queensland into the large estuaries in the SMP region (Heupel et al., 2015; Smoothey et al., 2019).

The Bull Shark is well known to cause bites on humans that result in serious injury or death in Australia and overseas (Hazin et al., 2008; West, 2011; McPhee, 2014; Ricci et al., 2016). Serious or fatal bites from Bull Sharks are relatively common compared with other species (West, 2011; McPhee, 2014). Overall, the Global Shark Attack File records identify at least 11 fatal bites attributable to Bull Sharks in Australia, and in further instances Bull Sharks are likely to have been involved given the bites occurred in rivers where Bull Sharks are likely to be the only very large shark species present. Between 1982 and 2011 in Australia, 16 unprovoked shark bites were attributed to Bull Sharks with two of these being fatal (McPhee, 2014). Globally, Bull Sharks are implicated in many unprovoked bites including fatalities across a large geographic range. Unprovoked bites that have resulted in serious injuries or fatalities are recorded from Brazil, Reunion, Bahamas, USA, Iran, Nicaragua and South Africa.

The last fatal bite in Australia attributed with a high degree of certainty to a Bull Shark was at Ballina (NSW) in 2008. Bull Sharks may have been involved in several recent fatalities in Queensland, but this has not been confirmed.

Bull Sharks are identified internationally by the IUCN as “near threatened”, but the species is not listed as a threatened species under Commonwealth or State legislation. There is no information on population size or trends. Similar to Tiger Sharks, since 2012/2013 catches of this species have been small, generally totalling <5 sharks per season (**Figure A1**). The figure does, however, appear to have trended upwards in 2020-2021 which may be linked to climate-induced changes in Bull Shark distribution as predicted by Niella et al., (2021a).

APPENDIX

B

INCIDENT DATA AND ANALYSIS

Detailed Methods

Reported (and verified) interactions between humans and sharks in coastal waters of NSW were sourced from the Australian Shark Attack File (2021). In general, each record in the data set ('incident dataset') comprised a range of fields including (but not restricted to):

> Spatial information (i.e. beach, headland, coastal waterbody or offshore reef/island);

> Temporal information (usually date, but at least year);

> Activity (swimming, wading, board or body surfing, surf ski paddling, spearfishing, SCUBA diving, snorkelling, etc.);

> Outcome (fatal, injured or uninjured) and details of injuries; and

> Type of shark (species or family) and other details of the incident.

The untruncated shark incident dataset comprised a total of 379 records of interactions, with the earliest dating back to 1791 and most recent in March 2021. A total of 22 records from the pre-1900 period, along with an additional 88 records relating to incidents that occurred in a river, estuary or harbour, or at an offshore reef or island, were excluded from further consideration because of ambiguity in these records, leaving 269 records for the assessment.

The smaller incident dataset (i.e. 1900-2021) was first inspected for obvious inconsistencies that need to be rectified (e.g. local media articles from the time). An example of this was the record of an incident at South West Rocks in 2008. This record contained a categorisation of the victim as 'uninjured' in the 'Recovery Status' field, but also comprised other fields further detailing the attack and injury to the victim as 'bit victim on leg', and 'severe wounds – loss of flesh' to the 'left thigh and calf'. A simple internet search cleared this up, with a local news article from that time confirming the surfer was uninjured after a 'bump' to a wetsuited elbow.

Part of this review required assessment of the performance of SMS mitigation measures through evaluation of the number of shark incidents. Given the mitigation measures were only trialled at ocean beaches and headlands, the incidents were screened to only included those from ocean beaches, headlands or breakwalls.

Additional fields were created in the incident dataset to assist with this review including:

> REGION: 'FAR NORTH' (Qld border to Grassy Head); 'MID NORTH' (Stuarts Point Beach to Birubi Beach); 'METRO' (Stockton Beach to South Wollongong); and 'SOUTH' (Port Kembla to Vic border) regions. The METRO region was specifically defined such that it included the northern- and southern-most meshed beaches included in the SMP as its bookends (**Figure 1-2**).

> PERIOD: 'Pre-SMS' (1900 to 2015 inclusive) and 'Since SMS' (2016 to 2021) periods. While the initial formal period of the SMS project was five years (2016-2020), the current one-year extension has been included in the Since SMS category for the purpose of assessing the incident dataset against the implementation of the SMS (i.e. according to a Before-After comparison framework).

> ACTIVITY: 'SWIMMERS' (swimming, wading, floating, bodysurfing – all sans association with board/watercraft/facemask); 'SURFERS' (paddling, wading, floating, sitting, in water – with surfboard or bodyboard); 'OTHER' (all watercraft activities other than surf/bodyboard, kitesurfing, SCUBA/Hookah diving, snorkelling, spearfishing); and 'UNKNOWN'.

> OUTCOME: 'UNINJURED', 'INJURED' and 'FATALITY' outcomes.

> SPECIES: Potentially dangerous species categories 'WHITE', 'WHALER' (includes bull shark, bronze whaler and other whaler species) and 'TIGER'; relatively less dangerous 'WOBBEGONG/GNS' (wobbegong and Grey Nurse Shark incidents combined); and UNKNOWN (species responsible unidentified). Given the low degree of reliability around historical identifications of species responsible for incidents (particularly whaler species), it was considered prudent to combine all of the records referring to 'whaler shark', 'whaler', 'whaler sp.', Bull Shark, Bronze Whaler and Dusky Whaler into the one species

category ('WHALER'). Further to this, for summaries that required the three target species categories to be combined into one collective, termed 'BWT species', the incidents for which the species responsible was unidentified (i.e. the 'UNKNOWN' category) were included under the assumption that a target species was like to have been responsible.

> BEACH: For each included incident dataset record, the specific location information was cross-matched to the generated beach list to provide a 'nearest beach' location.

> SMP. Incident records associated with beaches within the METRO region that are part of the ongoing Shark Meshing Program were assigned to one of two categories: 'Pre-Net' (i.e. incident occurred prior to first deployment of a SMP net at that beach) and 'Since Netting' (i.e. incident occurred during the years after initial SMP net deployment at that beach). Notably, the specific year during which certain subsets of SMP beaches were added to the SMP varies, with most Sydney beaches meshed from 1937 and most Newcastle and Illawarra beaches added in 1949 (Green et al., 2009). An additional nine beaches along those three stretches of coast were included in 1972, while 11 Central Coast beaches were added to the program in 1987.

