An evaluation of shark nets and drum lines for Northern NSW beaches.

Abstract

A recent increase in the number of shark attacks in Northern NSW coastal waters has galvanized local communities and government authorities in a quest for a local shark control program. In November 2016 the Department of Primary Industries began a six-month North Coast Shark Net Trial involving the use of shark nets and drumlines. The Queensland Shark Control Program has a history of using both nets and drumlines, however this is the first trial of this type using SMART (Shark Management Alert in Real Time) drumlines in Northern NSW waters. In this study catch statistics from shark control programs in Queensland and NSW were analysed to determine the most effective shark control program for Northern NSW. The analysis reveals that a single net catches significantly more target sharks than a drumline but also catches significantly more by-catch than a drumline. A reduction in by-catch could be pivotal in the conservation of a number of threatened species that are inadvertently caught and killed by shark control programs each year. A number of target sharks too are listed as threatened. The challenge is to implement a program that maintains its public safety mandate alongside conservation values. SMART drumlines technology reduces the occurrence of by-catch and reduces mortality rates in all captures. Findings indicate that replacing nets with drumlines at a ratio of 2:1 will maintain the frequency of target sharks caught by nets, whilst significantly reducing by-catch. The capture of sharks with SMART drumlines and subsequent release out to sea, has been shown to significantly reduce risk to beach users.

Key words: Shark nets, SMART drumlines, Northern NSW, shark attack, shark net trial.

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1. Introduction

Since 2010 there have been 18 unprovoked shark attack incidences reported in between Evans Head and Tweed Heads on the New South Wales North Coast, Australia. Fifteen of those in the past 2 ½ years and 2 of these attacks proved fatal (Shark Research Institute, 2016). This compares with 10 incidences (1 fatal) in the decade 2000-2010. This increase in occurrences spread fear amongst local communities. The Federal Government was prompted to act. A phone and online survey conducted by the DPI showed 54% of Ballina and Evans Head residents felt a shark net trial would have a “positive effect on the community” (NSW DPI, 2016). Subsequently, in November 2016 the DPI began a six-month North Coast Shark Net Trial. Both shark nets and drumlines have been deployed in 5 locations between Ballina and Evans Head (DPI, 2016b).

Historically the use of drumlines in the New South Wales Shark Meshing Program has not been permitted due to legislation prohibiting the contractor from using baits or lures (DPI, 2015b). However, nets have been used to reduce the incidence of shark attacks in New South Wales for nearly 80 years. Queensland first established a Shark Control Program in 1962 after a number of fatal attacks. It was decided that a mixed strategy using a combination of nets and drumlines would be most effective in reducing shark populations near local swimming beaches (DPI, 2016).

Conservationists often oppose these programs, citing that the indiscriminate nature of these fishing devices. By-catch often includes whales, dolphins, turtles, harmless and non-target sharks and fin fish and mortality rates can be significant (Shiffman, 2014). Threatened species also make up a considerable portion of the catch each year. Target species such as mako’s (*Isurus spp*.) and white sharks (*Carcharodon carcharias*) are listed as vulnerable by the IUCN. Large numbers of hammerhead sharks (*Sphyrana spp*.) are implicated in the programs each year as by-catch. Three of these hammerhead species are listed as Endangered (IUCN 2016).

Concern has also been raised in regards to the effectiveness of the nets in keeping swimmers safe. There is a belief that shark nets act as a comprehensive barrier to sharks. This is not the case. The nets lie 150m parallel to the beach and often don’t extend from the sea floor to the surface (McPhee & Blount, 2016). This enables sharks to swim around and in some cases over or under the nets. Nonetheless it appears the presence of shark nets and drumlines provide swimmers with a sense of safety. Many north coast beach users including the local surfing community have indicated a strong preference for nets over other methods. Subsequently the implementation of the Shark Net Trial has divided opinions in the Northern NSW community.

Some evidence suggests the programs are working. Since the inception of the New South Wales Shark Meshing Program in 1937, there has been only 1 shark attack fatality in the areas where the nets are installed (Green, 2009). Similarly, in Queensland there has been one fatality in waters with shark safety program measures in place (Department of Primary Industries and Fisheries, 2006). Citing these statistics has stakeholders arguing that the low number of fatalities is testament to the effectiveness of the nets and drumlines. However, some shark bite incidences continue to occur where programs exist. This has divided expert opinion on the effectiveness of programs.

Queensland and New South Wales State Government departments file annual reports on their local shark control programs; the Queensland Shark Control Program (DAF, 2016b) and the New South Wales Shark Meshing (Bather Protection) Program (DPI, 2015b) . These reports are a valuable resource providing reference for the formulation of future programs in Australia. A program that reduces the incidence of shark attack and minimizes any detrimental ecological effects on target sharks and bycatch might best represent the interests of beach users and conservationists in Northern New South Wales.

Aim

To review annual reports and catch data provided by the Queensland Shark Control Program and the New South Wales Shark Meshing (Bather Protection) Program and compare catch rates in shark nets and drumlines.

Objectives

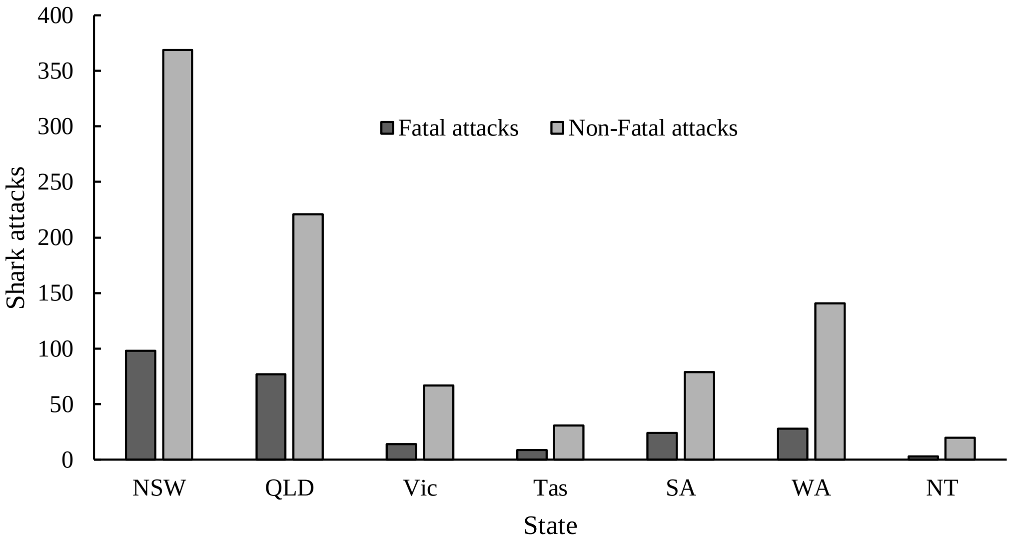
To expose any significant differences in;

- The numbers of by-catch caught by shark nets compared to drumlines.
- The number of target sharks caught by shark nets compared to drumlines.
- To make a determination on the suitability of shark nets and drumlines for Northern New South Wales.

2. Shark attacks in Australia

In Australia 1,181 shark attacks have been recorded from the year 1700 to June 2016 (Shark Research Institute, 2016). Of these 253 proved fatal and 928 were non-fatal (Appendix 1.) In New South Wales (NSW) there has been 467 shark attacks recorded, 98 were fatal and 369 non-fatal (Figure 1). These records include both unprovoked and provoked incidences. The Australian Shark Attack File (Shark Research Institute, 2016) identifies unprovoked and provoked shark attacks as:

> *"An 'unprovoked' encounter between a human and a shark is defined as an incident where a shark is in its natural habitat and has made a determined attempt to bite a human without any human provocation. A 'provoked' incident occurs when a human attracts or initiates physical contact with a shark, e.g. a person is bitten after grabbing a shark, a fisherman bitten while removing a shark from a hook, interactions with spearfishermen while spearing fish or the shark, a person steps on a shark, etc."*



(Source: Shark Research Institute, 2016)

Figure 1. Australian shark attack records (1700 to June 2016) by state. (Total fatal and non-fatal statistics include both provoked and non-provoked attacks.

Dangerous sharks

Any increase of localized shark attack incidences often gives rise to a need to better understand shark behaviour and spatial movements within their home range and migration routes. McPhee (2014), identifies three shark species commonly responsible for the majority of shark attacks in Australia and throughout the world; the white shark (*Carcharadon carcharias*), the tiger shark (*Galocerdo curvier*), and the bull shark (*Carcharhinus sp*).

White shark *(Carcharadon carcharias)*

White sharks are an apex predator in any marine food web they occupy (Ramón, Michael, Scholl, Johnson, & et al., 2005). They consume a wide variety of vertebrates including seals, birds and other sharks. With an ability to regulate their bodies temperature, the white shark is able to frequent both tropical and temperate waters.(Oerding & Klimley, 2013). Populations are primarily concentrated in oceans around Australia/New Zealand, South Africa and the north eastern Pacific (Pardini et al., 2001). Two white shark clades have been identified by DNA analyses indicating that Australia/New Zealand and South Africa are separate from the south eastern Pacific clade and as such form genetically distinct populations (Pardini et al., 2001).

