FISHERIES FINAL REPORT SERIES | NO. 154

NSW NORTH COAST SHARK-MESHING TRIAL FINAL REPORT

Published by the NSW Department of Primary Industries

NSW North Coast shark mesh-net trial

NSW DPI – Fisheries Final Report Series No. 154

First published August 2017

ISSN 2204-8669*

More information

NSW DPI Fisheries

www.dpi.nsw.gov.au

Cover image: Matt Broadhurst

*Before July 2004, this report series was published by NSW Fisheries as the 'NSW Fisheries Final Report Series' with ISSN 1440–3544. Then, following the formation of the NSW Department of Primary Industries it was published as the 'NSW Department of Primary Industries – Fisheries Final Report Series' with ISSN 1449–9967. It was then published by Industry & Investment NSW as the 'Industry & Investment NSW – Fisheries Final Report Series' with ISSN 1837–2112. It is now published as the 'Fisheries Final Report Series' with ISSN 2204–8669

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Non-technical summary

NSW North Coast shark mesh-net trial

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Objectives

A management plan drafted for the trial and available at http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/685597/PDF-INT16-144869-Management-Plan-for-the-NSW-North-Coast-Mesh-Net-Trial-Nov-2016.pdf. Within a broader directive of reducing rates of unprovoked shark–human interactions, the stated purposes of the 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 DPI staff
- minimise impacts of the shark management measure on fauna
- collect, analyse and report on data collected during the trial
- inform continuous improvement in protecting swimmers from shark bites and complement the NSW Shark Management Strategy, which included trials of emerging technologies (such as SMART drumlines).

The specific research objectives relevant here were to:

- compare the use of nets with SMART drumlines in terms of their effectiveness at catching White, Tiger, Bull or other potentially dangerous sharks while minimising the impacts on fauna
- test new devices and procedures which might deter whales or dolphins from approaching or becoming entangled in the nets, and new devices which might alert researchers in real time when a large animal is caught in the nets
- monitor the level of community acceptance to the presence and operation of the nets during the trial.

Key words

Shark mitigation; shark nets; SMART drumlines; community engagement

Summary

Background

Globally, unprovoked interactions between sharks and humans are rare events, but nevertheless generate substantial anguish for those involved, and create negative cascading social and potential economic effects among the broader community. Despite historical shark–human interactions in many countries, very few have initiated sustained resolution policies.

In New South Wales (NSW), Australia, several approaches have been adopted to mitigate shark–human interactions, with varying efforts across different areas. Aerial surveillance has been used for several years to inform beach authorities and users about the proximity of sharks to high-use beaches, and permanent swimming enclosures are an established feature in some estuaries and at coastal beaches. Mesh nets ('nets' 150 m long × 6 m deep and made from 600-mm mesh) have also been used at beaches within the greater Sydney region for 80 years; 51 beaches are currently netted between Newcastle and Wollongong.

The success of the netting program off Newcastle to Wollongong has been measured by fewer shark–human interactions at netted than pre-netted or un-netted beaches. Similar results have been observed at other locations where nets have been deployed, including throughout Queensland and South Africa, where baited hooks (termed 'drumlines') are also used.

While nets and drumlines are effective at depleting potentially dangerous target sharks (mostly considered to be White Sharks, *Carcharodon carcharias*; Tiger Sharks, *Galeocerdo cuvier*; and Bull Sharks, *Carcharhinus leucas*) from a particular area, there is an environmental cost, measured as the mortality of other non-target animals (termed 'bycatch'). In an attempt to reduce such mortality among drumlines, French 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', or SMART, drumlines). Owing to the short time between when an animal is hooked and retrieved, many remain alive and can be released.

NSW North Coast Shark Mesh-Net Trial

In response to increased shark–human interactions off northern NSW, a 'North Coast Shark Mesh-Net Trial' was initiated with a 4-day pilot study in November 2016, followed by consistent deployments of nets 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.

The trial was preceded by community consultation involving surveys to monitor the level of acceptance to the presence and operation of the nets. Two surveys were conducted: one before installing the nets (pre-trial survey, October–November 2016), and one during the last month of the trial (post-trial survey, May 2017).

On the basis of community consultation during the pre-trial survey, five beaches were selected for netting: Seven Mile Beach off Lennox Head; Lighthouse, Shelly, and Sharpes beaches off Ballina; and Main Beach at Evans Head. A single net was continuously deployed (weather permitting) at each beach. All nets measured 150 m long and 4 or 6 m deep, comprised 600-mm mesh, and were rigged with acoustic deterrents to mitigate catches of marine mammals. The trial coincided with the daily daytime deployment and retrieval of 25 SMART drumlines: 15 interspersed among the nets off Ballina and Lennox Head, and 10 around the net at Evans Head.

During each day of the trial, NSW Department of Primary Industries (DPI) scientific observers accompanied the net and SMART drumline contractors and collected environmental, biological and technical data to inform operational and catch characteristics. Nets were deployed for 144 to 167 days and nights (3440–3924 h), and the SMART drumlines were deployed for 128 to 132 days only (1024–1056 h). Nets and SMART drumlines were removed or not deployed only during adverse weather.

While the management plan stipulated that the contractors were required to check the nets twice a day to maximise releasing animals alive, the five nets were each checked 125 to 227 times out of a possible 288 to 334 occasions. Difficulties in checking the nets twice a day were due to either poor sea conditions that precluded access or dangerous river-bar conditions which prevented the vessels leaving port. On average, the nets were checked every 17 hours at Evans Head and every 27 to 28 hours at Ballina.

The nets caught a total of 275 animals, including three White, three Tiger, and three Bull sharks (mostly overnight). The remaining 266 animals comprised at least 18 species, including 16 sharks from three species or groups listed as potentially dangerous (Common Blacktip Shark, *Carcharhinus limbatus*; Spinner Shark, *C. brevipinna*; and unidentified Whaler Sharks). The most abundant non-target animals were the Australian Cownose Ray (*Rhinoptera neglecta*, 81 caught), Pygmy Devilray (*Mobula kuhlii cf. eregoodootenkee*, 63), Whitespotted Eagle Ray (*Aetobatus ocellatus*, 38) and the vulnerable-listed Great Hammerhead (*Sphyrna mokarran*, 24). One critically endangered Greynurse Shark (*Carcharias taurus*), four Indo-Pacific Bottlenose Dolphins (*Tursiops aduncus*), eight endangered Loggerhead Turtles (*Caretta caretta*) and three vulnerable Green Turtles (*Chelonia mydas*) were also caught. The relative abundances of these different species in nets varied substantially among beaches and across time.

Except for one occasion when ten animals were caught in one net (at Evans Head), total catches were six animals or fewer per net, irrespective of the time between net checks. It was clear that the more frequently the nets were checked, the more animals they caught. For example, the most frequently checked net (Evans Head) caught twice as many animals (108) as each of the other nets (28–54 animals). The Evans Head net also incurred twice the damage as the Ballina nets—thought to be due to escaping animals.

The total immediate survival of netted animals was 47% (i.e. 128 of the 275 netted animals survived), comparable to the estimated average survival associated with gillnets fished globally (40%). The pooled survival among all target sharks was 44% (two White, one Tiger and two Bull sharks died), but varied between 0% and 76% for other relatively abundant species (i.e. where >10 were caught). All four Indo-Pacific Bottlenose Dolphins, two of the eight Loggerhead Turtles and all three Green Turtles died.

The total survival rates (and those of key species) were comparable between 24- and 48-hour checks, but declined after 72 hours. When considered with the relationship between catches and net checks (above), the data support checking the net no sooner than every 48 hours to reduce the mortality of bycatch.

By comparison, during the 128 to 132 days they were deployed, the SMART drumlines caught more target sharks, hooking 31 White, three Tiger and two Bull sharks, along with one Dusky Whaler (*C. obscurus*) and two Greynurse Sharks. The White Sharks were caught at any time during the day and were most abundant during December, early January, April and May. When standardised for effort, catches were greatest at South Wall, Ballina.

One White Shark died while on a SMART drumline, giving a total immediate survival across all species of 97%. All other hooked animals were released alive within 48 minutes of hooking. One hooked-and-released White Shark was subsequently found dead on a beach 4 days after release, but all other tagged animals survived over the longer term.

The community response to the nets was mixed. Generally, local residents were more positive than negative towards using nets both at the start and the end of the trial, but the bias towards negativity increased, primarily in response to bycatch (and mortality) in the nets. Most non-residents remained critical of the nets at the start and end of the trial, again because of bycatch,, but also because of a perceived ineffectiveness of nets for minimising shark–human interactions.

However, 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 approaches to shark mitigation, including new technologies and education.

Conclusions

Nets and SMART drumlines are very different fishing methods, which dictate the extent not only to which they can satisfy a particular objective for minimising shark–human interactions, but also how they might be modified to reduce unwanted impacts. Nets have an established, historical utility for minimising shark–human interactions in the Newcastle to Wollongong region, but it remains unclear the extent to which long-term effects can be apportioned to: (1) some reduction in the relative abundance of target sharks (either via mortality or perhaps temporarily due to entanglement and escape); (2) fewer prey (e.g. other netted animals) to attract potentially dangerous target sharks to the area; or possibly even (3) chemical repellent from netted decaying sharks.

While technical modifications to nets might be implemented to reduce bycatch, it is not possible to configure them to catch only the target sharks. The selectivity of nets will always encompass other animals of similar size that inhabit the same area. Nevertheless, considering the concerns of the community about their efficacy and collateral mortalities, if nets are to be used to minimise shark–human interactions, then attempts at developing appropriate applied modifications are required.

Such work should encompass simple operational changes, including checking the nets no less than every 48 hours to limit bycatch while maintaining survival, and possibly subtle short-term variations in their spatial deployment (both horizontally and vertically) to reduce catches of some non-target species. Simple changes to mesh size and material warrant investigation, along with more novel modifications, might minimise catches of dolphins and turtles. Modifications should improve selectivity, but it is important to note that nets need to be fished at night to maximise the efficiency of catching the target species. This operational characteristic will always result in some bycatch.

Unlike nets, it is clear that the SMART drumlines used in daylight hours can achieve good selectivity for White Sharks, with high survival (this shark is listed as threatened in NSW waters under the *Fisheries Management Act 1994*). More data are required to determine whether the immediate release of hooked sharks reduces shark–human interactions in the fished area. 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 catch target 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 as for nets, the potential for catching threatened species would need to be assessed.

The community attitude to nets as a method for minimising shark–human interactions was divided, with some sectors unsupportive primarily because of the bycatch, while others (particularly surfers) considered this less of a concern. Nevertheless, the community was collectively supportive of applied methods involving fishing gear to reduce shark–human interactions, but with fewer impacts on non-target species.

It is likely a multifaceted approach encompassing various strategies to minimise shark–human interactions is required. Where fishing gear is identified as a coherent approach, the challenge is to clearly state and communicate the required objectives. Research should then be directed towards understanding the key mechanisms that might contribute to reduced interactions by particular fishing gear and the broader consequences for the marine environment.

Recommendations

The conclusions from the six-month trial support nine recommendations:

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. Undertake social research focusing on surfers to identify the protective measures (including key locations) that would improve their feelings of safety regarding sharks.
3. 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.
4. Nets used to minimise shark–human interactions need to be deployed overnight to maximise their efficiency at catching target sharks.
5. Nets should be checked and cleared of catches no less than every 48 hours to maximise their fishing effectiveness while limiting bycatch.
6. The short-term (<12 hours) continuous movement and behaviour of target sharks released from SMART drumlines should be quantified to better inform the utility of these measurements in minimising shark–human interactions.
7. Future trials of SMART drumlines and nets need to clearly define the terms of reference for using fishing gear to minimise shark–human interactions.
8. Assess key operational and novel technical modifications to nets that reduce the collateral mortality of bycatches, especially turtles and dolphins, while maintaining their long-term efficiency as a tool for minimising shark–human interactions.
9. Identify and quantify the relative importance of key factors that contribute to how nets reduce shark–human interactions.

Introduction

Concerns associated with sharks (predominantly White Sharks, *Carcharodon carcharias*; Tiger Sharks, *Galeocerdo cuvier*; and Bull Sharks, *Carcharhinus leucas*) biting or bumping people (collectively termed 'shark–human interactions') date back to earliest historical records, and have presented throughout many coastal countries (Dudley, 2006; Hazin et al., 2008). However, few countries have implemented sustained intervention policies (Dudley and Cliff, 2010). Where this has occurred, the chosen strategies can be encapsulated within three broad categories:

1) Directing people not to enter the water via either long-term restrictions at a particular location associated with frequent shark–human interactions (e.g. Brazil: Hazin and Afonso, 2013; and Réunion Island) or short-term advice for vacating areas via the real-time surveillance of sharks (e.g. in South Africa: Dudley and Cliff, 2010).
2) Exclusion devices designed to minimise shark–human interactions, most commonly via physical enclosures, to prevent sharks entering an area (Dudley and Cliff, 2010), or repellents (e.g. Huveneers et al., 2012), or combinations thereof (e.g. O'Connell et al., 2014).
3) Fishing gear (usually gill or 'mesh' nets or baited hooks termed 'drumlines') designed to deplete or, in some cases, relocate target sharks at key locations (e.g. South Africa: Dudley et al., 1998; Australia: Reid et al., 2011; Sumpton et al., 2011; Brazil: Hazin and Afonso, 2013).

At several locations, all three categories have been used concurrently to minimise (the risk of) shark–human interactions. The use of a collective approach reflects both the complexity of the issue and the difficulty in achieving a desirable outcome via one single category of strategies. Considerable efforts have been directed towards investigating ways that various combinations of the three strategies can be optimised.

Such a holistic approach has been adopted in New South Wales (which has accounted for ~39% of all shark–human interactions in Australia; West, 2011; ASAF, 2017). In response to a series of fatal bites off Sydney during the early 1900s, bottom-set mesh nets (nets measuring 150 m in length, 6 m deep, with a mesh size of up to 600 mm) were introduced off Sydney's beaches in 1937 to target sharks. Newcastle and Wollongong were subsequently included in the shark meshing program (SMP) in 1949, and the Central Coast in 1987. Nets are currently deployed across 51 beaches between 1 September and 30 April each year (and checked for catches every 3 days), and removed between these dates to minimise interactions with migrating whales.

The success of the SMP has been 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 80 years following introduction (Green et al., 2009). Some concordance between the use of similar nets and reduced shark–human interactions have been implied in other areas where they are deployed, such as in Queensland (Sumpton et al., 2011) and South Africa (Dudley and Cliff, 1993), where nets are currently complemented by baited (single or double) hook-and-line configurations (termed 'drumlines').

Irrespective of where they are used, a key concern associated with nets is the incidental catch of non-target species (termed 'bycatch'), including sharks and rays not considered to be a threat to humans, along with turtles, dolphins and whales (Uhlmann and Broadhurst, 2015). The nets work by catching various species of broadly similar sizes, and it is not possible to configure them to catch only target sharks.

By comparison, baited drumlines can have better species selectivity than nets, although these are by no means 100% selective for the target sharks (Dudley et al., 1997; Sumpton et al., 2011). In fact, drumlines used in Queensland can catch individuals of many of the species that are commonly netted, especially the endangered Loggerhead Turtle (*Caretta caretta*) (Sumpton et al., 2011). Nevertheless, there should be fewer mortalities among animals that are hooked (in the mouth) than those entangled in nets, especially if catches can be quickly released.

One system that was recently developed on Réunion Island by French researchers to reduce the time animals remain hooked on drumlines is the ‘shark management alert in real time’ (SMART) unit. This configuration comprises a simple trigger (a protected magnet linked to an electronic Global Positioning System [GPS] buoy) installed between the hook and the fishing line secured to a buoy. When an animal is hooked, the force releases the magnet from its external compartment and the buoy sends a GPS alert via satellite, and the catch can be quickly checked.

Increased shark–human interactions off northern NSW and emerging mitigation strategies

In response to an increase in shark–human interactions along the northern NSW coast (which included 14 interactions off the Far North Coast in 2015–16), the NSW Department of Primary Industries (DPI) initiated a trial of SMART drumlines to catch, tag and release key species in December 2015. This work fits within a broader objective of not only better understanding movements and biology, but also providing a warning system (via acoustic tags and buoyed satellite receivers along the coast) of tagged shark presence and an index of relative population abundance—all within the first category of strategies for minimising shark–human interactions above. This work is complemented by other emerging technologies, including aerial surveillance, not only from planes and helicopters, but also by drones. Other novel systems for detecting sharks at beaches are also being trialled.

In addition to these emerging technologies and trialling SMART drumlines off northern NSW, in October 2016, NSW DPI was directed to undertake a six-month trial to assess the utility of nets, using the same configurations currently fished in the SMP. Justification for trialling nets off the North Coast of NSW reflected their considered effectiveness in the SMP and elsewhere (Dudley et al., 1998; Dudley and Cliff, 2010), and fits within the third category of minimising shark–human interactions above (i.e. local depletion/removal of sharks).

The decision about which beaches to net was based on community consultation via telephone and online surveys, which were also used to monitor social attitudes toward the trial. Two surveys were conducted: one immediately before the nets were installed and the second in the last month of the trial.

Irrespective of the underlying rationale for trialling nets off the North Coast of NSW, few studies describe the relative catching performances (in the same space and time) of any configuration of drumlines and nets anywhere (e.g. Dudley et al., 1998; Sumpton et al., 2011), and no data are available for NSW. Similarly, while long-term patterns in catches from nets used in the SMP have been described (e.g. Reid et al., 2011), less is known about shorter-term variations, or whether the fate of catches can be improved by more regular (e.g. daily) or more proactive monitoring. Such data are required to inform discussions about the choice of appropriate strategies to minimise shark–human interactions in the future.

Methods

Approvals process

On 12 October 2016, following several shark–human interactions on the North Coast of NSW, the then NSW Premier, Mike Baird, announced that the NSW Government would pursue a regional trial of nets. To allow urgent commencement of the trial, the Minister for Primary Industries sought 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 to 9 of Chapter 4 of the Act, by the Commonwealth Minister for the Environment and Energy on 16 November 2016. Urgent amendments were also made to the *Fisheries Management Act 1994* and related legislation to promote the safe use and enjoyment by the public of coastal beaches and tidal waters by facilitating shark-management trials.

The trial was undertaken in accordance with an approved management plan for the NSW North Coast Shark Mesh-Net Trial, signed by the Secretary of the NSW Department of Industry, and the Fisheries Management (Shark Management Trial Ballina Shire and Richmond Valley councils) Order 2016 signed by the Minister for Primary Industries on 16 November 2016 in accordance with Schedule 6D of the *Fisheries Management Act*. The management plan for the trial commenced on 17 November 2016 for 12 months, with 6 months in total allocated for the deployment of nets.

Community consultation

Community consultation and engagement was undertaken before and at the end of the trial using various media, including surveys, drop-in stands, visits to businesses and formal meetings. A total of 28 community drop-in stands were located in the Ballina, Lennox and Evans Head regions during November–December 2016 (immediately before the trial) and May–June 2017 (at the end of the trial). The stands were located at relevant beach sites and other high-traffic locations and allowed the NSW DPI community engagement team to speak directly with an estimated 2235 people.

