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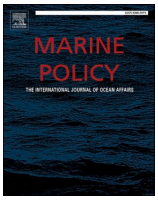

# The social dimension to the New South Wales Shark Management Strategy, 2015–2020, Australia: Lessons learned

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ABSTRACT

The future of shark mitigation worldwide, not only depends on economic and environmental considerations but on community support and acceptance of mitigation approaches. Shark mitigation strategies and policy development based on publicly held values in combination with expert knowledge is more likely to be supported and accepted by the public and society in general. In 2015, the New South Wales (NSW) government implemented a five-year Shark Management Strategy (SMS) to trial new and emerging technologies following a cluster of shark bites in 2014 and 2015 (including fatalities); most notably on the NSW north coast. The strategy aimed to increase protection of beachgoers while minimising harm to sharks and other marine animals. This paper synthesises various SMS-related social research studies to generate knowledge and improve understanding of community attitudes, support and preferences for different shark mitigation approaches trialled in the SMS. Our findings show non-invasive mitigation approaches involving shark detection and tracking, and public notifications were supported and preferred over invasive and/or lethal approaches such as nets. Drone surveillance was very highly supported (and preferred over helicopters) for being localised, having the capacity to be incorporated into beach safety operations, and with future potential for automation and the use of artificial intelligence to increase detection capability. Community education was seen as a fundamental component of shark mitigation to help people increase their ability to take personal responsibility for their own safety, improve public knowledge and understanding of sharks, and to mitigate fear; ultimately, to foster coexistence without jeopardising public safety.

## 1. Introduction

Although uncommon, the number of unprovoked shark bites has increased worldwide [7,40]; especially in Australia and the United States where incident rates have doubled in the last 20 years [41]. However, fatalities still represent a rare ocean hazard to beachgoers in comparison to other hazards such as drowning [57]. Nonetheless, the impacts of shark bites (especially fatalities) can be widespread and long-lasting; often intensified by prolonged media coverage over months or years. A shark bite is traumatic for the victims, first responders, witnesses, victims' families, and the wider community [71]. This can catalyse the community to call on governments to take some form of action to mitigate shark bites and increase protection of beachgoers.

Globally, lethal approaches such as mesh nets and conventional drumlines are common mitigation strategies applied to reduce the risk of shark-human interactions (e.g. Australia, South Africa, Hawaii) [16,76]. For example, in New South Wales (NSW), Australia, the Shark Meshing (Bather Protection) Program (SMP) has been operating in the metropolitan areas of Sydney since 1937, Newcastle and Wollongong since 1947, and the Central Coast since 1987 [54]. However, nets have become increasingly controversial due to their impacts on both target and non-target marine animals, including threatened, endangered, and protected species [8,16,22]. Until the 1990 s, the public was largely unaware of those impacts due to limited reporting on the programme. Increased reporting [16,26,27,33,34] has led to a shift in community sentiment towards sharks, and the popularity of lethal mitigation

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methods has declined [24,51,52,61]. Societal perceptions towards sharks have evolved over decades from one initially focused on protecting humans from sharks, to greater acknowledgement of the critical role of sharks as apex predators in ocean ecosystems, and the need for their conservation [21,24,67]. Recent advancements in technology has seen the development of less invasive technologies, such as helicopter and drone aerial surveillance, and SMART drumlines (Shark Management Alert in Real-Time) (SD), designed to increase beachgoer protection while minimising harm to sharks and other marine animals [5,28,56].

In October 2015, following a cluster of shark bites on the NSW far north coast in 2014/15, the NSW Government implemented the Shark Management Strategy (SMS), managed by NSW Department of Primary Industries (DPI). The scientifically driven strategy aimed to test and trial new and emerging mitigation technologies and learn more about target sharks; exploring how to increase protection of beachgoers while minimising harm to sharks and other marine animals. The SMS specifically focused on mitigating shark bite from target sharks that are responsible for most serious bites and fatalities, i.e. White (*Carcharodon carcharias*), Bull (*Carcharhinus leucas*) and Tiger (*Galeocerdo cuvier*) sharks [40,75]. Technologies trialled in the SMS included SD, which involved a direct comparison between mesh nets in northern NSW and the Newcastle to Sydney region, aerial surveillance (using drones and helicopters), real-time alerts about the presence of tagged sharks using satellite-linked listening stations (VR4G), and education and shark awareness using the SharkSmart app (Table 1). Community education was an important element of the SMS to both raise awareness of the strategy and provide advice to beachgoers about risk factors to reduce the chance of a shark encounter.

Community attitudes towards sharks and shark bite mitigation are complex and multifaceted, and influenced by a number of factors such as local context, density and demography of human population, social dynamics, lethal or non-lethal nature of management actions, as well as personal experiences and risk perceptions, characteristics of particular species such as the White Shark, and sensationalised media coverage of shark incidents [1,11,24,61,71,75]. Future shark bite mitigation in NSW (and worldwide) not only depends on the economic cost and capacity of technologies to detect or catch target sharks, but on community support and acceptance of them as mitigation tools. Local communities, and society in general, are more likely to accept and support shark mitigation strategies and policy development based on publicly held values in combination with expert knowledge [2]. When authorities seek out the aspirations, concerns and values of communities, and incorporate these into decision-making processes, they are better able to understand the needs of communities [42]. Further, recognising conflicting interest groups with differing objectives allows a balanced perspective, and ensures decisions are not reactive to one side of an argument [12]. The community has indicated they are not tolerant of 'top-down' decision making and knee-jerk reactions by authorities in response to shark bite incidents [12,23,63,64].

Social research was an important element of the SMS to assess and monitor community attitudes towards different shark mitigation technologies trialled in the strategy. Engaging with communities and undertaking social research to gain knowledge about community attitudes, values and preferences facilitates improved outcomes for both authorities and communities [42]. This includes greater levels of trust and satisfaction with authorities, improved decision-making incorporating community desires, and increased likelihood the community will accept and support recommendations relating to shark mitigation policy in NSW [4]. Initially, social research focused on the NSW north coast Ballina and Evans Head communities impacted by the cluster of interactions (Fig. 1). The need for social research was catalysed by community conflict over the proposed trials of shark barriers and mesh nets on this coast in 2016. Nevertheless, the community was collectively supportive of trialling other mitigation technologies (with fewer impacts on non-target species) such as SD, helicopter and drone aerial

**Table 1**
Details of shark bite mitigation measures trialled in the NSW Shark Management Strategy (refer to the NSW SharkSmart website for more information about the trials and results https://www.sharksmart.nsw.gov.au/technology-trials-and-research). Note. Strategy approach subheadings were sourced from [66].