White sharks have been found to migrate thousands of kilometres in the pursuit of breeding and feeding sites. Radio tracking was used to demonstrate that white sharks undergo trans-oceanic migrations between Africa and the west coast of Australia, travelling up to 1,100 km between aggregation and feeding sites (Ramón et al., 2005). Similar studies revealed white sharks in the South-West Pacific Ocean are attracted by food sources such as seal colonies off the coast of Stewart Island New Zealand. White sharks were found to aggregate in the area for an average of 4 months over autumn. This period would coincide with an increase in fur seal activity. During winter their annual migrating would then take them to the tropical and warm temperate waters of Queensland (QLD) and NSW for a period of up to 6 months (Francis, Duffy, & Lyon, 2015). However not all white sharks in eastern Australian waters follow these migration routes. Many appear to have more localized seasonal migrations moving northwards along the east coast during the autumn-winter months and south in spring-summer (Bruce, Stevens, & Malcolm, 2006).

White sharks are most often implicated with shark attacks in NSW waters (West, 2011). As such shark control programs such as those in NSW and QLD identify white sharks as a target species. Since the 1950's annual capture rates under the NSW program have fallen, giving indication to the declining number of the species (Reid, Robbins, & Peddemors, 2011). Incidental captures of white sharks by commercial fishers also continues despite their protected status in Australian and New Zealand waters. Due to this decline in population, white sharks are currently listed as 'Threatened' by the International Union for the Conservation of Nature's (IUCN) Red List of Threatened Species (IUCN, 2016).

Tiger shark (Galocerdo curvier)

Tigers sharks are also one of the top level marine predators feeding on a range of vertebrates including sea turtles, birds and dugongs (Oerding & Klimley, 2013). Tiger sharks occur in tropical and warm-temperate waters throughout the world including South Pacific and the Coral Sea. Their distribution includes the entire east coast of Australia, extending to the southern coast of NSW during summer (Holmes et al., 2014). Studies in Hawaii with acoustic telemetry tracking suggest tiger sharks have a home range of at least 109km and oceanic movements of up to 6,747 km have been observed (Kohler, Casey, & Turner, 1998). However, tiger shark migration movements tend to be less regular and more unpredictable compared to the annual seasonal migrations of some species such as white sharks.

For tiger sharks in the Coral Sea between New Caledonia and the QLD coast, the connectivity of reefs appears to dictate their movements (Werry et al., 2014). The availability of food, suitable breeding and pupping grounds can then influence duration of residency at a reef (Papastamatiou et al., 2013). The transient behaviour of tiger sharks has also been shown to be associated with a change in water temperature (Holmes et al., 2014). During the warmer & summer months the EAC (East Australian Current) intensifies, flowing southward influencing the distribution of pelagic fishes such as billfishes, tunas, mackerels and kingfish

(Zischke, Griffiths, & Tibbetts, 2012). The movement of tiger sharks during this period coincides with that of the pelagic fish. Holmes et al, (2014) found when water temperatures drop below 19^{o}C, tagged tiger sharks returned to the comparatively warmer tropical waters in July-September.
Declining trends in tiger shark captures under the shark control program in NSW (1950-2010) have been identified (Reid et al., 2011). Due to their relatively fast growth and high juvenile survival rates compared to other sharks, the tiger shark is often thought of as less subject to the impacts of overfishing (Holmes et al., 2012). Although tiger shark numbers appear to be stabilizing, increased exploitation of the species by commercial and recreational fishers continues to put pressure on their abundance (Holmes et al., 2012). Tiger sharks are currently listed as near threatened by the IUCN, (2016).

Bull and whaler sharks (Carcharhinus spp.*)*

The bull sharks and a number of other members of the genus *Carcharhinus* have a history of shark attack in Australia (Shark Research Institute, 2016). The black tip shark (*Carcharhinus limbatus*), bronze whaler (*Carcharhinus brachyrus),* dusky whaler (C*archarhinus obscurus*), silky shark (*Carcharhinus falciformis*) and spinner shark *(Carcharhinus brevipinna)* are all regular captures in Australian shark control programs (DAF, 2016b), (DPI, 2013b). Although all these sharks are labelled as target species under control programs in both NSW and QLD, quantifying which species are implicated with shark attack is not so clear. In the heat of an attack identifying the culprit is likely the last thought in the victim's mind. In addition, the similar characteristics within the *Carcharhinus* spp would make accurate identification to the species level unlikely (Lowry et al., 2009).

McPhee (2014) analysed Global Shark Attack File Statistics and found where a species of shark was assigned, white sharks were responsible for the most attacks, followed by tiger sharks and bull sharks (http://www.sharkattackfile.net/). Bull sharks are a large shark growing up to 4m and are found in tropical and warm temperate waters (Lea, Humphries, Clarke, & Sims, 2015). As with the white shark and the tiger shark, the bull shark is a quarternary consumer. One trophic level higher than the tertiary consumer, their diet includes smaller sharks and teleosts (Oerding & Klimley, 2013). Bull sharks are euryhaline (able to tolerate a wide range of salinity) so can remain for extended periods living in both fresh water and marine environments (Jensen, 1976). Evidence suggests that bull sharks require both these habitats to complete their life histories.

Bull sharks are also capable of transoceanic migrations. A large pregnant female bull shark was recently tracked migrating 4,000 km across the open ocean from Seychelles to Madagascar and back again (Lea et al., 2015). More locally studies reveal parturition occurs close to or with estuarine systems of north eastern Australia (Tillett, Meekan, Field, Thorburn, & Ovenden, 2012). Werry et al. (2012) demonstrated that neonatal and juvenile sharks remained the upper reaches of the Nerang River for the first 5-6 years of life. These mangrove lined estuarine habitats serve as nurseries for juvenile bull sharks, before moving offshore as adults (Werry, Lee, Lemckert, & Otway, 2012).

Bull sharks have also been observed to frequent shallow coastal and estuarine waters (Tillett et al., 2012). Their affinity for inhabiting coastal waters means they are often captured by nets and drumlines under shark control programs. Fisherman too target the species both offshore and in rivers and estuaries (Werry et al., 2012). The combination of overfishing and the destruction of mangrove habitat by coastal development, has led to a decline in numbers worldwide. Bull sharks are presently listed as near threatened by the IUCN, (2016).

Shark attack behaviour

Humans are not considered to be a natural food source for sharks, so a number of theories have been posed to determine why unprovoked shark attacks occur (Oerding & Klimley, 2013). A common belief is that sharks mistakenly identify swimmers or surfers for seals or turtles. This is backed up by data that shows the majority of attacks or 'shark bites' result in the shark leaving the scene after the initial bite (McPhee, 2014). This aligns with statistics that show the majority of unprovoked shark attacks result in minor injuries (Woolgar, 2001). A number of observations have revealed that after the initial bite, white sharks often don't return to eat their prey unless the food source contains a high level of fat such as that found in seals and whales (Anderson, 1996a).

Another theory is that certain species such as white sharks exsanguinate their prey before consumption (Anderson, 1996a). White sharks have regularly been observed to administer a single bite to a seal before leaving its prey to presumably to bleed out, before returning to eat it after some time (Anderson, 1996b). This behaviour is analogous to the majority of attacks on humans, where a single bite is inflicted before the shark retreats (McPhee, 2014).

An increase in shark attacks

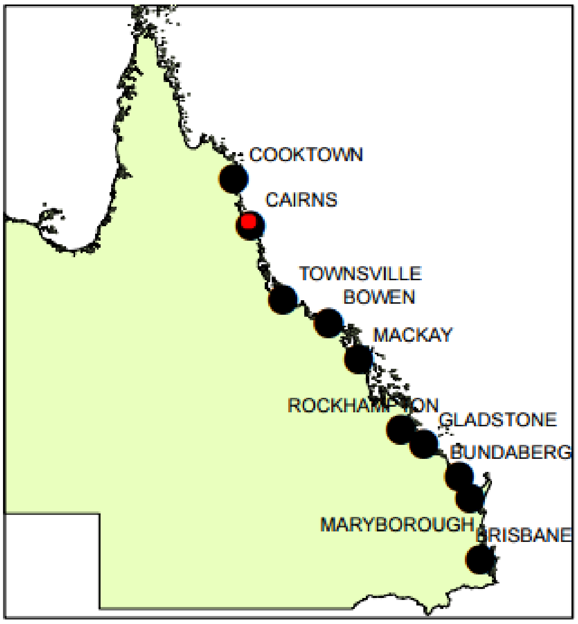
McPhee (2014) identifies an increase in unprovoked shark attacks globally between 1982-2012. It appears an increase in numbers of beach users correlates with an increase in shark attacks (Lemahieu et al., 2017). With more people in the water the likelihood of attack is increased (Chapman & McPhee, 2016). However, this is not always the case. Amin, Ritter, and Kennedy (2012) found that an increase in beach users in Florida did not equate to an increase in shark attacks. It is likely that a number of other factors are responsible for the rise in attacks; the seasonal migration of prey species such as whales, may determine the abundance of shark numbers as they follow their food source; anthropogenic influences such as climate change, costal development and pollution which may affect the pattern of habitat use for some sharks; and an increase in populations of certain shark species due to overfishing of relevant predators (McPhee, 2014).