The community engagement team visited over 100 businesses in the Ballina, Lennox and Evans Head areas to discuss the nets. Following the trial announcement and subsequent deployment of nets, four meetings were held with the North Coast Shark Management Strategy Stakeholder Group (advisory body with representatives from three North Coast councils, beach authorities, local surfers, local businesses, and North Coast Chamber of Commerce representatives) to listen to concerns and aspirations and to provide feedback on how engagement influenced Government decisions. In addition, signage was placed at the five netted beaches before, during and after the trial to keep beach users informed throughout and to ensure that they were aware of opportunities to provide feedback. This extension work was complemented by content on the NSW DPI Shark Management website, including information about the trial, an explanation that the nets were not barriers, monthly updates on catches (http://www.dpi.nsw.gov.au/fishing/sharks/management/shark-net-trial), animations describing how the SMART drumlines work and catch details (http://www.dpi.nsw.gov.au/fishing/sharks/management/smart-drumlines), fact sheets, radio interviews, traditional media, and social media.

Two telephone surveys were undertaken to assess social attitudes to the nets. The pre-trial survey, from 27 October to 5 November 2016, included questions about the preferred placement of the nets. The post-trial survey, during the last month (22–31 May 2017) of the trial, assessed attitudes in the context of other strategies for minimising shark–human interactions, and included questions on the use of SMART drumlines. Both surveys, done by Jetty Research Pty Ltd, comprised random and representative telephoning of residents in the Ballina Shire and Evans Head region, as well as online questions available for anyone to answer. The questions were virtually identical between telephone and online formats and were designed to compare community views before and at the end of the 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 residents population were excluded because only 26% of them live in Ballina Shire (source: Australian Bureau of Statistics). 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 were sourced from SamplePages.com.au and were called from 15:30 to 20:00 on weekdays and from 12:00 to 17:00 on Saturdays. Potential respondents were screened to ensure they were 18 years or older 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 questionnaires were delivered using Survey Monkey software and 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. computer within a family or at a library). Online questionnaires were promoted via email to the North Coast Shark Management Strategy Stakeholder group (comprising representatives from Ballina, Richmond Valley, Byron and Lismore councils and Chambers of Commerce representatives, Surf Life Saving NSW, local surf clubs, Australian Lifeguard Services, local businesses, local Members of Parliament, and Le-Ba Boardriders); mail-outs to residents of the Ballina and Richmond Valley shires; advertisements in local papers; community drop-in stands at high-traffic locations, including surf lifesaving clubs and other beachfront locations; and local business drop-ins conducted by NSW DPI staff.

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). As the online response was 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 received from the online questionnaires, 600 comments from each open-ended question were selected at random for coding, and included the same proportion of 'Ballina Shire and Evans Head' vs 'other' respondents as the total online sample.

Nets used during the trial

At the start of the trial, a 5-day pilot study (17–21 November 2016) was undertaken at Lighthouse Beach and Evans Head to assess and refine key operational aspects associated with net deployments. On the basis of the community pre-trial survey findings, the five beaches selected for netting were Seven Mile Beach, Lennox Head ('Lennox Head Beach'); Sharpes, Shelly and Lighthouse beaches, Ballina; and Main Beach, Evans Head ('Evans Head Beach'). Between 8 December 2016 and 30 May 2017, a single net was deployed at each of these beaches. The management plan allowed for the deployment of up to ten nets in the trial area; however, only five nets were ever deployed at the same time.

The nets used followed the broad specifications of those used in the SMP (Green et al., 2009). Each net measured 150 m long and comprised 600-mm knotted mesh (inside stretched mesh opening) made from either 1.8- or 2.1-mm-diameter (ø) braided polyethylene (PE) twine attached to 20-mm ø polypropylene (PP) floatlines and 8-mm ø polyamide (PA) foot ropes at a handing ratio (= floatline and foot rope lengths ÷ stretched length of meshes) of 0.67 (Fig. 1). The only major difference among nets was that those used off Ballina had a fishing depth of 6 m, while that used at Evans Head measured 4 m deep (owing to shallower water). All nets had 30-kg anchors at each end, with buoyed trip-ropes (16-mm ø twisted PP), and four or five large surface floats (~300 mm ø) attached to ~2-m ropes (16-mm ø twisted PP) between the surface and the floatline (Fig. 1). The nets were designed to orientate so that the foot rope was at least 0.5 m off the bottom, and so minimise the catches of bottom-dwelling animals such as stingrays.

Three different acoustic deterrents ('pingers') designed to deter whales and dolphins were either attached to the floatlines (Fig. 1) or, for some dolphin pingers, secured to separate lines anchored 20 m from each end of the net. The pingers produced variable-frequency noises to alert whales and dolphins to the presence of the nets and were used with every net throughout the trial (Table 1). As part of the trial and in accordance with the management plan, a 'fauna disentanglement plan' was developed to facilitate the release of live animals (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/709823/Fauna-disentanglement-plan.pdf).

Table 1 Specifications of various acoustic deterrents ('pingers') deployed with all nets during the trial.

Name of acoustic deterrent (model)	Manufacturer	Number per net and distance apart	Species for which designed	Signal
Future Oceans 10 kHz Porpoise Pinger (FF10)	Future Oceans	3: at 25, 75 and 25 m from each net end	Small cetaceans (porpoises)	10 kHz, 132 dB every 4 s for 0.3 s
Future Oceans 70 kHz Dolphin Pinger (FF70)	Future Oceans	3: at 25, 75 and 25 m from each net end	Medium cetaceans (dolphins)	70 kHz, 145 dB every 4 s for 0.3 s
Future Oceans 3 kHz Whale Pinger (FF3)	Future Oceans	2: at 50 m from each net end	Large cetaceans (whales)	3 kHz, 135 dB
Dolphin Dissuasive Device (DDD)	STM Products	2: at 20 m from each net end	Small to medium cetaceans	20–160 kHz (variable) at 145 dB with pulsed interval of 4–30 s for 0.3 s

GPS units were installed into buoys attached to the floatlines of all nets. They were configured to produce an alert (via email and SMS) if a net was displaced more than 200 m from its anchored location.

SMART drumlines used during the trial

Twenty-five SMART drumlines were used during the trial. They were deployed in accordance with a Section 37 permit issued under the *Fisheries Management Act 1994* and Part 2 of the Marine Estate Management Regulation 2009. Each configuration included an anchor (either 3 m of 10-mm ø galvanized chain by itself or with a 4.5-kg Danforth Sand Anchor on the end—see below) and 20 m of 8-mm ø PP rope and an A1 Polyform anchor buoy (279 mm × 381 mm) (Fig. 2). A second (surface) line (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 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 at the end. Each hook was constructed of 9-mm ø stainless steel wire with shaft, bend and gape lengths of 122, 113 and 56 mm, respectively. Various semi-barbed and barbed hooks were used as part of other ongoing research with SMART drumlines, but all were baited with ~0.75–1 kg Sea Mullet (*Mugil cephalus*). A 1.5-m monofilament 'trigger line' (2.0-mm ø) was attached between the elasticised cord and the SMART buoy (Fig. 2). 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 SMS, telephone call and email.

All SMART drumlines were equipped with chain as anchors at the start of the trial. Although this configuration was maintained at Evans Head for the duration of the trial, 12 of the 15 SMART drumlines off Ballina and Lennox Head had sand anchors added in January 2017. The configuration was revised to prevent SMART drumlines dragging during strong currents or winds (i.e. typically >20 knots from the north-east). Attempts were made to test the same SMART system (and a derivative) used with the drumlines on the nets, but were not successful (see Results).

Where and how nets and SMART drumlines were fished

A single 6-m-deep net was anchored off each of Lighthouse, Shelly, Sharpes and Lennox Head beaches. Fifteen SMART drumlines were inter-dispersed between the nets over 13 km of coastline (Fig. 3). By comparison, one 4-m-deep mesh net was deployed off Evans Head main beach with ten surrounding SMART drumlines within 1 km either side of it (Fig. 3). Following current practices in the SMP, all nets were deployed ~500–600 m directly opposite and parallel to patrolled areas on the beaches, at depths of 5–12 m. The nets remained in the water for most of the trial, and were removed only during adverse weather (e.g. a predicted swell >3 m). Similarly, SMART drumlines were deployed across the same areas and distance offshore, but at depths between 6 and 16 m.

Two contractors serviced the four nets and 15 SMART drumlines deployed off Ballina, and a third contractor serviced both the single net and 10 SMART drumlines at Evans Head. Depending on the conditions, the contractors were required to check the nets twice a day (no earlier than 4 hours and within 24 hours of the last inspection, weather permitting), typically by lifting the floatline from the water, and to replace the nets every 2 weeks, weather permitting. In contrast, all SMART drumlines were deployed between 05:00 and 08:00, checked when triggered, and then retrieved between 16:00 and 19:00 (weather permitting). The period between checks of both gear types was called the ‘soak time’

Figure 1. **Diagram of the nets used off Evans Head (EH; 4 m deep) and Ballina (B; 6 m deep) during the trial. ø, diameter; PP, polypropylene; PE, polyethylene.**

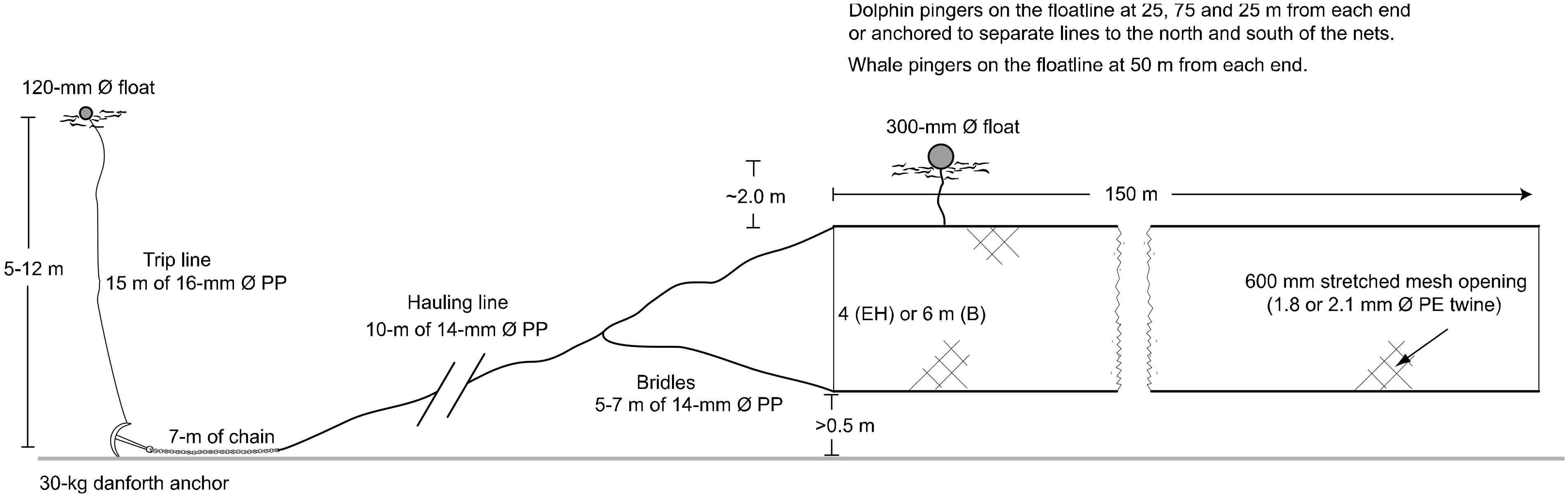


Figure 2. Diagram of a SMART drumline, showing the trigger line, which is released when the baited hook is taken.

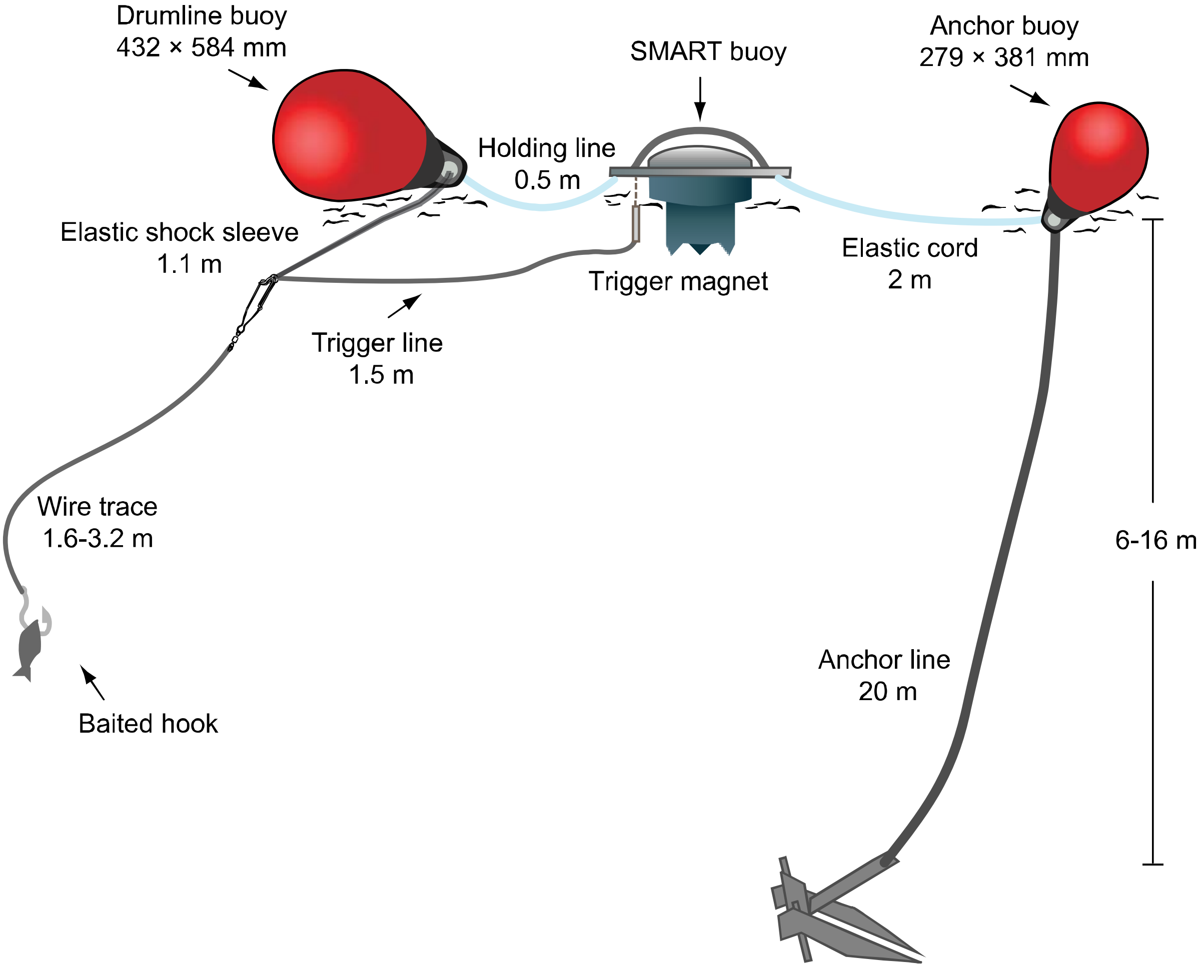
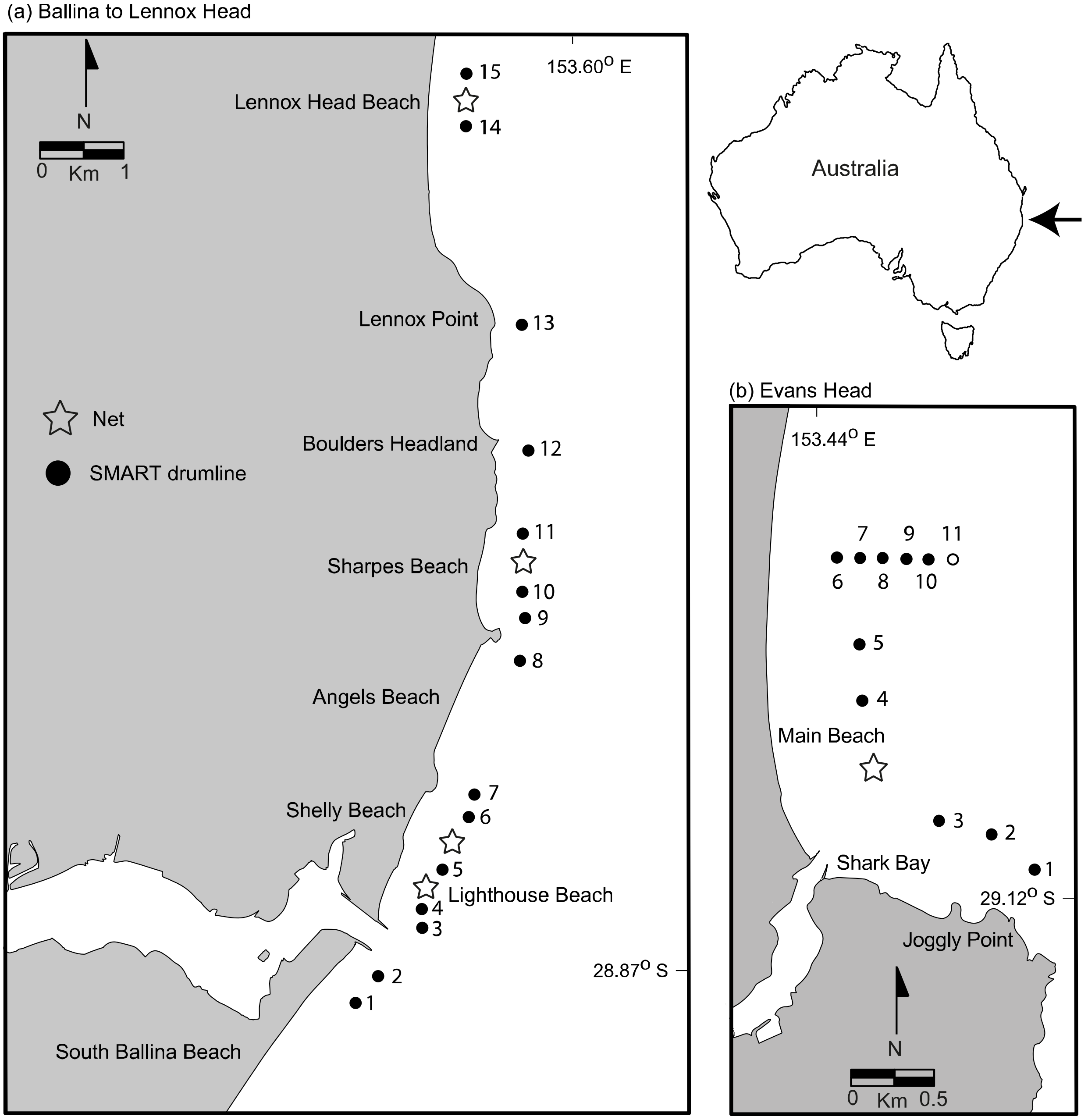