Pre-SMS Interactions vs. Since SMS Interactions across all NSW Beaches (Regional level)

The derivative fields and associated categories outlined above were used to generate a range of tabular and graphical summaries of the shark incident dataset (ocean beaches, 1900-2021), with particular primary focus on comparisons between the Pre- and Since SMS periods. Shark incidents were examined according to the activity, outcome and species fields and summarised by Pre- and Since SMS periods for each of the four regions.

Pre-nets Interactions vs. Since Nets Interactions for SMP Beaches (Regional level)

Of secondary, but equally informative, interest was an assessment of incidents at beaches included in the SMS that involved BWT species, but also including incidents for which the species was unknown. In other words, incidents involving Wobbegongs, Grey Nurse Sharks or other relatively non-dangerous species were excluded, with the remaining incidents represented as BWT species (combined).

As explained above, the particular year of commencement of net deployments ranges across those SMP beaches, so a simple Before-After categorisation framework was applied to categorise incidents for each beach independently of other SMP beaches. Calculation of annual rates of interactions per beach also duly reflected the variation in SMP commencement years across SMP beaches. These rates of interaction were graphically summarised by activity and outcome.

Beach-level Interactions

To investigate early indications of the efficacy of drones, SMART drumlines and the VR4G listening stations at demonstrably reducing the likelihood of human-shark interactions specifically involving BWT species, the specifics of the spatial (by beach) and temporal roll-out of those technologies was correlated against recorded interactions as listed in the Australian Shark Attack File (2021). Only interaction data from 2010 onwards was used to ensure a reasonable parity of timeframes for before/after-type comparisons.

Drones

Flight data reports (in spreadsheet format) provided by SLSCs to NSW DPI were examined to determine:

- Which beaches/SLSCs have been involved in the SLSC-piloted drone operations;
- When drone flights were first completed; and
- The number of siren activations and water evacuations triggered by shark detections.

For each beach at which SLSC-piloted drones have been in operation, the number of human-shark interactions occurring during the following three temporal categories was summarised:

- Between the start of 2010 and the date of the first SLSC-piloted drone flight;
- On days since the first SLSC-piloted drone flight that a drone had been flown; and
- On days since the first SLSC-piloted drone flight that a drone had not been flown.

SMART Drumlines

Information regarding the positions of SMART drumlines deployed as part of ongoing operations and trials completed since 2016, along with the dates of deployment and de-commission, were summarised by beach. For each beach off which SMART drumlines are (ongoing operations) or were (trials) deployed, the numbers of human-shark interactions occurring during the following two temporal categories (bounded by the start of 2010 and the present) were summarised:

- While SMART drumlines were deployed and operational; and
- While SMART drumlines were absent or non-operational.

VR4G Listening Stations

Information regarding the positions and dates of deployment of VR4G Listening Stations deployed as part of the SMS since 2016 were summarised by beach. For each beach off which VR4G Listening Stations are deployed, the number of human-shark interactions occurring during the following two temporal categories (bounded by the start of 2010 and the present) was summarised:

- Prior to deployment of VR4G Listening Stations; and
- Since deployment of VR4G Listening Stations.

Detailed Findings of Broad-scale Patterns

Broad-scale Patterns in Interactions

Interactions Prior to and After Implementing the SMS

Approximately 12% of the total of 269 interactions between humans and sharks since 1900 have been fatal and around half of all interactions have involved surfers. (**Table B1**). Fatalities account for 11.9% of total incidents but fatalities were higher historically in the Metro region prior to the introduction of netting.

Since 1900, most human-shark interactions have been in the Metro region, but most of these occurred prior to the SMS and indeed prior to netting for the SMP. Of the other regions, most incidents have been in the Far North, followed by Mid North and the South region had the least (**Table B1**). Surfers were involved in a large proportion of incidents. Since the SMS these have ranged between 70 – 85% of incidents in all regions, except Metro where they were 53.3%. Since the SMS was implemented, the Far North has had the highest number of incidences.

Of the 590 ocean beaches in NSW, 129 include a SLSC. The Metro region has the most SLSCs along the NSW coast. Currently a total of 51 beaches within the Metro region are netted as part of the SMP (**Table B1**).

Table B1. Overview by region of beaches, SLSC coverage and shark incidents

REGION	No. Beaches	No. SLSCs	Total no. Incidents (% fatal / % surfers) Pre-SMS 1900-2015	Since SMS 2016-2021	TOTAL 1900-2021	No. Netted Beaches (SMP)
FAR NORTH	124	19	67 (9.0% / 59.7%)	24 (8.3% / 75.0%)	91 (8.8% / 63.7%)	0
MID NORTH	90	16	33 (0% / 66.7%)	14 (7.1% / 85.7%)	47 (2.1% / 72.3%)	0
METRO	147	76	90 (23.3% / 23.3%)	15 (0% / 53.3%)	105 (20.0% / 27.6%)	62
SOUTH	229	18	16 (12.5% / 50.0%)	10 (0% / 70.0%)	26 (7.7% / 57.7%)	0
TOTAL	590	129	206 (14.1% / 44.2%)	63 (4.8% / 71.4%)	269 (11.9% / 50.6%)	

Rates of Interactions since 1980

To potentially avoid effects of large changes in the proportions of Swimmers, Surfers and Other water users (particularly surfers, where popularity increased since the mid part of the 20th Century) confounding interpretation of trends among these groups in interactions with sharks, we restricted analysis to records since 1980. Since 1980 there have been 194 recorded instances of human-shark interactions, with 136 of these involving BWT species and records where the species responsible was unknown.