Although unprovoked shark attacks are extremely rare and often result in very minor injuries, (Woolgar, 2001) fear of being attacked by a shark haunts the minds of many beach users. A response by authorities to mitigate an increase in localized attacks is often driven by sensationalized media and heightened fear in the public (Chapman & McPhee, 2016). These authorities are often faced with a conflict of interest between beach users, capitalism and conservationists (Neff, 2012). Often authorities first response is to implement a shark control program. This alleviates public anxiety, at least in the short term, and instils confidence in beach users which in turn benefits tourism. Outcries by conservationists ensue, quoting the statistics of threatened species inadvertently caught and killed by these control programs each year (Neff, 2012).

3. Queensland and New South Wales Shark Control Programs

Queensland Shark Control Program (QLD SCP)

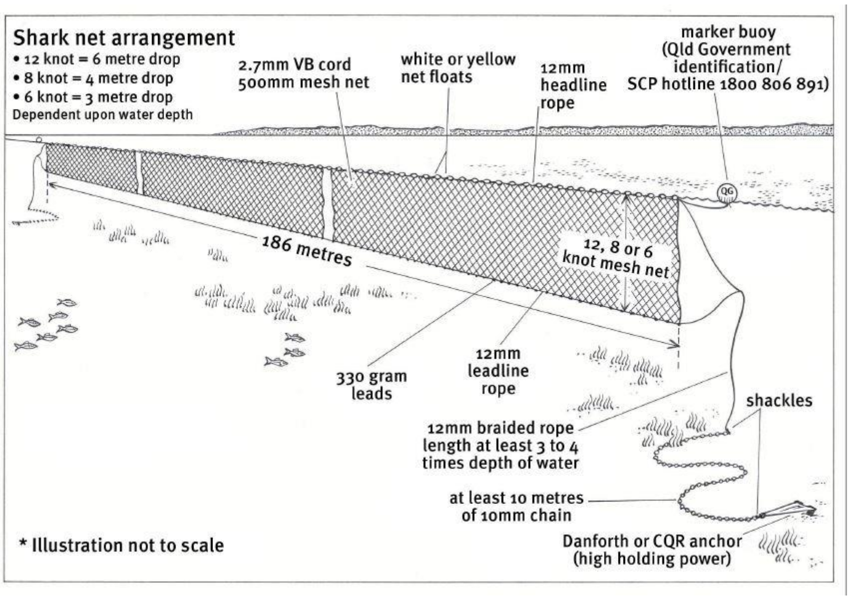
The QLD Shark Safety Program was established in 1962 following a number of fatal shark attacks in South East Queensland waters. Today the Queensland Shark Control Program (QLD SCP) manages shark control equipment at approximately 84 beaches (Department of Primary Industries and Fisheries, 2006) from the Gold Coast in the south to Cairns in the north (Figure 2). A combination of shark nets and drumlines are installed at beaches where the chance of human-shark interaction is the highest. Independent contractors working under the supervision of the Queensland Boating and Fisheries Patrol service the equipment every second day (Department of Primary Industries and Fisheries, 2006).



(Source: DAF, 2016b)

Figure 2. Locations of shark control equipment in Queensland.

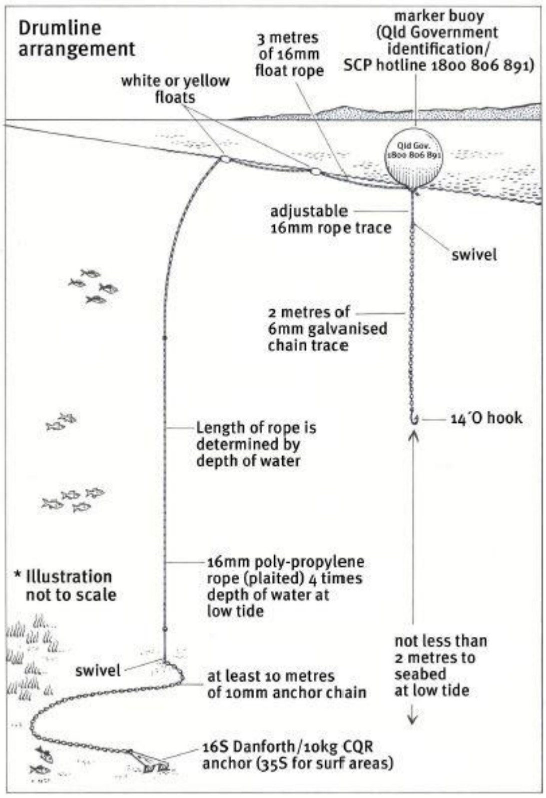
There are 30 shark nets deployed year round off the QLD coast (DAF, 2016c). The shark nets are made up of 3 x 62m sections and total 186m in length and 3-6 meters high depending on the depth of water. They are generally set parallel to the shore line and are anchored to the sea floor and marked with inflatable buoys (Figure 3). As with drumlines, the nets are designed to reduce the number of potentially dangerous sharks in a particular area. The nets are not designed to be an impenetrable barrier against sharks. The nets are suspended from the surface with floats (surface set) but often don't extend from the surface to the sea floor. The mesh diameter of 500mm is designed to catch large sharks >2m in length (Department of Primary Industries and Fisheries, 2006)



(Source: DAF, 2016b)

Figure 3. Queensland shark net arrangement.

There is currently 367 drumlines set off the QLD coast year round (DAF, 2016c). The configuration of a drumline consists of a 14/0 baited fish hook attached a large plastic float by a 2-metre-long galvanized chain (Figure 4). The float is anchored to the sea bed via a rope and chain using a Danforth or CQR high-holding anchor. The hook is baited approximately every other day with fresh mullet. Drumlines are designed to capture actively feeding sharks (DAF, 2016c).



(Source: DAF, 2016b)

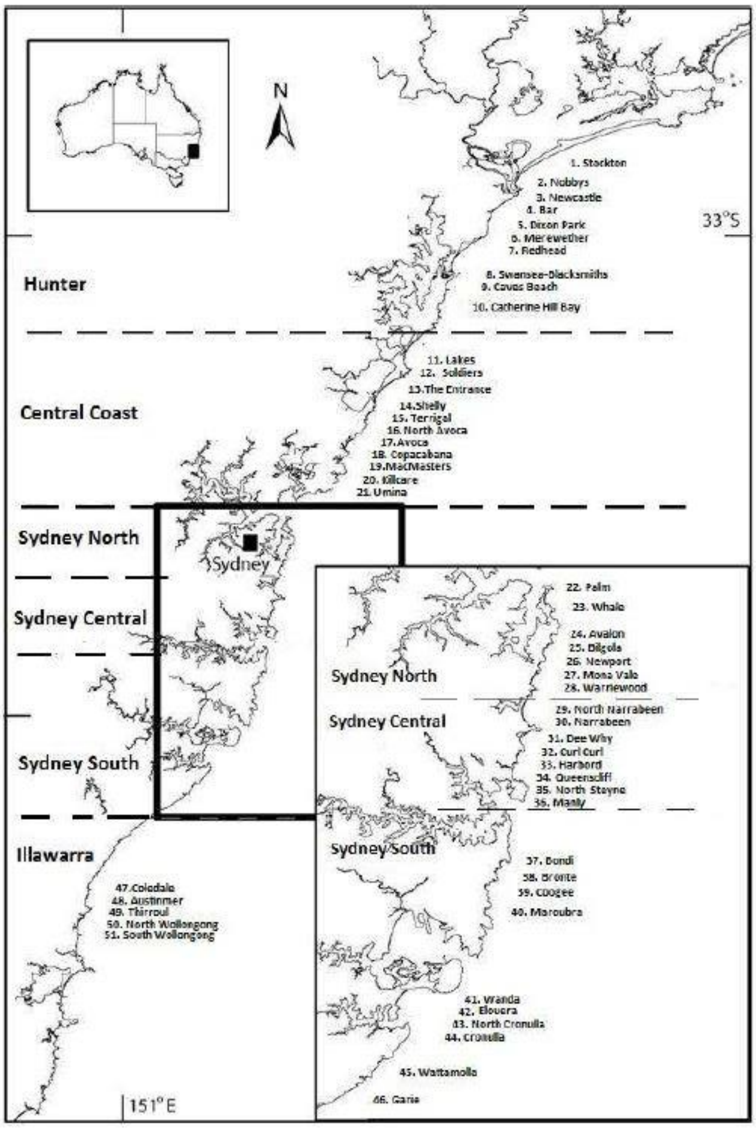
Figure 4. Queensland drumline arrangement.