Figure 3. **Maps showing the approximate locations of the nets (☆) and SMART drumlines (●) off (a) Ballina to Lennox Head and (b) Evans Head. SMART drumlines were numbered 1−15 between Ballina and Lennox Head and 1−10 at Evans Head. '○' represents GPS location number 11 at Evans Head, which was used when location 6 was too rough for deployment.**



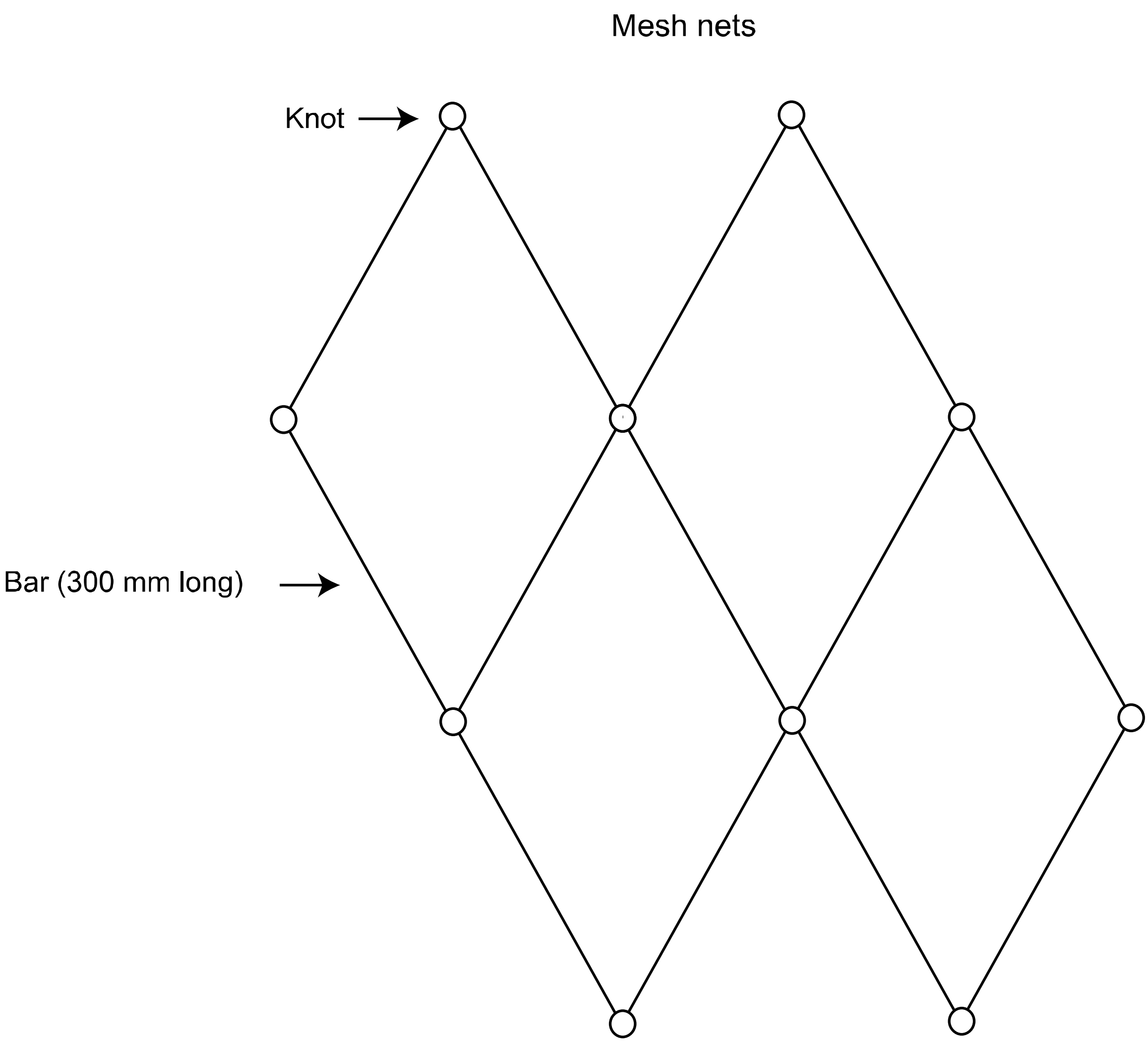
Data collected during the trial

Technical, biological and environmental data were collected every time the nets or the SMART drumlines were deployed, checked or retrieved by on-board NSW DPI observers. 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, and 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. All net and SMART drumline catches were photographed, assessed for their status (alive or deceased) following established protocols, and sampled (typically a small fin sample, which was stored in ethanol or 'RNA storage solution' later). Where possible, the sex was determined, and various sizes were recorded for all animals, including total length (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, although some animals were too decayed for accurate identification. Live animals that could be safely reached by the observer were tagged and released away from the nets or SMART drumlines. Deceased animals were either processed on board and then disposed of at sea or retained for necropsies on land before disposal by burial.

Any damage or technical problems with the nets or SMART drumlines were also recorded, including when there were no catches in the nets or no bait on the hooks, to quantify the frequency at which animals contacted the gear but were not caught. For nets, contact and escape was considered to have occurred when there was no animal entangled but there were at least two adjacent broken bars (creating a hole at least 600 mm × 600 mm; Fig. 4).

Figure 4. Section of netting showing knots and bars.



Results

Community consultation

Demographic characteristics, visitation rates and main activities undertaken

In both the pre- and post-trial surveys, the largest numbers of the telephoned respondents lived in Ballina (postcode 2478) and were ≥40 years of age (Table 2). Participation rates for pre- and post-trial surveys were 29% and 36%. Gender representation remained similar, with slightly more females in the pre-trial telephone interviews (Table 2).

Table 2. Total number and percentages of respondents to pre- and post-trial surveys involving telephone interviews and online questionaries.

	Telephone interviews		Online questionnaire	
	Pre-trial	**Post-trial**	**Pre-trial**	**Post-trial**
Total no. of respondents	600	602	4377	1469
Postcodes of respondents (%)				
2473 (Evans Head)	20	26	3	3
2477 (e.g. Wollongbar)	32	16	3	4
2478 (Ballina)	48	58	29	33
2479 (e.g. Bangalow)	na	na	2	2
All other locations	na	na	63	58
Age* (%)				
<18	na	na	2	2
18–39	10	26	na	na
18–34	na	na	30	19
35–44	na	na	44	48
40–59	39	37	na	na
55+	na	na	24	31
60+	51	38	na	na
Gender* (%)				
Male	43	47	49	45
Female	57	53	49	53
No answer	na	na	2	3
Children at home? (%)				
Yes	40	33	45	45

*Telephone samples were post-weighted by age and gender to match the profile of the combined 2473, 2477 and 2478 postcodes based on 2011 Australian Bureau of Statistics census data. 'na', not applicable. Note that age categories differed between telephone and online questionnaires.

In the online questionaries, there were 4377 valid responses to the pre-trial survey and 1469 to the post-trial survey, with a greater response from people living outside the Ballina Shire and Evans Head region, including other states. Most of these respondents were ≥35 years old (Table 2). Genders were well represented in both questionnaires, and 33-45% of respondents had children living at home.

The percentage of people visiting the beach weekly or more often and the main activities undertaken were similar during pre-and post-trial surveys. Residents frequented the beaches the most, especially those that responded to the online surveys (Table 3). The main activities undertaken by residents were walking, swimming and surfing; those that were telephoned had a stronger preference for walking and swimming (Table 3). All other respondents also mostly swam and surfed, but visited less frequently (Table 3).

Table 3. Visitation rates and main beach activities undertaken by respondents of pre- and post-trial telephone and online surveys.

	Ballina Shire and Evans Head residents				All other respondents	
	Telephone interviews		Online questionnaire		Online questionnaire	
	Pre-trial	Post-trial	Pre-trial	Post-trial	Pre-trial	Post-trial
Sample size	600	602	1645	621	2732	848
Visiting North Coast beaches weekly or more (%)	56	65	88	88	49	41
Main activities undertaken (%)						
Walking	38	40	11	16	0	13
Swimming	33	28	33	29	45	40
Surfing	8	12	36	37	22	18
Diving	0	0	0	0	8	0
Unspecified	21	20	20	18	25	29

The post-trial survey also asked respondents whether they, a family member or a close friend had been involved in a shark–human interaction on the North Coast, including being bitten, approached or bumped by a shark or being involved in the rescue or treatment of shark bite victims. On the basis of this definition, 37% of telephone respondents and 45% of online respondents indicated such involvement.

Community attitudes towards the nets used during the trial

Most respondents (85%–97%) in the pre- and post-trial surveys were aware of the trial before their participation. All respondents were asked how they thought the nets would affect or had affected them, their family and the wider community.

In the pre-trial survey, telephone respondents were more positive than negative about the expected effects of the nets; this was more pronounced when respondents were asked about perceived impacts on their family (45% positive vs 11% negative) and the wider community (54% vs 12%), relative to themselves (38% vs 12%). Most online respondents living in the Ballina Shire and Evans Head region were also positive about the nets regardless of considering effects on their families (56% positive vs 28% negative), the wider community (45% vs 26%) or themselves (55% vs 30%). Surfers living in the Ballina Shire and Evans Head region were particularly positive about the effects of the nets on the wider community during both telephone (63% positive vs 9% negative) and online surveys (62% vs 23%). In contrast, online respondents from other regions (and states) were consistently negative about the effects of the nets on themselves (71% negative vs 15% positive), their families (67% vs 15%) and the community (65% vs 15%).

In terms of deciding which beaches to net, pre-trial survey respondents were asked whether their level of concern was the same for all beaches: 78% of telephone respondents and 75% of online respondents answered yes. Telephone respondents who felt some beaches were more dangerous than others were then asked to rank their concerns: Lighthouse Beach caused most concern (69% of respondents), followed by Shelly (47%), Seven Mile/Lennox Head (34%), Sharpes (22%) and Evans Head main beaches (11%). These rankings dictated the locations of the five nets.

In the post-trial surveys, telephone respondents were slightly more positive than negative towards the nets when considering themselves (32% positive vs 27% negative), their families (32% vs 21%) and the wider community (36% vs 26%). However, the proportion of respondents with positive feelings declined by 6%–18% in the post-trial survey, and the proportion of people with negative feelings approximately doubled (Fig. 5; Table 4).

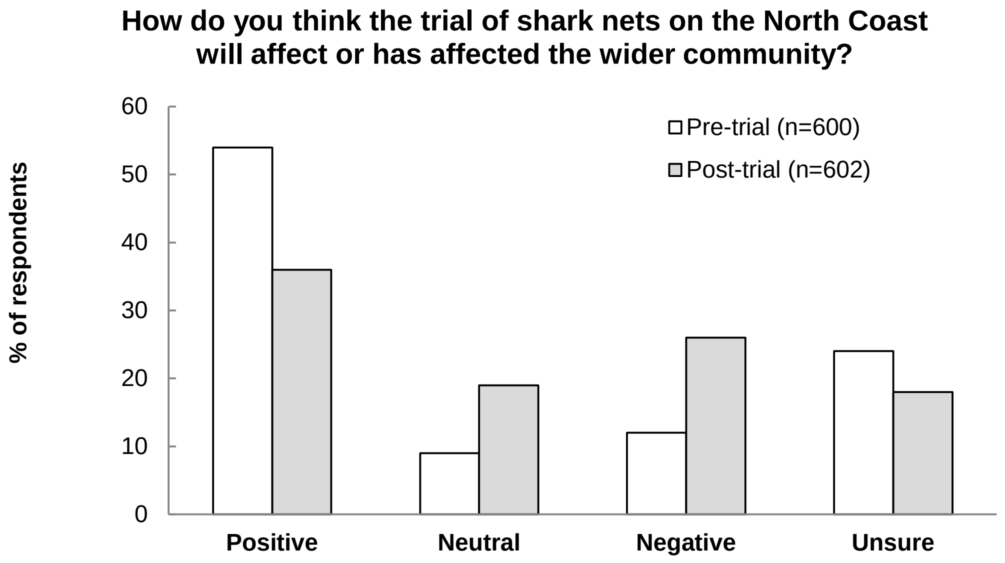
For example, 54% of respondents felt that the nets would have a positive effect on the wider community before the trial, compared with 36% post-trial. Correspondingly, 12% felt that the nets would have a negative effect before the trial, compared with 27% after the trial (Fig. 5). Relatively more surfers surveyed via telephone were also negative towards the nets after the trial (32%) than before (9%). The same trend was consistent among online respondents living in Ballina Shire and at Evans Head (Table 4). The exceptions was surfers who maintained strong support for the nets before and after the trial (62% vs 56%), with little change in negativity (23% vs 24%). In contrast, the vast majority of online respondents who lived in other regions (and states) maintained their negativity about the effects of the nets on themselves (71% pre-trial vs 72% post-trial), their families (67% vs 64%) and the community (65% vs 58%).

Table 4. **Pre- and post-trial telephone and online survey results (%) summarising the effects of the trial on self, family and the wider community.**

	Ballina Shire and Evans Head residents				All other respondents	
	Telephone interviews		Online questionnaires		Online questionnaires	
	Pre-trial	Post-trial	Pre-trial	Post-trial	Pre-trial	Post-trial
Sample size	600	602	1645	621	2732	848
Effect on self?						
Positive	38	32	55	39	15	9
Negative	12	27	30	44	71	72
Effect on family?						
Positive	45	32	56	39	15	8
Negative	11	21	28	41	67	64
Effect on community						
Positive	54	36	45	41	15	8
Negative	12	26	26	36	65	58

Respondents were asked, in an open-ended question, to briefly explain why they felt positive, negative or neutral about the nets. In the pre-trial telephone interviews, those perceiving the nets as positive focused on three main factors: the nets would make them feel safer (for their families or the community), nets were important for the local economy, and something needed to be done to address shark–human interactions. In general, all respondents who perceived the nets as negative were concerned about possible impacts on other marine life, a belief that the nets do not minimise shark–human interactions, and a philosophy that people should enter the water at their own risk (Fig. 6).

Figure 5. **Pre- and post-trial responses from telephone interviews in the Ballina Shire and Evans Head region in terms of their general positivity or negativity to the trial.**



In the post-trial surveys, telephone respondents who saw the nets as positive focused largely on two factors: the nets made them feel safer (for their families or the community; 42%), and there had been a perceived decrease in shark–human interactions. Respondents perceiving the nets as negative were generally concerned about bycatch (58%), especially of dolphins and turtles. Those who felt neutral were more likely to believe that the nets were ineffective at preventing shark–human interactions. These responses were generally similar among online respondents, but these people had relatively greater concerns about the impacts on other marine animals (raised by 45% of Ballina Shire and Evans Head residents and by 66% of those from other regions who were negative).

Success of the nets

In the pre-trial survey, respondents were asked, in an open-ended question, how they would judge the success of the nets. In telephone interviews, 69% of respondents nominated reduced or no shark–human interactions as a key measure of success and 18% nominated the amount of bycatch (or, more specifically, the collateral mortalities) as important benchmarks. Results were generally consistent among demographic groupings, regardless of whether respondents felt that the nets would be positive or negative. Similar indicators of success were nominated by online respondents from the Ballina Shire and Evans Head region, with 62% mentioning reduced or no shark–human interactions, 21% stating low bycatch, and 12% suggesting reduced shark sightings (Fig 6). Of the online respondents from other locations, the largest proportion did not agree in principle with the nets: 29% mentioned reduced or no shark–human interactions and 23% mentioned low bycatch as key indicators of success (Fig 7).

Figure 6. Pre-trial explanations from telephoned Ballina Shire and Evans Head respondents for positive, negative and neutral feeling towards the nets.

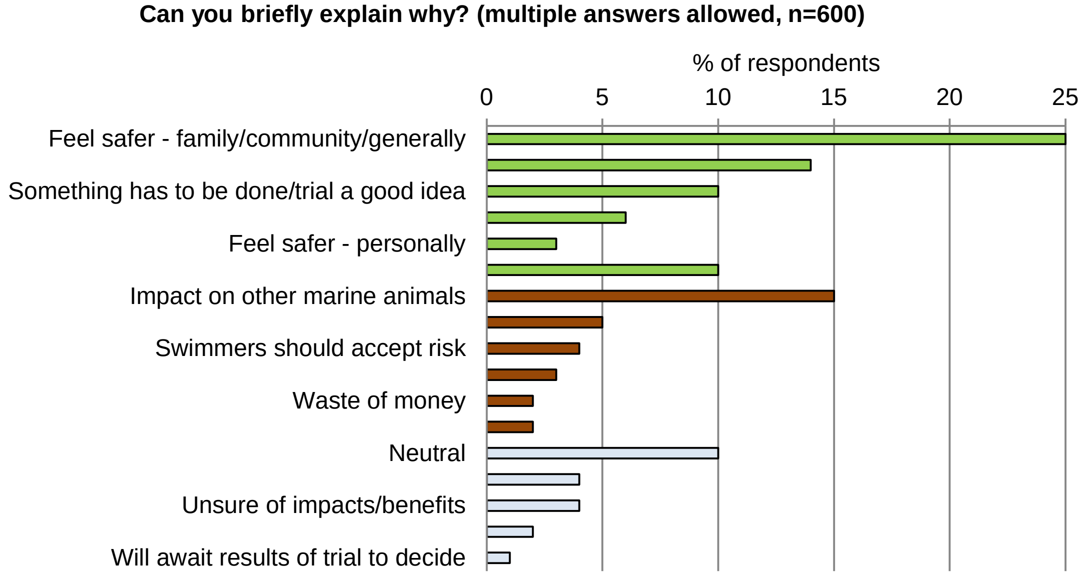
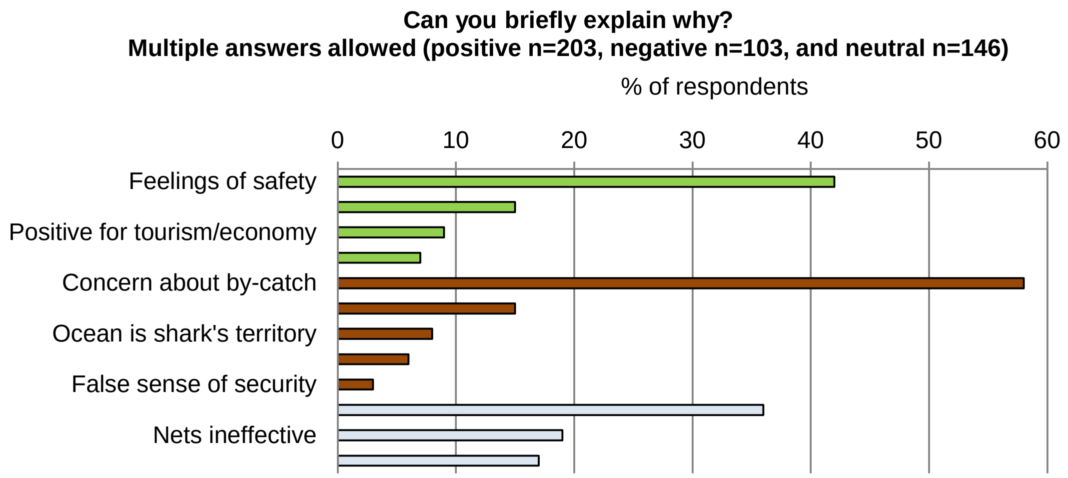


Figure 7. Post-trial explanations from telephoned Ballina Shire and Evans Head respondents for positive, negative and neutral feeling towards the nets.