| Strategy approach | Type of mitigation | Brief description of trials/research |
|---|---|---|
| In-water management | Shark mesh nets | – Nets were trialled together with SMART drumlines on the NSW north coast and the Newcastle to Sydney region to test and compare the effectiveness of both methods at intercepting target sharks, while minimising harm to other animals.<br>– Nets are currently used in the Shark Meshing (Bather Protection) Program (SMP) (since 1937), in which 51 beaches are netted in metropolitan areas (Newcastle, Sydney, Wollongong) each year between September and April (austral spring/summer).<br>– Nets are 150 m long and set 500 m from shore.<br>– Designed to intercept and remove target sharks at ocean beaches to reduce the chance of shark-human interactions.<br>– Checked every three days and live animals are released; any target sharks are tagged before release. |
| | SMART drumlines (SD) (shark-management-alert-in-real time) | – Trialled off numerous NSW ocean beaches to intercept target sharks (Whites, Bulls, Tigers).<br>– Designed to have minimal impact on sharks and other marine animals.<br>– Set in the morning (500 m offshore in 8–15 m of water) and retrieved every day; use a single hook baited with a fish (mullet).<br>– When an animal is caught, it is tagged and released about 1 km offshore.<br>– Effective fishing method for catching target sharks with minimal bycatch.<br>– Preliminary data shows, after tagging and release, sharks tend to move further offshore |
| | Clever Buoy™ | – Developed by Smart Marine Systems (formerly Shark Mitigation Systems) to use sonar technology and specialised video software to detect sharks and transmit critical information to beach authorities.<br>– Tested in collaboration with the University of Technology Sydney and Shark Mitigation Systems to evaluate if it could detect White sharks and estimate their length. This also included testing the range at which sharks could be detected.<br>– Trialled at Port Stephens in November 2016 for 13 days. The unit was installed around 800 m offshore, in about 9 m of water.<br>– Found to be unsuitable in its current form – no community attitudes data was collected for this technology. |
| | Eco Shark Barrier | |

(*continued on next page*)

**Table 1** (*continued*)

| Strategy approach | Type of mitigation | Brief description of trials/research |
|---|---|---|
| | | – NSW DPI aimed to trial two shark barriers in 2016 for three years to provide an enclosed shark-free area for Northern NSW beachgoers.<br>– As the barriers could not be installed effectively and safely, both trials were discontinued. |
| Technology and monitoring | Shark listening stations (VR4G) (detection, tracking) | – Satellite-linked receivers that detect the presence of tagged sharks within a 500 m radius of the device.<br>– Real-time notifications of detections are relayed to the public and beach authorities via Twitter and the SharkSmart app.<br>– Listening stations were trialled at 21 locations along the NSW coast. |
| | SharkSmart app (notifications, alerts) | – The app receives real-time notifications of sharks detected by aerial surveillance and tagged sharks detected by listening stations, and issues alerts to mobile devices installed with the app that can be used by the public and beach authorities.<br>– Also provides useful tips on reducing the risk of shark-human interactions, as well as information about different shark species. |
| | Personal shark deterrents | – Designed to reduce the chance of a shark interaction or bite to an individual; can be worn or attached to a board.<br>– Different types of devices including electric, magnetic, chemical and visual; designed to deter sharks.<br>– Independent research done by Flinders University, South Australia, (funded by SMS Annual Grants Program) tested the effectiveness of five commercially available devices developed for surfers in reducing the likelihood of an interaction with White Sharks [31]. |
| Aerial surveillance | Drone surveillance | – Drones were trialled in partnership with Surf Life Saving NSW to detect potentially dangerous sharks (any shark >2 m in length), and determine if drones can become part of standard beach safety equipment.<br>– Provide beach-based real-time aerial surveillance of coastal waters.<br>– Trialled at numerous locations, with a minimum of two flights per day.<br>– If a potentially dangerous shark is spotted within 100 m of water users, beach authorities will initiate beach evacuations.<br>– The public is notified of potentially dangerous sharks via the SharkSmart app and Twitter. |
| | Helicopter surveillance | – Helicopter surveillance has been operating in NSW metropolitan coastal waters since 2009 as part of the Shark Meshing (Bather Protection) Program.<br>– Since 2015, additional surveillance was trialled in six coastal regions during school holiday periods (austral spring/summer), in which helicopters fly over beaches twice a day: northbound in the early morning and southbound around midday.<br>– When a potentially dangerous shark is spotted close to water users, the helicopter reduces height to hover, activates a siren, and a loudspeaker is used to alert water users of the shark nearby.<br>– Sightings of potentially dangerous sharks are reported in real-time to the public and beach authorities (who may initiate beach evacuations) by Twitter and the SharkSmart app. |
| Education | Community education | – Education is an important element of the SMS to improve the public's awareness of sharks and how to minimise the chance of encountering sharks by avoiding risk factors.<br>– The "Be SharkSmart" initiative provides tips to reduce the risk of shark-human interactions, promoting personal responsibility.<br>– Education also aims to increase public awareness of the SMS and different mitigation measures trialled in the strategy, through community forums, meetings, drop-in stands, key events, school visits and social media posts. |

surveillance, and listening stations. Based on the findings of these trials, these technologies were trialled at other locations along the NSW coast. This further established the need for rigorously collected qualitative and quantitative social research data to explore and quantify community attitudes, support, and preferences for shark mitigation approaches trialled in the SMS. Various social research projects were done; comprising of DPI-led research (including commissioned projects), DPI co-investigator collaborative research, and independent research funded though the SMS Annual Competitive Grants Program (Appendix A).

Our aim was to review the new knowledge acquired during the SMS about community attitudes towards the different shark bite mitigation approaches tested and trialled in the SMS. Our primary objectives were to synthesise primary social research studies (qualitative and quantitative) conducted during the 5-year SMS and identify shark bite mitigation approaches supported and preferred by the community; and to provide a balanced community perspective to inform future shark policy and mitigation in NSW. The "community" population sampled in the studies comprised of NSW residents with a range of beach and ocean interests including recreational users, professional lifeguards, volunteer lifesavers, conservationists, and local tourism and business operators.

## 2. Methods

A research synthesis was undertaken to combine the findings of multiple primary social research studies (published articles and grey literature) done during the 5-year SMS (2015–2020), to produce a summary of overall findings of community attitudes, support and preferences for different types of shark mitigation approaches trialled in the SMS. The main advantage of a research synthesis is that it helps to