Of all interactions between humans and BWT, surfers were involved in ~75% of the total and ~46% of these occurred in the Far North region. Very few incidences to swimmers have occurred in the Far North and Mid North regions since 1980. The annual rate of interactions (i.e. total no. interactions (beaches pooled) divided by no. years) between humans and BWT has, in general, been substantially higher during the six-year period Since-SMS (2016-2021) than during the 36-year Pre-SMS period for all four regions, (**Table B1, Figure B1)**. This trend is most prominent for surfers, with 0.94 vs 2.83 surfers involved in an interaction per year, respectively, at beaches in the Far North region; and 0.47 vs 1.33 surfers per year, respectively, in the Mid North region; 0.33 vs. 1.00 surfers per year, respectively, in the Metro region; and 0.11 vs. 0.83 surfers per year, respectively, in the South regions.

For surfers, in periods before and after implementation of the SMS, the annual rate of interactions decreased from north to south. For swimmers, there have been few interactions with BWT since 1980 at beaches in the Far North and Mid North regions, while annual interaction rates for swimmers rose slightly from the Pre- to the Since SMS period in the Metro (0.03 to 0.16 swimmers per year) and South (0.06 to 0.33 swimmers per year) regions. There were also rises in rates of interaction for the ‘Other activities’ category for the Far North (0.17 to 0.83 per year) and Metro (0.17 to 0.50 per year), with SCUBA diving, spearfishing and kayaking prominently represented among those records.

A more detailed examination of annual rates of interactions between humans and BWT indicated that, despite there being substantially fewer patrolled than unpatrolled beaches in the Far North, Mid North and South regions, interactions since 1980 generally occurred most often to surfers at patrolled beaches (**Figure B2**). However, following implementation of the SMS in the Far North and Mid North regions, the rate of interactions with surfers at non-SLSC beaches has been only marginally less than for beaches with SLSCs.

The same pattern in spatial distribution of interactions was apparent for the Metro region, although there are more patrolled than unpatrolled Metro beaches.

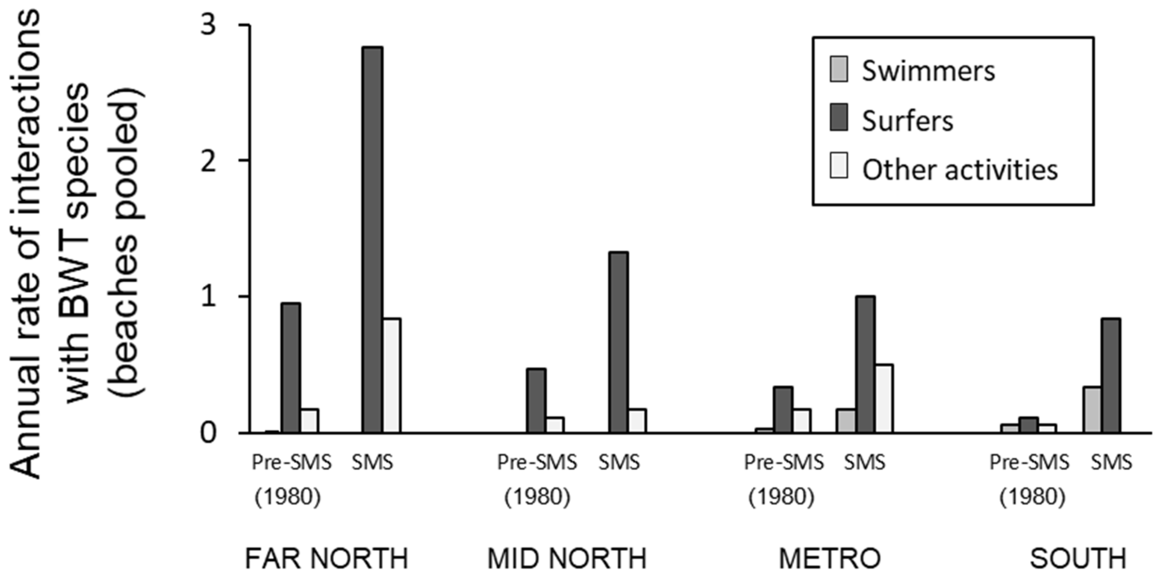

Figure B1. Annual rate of human-shark interactions (no. per year) involving BWT sharks in the Far North, Mid North, Metro and South regions (beaches pooled) during Pre-SMS (1980-2015, 36 years) and Since SMS (2016-2021, 6 years) periods. Data are presented separately for incidents involving swimmers, surfers and other activities.