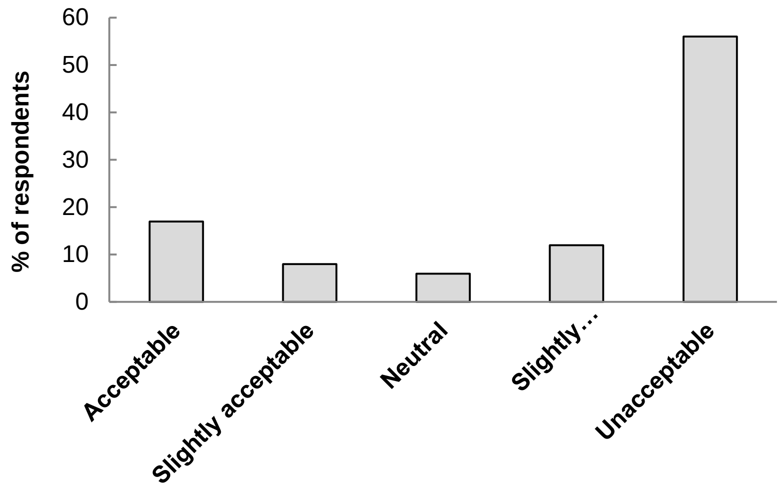
It is important to note that no shark–human interactions were subsequently recorded at or near the study area during the trial. But three incidents were reported well to the south, involving a White Shark (3.2–4.5 m total length; TL) that attacked a surfer on 1 December 2016 near Forster (at ‘The Ruins’), causing minor injuries; an unidentified shark that caused minor injuries to a bodyboarder at Killalea Beach, Illawarra (19 March 2017); and a Greynurse Shark that caused minor injuries to a surfer at One Mile Beach, Port Stephens (2 April 2017).

In the post-trial survey, respondents were provided with the following statements: '*Shark nets catch animals other than sharks. During the trial on the north coast a total of 247 non-target animals were caught in the nets, including 3 dolphins and 12 turtles. 48% of non-target animals were released alive and 52% died*.' Respondents were then asked whether this level of non-target catch was acceptable in the overall context of the trial. In the telephone surveys, 68% of respondents felt that the amount was unacceptable vs 25% who felt it was acceptable (the latter was greater among males, frequent beach visitors and those involved in a shark–human interaction) (Fig. 8). This pattern was consistent with the online sample of Ballina Shire and Evans Head respondents (60% unacceptable vs 37% acceptable), but not for local surfers, 52% of whom considered the bycatches to be acceptable, compared with 42% who said they were not. Online respondents from other regions exhibited the strongest opposition to bycatch, with 91% finding it unacceptable vs 8% acceptable.

Following the question about bycatch in the post-trial survey, participants were asked whether they felt that the trial (nets) was a success. Of Ballina Shire and Evans Head residents, 48% of telephone respondents felt the trial was not successful vs 37% who believed it was, with the balance unsure. Online results were similar, with 55% feeling that the trial was unsuccessful vs 38% successful. The ratio of respondents considering the trial to be unsuccessful vs successful was much greater in those living in other regions (87% vs 9%) in the online sample.

There was a strong correlation between attitude to bycatch and the perceived success of the trial from the telephoned respondents. Of those who felt bycatches were acceptable, 82% felt that the trial had been a success. In contrast, 65% of the respondents who assessed the bycatch as unacceptable deemed the nets to be unsuccessful.

Figure 8. Percentage of responses to telephone surveys of Ballina Shire and Evans Head residents when asked whether the level of bycatch in the nets was acceptable or unacceptable (*n* = 602).



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

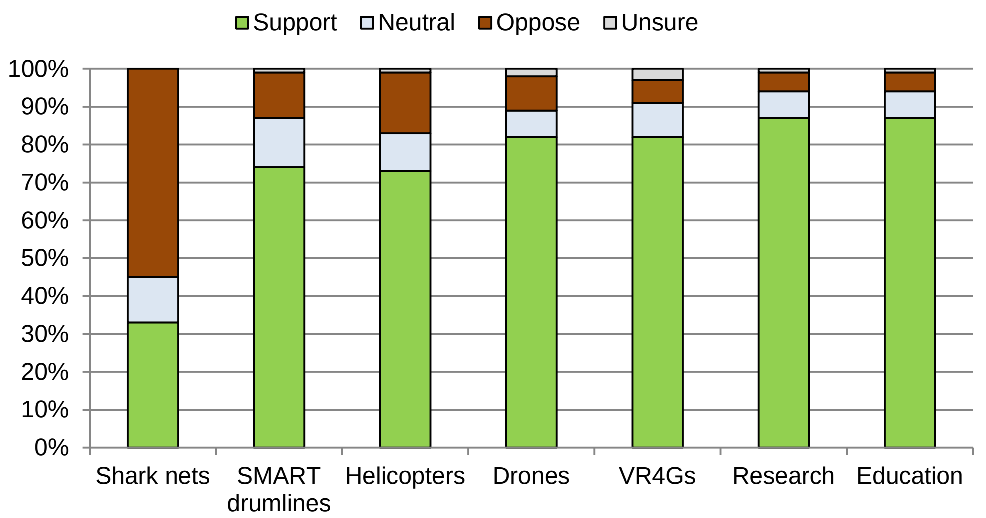
In the post-trial survey, questions about the nets were followed by statements and questions relating to the SMART drumlines. Statements presented included how SMART drumlines work and the numbers of target sharks and non-target species caught by SMART drumlines vs nets. Online respondents living in the Ballina Shire and Evans Head region were more aware of both the net and SMART drumline results before the survey than residents who participated in telephone surveys (55% vs 28%) and online respondents from other locations (34%).

The final post-trial survey question asked respondents to what extent they supported or opposed a range of measures to reduce the risk of shark bites on the NSW North Coast. In this context, nets consistently had the lowest support in telephone surveys (33%) and in online surveys of residents (40%) and non-residents (12%) (Table 5). During the random telephone interviews of Ballina Shire and Evans Head residents, 55% of respondents were opposed to nets, while only 5% to 16% were opposed to other measures (Fig. 9).

Table 5. Percentage of respondents who were 'strongly' or 'somewhat' supportive of each protection measure.

Potential shark protection measure	Ballina/Evans Head residents		All other respondents
	Telephone	Online	Online
Shark nets	33	40	12
SMART drumlines	74	66	44
Helicopter surveillance	73	80	76
Drone surveillance	82	82	84
Listening stations to detect tagged sharks	82	82	84
Research to better understand shark numbers/movements	87	87	94
Education about how to be 'SharkSmart'	87	82	93

Figure 9. Percentage of telephoned Ballina Shire and Evans Head residents who supported (somewhat or strongly) and opposed (somewhat or strongly) different protective measures to reduce the risk of shark–human interactions on the North Coast (*n* = 602).



Operational logistics and catches of nets during the trial

Operation

The nets were deployed for totals of between 144 and 167 days, representing 83% to 96% of the total time between the start and end of the trial (8 December 2016 to 30 May 2017, or 174 days). During the trial, the net contractors at Ballina and Evans Head were at sea either deploying or checking nets for totals of 99 and 145 days, respectively.

Each net was checked for catches between 125 and 227 times, for a total of 732 net checks (Table 6). The contractors tried to check the nets twice a day, but owing to weather conditions, an afternoon check was possible for only 210 checks (done during 31 days for the Shelly and Sharpes nets, 32 days for the Lighthouse and Lennox Head nets, and 84 days for the Evans Head net). The time between net checks ranged from 1 hour to nearly 145 hours, but average checks were made every ~17 hours at Evans Head and every 27–28 hours at Ballina (Table 6).

The management plan for the trial stated that the nets needed to be checked no earlier than 4 hours or within 24 hours of prior inspection, weather permitting. This rate occurred for 64% of the total checks. There were 49 occasions (7% of the total checks) when the nets were checked within 4 hours and 213 occasions (29% of the total) when nets were checked after 24 hours. The earlier checks sometimes occurred because of a perceived problem with the net or its orientation, but more often because of inclement weather or bar conditions and a need to return to port. Poor weather was the reason for all net checks after 24 hours.

Table 6. The number of actual hours and separate days that each net was deployed at each beach, number of times nets were checked, and the mean and range of time between consecutive checks.

Beach	Number of hours (h) and days (d) nets deployed	Number of times checked	Mean and range of hours: minutes between consecutive checks
Lennox Head	3592 h over 151 d	128	28:04 (1:16–144:59)
Sharpes	3551 h over 151 d	126	28:11 (1:06–144:00)
Shelly	3430 h over 144 d	125	27:26 (1:56–139:26)
Lighthouse	3466 h over 150 d	126	27:31 (1:42–138:35)
Evans Head	3924 h over 167 d	227	17:19 (1:48–114:45)

The net-checking periods varied substantially, but on average were less at Evans Head owing to protection afforded by the headland (Tables 6, 7). Often the bar conditions at the entrance to the Richmond and Evans Head rivers, which varied according to tide and swell direction, were the main factor precluding net checks. During checks the water visibility (which was affected by swell, currents, rainfall, river discharge and tides) was similar across the Ballina net sites, which was typically better than at the Evans Head net site. Sea surface temperatures across the area varied from 17.0 to 26.8 °C, with an average of 21.9 °C.

Table 7. Average and range of general wind and sea conditions during each net check off Ballina and Evans Head.

Location	Wind (kn)	Sea (m)	Swell (m)	Water visibility (m)
Ballina	7.6 (0.0–22.0)	0.7 (0.0–1.8)	1.6 (0.5–3.0)	4.5 (0.5–12.5)
Evans Head	7.7 (0.0–20.0)	0.5 (0.0–1.5)	1.6 (0.5–3.5)	3.8 (0.5–8.5)

Of the total net checks, 73% comprised floatline checks, 19% visual checks and 8% full removals. Either the main vessel or a small tender was used to complete floatline and visual checks (although any large animals had to be removed from the main vessel), while full net removal and deployment always required the main vessel. Visual checks were done only when conditions (including swell and current) precluded a floatline check. During three visual checks, a total of eight animals were not observed, but on the basis of their decomposition status during a subsequent floatline check, had clearly had been in the nets for an extended period. Relevant data describing soak times for these animals were adjusted accordingly.

In between checks, the nets at all beaches sometimes incurred damage that frequently comprised multiple broken bars (between 1 and 7290) at up to seven separate locations per net. There were often broken and some missing meshes associated with a large animal being meshed and removed, and sometimes with more than one animal per net (Table 8). However, there were a similar number of occasions when a large hole (>0.36 m^2) was present but no animal was caught, especially at Evans Head (Table 8). In some cases, netting was lost.

Table 8. Number of times a net was damaged with and without an animal present.

Beach	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	11	12
Sharpes	20	10
Shelly	7	5
Lighthouse	12	5
Evans Head	18	28
Total	**68**	**60**

*See Fig. 4 for an explanation of mesh bars.

During the trial, attempts were made to fit SMART buoys (used with the drumlines) to the ends of the nets to provide an alert when an animal was caught. However, the movement of the net in the current precluded any utility of the system, and accurate triggering could not be achieved. Attempts were also made to place small (100-mm ø), brightly coloured floats along the floatlines (on ropes to the surface) so that as animals were entangled in the net they would displace the floatline and the coloured float would disappear, alerting the contractor. On several occasions (during calm weather), some of these small floats provided a useful indication of meshed animals, but the current also precluded broad-scale utility. In any case, net checks were entirely dictated by the weather, and the contractors tried to check whenever possible within the management plan requirements for the trial.

Total catches

In total, 275 animals were caught in the five nets (Table 9). All but eight animals were identified to species level. Of the unidentified animals, three Whaler sharks and two tuna were too decomposed (they were caught during longer-than-average periods between net checks), while two manta rays and one turtle escaped during net retrieval, preventing identification.

The remaining animals comprised 18 species: Australian Cownose Ray (*Rhinoptera neglecta*), Pygmy Devilray (*Mobula kuhlii cf. eregoodootenkee*), Whitespotted Eagle Ray (*Aetobatus ocellatus*), Great Hammerhead (*Sphyrna mokarran*), Common Blacktip Shark (*Carcharhinus limbatus*), Whitespotted Guitarfish (*Rhynchobatus australiae*), Tiger Shark (*Galeocerdo cuvier*), White Shark (*Carcharodon carcharias*), Bull Shark (*Carcharhinus leucas*), Spinner Shark (*Carcharhinus brevipinna*), Greynurse Shark (*Carcharias taurus*), Manta Ray (*Manta alfredi*), Loggerhead Turtle, Mulloway (*Argyrosomus japonicus*), Longtail Tuna (*Thunnus tonggol*), Indo-Pacific Bottlenose Dolphin (*Tursiops aduncus*), Green Turtle (*Chelonia mydas*) and Mackerel Tuna (*Euthynnus affinis*) (Table 9). Four species (Australian Cownose Ray, Pygmy Devilray, Whitespotted Eagle Ray and Great Hammerhead) comprised 75% of the catch (Table 9).

Table 9. **Numbers of each species (within broad groups) caught by the nets at each beach and cumulative totals and sizes.**

	Lennox Head	Sharpes	Shelly	Light-house	Evans Head	Total (mean size and range in m)
Sharks and rays						
Australian Cownose Ray	3	4	7	14	53	**81** (0.8; 0.4–1.1 m DW)
Pygmy Devilray	21	11	2	6	23	**63** (1.1; 0.9–1.3 m DW)
Whitespotted Eagle Ray	0	3	10	11	14	**38** (1.4; 0.9–2.2 m DW)
Great Hammerhead	5	4	1	6	8	**24** (3.0; 2.0–3.8 m TL)
Common Blacktip Shark	1	3	3	3	2	**12** (1.9; 1.5–2.3 m TL)
Whitespotted Guitarfish	5	0	1	1	2	**9** (2.2; 1.6–2.5 m TL)
Tiger Shark	1	2	0	0	0	**3** (3.4; 3.0–3.7 m TL)
White Shark	0	3	0	0	0	**3** (3.2; 2.9–3.4 m TL)
Unidentified whaler sharks	0	0	0	2	1	**3** (na)
Bull Shark	1	0	0	2	0	**3** (2.4; 1.9–2.8 m TL)
Unidentified manta rays	0	1	0	1	0	**2** (na)
Spinner Shark	0	0	0	0	1	**1** (2.6 m TL)
Greynurse Shark	0	1	0	0	0	**1** (2.8 m TL)
Manta Ray	1	0	0	0	0	**1** (2.5 m DW)
Other animals						
Loggerhead Turtle	2	2	1	2	1	**8** (1.0; 0.8–1.1 m CCL)
Mulloway	0	0	0	4	2	**6** (1.2; 0.9–1.3 m TL)
Longtail Tuna	1	2	0	1	0	**4** (1.1; 1.0–1.1 m TL)
Indo-Pacific Bottlenose Dolphin	1	0	2	1	0	**4** (2.2; 1.6–2.4 m TL)
Green Turtle	0	1	1	0	1	**3** (0.7; 0.4–0.9 m CCL)
Mackerel Tuna	3	0	0	0	0	**3** (0.5; 0.4–0.6 m TL)
Unidentified tuna	1	1	0	0	0	**2** (na)
Unidentified turtle	0	1	0	0	0	**1** (na)
Total	**46**	**39**	**28**	**54**	**108**	**275**

na, Not available. TL, total length: sharks, fish and dolphins; disc width, DW: rays; curved carapace length, CCL: turtles.

Among target sharks, three White Sharks (all females: 2.9, 3.2 and 3.4 m TL), three Tiger Sharks (all males: 3.0, 3.5 and 3.7 m TL) and three Bull Sharks (all females: 1.9, 2.5, and 2.8 m TL) were caught (Table 9). Using the total hours fished across all nets (Table 6), it is possible to standardise the catches of target sharks to 0.002 individuals caught per net per 24-hour soak.

The White Sharks were netted at the start (December and January) and end (May) of the trial (and within soak times of 19, 49 and 94 hours). The Bull Sharks were caught throughout the trial (January, March and April; 3, 18 and 101 hour soak times) and the Tiger Sharks (two in December and one in March; 15, 19 and 19 hour soaks) in the first 4 months. All White Sharks and two Tiger Sharks were caught at Sharpes Beach (Table 9). The remaining Tiger Shark and one of the Bull Sharks were caught at Lennox Head Beach, and the other two Bull Sharks were caught at Lighthouse Beach (Table 9). Sixteen other sharks of species listed in the management plan as ‘potentially dangerous’ (all <2.6 m TL) were netted (Table 9).

Where entanglement could be determined, most animals caught in the four nets off Ballina made contact at the eastern (or seaward) side, but the opposite occurred in the net at Evans Head

(Table 10). Of the nine White Sharks, Tiger Sharks and Bull Sharks, three were caught on the western side and three on the eastern side, but the meshing side of the other three could not be determined. Across most beaches, there was a slight bias towards animals being entangled in the middle and southern end of the nets (Table 10).

Table 10. Numbers of animals entangled on the eastern or western side of the nets at each beach.

	Lennox Head	Sharpes	Shelly	Lighthouse	Evans Head
Side of the net					
Eastern (seaward)	29	20	20	24	31
Western (landward)	11	7	4	12	51
Not determined	6	12	4	18	26
Length of the net					
Southern third	17	14	9	23	36
Mid third	19	13	9	18	45
Northern third	10	12	10	13	26
Not determined	0	0	0	0	1

Entanglement side and, to a lesser extent, position along the nets could not always be accurately determined owing to the amount of entanglement and/or net damage.

Variability among catches over time

On days when two net checks were made (210 times), 87% of the total catch was caught during the first check. During the 210 second daily net checks, only 17 animals were caught (all but four at Evans Head). Except for a single incidence when 10 animals (seven Australian Cownose Rays and three Whitespotted Eagle Rays) were caught in the Evans Head net, the maximum catch was six animals per net, irrespective of time between net checks (Fig. 10). Given no clear relationship between soak time and catches, for the purposes of comparing relative catches among nets across the six reporting months of the trial, the numbers of total animals and the most abundant species at Ballina and Evans Head were standardized to catch-per-net-check.

Catches-per-net-check peaked at Evans Head in the second month, largely owing to Australian Cownose Rays, which were also relatively abundant off Ballina during the same period. At both locations, catches of most species tended to decline towards the last monitoring month, except Pygmy Devilrays, which were most abundant during the fifth month (April–May) (Fig. 11).

Figure 10. Numbers of animals caught per net in (a) all Ballina nets and (b) Evans Head net during checks within approximately 1.5 days (3–34 h), 2.5 days (43–54 h), 3.5 days (65–76 h), 4.5 days (96–101 h), 5.5 days (115–128 h) and 6.5 days (138–145 h).