South East Queensland (SE QLD)

Due to the high number of beach users, 22 of the 30 nets deployed year round under the QLD SCP are located in SE QLD. In addition to the nets 145 of the 367 drumlines set off the QLD coast are also located in SE QLD (DAF, 2016c).

New South Wales Shark Meshing (bather protection) Program (NSW SMP)

Since 1937 shark nets have been used each year between Newcastle and Woolongong on the NSW coastline. Netting is currently undertaken between September and April each year at 51 beaches (Figure 5) under the New South Wales Shark Meshing (Bather Protection) Program (NSW SMP). Shark nets in NSW are 150m long, 6m high and have a mesh size of 60cm. They are generally set parallel to the shoreline within 500m from the beach. They are set in 10-12m of water approximately 4m below the surface (McPhee & Blount, 2016). The nets in NSW are at times fitted with acoustic dolphin deterrents (ADDs) or 'pingers' designed to deter whales and dolphins from the netting area (DPI, 2015b). Contractors are required to check their nets every 72 hours (DPI, 2015b).

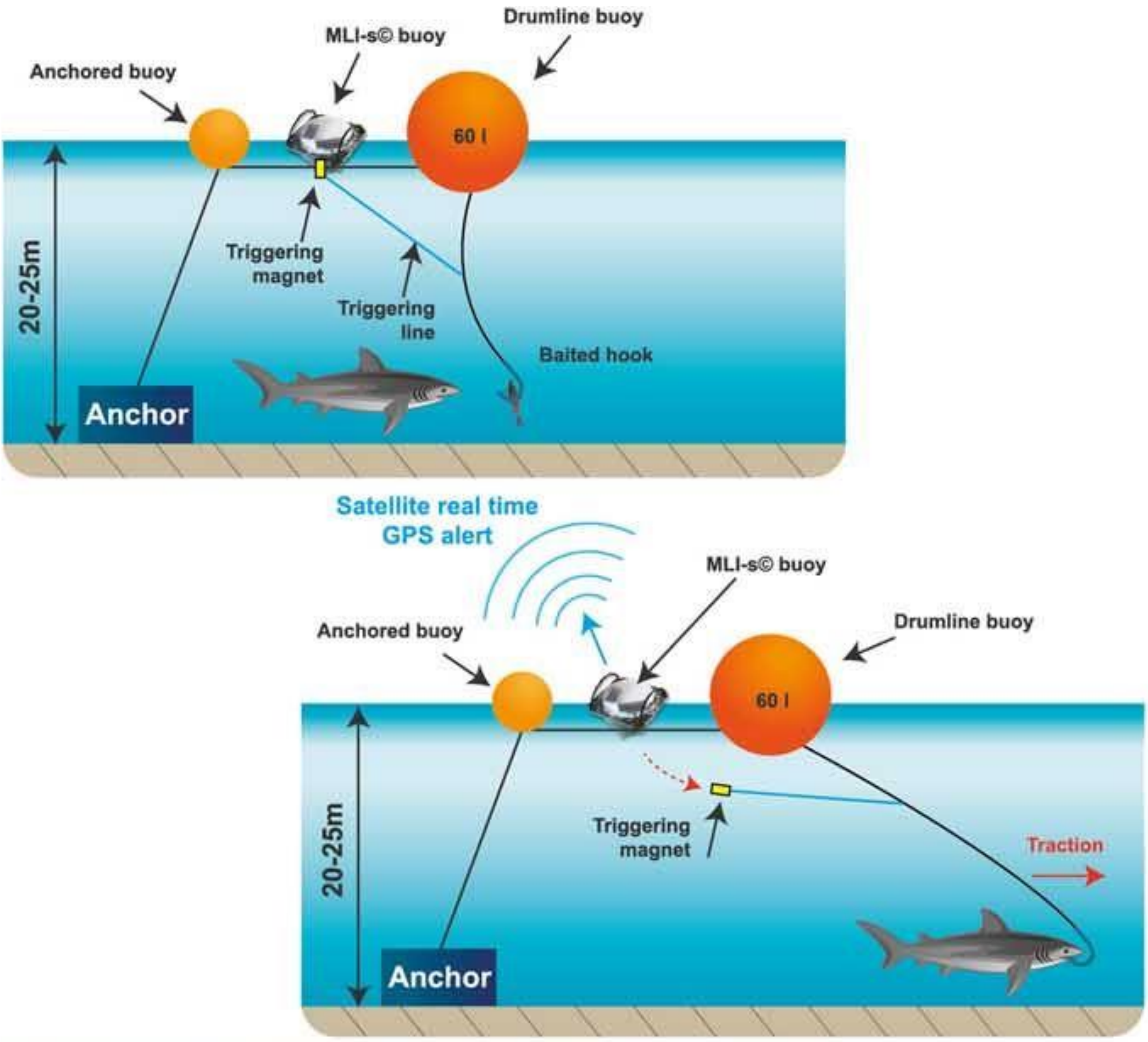


(Source: DPI, 2015b)

Figure 5. NSW SMP net locations.

SMART drumlines in NSW

In 2015 initial testing of SMART (Shark Management Alert in Real Time) drumline technology in Australia was undertaken in the Bellinger River south of Coffs Harbour (DPI, 2016d). Since then 15 SMART drumlines have been trialled in a number of locations with plans for an additional 85 by the end of 2016. The ‘Catch-A-Live system’ differs from traditional drumlines in that they are not designed to kill sharks (Figure 6). Once a shark is hooked, a trigger system alerts a remote MLI-S GPS satellite buoy (Perry, Guyomard, Pino, & Bodilis, 2016). The buoy sends a message along with the GPS position via email or smartphone to the contractor/fisherman. The contractor crew are then able to release or kill the shark at their discretion (McPhee & Blount, 2016).



(Perry et al., 2016)

Figure 6. SMART drumline configuration utilizing the ‘Catch-A-Live system.’

Some shark control programs advocate the release of both by-catch and target species. The Shark Monitoring Program in Recife Brazil aims to remove dangerous sharks from potential human-shark interaction by capturing, transporting and releasing sharks offshore (Hazin & Afonso, 2014). During a trial of the program a combination of long lines and drumlines were found to increase selectivity of sharks and reduce by-catch compared with shark meshing. With regular checking of hooks and careful relocation of sharks offshore, 100% survival rate at time of release was observed. During the 7 year trial of the program, shark attack incidences were reduced by 97% (Hazin & Afonso, 2014).

A number of other measures are taken to further increase survival such as hook and bait selectivity. The use of circle hooks can lower injury incurred by deep hooking (Sumpton, 2010). Circle hooks are designed to penetrate the mouth of the catch as opposed to the more vulnerable parts of the stomach or throat (Sales et al., 2010). A hook injury to the throat or stomach can result in internal bleeding, lowering the chance of survival. Hook injuries to mouth parts are more superficial in nature allowing for better survival of many by-catch species including turtles dolphins, undersized target sharks and teleost (Sumpton, 2010). The survival of air breathing animals such as cetaceans and chelonians is also subject to early detection, unhooking and releasing of the by-catch (Hazin & Afonso, 2014).

Initial trials of new SMART drumline technology at Reunion Island, by David Guyomard Reunion Island Regional Committee of Sea Fisheries and Aquaculture (as cited in McPhee & Blount, 2016, p18) has shown a considerably higher survival rate compared to animals captured under the QLD SCP using standard drumlines. However, due to the recent development of this technology, little evidence is available to support the findings. Trials utilizing SMART drumlines such as that under the North Coast Shark Net Trial will provide much needed data to quantify their effectiveness.

North Coast Shark Net Trial

The North Coast Shark Net Trial began in November 2016 and is set to run for 6 months (DPI, 2016b). According to the DPI, 5 nets have been deployed at 5 north coast beaches; Sharpes, Shelly and Lighthouse Beaches at Ballina; Seven Mile Beach at Lennox Head; and Main Beach at Evans Head (Figure 7). Nets are to be fitted with acoustic warning devices to deter whales and dolphins and SMART alert technology to alert contractors and scientists of captures (DPI, 2016b). SMART drumlines will also be trialled in Northern NSW for the first time. A total of 25 SMART drumlines (Figure 7) have been in use since December 2016 (DPI, 2016c). SMART drumlines used in the trial area are not a shark management measure for the purpose of the trial. However, they may be used to allow comparison of the CPUE (catch per unit effort) between the nets and drumlines (DPI, 2016b). Contractors have been employed to check the fishing gear regularly. The contractors are to be accompanied by a trained observer from the Department of Primary Industries (NSW DPI, 2016).

Drones have also been under trial in the North Coast area as part of the Shark Management Strategy (DPI, 2016a). On board cameras relay live footage of aerial surveillance back to users that can alert beach goers of any shark activity seen in the area. Satellite linked VR4G listening stations are also located within the trial area (Figure 7). These devices record the presence of tagged sharks swimming in the vicinity of the receivers. This provides real-time tracking data of tagged sharks for research purposes (DPI, 2016d).