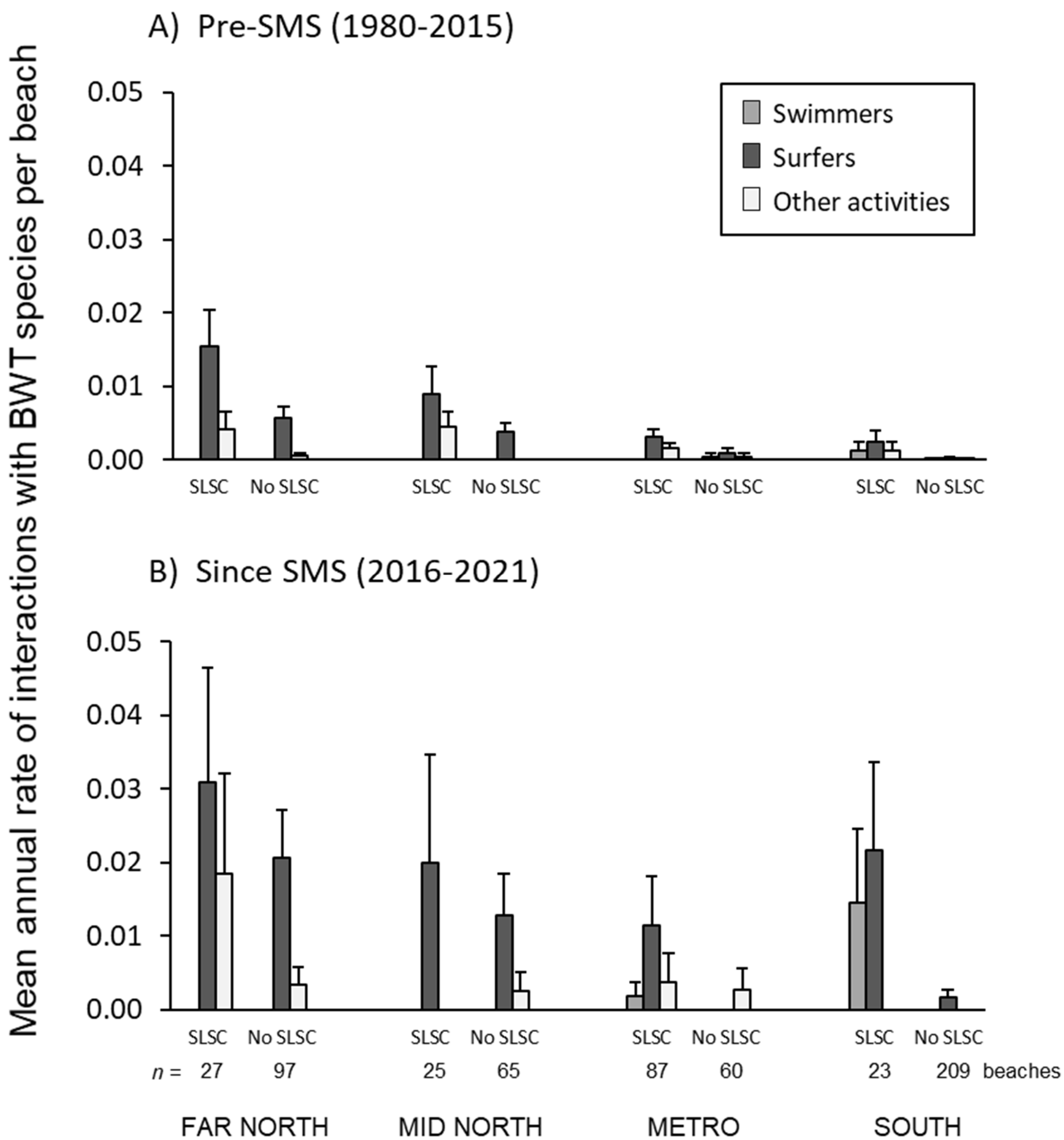

Figure B2. Mean annual rate (no. per year) of human-shark interactions (BWT species) per beach during the: A) Pre-SMS period (1980-2015); and B) period since commencement of implementation of the SMS (2016-2021); for patrolled (SLSC) and unpatrolled (No SLSC) beaches in the Far North, Mid North, Metro and South regions. Data are presented separately for incidents involving swimmers, surfers and other/unknown categories.

Outcomes of Interactions

The patterns in relative proportions of victims that were either uninjured, injured or died as a consequence of an interaction were generally similar between the Pre-SMS and Since-SMS periods for each of the four regions (**Figure B3**), noting that for these comparisons the Pre-SMS period extends back to 1900. In the Far North region the proportions of interactions during the Pre-SMS and Since-SMS periods resulting in no injury were 25.4% and 45.8% respectively (**Figure B3**). In contrast, the proportions suffering injury were 65.7% and 45.8% respectively. The fatality rate per interaction was similar for the two periods, at 9.0% and 8.3%, respectively. A similar pattern for non-fatal interactions was evident in the Metro region, with lack of injury representing 18.9% and 53.3% of Pre- and-Since SMS outcomes respectively, and non-fatal injury representing 57.8% and 46.7% of those outcomes, respectively. However, while fatalities accounted for

23.3% of Pre-SMS interactions, there have been no fatal interactions in the Metro region since commencement of the SMS.

The proportions of no injury interactions for Pre-SMS and Since SMS periods were very similar in the cases of the Mid North (33.3% and 28.6% respectively) and South (18.8% and 20.0% respectively) regions, as was also true for non-fatal injuries (Mid North, 66.7% and 64.3%, respectively; and South, 68.8% and 80.0%, respectively) (**Figure B3**). However, while there were no fatal Pre-SMS interactions in the Mid North region, 7.1% of interactions in the Metro region since commencement of the SMS have been fatal. The opposite is the case for the South region, with 12.5% of Pre-SMS interactions resulting in a fatality and no fatalities since SMS commencement.

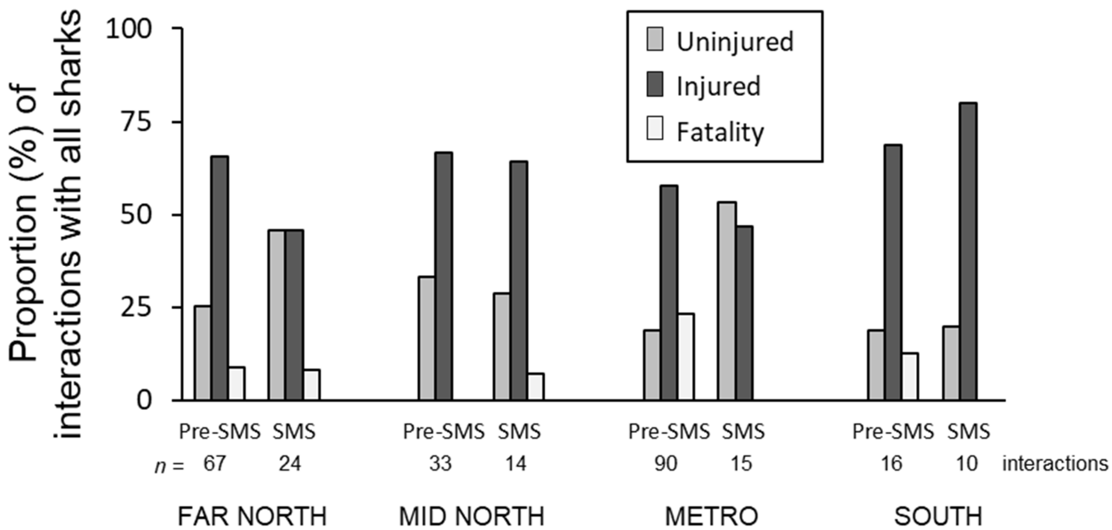

Figure B3. Proportions (%) of human-shark interactions (all shark species) that resulted in either no injury, injury or death to the victim, during the Pre-SMS (1900-2015) and Since SMS (2016-2021) periods in the Far North, Mid North, Metro and South regions (beaches combined).