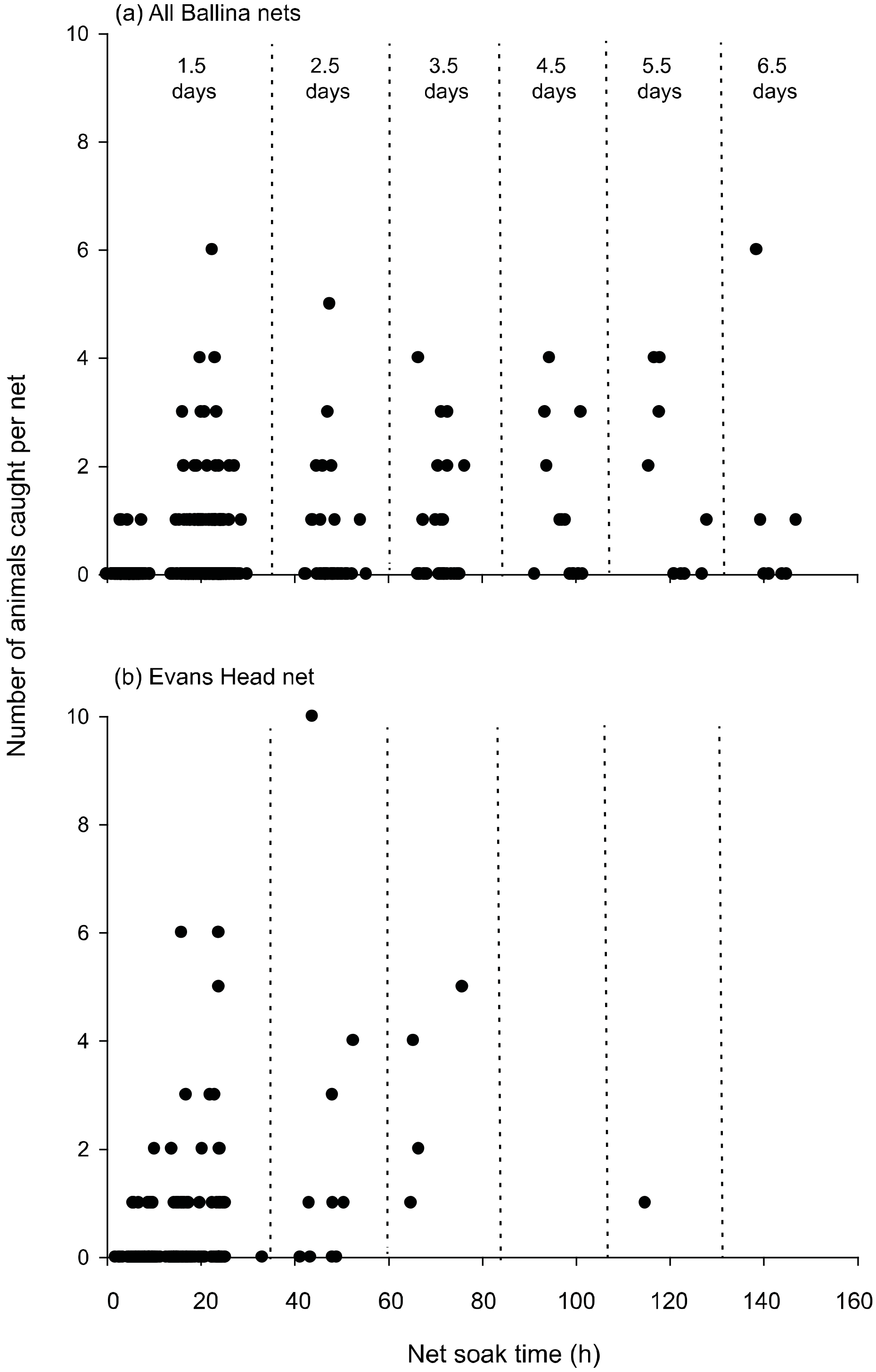
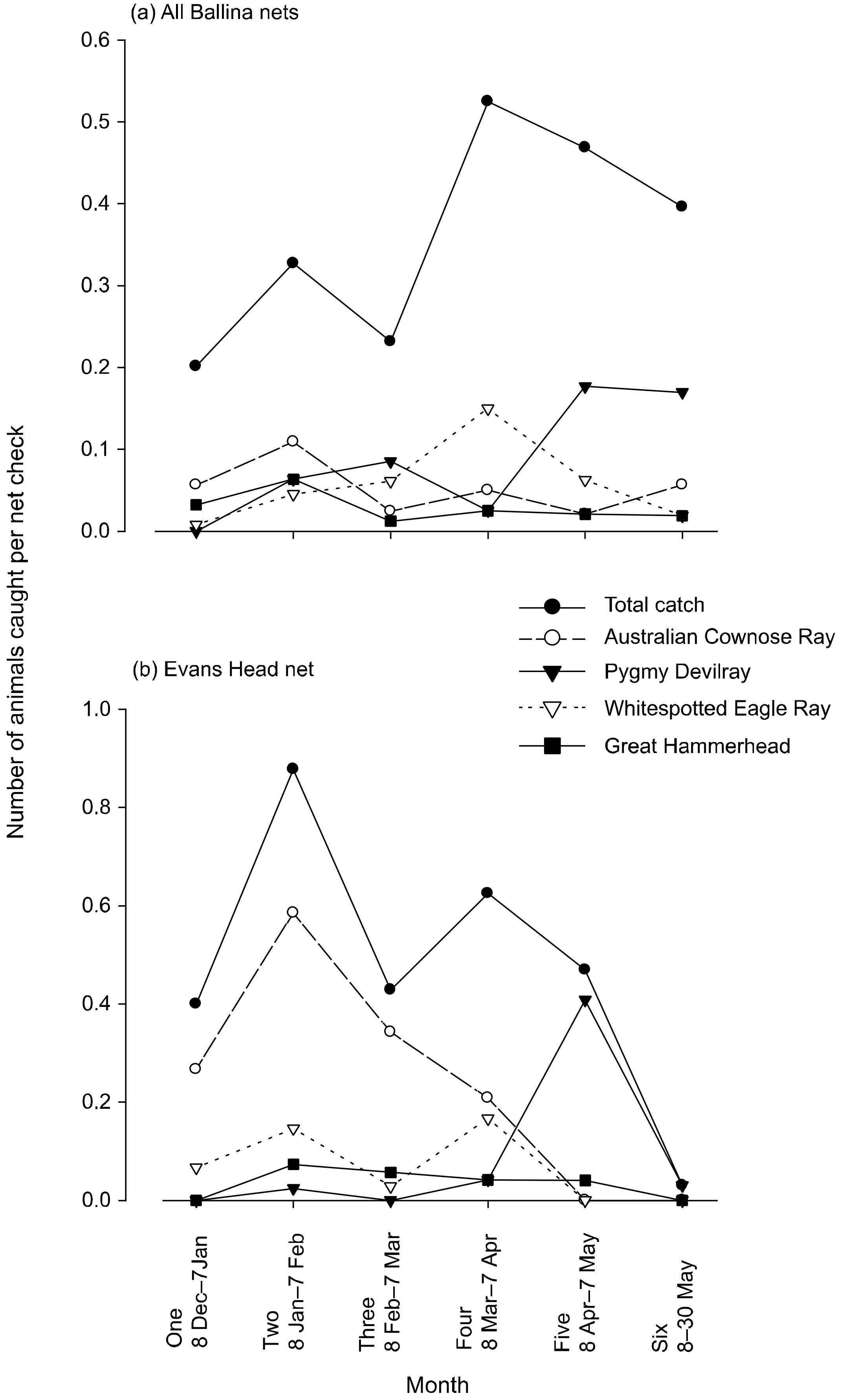


Figure 11. Numbers of total catch and key species per net check in (a) all Ballina nets and (b) Evans Head net during each reporting month of the trial.



Survival of catches

Overall, 128 animals were alive and 147 were dead during net checks, giving a survival rate of 46.5% (rounded to 47%; Table 11). There was considerable variability in the survival of the various species (Table 11). Among the most abundant species, Whitespotted Eagle Rays and Australian Cownose Rays had the greatest survival (76% and 70%, respectively; Table 11). Great Hammerheads and Common Blacktip Sharks had the poorest survival, with virtually all dead during net checks. Relatively few individuals of the remaining species were caught, precluding definitive statements about species-specific trends in survival; however, it is noteworthy that all teleosts (four species) died (Table 11).

Some of the teleosts were quite small, and the Mackerel Tuna measured only 40 to 60 cm in TL (Table 9). These sizes should easily pass through the mesh, but they were typically caught in a convoluted section of netting or were trapped by the gills. Perhaps some teleosts collided with the net at speed, possibly while chasing prey, and damaged their gills.

Table 11. Number of live and dead animals observed during each net check, and percentage survival.

Species	Number alive	Number dead	Percentage survival
Sharks and rays			
Australian Cownose Ray	57	24	70
Pygmy Devilray	18	45	29
Whitespotted Eagle Ray	29	9	76
Great Hammerhead	1	23	4
Common Blacktip Shark	0	12	0
Whitespotted Guitarfish	7	2	70
Tiger Shark	2	1	67
White Shark	1	2	33
Unidentified whaler sharks	1	2	33
Unidentified manta rays	2	0	100
Bull Shark	1	2	33
Spinner Shark	1	0	100
Greynurse Shark	0	1	0
Manta Ray	1	0	100
Other animals			
Loggerhead Turtle	6	2	75
Mulloway	0	6	0
Longtail Tuna	0	4	0
Indo-Pacific Bottlenose Dolphin	0	4	0
Green Turtle	0	3	0
Mackerel Tuna	0	3	0
Unidentified tuna	0	2	0
Unidentified turtle	1	0	100
Total	**128**	**147**	**47**

Only four animals had evidence of depredation while entangled in the nets, and all were dead: an Indo-Pacific Bottlenose Dolphin (several bites from an unidentified shark; Table 12), an

Australian Cownose Ray (one bite on the left side from a Great Hammerhead), a Whitespotted Guitarfish (bites on both sides from an unidentified species), and a Mulloway (the tail was missing and the body was badly decomposed).

All four Indo-Pacific Bottlenose Dolphins, three Green Turtles (listed as vulnerable) and two (of eight) Loggerhead Turtles (endangered) died in the nets. Where possible, they were necropsied (Table 12). The Indo-Pacific Bottlenose Dolphins were observed in the nets after soaks of 15, 72, 128 and 140 hours; two were caught in nets with an FF70 or an FF3 pinger and two in nets with a DDD and an FF3 pinger. The Green Turtles were caught after 7, 23 and 116 hours, and the Loggerhead Turtles after 48 and 52 hours.

Table 12. Summary of the Indo-Pacific Bottlenose Dolphins and turtles that died in the nets with key necropsy findings.

Species	Capture date	Size and sex	Key necropsy findings
Indo-Pacific Bottlenose Dolphin #1	04/01/2017	~1.6 m TL, female	Juvenile with a body condition that precluded detailed necropsy (owing to depredation by possibly a Tiger Shark while entangled).
Indo-Pacific Bottlenose Dolphin #2	28/01/2017	2.4 m TL, female	Adult in good external physical condition (food in stomach) but with some new propeller marks. It had trematodes (worms) in the liver, pneumonia and some inflammation in the brain.
Indo-Pacific Bottlenose Dolphin #3	26/03/2017	2.4 m TL, male	Very old adult with no teeth (but food in stomach). It had trematodes (worms) in the liver and pneumonia.
Indo-Pacific Bottlenose Dolphin #4	13/05/2017	~2.4 m TL, female	Adult with a decomposed body condition that precluded detailed necropsy.
Green Turtle #1	09/12/2016	43 cm CCL, female	Juvenile with no obvious diseases or disorders, but the animal had a poor body condition and was emaciated.
Green Turtle #2	05/02/2017	92 cm CCL, male	No obvious abnormalities.
Green Turtle #3	30/04/2017	69 cm CCL, male	Old wounds to carapace and right front flipper.
Loggerhead Turtle #1	01/02/2017	83 cm CCL, male	No obvious abnormalities.
Loggerhead Turtle #2	01/03/2017	92 cm CCL, male	No obvious abnormalities.

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 is, and so the effect of net soak time (i.e. net checking frequency) on survival was plotted for total catch and the three most abundant species (with variable survival). When pooled across all catches, the total survival was comparable after 1- and 2.5-day checks (at 56% and 54%, respectively), but dropped considerably during 3.5- to >4.5-day checks, although the few animals were caught (Fig. 12). Of the key species, Australian Cownose Rays and Whitespotted Eagle Rays had survival rates of ≥50% after ≤3.5-day checks (Fig. 13a, c), but only 30% of Pygmy Devilrays were alive after 1.5-day checks, and none after 2.5 days (Fig. 13b).

Figure 12. 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 (3–29 h), 2.5 (43–54 h), 3.5 (65–76 h), 4.5 (96–101 h) and >4.5 days (>108 h).

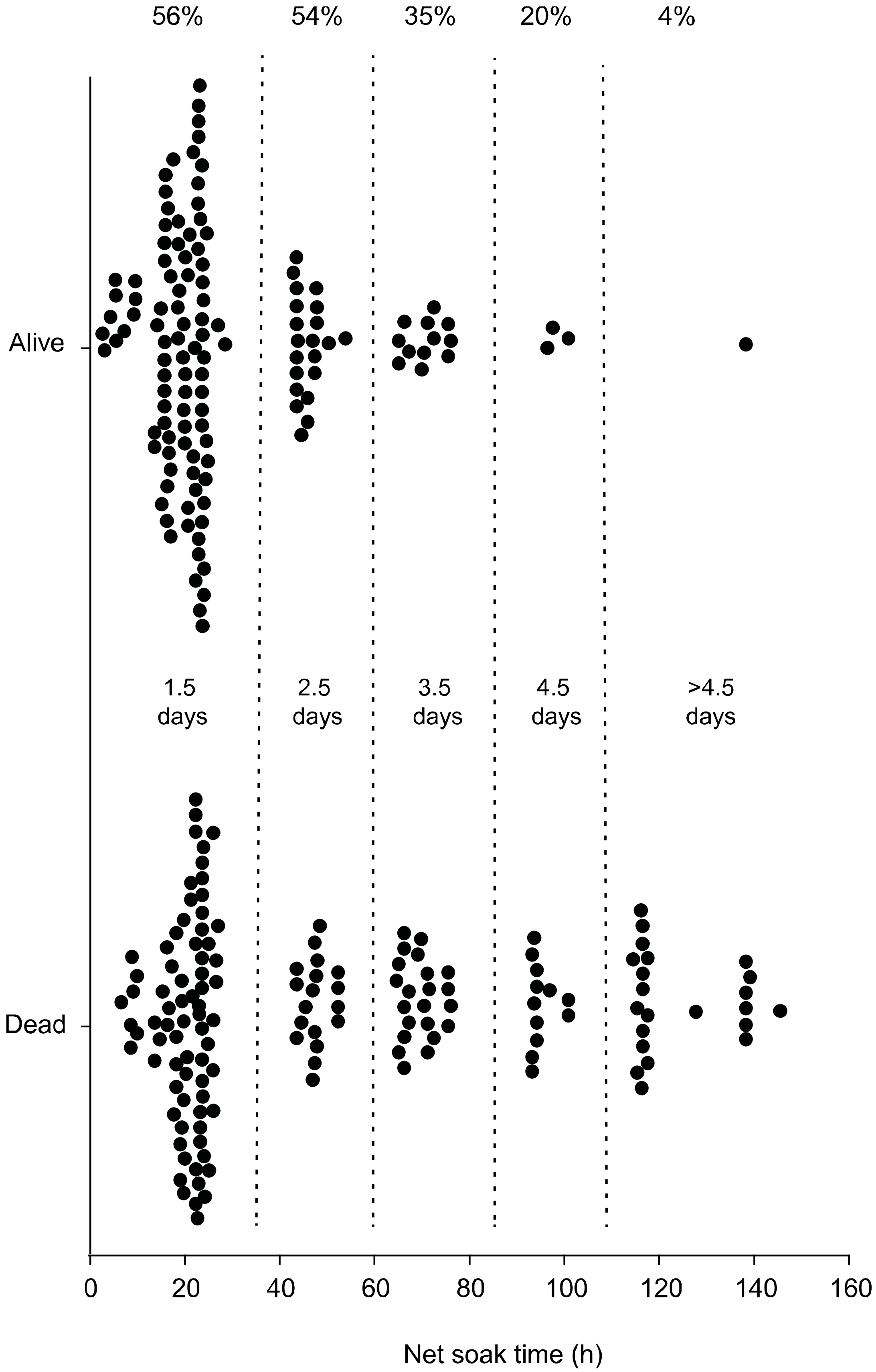
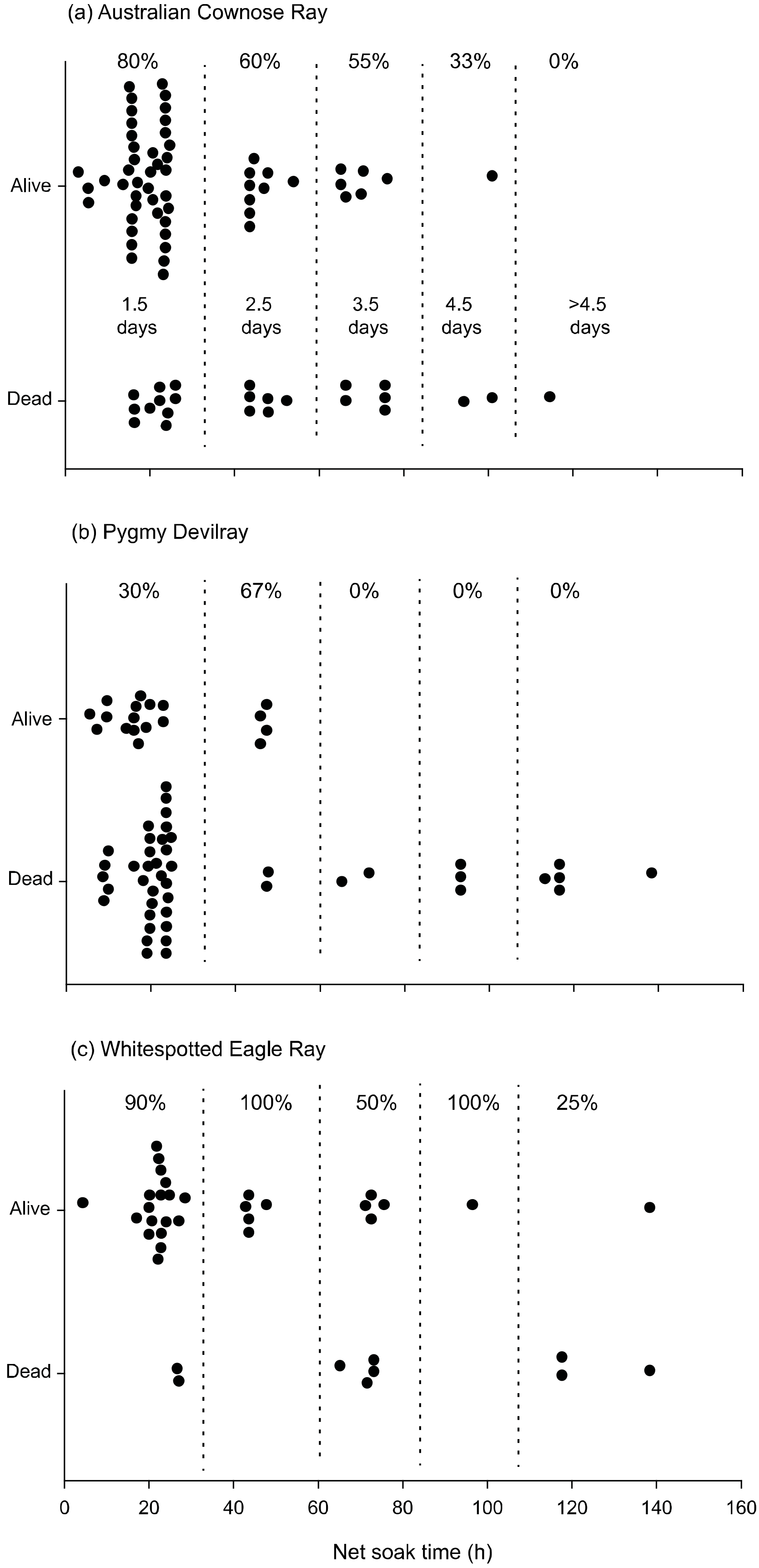


Figure 13. Jitter plots showing the numbers of (a) Australian Cownose Rays, (b) Pygmy Devilrays and (c) Whitespotted Eagle Rays (each dot is an animal) that were alive or dead at each net check (soak time), with percentage survival after approximately 1.5 (3–29 h), 2.5 (43–54 h), 3.5 (65–76 h), 4.5 (96–101 h) and >4.5 days (>108 h).