(DPI, 2016c)

Figure 7. Shark Management Strategy identifying locations of nets, drumlines, VR4G listening stations and drones under the North Coast Shark Net Trial.

The research objectives outlined in the NSW North Coast Shark Meshing Trial Management Plan (DPI, 2016b) are;

a) "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.
b) testing of new devices and/or procedures which might deter whales or dolphins from approaching or becoming entangled in the nets, and also of new devices which might alert researchers in real time when a large animal is caught in the nets.

c) monitoring the level of community acceptance of the local community to the presence and operation of the nets during the Trial. This will be reported via the community engagement program under the NSW Shark Management Strategy" (DPI, 2016b).

The objectives and performance indicators are outlined as follows;

a) "Reduce the rate of unprovoked interactions with Potentially Dangerous Sharks within the area of the Trial;
b) Minimise the impact of the Trial on all Fauna; and
c) Assess the effectiveness of the nets against SMART drumlines used in the area of the Trial" (DPI, 2016b).

4. Methods

Identifying target sharks and by-catch

In comparing the annual reports, the classification of target and non-target species differed between NSW and QLD. For example, the NSW reports specified whether captures were target sharks or by-catch (DPI, 2013b), (DPI, 2015a) & (DPI, 2015b). Whereas the QLD reports classified all catch data as either; Shark catch statistics (DAF, 2016b) or Non-target catch statistics (DAF, 2016a). Further determination was made to identify by-catch in QLD Shark catch statistics.

In the QLD SMP the high risk species are considered to be bull and whaler sharks (*Carcharhinus* spp.), tiger sharks and white sharks. Hammerhead sharks are considered high risk in SE QLD only. A report into the QLD SCP states; "The hammerhead species is added to this group not so much for its proven attack history in the Queensland context, but for its local abundance" (Department of Primary Industries and Fisheries, 2006). In NSW hammerheads are not regarded as a target shark and make up a substantial portion of the by-catch each year. With no proven attack history and to ensure an analogous comparison was made of expected species composition for the Shark Net Trial, hammerheads are categorized as by-catch in this report.

In the QLD SCP mako sharks were not identified as being a high risk species (Department of Primary Industries and Fisheries, 2006). In the NSW SMP mako sharks are labelled as target sharks (DPI, 2015b). Again, to ensure an analogous comparison was made between QLD and NSW, mako sharks were categorized and counted as target sharks both in states.

All captures were counted and categorized as either target sharks or by-catch;

1. Target sharks- broadnose sevengill sharks (*Notorynchus cepedianus*), mako sharks (*Isurus* spp), tiger sharks (*Galeocerdo cuvier*), all bull and whaler sharks (*Carcharhinus* spp) and white sharks (*Carchardon carcharias*).
2. By-catch- includes all other captures; all non-target sharks and non-target species such as whales and dolphins (cetaceans), dugongs (sirenia) and seals (pinnipeds), turtles (chelonians), rays (batoids) and fin fish (teleosts).

Identifying threatened species

The common names for each animal captured under the QLD and NSW shark control programs were used to determine the threatened status on the IUCN Red list (IUCN, 2016). Species identified as Vulnerable, Endangered or Critically Endangered were categorized as Threatened. A number of threatened species can be found in both target shark and by-catch categories.

Identifying equipment locations

The location, distribution and abundance of species is driven by many factors including climate. It was recognized that the close geographical proximity of SE QLD to Northern NSW would provide an analogous comparison of the species composition that might be captured by the shark Net Trial (Lucifora, García, Menni, & Worm, 2012). In this report SE QLD includes the following areas; North and South Gold Coast, Point Lookout, North Stradbroke Island, North and South Sunshine Coast and Bribie Island (DAF, 2016c). Statistics gathered in these locations were used to determine the species composition caught by nets and drumlines (2011-15).

Data analysis

Queensland Shark Catch Statistics and Non-Target Catch Statistics, DAF (2016b) & (2016a) were used to determine the numbers of captures each year over the 5 year period (2011-15). NSW SMP Annual Performance Reports, DPI (2012), (2013a) (2013b), (2015a) & (2015b) were used to quantify captures for NSW each season over a five year period (2010-15). Total numbers of target sharks, by-catch and threatened species captured were analysed using a Chi-square (x^2), Cramer's V, and Lambda test (Anon, 2016) to determine any significant difference in catch composition between SE QLD and NSW.

Less than 2 years of data was available on both capture type (target sharks and by-catch) and gear type (nets and drumlines). Statistics from 2015 to Sept 2016 (DAF, 2016b), (DAF, 2016a) were totalled to determine the frequency (*f*) that nets and drumlines capture target sharks and by-catch. Further analysis using Chi-square (x^2), Cramer's V, and Lambda (Anon, 2016) was used to determine any significant difference in captures due to gear types used.

5. Results

A total of 24 threatened species (IUCN, 2016) were implicated in the QLD and NSW shark control programs for each 5-year period (Table 1). This consisted of 17 Vulnerable, 6 Endangered and 1 Critically Endangered species. In Queensland an average of 590 target sharks, 199 by-catch and 126 threatened animals were captured each year. An average of 44 target sharks, 117 by-catch and 51 threatened species were caught during the netting seasons in NSW. In SE QLD 80 target sharks, 77 by-catch and 46 threatened species were captured over the 5-years (Figure 8).

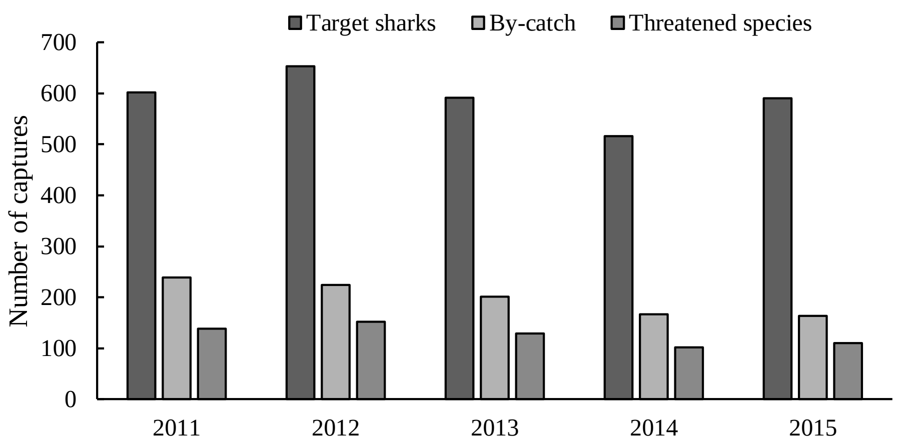
***Table 1**. The classification of threatened (IUCN and NSW listing status) captured during the QLD SCP (2011-15) and the NSW SMP (seasons 2010-15).*

V=Vulnerable, E=Endangered, CE=Critically Endangered.

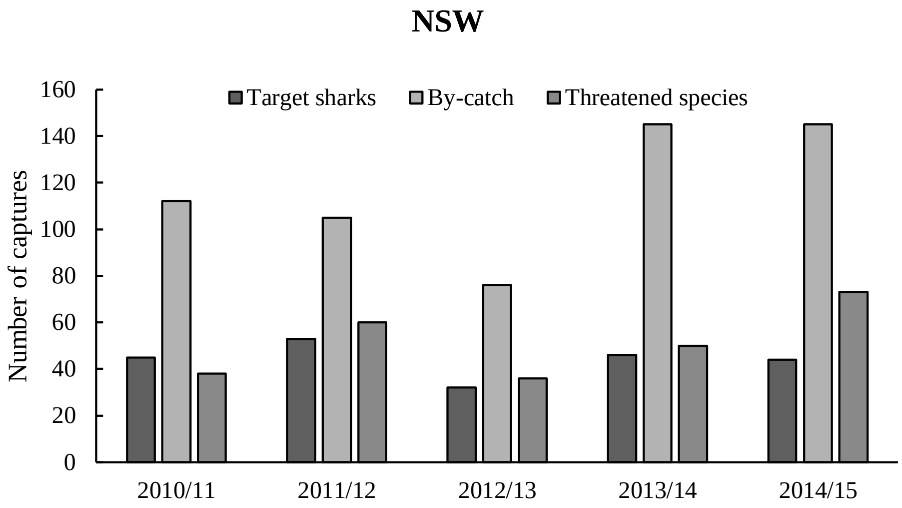
Common name	Genus species	IUCN listing	NSW listing
Dugong	*Dugong dugon*	V	E
Fossil shark	*Hemipristis elongate*	V	
Giant shovelnose ray	*Glaucostegus typus*	V	
Great hammerhead	*Sphyrna media*	E	V
Green turtle	*Chelonia mydas*	E	V
Grey nurse shark	*Carcharias taurus*	V	CE
Hawksbill turtle	*Eretmochelys imbricata*	CE	
Leatherback turtle	*Dermochelys coriacea*	V	E
Loggerhead turtle	*Caretta caretta*	V	E
Longfin mako	*Isurus paucus*	V	
Manta ray	*Manta alfredi*	V	
Manta ray	*Manta birostris*	V	
Narrow sawfish	*Anoxypristis cuspidata*	E	
Queensland grouper	*Epinephelus lanceolatus*	V	
Reticulate whip ray	*Himantura uarnak*	V	
Scalloped hammerhead	*Sphyrna lewini*	E	E
Sharp tooth lemon shark	*Negaprion acutidens*	V	
Shortfin mako	*Isurus oxyrinchus*	V	
Spear tooth shark	*Glyphis glyphis*	E	
Thresher shark	*Alopias vulpinus*	V	
Tawny nurse shark	*Nebrius ferrugineus*	V	
White shark	*Carchardon carcharias*	V	V
Winged hammerhead	*Eusphyra blochii*	E	
Zebra shark	*Stegostoma fasciatum*	V	