Species Responsible

Since 1900, White Sharks have been responsible for 13 of the 72 interactions involving swimmers (18.1%), with the vast majority (84.6%) resulting in a fatality and the remainder resulting in non-fatal injury (**Figure B4A**). Notably, a relatively large proportion (30.1%) of all swimmer interactions involved Wobbegongs or Grey Nurse Sharks, with all resulting in non-fatal injury. An even greater proportion (40.3%) involved unknown species, with 27.6% fatalities and 72.4% of victims injured, and it must be assumed that many of these would also have been from BWT. Whaler Sharks were generally unable to be classified to species, but probably included mostly Bull Sharks. Whalers were attributed to six (8.3%) of the interactions involving swimmers, resulting in a high proportion of fatalities (66.7%). Only two swimmer interactions were attributed to Tiger Sharks, with both resulting in a non-fatal injury. Only one of the 72 swimmer interactions resulted in no injury to the victim.

In contrast to swimmers, White Sharks were attributed to almost half (48.5%) of the 136 interactions involving surfers, with Whalers (16.2%), Tigers (2.9%) and Wobbegongs or Grey Nurse Sharks (19.1%) deemed responsible for far fewer interactions. The fatality rate across the 136 interactions involving surfers has been relatively low when compared to swimmers, with patterns in outcomes for White (45.5% uninjured, 48.5% injured and 6.1% fatal) and Whaler (36.4% uninjured, 54.6% injured and 9.1% fatal) shark interactions very similar (**Figure B4B**). As with swimmers, confirmed surfer interactions with Tiger Sharks have been rare relative to White and Whaler sharks, with one fatality, two victims non-fatally injured and one instance of no injury. Interactions between surfers and Wobbegongs or Grey Nurse Sharks, have almost always resulted in injury (92.3%) but none were fatal. A loosely similar pattern is evident in the cases of surfer interactions for which the responsible shark species is unknown, with 72.2% resulting in injury and none in fatalities.

As given above, the ‘other activity’ portion of the Other/Unknown activity category comprises: all watercraft activities other than surf/bodyboarding; surface/underwater activities usually in deeper waters, such as SCUBA/Hookah diving, snorkelling and spearfishing; along with other activities not falling into the swimming or surfing categories. White Sharks were attributed to 26.2% of the 61 interactions in this category, with Whalers (16.4%), Tigers (6.6%), Wobbegongs or Grey Nurse Sharks (19.7%) and unknown species (31.1%) attributed to the remainder. Most interactions with White (81.3%) and Whaler (80.0%) sharks did not result in any injury, with non-fatal injuries resulting in the cases of all remaining White and Whaler Shark interactions, bar one (a fatal White Shark interaction with a SCUBA diver) (**Figure B4C**). Two of the four Tiger Shark interactions resulted in no injury, while the other two sustained non-fatal injuries.