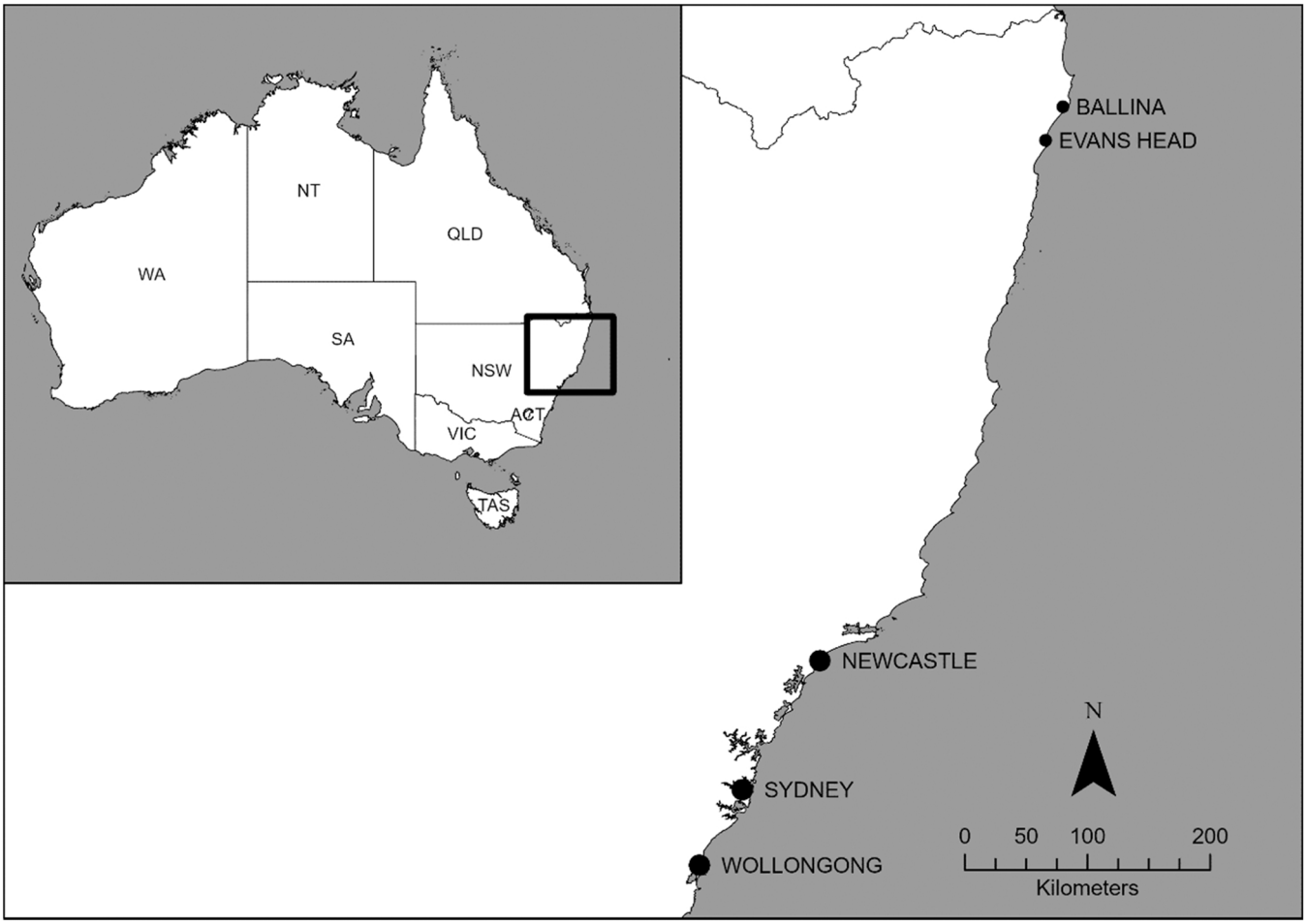


**Fig. 1.** Map showing locations of New South Wales north coast towns in relation to other major coastal cities: Newcastle, Sydney and Wollongong (i.e. metropolitan areas where the NSW Shark Meshing (Bather Protection) Program operates).

overcome the challenge of 'information overload' by distiling relevant evidence about a particular topic into a summary that can be used by policy-makers and decision-makers [77]. A research synthesis is an important part of the knowledge translation process and increases the accessibility and understanding of scientific information for use in evidence-based decision-making [29,69], and provides vital knowledge that can improve understanding of complex social-ecological issues such as human-shark conflict [6]. It also highlights knowledge gaps for future research agendas.

Only studies that specifically assessed community attitudes, support and/or preferences for shark mitigation approaches trialled in the SMS were selected for the synthesis. A total of nine studies were selected that comprised of DPI-led research (n = 5), DPI co-investigator in collaborative research (n = 2) and independent research funded by the SMS Annual Grants Program (n = 2) (Table 2). Individual social research studies varied in context, geographical coverage (in NSW), methodologies and target/sampled populations. The nine studies used a range of participatory research methods (qualitative and quantitative) that engaged people with various beach and ocean interests in NSW who are potentially impacted by shark bite incidents, with respect to either the incident itself and/or the government response to the incident. This included the general public, beach and ocean recreationists, lifeguards and volunteer lifesavers, conservationists and environmentalists, and tourism and business operators (Table B; refer to Appendix A for more details about these studies). Study methodologies were considered appropriate and robust for both qualitative and quantitative research. The nine studies had human research ethics approval through various Human Research Ethics Committees, in accordance with the Australian National Statement on Ethical Conduct in Human Research (2007).

## 3. Results

### 3.1. Shark nets

We assessed and monitored support for nets trialled in the SMS on the north coast using community surveys pre- and post-trials (2016, 2017, & 2018; refer to Appendix A). In the 2016 pre-trial survey, local residents generally had positive attitudes towards the trial, especially local surfers. This was attributed to perceptions that the risk of shark-human interactions was being actively addressed, increased feelings of safety, and the perceived positive impact on tourism and the local economy [44]. Conversely, residents in other regions had more negative attitudes, because of concerns about bycatch and mortality of marine animals, beliefs that nets provide a false sense of security (since they are only a partial barrier) and do not minimise shark-human interactions, and the notion that people enter the ocean at their own risk [44]. However, north coast residents' attitudes changed during the trials and by 2018 (post-second trial), residents had substantially more negative than positive attitudes about the effects of nets on themselves, family members and the wider community [44,46,61,66]. This was primarily driven by concerns about bycatch, which was apparent in focus group discussions on the north coast (see excerpt in Box 1 below).

Negative attitudes to nets were also evident among the broader NSW community. A 2016 social media analysis found sentiment for nets was three times more negative and hostile than positive compared to other shark mitigation approaches; extreme levels of negativity related to the

**Table 2**
Summary table of Shark Management Strategy-related social research studies (n = 9) selected for the research synthesis.

