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Second NSW north coast shark-meshing trial

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Second NSW north coast shark-meshing trial

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Objectives

A Management Plan was drafted for the second trial and is available at https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0017/740411/Management-Plan-for-Second-Shark-Meshing-Trial-Nov17.pdf. Within a broader directive of reducing rates of unprovoked shark–human interactions, the stated purposes of the second trial were to:

- deploy nets and various devices at coastal beaches and tidal waters in the trial area under the direction of highly qualified NSW Department of Primary Industries (DPI) staff;
- minimise the impacts of the shark management measure on fauna;
- collate, analyse and report on data collected during the trial; and
- inform continuous improvement in protecting swimmers from shark bites and complement the NSW Shark Management Strategy, which included trials of emerging technologies.

The specific research objectives were to:

- compare the use of nets with SMART drumlines, in terms of their effectiveness at catching target sharks while minimising the impacts on other fauna;
- test new devices and procedures which might deter marine animals other than target sharks from approaching or becoming entangled in the nets, and also of new devices which might alert researchers in real time when an animal is caught in the nets; and
- monitor the level of acceptance of the local community to the presence and operation of the nets during the trial.

Key words

Second shark-meshing trial; shark mitigation; shark nets; SMART drumlines; community engagement

Summary

Background

Historically, the New South Wales (NSW) Government has proactively initiated various strategies to mitigate the risk of shark–human interactions. For more than a century, permanent swimming enclosures have been a feature in some estuaries and at ocean beaches, along with fixed-location towers for lifeguards and, in recent decades, aerial surveillance to inform authorities about the proximity of sharks to beaches. In 1937, bottom-set gillnets or ‘mesh-nets’ (hereafter ‘nets’ measuring 150 m long × 6 m deep and comprising 600 mm stretched mesh opening [SMO]) were introduced off 18 Sydney beaches as a lethal measure to target virtually all species of sharks. The nets currently are anchored off 51 beaches between Wollongong and Newcastle from 1 September to 30 April each year in what is collectively termed the ‘shark-meshing program’ (SMP).

The SMP has been deemed an effective strategy, measured by relatively fewer total shark–human interactions at netted than pre-netted or un-netted beaches, including a reduction from 13 fatalities in the three decades before meshing to a single fatality (in 1951) in the following eight decades. Similar conclusions about the effectiveness of nets for mitigating shark–human interactions have been made in the only two other jurisdictions where they have been regularly fished: Queensland and South Africa. However the nets fished in Queensland have always been complemented by baited hook (single or double) configurations (termed ‘drumlines’), which were also introduced off South Africa in 2007.

Nets (and conventional drumlines) are effective at depleting local populations of various sharks, but they have an additional ecological cost measured as the mortality of non-target animals (termed bycatch), which includes individuals between ~1 and 4 m of most species inhabiting the fished areas. Recognition of the ecological costs associated with using fishing gears to minimise shark–human interactions have resulted in attempts at modifying their operation, and mostly with a focus on drumlines, because unlike nets, the more selective catching mechanisms of baited hooks (i.e. one animal at a time) facilitates adaptations to minimise unwanted mortalities. In particular, researchers from Réunion Island recently developed an electronic monitoring system whereby a hooked animal triggers an alarm that allows rapid attendance, termed ‘shark management alert in real time’ (SMART) drumlines. Owing to the short time between when an animal is hooked and retrieved, many remain alive and can be removed from the area and released. Doing so is thought to mitigate the risk of shark–human interactions; a concept supported by research done off northern Brazil over the past decade.

Following a cluster of shark–human interactions off northern NSW, a decision was made to deploy and compare conventional nets (the same as those fished in the SMP) and SMART drumlines during a first ‘NSW north coast shark-meshing trial’ between 8 December, 2016 and 30 May, 2017. The trial was approved under state legislation and exempted from Commonwealth approval, subject to compliance with a Management Plan and was preceded by, and followed with, community consultation (NSW DPI, 2017).

Based on substantial data collected during the first trial, nine recommendations were made; a key theme among many was developing operational and technical modifications to nets that reduce bycatch while maintaining effectiveness for the three target sharks, and to further investigate the relative utility of SMART drumlines within a strategy for minimising shark–human interactions involving fishing gears. A second trial was subsequently approved.

The second NSW north coast shark-meshing trial

The second trial occurred between 23 November, 2017 and 2 May, 2018 at the same locations as the first and followed a similar approvals process. Like for the first trial, a community survey was undertaken (in the last month) as required by the Management Plan.

Operational and technical changes to the nets approved for testing during the second trial included altering the: (1) checking frequency (from twice daily to once every 12–52 h); (2) vertical fishing height (conventional midwater- vs shallow-set); (3) mesh size (conventional 600- vs 800-mm SMO); and (4) twine material (conventional polyethylene [PE] vs polyamide [PA]). Irrespective of the modifications, all nets measured 150 m long by either 6 m (off Ballina) or 4 m (Evans Head) deep, and were rigged with acoustic deterrents to mitigate catches of marine mammals. Concurrent with the net deployment was the daily daytime deployment and retrieval of 30 SMART drumlines: 15 interspersed among the nets off Ballina and Lennox Head; and 15 around the net at Evans Head.

During each day of the trial, NSW DPI scientific observers accompanied the net contractor and collected environmental, biological and technical data describing operational and catch characteristics. SMART drumline contractors collected similar data for their catches. All nets were deployed for 148 days and nights (each 3,539–3,573 h), and the SMART drumlines were deployed for 101 to 104 days (each 866–951 h). Nets and SMART drumlines were removed or not deployed during adverse weather.

The Management Plan stipulated the net contractor was required to check the nets within 12–52 h of the previous check and this criterion was satisfied for 392 out of a total 423 checks (93%); representing an improvement on the first trial when only 64% of scheduled checks were achieved. By comparison, the SMART drumline contactors achieved a deployment rate of 65% and slightly less than the first trial (75%). Differences in checking rates were because the net contactor used a purpose-built, cylinder-hull vessel that allowed bar crossings in poor weather and the latter conditions precluding SMART drumline contractors handling catches alongside their vessels.

The nets caught 145 animals, including two Bull Sharks. The remaining 143 animals comprised 17 species. The most abundant non-target animals were the Whitespotted Eagle Ray (*Aetobatus ocellatus*, 43 caught), Australian Cownose Ray (*Rhinoptera neglecta*, 42), Pygmy Devilray (*Mobula kuhlii* cf*. eregoodootenkee*, 14), the Vulnerable-listed Great Hammerhead (*Sphyrna mokarran*, 11), and Common Blacktip Shark (*Carcharhinus limbatus*, 8). One Critically Endangered Greynurse Shark (*Carcharias taurus*), three Indo-Pacific Bottlenose Dolphins (*Tursiops aduncus*), one Common Dolphin (*Delphinus delphis*), three Manta Rays (*Manta alfredi*), four Endangered Loggerhead Turtles (*Caretta caretta*), two Vulnerable Green Turtles (*Chelonia mydas*), one Endangered Hawksbill Turtle (*Eretmochelys imbricata*), and one Endangered Leatherback Turtle (*Dermochelys coriacea*) were also caught.

Like for the first trial, except for one occasion when ten animals were caught in one net (at Evans Head), total catches were always seven animals or fewer per net, irrespective of the soak time. These data support the supposition that the nets have a low maximum catch saturation, and therefore should not be checked and cleared daily because this will maximise their fishing power.

Owing to the low total catch there were insufficient data to describe the effects of the three modifications to the technical aspects of the nets. But, fishing the nets closer to the surface appeared to have some merit, and was associated with a slightly lower standardised catch rate of all dolphins combined, all turtles combined and Australian Cownose Rays. If this effect is real, it might be attributed to more ambient light allowing dolphins and turtles to see the nets at the surface, and Australian Cownose Rays orientating lower in the water column at night when nets catch the most animals. The catch of all sharks combined was not similarly lower in shallow-set nets, and there were no appreciable differences in net damage rates (indicating sharks that escaped capture).

The total immediate survival of netted animals was 60% (i.e. 88 of the 145 netted animals survived). However, the single Leatherback Turtle that was released alive was subsequently found dead on a beach 65 km to the south, and a netted Manta Ray that was released alive was later recorded as possibly dead after a specimen was stranded near the Evans Head net. All four dolphins, the two Green Turtles and the Hawksbill Turtle were found dead in the nets.

Overall, survival was better than in the first trial and attributed to greater precision with net checks every 12–52 h. This was especially the case for three species (Australian Cownose Rays, Whitespotted Eagle Rays and Common Blacktip Sharks), which all had improved individual survival than during the first trial.

By comparison, during the 101–104 days they were deployed, the 30 SMART drumlines caught more target sharks than the five nets, hooking 32 animals; 50% of which were target sharks (nine White Sharks [*Carcharodon carcharias*], four Tiger Sharks [*Galeocerdo cuvier*], and three Bull Sharks [*Carcharhinus leucas*]). The White Sharks were caught at all times during the day and were most abundant during December and early January but, unlike during the first trial, none were caught during March–May.

The remaining animals caught on the SMART drumlines comprised six species of mostly sharks, including seven Smooth Hammerheads (*Sphyrna zygaena*), four Common Blacktip Sharks, one Sandbar Shark (*Carcharhinus plumbeus*), one Dusky Whaler (*Carcharhinus obscurus*), and one Black Marlin (*Istiompax indica*). The latter was the only fatality and died after being hooked by the dorsal fin. All other animals were released alive.

The community response to the nets at the end of the second trial was mixed. Generally, local residents were evenly divided between negative and positive reactions to using nets. Negative responses were related to bycatch and its mortality in the nets. Most non-residents were critical of the nets because of bycatch, but also because of the perceived ineffectiveness of nets for minimising shark–human interactions. However, like for the first trial and despite the bycatch, surfers (i.e. the group with whom most shark interactions have occurred) maintained support for using the nets. There was strong support among all respondents for alternative, nonlethal approaches to shark mitigation, including new technologies and education.

Conclusions

Notwithstanding some differences in netted catches from the first trial, which were possibly at least partially in response to the operational and technical changes, the composition of netted catch during the second trial conforms to the general trend observed over almost 200 cumulative years of data describing similar nets fished elsewhere. These data reiterate the well-established fishing mechanism of nets: they are effective for entangling various species between 1–4 m in length that move through the fished area.

Such characteristics mean non-target catches from bather-protection nets have been, and always will be, the largest catch component. But obviously, by maintaining the same generic design of nets in the second trial as those used in the SMP for 80 years, while revising the classified target catch from virtually all shark species in 1937 (i.e. the original objective of using nets) to only three species in 2016, will result in an strong disproportionate ratio of bycatch-to-target catch. Net selectivity will never approach that observed for SMART drumlines or other baited configurations.

While the poor selectivity of nets has ecological costs, it remains unknown how much this contributes towards their perceived historical effectiveness. In particular, no data are available to decipher the extent to which the quoted long-term bather protection of nets can be apportioned to the original objective of: (1) reducing the relative abundance of target sharks; and/or the subsequent consequence of (2) fewer prey (e.g. other netted animals) to attract target sharks to the area; and/or possibly even (3) chemical repellent from netted, decaying sharks and rays.

While technical modifications to nets might reduce some bycatches of concern, it is not possible with existing technology to configure them to catch only the three target sharks. Irrespective of where they are fished, the selectivity of nets will always encompass other animals of similar size that inhabit the same area—a characteristic that supported their original logical choice as a low-cost fishing gear for targeting virtually all shark species >1 m long (because most were perceived as a threat) in 1937 off Sydney. That exact same technical logic would dictate using a more selective gear, such as SMART drumlines or baited-hook derivatives, to target only three species of sharks in the 21st century.

Clearly, SMART drumlines fished during daylight hours can select for White Sharks, with good survival. More data are required to determine whether the immediate release of these sharks reduces their short-term probability of interacting with people. It might also be feasible to assess the efficiency of SMART drumlines (or other midwater- or bottom-set multi-hook configurations) fished at night to target Bull and Tiger sharks, especially during those months when few White Sharks are caught on daily deployed SMART drumlines. The survival of sharks hooked on such gear should still exceed those that are netted, and with less bycatch. But like for nets, the potential for catching threatened species needs to be assessed.

If nets are to be used within a strategy involving fishing gear to minimise shark–human interactions, given the concerns of the community about their efficacy and collateral mortalities (especially of threatened fauna), attempts at developing appropriate applied modifications are required. An obvious modification for ongoing testing would be the effects of net-setting depth. More data are required to determine whether shallow-set nets catch relatively fewer threatened species while maintaining efficiency for target sharks. While some data were collected in this trial, the utility of increasing mesh size and/or using more resilient netting (PA) warrants ongoing testing, especially considering White and Bull sharks are among the largest of the target sharks.

The results of this trial reinforce those of the first shark-meshing trial that any strategy involving fishing gear to mitigate shark–human interactions (and therefore with at least some lethal outcomes to marine life) should be chosen with regard to community consultation and expectations. But it is important to note that social expectations are subject to considerable short-term variation, whereas the science and mechanisms supporting a particular environmental outcome are not, and in fact require extensive periods to decipher. This dichotomy means that coherent strategic discussions with appropriate risk analyses are required to achieve satisfactory socio-economic outcomes around mitigating shark–human interactions that will be positively acknowledged by future generations.

It is likely a multifaceted approach encompassing various strategies to minimise shark–human interactions is required. Where fishing gear is identified as one coherent facet, the challenge is to clearly state and communicate the required objectives, and especially the certain outcome of some mortality to catches. Research should then be directed towards understanding the key mechanisms that might contribute to reduced interactions/mortalities with unwanted catches by particular fishing gears and the broader consequences for the marine environment.

Recommendations

The results from the second trial support ten recommendations:

Recommendation 1:	Unless community sentiment changes, discontinue trials of nets on the north coast *in lieu* of more environmentally benign fishing methods (e.g. SMART drumlines and their variation).
Recommendation 2:	Use purpose-built water craft to maximise specified net-checking frequencies and SMART drumline deployments.
Recommendation 3:	Check and clear nets no less than every 48 hours to maximise their fishing effectiveness while limiting bycatch.
Recommendation 4:	Assess the effects of fishing nets at different positions in the water column for improving species selectivity.
Recommendation 5:	Assess the utility of larger mesh for improving the selectivity of nets.
Recommendation 6:	Strategically test retroactive modifications for limiting bycatch on SMART drumlines.
Recommendation 7:	Assess the movement and behaviour of target sharks released from SMART drumlines.
Recommendation 8:	Clearly reiterate the terms of reference for using fishing gear to minimise shark–human interactions in ongoing trials of SMART drumlines and nets.
Recommendation 9:	Modify nets to reduce the mortality of turtles and dolphins while maintaining their long-term efficiency as a tool for minimising shark–human interactions.
Recommendation 10:	Identify and quantify all of the factors that contribute to how nets minimise shark–human interactions.

Introduction

For more than a century, the New South Wales (NSW) Government has initiated various strategies to mitigate the risk of shark–human interactions (NSW Shark Menace Committee, 1929). Some of the longest-standing approaches have included permanent swimming enclosures in estuaries and at ocean beaches, along with both fixed location (lifeguard towers) and, in recent decades, aerial surveillance to inform authorities about the proximity of sharks to beaches. Another long-term approach involves anchored bather-protection mesh nets (conventionally known as gillnets or simply 'nets'; 150 × 6 m and with 60 cm stretched mesh opening [SMO]) which were first deployed at 18 beaches off Sydney in 1937, and currently are anchored off 51 beaches between Wollongong and Newcastle from 1 September to 30 April each year (collectively termed the 'shark-meshing program'; or SMP).

The SMP was initiated following a cluster of shark–human interactions in the early 20th century, and was preceded by considerable political debate through a state government 'NSW Shark Menace Committee' (NSW Shark Menace Committee, 1929), which proposed broad, lethal shark management because "*with the exception of the Port Jackson shark it is best to regard them all as possible man-eaters*" (p 6. presentation to meeting of NSW Shark Menace Committee, 9 August, 1929). During the introduction of nets, the target species were refined to all whaler (*Carcharhinus* spp.), Tiger (*Galeocerdo cuvier*), White (*Carcharodon carcharias*), Shortfin Mako (*Isurus oxyrinchus*), Greynurse Shark (*Charcharias taurus*), and hammerheads (*Sphyrna* spp.) larger than ~1 m total length (TL) (NSW Shark Menace Committee, 1935). Over the next 50–60 years, the Greynurse Shark and hammerheads were removed as targets, but the other species, along with Broadnose Sevengill Shark (*Notorhynchus cepedianus*) remained. In 2016, the target species were reclassified as only Bull (*Carcharhinus leucas*), White and Tiger sharks—the three coastal species deemed globally responsible for most interactions with humans (ASAF, 2017).

The SMP effectiveness has been measured by relatively fewer total shark–human interactions at netted beaches than at pre-netted or un-netted beaches, including a reduction from 13 fatalities in the three decades before meshing to a single fatality (in 1951) in the following eight decades (Green et al., 2009; ASAF, 2017). Similar conclusions about the utility of nets for mitigating shark–human interactions have been implied in the only two other jurisdictions where they have been regularly fished: Queensland (Sumpton et al., 2011); and South Africa (Dudley and Cliff, 1993). However, the nets fished in Queensland have always been complemented by baited hook (single or double) configurations (termed 'drumlines'), which were also introduced off South Africa in 2007 (Sumpton et al., 2011).

The complete mechanisms supporting the perceived long-term effectiveness of nets in NSW (and nets and drumlines off Queensland and South Africa) for reducing shark–human interactions are not entirely clear. Intuitively, any local mortality of potentially dangerous sharks should infer a reduced probability of shark–human interactions, and certainly a positive correlation between the abundance of potentially dangerous sharks and bites has been demonstrated elsewhere (e.g. in Brazil; Afonso et al., 2017).

But, it is also well established that nets have a very broad selectivity. Various non-target animals (collectively termed 'bycatch'), comprising mostly elasmobranchs, but sometimes fish, dolphins, and turtles are also netted. The nets function by entangling animals within a broadly similar size range (~1–4 m long) inhabiting the same space and time—a characteristic that means it is impossible to achieve 100% selectivity for virtually all sharks (NSW Shark Menace Committee, 1929), let alone ten classified target species, and certainly not three. Disproportionate ratios of bycatch-to-target catches have always been a characteristic of bather-protection nets. This is an important point for consideration, because any perceived long-term effectiveness of nets for reducing shark–human interactions reflects all of their characteristics, including poor selectivity. More specifically, it has been proposed that beyond reducing the local abundances of the three target sharks responsible for most shark–human interactions, the long-term effectiveness of nets might be apportioned to fewer prey (e.g. regional depletions in populations of bycatch) to attract target sharks to the netted areas, and/or possibly even chemical repellent from netted decaying sharks and rays (Stroud et al., 2014; NSW DPI, 2017).

The first NSW north coast shark-meshing trial

During the entire 20th century in NSW, shark–human interactions averaged around 1.5 per year, but notably increased to seven per year (on average) between 2000 and 2015. The spatial extent of interactions has also changed over time, with the majority of historical incidents occurring between Sydney and Newcastle, but the majority of recent incidents (including fatalities) occurring off the north coast.

In October 2015, the NSW Government commenced its five-year, $16 million Shark Management Strategy (SMS), which includes trials of new technologies to detect and deter sharks. The objective of the SMS is to increase protection for beachgoers from shark interactions while minimising harm to sharks and other marine animals. The initial focus of the SMS was on the north coast, in particular the area between Evans Head and Byron Bay.

The north-coast community was supportive of the SMS; however ongoing shark–human interactions throughout 2016 triggered a shift in community attitudes towards more traditional strategies, such as nets like those used in the SMP. In response, the NSW Government decided to trial nets at five north-coast beaches: Seven Mile, Lighthouse, Shelly, and Sharpes beaches at Ballina; and Main Beach, Evans Head in what was termed the first 'north coast shark-meshing trial' (174 days between 8 December 2016 and 30 May 2017—full report available at: https://www.dpi.nsw.gov.au/fishing/sharks). The first trial was preceded and followed by community consultation via surveys to monitor the level of acceptance of the presence and operation of the nets.

During the first trial, and within broader objectives (as part of the SMS) to assess emerging technologies, 25 so-called 'shark management alert in real time' (SMART) drumlines were also diurnally fished off the same beaches as the nets (15 off Ballina and Lennox Head and ten off Evans Head). The SMART drumline system represents an amalgamation of ideas developed to mitigate shark–human interactions at Réunion Island and off Brazil (Hazin and Afonso, 2014). Unlike conventional drumlines, which typically are baited and left to fish night and day with periodical checks, SMART drumlines are rigged with an electronic system for alerting operators immediately after an animal is hooked. The operators can attend the animal (typically within 30 min), and then tag and release it alive away from the area. By immediately removing hooked target sharks from a beach (and typically 1 km offshore), their risk of interactions with humans is thought to be reduced. Some support for such a theory is provided by Hazin and Afonso (2014), who postulated a 97% reduction in the rate of shark–human interactions over an eight-year period attributed to the capture (using conventional baited lines) and in many cases (>50%) relocation of live target sharks (mostly Bull and Tiger sharks) off north-eastern Brazil.