Operational logistics and catches of SMART drumlines during the trial

Operation

During the 174-day trial, 3231 SMART drumline deployments totalling 25 749 hours were completed on 128 days (1911 deployments at an average of 8 h 16 min per day) off Ballina to Lennox Head and 132 days (1320 deployments at an average of 7 h 45 min per day) off Evans Head (Table 13). Deployment duration was influenced by environmental conditions, which varied daily between locations and were often better at Evans Head than at Ballina to Lennox Head, and in the morning than in the afternoon (Table 14). Contractors worked in winds of up to 30 knots, seas of up to 2.0 m and swells of up to 3.8 m (Table 14). Mean sea surface temperatures were 22.3 °C off Ballina to Lennox Head (17.4–26.8 °C) and 21.9 °C off Evans Head (19.0–26.4 °C).

All ten SMART drumlines were deployed at the designated locations off Evans Head each day, although owing to dangerous surf conditions, that at location 6 had to be moved to location 11 on 50 fishing days (Fig. 3). Gear repairs meant that on 7 days, 1 or 2 of the 15 SMART drumlines were not deployed at Ballina to Lennox Head. Deploying SMART drumlines at the same locations was problematic at Boulders Headland, Lennox Point and Main Beach, Lennox Head, when strong north-easterly winds were present over summer. Subsequently, weather conditions prevented deployment at these locations on 12, 14 and 43 days, respectively, and the SMART drumlines were repositioned between South Ballina Beach and the northern end of Angels Beach, Ballina.

Table 13. Number of days SMART drumlines were deployed, mean and range of daily deployment duration, number of alerts and reason for alerts at each location.

Location	No. of days SMART drumlines were deployed	Mean and range of deployment (hours: minutes)	No. of alerts	Reason for alert
Ballina to Lennox Head	128	7:45 (2:02–11:48)	35	16 White Sharks 2 Tiger Sharks 2 Bull Sharks 15 No catch
Evans Head	132	8:16 (2:37–12:39)	28	14 White Sharks 2 Greynurse Sharks 1 Tiger Shark 11 No catch

On two occasions, one White Shark and one Dusky Whaler were caught but did not trigger the SMART unit.

Table 14. Average and range of general wind and sea conditions when SMART drumlines were deployed and retrieved daily off Ballina to Lennox and Evans Head.

Location	Action	Wind (kn)	Sea (m)	Swell (m)
Ballina to Lennox Head	Deployment Retrieval	10.1 (0.0–25.0) 16.1 (0.0–29.0)	0.5 (0.0–1.5) 0.6 (0.0–2.0)	0.6 (0.0–3.1) 0.6 (0.0–3.0)
Evans Head	Deployment Retrieval	6.24 (0.0–19.0) 10.3 (0.0–30.0)	0.4 (0.0–1.5) 0.6 (0.0–1.5)	1.3 (0.5–3.8) 1.3 (0.5–3.2)

Overall, 90% of the total numbers of hooks on SMART drumlines deployed off the Ballina to Lennox Head region and 97% off Evans Head had all of their baits remaining at the end of each day. While most baits remained intact, 3% of the hooks deployed off Ballina to Lennox Head and 2% off Evans Head had no bait left on retrieval, while other baits had various bite marks consistent with smaller Hammerhead Sharks (*Sphyrna* spp.), Whaler Sharks (*Carcharhinus* spp.) or Mackerel (*Scomberomorus* spp.).

Total catches

A total of 36 target sharks were caught: 31 White Sharks (TL: mean, 2.8 m; range, 2.0−4.5 m; 4 males, 25 females, 2 unsexed), 3 Tiger Sharks (2.4, 3.7 and 3.9 m; male), 2 Bull Sharks (male 1.5 m, female 1.6 m), 2 Greynurse Sharks (female 2.7 m, male 2.5 m) and 1 Dusky Whaler (sex unknown, 1.2 m) as bycatch (Tables 13, 15). The SMART drumlines sent 64 alerts, of which 38 resulted in the capture of sharks. However, 1 White Shark (3.0 m TL) and the Dusky Whaler (1.2 m TL) were found on the line at the end of the day without any alert (Table 13). The White Shark had bitten through the monofilament triggering system, but there was no evidence as to why the Dusky Whaler had not triggered the alert. Twenty-six alerts had no catch on arrival, 61% of which had no bait on the hook when the contractor arrived.

There was no clear trend in the time of day when White Sharks were caught on SMART drumlines (and alerts with no catch) (Table 15, Fig. 14). However, relatively more sharks were caught in December–January and in April–May than in February–March at both locations (Table 15, Fig. 15). In fact, only one White Shark was caught between 19 January and 20 April 2017. Too few Bull, Tiger, Dusky and Greynurse sharks were caught to discuss trends.

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 0.01 individuals per SMART drumline per 8-hour soak (or 0.03 individuals per SMART drumline per 24-hour soak) (Fig. 15). Sharks were caught more frequently at Main Beach, Evans Head (seven drumlines distributed over 1 km catching 14 sharks), South Wall, Ballina (two drumlines 300 m apart catching nine sharks), and Lighthouse Beach, Ballina (three drumlines within 900 m catching six sharks) (Table 15, Fig. 3). Although up to three sharks were caught daily off Ballina to Lennox Head and two off Evans Head, multiple captures on the same drumline did not occur. However, sharks were caught between adjacent drumlines and within 2 to 6 minutes of each other on 3 May 2017 at Angels Beach, Ballina, and on 10 December 2016 at Evans Head.

Survival of catches

Overall, all but one of the animals caught (97%) were released alive (Table 15). The exception was a female White Shark (3.2 m TL). Although the contractor responded to the alert within 30 minutes, on arrival the SMART drumline was not present. The gear and dead shark were subsequently found 500 m away on South Ballina Beach. The shark appeared to have bitten the anchor rope and subsequently entangled itself, which prevented it from swimming.

Another female White Shark (2.5 m TL) was released alive from Main Beach, Evans Head, on 7 May 2017, but was subsequently found washed ashore dead on Airforce Beach, Evans Head, on 12 May 2017. Although it had been hooked in the corner of the mouth, the contractor had noted some blood coming from the gills during release. During necropsy there was no evidence of damage to the gills or mouth that may have contributed to its death.

Figure 14. Time of capture on SMART drumlines for 31 White Sharks (●), 3 Tiger Sharks (●), 2 Bull Sharks (X), 2 Greynurse Sharks (○) and 1 Dusky Whaler (◇) at all locations combined.

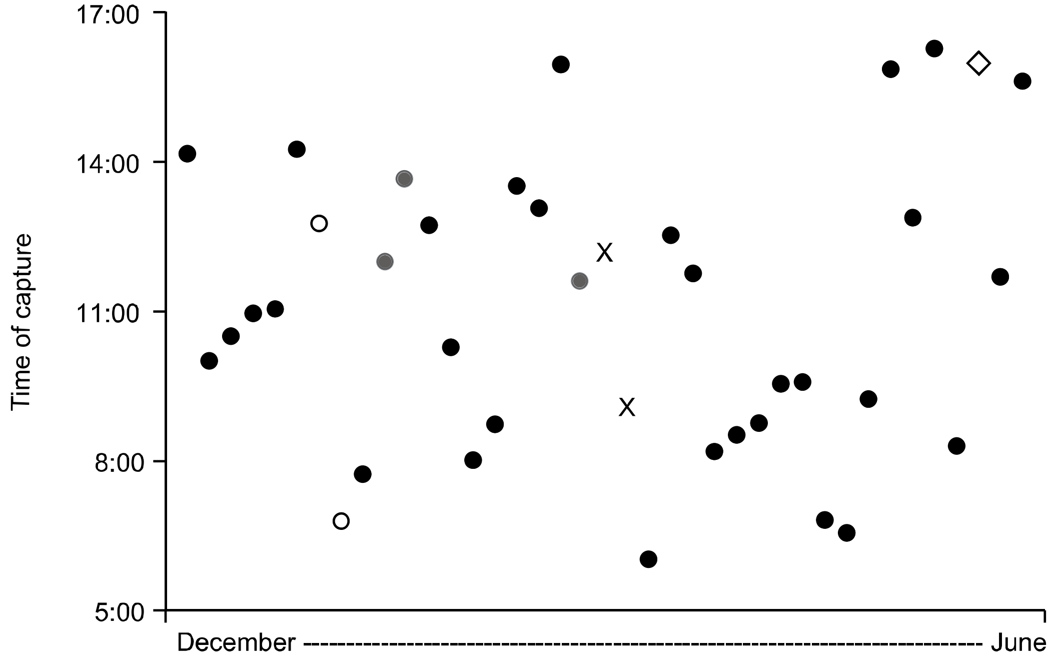


Figure 15. Numbers of target sharks caught per 8-h daily deployment of SMART drumlines off Ballina to Lennox Head (- - -) and off Evans Head (—) during each reporting month of the trial.

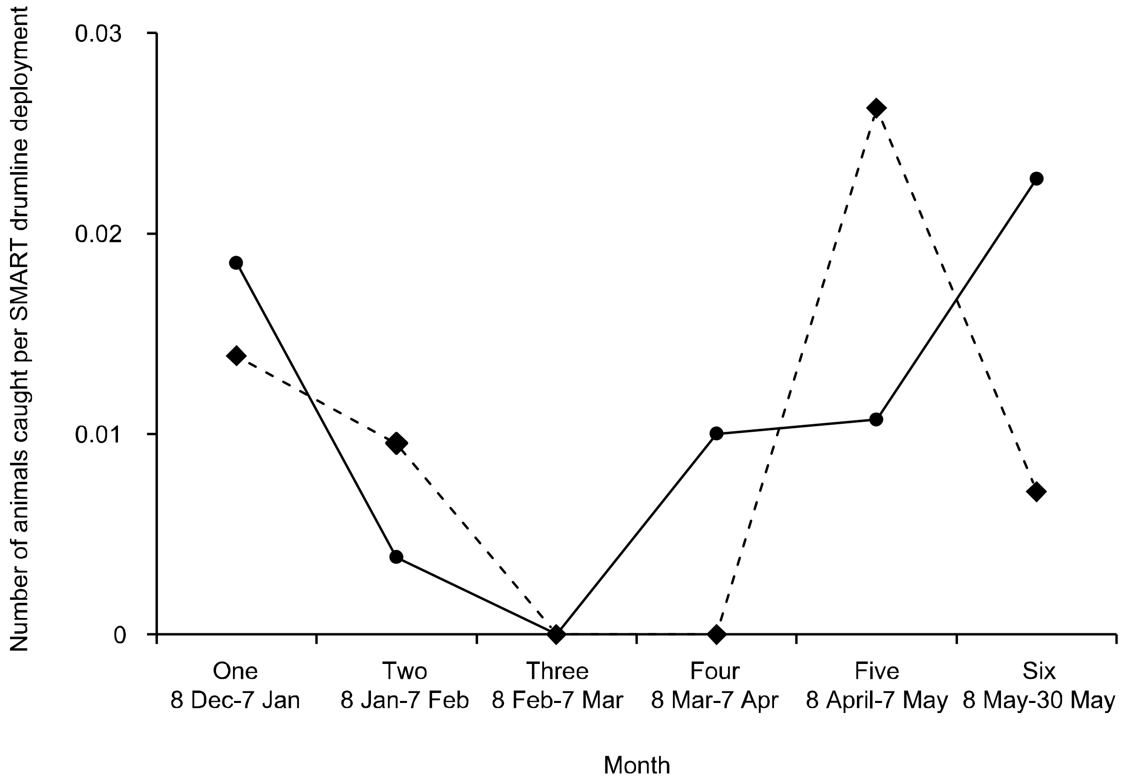


Table 15. Locations of SMART drumlines (SD) off Ballina to Lennox Head and off Evans Head, and dates and times of capture of species and their sizes (total length in m), sex and status.

Beach name	Date	Time	Species	Size and sex	Status
Ballina to Lennox Head					
Lennox Head Beach (SD nos 14, 15)	10/12/2016	10:31	White Shark	3.0, unknown	Alive
Lennox Point (SD no. 13)	16/01/2017	08:40	White Shark	3.6, female	Alive
Angels Beach (SD nos 7, 8)	11/12/2016	14:25	White Shark	2.7, male	Alive
	16/04/2017	09:05	Bull Shark	1.6, female	Alive
	03/05/2017	09:31	White Shark	2.1, female	Alive
	03/05/2017	09:33	White Shark	2.0, female	Alive
Lighthouse Beach (SD nos 3–5)	08/12/2016	14:19	White Shark	2.0, male	Alive
	29/12/2016	12:04	Tiger Shark	3.7, female	Alive
	04/01/2017	13:48	Tiger Shark	3.9, female	Alive
	16/01/2017	07:55	White Shark	3.0, female	Alive
	03/05/2017	08:42	White Shark	2.3, female	Alive
	30/05/2017	11:45	White Shark	2.6, female	Alive
South Wall (SD nos 1, 2)	10/12/2016	10:00	White Shark	2.7, male	Alive
	18/01/2017	13:11	White Shark	3.4, female	Alive
	6/02/2017	16:11	White Shark	3.2, female	Alive
	15/04/2017	12:17	Bull Shark	1.5, male	Alive
	20/04/2017	05:51	White Shark	2.5, male	Alive
	20/04/2017	12:37	White Shark	3.2, female	Dead
	30/04/2017	08:06	White Shark	3.2, female	Alive
	07/05/2017	06:40	White Shark	3.0, female	Alive[2]
	14/05/2017	12:59	White Shark	3.1, female	Alive
Evans Head					
Main Beach (SD nos 4–10)	10/12/2016	10:59	White Shark	2.4, female	Alive
	10/12/2016	11:05	White Shark	2.6, female	Alive
	15/12/2016	06:39	Greynurse Shark	2.5, male	Alive
	24/12/2016	07:38	White Shark	3.1, female	Alive
	04/01/2017	12:50	White Shark	2.6, female	Alive
	06/01/2017	10:17	White Shark	2.3, female	Alive
	17/01/2017	13:39	White Shark	4.5, unknown	Alive
	22/04/2017	11:49	White Shark	2.9, female	Alive
	07/05/2017	06:24	White Shark	2.5, female	Alive[1]
	08/05/2017	09:12	White Shark	2.4, female	Alive
	10/05/2017	16:05	White Shark	2.9, female	Alive
	16/05/2017	16:31	White Shark	2.6, female	Alive
	18/05/2017	16:15	Dusky Whaler	1.2, unknown	Alive[2]
	30/05/2017	15:50	White Shark	3.9, female	Alive
Shark Bay to Joggly Point (SD nos 1–3)	12/12/2016	12:52	Greynurse Shark	2.7, female	Alive
	29/03/2017	11:38	Tiger Shark	2.4, female	Alive
	02/05/2017	08:27	White Shark	2.2, female	Alive
	17/05/2017	08:13	White Shark	2.4, female	Alive

[1] Found dead on adjacent beach 5 days after capture and release.

[2] No alert from the SMART drumline.

Discussion

Community consultation associated with the trial

Clear trends in community attitudes could be identified by place of residence (Ballina Shire and Evans Head vs other regions and states) and for regional surfers vs non-surfers. Overall, Ballina Shire and Evans Head residents were more positive than negative towards the concept of nets in pre- and post-trial telephone interviews, a method generally acknowledged to provide a more robust measure of community views than online questionaries, which have inherent biases related to self-selection and accessibility (e.g. multiple entries from a single IP address), and might not be considered representative of wider attitudes (Fricker et al., 2005; Couper, 2011).

The primary reasons for positivity towards deploying nets were feelings of safety for the respondents, their families or the community, a perceived reduction in shark–human interactions (which was reinforced by no reported interactions at the area of the trial, but three elsewhere in NSW) and, to a lesser extent, perceived positive impacts on the local economy and tourism. But despite general positivity, the percentage of respondents who felt that the nets were worthwhile declined in the post-trial survey, and the percentage of respondents that considered the nets negative approximately doubled. This trend was driven primarily by the amount of bycatch and mortality. A perception that nets are ineffective for preventing shark–human interactions was also common among those feeling negative or neutral about the nets. Online surveys of Ballina Shire and Evans Head residents were largely consistent with these trends.

The difference in acceptance of nets was greatest between Ballina Shire and Evans Head residents and the non-resident respondents of online surveys. Non-residents had strong and consistently negative views of the nets before and towards the end of the trial. Such contrasting opinions are likely to be influenced by disparate historical and social contexts relating to predator interactions and different world views and ways of valuing predators (Pooley et al., 2017). For example, non-residents are unlikely to experience the same magnitude of direct and flow-on negative effects of local shark–human interactions as residents.

Further, independent of the local context, those motivated to respond to online questionaries from other locations are likely to have broader views on the relatively utility of the three categories of shark–human mitigation strategies. Evidence of this in the results included strong and consistent negativity towards the nets in pre- and post-trial surveys regardless of whether respondents were considering themselves, family or community; dominance of commentary on bycatch, and the sentiment of no fundamental belief in the utility of nets; and low support for SMART drumlines relative to other respondents. These views exemplify decadal changes in societal perceptions of sharks from one focused on protecting humans to an acknowledgement of the need for marine conservation and management (Gibbs and Warren, 2015).