| Research type | Year | Purpose of Research | Methods | Community/Stakeholder Type |
|---|---|---|---|---|
| DPI-led research | 2016<br>2017<br>2018 | To monitor community attitudes before and after mesh net trials on the North Coast, to SMART drumlines and other types of mitigation approaches, and concern about the risk of harm from sharks | Quantitative survey research comprising:<br>• Random and representative telephone interviewing of North Coast residents<br>• Opt-in self-administered on-line questionnaire for the broader community to complete | General public including a range of beach and ocean users (e.g. surfers, swimmers, walkers, anglers, kayakers, divers, etc.) |
| | 2018 | To understand community attitudes towards the use of drone surveillance to increase protection of beachgoers | Quantitative survey research:<br>• Intercept survey of beachgoers | Range of beach and ocean users (i.e. surfers, swimmers, walkers, kayakers, etc.) |
| | 2020 | To quantify community support and preferences (state-wide) for shark mitigation measures trialled in the SMS | Quantitative research comprising:<br>• State-wide representative online survey of NSW general public<br>• Opt-in self-administered on-line survey | Range of beach and ocean users (i.e. surfers, swimmers, spear fishers, anglers, walkers, conservationists, tourism and business operators) |
| DPI co-investigator in collaborative research[a] | 2018 | To explore community perceptions and attitudes towards SMART drumlines in the context of other types of shark mitigation measures (post SMART drumline trials) | Qualitative research comprising:<br>• Focus group discussions at locations where SMART drumlines were trialled | Included people with a range of beach and ocean interests (i.e. swimmers, surfers, anglers, kayakers, tourism and business operators, conservationists, lifesavers) |
| | 2019 | To explore community perceptions and attitudes towards SMART drumlines (post SMART drumline trials | Qualitative research comprising:<br>• Focus group discussions at locations where SMART drumlines were trialled | Included people with a range of beach and ocean interests (i.e. swimmers, surfers, anglers, kayakers, tourism and business operators, conservationists, lifesavers) |
| Independent research (funded by Shark Management Strategy Annual Grants Program) | 2017 | To assess attitudes towards sharks and types of shark mitigation (lethal and non-lethal) | Qualitative research comprising:<br>• A social media sentiment analysis<br>• Focus groups discussions and/or personal interviews | Focus group/interview participants included people with a range of beach and ocean interests including surfers, anglers, lifesavers, swimmers, divers, tourism and business operators, conservationists, etc. |
| | 2020 | To identify variables that influence tolerance of shark-human interactions and attitudes to the acceptability of different approaches to management | Qualitative and quantitative methods:<br>• Social media sentiment analysis<br>• Focus group discussions<br>• Experimental survey to measure attitudes | Focus group participants and survey respondents included a range of people with beach and ocean interests (i.e. anglers, lifesavers, surfers, swimmers, kayakers, swimmers, divers, spear fishers, tourism and business operators, etc.) |

[a] DPI (NSW Department of Primary Industries); CSU (Charles Sturt University); IWLS (Institute for Water and Society, CSU)

**Box 1**
Excerpt from Ballina focus group discussion:

*"We've now had 90 innocent marine creatures die in our net trial over the last four months, with the last report that just came out yesterday. When you tally them all up, that's a lot of animals that are all, most species that are protected under the EPBC Act. There's sea turtles, dolphins, all of these creatures that have nothing to do with sharks. Well, they do, because they live in the same environment, but these creatures are swimming into the nets and dying, and the target species are not being caught. They've only had six target species over four months. So it's just not working, it's a failure."*

Source: Simmons et al. [63] (p. 40)

indiscriminate killing capacity of nets [63]. Negative attitudes also resonated in focus groups in which participants with different beach and ocean interests (including surfers, lifeguards, tourism business owners/operators, swimmers, conservationists, anglers) discussed SD in the context of other mitigation approaches trialled throughout NSW [65,66]. Lack of support for nets is primarily due to socially unacceptable levels of bycatch and mortality, ineffectiveness at catching target sharks, and for providing a false sense of security. Nets are generally viewed as a waste of resources; considered 'old out-dated technology' that should be consigned to the past and replaced with newer technologies. Indeed, some focus group participants were optimistic the government may eventually replace nets with new technologies trialled in the SMS; they did not see mesh nets as a viable option for the future [61,65,66].

Community survey findings (from 2017 to 2020) also demonstrated nets had the least level of support (9–41%) compared to other mitigation measures (31–96%) (Fig. 2). However, support was greater among Ballina and Evans Head residents (in 2017 and 2018; 32–41%) who were most impacted by shark bite in recent years, compared to residents in other areas (Fig. 2) [18,44,46,48]. Similarly, there was more support for nets by respondents in the 2020 SMS state-wide representative survey (37%) (Fig. 2), of which 25% indicated moderate or strong support for nets. This was despite being aware that nets are a partial barrier (i.e. 150 m in length) and the poor efficacy of nets for catching target shark (including bycatch and mortality). Support for nets was greater among

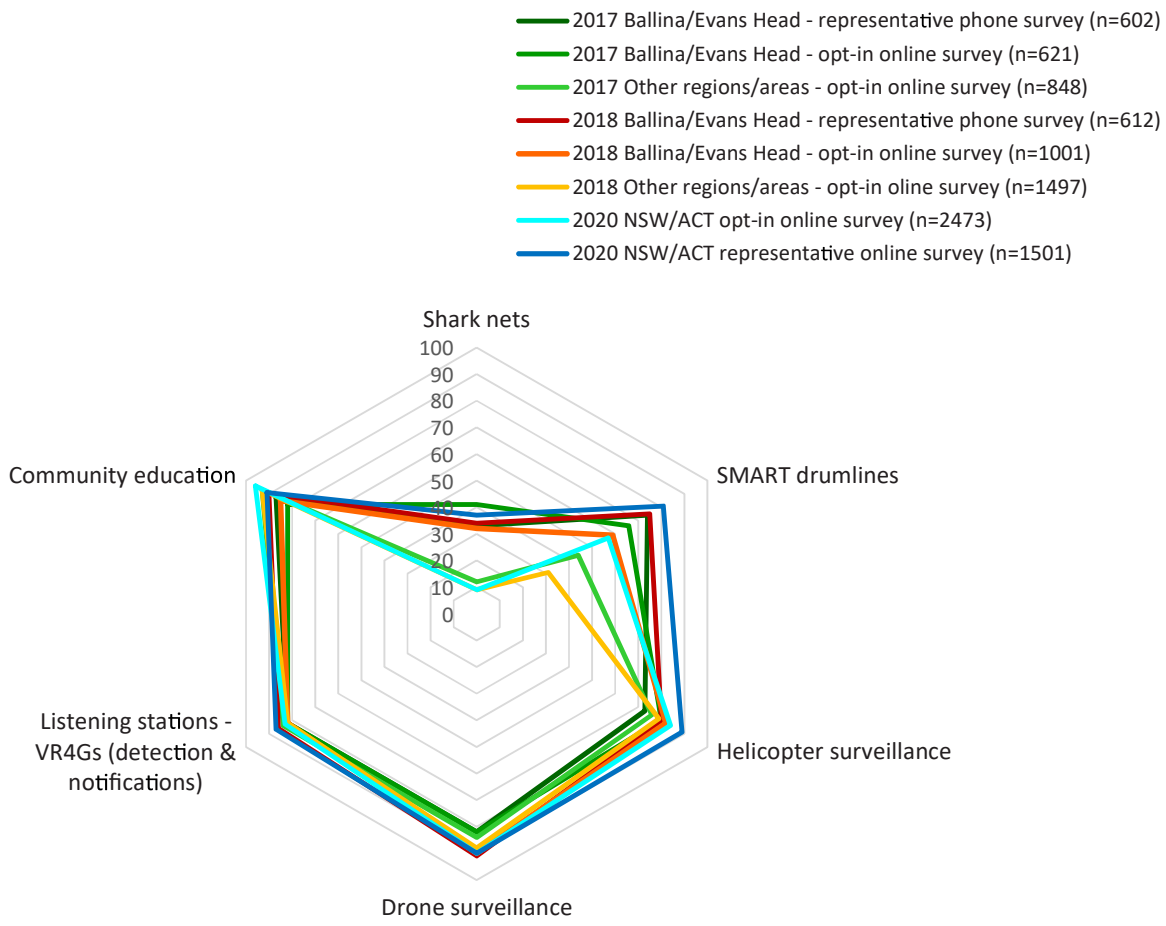


**Fig. 2.** Respondents' levels of support (%) in online and telephone community surveys (2017–2020) for different shark bite mitigation approaches trialled in the NSW Shark Management Strategy (refer to Appendix A for further details).

older people, males, and residents with young children, and those who viewed sharks as a medium or high threat and/or were very or extremely concerned about encountering sharks [18,48].