Recommendations to be addressed during a second shark-meshing trial

The key outcomes of the first trial were limited to providing data on the technical and operational limitations/benefits of nets and SMART drumlines and their relative catches off northern NSW, and associated public perceptions (NSW DPI, 2017). Although short-term catch data will never inform on the effectiveness of either gear for minimising shark–human interactions, these data are of most social importance simply because the composition and number of catches ultimately influence public opinion on any gear-specific benefits.

Based on the catch data and social response to the first trial, nine recommendations were proposed; of which the following five were deemed suitable to be addressed/encompassed within the research objectives of a second north coast shark-meshing trial:

1. Given the unacceptability of bycatch among many Ballina Shire and Evans Head residents and throughout the wider community, research should be undertaken to design a net that reduces bycatch.
2. Continue trials of new technologies to minimise shark–human interactions that provide the same protective approach as nets over the same or greater spatial and temporal scales as the trial, and with associated community consultation.
3. Nets used to minimise shark–human interactions need to be deployed overnight to maximise their efficiency at catching target sharks.
4. Nets should be checked and cleared of catches no less than every 48 hours to maximise their fishing effectiveness while limiting bycatch.
5. Assess key operational and novel technical modifications to nets that reduce the collateral mortality of bycatches, especially of turtles and dolphins, while maintaining their long-term efficiency as a tool for minimising shark–human interactions.

Where relevant, these recommendations were addressed within changes to the operational characteristics and technical specifications of existing nets. Decisions concerning appropriate modifications were based on consultations with fishing-gear technologists and commercial fishers, and with regard to numerous previous studies identifying those key factors affecting the size and species selectivity of similar gillnets used elsewhere (Hamley, 1975; Gray et al., 2005; Uhlmann and Broadhurst, 2015).

Beyond reducing bycatch (but still maintaining maximum survival) by checking nets less frequently than twice daily, one operational modification considered feasible was to vary the vertical position of the nets in the water column. Previous studies have shown that altering the distance of similar nets from the sea surface can affect the catches of various species, depending on their depth preferences (Hamley, 1975; Gray et al., 2005). In fact, nets in the SMP have been fished on the seabed, but were then suspended off the bottom to successfully reduce the bycatch of some rays (Green et al., 2009).

Other modifications recommended in the first trial that were deemed appropriate for testing included changing the mesh size and twine material; both of which have been demonstrated to strongly affect the size and species selectivity of other gillnets (Hamley, 1975; Broadhurst et al., 2003; Gray et al., 2005). The changes included increasing mesh size (SMO) from 600 to 800 mm in an attempt to catch large individuals of the revised targeted Bull, White and Tiger sharks, along with stronger and more elastic twine (polyamide; PA) aimed at more securely entangling these large animals, but sufficiently stiff to prevent catching some smaller animals (e.g. rays and fish).

In addition to relative catch comparisons among net configurations, and like during the first trial, SMART drumlines were concurrently fished adjacent to the netted beaches; not only to collect more data describing relative technical and catching performances, but also as part of longer-term work to inform on the utility of SMART drumlines. These various data were considered essential for coherent, ongoing discussions concerning socially acceptable and scientifically defensible strategies to mitigate shark–human interactions.

Methods

Approvals process

Following the report of the first trial, the NSW Government applied for and was granted a national interest exemption under section 158 of the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 from the application of sections 18, 18A, 20, 20A, 23 and 24A of Part 3 and Parts 7–9 of Chapter 4 of the Act, for further north coast shark mesh-net trials during the period 1 November 2017 to 31 October 2019. In accordance with Schedule 6D of the Fisheries Management Act 1994, the second trial was authorised by the Fisheries Management (Shark Management Second Trial Ballina Shire and Richmond Valley councils) Order 2017, and operated in accordance with the Management Plan for the second shark-meshing trial, November 2017.

The Management Plan started on 1 November, 2017 and made provision for 12 months in which to conduct the second trial with a total of 6 months or 182 days for fishing effort (whereby a fishing day was 24 h the nets were in the water). The Management Plan also made provision for a fauna disentanglement plan to facilitate the safe release of live marine mammals and reptiles. The three approval documents are available at https://www.dpi.nsw.gov.au/fishing/sharks/management/shark-net-trial.

In accordance with the recommendations from the first trial, there were four operational and technical changes to the nets approved for investigation. These included altering the:

(1) checking frequency (from twice daily to once between 12 and 52 h);

(2) vertical fishing height (midwater- vs shallow-set);

(3) mesh size (600 vs up to 900 mm SMO); and

(4) twine material (polyethylene–[PE] vs PA).

Community consultation

Community consultation and engagement were undertaken before, and then at the end of, the second trial using various platforms, including surveys, a drop-in stand, visits to businesses, and formal meetings. Following the first trial, three meetings were held in May, August and November, 2017 with the ‘north coast shark management strategy stakeholder group’ (NCSMSSG; comprising representatives from north-coast councils including Ballina, Richmond Valley and Byron Shire; Chambers of Commerce representatives; Surf Life Saving NSW; local surf clubs; Australian Lifeguard Services; local businesses; local Members of Parliament; local surfboard riders; and members of the public directly affected by shark–human interactions) to listen to concerns and aspirations and provide feedback on how engagement influenced government decisions.

Signs were placed at the five netted beaches before, during, and after the net trial to inform beach users on the status of the trial and communicate opportunities to provide feedback. This extension work was complemented by content on the NSW DPI shark management website, which included: information about the second trial; an explanation that the nets are not barriers; monthly updates on catches; and animations describing how the nets and SMART drumlines work (http://www.dpi.nsw.gov.au/fishing/sharks/management/shark-net-trial and http://www.dpi.nsw.gov.au/fishing/sharks/management/smart-drumlines). Information was also provided via fact sheets, radio interviews, and traditional and social media.

A formal community survey was undertaken at the end of the second trial (10–31 May, 2018) to assess social attitudes in the context of other strategies for minimising shark–human interactions. The survey was done by ‘Jetty Research PTY Ltd’ and comprised random and representative telephoning of residents in the Ballina and Evans Head region, as well as an online questionnaire available for anyone to answer. The questions were virtually identical between telephone and online formats, and designed to facilitate comparing community views with surveys done before and after the first trial.

Telephone interviews were conducted using a ‘computer-assisted telephone interviewing’ technique and focused on households in the 2473, 2477, and 2478 postcodes. The postcode 2479 population was not targeted because only 26% of residents live in the Ballina Shire (source: Australian Bureau of Statistics). Where residents self-recorded living in the 2479 postcode and in the Ballina Shire, their responses were included. The target sample size was 600 adults, which has a random sampling error of ± 4.0% at the 95% confidence level, meaning that results should be accurate to within ± 4.0% in 19 of any 20 random surveys conducted among the target population. Telephone numbers (fixed line and mobile) were sourced from SamplePages and were called during 15:30–20:00 on weekdays or 12:00–17:00 on Saturdays. Potential respondents were screened to ensure they were ≥18 years old and lived in the relevant postcodes. To minimise bias, no mention of the subject matter or NSW DPI was made until the resident agreed to participate.

The online questionnaire was delivered using the Survey Monkey software and responses were considered to be valid if the relevant demographic details were completed. While multiple, completed questionnaires from the same IP address were identified and inspected, no responses were deleted on that basis because it was possible that the same computer was used by multiple respondents (e.g. a computer within a family or at a library). The online questionnaire was promoted via: media releases; emails and briefings to the NCSMSSG; advertisements in local newspapers; the NSW DPI website and social-media channels; traditional media; Ballina Council and Richmond Valley Council websites and their social-media channels; 15 signs at the netted beaches; and a community drop-in stand at a local beach.

The results from the random telephone interviews were post-weighted to reflect the age and gender of people in each postcode (based on the 2011 Australian Bureau of Statistics census). Because the online responses were non-random (i.e. self-selecting), these results were not post-weighted. Open-ended comments were coded to identify key themes. Owing to the large number of responses to the online questionnaire, 600 comments from each open-ended question were selected at random for coding, and included the same proportion of ‘Ballina and Evans Head’ vs ‘other’ respondents’ as the total online sample.

Nets

Following the provisions of the Management Plan, replicate nets were configured within three broad modifications for sequential testing (Table 1), although the generic design and installation of all nets followed those fished during the first trial and in the SMP. Each net measured 150 m long and comprised knotted mesh attached to 20-mm diameter (Ø), polypropylene (PP) floatlines and 8-mm Ø PA foot ropes at a hanging ratio (floatline and foot rope lengths divided by stretched length of meshes) of 0.67 (Figs 1 and 2). All nets used off Ballina and at Lennox Head (hereafter all net locations referred to as ‘Ballina’) had a fishing depth of 6 m, while the net used at Evans Head measured 4 m deep (owing to shallower water).

Each net had two 30-kg anchors at each end, with buoyed trip ropes (16-mm Ø twisted PP), and up to eight surface floats/buoys (~300-mm Ø) attached to ‘buoy ropes’ (16-mm Ø twisted PP) between the surface and the floatline (Fig. 1). One of the buoys on each net contained a GPS unit configured to produce an alert (via email and SMS) if displaced more than 200 m. The buoys regulated the fishing height of the nets as required (Table 1), but the footropes were always at least 0.5 m off the bottom.

To assess the first modification to the nets (different fishing depths), various buoy ropes were configured at either 0.5 or 2.0 m long and could be attached to all nets (comprising 600-mm mesh made from 1.8-mm Ø PE twine) at Ballina (each 375.0 meshes across × 13.5 meshes down) and Evans Head (375.0 meshes across × 9 meshes down), according to whether they were midwater- or shallow-set (Table 1, Fig. 1). The second modification to nets (different mesh sizes) was restricted to those fished at Ballina, with replicate nets constructed from either 600-mm mesh (as above) or 800-mm mesh (282.0 meshes across × 10.0 meshes down), and all made from 1.8-mm Ø PE twine and rigged with 2.0-m buoy ropes (i.e. midwater-set; Table 1, Fig. 2). The third modification (different twine materials) was also restricted to nets deployed off Ballina, and involved all made from 800-mm mesh (same area dimensions as above), but either conventional 1.8-mm Ø PE or 2.5-mm Ø PA twine (Table 1). The PA twine was the same as that used to construct some bather-protection nets fished in Queensland.

Table 1. Specifications of the sequentially tested net modifications (achieved via the text in bold) and their fished locations and periods during the second trial.

Type of modification	Net specifications	Location fished	Days fished (and dates)
Vertical fishing height (midwater; 2.0 m vs shallow; 0.5 m)	Mesh size: 600 mm SMO Mesh twine: 1.8-mm Ø PE **Buoy lines: 2.0 vs 0.5 m**	Ballina and Evans Head	Ballina: 82 (23/11/17–17/02/18) Evans Head: 148 (23/11/17–02/05/18)
Mesh size (600 vs 800 mm)	**Mesh size: 600 vs 800 mm SMO** Mesh twine: 1.8-mm Ø PE Buoy lines: 2.0 m	Ballina	51 (22/02/18–17/04/18)
Twine material (PE vs PA)	Mesh size: 800 mm SMO **Mesh twine: 1.8-mm Ø PE vs 2.5-mm Ø PA** Buoy lines: 2.0 m	Ballina	15 (17/04/18–02/05/18)

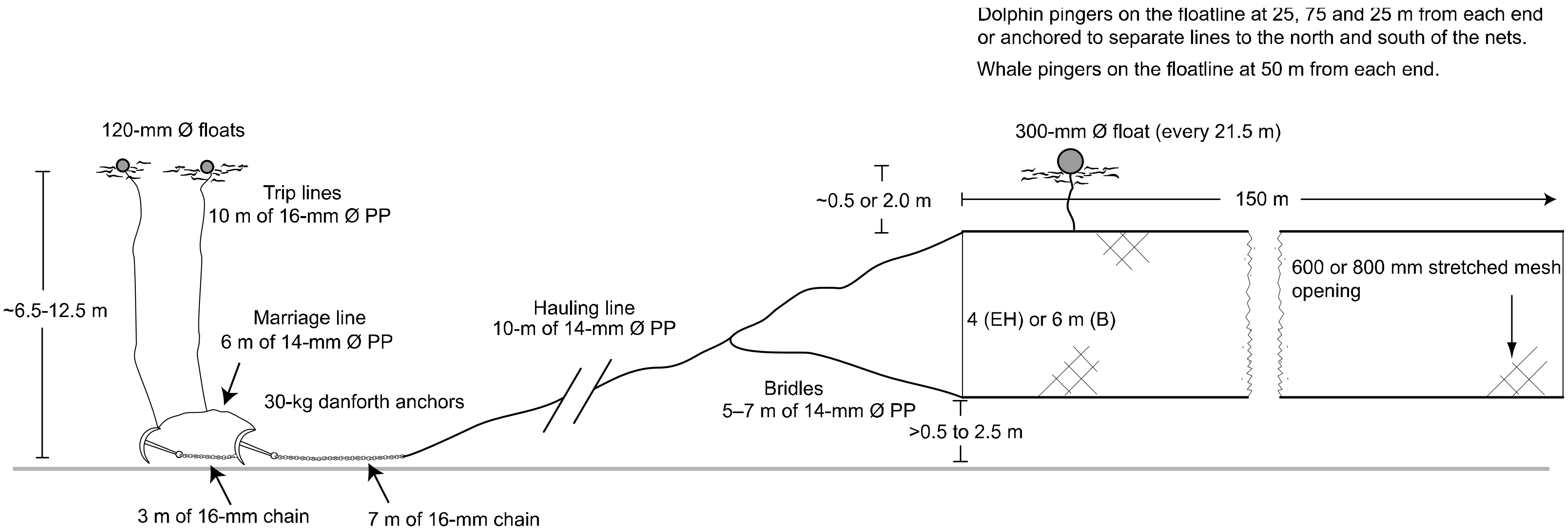
PP: polypropylene; SMO: stretched mesh opening; PE: polyethylene; PA: polyamide; and Ø: diameter.

Irrespective of the nets being fished, all had acoustic deterrents ('pingers') designed to mitigate interactions with whales and dolphins (Table 2). Pingers were either attached to the floatlines or, for the 'dolphin dissuasive device' (DDD) secured to separate lines anchored 20 m from each end of each net (Fig. 1). Each pinger produced variable frequency noises to alert whales and dolphins to the presence of the nets.

Table 2. Specifications of the three types of acoustic devices (pingers) deployed with all nets to deter marine mammals.

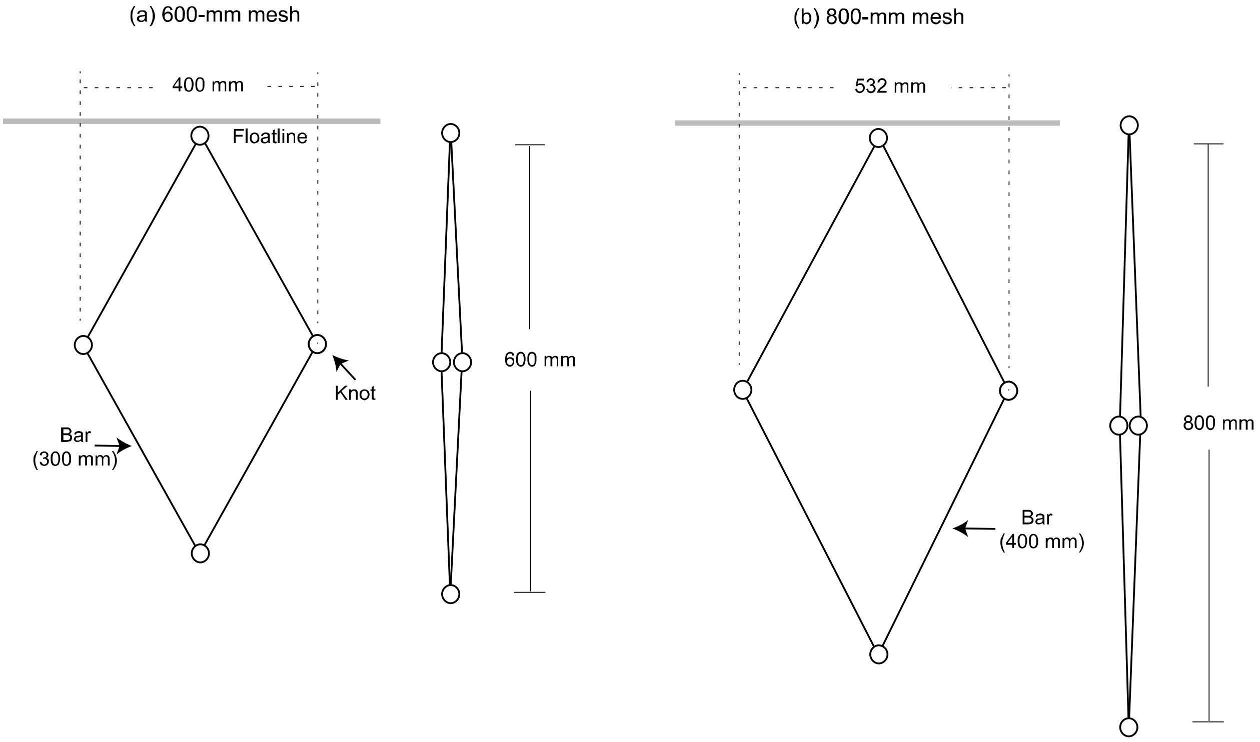
Name of acoustic deterrent (model)	Manufacturer	Number per net and distance apart	Species for which designed	Signal
Future Oceans 10 kHz porpoise pinger (FO10)	Future Oceans	Three: at 25, 75 and 25 m from each net end.	Small cetaceans (porpoises)	10kHz–132 dB every 4 sec for 0.3 sec.
Future Oceans 3 kHz whale pinger (FO3)	Future Oceans	Two: at 50 m from each net end.	Large cetaceans (whales)	3kHz–135 dB.
Dolphin dissuasive device (DDD)	STM products	Two: at 20 m from each net end.	Small to medium cetaceans	20–160 kHz (variable) at 145 dB with pulsed interval of 4–30 sec for 0.3 sec.

Figure 1. Diagram of the general configurations of nets used off Ballina (B; 6 m deep) and Evans Head (EH; 4 m deep).



PP: polypropylene; and Ø: diameter.

Figure 2. The (a) 600- and (b) 800-mm meshes showing their stretched lengths and the horizontal distance each was attached to the floatline and foot ropes to achieve a hanging ratio of 0.67.

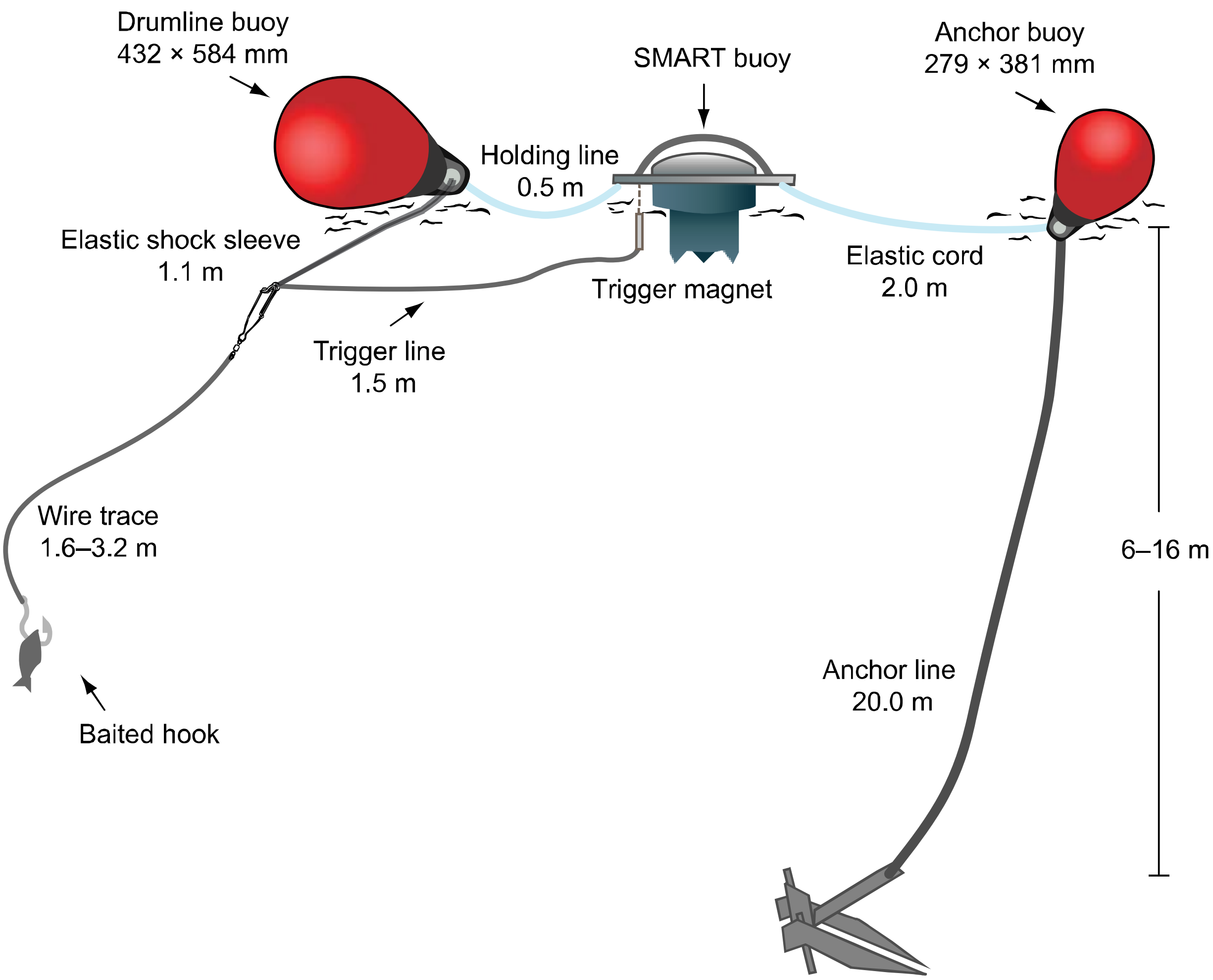


SMART drumlines

Thirty SMART drumlines were fished during the second trial. Each configuration included an anchor (either 3 m of 10-mm Ø galvanised chain by itself or with 1.5 m of 10-mm Ø galvanised chain attached to a 4.5-kg Danforth sand anchor) and 20 m of 8-mm Ø polypropylene (PP) rope and an A1 Polyform™ anchor buoy (279 mm × 381 mm; Fig. 3). A second surface line comprising 2.0 m of 8-mm Ø elasticised cord was attached to a SMART buoy (model MLI-s) and then a holding line of 0.5 m of 8-mm Ø PP rope and a larger A3 Polyform drumline buoy (432 mm × 584 mm). A 'shock sleeve' (incorporating two 1.1-m lengths of 10-mm Ø elasticised cord encased in herringbone material) and trace (either 1.6 or 3.2 m of 3.0-mm wire cable) were suspended from the buoy with a circle hook (Mustad™ © 39937NP-DT) at the end. Each hook was constructed of 9-mm Ø duratin-coated galvanised steel with shaft, bend and gape lengths of 122, 113 and 56 mm, respectively. Various semi-barbed and barbed hooks baited with ~0.8–1.0 kg (or 40 to 50 cm) of Sea Mullet (*Mugil cephalus*) or Australian Salmon (*Arripis trutta*) were used as part of other ongoing research with SMART drumlines.