Despite differences in attitudes between residents and non-residents, most stakeholders within both groups were united on the unacceptability of bycatch in terms of the overall success of the trial. Of the sampled residents, 68% of telephone and 60% of online respondents thought that the bycatches in the nets were unacceptable (vs 91% of non-residents). These attitudes appear to reinforce perceptions regarding the overall success of the trial, with more Ballina Shire and Evans Head residents indicating that the nets were unsuccessful rather than successful during telephone interviews (48% vs 37%) and online questionnaires (55% vs 38%). Non-residents were more extreme in their views, with 87% saying that the nets were unsuccessful. Given the lack of any reported shark–human interactions during the trial (which was considered a key performance indicator in the pre-trail survey), the shift in opinions reiterates that while the attitudes of community groups can be driven by different objectives (e.g. safety vs conservation), they also share common views and values (e.g. environmental stewardship) (Voyer et al., 2015).

Recommendation 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.

Within community groups, Ballina Shire and Evans Head surfers were the most positive about the nets. Negativity towards the nets among surfers surveyed via telephone increased from before (9%) to after the trial (32%), but surfers who completed the online survey maintained strong support for the nets from before to after the trial (62% vs 56%), with little change in negativity (23% vs 24%). The latter were also much more accepting of bycatch: 52% responded that it was acceptable, compared with 42% that it was unacceptable.

Different social groups will have varying resilience and tolerance to shark–human interactions. Intangible costs (e.g. fear) have been shown to be significantly more important than tangible costs (e.g. direct monetary losses) when explaining attitudes towards predators (Pooley et al., 2017). Given that all recent shark–human interactions in the region have involved surfers, this group is likely to have a greater level of concern for their safety than the general community, and may be more willing to accept any environmental impacts associated with nets. However, further research is required to understand how representative this attitude is of local surfers, considering that ≤12% of the random telephone respondents nominated surfing as their main activity, and online surveys can be biased towards those most motivated to express their views.

Recommendation 2: Undertake social research focusing on surfers to identify the protective measures (including key locations) that would improve their feelings of safety regarding sharks.

Beyond quantifying community acceptance of the nets, the surveys revealed that Ballina Shire and Evans Head residents support alternative methods for minimising shark–human interactions. Specifically, while residents were relatively positive about the trial, their support for nets was lower than that for alternative protective measures. This difference was likely driven by the presentation of the SMART drumline results in the post-trial survey, of which most respondents were previously unaware. Although a new approach to minimising shark–human interaction, SMART drumlines may be perceived as an equivalent protective measure to nets with fewer ecological costs. Also, SMART drumlines represent a proactive approach, which probably reinforces positive attitudes towards actively minimising the risk of shark–human interactions.

Recommendation 3: Continue trials of new technologies to minimise shark–human interactions that provide an equivalent protective approach as nets over the same or greater spatial and temporal scales as the trial, with associated community consultation.

Operational aspects of the trial

The objectives of the trial required that, conditions permitting, SMART drumlines should be deployed each day and the nets needed to be checked no earlier than 4 hours and within 24 hours of the previous inspection. The net-checking requirement was motivated by concerns about effects on bycatch and a desire to increase the capacity to release animals alive. However, strong winds, unfavourable seas and currents and challenging river-bar crossings, the latter influenced by flooding events, and the build-up of sand at Evans Head reduced the ability of the contractors to deploy SMART drumlines or check the nets within the required timeframes.

Poor weather meant that only 64% of net checks happened within 4 to 24 hours of the previous check. Most checks involved either full removal or floatline checks, with visual checks restricted to 18% of the total. While such checks were beneficial in ensuring correct net orientation and position, their utility for assessing catch or mesh-bar damage was marginal and was considerably affected by water visibility. In fact, during three visual checks when water visibility was 1–3 m, eight netted animals were not observed.

While the contractor at Evans Head was able to check the net more frequently than deploy SMART drumlines (145 vs 132 days), the contractor at Ballina found the opposite (99 vs 128 days). But these differences simply reflect access across the Richmond River bar, which was often restricted to short periods around tides. The Ballina net contractor required a displacement-hull vessel (with a maximum speed of <10 knots) to remove large animals and to deploy and retrieve the four nets (each of which often took an hour or more). This limitation also accounted for many of the net checks that were done earlier than 4 hours after the previous inspection—the contractor had to complete these and return safely across the bar. By comparison, the SMART drumline contractor at Ballina had a high-speed planing-hull vessel (~20 knots) and could rapidly deploy and retrieve SMART drumlines in most conditions. Nevertheless, because SMART drumlines were deployed and then removed during daylight hours, their total cumulative fishing time was <30% of that of the nets.

Notwithstanding the limitations that weather placed on the contractors, their numbers of days at sea over the trial period were substantially greater than those of local commercial fishing vessels (which also had to cross both river bars, and deploy and retrieve heavy fishing gear). In particular, compulsory logbook data collected by NSW DPI revealed that regional prawn trawlers worked for 49 nights during the trial period, or approximately 2 nights a week on average. By comparison, the contractors achieved up to three times this rate: up to nearly 6 days a week on average (e.g. at Evans Head).

While additional technology, including sonar and cameras, would facilitate more accurate checks of nets during poor weather conditions, it nevertheless would not be possible to reach and remove any entangled animals until conditions were appropriate. It is important to acknowledge that the nets were deployed close to the beaches (~500–600 m) and at times near breaking surf. Any large animals had to be removed using the contractor's main vessel, which was always considerably hindered in terms of steerage when servicing a net.

The above limitations are an important consideration for spatial expansion of either net or SMART drumline deployments along the coast. Appropriate ports are needed to enable safe access to the fishing gear, or contractors will have to remain at sea for extended periods.

Catches of target sharks

The species selectivity of the nets and the SMART drumlines were very different, manifesting as 9 target sharks from a total of 275 animals in the nets (3% of the total catch) to 36 target sharks from 39 animals caught by SMART drumlines (92%). In relative terms, accounting for the different soak times (and notwithstanding their confounded deployment periods), the catch-per-unit-of-effort of SMART drumlines (0.03 individuals per SMART drumline per 24-hour soak) was 15 times that of the nets for the target sharks (0.002 individuals per net per 24-hour soak).

In absolute terms, the 25 SMART drumlines were very selective for White Sharks, but less so for Bull Sharks and Tiger Sharks, with both fishing gear types catching these species in similar numbers. These differences reflected not only differences in how SMART drumlines and nets catch, but also their contrasting temporal variation in deployment and possible confounding effects of where the gear sets were positioned relative to each other. These issues are discussed separately below.

The efficiency of nets is affected by many factors, including the mesh size, material and twine thickness, how tightly meshes are stretched open, the length and depth of the panels, and where (including the position in the water column) and when they are fished relative to the movements and the habits of vulnerable species (Hamley, 1975; Uhlmann and Broadhurst, 2015). Other variables like water turbidity and even the amount of debris or sediment in the water (which can foul meshes and affect visibility) can affect the catching performance of nets. Even the presence of catches already in the net might affect subsequent catches. Depending on the species, such effect might be positive via depredation of freshly caught animals ('baiting'; Engås et al., 2003), or negative owing to greater visibility (Hamley, 1975).

On the basis of the catches during the 6 months, nets were selective for individuals approximately 1–4 m in length or width (depending on body shape). It is also clear that the ability of the nets to retain all animals that met them was <100% effective, as shown by the total of 60 large holes in nets across all beaches (especially Evans Head). If these 60 holes were made by animals with teeth, this is equivalent to 50 sharks across all species that were caught, which equates to <50% effectiveness for such animals. Further, some sections of netting were lost, possibly entangled around escaping animals, and as marine debris.

In addition to technical parameters, it is clear that there were diel effects on the catches of the nets, with very few animals caught between morning and afternoon net checks. One Bull Shark was caught during the day (between net checks), but all three Tiger Sharks, one White Shark and one Bull Shark were caught overnight (the time of capture for the other target sharks could not be determined because the time between checks encompassed >24 hours). Relatively greater catches among nocturnally than diurnally deployed gillnets is common in many commercial fisheries (e.g. Gray et al., 2005), and can be explained by some bias towards greater nocturnal activity among many species, but perhaps, most importantly, reduced visibility of the meshes (Hamley, 1975).

Recommendation 4: When using nets as a method for minimising shark–human interactions, they need to be deployed overnight to maximise their efficiency at catching target sharks.

Compared with the nets and many other passive fishing gear used around the world (e.g. Uhlmann and Broadhurst, 2015), the SMART drumlines used here were very selective. Clearly, setting baited hooks approximately 2–4 m below the surface across the trial area during the day was effective at catching mostly White Sharks between 2.0 and 4.5 m TL.

Such selectivity contrasts with drumlines fished in Queensland, which in addition to the target sharks also catch various other sharks (Gribble et al., 1998; Sumpton et al., 2011). While this gear has smaller hooks (increasing the probability of catching smaller sharks across all species) than those used on SMART drumlines in NSW, they are deployed continuously and catch large numbers of Tiger Sharks and Bull Sharks, which typically are more active at night.

It might be possible to catch more Tiger Sharks and Bull sharks on SMART drumlines off the NSW North Coast simply by extending their deployment into the night. Certainly, SMART drumlines have been effective at catching Bull Sharks throughout Northern NSW rivers, and especially in the Richmond River at Ballina. Fishing SMART drumlines at night would also facilitate a clearer comparison of their relative efficiency compared with nets (by fishing both gear types during the same time). Owing to the safety issues associated with river bar crossings at night, the contactors would have to remain at sea and respond to SMART drumline catches as required.

A final important consideration in interpreting the relative performance of the two gear types for the target sharks was their relative positions. There were 10 SMART drumlines within a 1-km radius (and either side) of the Evans Head net versus fewer than 5 within the same distance of each net off Ballina. The differences in relative effort, along with other important factors (such as where gear was set in relation to bottom topography, including reefs) might have affected the catches of target sharks. Future research should assess the potential for any confounding effects of drumlines and nets fished close to each other.

Catches of non-target species

The fishing mechanism of nets makes it impossible to completely control selectivity for any one species within any area known to have large assemblages of similar-sized animals (Hamley, 1975; Uhlmann and Broadhurst, 2015). Such a characteristic probably explains why the types of bycatch and their sizes caught by the nets in Northern NSW were broadly comparable to those of the same nets fished between Newcastle and Wollongong in the SMP (Reid and Krogh, 1992; Green et al., 2009; Reid et al., 2011) and similar to those of net catches in Queensland (Paterson, 1990; Gribble et al., 1998; Sumpton et al., 2011). Certainly, the dominance of rays and hammerheads among sharks and of Mulloway and tuna among fish is consistent with that of the same nets used in the SMP (Krogh and Reid, 1996).

Like most fishing gear, gillnets have a peak efficiency within a particular soak time (Hamley, 1975; Minns and Hurley, 1988). Of the nets tested here, and irrespective of the soak time, the maximum number of animals caught exceeded six only once. This result implies that the more often a net is checked (e.g. daily), the greater the number of animals it might catch (including both target sharks and bycatch).

To illustrate this concept, a net left unchecked for 3 days might catch a maximum of six animals. But the same net retrieved every morning (i.e. three times over 3 days), cleared of catches or any entrained material on meshes and reset, could catch a total of 18 animals over the same cumulative soak time. This effect probably contributed to the large number of animals caught in the Evans Head net (twice as many as in any other net), which was checked nearly twice as often as any other net. Also, the Evans Head net had the most mesh-bar damage (without catches), which might also partially reflect its relatively greater fishing power (as more animals encountered the net).

It is important to appreciate that because of the broad selectivity of nets, any recommendations to reduce bycatch by checking the nets less frequently probably will have a similar effect on catches of the target sharks (all but two were caught within ~49 hours, and six within 24 hours). Nevertheless, longer periods between net checks warrant application.

Recommendation 5: Nets should be checked and cleared no less than every 48 hours to maximise their fishing effectiveness while limiting bycatch.

Survival of animals

The fate of animals caught and then discarded by fishing gear is affected by various biological (e.g. species, including physiology and size), technical (e.g. gear design and deployment duration) and environmental (e.g. water temperature and salinity, sea state and available light) factors (Davis, 2002; Broadhurst et al., 2006). Rarely does a single factor cause death (Davis, 2002). Rather, there are cumulative influences that often result in variable mortalities among the same species across different gear types.

Numerous studies have shown that some animals die within a few days after being released from fishing gear (Broadhurst et al., 2006; Uhlmann and Broadhurst, 2015). At least some delayed mortality occurred among White Sharks released from SMART drumlines, one of which was found dead 4 days after being tagged and released. No data are available on the eventual fate of netted and released catches, but there were no reports of any tagged animals stranded on adjacent beaches during the trial. The discussion of survival here is therefore limited to immediate, on-board observations.

Notwithstanding the above caveat, the data clearly illustrate intraspecific differences in survival due to gear type, with 97% of White Sharks surviving immediate catch and release from the SMART drumlines versus 33% found alive in the nets. The survival of other netted sharks was also minimal, at 0% to 4% for the most abundant species (Common Blacktip Sharks and Great Hammerhead). Although the data are few, given the similar environmental conditions (both gear types fished in the same area and at overlapping times), such differences most likely reflect the very different catching mechanisms of SMART drumlines and nets and the associated trauma, which would also be affected by the duration of time an animal spends on either gear.

In general, immediate survival varied considerably among the netted species; among the four most dominant species, it ranged from 4% for Great Hammerheads to 76% for Whitespotted Eagle Rays. Total survival across all animals was 47%, close to the estimated global average of 40% for this gear type (Uhlmann and Broadhurst, 2015). This pooled survival rate is poorer than that of other passive gear (e.g. traps or hook-and-line), primarily because of the fishing mechanisms: nets are designed to entangle, restrict and ultimately suffocate most fish.

For air-breathing animals such as dolphins and turtles, even short periods of net entanglement can cause death, although the size of the animal is also important (Uhlmann and Broadhurst, 2015). Here, six Loggerhead Turtles (mostly >100 cm CCL) had the strength to push the nets to the surface and breathe for sufficient periods before release. The two Loggerhead Turtles that died were among the smallest caught, with CCLs of 83 and 92 cm, while all Green Turtles were approximately these sizes or less, and they died. At a broad level, larger animals typically are more resilient to catch stressors; several studies have identified positive relationships between size and survival of various species (reviewed by Broadhurst et al., 2006; Uhlmann and Broadhurst, 2015).

The effects of net soak time (or the checking rate) on survival were clearly illustrated by the fates of the three dominant species which contributed most to total survival. Specifically, while there were few differences among the survival of animals in the nets during checks between 12 and 24–48 hours, rates dropped appreciably as soak time extended beyond 3 or 4 days. Nevertheless, the reductions in survival over time were not sufficient to support more regular net checks, if the effects on fishing power are concurrently considered.

In particular, following on from the general example above regarding soak time and catches, a net left for 3 days without being checked might catch a maximum of six animals, with a collective survival of 35% (two alive and four dead). If the same net were cleared daily, total survival might be 56%, but because potentially 18 animals could be caught (six a day for 3 days), nearly eight would be killed (twice as many as for 3-day checks). While such extrapolations are subject to many assumptions, they clearly illustrate the need to collect appropriate environmental and biological data across as broad a range of technical and operational conditions as possible to inform coherent management decisions regarding the collateral impacts (e.g. mortalities) of fishing gear (Uhlmann and Broadhurst, 2015).

The immediate survival of sharks caught on SMART drumlines was dramatically greater than that of sharks caught on nets, and comparable to that of similarly mouth-hooked species (reviewed by Bartholomew and Bohnsack, 2005). Although few previous data are available for White Sharks, clearly being hooked in the mouth caused minimal damage and few if any longer-term effects. This hypothesis is illustrated by telemetry data indicating that some tagged animals have returned to the same area off Northern NSW, some of which have been recaptured. Studies of other species reveal that most mouth-hooked animals suffer few longer-term harms, and certainly large proportions of other large sharks released quickly (within 3 hours or so) from commercial longlines can survive (e.g. Marshall et al., 2015). Even protracted soak times (e.g. 7–14 hours overnight) can still allow good survival among some species of Whaler Sharks (Gallagher et al., 2014a; Butcher et al., 2015).

Utility of each method for minimising shark–human interactions

Neither nets nor SMART drumlines (nor any other fishing gear) will ever completely remove the possibility of shark–human interactions, because no conventional fishing gear is 100% effective at catching all animals in any area, and very few (if any) can be continuously deployed. While long-term data (measured in decades) support the success of nets used elsewhere, the trial was not sufficient to gauge the use of either method (in isolation or together) for minimising shark–human interactions in the study area. Any such assessment is further confounded by the use of other mitigation methods, such as aerial surveillance and advice from tagged shark detections on buoyed receivers. Substantially longer periods are required to quantify either the relative or combined utility of nets and SMART drumlines for minimising shark–human interactions off Northern NSW.

Nevertheless, it is possible to postulate how each gear type might reduce shark–human interactions—assuming appropriate levels of effort (i.e. sufficient numbers of replicates in an area). The SMART drumlines tested here were quite selective for catching actively feeding White Sharks (during the day), which were then released. Preliminary data suggest that 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., 2014a, 2014b; Barnes et al., 2016).

Few data are available on the hooking-related stress responses of White Sharks, but surviving hooked-and-released Tiger Sharks incur minimal stress (Gallagher et al., 2014b). Larger sharks might also be less affected than smaller sharks (Gallagher et al., 2014b). Ideally, hooked-and-released sharks would be sufficiently stressed to a level that precluded interest in their immediate surroundings and thereby reduce the probability of interactions with humans, but without longer-term negative effects. Any long-term harms appear limited for many White Sharks, simply because at least some eventually returned to the trial area.

Recommendation 6: The short-term (<12 hours) continuous movement and behaviour of target sharks released from SMART drumlines should be quantified to better inform the drumlines' utility for minimising shark–human interactions.

Unlike SMART drumlines, nets do not select for the targeted animals, and it is unlikely that their historical use for minimising shark–human interactions can be completely attributed to just catching the target shark species. Rather, conventional nets catch similar-sized animals, but never with any major bias towards the three target shark species responsible for interactions with humans. The implied bather protection effect of nets is not clear, but probably combines some reduction in target shark density (either by mortality or perhaps after entanglement and escape; similar to catch and relocation via SMART drumlines); fewer prey to attract potentially dangerous targeted sharks to the area (e.g. Heithaus et al., 2002); and possibly even chemical repellency by netted decaying sharks (e.g. Stroud et al., 2014).

The 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 the trial). However, the mortality of non-target species is an inseparable component of how nets work, and so the concept of making SMART nets (for rapid attending and release) is not really coherent. Perhaps a better approach would be to clearly define the terms of reference within the general category of strategies for minimising shark–human interactions involving fishing gear. Once the key objectives are clear, decisions can be made about the most appropriate gear.

If the objective is to just target the three main species of sharks and reduce their relative numbers in an area via actively relocating live individuals of concern, then nets would not be the first choice in many areas. SMART drumlines and various other configurations of baited hooks deployed across appropriate space and time are a more logical option.