Nevertheless, while there is some support for the use of nets, they were the least preferred mitigation approach in the SMS state-wide community survey (Table 3). This trend was also evident across regions and by respondents who undertook different water activities (i.e. surfing/body boarding, body surfing, nearshore and ocean swimming, diving/snorkelling, boat-based activities, recreational spearfishing, and other board-based water activities) [18,48,64]. Survey respondents who selected nets as their most preferred option, believed that nets were an effective historically-proven mitigation approach that increased their 'feelings of safety'. In particular, nets are believed to be beneficial for local tourism and economies [18,48,66] (Box 2).

**Table 3**
Table of ranked preferred shark bite mitigation approaches trialled in the NSW Shark Management Strategy to increase protection of beachgoers at patrolled ocean beaches in NSW (Note: data obtained from 2020 DPI Shark Management Strategy state-wide community survey [18,48].

| Mitigation measures | State-wide representative online survey (n = 1501) | | Opt-in online survey (n = 2473) | |
|---|---|---|---|---|
| | Rank | % Score | Rank | % Score |
| Drone surveillance | ❶ | **57** | ❷ | **64** |
| Helicopter surveillance | ❷ | **45** | ④ | 41 |
| Listening stations (VR4Gs) | ❸ | **43** | ❸ | **54** |
| SMART drumlines | ④ | 41 | ⑤ | 34 |
| Community education | ⑤ | 40 | ❶ | **66** |
| Personal deterrents | ⑥ | 28 | ⑥ | 19 |
| Shark nets | ⑦ | 13 | ⑦ | 5 |

### 3.2. SMART drumlines (SD)

Qualitative and quantitative social research findings revealed attitudes towards SD varied. A valued feature of SD was that sharks could be tagged prior to release, contributing to research to improve knowledge of shark movement and behaviour, and aid the effectiveness of shark listening stations (VR4Gs). They were particularly valued on the NSW north coast as they are more effective than nets at catching and removing target sharks close to beaches, which equates to reducing the chance of an interaction, with minimal bycatch and mortality. It was also perceived that sharks caught, tagged, and relocated on SD, were deterred from returning to the area [63,65]. Negative attitudes to SD were mainly driven by concerns that baited hooks may attract sharks and some people were reluctant to swim or surf in the water near SD. While SD were generally considered a better option than nets for minimising harm to sharks and other species, they were largely perceived as an ineffective mitigation tool since sharks are released and can return [61,65]. Other than the NSW north coast, most NSW regions did not feel there was a need for shark mitigation using SD as sharks were not perceived to be issue. Especially on the NSW south coast, where there were concerns about the welfare of sharks during the tagging/relocation process, and where SD trials were perceived to heighten anxiety about sharks in the community and among visitors/tourists [61,65].

While support for SD was generally greater than for nets, support for SD was less than for other non-invasive/non-lethal mitigation approaches (Fig. 2). However, support varied across regions, with the NSW north coast community more supportive of SD. Overall, SD were ranked

**Box 2**
Examples of reasons stated by survey respondents for selecting nets as their most preferred option:.

*"Fear destroys enjoyment of the water, and netting of some beaches only would be a tourism draw to those beaches."*

*"It's a proven method for preventing shark attacks on beaches. Has worked on Sydney beaches for close to 100 years to great effect. I am not sure other methods are able to meet this success rate."*

*"We have had nets for as long as I can remember. They have kept me safe so far."*

Source: NSW Department of Primary Industries [48]

fourth or fifth (out of seven) as a preferred mitigation measure (Table 3), but ranking position varied across regions. SMART drumlines were in the top three preferred mitigation measures for seven of 12 regions, inferring this mitigation measure was more highly valued in certain locations. Reasons for respondents selecting SD as a preferred mitigation measure were primarily due to functional benefits, such as the accurate targeted removal of sharks close to beaches. Overall, SD were seen as a better alternative to nets [18,48,62,63,65,66] (Box 3).

### 3.3. Aerial surveillance (drones and helicopters)

Aerial surveillance using helicopters has been operating in NSW metropolitan coastal waters since 2009, as part of the SMP. During 2015–2019, helicopter shark surveillance was trialled in six coastal regions during school holidays. Drones for aerial surveillance were trialled in partnership with Surf Life Saving NSW (SLS) to assess their technical capabilities for shark spotting. Automatic real-time alerts of sharks detected by aerial surveillance are communicated to the public via the SharkSmart app and Twitter account. Social research findings showed unanimous support for aerial shark surveillance as a mitigation measure due to the non-invasive nature of the technology; considered a better alternative to nets [18,48]. However, it was recognised its effectiveness was reliant on good weather and clear water conditions. Community surveys showed strong support for both helicopter and drone surveillance trialled in the SMS (73–91% and 82–96% respectively) (Fig. 2). In particular, respondents in the 2020 state-wide representative and interstate-visitor survey were very supportive of both drone surveillance (90–96%) and helicopter surveillance (89–91%) (Fig. 2). There were no significant drivers of support for drone surveillance. However, support for helicopter surveillance was significantly stronger among males, those aged $\geq 65$ years, those slightly to moderately concerned about encountering sharks, and those who perceived sharks to be a medium to high threat [18,48]. Despite strong support for both aerial surveillance methods, drone surveillance was ranked as the most preferred mitigation measure by respondents in the SMS state-wide representative survey, and in the top two preferred measures by respondents in the opt-in survey (Table 3) [18,48,64]. This trend was also evident across regions and respondents who engaged in key water activities (i.e. surfing/body boarding, ocean and nearshore swimming, and diving/snorkelling). For instance, drone surveillance was ranked above helicopter surveillance, either as the most preferred, or second most preferred mitigation measure for 10 out of 12 regions [18,48].

Whilst there was general support for helicopter surveillance to survey long tracks of coastline including remote beaches, and to alert water users to sharks (especially surfers) and herd sharks away, it was often dismissed as being too expensive compared to drones. Further, helicopters were seen as being less effective than drones due to the limited time spent over a beach, resulting in limited surveillance at any one location. Also, they were considered by some to contribute to local air and noise pollution [61,65,66]. Drone surveillance was preferred over helicopters as they are localised, less audibly intrusive, more cost-effective, and environmentally friendly, with increased flying frequency and the capacity to be incorporated into beach safety operations at patrolled beaches [45,61,65,66]. Additionally, beachgoers on the north coast stated they would feel safer from sharks with drone surveillance rather than helicopter surveillance (38% versus 9%); especially swimmers (19% versus 3%) and surfers (12% versus 3%) [45]. Drones are perceived to be the future for detecting sharks and other beach hazards due to advances in sensory technology and artificial intelligence likely resulting in autonomous flight [66]. There were some concerns relating to the potential for human error, or the malfunction of drones, causing injury to beachgoers, and concerns about privacy and the potential for misuse by drone operators [45] (Box 4).