A 1.5-m monofilament 'trigger line' (2.0-mm Ø) was attached between the elasticised cord and the SMART buoy (Fig. 3). When an animal bites the hook, the trigger line separates the magnet in the SMART buoy, and a signal is transmitted via satellite, alerting staff via short message service, telephone call, and email.

Figure 3. Diagram of a SMART drumline, showing the trigger line, which is released when the baited hook is taken.



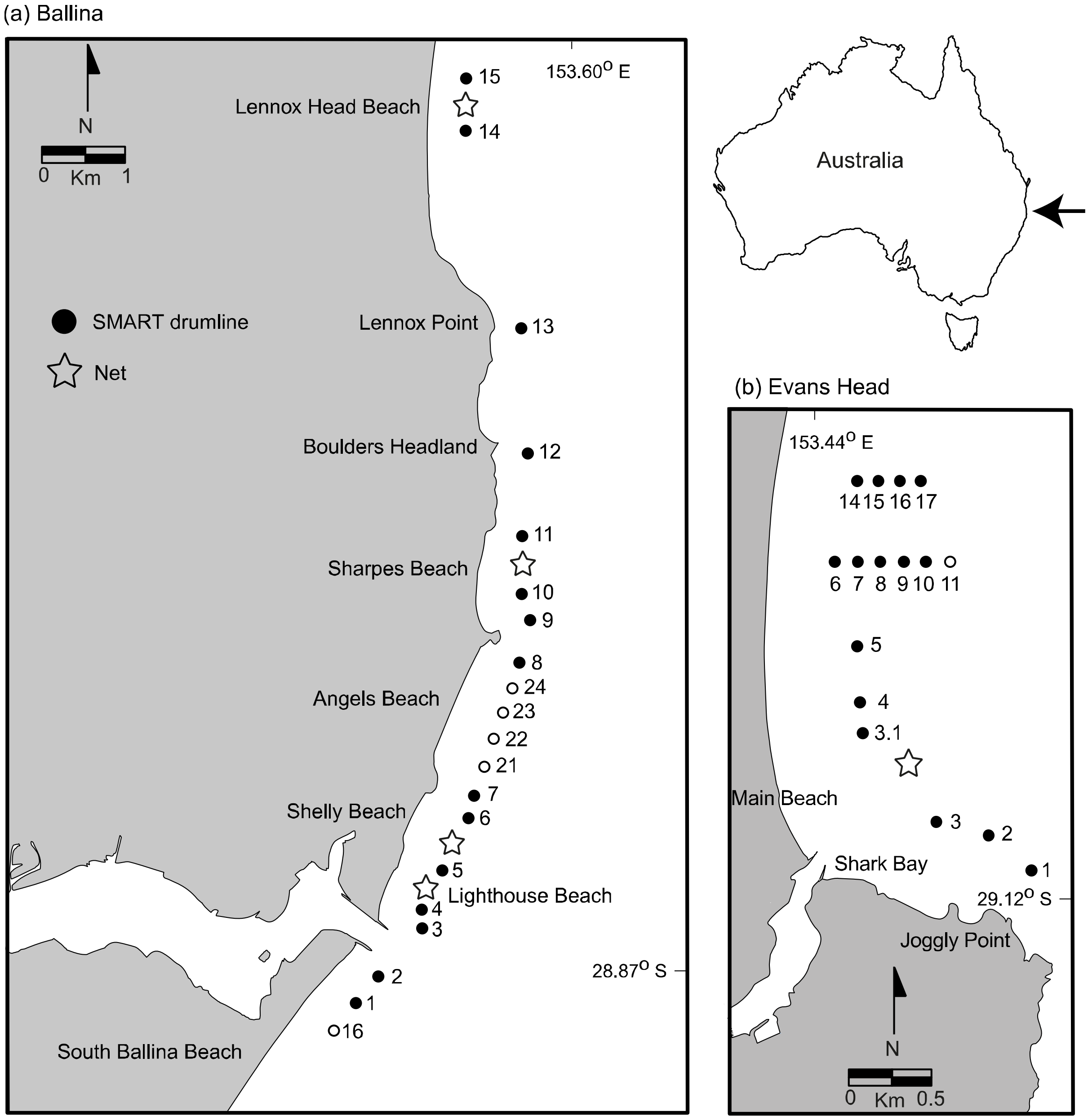
Where and how the nets and SMART drumlines were fished

Irrespective of differences between vertical fishing height, mesh size or twine during the trial, a single 6-m deep net was always anchored off each of Lighthouse, Shelly, Sharpes and Lennox Head beaches, and 15 SMART drumlines were dispersed over 13 km of coastline (Fig. 4). On days when any of the SMART drumlines could not be deployed at a particular location (but the contractor was at sea) they were redeployed off either South Ballina or Angels beaches, (locations 16, 21 and 24; Fig. 4). Similarly, when dangerous surf conditions prevented deploying a SMART drumline at location 6, it was placed at location 11 (Fig. 4). By comparison, one 4-m deep mesh net was deployed off Evans Head Main Beach with 15 surrounding SMART drumlines within 1−2 km either side (Fig. 4).

Following current practices in the SMP, where practical all nets were deployed ~500–600 m directly opposite and parallel to patrolled areas on the beaches, at depths of 7–12 m. The nets remained in the water, and were removed only during adverse weather (defined as a predicted swell >3 m for >two days on the Australian Bureau of Meteorology coastal-waters forecast). Similarly, when weather permitted, SMART drumlines were deployed across the same areas and distance offshore, but at depths of 6–16 m.

The three groups of net modifications were sequentially tested off Ballina (i.e. different vertical fishing heights during the first 82 fishing days: different mesh sizes during the next 51 days; and different twine materials for the last 15 fishing days; Table 1) in variable 'fishing blocks' (of ~two weeks) throughout the trial, with the general procedure remaining the same. At the start of each fishing block, two of the four Ballina nets were randomly assigned as one of the designated configurations (e.g. midwater- or shallow-set; 600- or 800-mm mesh; and PE or PA twine), while the other two nets were assigned the alternative configuration. After a ~two-week fishing block, the nets were replaced and randomly reconfigured as either of the other options (although at times it was not possible to access the nets at the scheduled block change). Because there was only ever one net at Evans Head, it was alternately midwater- or shallow-set throughout the trial.

Figure 4. Locations of nets (☆) and SMART drumlines (● and numbered) off (a) Ballina and (b) Evans Head.



Open circles are alternative positions for SMART drumlines when weather precluded deploying at any of the positions marked by dark circles.

All nets were serviced by one contractor, while the 15 SMART drumlines deployed off Ballina and Evans Head were attended by two other, separate contractors. Weather permitting, the net contractor was required to check the nets between 12 and 52 h of the previous inspection (typically by lifting the floatline from the water) and to replace each every two weeks (as per the fishing blocks stated above). The SMART drumline contractors were required to deploy their gear between 05:00 and 08:00 every day, check them if triggered, and then retrieve between 16:00 and 19:00. The period between checks of both gear types was called the ‘soak time’.

Data collected

Comprehensive technical, biological, and environmental data were collected every time the nets or the SMART drumlines were deployed, checked, or retrieved by onboard NSW DPI observers (nets) and/or the contractors (nets and SMART drumlines). The net checks involved ‘full removal’ (i.e. the net was hauled on board the vessel), ‘floatline check’ (the floatline was lifted clear of the water so that the entire net could be sighted), or ‘visual check’ (the vessel steamed along next to the net without touching it unless an animal was observed). The net-check type depended on the weather, especially the current and swell. The contractors always attempted either a full removal or floatline check, but if the net could not be reached safely, a visual check was done.

Irrespective of the type of net check, data for all catches included the species and where and how they were entangled (extreme—with 100% of the body covered by mesh; moderate—with 50–100% of the body covered in mesh; and mild—<50% covered in mesh), including the side of the net. All net and SMART drumline catches were photographed or videoed, assessed for their status (alive or deceased) following established protocols, and had biological samples taken (typically a small fin sample, which was stored in ethanol or ‘RNA later storage solution’). Where possible, the sex was determined, and body size (to the nearest 1 cm) were recorded for all animals, including TL for sharks, fish and dolphins, disc width (DW) for rays, and curved carapace length (CCL) for turtles. All available data were used to identify animals to the lowest possible taxonomic level. Live animals that could be safely reached by the observer were tagged and released away from the nets. Deceased animals were assessed on board for their decomposition status (fresh, medium or advanced), and any depredation before being retained for necropsies at a NSW DPI or veterinary facility and eventually disposed of by burial. Only a few catches were too decomposed to necropsy and were disposed of at sea.

For the SMART drumlines, the following data were recorded for all animals caught: species name; identification code; date caught; SMART drumline number; deployment time; time hooked; time boat arrived; time animal was secured at the boat; time released; sex; TL (cm); tag number (conventional, acoustic and satellite); and if there was any damage to the animal or SMART drumline. The release location was recorded as beach name, latitude and longitude (decimal degrees), distance offshore, water temperature (°C), and depth (m).

In addition to netted animals, and with the cooperation of other government departments (e.g. National Parks and Wildlife Service) and non-government organisations (e.g. Australian Seabird Rescue and Organisation for the Rescue and Research of Cetaceans in Australia) attempts were made to obtain records of all other charismatic fauna reported stranded on northern NSW beaches from Wooli (29.9°S) to the Tweed River (28.1°S) and, where possible, to undertake necropsies to assess for potential net or SMART drumline interactions. Where necropsies could not be done as many details as possible were collected for each animal.

Any damage or technical problems with the nets or SMART drumlines were also recorded, including no catches in the nets or no bait on the hooks, to quantify the frequency at which animals contacted the gear but escaped. For nets, contact and escape was considered to have occurred when there was no animal entangled and there were at least two adjacent broken bars (Fig. 2; creating a hole at least 600 × 600 mm). If the net damage was minor, repairs were done during the net check, otherwise the net was removed (and replaced) and repaired on land.

Results

Community consultation

Demographics and beach visitation and the main activities undertaken

A total of 612 people were interviewed via telephone; most of whom lived in Ballina (postcode 2478) and were ≥35 years of age (Table 3). The participation rate for the telephone interviews was 31%, with an average completion time of 13 min. For the online questionnaire, there were 2,498 valid responses, with greater responses from people residing outside Ballina and Evans Head region, including other states. The representation of genders and those with children living at home were similar between telephone and online surveys. The online questionnaire was characterised by a greater response rate among those 18–34 years of age, and a lesser response rate in the 55+ year category than for the telephone interviews (Table 3).

Table 3. Characteristics of respondents to the 2018 community survey involving telephone interviews and an online questionnaire.

	Telephone interviews	Online questionnaire
Total number of respondents	612	2498
Postcodes of respondents (%)		
2473 (Evans Head)	26	2
2477 (e.g. Wollongbar)	21	4
2478 (Ballina)	51	32
2479 (e.g. Bangalow)	2	2
All other locations	0	60
Age* (%)		
18–34	13	28
35–54	36	42
55+	51	30
Gender* (%)		
Male	47	46
Female	53	54
Children at home? (%)		
Yes	36	41

*Telephone samples were post-weighted by age and gender to match the profile of the combined 2473, 2477 and 2478 postcodes based on the 2011 Australian Bureau of Statistics census data.

Most respondents to the telephone interviews and online questionnaire had visited north-coast beaches for ≥10 years (Table 4). Residents who completed the online questionnaire frequented north-coast beaches more regularly than those who agreed to telephone interviews and more than those who responded from other locations (Table 4). The main activities undertaken by respondents were broadly categorised as: swimming (e.g. body surfing, surf lifesaving activities, diving, spearfishing or snorkelling); surfing (e.g. board riding, body boarding, kite surfing, stand-up paddle boarding or surf-skiing); and non-water (e.g. walking or line fishing) (Table 4). Water-based activities were undertaken by 47% of all telephone respondents, 77% of online respondents from Ballina and Evans Head, and 75% of respondents from other locations.

Table 4. History of beach use, visitation rates and main beach activities undertaken by respondents (numbers) to the telephone interviews and the online questionnaire. Surfing also includes body boarding, kite surfing, windsurfing, stand-up paddle boarding, and surf-skiing. Swimming also includes body surfing, surf life-saving, snorkelling, diving and spearfishing. Non-water activities include walking or line fishing.

	Ballina and Evans Head residents		All other respondents
	Telephone interviews	**Online questionnaire**	**Online questionnaire**
Sample size (no.)	612	1,001	1,497
Visited north coast beaches for ≥10 years (%)	89	83	68
Visiting north coast beaches weekly or more (%)	65	85	43
Main activities undertaken (%)			
Surfing	13	32	20
Swimming	34	45	55
Non-water activities	53	23	25

The survey also asked respondents whether they, a family member, or close friend had been involved in a shark–human interaction, including being bitten, approached or bumped by a shark or being involved in the rescue and treatment of shark-bite victims. Based on this definition, 35 and 40% of telephone and online respondents indicated such involvement.

Community attitudes towards the nets used during the second trial

Most respondents were aware of the second trial prior to their participation, with awareness being greater among residents (78% of telephone interviewees and 90% of respondents to the online questionnaire) than among those from other locations (65%). All respondents were asked how they thought the nets had affected them, their family, and the wider community.

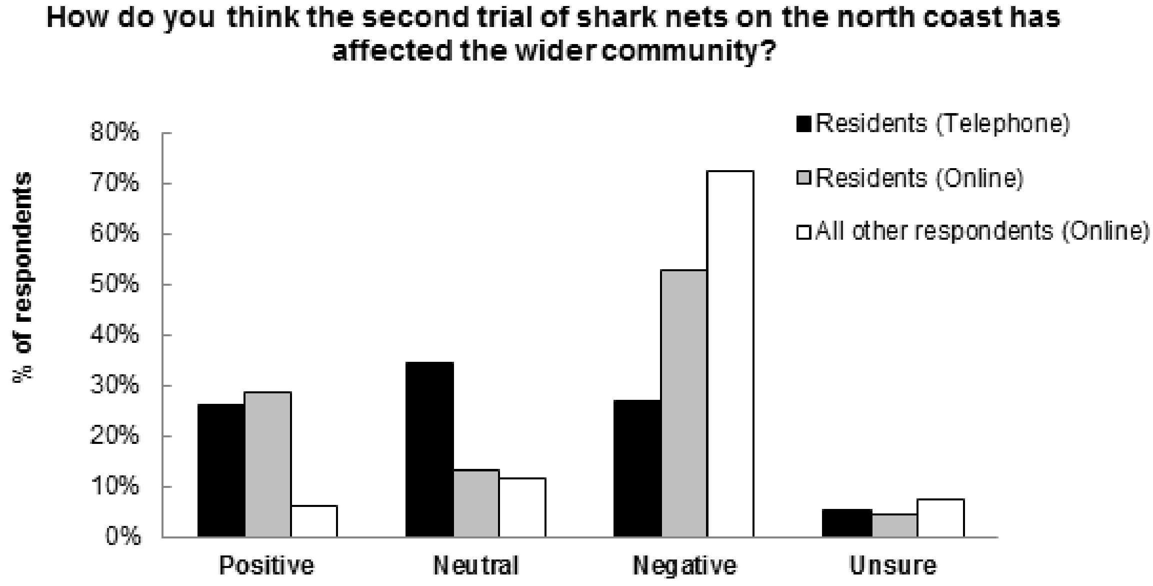
During the telephone interviews of residents, a similar proportion were positive as negative about the effects of the nets regardless of whether they were asked about themselves (26% positive vs 27% negative), their family (26 vs 26%) or the wider community (26 vs 23%; Table 5). A large proportion of respondents indicated they were neutral about the effects of the nets relative to those that completed the online questionnaire (Fig. 5). Specifically, about half of the 612 people sampled felt that the trial did not affect them personally, simply because they did not undertake water-based activities.

In contrast, residents who filled out the online questionnaire were consistently more negative than positive about the effect of the second net trial on themselves (29% positive vs 53% negative), their family (30 vs 50%), and the community (28 vs 46%). Online respondents from other regions (and states) exhibited the strongest negativity towards the nets for self, family and the community (6% positive vs 63–73% negative; Table 5).

Table 5. **Survey results from telephone interviews and the online questionnaire summarising the effects of the nets fished during the second trial on self, family and the wider community. The number of responses for each question varied: Ballina and Evans Head residents self (992), family (989), and the community (981); all other respondents self (1486), family (1469), community (1467).**

	Ballina and Evans Head residents		All other respondents
	Telephone interviews	**Online questionnaire**	**Online questionnaire**
Sample size	610	1,001	1,497
Effect on self? (%)			
Positive	26	29	6
Negative	27	53	73
Effect on family? (%)			
Positive	26	30	6
Negative	26	50	67
Effect on community? (%)			
Positive	26	28	6
Negative	23	46	63

Figure 5. **Survey responses for the perceived effect of the nets fished in the second trial on the wider community. Results are shown for residents of the Ballina and Evans Head region (telephone interviews and the online questionnaire) and for respondents residing at other locations (online questionnaire).**



Surfers residing in the Ballina and Evans Head region were more positive than negative about the effects of the second trial. Positivity was more pronounced among local surfers who responded to the online questionnaire (self: 47% positive vs 34% negative; family: 49 vs 33%; and community: 46 vs 32%) than for surfers who took part in the phone interviews (self: 35% vs 28%; family: 33 vs 27%; and community: 28 vs 21%). Surfers from other regions who responded to the online survey were consistently negative about the nets regardless of whether they were considering impacts to themselves (15% positive vs 65% negative), their family (14 vs 61%) or the community (14 vs 58%).Respondents were asked, in an open-ended question, to explain why they felt positive, negative, or neutral about the nets used in second trial (Table 6). Those perceiving the nets as being positive focused largely on the belief that something was being done to mitigate shark–human interactions and so they felt safer for their families and/or the community. The major reason for negative attitudes towards the net trial was the impact on bycatch. This was a particularly strong concern among those answering the online questionnaire regardless of their residence. Nets were also viewed as being ineffective for mitigating shark–human interactions and providing a false sense of security to beachgoers. Neutral attitudes towards the nets were largely due to the belief that 'the ocean is the shark's domain', there is a very low likelihood of shark bite and, for telephone respondents, the belief that they were not personally affected (i.e. their major beach activity was land-based).