(Source: DPI 2016b, IUCN 2016)

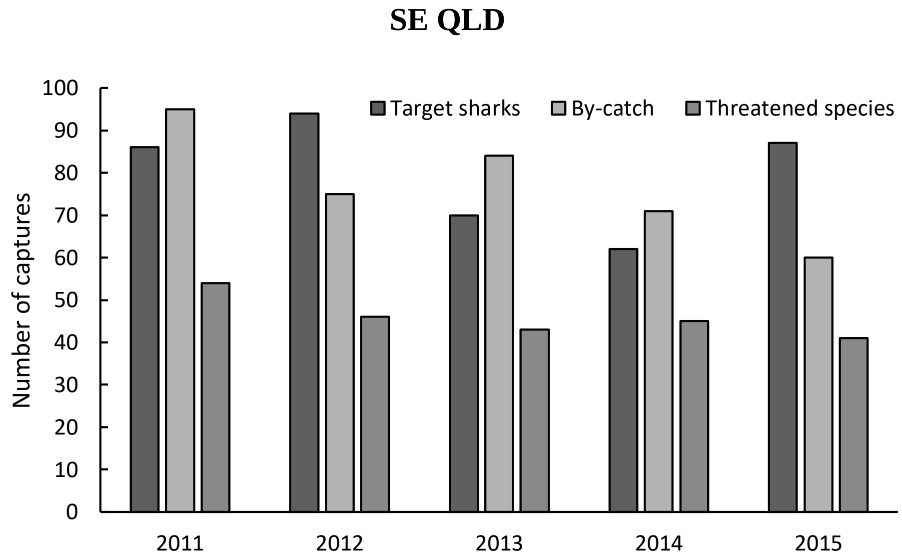
QLD



(Source: DAF 2016a, 2016b)



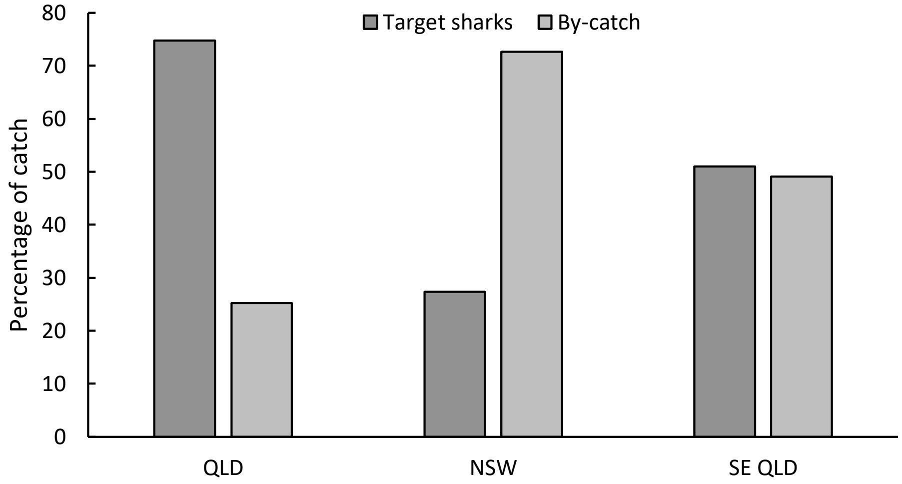
(Source: DPI 2012, 2013a, 2013b, 2015a, 2015b)



(Source: DAF 2016a, 2016b)

Figure 8. Composition of target sharks, by-catch and threatened species caught in the QLD SCP (2011-15) NSW SMP (seasons 2010-15) and in SE QLD SCP (2011-15).

Target sharks made up 75% of the catch in QLD, 28% in NSW and 51% in SE QLD. This equated to by-catch comprising of 25% of the catch in QLD, 73% in NSW and 49% in SE QLD (Figure 9). When catch numbers were analysed using a Chi-square test a significant difference in the composition of target sharks and by-catch was found between NSW and SE QLD (x^2= 92.86, *df*= 2, *P*= <0.0001). The capture of target sharks in SE QLD was 40% greater than expected in NSW. The by-catch in NSW was 17.8% greater than expected in SE QLD (Table 2).



(Source: DAF 2016a, 2016b. DPI 2012, 2013a, 2013b, 2015a, 2015b)

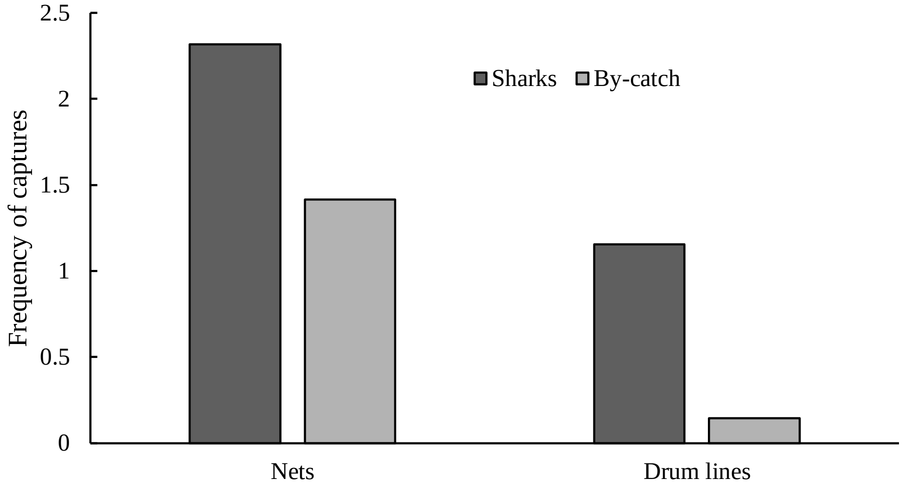
Figure 9. Percentage of yearly average numbers of target sharks and by-catch caught in the QLD, NSW and SE QLD over the 5-year period.

Table 2*. The Chi-square table for catch type caught in the NSW and SE QLD shark control programs.*

	NSW	**SE QLD**	Total
Target sharks	220	399	619
By-catch	583	385	968
Threatened species	257	229	486
Total	1060	1013	2073

(Source: DAF 2016a, 2016b. DPI 2012, 2013a, 2013b, 2015a, 2015b)

A total of 22 nets and 145 drumlines (a ratio of 1:7) operate year round in SE QLD. For the rest of QLD 8 nets and 222 drumlines (a ratio of 1:28) are also deployed (DAF, 2016c). Under the QLD SCP for the period of 2015-Sept 2016 nets caught target sharks at approximately twice the frequency of drumlines (*f nets*= 2.32, *f drumlines*= 1.15). During the same period by-catch was caught in nets at almost 10 times the frequency of drumlines (*f nets*= 1.42, *f drumlines*= 0.14 (Figure 10). Further analysis using a Chi-square test identified a significant difference in the numbers of target sharks and by-catch caught in nets and drumlines (x^2= 109.8, *df*= 1, *P*= <0.0001). The observed frequency of by-catch caught in nets was 149% greater than expected. The observed frequency for target sharks caught in nets and by-catch caught by drumlines was considerably smaller than expected with -27% and -35% respectively. (Table 3).



(Source: DAF 2016a, 2016b)

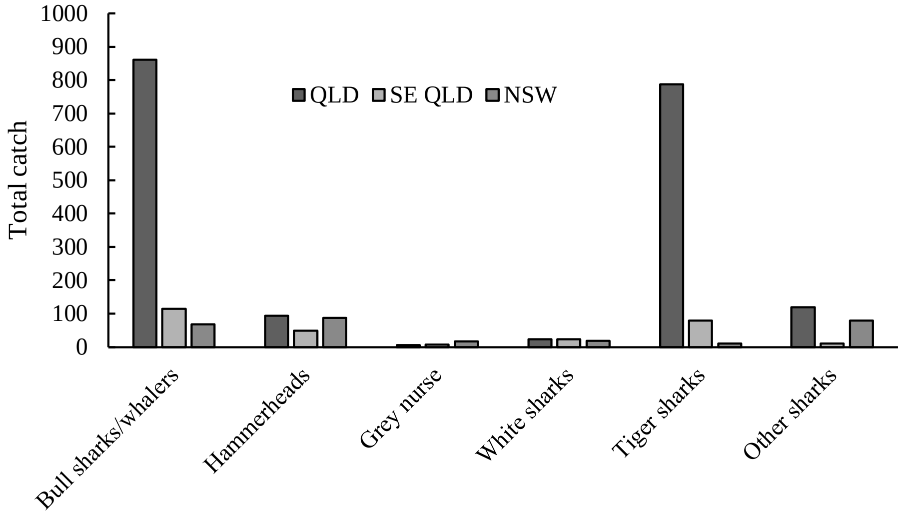
Figure 10. Frequency of sharks and by-catch caught in nets and drumlines under the QLD SCP (2015-Sept 2016).