### 3.4. Listening stations (detection and notifications including the SharkSmart app and Twitter account)

Community surveys (2017–2020) showed consistent levels of support (82–89%) for listening stations (Fig. 2). In the 2020 community survey, the combination of listening stations and SharkSmart app and Twitter account was ranked as the third most preferred shark mitigation measure trialled in the SMS (Table 3). Regionally, they were ranked in the top three preferred measures for six out of 12 regions, and in fourth position for five out of 12 regions. Similarly, they were ranked in the top three preferred mitigation measures by respondents who undertook key water activities, including surfing/body boarding, swimming (ocean and nearshore), and diving/snorkelling [18,48]. Listening stations were valued by the community for functional benefits such as the capacity to accurately detect, track, and monitor tagged sharks, cost effectiveness, the provision of real-time alerts, minimising harm to sharks, and improving knowledge about sharks [18,48,66]. However, their effectiveness as a shark mitigation tool was criticised due to the limited

**Box 3**
Examples of reasons stated by survey respondents for selecting SMART drumlines as their most preferred option:.

*"Because the drumlines actively target sharks near beaches frequently used by humans, and discourage them from returning to the drumline area - also by tagging them there is more information available for subsequent tracking."*

*"Effective for removal of threat posed by sharks and little impact on oceanic wildlife."*

Source: NSW Department of Primary Industries [48]

**Box 4**
Examples of reasons stated by survey respondents for selecting aerial surveillance (drones or helicopters) as their most preferred option:.

**DRONES**

*"Given that each beach can run its own patrols, it allows for a better response time."*

*"Drone technology would be cheaper and use less energy than helicopter surveillance. It would also be more frequent and provide greater coverage."*

*"Because it does not cause death to animals, and can be done without putting anyone in danger and is less costly than a helicopter."*

**HELICOPTERS**

*"A very effective method, I feel safe when the helicopter flies over, it has spotted so many sharks and potentially saved many lives."*

*"Because the helicopters can cover a lot of area and stay around a lot longer - giving real time warning of sharks and where they actually are."*

*"Doesn't harm sharks. Alerts people to the shark's presence and is effective in moving the shark away without harming it."*

Source: NSW Department of Primary Industries [48]

number of listening stations along the coastline, small number of tagged sharks, reliance on a tagging programme, the impossibility of tagging all target sharks in the ocean, and the limited lifespan of tag batteries preventing long-term monitoring/tracking of tagged sharks [66].

Support for listening stations and the SharkSmart app largely depended on the role of the user. Those with a responsibility for public safety, such as lifeguards, SLS NSW volunteers and water-based tourism operators, favoured the technologies for instant real-time notifications that aid in managing the safety of beachgoers or clients [65]. However, attitudes towards the SharkSmart app were mixed. Some people felt the app was good for issuing alerts that help people take responsibility for their own safety in deciding when and where to enter the water. Conversely, others criticised the app for multiple alerts that were perceived to heighten fear in the community and among visitors/tourists [65]. In particular, surfers felt the technologies were of no use to them in the water, and it was suggested listening stations be fitted with lights/sound to alert nearby water users when a shark is detected [65]. Many said they had abandoned the app due to over-frequent alerts that continually reminded them of the risk of sharks, when previously they had not been concerned. Indeed, some surfers said alerts had changed their behaviour and stopped them from entering the water to surf, or they had decided to surf elsewhere. There was also concern that the alerts did not specify the tag number of the detected shark, meaning the app user was unable to determine if it was one shark staying in the vicinity of the listening station, or multiple sharks swimming straight past. Nonetheless, there was consensus that the technologies had a role to play in managing the safety of beachgoers and helping people take personal responsibility for their safety [66] (Box 5).

### 3.5. Personal shark deterrents

Personal shark deterrents are devices designed to reduce the chance of a shark interaction or bite to an individual. There are different types of devices (electric, magnetic, chemical, and visual) designed to deter sharks. Whilst community survey results indicated relatively strong support for the use of personal deterrents to mitigate the risk of shark bite (67–80%) (Fig. 2) [18,48], they were ranked below all other types of mitigation; except for nets (Table 3). This trend was also apparent across regions and key water activities. Reasons for people selecting personal deterrents as a preferred mitigation measure were largely driven by perceived safety benefits, and the desire to minimise harm to sharks and other animals. However, community opinions and attitudes to personal deterrents were divided. Many people were sceptical about the effectiveness of devices and not many people trusted them. Some believed that the 'better devices' were too expensive. Further, there was speculation they could provide a false sense of security causing water users to become more incautious by ignoring danger signs and making poor decisions. Also, it was suggested that electrical devices could potentially attract sharks, increasing the risk of harm to nearby surfers [66]. Further, there were some ethical concerns regarding the use of electrical devices to shock and repel sharks [66]. Despite uncertainties, lack of confidence and trust in the devices, there was general consensus that personal deterrents can help individuals take responsibility for their safety, especially surfers who are most at risk of shark bite [18,48,63,66]. There was strong support for further investment and research into the development of personal deterrents [63].

Despite relatively strong support for personal deterrents as a mitigation measure, most survey respondents indicated they would probably not, or definitely not, consider purchasing a device for themselves and/or family member(s) (40–51%); whilst around a third indicated they probably would/definitely would. The likelihood of purchasing a device appears to be driven by fear. Those who perceived sharks as a high threat and/or were very or extremely concerned about encountering sharks, as well as those who engaged in more riskier water activities (i.e. ocean swimming, diving/snorkelling, and surfing/bodyboarding), were more likely to consider purchasing a device. This infers personal deterrents may help certain people feel safer or more confident in the water [18,48]. Nonetheless, there was relatively strong support for a

**Box 5**
Examples of reasons stated by survey respondents for selecting listening stations/SharkSmart app as their most preferred option:.

*"Alerts people to tagged sharks, but does no harm to sharks or other animals."*

*"Good to track sharks and alert people and authorities when in the local area."*

*"Helps people make an informed decision about being in the water. Operates all year. Is passive without any impacts to sea life."*

Source: NSW Department of Primary Industries [48]

government rebate (64–77%) to help cover the costs of individuals purchasing a scientifically proven device; although some felt this would be a waste of public funds [48,66]. Again, support for a rebate was driven by fear, with those who perceived sharks to be a medium to high threat, and/or were very or extremely concerned about encountering sharks being more supportive of a rebate; although there was no real consensus on the ideal amount of a rebate [18,48] (Box 6).