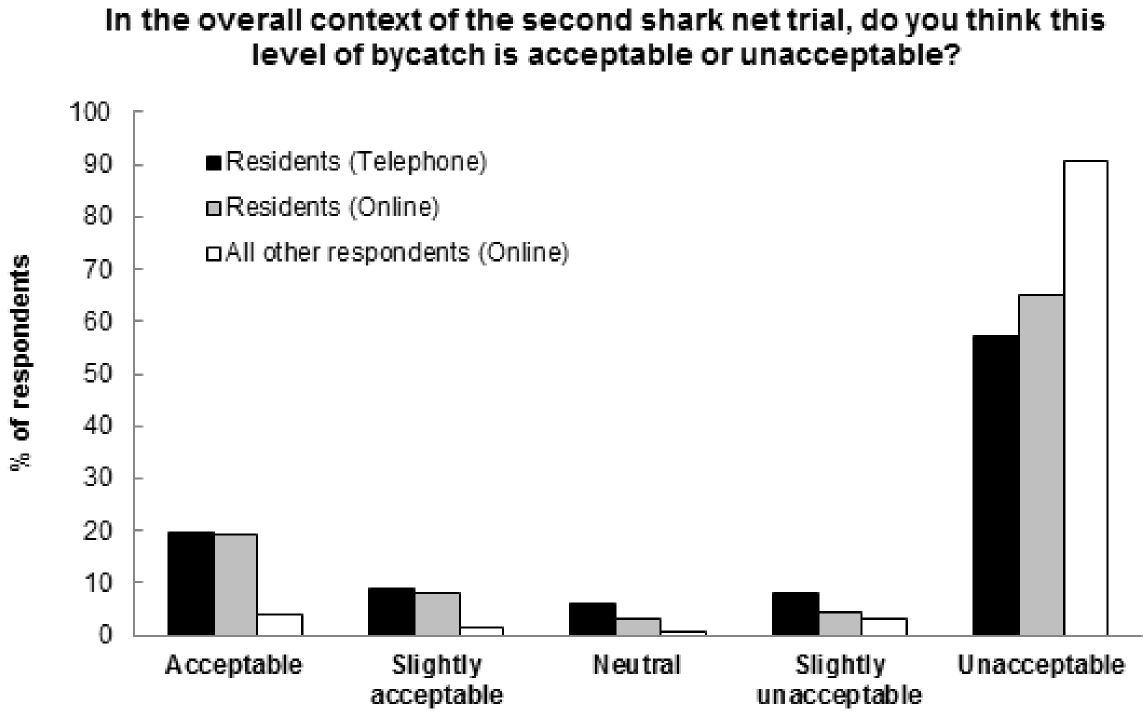
Table 6. Top five reasons provided for being positive (+), negative (–) or neutral (n) about the second net trial for Ballina and Evans Head residents, and those from other locations.

Ballina and Evans Head residents				All other respondents	
Telephone interviews	**%**	**Online questionnaire**	**%**	**Online questionnaire**	**%**
Bycatch a concern (–)	20	Bycatch a concern (–)	55	Bycatch a concern (–)	67
Positive/something's being done (+)	13	Nets ineffective (–)	16	Nets ineffective (–)	23
Nets ineffective (–)	10	Feelings of safety (+)	11	Ocean is shark's territory (n)	21
Does not affect me (n)	8	Decrease in bites/incidents (+)	11	False sense of security (–)	8
Negative – other (–)	8	Ocean is shark's territory (n)	7	Minimal risk of shark bite (n)	7

In both telephone interviews and the online questionnaire, respondents were provided with the following statements: '*Shark nets catch animals other than sharks. During the most recent trial a total of 143 non-target animals (bycatch) were caught in the nets, these included 107 rays, 23 sharks, 8 turtles, 4 dolphins and 1 fish. 60% of non-target animals were released alive and 40% died.'* Respondents were then asked whether this amount of bycatch was acceptable in the overall context of using nets. Possible responses were: 'slightly acceptable or acceptable' (combined for discussion here as 'acceptable'); and 'slightly unacceptable or unacceptable' (combined as 'unacceptable').

During the telephone interviews, 65% of respondents stated the bycatch was unacceptable and 29% said it was acceptable (Fig. 6). This pattern was consistent with the online sample for Ballina and Evans Head residents (69% unacceptable vs 28% acceptable). Respondents from other regions had the strongest opposition to the bycatch, with 94% finding it unacceptable. Local surfers who were randomly selected in the telephone interviews and surfers from other locations who responded to the online questionnaire were also largely unaccepting of the bycatch (telephone: 67% unacceptable vs 31% acceptable; online questionnaire: 77 vs 15%). An exception to this general trend was among local surfers who filled out the online questionnaire. This group was divided in their attitude towards bycatch: 47% found bycatch unacceptable; while 49% found it acceptable.

Figure 6. Percentage of Ballina and Evans Head residents (responding to telephone interviews and the online questionnaire) and those from other locations (online questionnaire) who considered bycatch in the nets acceptable or unacceptable.



Community support for nets compared to other strategies for minimising shark–human interactions

During the survey, questions about the nets were followed by statements and questions relating to the SMART drumlines. The statements presented included: how SMART drumlines work and the numbers of target sharks and non-target species caught by SMART drumlines vs nets. Telephone and online respondents residing in Ballina and the Evans Head region were much more aware of the SMART drumlines prior to the survey (80 and 90%) than online respondents from other locations (62%).

The final survey question asked respondents to what extent they supported ('somewhat support' or 'strongly support') or opposed ('somewhat oppose' or 'strongly oppose') various strategies to mitigate the risk of shark–human interactions on the NSW north coast. In this context, nets consistently had the smallest percentage of support and the largest percentage of opposition by residents during the telephone interviews (34% support vs 56% oppose) and those that completed the online questionnaire (32 vs 66%), and for non-residents (9 vs 89%) and surfers from other locations (20 vs 76%) (Table 7). In all cases, respondents were generally 'strongly' rather than 'somewhat' opposed to nets (Fig. 7a). Surfers from Ballina and Evans Head were more supportive of nets as a protective measure. Among those that responded to the online questionnaire, the majority (53%) were somewhat or strongly supportive rather than opposed (44%), whereas this pattern was reversed for surfers interviewed by telephone (40% support vs 54% oppose).

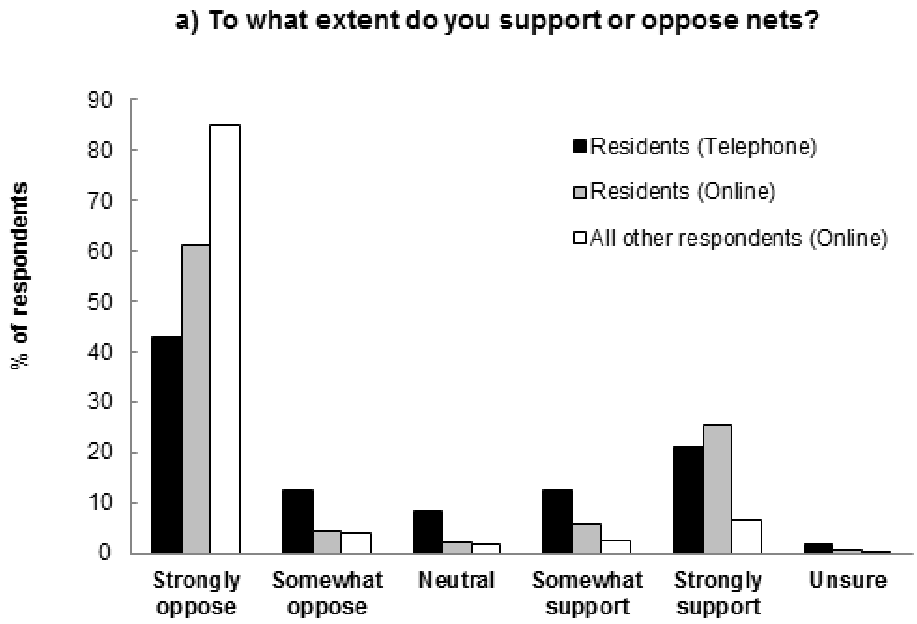
While most residents responding to telephone interviews and the online questionnaire were 'somewhat' or 'strongly' supportive of SMART drumlines, most respondents from other locations indicated they did not support this protective measure (Table 7; Fig. 7b). Surfers from Ballina and Evans Head supported SMART drumlines during telephone interviews (73% support vs 12% oppose) and the online questionnaire (74 vs 21%). In contrast, surfers from other locations were divided (43 vs 45%) about this approach.

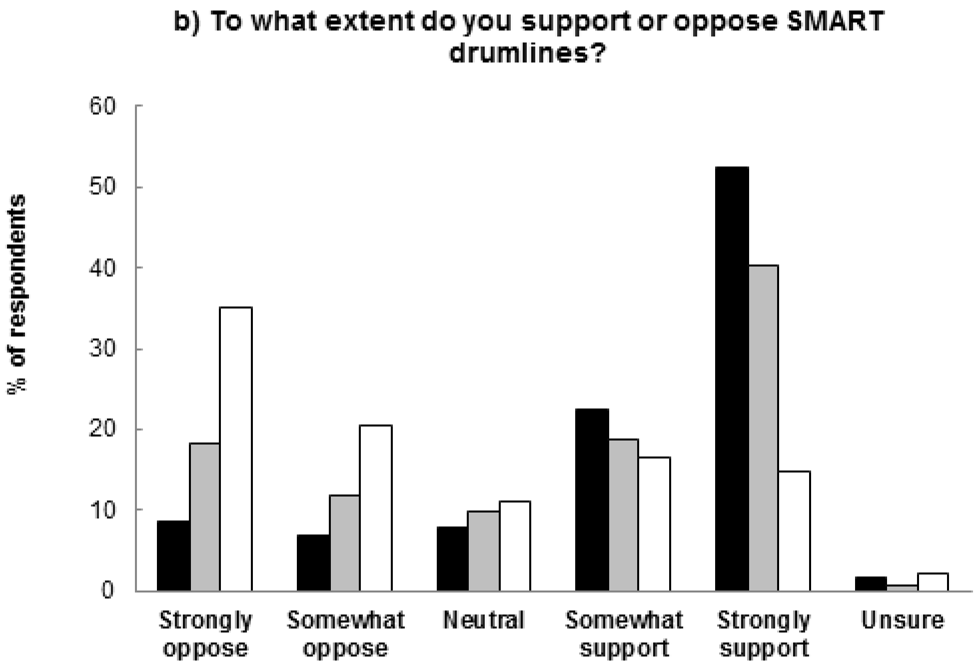
Table 7. Percentage of respondents who 'strongly supported' or 'somewhat supported' (+) vs 'strongly opposed' or 'somewhat opposed' (–) various strategies for mitigating the risk of shark–human interactions.

Strategies to mitigate the risk of shark–human interactions	Ballina and Evans Head residents				All other respondents	
	Telephone interviews		Online questionnaire		Online questionnaire	
	+	–	+	–	+	–
Nets	34	56	32	66	9	89
SMART drumlines	75	16	59	30	31	56
Helicopter surveillance	81	9	82	7	79	8
Drone surveillance	91	4	90	4	88	5
Listening stations to detect tagged sharks	86	4	82	5	82	6
Research to better understand shark numbers/movements	91	3	88	4	93	2
Education about how to be SharkSmart*	90	4	85	4	93	2
Personal responsibility (e.g. personal deterrents, and appropriate precautionary behaviour)	92	1	77	7	87	3

*SharkSmart is a statewide DPI information campaign to help swimmers, surfers, and other water users be aware of how they can minimise the risk of being in waters where sharks may be present (https://www.dpi.nsw.gov.au/fishing/sharks/sharksmart).

Figure 7. Percentage of Ballina and Evans Head residents (telephone interviews and online questionnaire) who and those from other locations (online) who supported and opposed a) nets and b) SMART drumlines to reduce the risk of shark–human interactions son the north coast.





All other proposed strategies to mitigate the risk of shark–human interactions received ≥74% support and ≤12% opposition, regardless of the survey method, the respondent's place of residence or whether they were a surfer (Table 7). An exception to this was for local surfers responding to the online questionnaire, who showed less support (65%) for 'personal responsibility' (e.g. personal deterrents and appropriate precautionary behaviour).

Operational logistics and catches of nets

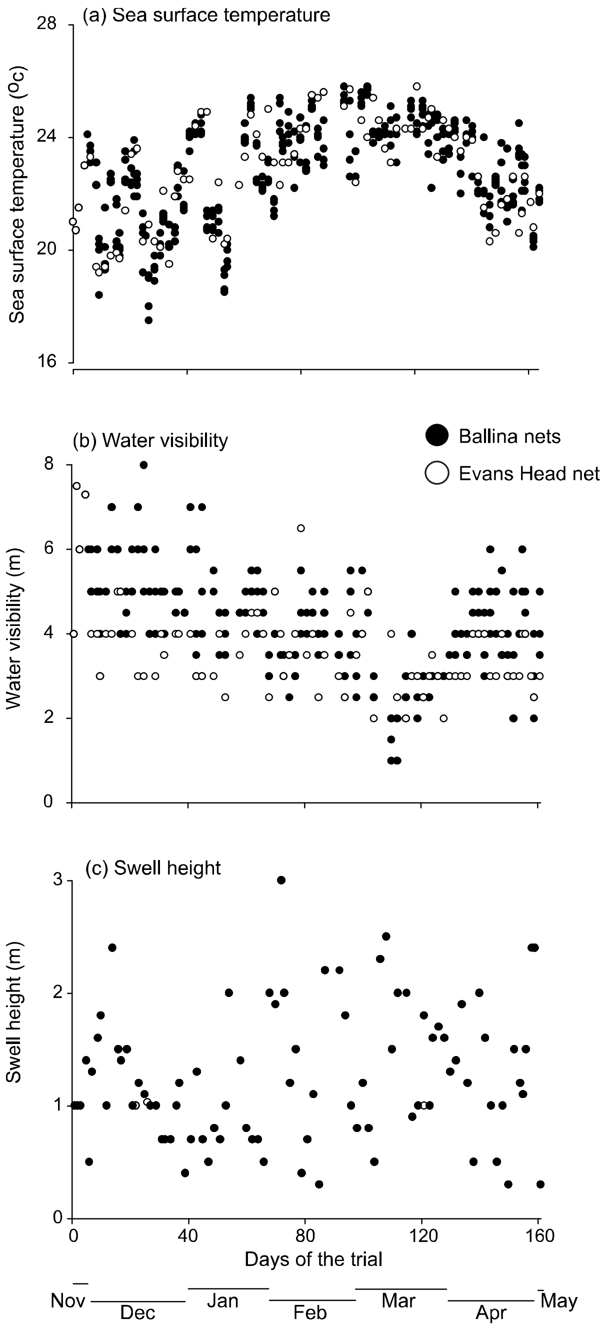
Operational and environmental conditions

The start and end dates of the second trial were 23 November 2017 and 2 May, 2018, encompassing 161 days (inclusive); of which the five nets were each deployed for 148 fishing days (or 93% of the total trial period permitted under the Management Plan). During the fished days, sea surface temperatures warmed from 17.5°C off Ballina in December, 2017 to 25.8°C in March, 2018 at both locations, followed by a steady cooling throughout the remaining six weeks (Table 8, Fig. 8a). Water visibility was similar at the four Ballina nets and at times better than at the Evans Head net, but was poorest at both locations during March (and opposite to peak sea surface temperature; Table 8, Fig. 8b). Swell height remained consistent at both locations, although local seas were variable, and often calmer at Evans Head owing to the protection afforded by the headland (Table 8, Fig. 8c).

Table 8. Average and range of general wind and sea conditions during each fishing day off Ballina and Evans Head.

Location	Water temperature (°C)	Water visibility (m)	Swell (m)	Wind (kn)
Ballina	22.8 (17.5–25.8)	4.3 (1.0–8.0)	1.2 (0.3–3.0)	9.9 (3.0–20.0)
Evans Head	22.8 (19.2–25.8)	3.6 (2.0–7.5)	1.3 (0.3–3.0)	10.0 (3.0–20.0)

Figure 8. Measurements of (a) sea surface temperature (°C), (b) water visibility (m), and (c) swell height (m) at each of the five nets off Ballina and Evans Head for each fishing day (148 days) during the trial (161 days from 23 November, 2017).



All nets were removed three times due to poor weather and for between three and five days (starting 15 January, 17 February and 14 March, 2018). The net contractor was at sea with either their main vessel or a high-speed, cylinder-hull power boat (i.e. purpose designed for river bar crossings) deploying or checking nets across a total of 85 days (or 57% of the days the nets were deployed; Table 9).

Each net was checked 80–82 times, for a total of 403 net checks (Table 9). The time between net checks was 7–70 h but, on average, checks were made every 43 or 44 h (Table 9).The Management Plan stated the nets needed to be checked 12–52 h after the prior inspection, weather permitting. This rate of checking occurred for 93% of the total (i.e. 392 of 423 checks). There was only one occasion when a net was checked within 12 h, which reflected a decision to remove the nets owing due to poor weather on the afternoon after a morning check. There were 30 checks made after 52 h, but 25 of these were still within 56 h of the previous check (i.e. within two fishing nights). Only 5 (or 1%) of the total net checks were between 56 and 70 h (or three fishing nights), which means the contractor was able to achieve a 99% success rate in checking nets as per the required schedule of once every two days. Poor weather and/or a need to coordinate bar crossings with high tide were the reasons for all checks after 52 h.

Of the 403 net checks, 84% comprised floatline checks, 15% were full net removals (for repair or replacement) and 1% were visual checks only. Either the main vessel, high-speed power boat, or a small tender was used to complete floatline and visual checks, while full net removal or deployment usually required the main vessel. The visual checks were typically done as part of a check to ensure the gear was fishing correctly and/or if an animal was observed entangled.

Table 9. **The number of hours within the 148 fishing days that each net was deployed at each beach, the number of times they were checked, and the average and range of time between consecutive checks.**

Beach	Number of hours nets were deployed	Number of times nets were checked	Average and range of h:min between consecutive checks
Lennox Head	3,540	80	44:14 (16:10–70:18)
Sharpes	3,539	80	44:14 (18:13–70:32)
Shelly	3,542	80	44:16 (15:22–70:36)
Lighthouse	3,543	82	43:13 (15:51–70:33)
Evans Head	3,573	81	44:07 (07:44–59:00)

Net damage

During checks, the nets were occasionally observed to have moved slightly (e.g. <20 m) from their deployed positions, and there were two occasions when they were displaced >100 m. The first occasion involved the Lighthouse Beach net on 2 February, 2018 which moved northeast ~100 m and became entangled around one of the SMS's anchored 'VR4G' buoys (used to inform of electronically tagged target sharks in the area). The net was extensively damaged throughout and it remains unknown if displacement was caused by a large animal which then escaped, or adverse weather conditions (i.e. 3-m swell). The net was immediately recovered and a new net positioned further south of the VR4G.

The second major net displacement occurred at Evans Head on 30 March, 2018. The net was located ~1 km east of its anchored position and was extensively entangled with kelp. Possibly, the kelp was washed into the net by the tide, displacing the anchors, and then the configuration moved eastwards. The net was recovered with minimal damage.

In between checks, nets at all beaches sometimes incurred damage that frequently comprised multiple broken or missing bars (2–4,050) at up to seven separate locations per net. Broken or missing bars were sometimes associated with a large animal being meshed and removed (total of 42 times pooled across all net types). However, among all net types, on 67 occasions (or during 16% of net checks) a large hole was present and no animal was caught (Table 10).

In terms of bar damage among modified nets, there were few relative differences between midwater- and shallow-set nets or those made from PA or PE twine, but the 800-mm PE twine nets were more readily damaged than the 600-mm PE twine nets; presumably owing to less overall twine area (Table 11). One consideration with the PA nets was that, owing to the greater wet weight (because of thicker twine), they were slightly more difficult to check or remove in rough weather. By comparison, the lighter PE nets could be rapidly and easily removed during all of the experienced sea conditions.

Table 10. Number of times a net was checked and observed to be damaged with and without an animal present (pooled across all types of nets fished at each beach).

Beach	Number of net checks	Number of times mesh bars* were broken with an animal caught	Number of times ≥2 mesh bars (>0.36 m^2) were broken with no animal caught
Lennox Head	80	8	11
Sharpes	80	5	16
Shelly	80	5	14
Lighthouse	82	8	13
Evans Head	81	16	13
Total	**403**	**42**	**67**

*See Fig. 2 for an explanation of mesh bars.

Table 11. Number of times nets within the three different modifications were damaged with and without an animal present (pooled across beaches).

Type of modification	Number of net checks	Number of times mesh bars* were broken with an animal caught	Number of times ≥2 mesh bars (>0.36 m^2) were broken with no animal caught
Vertical fishing height (all 600-mm PE-mesh nets)			
Midwater (2.0 m)	144	20	29
Shallow (0.5 m)	123	17	19
Mesh size (all midwater-set PE-mesh nets)			
600 mm	55	4	4
800 mm	49	1	11
Material (all midwater-set 800-mm mesh nets)			
PE	16	0	2
PA	16	0	2
Total	**403**	**42**	**67**

*See Fig. 2 for an explanation of mesh bars. PE: polyethylene; and PA: polyamide.

Another noteworthy operational consideration was that because the shallow-set nets were rigged with short buoy lines they were more vulnerable to movement by swell, and wear on the floatlines. On several occasions the floatlines broke and had to be replaced. This issue was not observed for midwater-set nets because the 2.0-m buoy lines presumably dampened some of the vertical movement.