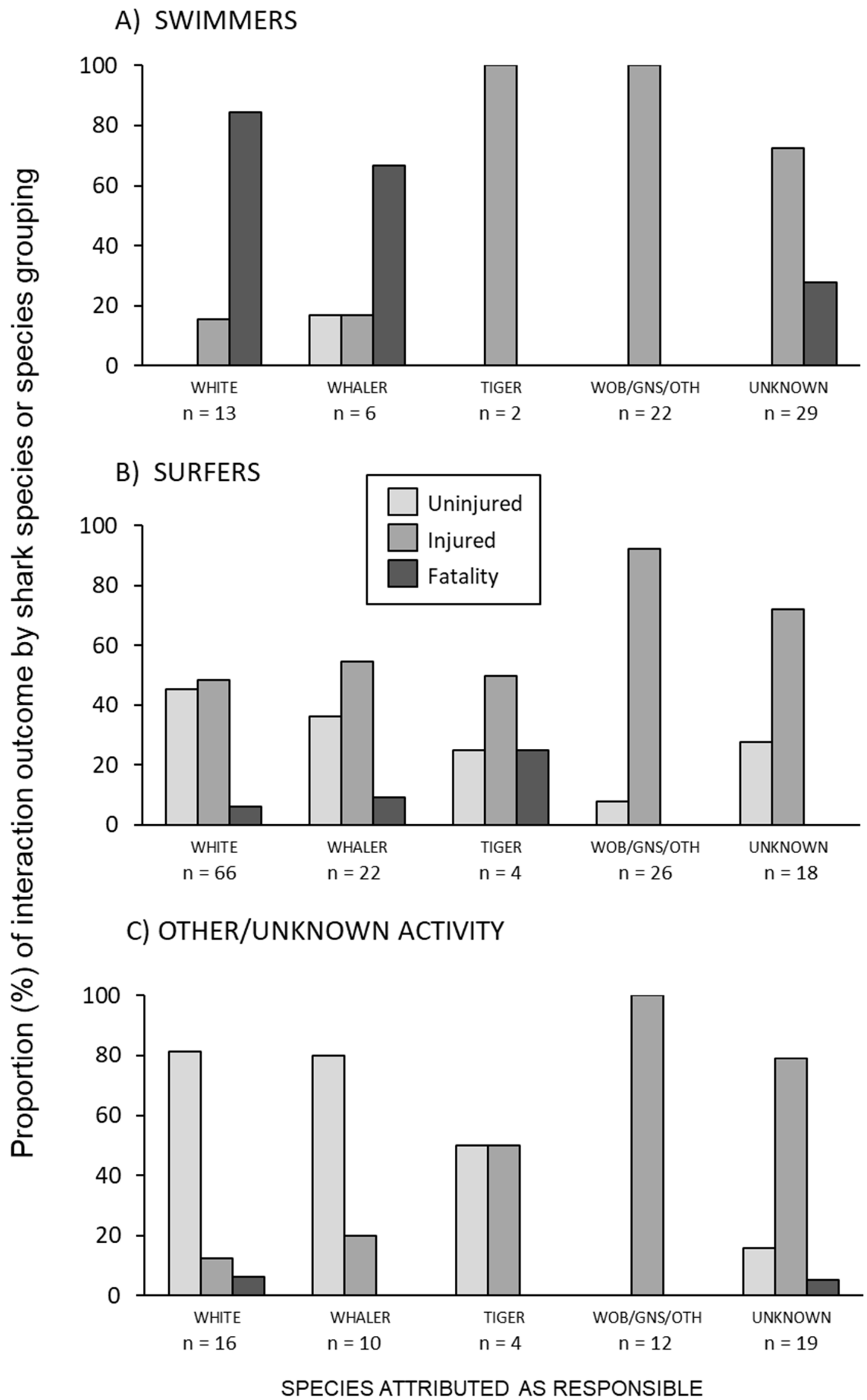

Figure B4. Proportions (%) of human-shark interactions since 1900 resulting in no injury, a non-fatal injury or a fatality according to species responsible (White, Whalers, Tiger, Wobbegong/GNS/Other or Unknown) for interactions involving: A) Swimmers; B) Surfers; and C) Other (or unknown) activities.

Overall, the annual rate of interactions (i.e. total no. interactions (beaches pooled) divided by no. years) was at least double for the six-year Since-SMS period than for a 36-year Pre-SMS period from 1980 for all but one of the three species category / region combinations (**Figure B5**). In the Far North region where there have been 3.2 BWT shark interactions per year since the commencement of the SMS, compared to 1.1 per year between 1980 and 2015, 1.3 vs. 0.5 per year in the Mid North. 1.3 vs. 0.5 per year in the Metro and 0.5 vs. 0.2 per year in the South regions.

The annual rate of interactions (i.e. total no. interactions (beaches pooled) divided by no. years) involving Wobbegongs or Grey Nurse Sharks also increased from the Pre-SMS period to the Since SMS period in the Mid North, Metro and South regions, while no increase was apparent in the case of the Far North regions (**Figure B5**). Increases from Pre- to Since SMS in the annual rate of interactions involving other or unknown species were apparent across all four regions.

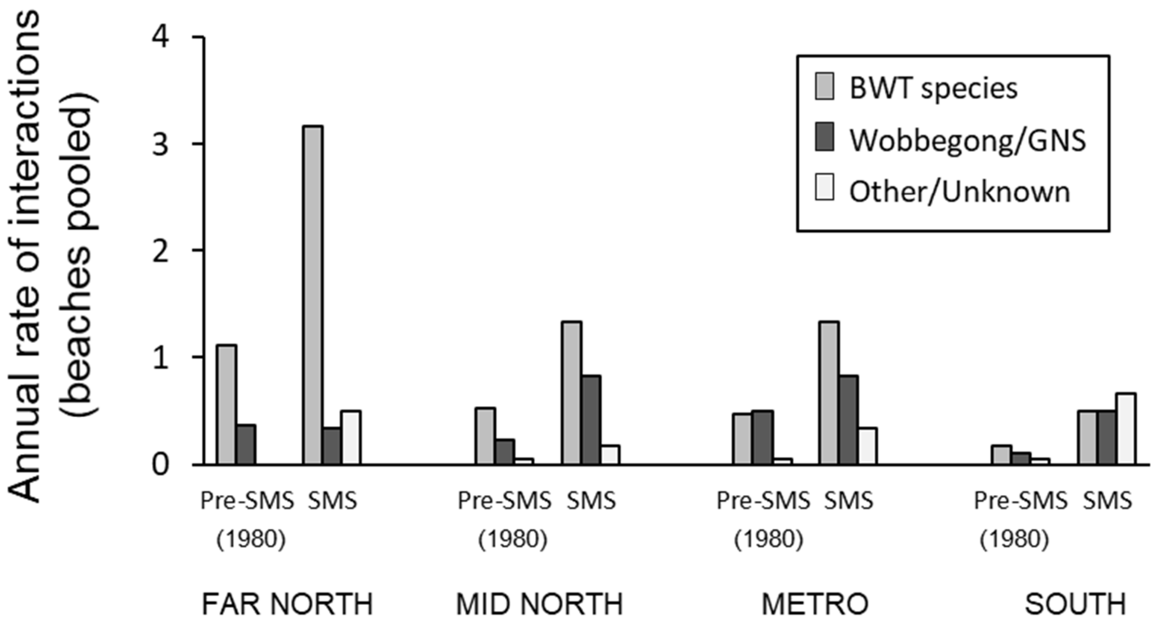

Figure B5. Annual rate of human-shark interactions for three separate species groupings (BWT species, Wobbegong/GNS and Other/Unknown) in the Far North, Mid North, Metro and South regions (beaches pooled) during the Pre-SMS (1980-2015, 36 years) and Since SMS (2016-2021, 6 years) periods, irrespective of activity and outcome.

When interactions involving Wobbegongs or Grey Nurse Sharks are disregarded and the Pre-SMS period is expanded to include interaction records as far back as 1900 to include the numerous interactions that occurred off Metro beaches prior to the implementation of SMP netting in 1937, it appears that while White and Whaler Sharks were attributed to similar proportions of surfer interactions during the Pre-SMS period in the Mid North region (44.4% and 33.3% respectively), White Sharks were responsible for 75.0% of encounters during the Since SMS period. In the case of the Metro region, half of the 38 swimmer interactions during the Pre-SMS period were not attributed to a species, while 32% were attributed to White Sharks, 11% to Whalers and 5% to Tiger Sharks (**Figure B6)**. The one swimmer interaction that has occurred during the Since-SMS period in the Metro region was attributed to a Dusky Whaler Shark.