### 3.6. Community education

There was consistent positive community attitudes and strong support for education, which was considered important to promote behaviour to reduce the risk of encountering sharks, improve public knowledge about the important ecological role of sharks as apex predators, combat negative media reporting about sharks, and to mitigate fear of sharks through delivery of factual/scientific information. Overall, community education was seen as a fundamental element of shark mitigation to encourage and enable people to take personal responsibility for their safety [63,65,66]. Also, it was recognised that education needs to be targeted to specific beach/ocean user groups such as children, visitors and international tourists, inland and urban residents [39,61].

Community survey findings demonstrated very strong support for education promoting personal responsibility (82–96%) (Fig. 2); however, levels of support varied among respondents. Males, and those who perceived sharks to be a medium to high threat, were more likely to oppose education as a mitigation measure, or take a neutral stance. Conversely, females and those who perceived sharks to be a low threat, or were not at all concerned about sharks, were more supportive of community education [48]. Whilst community education was ranked as the most preferred mitigation approach by respondents in the 2020 SMS opt-in survey, it was ranked in fifth position overall as a preferred mitigation approach in the state-wide representative survey (Table 3). This was despite respondents indicating strong support for education as a mitigation approach (91%) [18,48]. Similar trends were evident across regions and for key water activities undertaken by respondents [18,48]. Reasons for selecting community education as the most preferred mitigation approach were largely based on behavioural and attitudinal benefits that education can cultivate. Education was also highly favoured for being non-invasive, non-lethal, ethical and humane, and cost effective; and a good education strategy can have enduring broadscale effects [18,48]. These findings are consistent with a SMS-related study by Simmons et al. [64] that found very strong support for education, to both help people take responsibility for their own safety and raise awareness of the important ecological role of sharks, as well as research to improve knowledge of how to avoid risk of harm from sharks (Box 7).

## 4. Discussion

Assessments of the NSW community attitudes towards shark mitigation approaches during the 5-year SMS have employed a range of methods and instruments, from focus groups to random telephone surveys. They all provide a consistent state-wide view that community preference is for non-invasive shark mitigation approaches involving detection, tracking, and notifications. Invasive and/or lethal approaches, such as bather protection nets, were the least supported and preferred mitigation approach. Drone surveillance was very highly supported (and preferred over helicopters). Drone operations are beach-based, can be part of broader beach safety operations, and there is potential for automation with advancements in technology and artificial intelligence. SMART drumlines were preferred over nets for effective targeted capture and relocation of target sharks with minimal bycatch and mortality. They were also valued for tagging and research purposes. Alongside surveillance, community education was seen as a fundamental component of shark mitigation to help people increase their ability to take personal responsibility for their own safety, improve public knowledge and understanding of sharks, and to mitigate fear; ultimately, to foster coexistence without jeopardising public safety.

There was substantial opposition to shark nets, and only 9–37% of people in the opt-in and representative survey supported the use of nets for shark mitigation. Nets were supported by people who appear to be more tolerant of bycatch and mortality issues, or they have firmly held beliefs, even in the face of evidence that contradicts the belief [19,74]. Fear can bias processing of information in a way that justifies existing beliefs. Similar research by Gray and Gray [25] found beachgoers at two Sydney beaches (Bondi and Cronulla) were very supportive of nets for shark mitigation, despite little understanding of how nets work. Many people believe nets are effective at deterring sharks and reducing 'attacks' possibly because of the long-term use of nets (>80 years in the Sydney region [25]. This might also explain why older people tend to be more supportive of nets since they are more familiar with this method. Alternatively, it may say something about the trust those respondents had in successive governments, fear-driven media that was supportive of nets, and the historical messaging around shark nets, which focused on reduced fatalities over time and was silent on the numerous shark bites at meshed beaches [13].

It has been hypothesised that beach patrols, established around the same time as the SMP was introduced, may be responsible for reducing shark hazards; rather than nets of the SMP [22]. This is further supported by the Shark Spotters Program in South Africa, a surveillance programme, which has contributed to reduced shark-human interactions [17]. Further, Gibbs et al. [22] and Dalton et al. [13] reported that there were 24 and 34 (respectively) unprovoked shark bites and one fatality at meshed beaches during the time the SMP has been operating (>80 years). This finding is consistent with perceptions that nets do not prevent shark bites; thus, nets are not guaranteed to prevent shark-human interactions [47]. Rapid medical response and advances in first aid and trauma treatment, may also help to explain reduced fatalities from shark bites [35,58].

Another key reason stated by those who preferred nets over other mitigation approaches was the perceived emotional benefits related to increased 'feelings of safety'. In particular, tourism business owners/operators believed nets helped visitors and tourists feel safer, which was seen as beneficial for local tourism and economies [18,48,66]. Many

**Box 6**
Examples of reasons stated by survey respondents for selecting personal shark deterrents as their most preferred option:.

*"It seems to me to be the best way to protect yourself from shark attack anywhere at any time."*

*"Many attacks are on surfers so they should increase their personal responsibility in the same way that people reduce driving risks with seatbelts and airbags. Humans do not have a monopoly on the ocean and need to respect the rights of sharks to exist."*

*"Take responsibility for you own actions. Personal deterrents can be used anywhere, not just a section of beaches near town. I already use one and I know it works. This technology will only get better."*

Source: NSW Department of Primary Industries [48]

**Box 7**
Examples of reasons stated by survey respondents for selecting community education as most preferred option:.

*"A better understanding of shark behaviour and appreciation of their important role in the marine ecosystem (as well as the threatened status of many sharks) is very valuable in ensuring people understand how to minimise risk, at the same time as preventing sharks from being unnecessarily harmed."*

*"Because it educates both about safety and also opens the door to people to learn about sharks and care for the ocean."*

*"Community education programs have the potential to reach more people and make them aware of danger signs that indicate the presence of a shark. It is relatively low cost and potentially has the greatest impact on the broader community, not just regular beach goers."*

Source: NSW Department of Primary Industries [48]

Australian and international visitors/tourists support the use of nets [25], and we infer that nets may indeed help promote a sense of safety (albeit a placebo effect). However, beachgoers do not necessarily select beaches based on the presence of shark mitigation measures [11]. Concern about encountering sharks was not a key factor for visitors deciding to engage in water activities at ocean beaches. For example, visitors to Ballina preferred easy access to patrolled beaches and the presence of beach amenities [15]. Furthermore, beachgoers in NSW expressed more concern about the risk of getting sunburn or stung by jellyfish than being 'attacked' by sharks [11]. Clearly, there are some divided opinions in the broader community about the use of nets. Therefore, more research is required to better understand the beliefs of those who support nets, community/visitor demand for nets at SMP beaches in NSW, and the social consequences of removing nets in favour of less-invasive community-preferred options.