Total catch

In total, 145 animals comprising 17 species were caught in the five nets (Table 12). The species included: Whitespotted Eagle Ray (*Aetobatus ocellatus*), Australian Cownose Ray

(*Rhinoptera neglecta*), Pygmy Devilray (*Mobula kuhlii* cf. *eregoodootenkee*), Great Hammerhead (*Sphyrna mokarran*), Common Blacktip Shark (*Carcharhinus limbatus*), Whitespotted Guitarfish (*Rhynchobatus australiae*), Manta Ray (*Manta alfredi*), Spinner Shark (*Carcharhinus brevipinna*), Bull Shark (*Carcharhinus leucas*), Greynurse Shark (*Carcharias taurus*), Loggerhead Turtle (*Caretta caretta*), Indo-Pacific Bottlenose Dolphin (*Tursiops aduncus*), Green Turtle (*Chelonia mydas*), Common Dolphin (*Delphinus delphis*), Hawksbill Turtle (*Eretmochelys imbricata*), Leatherback Turtle (*Dermochelys coriacea*), and Yellowfin Tuna (*Thunnus albacares*) (Table 12). Catches of five species (Whitespotted Eagle Ray, Australian Cownose Ray, Pygmy Devilray, Great Hammerhead, and Common Blacktip Shark) comprised 83% of the catch (Table 12). Using the total hours fished across all five nets (Table 9), the standardised catch of target sharks was 0.0005 individuals per net per 24-hour soak.

Table 12. Numbers of each species (within broad groups) caught by the nets (pooled across all types/modifications) at each beach and cumulative totals and sizes.

	Lennox Head	Sharpes	Shelly	Light-house	Evans Head	Total number (mean size* and range in m)
Sharks and rays						
Whitespotted Eagle Ray	5	6	11	11	10	**43** (1.6; 0.7–2.1)
Australian Cownose Ray	3	0	0	1	38	**42** (0.8; 0.7–1.0)
Pygmy Devilray[1]	11	1	1	1	0	**14** (1.1; 1.0.–1.2)
Great Hammerhead[1]	3	2	0	1	5	**11** (3.1; 2.7–3.6)
Common Blacktip Shark	1	2	3	0	2	**8** (2.0; 1.2–2.5)
Whitespotted Guitarfish	1	1	1	0	2	**5** (2.0; 0.7–2.6)
Manta Ray[1]	1	0	0	0	2	**3** (3.0; 2.4–3.5)
Spinner Shark	0	0	0	0	3	**3** (1.9; 1.1– 2.8)
Bull Shark	0	0	1	1	0	**2** (2.6; 2.5–2.8)
Greynurse Shark	0	0	0	0	1	**1** (2.5)
Other animals						
Loggerhead Turtle[1]	0	0	0	2	2	**4** (1.0; 0.8–1.1)
Indo-Pacific Bottlenose Dolphin[1]	0	0	0	1	2	**3** (1.9; 1.4–2.3)
Green Turtle[1]	0	1	0	0	1	**2** (0.7; 0.5–0.8)
Common Dolphin[1]	0	0	0	1	0	**1** (2.3)
Hawksbill Turtle[1]	0	1	0	0	0	**1** (0.4)
Leatherback Turtle[1]	0	0	1	0	0	**1** (1.3)
Yellowfin Tuna	0	0	0	1	0	**1** (0.6)
Total	**25**	**14**	**18**	**20**	**68**	**145**

[1]Species designated as 'Listed Fauna' in the Management Plan (i.e. threatened and protected); *Total length: sharks, fish and dolphins; disc width: rays; and curved carapace length: turtles.

Of the three target species, two Bull Sharks (both females, 2.5 and 2.8 m TL) were caught in the Shelly (28 November, 2017) and Lighthouse nets (5 February, 2018), respectively (both shallow-set nets; Table 12). The smaller Bull Shark was released alive, but the larger one died and during necropsy was found to be pregnant with six embryos.

In terms of entanglement, all but six animals (including one of the Bull Sharks) made contact at the eastern (or seaward) side of the nets, and most were either mildly or moderately entangled (Table 13). Across most beaches, there was a fairly even distribution of entanglement at either end or middle of the nets (Table 13).

Table 13. Numbers of animals entangled on the eastern or western side, and southern, mid or northern length of the nets and their extent of entanglement.

	Lennox Head	Sharpes	Shelly	Lighthouse	Evans Head
Side of the net					
Eastern (seaward)	24	14	15	18	68
Western (landward)	1	0	3	2	0
Length of the net					
Southern third	8	3	7	5	22
Mid third	11	9	6	10	27
Northern third	6	2	5	5	19
Entanglement status					
Extreme	5	1	0	1	0
Moderate	3	4	5	6	7
Mild	17	9	13	13	61

Variability among catches from all nets over time

Except for a single incident when 10 animals (all Australian Cownose Rays) were caught in the Evans Head net, the maximum catch was seven animals per net, irrespective of time between net checks (Fig. 9). While the larger single incidences of catches occurred during the longer soak times, owing to the large number of checks with zero catches (i.e. ~80% of net checks), there was no statistical relationship with net-checking frequency (Fig. 9). Therefore, for the purposes of comparing relative catches among nets during the trial, the numbers of total animals, and the five most abundant species were standardised to number-per-net-check (Fig. 10).

Figure 9. Numbers of animals caught per net in (a) all Ballina nets and (b) the Evans Head net during checks within approximately 1.5 days (or 1 night; 8–36 h), 2.5 days (2 nights; 38–60 h) and three days (3 nights; 70 h). The number of net checks done in each period is listed.

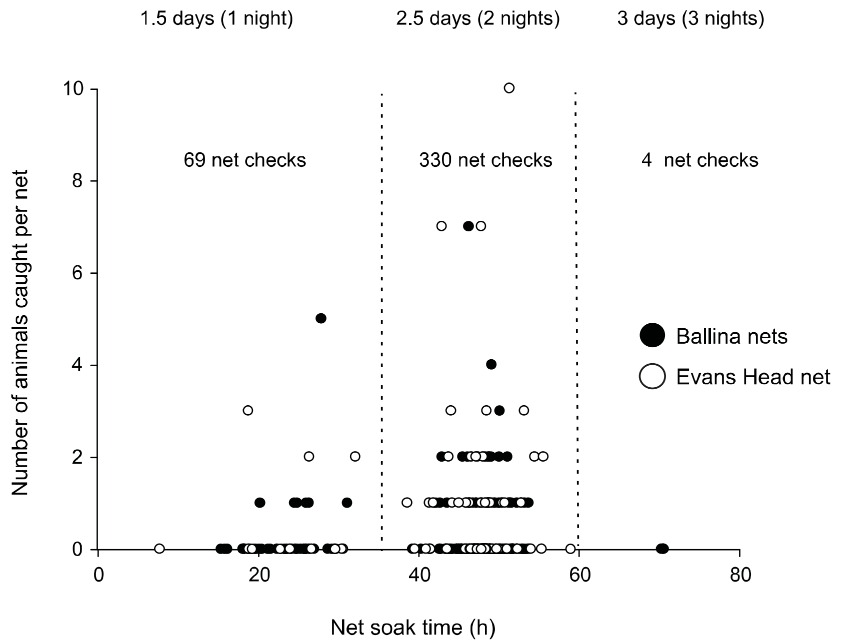
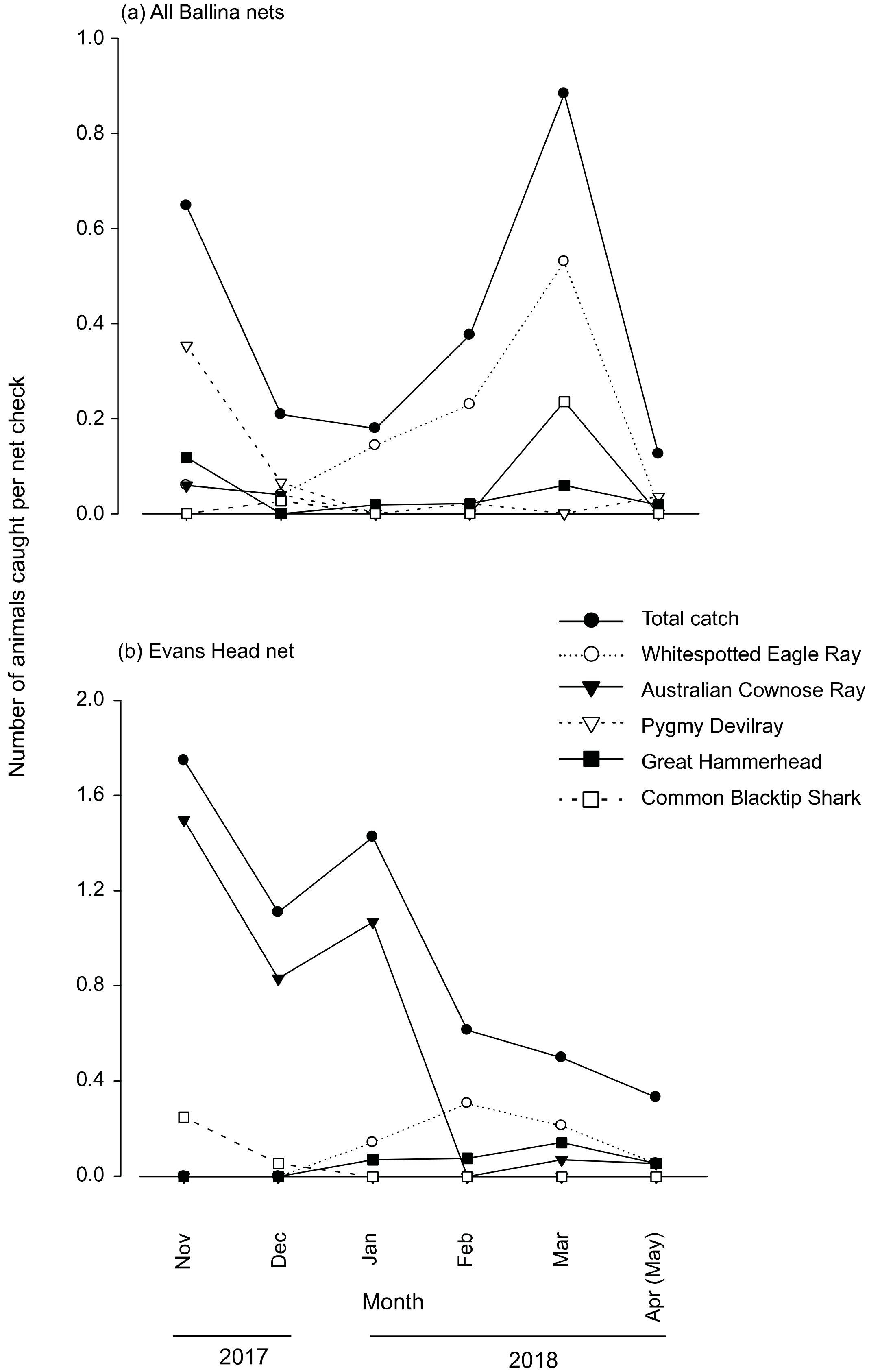


Figure 10. Numbers of total catch and key species per net check in (a) all Ballina nets and (b) the Evans Head net during each month of the trial (only two fishing days were in May and so these data were grouped with April).



Off Ballina, most numbers-per-net-check of the key animals peaked at the start of the trial (in late November, 2017), and then again in March, 2018; which was also the month with the warmest sea-surface temperatures and the poorest visibilities (Figs 8a and b, 10a and b). The total catch number-per-net-check at Evans Head was also relatively greater at the start of the trial, due to Australian Cownose Rays which were not very abundant after January (Fig. 10). Like off Ballina, all other key species showed peaks in numbers-per-net-check at Evans Head during February and March (Fig. 10).

Notwithstanding the above trends, an important consideration when interpreting variation in total catches over time is the confounding effects of the three different configurations of nets at each beach; especially the change in mesh size (Table 1). Variation in relative catches associated with the three groups of modifications is outlined below.

Variability among catches between modifications to nets

Given the low total catch during the second trial (145 animals), the utility of catch comparisons within the three different modifications was limited, and with the key species restricted to Whitespotted Eagle Rays and/or Australian Cownose Rays (Table 14, Fig. 11). Further, for the comparison of PA and PE twines, very few net checks (16 of each) and catches (two animals in each) prevented any coherent interpretation (Table 14).

Table 14. Number of times nets within the three different modifications were checked (pooled across beaches) and their catches of total species and the two most abundant.

Type of modification	No. of net checks	No. of total catch	No. of Whitespotted Eagle Ray	No. of Australian Cownose Ray
Vertical fishing height (all 600-mm PE-mesh nets)				
Midwater (2.0 m)	144	73	18	28
Shallow (0.5 m)	123	49	14	14
Mesh size (all midwater-set PE-mesh nets)				
600 mm	55	9	3	0
800 mm	49	10	8	0
Material (all midwater-set 800-mm mesh nets)				
PE	16	2	0	0
PA	16	2	0	0
Total	**403**	**145**	**43**	**42**

PE, polyethylene; and PA, polyamide

Notwithstanding the few data, during the comparison of midwater- and shallow-set nets (all 600-mm mesh and PE twine), the mean numbers-per-net-check of total catches and Whitespotted Eagle Rays were slightly greater in midwater-set nets, while Australian Cownose Rays, and pooled catches of all turtles and all dolphins were relatively less in shallow-set nets (Table 14, Fig. 11a–c and f–h). More specifically, three of the four Loggerhead Turtles and one Green Turtle were caught in midwater-set nets, while the single Hawksbill Turtle was caught in a shallow-set net. Similarly, three of the four dolphins were caught in midwater-set nets (although two were caught at the same time). Both of the Bull Sharks were caught in shallow-set nets, and when their catches were combined with other non-target members of the same genus (termed ‘carcharhinid sharks’, including

Common Blacktip and Spinner sharks), mean numbers-per-net-check were slightly greater in shallow-set nets (Fig. 11d). The mean numbers-per-net-check of Great Hammerheads and Pygmy Devilrays were similarly consistent, irrespective of net-setting depth (Fig. 11d and e).

Figure 11. Differences between midwater- and shallow-set nets (all made from 600-mm polyethylene mesh) for mean (+ the standard error) numbers-per-net-check of: (a) total catch; (b) Whitespotted Eagle Ray; (c) Australian Cownose Ray; (d) Pygmy Devilray; (e) Great Hammerhead; (f) all carcharhinid sharks (Bull, Common Blacktip and Spinner); (g) all turtles (Loggerhead, Green, and Hawksbill); and (h) all dolphins (Common and Indo-Pacific).

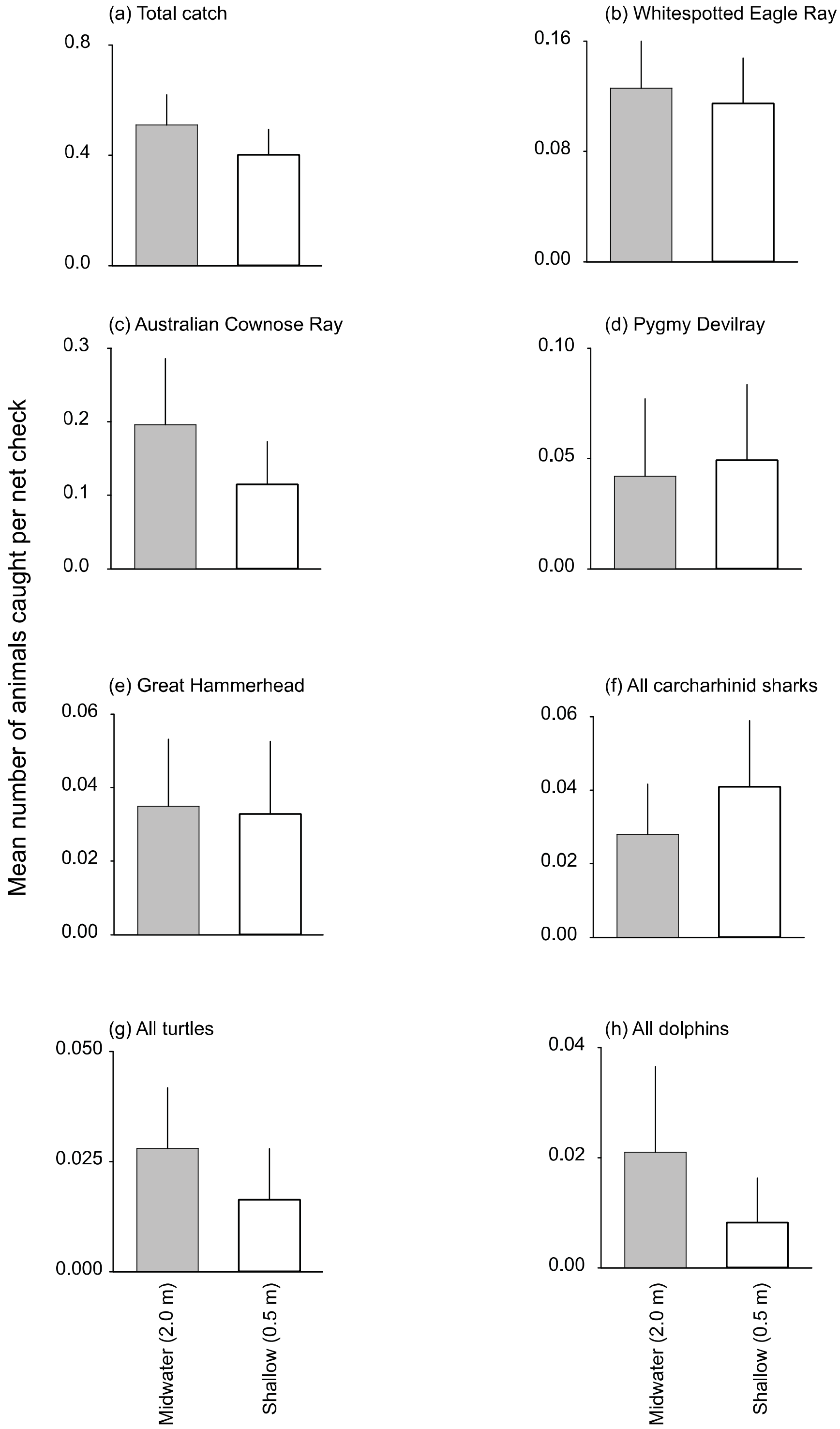
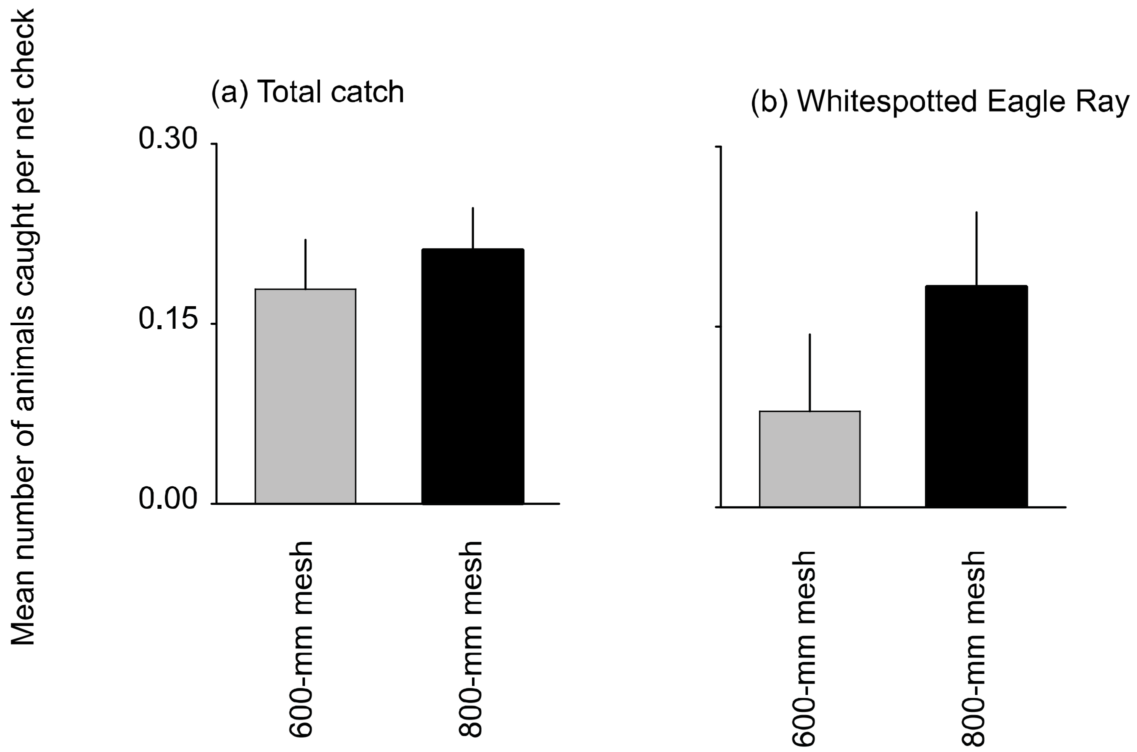


Figure 12. Differences between nets (all made from polyethylene twine) with 600- and 800-mm mesh for mean (+ standard error) numbers-per-net-check of: (a) total catch; and (b) Whitespotted Eagle Ray.



Owing to few data, the effect of changing mesh size was marginal (Table 14, Fig. 12). Whitespotted Eagle Rays were the dominant catch and their mean number-per-net-check was slightly greater in the 800-mm mesh which accounted for the greater mean total catch (Table 14, Fig. 12).

Survival of catches

Irrespective of the net configurations, 88 animals were released alive and 57 were observed dead during net checks. A Leatherback Turtle that was released alive was subsequently found stranded and dead on a beach 65 km to the south, while a Manta Ray found dead on a beach at Evans Head was thought to have been released from the Evans Head net (Table 15). With or without the latter animal, total survival was 60 or 61% (Table 15).