Table 3*. The Chi-square contingency table for numbers of target sharks and by-catch caught by nets and drumlines in the QLD SCP (2015-Sept 2016).*

	Nets	**Drumlines**	Total
Target sharks	139	852	991
By-catch	85	92	177
Total	224	944	1168

(Source: DAF 2016a, 2016b)

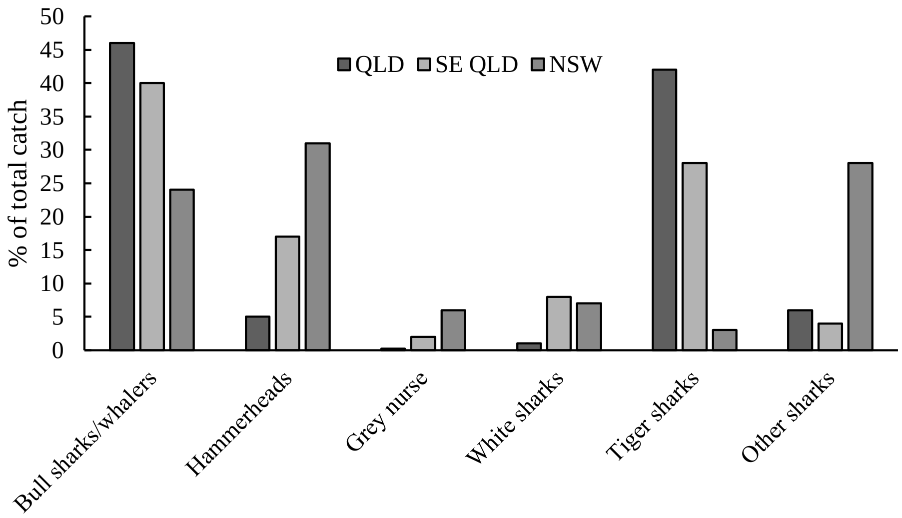
Species composition was analysed over a 3-year period, NSW SMP (seasons 2012-15) and QLD SCP (2013-15). Bull sharks/whalers and tiger shark both substantially dominated the composition of the catch in QLD with 861 and 788 captures respectively. Threatened species caught in QLD included 24 white sharks and 5 grey nurse. In SE QLD bull shark/whalers and tiger sharks again dominated the catch with 114 and 80 individuals respectively. Threatened species caught were 23 white sharks and 7 grey nurse. In NSW the catch was dominated by 88 hammerheads, 80 other sharks and 68 bull shark/whalers. A total of 19 white and 17 grey nurse sharks were also caught in the nets (Figure 11).



(Source: DAF 2016a, 2016b. DPI 2012, 2013a, 2013b, 2015a, 2015b)

Figure 11. Total catch composition over a 3-year period.

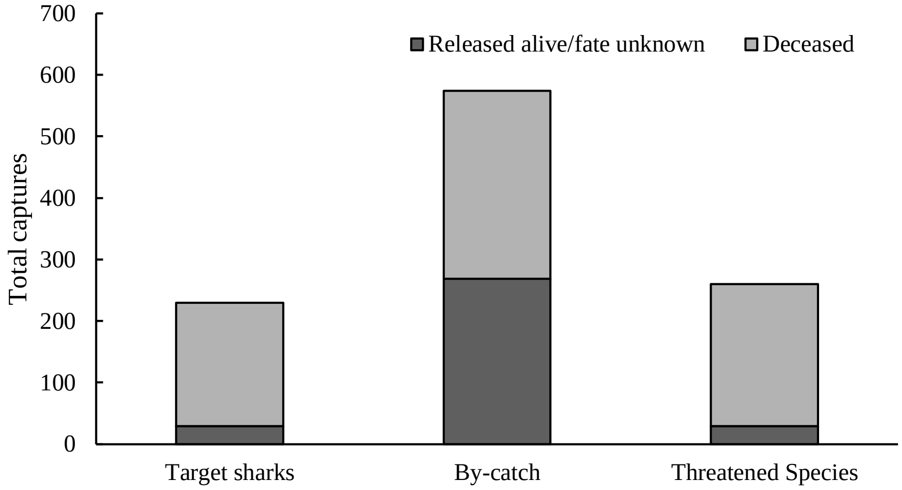
The catch for QLD was mostly comprised of bull sharks/whalers (46%) and tiger sharks (42%) with very few white (1%) or grey nurse sharks (<1%). In comparison NSW catch was mostly hammerheads (31%) and other sharks (28%) followed by bull sharks/whalers (24%). White sharks (7%) and grey nurse (6%) also made up a larger percentage of the catch in NSW compared to QLD The catch composition in SE QLD was similar to the rest of QLD in that bull sharks/whalers (40%) and tiger sharks (28%) dominated the catch. However, a large percentage of hammerhead sharks (17%) were also caught. Similar to NSW, SE QLD had a higher percentage of white sharks (7%) and grey nurse sharks (6%) compared to the rest of QLD (Figure 12).



(Source: DAF 2016a, 2016b. DPI 2012, 2013a, 2013b, 2015a, 2015b)

Figure 12. Percentage of total catch over a 3-year period.

In the NSW SMP (2010-15) 29 target shark were released alive shortly after capture and 201 were found to be deceased. A total of 269 animals classified as by-catch were released after capture and 305 were found deceased. Out of 260 threatened animals caught in the nets only 29 were released alive. Both by-catch and threatened species caught in the nets outnumbered target sharks. The number of deceased by-catch and target sharks also outnumbered deceased target sharks (Figure 13).



(Source: DPI 2012, 2013a, 2013b, 2015a, 2015b)

Figure 13. The fate of all captures entangled in nets in the NSW SMP (2010-15).

Of the 99 by-catch individuals captured in the QLD SCP (2015), 25 captured by nets were found deceased and 33 were released alive. For the same period 13 by-catch numbers were found deceased and 28 released alive. No further data was available on the fate of captures in QLD (Figure 14).

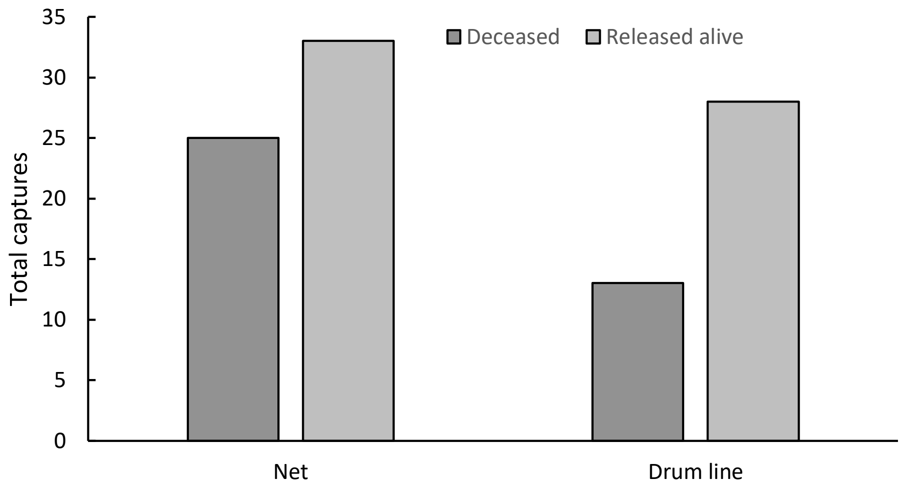


Figure 14. The fate of by-catch in nets and drumlines under the QLD SCP (2015).

Each year nets become damaged by marine life or extreme weather in the NSW SMP. Some nets are damaged by vessels or anchors and sometimes nets are intentionally damaged by members of the public (DPI, 2013b). From 2010 to 2015 4 nets were found washed up on beaches due to entanglement by wales and/or extreme weather conditions. Whales damaged a total of 4 nets and 5 nets were reported as missing over the 5-year period (Table 4).