Alternatively, if the objective is not to target the three species but to remove a few individuals of several species across one or two trophic levels, then nets might be more suitable than baited gear. This concept might be crudely illustrated by considering two extremes: a pristine marine environment with no fishing effort versus one that is subjected to intense fishing of various forms. If all other factors remain constant, then the risk of shark–human interactions should be greater in the first scenario than in the second. Some support for such logic can be provided by considering that artisanal gillnets (typically involving varying sizes of smaller mesh) similar to the general design of the nets used during the trial are deployed off the coasts of many developing and highly populated coastal nations within the preferred habitats of all three target sharks (especially Bull Sharks and Tiger Sharks). Several of these countries have fewer shark–human interactions per capita than Australia. So, assuming that no other fishing gear with overlapping selectivity is used in a particular area, nets might be appropriate for controlling a shift between the two scenarios above. Irrespective of the objectives outlined above, the long-term ecological consequences of using any fishing gear to minimise shark–human interactions warrant assessment.

Recommendation 7: Future trials of SMART drumlines and nets need to clearly define the terms of reference for using fishing gear to minimise shark–human interactions.

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

Both gear types 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 would be impossible to alter the selectivity of the nets tested here to even 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 while still achieving sufficient function to match their apparent historical success. Beyond increasing the net-checking rate from twice a day during the trial to once every 48 hours, removing the Evans Head net or moving it away from the river mouth—an area of greater densities of animals that use the river–sea interface habitat—might reduce bycatch and collateral mortalities.

Pending additional data, decisions about where and when to set nets might reflect the environmental conditions. A recent 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 greater entanglements of Common Dolphins (*Delphinus delphis*) in winter, during windy conditions or rough seas, during spring tides, and in strong westerly currents. Over the long term, such data might be used to guide recommendations for net deployments and checking frequencies.

Another operational modification to reduce catches of some rays might be to set the nets closer to the surface (like those in Queensland), rather than as close as 0.5 m to the bottom. Surface-set nets might also increase survival among Indo-Pacific Bottlenose Dolphins and all turtles by allowing them to more easily reach the surface. However, catches of these animals could increase if they cannot easily swim over the floatlines, so the vertical orientation of the net in the water column requires careful consideration.

In terms of 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, increasing the strength of the net twine and the size of mesh (e.g. to 800 mm) should reduce the catch of the abundant Australian Cownose Rays and Pygmy Devilrays and all fish, while still retaining similar quantities of the largest White, Tiger, and Bull sharks.

One applied modification for reducing turtle catches in the nets might involve light. In a recent study, 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 capture of Green Turtles by 64% without affecting target catches of fish. Wang et al. (2010, 2013) noted similar results after illuminating gillnets with LEDs (spaced every 5 to 10 m) off Mexico. Considering the threatened status of Loggerhead Turtles and Green Turtles, such work supports ongoing testing, a key component of which is the effect of light on other catches in nets, especially sharks and rays. Visual stimuli are known to affect catches of various species among longline fisheries (Broadhurst and Hazin, 2001), and light is often used as an attractant (Hazin et al., 2005).

Recommendation 8: Assess key operational and novel technical modifications to nets to reduce the collateral mortality of bycatch, especially 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 how 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. Work should also focus on the effects of chemical stimuli associated with decaying sharks or rays in nets being responsible for excluding other sharks from an area over the short term.

Recommendation 9: Identify and quantify the relative importance of key factors that contribute to how nets minimise shark–human interactions.

While the SMART drumlines are clearly species selective, their absolute catching efficiency might be increased via simple modifications to their deployment or design. Further, within such work it might be fruitful 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, other gear and technology might be tested, including nocturnally deployed bottom- and midwater longlines and drop lines. These gear types could be rigged with hook timers modified to release hooks after some predetermined period (e.g. 3 or 4 hours) if the contractor cannot attend the gear (to allow sharks to escape alive). Such configurations would mean that gear could be simply deployed late in the day and left overnight, which should translate to lower costs than if the contractor has to remain at sea.

Previous studies have shown that the survival of several shark species hooked by the above types of gear can exceed 55%, which is greater than observed among many netted sharks, especially when overnight soak times are ≤7 hours (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 bottom-set longlines in summer to catch Tiger Sharks and Bull Sharks, versus SMART drumlines in winter 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 must quantify the longer-term effects of 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 Queensland have double hooks, and similar gear is deployed commercially (‘drop lines’). Such configurations might be tested for their effectiveness in increasing the rates of hooking target sharks in key areas.

One potential issue associated with deploying drumlines and other midwater, baited hooks is depredation by dolphins. Drumline baits used in Queensland are regularly depredated by the

Common Dolphin (*Delphinus* delphis) and Bottlenose Dolphin (*Tursiops* spp.), sometimes within minutes of deployment (Geoff Krause, pers. com.). None of the SMART drumlines were depredated during the trial or the 12 months before it, when fewer SMART drumlines were deployed by researchers along the coast. But depredation of midwater baited hooks by dolphins is a major issue in many commercial hook-and-line fisheries globally, and is typically acknowledged as 'learned behaviour' (reviewed by Werner et al., 2015). Bottom-deployed baited hooks might be less affected by dolphin depredation, and certainly having multiple hooks on the same configuration will reduce the probability of the gear being made ineffective by the loss of one or two baits as per the configuration of drumlines.

It is possible that during the trial, the pingers at the nets deterred some dolphins around the adjacent SMART drumlines (all but one were within 2 km), especially the DDD pingers (which have a range of up to 2 km), but Werner et al. (2015) implied that such devices are unlikely to remain effective over the long term. Certainly, the FF70 and DDD pingers used here did not preclude dolphins being caught in the nets. Perhaps more likely is that insufficient time has passed for local Indo-Pacific Bottlenose Dolphins to associate the SMART drumlines with food. Given that there are documented associations between regional dolphins and other fishing activities (e.g. Broadhurst, 1998), the potential for future depredation of SMART drumline baits and novel mitigation strategies warrant strategic consideration. Such work might also extend to nets, given that the (rare) catches of fish could attract dolphins through depredation.

Bottom-set longlines might also be depredated by crustaceans, including spanner crabs (*Rania rania*), off Northern NSW, although this species tends to occur in waters deeper than the 5–10 m proposed for this gear (>20 m; Kennelly, 1992). In any case, technical strategies might be used to reduce such impacts, including floats to lift the hooks off the bottom, or simply using polypropylene mainlines (He, 1996). These and other issues warrant further consideration.

Conclusions

Reducing the risk of shark–human interactions is a complex and highly emotive issue that requires various combinations of the available resolution strategies within the three stated categories

1) Directing people not to enter the water via either long-term restrictions at a particular location associated with frequent shark–human interactions (e.g. Brazil: Hazin and Afonso, 2013; and Réunion Island) or short-term advice for vacating areas via the real-time surveillance of sharks (e.g. in South Africa: Dudley and Cliff, 2010).
2) Exclusion devices designed to minimise shark–human interactions, most commonly via physical enclosures, to prevent sharks entering an area (Dudley and Cliff, 2010), or repellents (e.g. Huveneers et al., 2012), or combinations thereof (e.g. O'Connell et al., 2014).
3) Fishing gear (usually gill or 'mesh' nets or baited hooks termed 'drumlines') designed to deplete or, in some cases, relocate target sharks at key locations (e.g. South Africa: Dudley et al., 1998; Australia: Reid et al., 2011; Sumpton et al., 2011; Brazil: Hazin and Afonso, 2013).

The relative importance of any particular strategy will reflect a plethora of regional issues, but with a strong focus on the spatio-temporal movements of the problematic species and the local environmental conditions.

Within the key objectives of the trial and a strategy of using fishing gear to remove problematic sharks from a particular area, it is clear that SMART drumlines and nets have very different functional mechanisms. Substantial historical data supports the utility of nets for minimising shark–human interactions (Dudley, 1997). While the exact mechanisms contributing to these reductions remain unclear and should be empirically assessed to guide future use, an established way in which nets work involves catching and killing non-target species, often in much greater abundance than the target sharks. Further, although operational or applied technical modifications can be developed to improve net selectivity (e.g. changes to vertical or horizontal fishing orientation, acoustic deterrents, or larger mesh sizes), it will be difficult, if not impossible with existing technology, to refine nets to approach a reasonable level of species selectivity.

Drumlines (and other baited hook-and-line gear) do have some bycatch, but on the basis of the trial data, they can be configured to minimise collateral mortality. The daily deployment and use of SMART drumlines during the trial clearly illustrates such effects: sharks can be caught, tagged and then released alive away from the capture area. While the effectiveness of this strategy for minimising shark–human interactions remains unknown (and requires long-term data), assuming at least some positive benefits, then other baited gear (e.g. nocturnally deployed bottom and midwater baited lines) might be similarly modified to expand and economise catch efforts. This gear might encompass some of the ways nets might function (i.e. some mortality of target catches, escape of animals, or stimuli from decaying animals on hooks), but with fewer collateral impacts. However, a key requirement of any such work would be 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 that a multifaceted approach to minimising shark–human interactions is required. The challenge is to clearly state, and convey among the community, the required objectives within each of the three general categories of strategies outlined here. Where fishing gear is identified as a coherent approach, research should be directed towards understanding the key mechanisms that might contribute to reduced shark–human interactions caused by particular fishing gear, and the broader consequences.

Literature cited

ASAF, 2017. Australian shark attack file, accesses 2017: https://taronga.org.au/animals-conservation/conservation-science/australian-shark-attack-file/latest-figures.

Barnes, C., Butcher, P., Peddemors, V., and Mandleman, J. 2016. Movements and mortality of two commercially exploited carcharhinid sharks following longline capture and release off eastern Australia. End. Sp. Res. 30, 193−208

Bartholomew, A., Bohnsack, J.A. 2005. A review of catch-and-release angling mortality with implications for no-take reserves. Rev. Fish Biol. Fish. 15, 129–154.

Broadhurst, M.K. 1998. Bottlenose dolphins, *Tursiops truncatus* removing by-catch from prawn-trawl codends during fishing in New South Wales, Australia. Mar. Fish. Rev. 60, 9–14.

Broadhurst, M.K., Hazin, F.H.V. 2001. Influences of type and orientation of bait on catches of swordfish (*Xiphias gladius*) and other species in an artisanal sub-surface longline fishery off northeastern Brazil. Fish. Res. 53, 169–179.

Broadhurst, M.K., Suuronen, P., Hulme, A. 2006. Estimating collateral mortality from towed fishing gear. Fish Fish. 7, 180–218.

Butcher, P.A., Peddemors, V.M., Mandelman, J.W., McGrath, S.P., Cullis, B.R. 2015. At-vessel mortality and blood biochemical status of elasmobranchs caught in an Australian commercial longline fishery. Glob. Ecol. Cons. 3, 878–889.

Couper, M. P. 2011. The Future of Modes of Data Collection. Public Opin. Q. 75, 889–908.

Davis, M.W. 2002. Key principles for understanding fish bycatch discard mortality. Can. J. Fish. Aquat. Sci. 59, 1834–1843.

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

Dudley, S.F.J. 2006. International review of responses to shark attack. In Nel, D.C., Peschak, T.P. (eds) Finding a balance: White shark conservation and recreational safety in the inshore waters of Cape Town, South Africa; proceedings of a specialist workshop. Pp. 95–109. WWF South Africa Report Series–2006/Marine/001.

Dudley, S.F.J., Cliff, G. 1993. Some effects of shark nets in the Natal nearshore environment. Env. Biol. Fish. 36, 243–255.

Dudley, S.F.J., Cliff, G. 2010. Shark control: methods, efficiency and ecological impact. *In* Sharks and their relatives II: biodiversity, adaptive physiology and conservation. CRC press, pp. 568–591.

Dudley, S.F.J., Haestier, R.C., Cox, K.R., Murray, M. 1998. Shark control: experimental fishing with baited drumlines. Mar. Freshwat. Res. 49, 633–661.

Engås, A., Jørgensen, T., Angelsen, K.K. 2003. Effects on catch rates of baiting gillnets. Fish. Res. 45, 265–270.

Fricker, S., M. Galesic, R. Tourangeau, and T. Yan. 2005. An Experimental Comparison of Web and Telephone Surveys. Public Opin. Q. 69, 370–392.

Gallagher, A.J., Orbesen, E.S., Hammerschlag, N., Serafy, J.E. 2014a. Vulnerability of oceanic sharks as pelagic longline bycatch. Glob. Ecol. Cons. 1, 50–59.

Gallagher, A.J., Serafy, J.E., Cooke, S.J., Hammerschlag, N. 2014b. Physiological stress response, reflex impairment, and survival of five sympatric shark species following experimental capture and release. Mar. Ecol. Prog. Ser. 496, 207–218.

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

Gray, C.A., Johnson, D.D., Broadhurst, M.K., Young. D.J. 2005. Seasonal, spatial and gear-related influences on relationships between retained and discarded catches in a multi-species gillnet fishery. Fish. Res. 75, 56–72.

Green, M., Ganassin, C, Reid, D.D. 2009. Report into the NSW Shark Meshing (Bather Protection) Program. NSW DPI. 134 pp. ISBN 978 0 7347 1942 3

Gribble, N.A., McPherson, G., Lane, B. 1998. Effect of the Queensland shark control program on non-target species: whale, dugong, turtle and dolphin: a review. Mar. Freshwat. Res. 49, 645–651.

Hamley, J.M. 1975. Review of gillnet selectivity. J. Fish. Res. Bd. Can*.* 32, 1943–1969.

Hazin, F.H.V., Afonso, A.S. 2013. A green strategy for shark attack mitigation off Recife, Brazil. An. Cons. Doi: 10.1111/acv.12096.

Hazin, H.G., Hazin, F.H.V., Travassos, P., Erzini, K. 2005. Effect of light-sticks and electralume attractors on surface-longline catches of swordfish (*Xiphias gladius*, Linnaeus, 1959) in the southwest equatorial Atlantic. Fish. Res. 72, 271–277.

Hazin, F.H.V., Burgess, G.H., Carvalho, F.C. 2008. A shark attack outbreak of Recife, Pernambuco, Brazil: 1992–2006. Bull. Mar. Sci. 82, 199–212.

He, P. 1996. Bait loss from bottom-set longlines as determined by underwater observations and comparative fishing trials. Fish. Res. 27, 29-36

Heithaus, M.R., Dill, L.M., Marshall, G.J., Buhleier, B. 2002. Habitat use and foraging behavior of tiger sharks (*Galeocerdo cuvier*) in a seagrass ecosystem. Mar. Biol. 140, 237–248.

Huveneers, C., Rogers, P.J., Semmens, J., Beckmann, C., Kock, A. A., Page, B., Goldsworthy, S. 2012. Effects of the Shark Shield™ electric deterrent on the behaviour of white sharks (*Carcharodon carcharias*). SARDI Res. Rep. Ser. (632).

Kennelly, S.J. 1992. Distributions, abundances and current status of exploited populations of spanner crabs, *Ranina ranina* off the east coast of Australia. Mar. Ecol. Prog. Ser. 85, 227–235.

Krogh, M., Reid, D. 1996. Bycatch in the protective shark meshing programme off south-eastern New South Wales, Australia. Biol. Cons. 77, 219–226.

Marshall, H., Skomal, G., Ross, P.G., Bernal, D. 2015. At-vessel and post-release mortality of the dusky (*Carcharhinus obscurus*) and sandbar (*C. plumbeus*) sharks after longline capture. Fish. Res. 172, 373–384.

Minns, C.K., Hurley, D.A. 1998. Effects of net length and set time on fish catches on gill nets. N. Am. J. Fish. Man. 8, 216–223.

O'Connell, C.P., Andreotti, S., Rutzen, M., Meÿer, M., Matthee, C.A., He, P. 2014. Effects of the sharksafe barrier on white shark (*Carcharodon carcharias*) behaviour and its implications for future conservation technologies. J. Exp. Mar. Biol. Ecol. 460, 37–46.

Ortiz, N., Mangel, J.C., Wang, J., Alfaro-Shigueto, J., Pingo, S., Jimenez, A., Suarez, T., Swimmer, Y., Carvalho, F., Godley, B. 2016. Reducing green turtle bycatch in small-scale fisheries using illuminated gillnets: the cost of saving a sea turtle. Mar. Ecol. Prog. Ser. 545, 251–259.

Pooley, S., M. Barua, W. Beinart, A. Dickman, G. Holmes, J. Lorimer, A. J. Loveridge, D. W. Macdonald, G. Marvin, S. Redpath, C. Sillero-Zubiri, A. Zimmermann, and E. J. Milner-

Gulland. 2017. An interdisciplinary review of current and future approaches to improving human–predator relations. Conserv. Biol. 31, 513–523.

Reid, D.D. Krogh, M. 1992. Assessment of catches from protective shark meshing off New South Wales beaches between 1950 and 1990. Aust. J. Mar. Freshwat. Res. 43, 283-96

Reid, D.D., Robbins, W.D., Peddemors, V.M. 2011. Decadal trends in shark catches and effort from the New South Wales, Australia, shark meshing program 1950–2010. Mar. Freshwat. Res. 62, 676–693.

Stroud, E.M., O'Connell, C.P., Rice, P.H., Snow, N.H., Barnes, B.B., Elshaer, M.R., Hanson, J.E. 2014. Chemical shark repellent: Myth or fact? The effect of a shark necrome on shark feeding behaviour. Ocean Coast. Man. 97, 50–57.

Sumpton, W.D., Taylor, S.M., Gribble, N.A., McPherson, G., Ham, T. 2011. Gear selectivity of large-mesh nets and drumlines used to catch sharks in the Queensland shark control program. Afr. J. Mar. Sci. 33, 37–43.

Uhlmann, S.S., Broadhurst, M.K. 2015. Mitigating unaccounted fishing mortality in gillnets and traps. Fish Fish. 16, 183−229.

Volep, E., Carroll, A.R., Stauss, D., Meynecke, J.-O., Kobashi, D. 2017. Effect of environmental conditions on cetacean entanglements: a case study from the Gold Coast, Australia. Mar. Freshwat. Res. Doi. 10.1071/MF16302

Voyer, M., N. Gollan, K. Barclay, and W. Gladstone. 2015. 'It's part of me'; understanding the values, images and principles of coastal users and their influence on the social acceptability of MPAs. Mar. Policy 52, 93–102.

Wang, J.H., Fisler, S., Swimmer, Y. 2010. Developing visual deterrents to reduce sea turtle bycatch in gillnet fisheries. Mar. Ecol. Prog. Ser. 408, 241–250.

Wang, J., Barkan, J., Fisler, S., Godinez-Reyes, C., Swimmer, Y. 2013. Developing ultraviolet illumination of gillnets as a method to reduce sea turtle bycatch. Biol. Let. 23; 9(5): 20130383.

Werner, T.B., Northridge, S., McClellan Press, K., Young, N. 2015. Mitigating bycatch and depredation of marine mammals in longline fisheries. ICES J. Mar. Sci. 72, 1576–1586.

West, J.G. 2011. Changing pattern of shark attacks in Australian waters. Mar. Freshwat. Res. 62, 744–754.

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