There was considerable species-specific variability in survival. Among the most abundant species, Whitespotted Eagle Rays and Australian Cownose Rays had the greatest survival (91 and 79%, respectively; Table 15). Great Hammerheads and Common Blacktip Sharks had the poorest survival, with many dead during net checks. Relatively few individuals of the remaining species were caught, precluding definitive statements about species-specific trends (Table 15).

Only three animals (or 2% of all caught) were depredated while entangled in the nets, and all were dead: a Whitespotted Guitarfish that was caught adjacent to the dead Bull Shark and had been virtually entirely consumed (only the tail remained); a Whitespotted Eagle Ray with a single bite mark to the right side; and the Yellowfin Tuna, which was missing ~50% of its anterior body. No other animals had any bite marks while entangled in the nets.

Table 15. Number of alive and dead animals observed during or after each net check, and the percentage survival.

Species	Number alive	Number dead	Percentage survival
Sharks and rays			
Whitespotted Eagle Ray	39	4	91
Australian Cownose Ray	33	9	79
Pygmy Devilray	2	12	14
Great Hammerhead	0	11	0
Common Blacktip Shark	1	7	13
Whitespotted Guitarfish	3	2	60
Manta Ray	3[a]	0	100
Spinner Shark	0	3	0
Bull Shark	1	1	50
Greynurse Shark	1	0	100
Other animals			
Loggerhead Turtle	4	0	100
Indo-Pacific Bottlenose Dolphin	0	3	0
Green Turtle	0	2	0
Common Dolphin	0	1	0
Hawksbill Turtle	0	1	0
Leatherback Turtle	0	1[b]	0
Yellowfin Tuna	0	1	0
Total	**87**	**58**	**60**

[a]One Manta Ray was found stranded at Airforce Beach, Evans Head and was probably a netted-and-released animal, but the sample was too decomposed to confirm. [b]Animal was released alive but later found stranded on a beach at Yamba (Table 13).

Table 16. Summary of the capture time (chronological order), sizes and sexes of turtles and dolphins that died in the nets, and the key necropsy findings by veterinarians.

Species	Capture date	Size* (m) and sex	Key necropsy findings
Green Turtle #1	13/12/2017	0.5 (possibly female)	Juvenile with no obvious diseases or disorders.
Hawksbill Turtle	06/12/2017	0.4 (female)	Sub-adult with chronic disease and very poor condition.
Common Dolphin	8/01/2018	2.3 (female)	Adult with no obvious abnormalities. Not recognised as a local resident in existing databases.
Indo-Pacific Bottlenose Dolphin #1	5/02/2018	2.3 (female)	Adult with no obvious abnormalities. Not recognised as a local resident in existing databases.
Indo-Pacific Bottlenose Dolphin #2	3/04/2018	2.0 (female)	Adult with no obvious abnormalities. Not recognised as a local resident in existing databases
Indo-Pacific Bottlenose Dolphin #3	3/04/2018	1.3 (male)	Calf caught with Indo-Pacific Bottlenose Dolphin #2 during the same net check. No obvious abnormalities.
Green Turtle #2	25/04/2018	0.8 (female)	Sub-adult with no obvious diseases or disorders.

*Size: Total length: dolphins; and curved carapace length: turtles.

Along with two Green Turtles (listed as Vulnerable), one Hawksbill Turtle (Vulnerable), all three Indo-Pacific Bottlenose Dolphins and the Common Dolphin died in the nets. These animals were necropsied by veterinarians and only the Hawksbill was considered to be unhealthy (Table 16). The dolphins were caught during net soaks of 47–50 h and in nets equipped with FO10 and FO3 pingers. All pingers were subsequently checked and found to be fully operational. Based on existing morphological databases, none of the four dolphins were identified as being local residents of the local population. The Leatherback, Green and Hawksbill turtles were caught during net soaks of 48–51 h.

Figure 13. Jitter plot of the total numbers of animals (each dot is an animal) that were alive or dead at each net check (soak time), with percentage survival after approximately 1.5 days (or 1 night; 8–36 h) and 2.5 days (2 nights; 38–60 h).

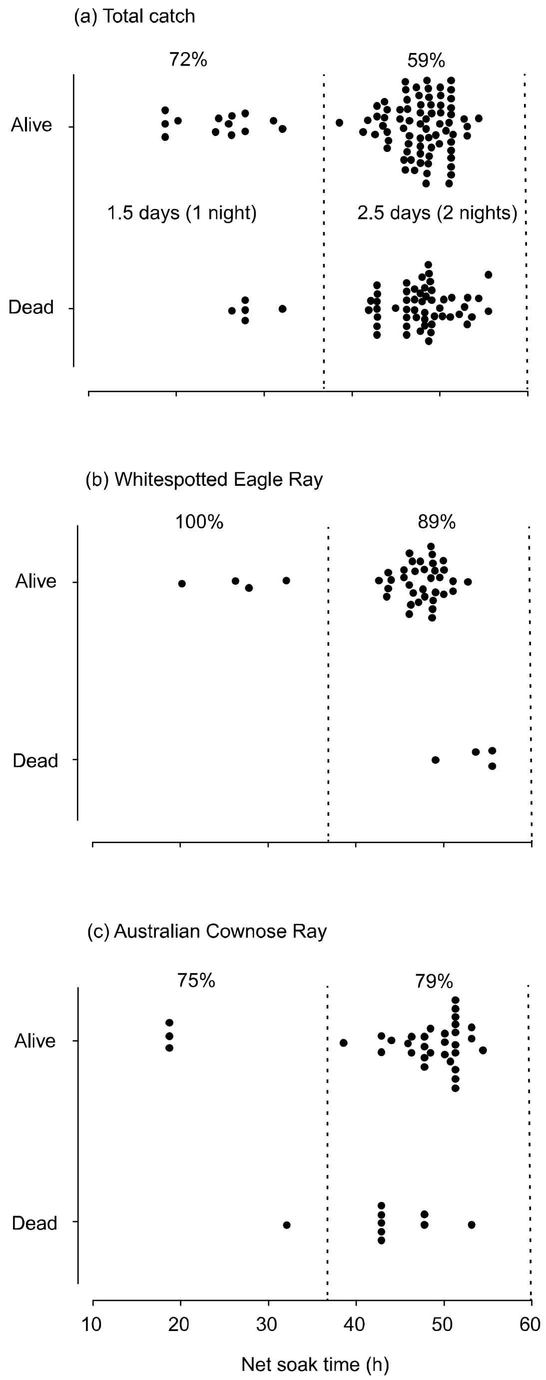


Table 17. Summary of stranded species (and dates) on beaches from Wooli to the Tweed River during the trial (23 November, 2017 to 2 May, 2018) and, where available, their size, sex, and key necropsy findings.

Species	Stranding date	Stranding location	Size* (m) and sex	Key necropsy findings/comments
Loggerhead Turtle	16/12/2017	Tyagarah Beach, Byron Bay	NA	Animal was buried on site without a necropsy.
Unknown turtle	01/01/2018	Evans Head	NA	Animal was caught in a crab trap and disposed of without a necropsy.
Green Turtle	04/01/2018	Wooli	NA	Animal was reported as being depredated by a shark.
Indo-Pacific Bottlenose Dolphin	05/01/2018	Broken Head, Byron Bay	2.4 (male)	Animal had evidence of substantial blunt force trauma between the 'blowhole' and dorsal fin.
Loggerhead Turtle	06/01/2018	Tallows Beach, Byron Bay	0.9 (female)	Adult with no obvious abnormalities. Did not match sizes or images of the four Loggerhead Turtles released from the nets.
Hawksbill Turtle	09/01/2018	Woody Head	NA	Animal had head missing, and was buried on site and without a necropsy.
Common Dolphin	09/02/2018	Wooyung Beach, Pottsville	1.2 (female)	Juvenile (4–6 weeks old) that died from pneumonia caused by lungworms.
Loggerhead Turtle	11/02/2018	Tyagarah Beach, Byron Bay	NA	Animal was buried on site and without necropsy.
Manta Ray	16/02/2018	Airforce Beach, Evans Head	~3.0 (female)	Animal was very decomposed, but possibly the same as that released from the Evans Head net three days earlier.
Fraser's Dolphin	23/02/2018	Airforce Beach, Evans Head	2.5 (male)	Adult with mild trauma to the rostrum, but extensive internal bacterial infection (diagnosed as cause of death).
Green Turtle	28/02/2018	Brunswick Heads	NA	A juvenile with severe boat-strike injuries. Buried on site without necropsy.
Hawksbill Turtle	08/03/2018	Wooli	NA	Animal was alive and with no obvious injuries, but emancipated. It was transferred to care.
Loggerhead or Hawksbill Turtle	11/03/2018	Lennox Head	NA	Animal buried on site without necropsy.
Pantropical Spotted Dolphin	01/04/2018	Wooli	2.3 (female)	Old adult in excellent physical condition and with no external injuries, but was not formally necropsied.
Leatherback Turtle	05/04/2018	Rabbit Island, Clarence River	1.3 (female)	Animal was confirmed as that released alive from the Shelly Beach net two days earlier. The carcass was depredated and was missing the left pectoral flipper and part of the posterior carapace. No other abnormalities.
Loggerhead Turtle	11/04/2018	Brunswick Heads	0.9 (female)	Adult with no obvious abnormalities. Did not match the four Loggerhead Turtles released from the nets.
Loggerhead Turtle	18/04/2018	Shelly Beach, Ballina	0.9 (female)	Adult with no obvious abnormalities and in good condition. Did not match the four Loggerhead Turtles released from the nets and had no external trauma.
Unknown cetacean	10/05/2018	Wooli	Na	Portion of carcass only.

NA: not available;*Size: Total length: dolphins; disc width: rays; and curved carapace length: turtles.

Lack of data precluded formal analyses of factors affecting the survival of individual species in the nets. Nevertheless, previous studies have established that the longer that animals remain in similar gillnets, the lower their survival, and so the effect of net soak time (i.e. net checking frequency) on survival was plotted for total catch. Total survival was 72 and 59% for net checks after 1.5 and 2.5 days, respectively (Fig. 13a). Similarly there was 100% survival for Whitespotted Eagle Rays during the shorter net checks vs 89% after 2.5 days, but the opposite occurred for Australian Cownose Rays (75 vs 79%; Fig. 13b and c).

In addition to the netted catches, 18 stranded dolphins, turtles and rays were reported along the coastline from the Tweed River (28.1°S) to Wooli (29.9°S), and seven were necropsied by veterinarians (Table 17). One of these animals, a Leatherback Turtle was confirmed by a veterinarian as being the same individual released from the Shelly Beach net three days earlier, while a stranded Manta Ray was identified as possibly being the same one released from the Evans Head net three days earlier (Table 17). None of the other necropsied animals were presumed to have interacted with the nets or SMART drumlines.

Operational logistics and catches of SMART drumlines

Operational and environmental conditions

During the 161-day second trial, 3,070 SMART drumline deployments, encompassing 27,271 h, were completed during 101 (1,515 deployments at an average of 8:34 h:m per day) and 104 (1,555 deployments at an average of 9:11 h:m per day) days off Ballina and Evans Head, respectively (i.e. fished for 65% of the trial days; Table 18). During each fishing day, SMART drumlines were deployed at 05:25–08:25 and retrieved at 11:30–18:03. The daily soak time was influenced by environmental conditions, which varied daily between locations and were often better in the morning than afternoon (Table 18). Weather conditions, including sea surface temperatures and water visibility, in the areas fished by SMART drumlines encompassed those recorded for the nets (Table 8).

SMART drumlines were deployed at their designated locations off Evans Head each day, but due to dangerous surf conditions, the SMART drumline at location 6 was moved to location 11 on 61 fishing days (Fig. 4). Further, owing to gear repairs, only 14 of the 15 SMART drumlines were deployed off Evans Head during the first five days of the trial. Deploying SMART drumlines at locations 14 and 15 off Main Beach, Lennox Head was also problematic during strong north easterly winds on nine days (Fig. 4). These SMART drumlines were sometimes repositioned at South Ballina Beach (location 16), but mostly (94%) at Angels Beach, Ballina (locations 21–24) (Fig. 4).

Table 18. The average and range of general wind and sea conditions when SMART drumlines were deployed and retrieved daily off Ballina and Evans Head.

Location	Time	Wind (kn)	Sea (m)	Swell (m)
Ballina	Deployment Retrieval	12.0 (4.0–26.0) 16.7 (7.0–29.0)	0.6 (0.0–1.5) 0.8 (0.0–2.0)	1.0 (0.0–2.5) 1.0 (0.0–2.0)
Evans Head	Deployment Retrieval	7.0 (0.0–24.0) 13.6 (4.0–37.0)	1.0 (0.0–1.5) 1.0 (0.5–2.0)	1.3 (0.6–2.5) 1.3 (0.6–3.0)

Overall, 94 and 73% of the total numbers of hooks on SMART drumlines deployed off Ballina and Evans Head, respectively, had 100% of their baits remaining at the end of each day. Only 4 and 12% of the hooks deployed off Ballina and Evans Head, respectively, had no bait left on retrieval, while other baits had various bite marks consistent with small hammerheads (*Sphyrna* spp.) and whaler sharks (*Carcharhinus* spp.).

Total catches

Target sharks comprised 50% of the total catch and included nine White Sharks (four males and five females with a mean size of 2.7 m TL and range of 2.3−3.9 m TL), four Tiger Sharks (three males and one unknown; 1.6, ~1.8, 2.1 and 2.2 m TL), and three Bull Sharks (one male, 1.9 TL; two female, 2.5 and 2.9 m TL). The remaining bycatch included seven Smooth Hammerheads (*Sphyrna zygaena*) (one male and six females; mean 1.8 m TL, range 1.4−2.1 m TL), two Greynurse Sharks (both female, 2.7 m TL), four Common Blacktip Sharks (three females, 2.0, 2.1, and 2.3 m TL and one unknown sex, ~1.5 m TL), one Sandbar Shark (*Carcharhinus plumbeus*) (male, 2.0 m TL), one Dusky Whaler (male, 1.7 m TL), and one Black Marlin (*Istiompax indica*) (unknown sex, 1.9 m TL) (Tables 19 and 20).

Sixty-five alerts were received from the SMART drumlines; of which 31 resulted in the capture of animals. One Bull Shark (male, 1.9 m TL) was found hooked at the end of the day without any alert from the SMART drumline system providing a total catch of 32 animals (Tables 19 and 20). One Tiger Shark (~ 1.8 m TL at Boulders Beach, Ballina) and one Common Blacktip Shark (Airforce Beach, Evans Head) escaped while being secured to the contractor vessel (Tables 19 and 20). Of the 34 alerts that had no catch on arrival, 41 and 47% had the bait missing or still fully intact, respectively when the contractor arrived.

Table 19. The number of days SMART drumlines were deployed, their mean and range of daily deployment hours (h) and minutes (min), number of alerts and the reason for alerts at each location.

Location	Number of days SMART drumlines were deployed	Mean and range of deployment (h:min)	Number of alerts	Reasons for alert
Ballina	101	8:34 (2:57–11:11)	38	7 Smooth Hammerheads 4 Tiger Sharks 3 White Sharks 2 Bull Sharks (3 total*) 2 Common Blacktip Sharks 1 Sandbar Shark 1 Black Marlin 1 Dusky Whaler 17 no catch
Evans Head	104	9:11 (4:31–10:59)	27	6 White Sharks 2 Greynurse Sharks 2 Common Blacktip Sharks 17 no catch

*One Bull Shark did not trigger the SMART buoy.

By considering the total hours of soak time and number of deployments across all SMART drumlines, the catch-per-unit-of-effort for target sharks equates to 0.005 individuals per SMART drumline per 8.0-hour soak (Fig. 14). Sharks were caught across the entire regions at Evans Head and Ballina, except at Shelly Beach or Angels Beach, Ballina (Fig. 4). There were four occasions when multiple sharks were caught on the same days. This occurred on the 23 November, 2017 (a White Shark at Main Beach, Evans Head and a Bull Shark at South Wall, Ballina), 9 December, 2017 (two White Sharks at Joggly Point and Airforce Beach, Evans Head), 27 January, 2018 (a Smooth Hammerhead at Sharpes Beach, Ballina and a Common Blacktip Shark at Lennox Headland) and 26 April, 2018 (a Greynurse Shark at Main Beach, Evans Head and a Bull Shark at Sharpes Beach, Ballina).

There was no trend in the time of day that White Sharks were hooked (Table 20, Fig. 15). However, there was a trend for month of capture with all White Sharks caught off Evans Head in November and early December and off Ballina from mid-December to mid-January (Table 20, Fig. 14). Too few sharks or other animals were caught to discuss other trends.

Table 20. The location of SMART drumlines (SD number) off Ballina and Evans Head, and the date and time of capture of species and their sizes (total length in m), sex and status.

Beach name	Date	Time	Species	Size (m) and sex	Status
Ballina					
Main Beach, Lennox Head (SD nos 14–15)	04/03/2018	13:26	Tiger Shark	1.6; male	Alive
	31/12/2017	11:05	White Shark	2.3; male	Alive
Lennox Headland (SD no. 13)	05/12/2017	09:38	Smooth Hammerhead	1.6; female	Alive
	08/12/2017	08:47	Dusky Whaler	1.7; male	Alive
	06/01/2018	14:52	Tiger Shark	2.1; male	Alive
	27/01/2018	11:52	Common Blacktip Shark	2.3; female	Alive
	19/03/2018	16:00	Common Blacktip Shark	2.0; female	Alive
Boulders Beach (SD no. 12)	25/02/2018	10:10[a]	Tiger Shark	~1.8; unknown	Alive
Sharpes Beach (SD nos 9–11)	29/11/2017	14:16	Smooth Hammerhead	1.8; female	Alive
	07/12/2017	08:48	Smooth Hammerhead	1.8; male	Alive
	02/04/2018	13:00	Smooth Hammerhead	2.1: female	Alive
	13/04/2018	08:45	Smooth Hammerhead	1.8; female	Alive
	26/04/2018	16:30[b]	Bull Shark	1.9; male	Alive
	04/01/2018	09:14	Black Marlin	1.9; unknown	Dead
	20/01/2018	09:23	White Shark	3.9; female	Alive
	23/01/2018	15:16	Bull Shark	2.5; female	Alive
	27/01/2018	10:51	Smooth Hammerhead	1.9; female	Alive
Lighthouse Beach (SD nos 3–5)	15/02/2018	09:55	Tiger Shark	2.2; male	Alive
South Wall (SD nos 1–2)	23/11/2017	13:21	Bull Shark	2.9; female	Alive
	18/12/2017	07:50	Smooth Hammerhead	1.4; female	Alive
	19/12/2017	16:39	White Shark	2.7; male	Alive
	24/02/2018	14:55	Sandbar Shark	2.0; male	Alive
Evans Head					
Airforce Beach (SD nos 14–17)	09/12/2017	12:26	White Shark	2.8; female	Alive
	18/03/2018	14:54[a]	Common Blacktip Shark	~1.5; unknown	Alive
Main Beach (SD nos 3.1–11)	23/11/2017	10:04	White Shark	2.6; Female	Alive
	30/11/2017	09:45	White Shark	2.5; Male	Alive
	30/11/2017	10:49	Greynurse Shark	2.7: Female	Alive
	04/12/2017	08:02	White Shark	2.4; Female	Alive
	17/03/2018	10:15	Common Blacktip Shark	1.8; Female	Alive
	26/04/2018	13:11	Greynurse Shark	2.7; Female	Alive
Shark Bay to Joggly Point (SD nos 1–3)	25/11/2017	16:22	White Shark	2.7; Male	Alive
	09/12/2017	09:56	White Shark	2.9; Female	Alive

[a]Individual dropped off the hook while it was secured alongside the boat, and therefore size was estimated. [b]No alert was received and the shark was found during the retrieval of the SMART drumlines at the end of the day.

Figure 14. Numbers of target sharks caught per 8-h daily deployment of SMART drumlines off Ballina (dotted line) and Evans Head (black line) during each reporting month of the trial.