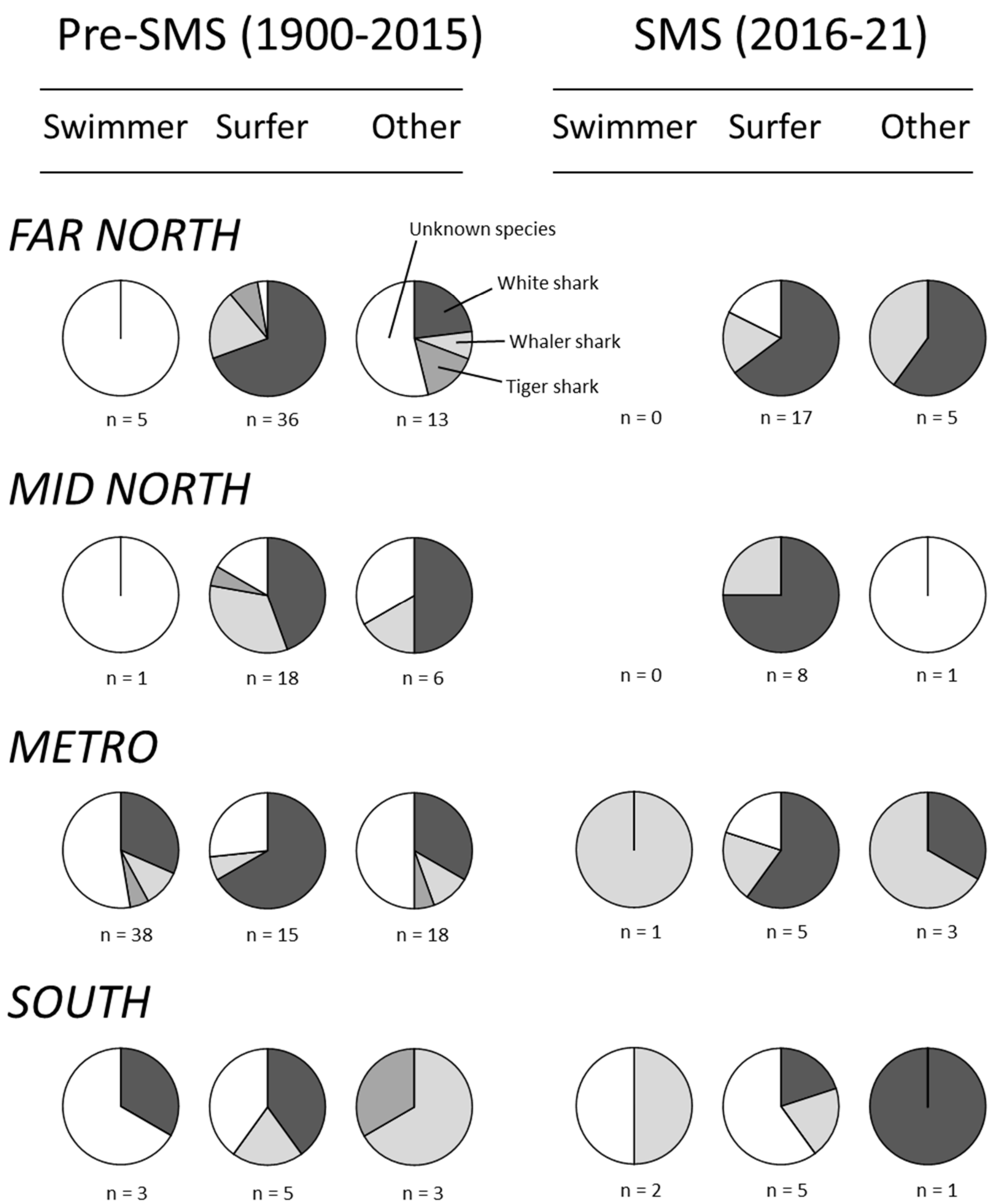

Figure B6. Proportions (%) of human-shark interactions involving white, whaler, tiger or unidentified species, for three activity categories (swimmers, surfers and other/unknown) in the Far North, Mid North, Metro and South regions (beaches combined) during the Pre-SMS (1900-2015) and Since SMS (2016-2021) periods, irrespective of outcome.

Interactions in the SMP Metro Region

Given the demarcation year between the periods prior to (Pre-netting) and following (Since-netting) first net deployment varied by SMP beach, temporal definitions for the Pre-netting and Since-netting periods for some beaches were beach-specific, although 1900 was considered as the starting point for the Pre-netting period across all beaches. For example, at Bondi Beach (nets first deployed in 1937) annual rates of interactions for the Pre- and Since- netting periods were calculated using *n* = 38 and 83 years, respectively, while the calculations were necessarily different for Stockton (1949; *n* = 50 and 71, respectively), North Narrabeen (1972; *n* = 73 and 48, respectively) and The Entrance (1987; *n* = 88 and 33, respectively) beaches.

There have been 70 interactions at SMP beaches since 1900, with 36 involving swimmers, 18 involving surfers and the remaining 16 involved in other or unknown activities. The mean of average annual frequency of interactions between swimmers and BWT species (including 'unknown species' records) per beach (*n* = 51 beaches) prior to first deployment of the SMP nets was 0.0138 (± 0.0034 SE) interactions per year per SMP beach (**Figure B7A**). Since first use of SMP nets this rate of interactions with swimmers has decreased substantially (by ~90%) to 0.0013 interactions (± 0.0007) per year per beach. Notably, 97% of all of those interactions with swimmers resulted in fatality or injury.

The opposite appears to be the case for surfers involved in interactions with BWT sharks at SMP beaches, with the mean of average annual frequency of interactions per beach increasing by an order of magnitude from 0.0006 (± 0.0005) interactions per year per beach prior to first SMP net deployment to 0.0065 (± <0.0021) interactions per year per beach since first net use (**Figure B7A**). The rate of fatality or injury (combined) associated with those interactions with surfers (61%) has been substantially lower than for swimmers.

The 'other activities' represented within this SMP beach interactions dataset included surf ski, kayaking, sailboarding, SCUBA diving, snorkelling and spearfishing[16]. There were seven interactions for which the species was unknown. As has been the case for surfers, the mean of average annual frequency of interactions per beach increased from 0.0013 (± 0.0008) interactions per year per beach prior to first SMP net deployment to 0.0034 (± <0.0010). The rate of fatality versus non-fatal injury (combined) associated with those interactions (44%) has been lower than for swimmers and surfers.

The frequency of interactions between swimmers and BWT species (including 'unknown' species records) increased steeply from the 1910s through the 1920s, before decreasing almost as quickly through the 1930s and 1940s decades (**Figure B7B**). From the 1950s through to the 1970s there was a further gradual decrease to zero. Since then, there has been only one interaction across all SMP beaches involving a swimmer.