There was very strong support for the use of drone surveillance for shark mitigation, which aligns with findings of a similar study on beachgoer attitudes to drone shark surveillance [68]. Drones have substantial potential in effectively detecting and monitoring ocean wildlife, and their efficacy is demonstrated in various studies [9,30,32,53,59]. While drones can fly under most environmental conditions, poor water visibility limits aerial detection of marine wildlife; however, sharks spend a lot of time near the surface and can be detected by drones [5]. Drones are effective for localised detection and tracking of White Sharks along coastal beaches, where they are typically observed behind the surf break parallel to the shoreline [10]. Overall, drones are a useful, non-invasive mitigation tool for localised patrolling of beaches and surf zones, to increase protection of beachgoers (especially surfers) from potential encounters with sharks. However, surfers can have lower confidence in the efficacy of drones as a shark mitigation tool compared to other beach and ocean users [68].

There are some concerns about the use of drones at beaches, due to loss of privacy, the potential for operator misuse, and the malfunction of drones and/or operator error causing injury to beachgoers, which is consistent with findings of similar research on drone surveillance at beaches by Stokes et al. [68] and Shekari [60]. However, fully trained drone pilots and comprehensive operating protocols reduces this risk. Privacy concerns are legitimate and privately-operated drones have been misused [20]. This risk is reduced by drones being operated by trusted organisations such as Surf Life Saving associations. The public are more likely to accept the use of drone surveillance at beaches if there is public trust in the operational and ethical use of drones [43]. Drone shark surveillance trials in the SMS were done in partnership with Surf Lifesaving NSW (SLSNSW), a volunteer organisation that has a long association with public beach safety in Australia [70]. One of their subsidiaries, the Australian Lifeguard Service NSW (ALSNSW), also has decades of experience providing professional lifeguard services in Australia [3]. There are also independent professional lifeguards that are contracted by coastal local government authorities for beach safety during weekdays that cannot be covered by volunteers. Drone operators in the aforementioned organisations undergo professional training. Volunteer lifesavers and professional lifeguards are trusted and often part of the local community, and beach surveillance drones operated by SLSNSW, ALSNSW, and other beach safety authorities are likely to foster public trust in the ethical use of drones for beach safety purposes, including shark detection at NSW beaches.

Community education is vital to help people make informed decisions about their safety by avoiding risk factors. Education can improve public knowledge and understanding of sharks that will help mitigate fear, promote coexistence, and support for shark conservation [50]. Community education can play a role in changing attitudes towards sharks, improving support for shark conservation, mitigating fear propagated by sensationalised media reporting, encouraging beach/ocean users to accept the risk of ocean use and risk factors to avoid, to minimise risk of shark encounters [1,24,49–51]. To be effective, educational approaches should be tailored to specific beach and ocean users who have different values, beliefs, knowledge levels, interests, and relationships with the ocean [50].

Prior to developing education initiatives, a thorough analysis of each community is necessary to identify any social conflicts related to sharks (often referred to as human-wildlife conflict). Deep-rooted social conflicts need to be analysed and addressed as they can threaten the identity, wellbeing, and security of many in the community, which can impact on support for education initiatives and longevity of mitigation [14,37]. Before commencing any education strategies/campaigns using persuasive communication, it is vital that audience research be undertaken to determine how to tailor materials for the general public and specific beach/ocean user groups (e.g. surfers, swimmers, divers, spear fishers, etc). Otherwise, audiences may ignore the information [36], or react negatively and protest against Government strategies. This strategy includes researching emotions and beliefs of audiences since emotions influence beliefs. Many beliefs are not based on direct experiences or personal observations, and some beliefs are firmly held even in the face of weak evidence that contradicts the belief. A person with a fixed belief may accept information as credible that is otherwise doubtful to others [19,74]. It is crucial that audience-relevant messaging is developed to foster attitude and behaviour change [38].

Care should be taken to ensure conservation-focused narratives do not disregard legitimate concerns held by people residing in areas of relatively higher rates of shark bite (e.g. NSW north coast), as this may create a disconnect between authorities and the public [72]. For instance, campaigns that devalue shark fears based on statistical rarity may be less effective on those who live in areas where shark bite is perceived to be more likely (based on past incidents). Separating the public into the "enlightened and unenlightened" can also lead to disconnects between public response and scientific consensus, in which individuals further entrench themselves in their beliefs (as seen in the climate change debate) [72]. Thus, disconnects between authorities and the public may cause additional problems in implementing educational campaigns to improve public knowledge about sharks and support for their conservation [72].

When developing educational material to communicate advice about potential indicators of an increased likelihood of encountering sharks, it is crucial that information is perceived as credible [55]. Credibility

affects the way people process information and how they subsequently perceive risk [73], and how they respond to the information. For example, a recent study by McClean et al. [39] found beachgoers on the NSW north coast contested the Government's advice "to avoid swimming and surfing at dawn or dusk", because shark incidents (including fatalities) have occurred during the day. Other risk factors recommended by the Government to avoid, relating to environmental conditions (e.g. avoid swimming/surfing in murky water, in river/harbour mouths) were also questioned since shark-human incidents have occurred in clear water. For many, this undermined and continues to undermine the Government's credibility in provision of information about risk factors to avoid; being generic rather than specific. Overall, Government advice about certain risk factors to avoid caused distrust in the community who preferred to rely on local knowledge and experience shared through local social networks [39].

## 5. Conclusions

Our study brings together the findings of multiple SMS-related qualitative and quantitative social research to provide a knowledge synthesis to inform shark mitigation policy and mitigation strategies, not just for NSW, but nationally and globally. The synthesis makes a major contribution to our knowledge of complex social-ecological issues such as human-shark conflict. This evidence-based balanced perspective shows non-invasive mitigation approaches (especially drone surveillance) are preferred over more invasive and lethal approaches, such as shark nets. However, there is still some support for the use of shark nets, demonstrating divided opinions and/or understanding of shark mitigation technology in the broader community.

Further research is required to better understand the beliefs of those who support nets, community and visitor demand for nets at SMP beaches in NSW, and the social consequences of removing nets in favour of less-invasive community-preferred options. This research will assist in addressing potential social conflict and backlash from certain sectors of the community and media that may be strong supporters of nets. Broader stakeholder groups with roles in beach safety and risk management should also be included in future research, such as local government authorities that provide a range of beach services including paid lifeguards, signage and school education programmes.

Education offers a power vehicle to improve public knowledge of sharks, shark conservation, and public attitudes towards sharks, and to promote personal responsibility and options for mitigating risk of shark-human interactions while minimising harm to the marine environment. Audience research is crucial to determine how to tailor education approaches and materials for the general public and specific beach and ocean user groups. Following this audience research, applying a framework of planning, implementation and evaluation is essential to ensure the efficacy of educational programmes/campaigns. Scientific information provided must be seen as independent, robust, defendable, and credible.

## CRediT authorship contribution statement

**Carol Martin**: Conceptualization, Project administration, Methodology, Investigation, Formal analysis, Visualization, Writing – original draft. **Belinda Curley**: Conceptualization, Resources, Writing – review & editing. **Kim Wolfenden**: Conceptualization, Resources, Writing – review & editing. **Marcel Green**: Writing – review & editing. **Natalie Moltschaniwskyj**: Writing – review & editing.

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*Declarations of interest*

None.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2022.105079.

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