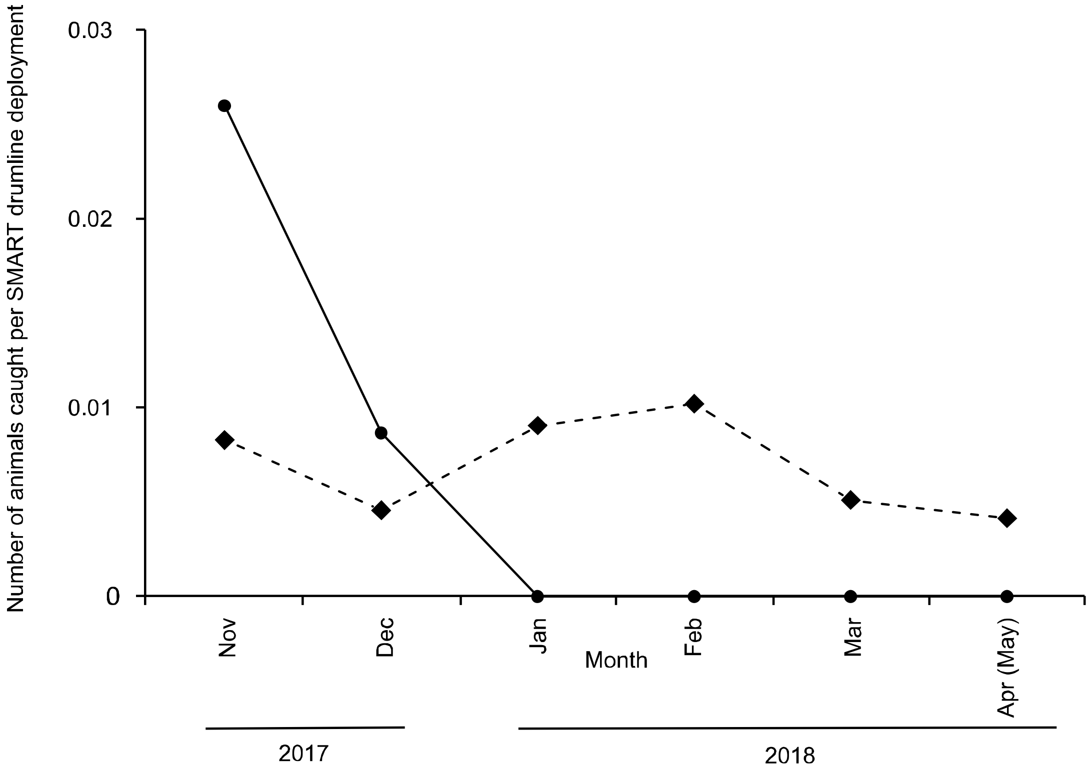
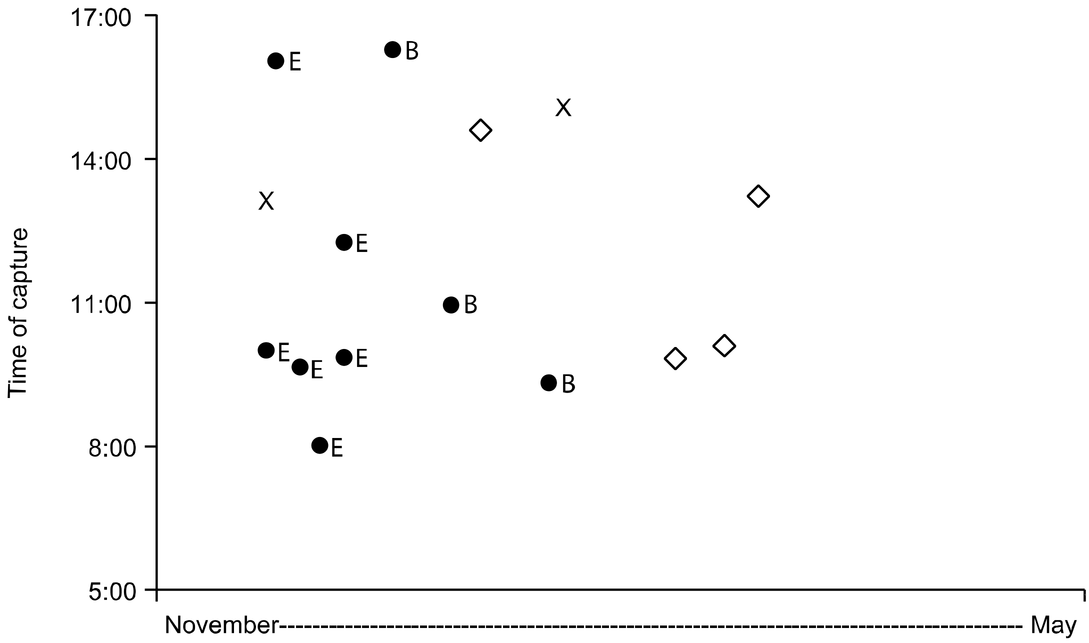


Figure 15. Time of capture on SMART drumlines of sharks at Ballina and Evans Head between 23 November, 2017 and 2 May, 2018



White Sharks: ●B = Ballina; ●E = Evans Head; Tiger Sharks: ◊ = Ballina; Bull Sharks: X = Ballina

Survival of catches

All animals except the Black Marlin (1.9 m TL) were released alive (Table 20). Although the contractor responded to the alert and was at the gear within 26 min, on arrival the Black Marlin was dead with the hook located in the dorsal fin. There was no other evidence to explain why this animal died.

Discussion

Community consultation

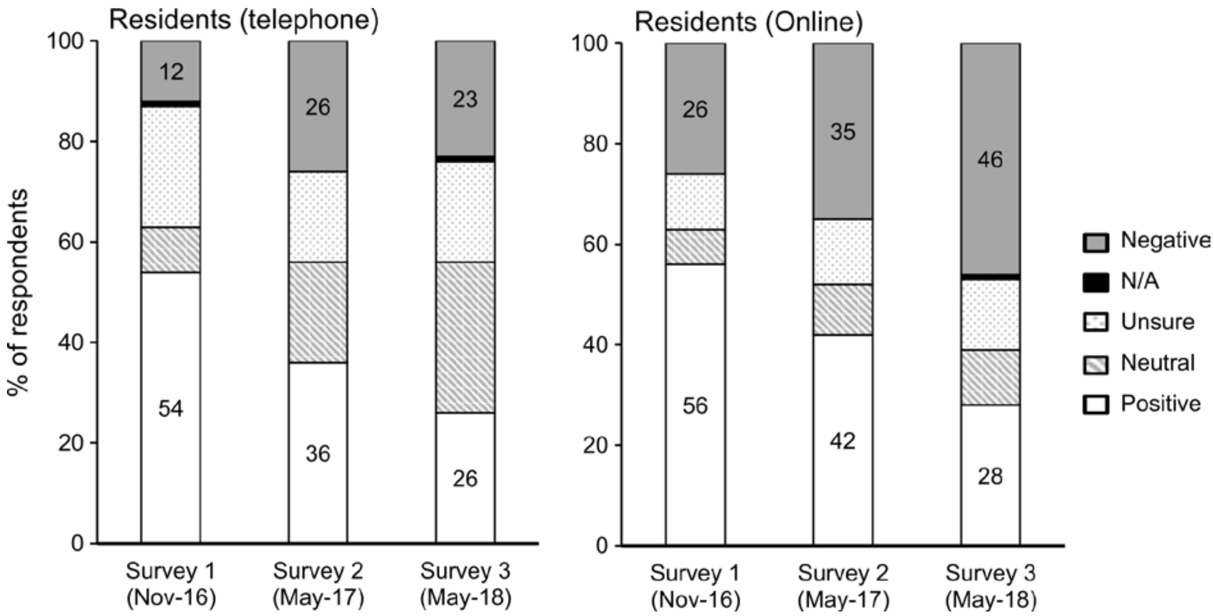
The community consultation at the end of the second trial revealed some differences between residents surveyed via phone and online (including surfers) and those responding from locations outside Ballina and Evans Head in their attitudes towards the nets. Similar proportions (around one quarter) of residents interviewed via telephone had positive and negative opinions about the nets. Conversely, residents who responded to the online questionnaire were more negative than positive.

Phone interviews are considered to provide a more robust measure of community views than online questionnaires (Fricker et al., 2005; Couper, 2011). But, owing to random selection, 53% of interviewees did not participate in water-based activities at north-coast beaches, leading to similar percentages of neutral or unsure about the personal effects of the net trial (Fig. 17). By comparison, most (77%) of residents responding to the online questionnaire that undertook water-based activities had clear attitudes.

Notwithstanding these differences, resident respondents in either survey method demonstrated a substantial decline in positivity towards the nets since the first community survey in November 2016 (prior to the first net trial). This outcome was particularly evident in responses about the effects of the trial on the wider community (~50% decline in positivity; Fig. 17) and also on themselves and their families, and was largely driven by the amount of bycatch and its mortality. Specifically, despite modified operational procedures contributing towards a substantial reduction in total bycatch and improved survival in the second trial, most telephone (65%) and online (69%) respondents thought the bycatch was still unacceptable within the overall context of using nets for mitigating shark–human interactions. Similarly, a perception that nets are ineffective for preventing shark–human interactions continued to be a common sentiment among those feeling negative about the net trials. Those who supported deploying nets mainly focused on improved feelings of safety for themselves, their family or the community, and the reduction in shark–human interactions in the area since the trials began. The latter outcome supports earlier surveys done in the other jurisdictions where nets have been deployed for decades (e.g. the SMP; Gray and Gray, 2017).

Short-term temporal changes in community attitudes towards wildlife-conflict scenarios and their resolution are not uncommon and can reflect relationships among many factors including the historical context of shark–human interactions and mitigation methods, and the magnitude and longevity of any social and economic impacts (Kansky and Knight, 2014; Liordos et al., 2017; Pooley et al., 2017). In the case of the NSW north coast, changes in attitudes towards the net trials may have been driven by improved feelings of safety due to the lack of recent shark bites and/or perceptions that SMART drumlines offer an equivalent level of protection with fewer ecological costs than nets. It is also important to acknowledge that social conscience is strongly driven and maintained by access to data; reiterated in NSW by considerably less concern for any perceived deleterious effects of nets in the SMP during a similar period as the trials, but where monthly summaries of catches were not provided (Gray and Gray, 2017).

Figure 16. **Survey responses (telephone and online) showing how residents of Ballina and Evans Head thought nets affected the wider community over the course of the two trials. Shown are the responses before (survey 1) and after the first net trial (survey 2), and at the end of the second net trial (survey 3). Numbers in the bars are the percentage. The numbers of respondents for each survey were 600, 602, and 601 for telephone and 1,645, 621, and 1,001 for online.**



As might be expected, positive responses among surfers to the second trial were more pronounced among locals who responded to the online questionnaire than those randomly selected for the phone interviews. In the online survey, surfers also remained more positive, but were more divided on the issue of bycatch than surfers interviewed by phone. Despite these outcomes, positivity towards the net trials by local surfers has decreased; similar to the results for other residents. For example, respondents in the online survey were 62% positive vs 23% negative about the impact of nets on the community prior to the first net trial, whereas after the second net trial 46% were positive vs 32% negative. Notwithstanding the slight shift in attitudes among surfers, their positivity and greater tolerance of the ecological costs is not surprising considering all recent shark–human interactions involved this group, and it is well established feelings of safety typically are prioritised above tangible costs (economical or environmental) among those people directly affected by wildlife conflict scenarios (Kansky and Knight, 2014; Pooley et al., 2017).

Unlike residents, negativity among non-resident online respondents was consistent across the two net trials. For example, the percent of respondents who were negative vs positive towards the impact of nets on the wider community was 65 vs 15% for survey one, 58 vs 8% for survey two and 63 vs 6% in the most recent survey. Contrasting temporal opinions between residents and non-residents were likely driven by different historical and social contexts relating to shark–human interactions, with non-residents unlikely to be impacted in the same manner as residents by shark bites. Those responding from other locations are also likely to be motivated by broader views and values related to shark–human interaction mitigation methods and marine conservation more generally. This outcome was evidenced by the lack of commentary on the social impacts of shark bites on the north coast (which was common among residents) and dominance of sentiment related to the unacceptability of bycatch, the ineffectiveness of nets, and a perception that the ocean is the shark's territory and water-users should accept the risk of shark bite. Such views exemplify decadal changes in societal perceptions towards sharks which have occurred in Australia, and other countries (Simpfendorfer et al., 2011; Gibbs and Warren, 2015).

Beyond monitoring attitudes towards the net trial themselves, the surveys also provided insight into the support for nets as a strategy for mitigating shark–human interactions involving fishing gears relative to other protective measures. In this context, nets had the least amount of support of any strategy by residents, including local surfers. This was probably influenced by an increase in awareness of SMART drumline operations and catches off north-coast beaches, and reflected in twice as many residents supporting SMART drumlines than nets. Such a result is not surprising considering that from a technical perspective the nets were chosen for a broad, virtually unconstrained outcome some 80 years ago; the terms of reference for which have substantially changed and are now more logically suited to SMART drumlines.

While there are few data on their utility for mitigating shark–human interactions, certainly SMART drumlines were locally perceived to be more effective than nets owing to the greater catch of White Sharks and lower rates of bycatch; and equivalent in terms of taking a proactive approach and resulting feelings of safety. But such perceptions may not be indicative of the broader community, with non-residents mostly opposing using any fishing gear for mitigating the risk of shark–human interactions. All other strategies including aerial surveillance, research, education, and personal responsibility continued to receive strong support by the community, regardless of their place of residence.

Recommendation 1: **Unless community sentiment changes, discontinue trials of nets on the north coast *in lieu* of more environmentally benign fishing methods (e.g. SMART drumlines and their variations).**

Operational logistics of the trial

The second north coast shark-meshing trial encompassed the same seasons (summer and autumn) as the first trial and consequently fairly similar weather and water conditions. One key environmental difference between trials was the current, with a considerably greater north-to-south movement in the second trial; to the point where the net contractor had to install additional anchors on the nets to secure their positions, and despite which there were still two occasions when nets were displaced.

The operational requirements of the trial dictated that, weather permitting, the nets were to be checked between 12 and 52 h of the previous inspection, while the SMART drumline contractors were required to deploy their gears each day between 05:00 and 08:00, and then retrieve between 16:00 and 19:00. Based on recognised difficulties with accessing the nets during the first trial (in which only 64% of the required checks were achieved and mostly owing to excessive swell at the river bars), the net contractor purchased a high-speed aluminium cylinder-hull vessel—similar in design to those used by the military and Surf Life Saving Australia. This vessel was designed to cross river bars and provide an open, stable platform while disentangling large animals (up to ~3.5 m TL) from nets and releasing (if alive) or bringing these onboard (if deceased) during extreme conditions. The utility of the cylinder-hull vessel and the experience of the contractor were illustrated by their ability to service the nets on 85 days during the trial and to achieve 93% of checks within the required times and 99% of checks after two fishing nights. Using this vessel, the contractor and crew were able to deploy and completely remove nets, each with four anchors and ancillary equipment.

By comparison, the SMART drumlines were deployed using conventional shark-cat and mono-hull vessels for 65% of the required total number of days during the second trial. This deployment rate represents a reduction from the first trial (during which 74% of the total available days were fished), and was attributed to conditions precluding contractors safely responding to captures and releasing live animals at sea. Unlike the net contractor, who could complete most net checks within a few hours and with regard to optimal tides and swell conditions, the SMART drumline contractors were directed to deploy the gears soon after first light and ideally retrieve at the end of the day, although owing to poor weather, some gears were retrieved as early as 11:30.

All fishing gears were deployed close to beaches (~500–700 m) and often near breaking surf and servicing equipment under such conditions is arduous and requires considerable skill and specialised equipment to select appropriate periods to safely work. Nevertheless, it might be possible to increase the number of days SMART drumlines are deployed by increasing flexibility around deployment and retrieval times with respect to weather and, like the net contractor, by using specialty craft to enable river-bar crossings and handling large animals during most conditions.

Recommendation 2: **Use purpose-built water craft to maximise specified net-checking frequencies and SMART drumline deployments.**

Catches of target sharks

The catches of target sharks by nets and SMART drumlines during the trial do not inform the utility of either gear for mitigating the risk of shark–human interactions. Rather, the catches are broadly indicative of the relative performances of the two gears and the regional abundances of key species, especially if these data are compared with those from the first trial.

More specifically, compared to the first trial and notwithstanding the potential for confounding effects of modifications to nets (different fishing heights, mesh sizes, and twine materials) and SMART drumlines (different baits) on catching efficiencies, there was a maintained greater efficiency of SMART drumlines for catching target sharks, but a substantial reduction in catches by both gears. During the first trial, the nets and SMART drumlines caught nine (0.002 per net per 24-h soak) and 36 (0.03 per SMART drumline per 24-h soak) target sharks, respectively, while in the second trial, only two (0.0005 per net per 24-h soak) and 16 (0.016 per SMART drumline per 24-h soak) target sharks were netted and hooked. These standardised catches represent 75 and 47% reductions between trials (i.e. years), respectively; most of which can be attributed to fewer White Sharks, with three netted and 31 hooked during the first trial, but none netted and only nine hooked in the second trial.

Considered collectively, these data reiterate not only the greater fishing power of 30 SMART drumlines actively fishing compared with five 150 m nets that are passively fishing, but also evidence that fewer White Sharks may have been present in the fished area during the second trial. While few broader environmental and ecological data make it difficult to postulate reasons for the temporal differences in catches of White Sharks, this probably reflects natural variations. Similar, and larger, annual variation among catches of various sharks, including White Sharks has been observed in the SMP (Reid and Krogh, 1992; Reid et al., 2011) and other jurisdictions that use nets and/or conventional drumlines (Paterson, 1990; Dudley, 1997). Although not directly comparable, it is also noteworthy there was minimal evidence of shark predation among the 17 stranded dolphins and turtles collected from beaches within and adjacent to the trial, which might also provide an index of regional abundance/feeding activity.

Water temperature often explains broad-scale movements and site fidelity among sharks (Heupel et al., 2015; Smoothey et al., 2016; Payne et al., 2017), which can then reflect catches in nets and on drumlines (Reid and Krogh, 1992; Dudley, 1997; Reid et al., 2011). During both trials, most White Sharks were hooked from cooler water (during November to mid-January), while Tiger and Bull sharks were hooked and netted closer to the peak in warm water during February and March. These differences reflect inter-specific preferences. Although tolerant of a range of temperatures (Bruce, 1992), White Sharks tend to prefer cooler water (Adams et al., 1994). Conversely, warm water has a positive effect on the abundance of Bull Shark off NSW (Heupel et al., 2015; Smoothey et al., 2016) and Tiger Sharks off coastal areas more broadly (Payne et al., 2017).

In the second trial, no White Sharks were caught from March to May as the water temperature cooled from the summer peak, while in the first trial 50% of all White Sharks were caught during those months. However, 12 of the White Sharks caught on SMART drumlines in the first trial were during the first three weeks of May which was outside the temporal limit of the current trial. By comparison, catches of Tiger Sharks, and especially Bull Sharks were more consistent between gears and trials with three Tiger and two Bull sharks hooked in the first trial, compared to four and three in the second. Three of each species were netted in the first trial, and two Bull Sharks were netted in the second. Although total numbers were low, the greater consistency in catches of Tiger and Bull sharks than White Sharks between trials off the north coast of NSW implies divergent environmental influences and inter-specific movement plasticity that warrant ongoing research (Bruce et al., 2006).

Catches of non-target species

There were sustained gear-specific differences in species selectivity during the second trial, but it is also clear the SMART drumlines were less selective than observed during the first trial (NSW DPI, 2017). Such results are best discussed separately, and with regard to the fishing mechanisms and abundances of key species.

The anchored nets function by entangling animals within a broadly similar size range (~1–4 m) inhabiting the same space and time (but mostly at night; NSW DPI, 2017), which makes it impossible to target any species, or even a broad group of species, within any area known to have large assemblages of similar-sized animals (Hamley, 1975; Uhlmann and Broadhurst, 2015). This characteristic explains why the general composition of bycatch (e.g. mostly rays, hammerheads and carcharhinids) and their sizes during the second trial were comparable to the first trial (NSW DPI, 2017) and similar to those by bather-protection nets fished between Newcastle and Wollongong over 81 years (Reid and Krogh, 1992; Green et al., 2009; Reid et al., 2011) and off Queensland (Paterson, 1990; Gribble et al., 1998; Sumpton et al., 2011) and South Africa (Dudley and Cliff, 2010) over 56 and 66 years, respectively. Considering there is some 200 cumulative years of data describing catches from bather-protection nets in the above jurisdictions, the broad compositions and quantities of bycatch observed during the second trial were entirely expected.

Nevertheless, while the five netted species (Australian Cownose Rays, Whitespotted Eagle Rays, Pygmy Devilrays, Great Hammerhead and Common Blacktip Sharks) that contributed most to total bycatch remained the same in the second trial as in the first, the key differences among most were the quantities, with a 46% reduction in total bycatch during the second trial. The only species caught in comparable numbers between trials was the Whitespotted Eagle Ray. It is also noteworthy that unlike during the first trial when animals were entangled on both sides of the nets, most animals were caught on the seaward side during the second trial, which might reflect the strong current causing nets to assume a more parabolic shape towards the beaches. Notwithstanding this anomaly, the general reduction in bycatch follows the trend for netted target sharks, and might reflect broader environmental cues that warrant further investigation.

The different configurations of nets confound accurate comparisons of bycatch between trials, but there is evidence some of the absolute reductions in bycatches in the second trial were due to decreasing the net-checking rate to an average of 44 h (after two fishing nights) rather than the average of 17–28 h (after one fishing night) during the first trial. The utility of decreasing the net-checking frequency reflects the catch ‘saturation’ of a net; after which it loses efficiency. For example, except for one occasion in the second trial when ten Australian Cownose Rays were caught in one net, the maximum number of netted animals was seven per net. Similar results were observed during the first trial (mostly six animals per net). Potentially, the nets lose effectiveness as they are saturated with other animals (with each entangling various meshes, and sometimes the footrope and floatline together). Put simply, the more frequently a net is cleared, the greater the potential for catching more animals, including bycatch.