Despite the more widespread popularity of surfboard and bodyboard riding arising from around the 1950s and 1960s, the frequency of interactions between surfers and BWT species did not come to prominence until the 2000s onwards (**Figure B7B**). It is notable that the mean annual frequency of surfer interactions rose as steeply from the 1990s decade to the 2000s decade. The frequency of surfer interactions with BWT species at SMP beaches has more-or-less remained fairly constant from the 2000s decade until the present.

Looking at more recent patterns at the beach level, there have been 48 interactions in the Metro region since 2000, with nine involving swimmers and 25 involving surfers. Of those 34 interactions with swimmers and surfers, 29 (85%) occurred at netted beaches while five occurred at non-netted beaches with the Metro region. Eight of those nine swimmer interactions involved Wobbegongs or Grey Nurse Sharks, with one reportedly involving a Dusky Whaler (Australian Shark Attack File 2021).

A total of 18 (72%) of the 25 surfer interactions at Metro region beaches since 2000 involved BWT species (or unidentified species) – and predominantly White Sharks (12) – with the remaining seven involving Wobbegongs or Grey Nurse Sharks. Of the 18 surfer interactions involving BWT or unidentified species, only two occurred at non-netted beaches and another three occurred during the winter months at netted beaches when nets are not deployed. Given this, it can be summarised that 13 of 18 (72%) surfer interactions with BWT (or unidentified) species at Metro region beaches since 2000 occurred at beaches that had nets deployed at the time of the incident.

[16] Spearfishing is prohibited except within 20 m of the ends of any beach. Most incidents would not be at beaches, but on rock reef north or south of beaches.

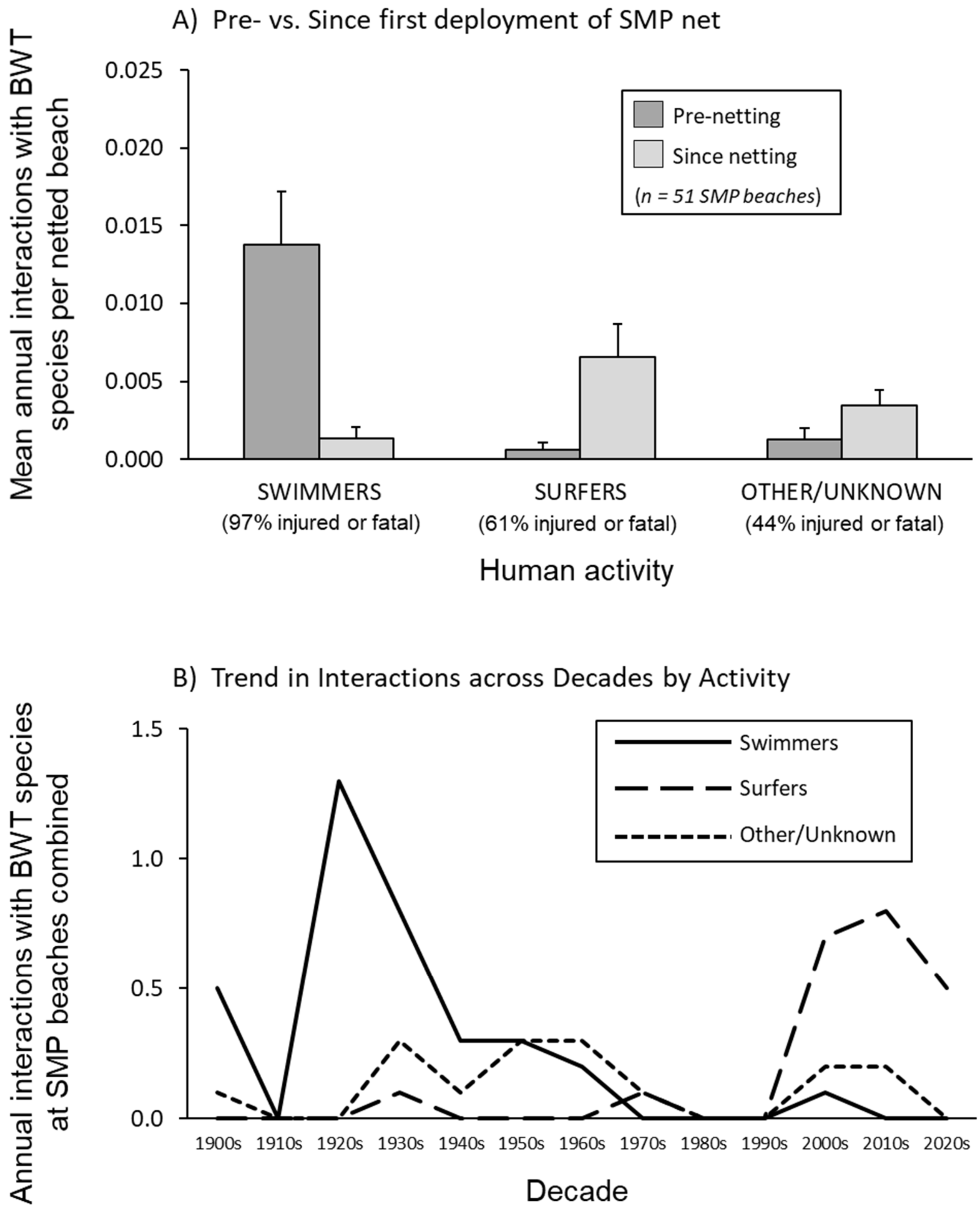

Figure B7. A) Mean of average annual rate of human-shark interactions involving BWT species (White, Whaler, Tiger and unidentified) per SMP beach (n = 51 beaches) for the periods prior to (Pre-net) and following (Since netting) first net deployment, with the durations of these periods determined separately for each beach. Data are presented separately for incidents involving swimmers, surfers and other/unknown categories, with the proportions of the total interactions either fatal or injured (combined) shown. B) Trends in annual rate of interactions involving BWT species through time (data compiled by decade) for all current SMP beaches combined.