Table 4. *Lost and damaged nets in the NSW SMP 2010-15.*

	2010/11	2011/12	2012/13	2013/14	2014/15
Net washed up on beach	1	1	2	0	0
Net missing	0	0	1	0	4
Whales damaging nets	0	0	2	2	0

(Source: DPI 2012, 2013a, 2013b, 2015a, 2015b)

6. Discussion

Data analysis

A comparison of the statistics analysed in this report revealed some significant differences in catch composition and gear types used. The frequency of captures in QLD (Figure 10) shows that nets catch both sharks and bycatch at a significantly higher frequency than drumlines. The frequency was also evident in a comparison of the percentage of catch (Figure 9) between all of QLD and SE QLD. The net to drumline ratio in SE QLD (1:7) compared to QLD (1:28) is consistent with the expectation that SE QLD should have a higher percentage of by-catch to target sharks compared to QLD. This was found to be the case with the percentage of target sharks to by-catch catch in SE QLD (51:49%) was significantly lower compared to QLD (75:25%). This trend was further evident in NSW (where only nets were used) with 73% of the catch consisting of by-catch and only 23% target sharks.

The frequency (Figure 10) also highlights the disproportionate numbers of target sharks to by-catch caught by nets compared to drumlines. Although nets clearly catch target sharks at approximately twice the frequency per net, nets also implicate by-catch at almost 10 times the frequency as drumlines. Considering the high numbers of threatened species implicated in the shark control programs (Figure 8) each year, this could have adverse effects on the conservation of these species. The disproportionate frequency does however highlight some potential options that would support conservation. Hypothetically if each net was replaced by 2 drumlines the frequency of target shark captures would be maintained. This would in effect match the rate that target sharks are presently removed from potential shark-human interaction. Furthermore, the replacement of each net by 2 drumlines would simultaneously reduce the frequency of by-catch nearly 5 times.

Other data suggests the removal of nets might also reduce mortality rates of by-catch caught under shark control programs. In the NSW SMP (2010-15) where only nets are used (Figure 13), statistics revealed more than half of by-catch was deceased (305) compared to released alive (269). Whereas in the QLD SCP (2015) the amount of by-catch by drumlines (28) released alive (Figure 14), far exceeded the by-catch found deceased (13). This is congruent with findings that the use of baited drumlines results in low by-catch and increased survival rates compared to nets (Shiffman, 2014). Studies in South Africa and Australia demonstrate that hook based fishing gear not only catches significantly more sharks but also less by-catch including cetaceans, chelonians and birds (Sumpton, Taylor , Gribble, McPherson, & Ham, 2011), (Gribble, McPherson, & Lane, 1999), (Cliff & Dudley, 2011).

Opposing these findings was a comparatively high survival rate of by-catch caught in the QLD SCP nets (Figure 14). By-catch caught in nets that was released alive (n = 33), exceeded (albeit only marginally), the by-catch found deceased (n = 25). These figures could indicate that there are other factors, aside from gear selectivity, influencing mortality. Some evidence suggests that frequent checking of nets reduces mortality of captured animals. Under the NSW SMP, an increase in the number of animals released alive was observed ever since more regular net checking times were introduced (DPI, 2015b). Liberation of fish from nets soon after capture reduces stress and leads to higher survival rates (Kojima, Ishii, Kobayashi, & Shimizu, 2004). Short soak times and frequent checking of the drumlines also increases the chance of survival (Hazin & Afonso, 2014).

Spatial and temporal responses

Shark species composition caught under the QLD SCP and NSW SMP revealed some trends in the distribution and abundance of shark species (Figure 12). Of particular relevance is the composition of target species captured in SE QLD. Due to the close proximity to SE QLD, a similar species composition could be expected in Northern NSW (Lucifora et al., 2012). The majority of shark species caught in SE QLD were bull sharks/whalers, followed by tiger sharks and hammerheads.

The spatial and temporal distribution of these species could be factored into gear location and fishing effort. For example, With the propensity of bull sharks to inhabit coastal and estuarine waters (Chapman & McPhee, 2016), drumlines could be set within these areas during the times that correlate with their life history requirements. In Northern NSW drumlines could be positioned at the mouth of the Richmond River where a number of incidences involving bull sharks have occurred (Shark Research Institute, 2016). During the warmer summer months when tiger sharks migrate south from the tropics, fishing effort could be adjusted accordingly on the north coast. Over the winter/spring time when white sharks migrate to the east coast of Australia fishing effort for this species could be increased. Upon capture, these species could be relocated offshore and released away from human-shark interaction as this approach has been shown to be effective elsewhere (Cliff & Dudley 2011).

Net implications

In NSW hammerhead sharks are not considered a target species (DPI, 2015a). Hammerheads have been shown to be highly susceptible to capture by nets as opposed to drumlines (Sumpton et al., 2011). With such a high portion of the annual catch consisting of hammerheads (17%) the use of nets in the north coast should be avoided if conservation of endangered species is sought. Grey nurse sharks also factor into the composition of catch in both states. This Critically Endangered by-catch species has been found to use areas on the north coast as aggregation sites (Lynch, Harcourt, Edgar, & Barrett, 2013). Further captures of this species by nets could have significant impact on the local population (Lynch et al., 2013). Whales are also on occasion implicated in shark nets (Table 4). Under the NSW SMP 2012-13, 2 humpback whales were caught up in nets. Both animals swam away entangled in the nets. The fate of both animals and one of the nets is unknown (DPI, 2013b). Due to bad weather and whale entanglements, 5 nets went missing under the NSW SMP (2010-15). Lost nets can cause substantial ecological problems by continuing to catch and kill organisms (ghost fishing) for years to come (Gilman, 2015).

Both SMART nets and SMART drumlines are currently under trail on the North Coast of NSW. Nets and drumlines are fitted with whale and dolphin deterrent devices and capture alert technology. An objective of the trial is to compare catch rates between the SMART nets and drumlines. The results are so far unknown. The statistical analysis in this paper demonstrates that nets have fundamentally indiscriminate selectivity of species compared to drumlines. The SMART technology is not designed to abate the incidence of the bulk species captured in nets. Stress such caused to high by-catch numbers would likely increase mortality rates even after release. The high capture rate intrinsic to the shark net will also demand a high attendance from contractors to release captured animals. Such frequency of net checking may equate to higher financial costs compared to drumlines.

Summary

In Northern NSW it is likely that an increase in the number of beach users has resulted an increase in the number of human-shark interactions. These incidences could also be influenced by a number of factors including; migration patterns of large sharks and anthropogenic influences such as overfishing. Shark control programs appear to alleviate some of the risk that beach users face by removing large sharks from popular beaches. If communities such as Northern NSW continue to vote in favour of shark control measures, gear selectivity appears to be a vital factor in the conservation of both target and by-catch species.

The implementation of SMART drumlines as opposed to SMART nets in Northern NSW would ensure by-catch numbers would be kept to a minimum. The use of circle hooks would reduce injury to captures. Regular checking of hooks would further reduce mortality by reducing undue stress on the animals. By-catch could be released appropriately and target sharks could be relocated offshore away from beach users. These measures would equate to a shark control program that maintains its public safety mandate whilst at the same time promotes conservation of marine life.

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7. Appendices

Appendix A. *All Recorded shark attacks in Australia from 1700 to June 2016*

State	Fatal attacks	Non-Fatal attacks	State Totals
NSW	98	369	467
QLD	77	221	298
Vic	14	67	81
Tas	9	31	40
SA	24	79	103
WA	28	141	169
NT	3	20	23
Total	**253**	**928**	**1181**

(Source: Shark Research Institute, 2016)

Appendix B. Captures in the QLD SCP 2010 - Sept 2016

All QLD	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Target sharks	493	602	653	591	516	590	402
By-catch	312	239	224	201	167	164	71
Threatened species	148	138	152	129	102	110	71
Bull sharks/whalers	308	361	406	335	256	270	194
Hammerheads	49	46	42	45	34	14	23
Grey Nurse	3	2	2	4	1	0	1
White sharks	6	6	12	6	7	11	6
Tiger sharks	178	231	229	248	253	287	167
Other sharks	45	43	59	39	35	45	31
Total	589	689	750	677	586	627	422

(Source: DAF 2016a, 2016b)

Appendix C. Captures in SE QLD under the QLD SCP 2010 - Sept 2016

SE QLD	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Target sharks	86	86	94	70	62	87
By-catch		95	75	84	71	60
Threatened species		54	46	43	45	41
Bull sharks/whalers				43	21	50
Hammerheads				14	20	15
Grey Nurse				3	1	3
White sharks				5	7	11
Tiger sharks				21	33	26
Other sharks				5	5	1
Total				91	87	106

(Source: DAF 2016a, 2016b)

Appendix D. Captures in the NSW SMP 2010 - 2015

NSW	2010/11	2011/12	2012/13	2013/14	2014/15
Target sharks	45	53	32	46	44
By-catch	112	105	76	145	145
Threatened species	38	60	36	50	73
Bull sharks/whalers			24	26	18
Hammerheads			23	22	43
Grey Nurse			9	4	4
White sharks			3	6	10
Tiger sharks			2	6	2
Other sharks			47	16	17
Total			108	80	94

(Source: DPI 2012, 2013a, 2013b, 2015a, 2015b)