Recommendation 3: **Check and clear nets no less than every 48 hours to maximise their fishing effectiveness while limiting bycatch.**

For SMART drumlines, the overall bycatch remained relatively low, but was greater in the second trial (16 animals across six species) than the first trial (three animals and two species). The differences in species compositions and total numbers caught are likely associated with environmental conditions that influence their spatial and temporal movements along eastern Australia (Reid et al., 2011). It is unlikely that the catches are related to any technical aspects associated with the SMART drumlines.

Although the data are few, some of the applied net modifications, especially varying the vertical fishing depth, might reduce the bycatches of some rays and other charismatic species, and with less effect on sharks. In particular, compared to midwater-set nets, those fished close to the surface appeared to have slightly less standardised catches of Australian Cownose Rays and all turtles and dolphins combined, while catches of carcharhinid sharks (i.e. the same genus as Bull Sharks) were slightly greater. The latter trend was complemented by the net-damage data, which showed a similar rate of broken mesh bars (with no animal, but presumably caused by sharks) between shallow- and midwater-set nets. If real, any such differences might reflect vertical water-column preferences in relation to the peak catching efficiency of the nets. Specifically, during the first trial it was recognised that like many other commercially fished gillnets (e.g. Gray et al., 2005), the nets mostly caught animals at night. While Australian Cownose Rays often are observed using the entire water column during the day, they might also presumably more easily visually detect the net. This species might be expected to orientate deeper at night to evade predation, and therefore less likely to encounter those nets set higher in the water column.

Air-breathing animals like dolphins and turtles might not display the same nocturnal behaviour but, irrespective of diel movements, some might more easily detect nets at the surface at night, due to greater visibility from reflected ambient light. Previous studies have shown some turtles positively respond to increased visibility of nets and/or contrasting patterns (Wang et al. 2010; 2013; Ortiz et al., 2016).

Recommendation 4: Assess the effects of fishing nets at different positions in the water column for improving species selectivity.

Few animals (and no target sharks) were caught during the comparisons of net mesh sizes and materials, precluding detailed assessments of any benefits or otherwise; however there was some indication relatively more Whitespotted Eagle Rays were caught in 800-mm mesh nets. This result may simply reflect greater selectivity for this species, which at a mean of 1.6-m DW was the widest of all rays. Nevertheless, because most Whitespotted Eagle Rays survive meshing (i.e. 91%; see below) and a larger mesh should also improve selection for target sharks, ongoing research might warrant collecting additional data to describe the effects of increasing mesh size in nets.

Recommendation 5: Assess the utility of larger mesh for improving the selectivity of nets.

While the composition of netted bycatch was similar between trials, and the absolute quantity was reduced, the opposite occurred for SMART drumlines. More specifically, during the first trial only three animals were bycaught (two species) or 8% of the total catch. But, in the second trial, the bycatch comprised 16 animals (six species) or 50% of the total. Without additional data, and acknowledging possible confounding effects of fishing different baits and hook types between and within trials, such differences are difficult to explain.

One suggestion is that owing to the considerably fewer White Sharks in the fished area during the second trial, the vulnerability of other species to capture, including considerably smaller individuals of Dusky Whalers, Smooth Hammerheads, and Common Blacktips (1.5–2.0 m) was greater simply because they were able to compete for bait. Certainly, based on their lower catches in the nets these animals presumably were less abundant in the area than during the first trial. But, any hypothesis concerning species-specific competition for baits is speculative and additional data are required to investigate any interaction between catches of White Sharks and other species, or relationships describing their spatio-temporal coexistence.

Nevertheless, unlike during the first trial, the broader range of species caught on SMART drumlines during the second trial was more comparable to that of conventional drumlines historically fished off Queensland (Sumpton et al., 2011) and South Africa (Dudley et al., 1998). Given the inter-trial variability in bycatches on SMART drumlines, the potential for increased interactions with other species should be considered and appropriate strategic work undertaken, including testing pingers and other deterrents to at least ascertain their effects on target catches, in the absence of interactions with charismatic species.

Recommendation 6: Strategically test retroactive modifications for limiting bycatch on SMART drumlines.

Survival of catches

Survival rates were greater during the second trial than the first, especially among netted animals (i.e. 47% in the first trial vs 60% in the second), but also for hooked White Sharks (94 vs 100%). Such improvements can be discussed with respect to the known variables affecting the fate of animals caught and then discarded by fishing gear, including biological (e.g. species, including physiology), technical (e.g. gear design and deployment duration) and environmental (e.g. water temperature) factors (Davis, 2002; Broadhurst et al., 2006).

Typically, the fishing mechanisms of nets (i.e. designed to constrict the gills/head and therefore suffocate animals) mean that they are always likely to evoke greater mortalities than among animals that are hooked, and especially if hooking depth is shallow (Bartholomew and Bohnsack, 2005; Uhlmann and Broadhurst, 2015). This trend was maintained during the second trial, with variable mortalities among netted animals, but very rarely 100% survival.

Nevertheless, for three (i.e. Australian Cownose Rays, Whitespotted Eagle rays and Common Blacktip Sharks) of the five dominant species caught in nets (i.e. 83% of the total catch) during the second trial, their immediate survival was greater than during the first trial. One likely variable affecting this result was the consistent checking rate (99% of checks after two fishing nights). During the first trial, there were protracted soak times beyond two fishing nights, which clearly increased mortality. While there was slightly greater survival after one fishing night than two for some species (e.g. Whitespotted Eagle rays) in the second trial, there were no clear effects for others (e.g. Australian Cownose Rays). Considering the logic associated with gear saturation on catching efficiency (discussed above), such results support checking the nets after two fishing nights. Such a recommendation might extend to the SMP, where nets currently are checked every 72 hours.

Notwithstanding the above, for air-breathing animals such as dolphins and turtles, even short periods of net entanglement can cause death, although the species and size are clearly important (Uhlmann and Broadhurst, 2015). Four Loggerhead Turtles (mostly >100 cm CCL) had the strength to push nets (including three in midwater-set nets) to the surface and breathe for sufficient periods before release. The two Green Turtles and Hawksbill Turtle that died were smaller. At a broad level, larger animals typically are more resilient to catch stressors (Broadhurst et al., 2006; Uhlmann and Broadhurst, 2015).

The immediate survival of sharks caught on SMART drumlines was dramatically greater than that of sharks caught in nets, and comparable to that of similarly mouth-hooked species (Bartholomew and Bohnsack, 2005). Although few data are available for White Sharks, being hooked in the mouth appears to cause minimal damage and few longer-term effects. This hypothesis is supported by telemetry data indicating that many tagged animals have been detected at other locations throughout NSW within 12 months of being released, and some have been recaptured. Studies of other species reveal that most mouth-hooked animals suffer few longer-term impacts, and certainly large proportions of other large sharks released quickly (within 3 h or so) from commercial longlines can survive (e.g. Marshall et al., 2015). Even protracted soak times (e.g. 7–14 h overnight) can still allow good survival among some species of Whaler sharks and Greynurse Sharks (Gallagher et al., 2014; Hazin and Afonso, 2014; Butcher et al., 2015).

The single mortality on SMART drumlines was a Black Marlin, which was hooked in its dorsal fin. This form of capture and mortality of the Black Marlin might also have broader implications when considering the number of SMART drumline alerts with no catch recorded (i.e. >50% of the total). Some incidents might represent strikes on the baits, although presumably if animals escape, any associated mortality is likely to be quite small. None of the assessed stranded dolphins or turtles had any evidence of hook strikes.

The latter raises an important point: except for those target sharks that were acoustically tagged and subsequently tracked, the fate of released catches, and particularly those that were netted, remains unknown. Most netted animals were tagged with plastic identification tags, but none were caught again during either trial. This might imply at least some subsequent mortality.

The post-release survival of most species from SMART drumlines is likely to be high due to the requirement of contractors to respond immediately to any captures and release animals quickly. Although all hooked sharks swam away after release, to quantify any negative impacts, further research might include assessing the blood biochemical status (Butcher et al., 2015), or condition (Braccini et al. 2012) after capture. These data would be relevant for threatened species (e.g. Greynurse Sharks) or those known to be relatively less robust to catch and release (e.g. Smooth Hammerheads; Butcher et al., 2015).

It is also worth noting that depredation did not appear to be a major cause of mortality among netted animals. While there are no data describing any animals that were entirely removed from the net by predators it is clear that, like during the first trial, very few animals that remained in the nets were depredated (i.e. only 2% of the total catch). The latter result refutes a common argument that entangled catches typically attract sharks to a net.

Utility of each method for minimising shark–human interactions

No fishing gear will completely remove the possibility of shark–human interactions, simply because none are 100% effective at catching all target sharks in any area, and very few can be continuously deployed. Nets have been fished over 80 years in the SMP and alongside conventional drumlines for >50 years off Queensland and also off South Africa. Their associated data are continually used to support the success of using fishing gears to mitigate shark–human interactions. More recent data suggest a combined approach involving attempts at relocating live individuals (but with some mortality) has mitigated shark–human interactions off Brazil for over a decade (Hazin and Afonso, 2014). However, neither the first nor the second trial were of sufficient duration to gauge the utility of nets or SMART drumlines for achieving such an outcome off northern NSW.

Assessing both nets and SMART drumlines off northern NSW is confounded by the simultaneous use of other mitigation methods within the SMS, such as aerial surveillance and advice from tagged shark detections on buoyed receivers (VR4Gs). Specifically, the alerts to the community via ShartSmart App and the Twitter feed may discourage water users from entering the water or result in evacuation of the water and beach closure by beach authorities. Substantially longer periods are required to ascertain either the individual or combined utility of nets, SMART drumlines or any other strategy for minimising shark–human interactions off northern NSW.

However, it is possible to postulate how each fishing gear might reduce shark–human interactions—assuming appropriate levels of effort (i.e. sufficient numbers of replicates in an area). The SMART drumlines caught some White, Bull and Tiger sharks (during the day and responsive to offered prey), which were then released. Preliminary data suggest most of these hooked-and-released sharks moved away from the area, reducing any immediate risk of interacting with people. Any such movement might be at least partially due to short-term stress associated with capture, although the extent and implications of that are probably quite variable (Gallagher et al., 2014; Barnes et al., 2016). More data are required to determine the levels to which target sharks are stressed, and their movements post release.

Recommendation 7: Assess the movement and behaviour of target sharks released from SMART drumlines.

Compared to SMART drumlines, nets are less selective for target sharks, and because they are designed to immobilise fish and restrict gills (leading to suffocation) they cause greater mortalities. There exist 200 cumulative years of data demonstrating that bather-protection nets are effective at catching various species of broadly similar sizes inhabiting the fished area. This bycatch and associated mortality is an integral outcome associated with nets, and cannot be ignored when discussing their perceived historical effectiveness for minimising shark–human interactions.

The mechanisms contributing towards the implied long-term bather-protection effect of nets are not entirely clear, but beyond the obvious implications of some reductions in target-shark density (either by mortality or perhaps after entanglement and escape; similar to catch and relocation via SMART drumlines), any sustained fishing mortality of bycatch (i.e. mostly large species) could affect local populations of key species and with some implications for prey to attract sharks to the area (e.g. Heithaus et al., 2002). The possibly also exists for chemical repellent by netted, decaying sharks/elasmobranchs (e.g. Stroud et al., 2014). While data to support the latter hypothesis are few, the idea cannot be discounted, especially considering the negligible depredation of any netted animals during either the first or second trial.

Any perceived benefits of nets for minimising shark–human interactions come with an ecological cost, measured mostly as collateral mortality of non-target species, including some that are threatened, and (to a lesser extent) some loss of net material as marine debris (as evidenced in both the first and second trials). However, the mortality of non-target species is possibly an inseparable component of how nets work and so the concept of making ‘SMART’ nets is not rational. A better approach when deciding what type of fishing gear to deploy to minimise shark–human interactions would be to clearly define the terms of reference against environmental, social and economic criteria. Once the key objectives are clear, decisions can be made about the most appropriate gear.

If the objective is to only target White, Bull and Tiger sharks and reduce their relative numbers in an area by relocating live individuals, then nets clearly would not be the first choice. Catch-and-release using SMART drumlines and/or other configurations of baited hooks (e.g. Hazin and Alfonso, 2014) deployed across appropriate space and time (including at night) are a more logical option. Alternatively, if the objective is to introduce some sustained fishing effort to remove individuals of several species, including target sharks, across one or two trophic levels (i.e. controlled regional depletion of an ecosystem), then nets might be more suitable than baited gear. Irrespective of the objective, the long-term ecological consequences of using any fishing-gear configuration to minimise shark–human interactions require assessment.

Recommendation 8: **Clearly reiterate the terms of reference for using fishing gear to minimise shark–human interactions in ongoing trials of SMART drumlines and nets.**

Modifications to improve the effectiveness of nets and SMART drumlines while maintaining the objectives for their use

Within more clearly defined terms of reference justifying their use, both gears might be modified in their operation or through applied technical changes. Such modifications can be discussed with respect to the stated theories supporting the applicability of each type of fishing gear for minimising shark–human interactions.

It is not possible to alter the selectivity of the conventional nets tested in this trial to approach that of the SMART drumlines (for White Sharks), but simple operational changes (without changing the existing design of the nets) might reduce collateral mortalities of some listed fauna, and especially dolphins and turtles, while still achieving sufficient function to match their apparent historical success. Removing the Evans Head net (responsible for 47% of total bycatch) or moving it further from the river mouth (an area of greater densities of animals that use the river–sea interface habitat) would substantially reduce bycatch and collateral mortalities.

Pending additional data, decisions about where and when to set nets to avoid dolphins and turtles might reflect the environmental conditions. A study correlating environmental parameters (sea and conditions, water quality, etc.) against entanglement rates among marine mammals in Queensland nets revealed some trends (Volep et al., 2017). In particular, there were more entanglements of Common Dolphins in winter, during windy conditions or rough seas, spring tides and in strong westerly currents. Over the long term, such data might be used to guide recommendations for net deployments or checking frequencies. Considering the data collected during the second trial for some rays, dolphins and turtles, another operational modification that clearly warrants ongoing testing is shallow-set nets, because these may have greater visibility to some species.

A related, applied modification might involve artificial illumination on nets, considering Ortiz et al. (2016) observed that green light-emitting diodes (LEDs) attached every 10 m to the floatlines of Peruvian bottom-set gillnets reduced the catches of Green Turtles by 64% without affecting catches of target fish. Wang et al. (2010, 2013) noted similar results after illuminating gillnets with LEDs (spaced 5–10 m) off Mexico. Using shark-shaped silhouettes adjacent to nets has also had some utility for reducing turtle catches (discussed by Gilman et al., 2010). Considering the threatened status of Loggerhead and Green turtles, such work supports ongoing testing—a key component of which should be the effects of light on other catches in nets, especially sharks and rays. Visual stimuli can affect catches of various species in longline fisheries (Broadhurst and Hazin, 2001), and light is often used as an attractant (Hazin et al., 2005).

In terms of other applied technical changes, if entangled animals that escape nets subsequently vacate an area, analogous to the SMART drumlines' release of sharks, then nets could be made longer but configured with light twine or escape panels (involving weak sections) so that most large animals that make contact will not become fatally entangled. This approach would involve some loss of material to the environment as marine debris. Conversely, more data are required to ascertain if increasing the strength of the netting twine and the size of mesh (e.g. to 800 mm) reduces the catches of some rays and all fish, while still retaining similar quantities of the largest White, Bull, and Tiger sharks.

Recommendation 9: Modify nets to reduce the mortality of turtles and dolphins while maintaining their long-term efficiency as a tool for minimising shark–human interactions.

Irrespective of the configurations to be tested, further research would benefit from empirical assessments to more clearly determine the various factors by which nets reduce the risk of shark–human interactions. There is a need to investigate which animals are escaping and whether these animals are the target species. Residual DNA on meshes might offer one way to answer this question. Research should also focus on whether chemical stimuli associated with decaying sharks or rays in nets has any effect on other sharks from an area over the short term.

Recommendation 10: Identify and quantify all of the factors that contribute to how nets minimise shark–human interactions.

The SMART drumlines are clearly more species selective than nets, but their absolute catching efficiency still might be increased via simple modifications to their deployment or design. Further, within such work it might be beneficial to identify possible issues that could affect the longer-term use of SMART drumlines.

In addition to assessing the utility of deploying SMART drumlines at night to improve catches of target sharks, other gear and technology could be tested, including nocturnally deployed bottom- and midwater longlines and drop lines (Hazin and Afonso, 2014), which could be rigged with SMART buoys. Irrespective of the time of day or night, bottom-set longlines are more efficient at catching Tiger and Bull sharks than drumlines (Hazin and Afonso, 2014). Further, SMART longlines could be rigged with hook timers modified to release hooks after a predetermined period (e.g. 3 or 4 h) if the contractor cannot attend the gear (to allow sharks to escape alive). Such configurations would mean that gear could be deployed late in the day and left overnight, which should translate to lower costs than if the contractor has to remain at sea.

The survival of several shark species hooked by the above types of gear can exceed 50% (Hazin and Afonso, 2014) which is greater than observed among many netted sharks, especially when overnight soak times are ≤7 h (e.g. Butcher et al., 2015; Marshall et al., 2015). Baited-hook configurations need to be rigorously assessed to maximise their species selectivity and ideally avoid mortality among threatened species (such as Greynurse Sharks and Hammerheads), but contractors could adjust their fishing effort to focus on the three target sharks according to abundance. For example, greater effort could be directed towards SMART bottom-set longlines in summer (e.g. water warmer than 22^{o}C) to catch Tiger and Bull sharks and SMART drumlines in winter (e.g. water cooler than 20^{o}C) for White Sharks. This approach would help maximise the benefits of paying for a contractor to be at sea. As part of any such work, empirical research should quantify the longer-term effects of consistently displacing sharks from a particular area on both the sharks and the local ecology.

Another modification to existing drumlines might be to use additional hooks (within the same SMART system). Some of the drumlines used in QLD have double hooks, and similar gear is deployed commercially (‘drop lines’). Such configurations could be tested for their effectiveness in increasing the rates of hooking target sharks in key areas.

Conclusions

There exist some 200 cumulative years of data describing the catches of bather-protection nets across three jurisdictions, and so their fishing characteristics are well established. As expected, and like for the first trial, the data from the second NSW shark-meshing trial conform to the general historical trend in netted catches. Considering these similarities and acknowledging the reported benefits of nets for reducing shark–human interactions, it might be argued that any long-term deployment of nets off northern NSW will produce comparable results as for other jurisdictions.

It is also clear any long-term deployment of nets off northern NSW will have an ecological cost in terms of the collateral mortality of bycatch, but it remains unknown to what extent this mortality positively contributes towards the perceived effectiveness of the nets—a question that should be empirically assessed to guide any future use of nets and/or their modification. Irrespective of clarification, it is also important to appreciate that while some operational or applied technical modifications might improve net selectivity it will be impossible, with existing technology, to refine nets to any socially reasonable level of selection for the target sharks.

The difficulty in controlling selection among nets is especially poignant when one considers the classification of target species has become more constrained over time in NSW (e.g. originally virtually all sharks, then reduced to fewer than ten, and more recently to only three species). Obviously, in the absence of revolutionary changes to nets, such reclassification will considerably increase bycatch. For this reason, there needs to be logical terms of reference supporting defined objectives for using fishing gear as a strategy to mitigate shark–human interactions.

Clearly, any strategy involving fishing gear to mitigate shark–human interactions (and therefore with the potential for lethal outcomes to marine life) should be chosen with regard to social consultation and expectations. But it is important to acknowledge that the latter are subject to considerable short-term variation, whereas the science and mechanisms supporting a particular outcome are not, and in fact require extensive periods to decipher. This dichotomy means that coherent strategic discussions with appropriate risk analyses are required to achieve satisfactory socio-economic outcomes around mitigating shark–human interactions that will be positively acknowledged by future generations.

Within the above process, if a socially acceptable mitigation strategy is focused more on catching and relocating live individuals of very few species rather than evoking mortality across many species from different trophic levels, then SMART drumlines will have much greater utility than nets. The effectiveness of SMART drumlines for minimising shark–human interactions remains unknown (and requires long-term data), but assuming at least some positive benefits, in addition to maximising fishing days through appropriate equipment (e.g. vessels) or operational procedures (overnight deployments), other baited gear (e.g. nocturnally or diurnally deployed bottom and midwater baited lines to more effectively target Tiger and Bull sharks) might be similarly modified with SMART buoys to expand and economise catch efforts.

If deemed appropriate within clear objectives for using fishing gear to minimise shark–human interactions, it should also be possible to fish other baited-hook configurations to encompass some of the ways nets might function (i.e. some mortality among target catches, escape of animals, or stimuli from decaying animals on hooks), but with fewer collateral impacts. Such an approach has been considered very effective for reducing shark–human interactions for over a decade off north-eastern Brazil. Nevertheless, a key requirement of any such work in NSW would be the close monitoring of catches of threatened species, including the Critically Endangered Greynurse Shark, the Endangered Scalloped Hammerhead and the Vulnerable Great Hammerhead.

It is clear multifaceted approaches for minimising shark–human interactions need to be prioritised, scientifically assessed and evaluated, and ultimately presented for social certification. The challenge is to state clearly, and convey among the community, the objectives of each particular strategy, and the underlying logic supporting its application. Where fishing gear is identified as a coherent approach, research must be directed towards understanding gear-specific mechanisms that might contribute towards reduced shark–human interactions, as well as the broader environmental consequences.

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