Review of the outcomes from the drum line component of the Shark Mitigation Strategy for the trial period January - April 2014

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Contents

INTRODUCTION

In response to the increases in shark related fatalities that occurred in WA over the past decade, including an unprecedented number in recent years, starting in 2008 the WA Government funded a number of initiatives in order to mitigate the risks of further shark incidents including attacks and fatalities. These initially included a series of research programs to provide both a better understanding of white shark behaviour and population in WA waters and methods to mitigate risks (e.g. DoF, 2012). There were also significant enhancements to the level of tagged shark monitoring and aerial patrols.

In November 2013, a surfer in the south west of the State became the seventh fatality in just over three years, which prompted the Government to take a more proactive approach to mitigation of shark attacks. The Government therefore proposed, in combination with the extensive shark hazard mitigation strategies already in place, the use of an additional direct action strategy (Strategy) for public safety purposes.

This proposal involved the capture of large sharks within two Marine Monitored Areas (MMAs) located off the metropolitan and south west regions using large-hook drum lines (see Map Figure 1). After obtaining the necessary State and Commonwealth exemptions/approvals for deploying up to a maximum of 36 baited drum lines in each MMA, this trial program began in late January and operated until 30 April 2014.

One of the key risk mitigation strategies identified within the risk assessment was that a review would be undertaken at the completion of this trial (DoF, 2014). Furthermore, the granting of the Commonwealth exemption and the non-referral of this trial program by the EPA -WA required a review that would provide a detailed description of the catches taken during the program (CoA, 2014; EPA, 2014).

This report provides a technical assessment of the outcomes of the trial including the level and composition of the individuals captured by the drum lines. It also provides some recommendations for the operation of any future drum line programs, especially how the efficiency of data recording and handling could be improved. Finally, it discusses the key opportunities that may be available to collect a greater level of scientific information during the operation of any future programs. These scientific programs could include the collection of information that could contribute to general scientific knowledge on shark biology and populations. This information could also assist future risk assessments on the impacts of any program on these species and the broader environment. Importantly, this review does not assess the efficacy of drum lines on public safety risk mitigation.

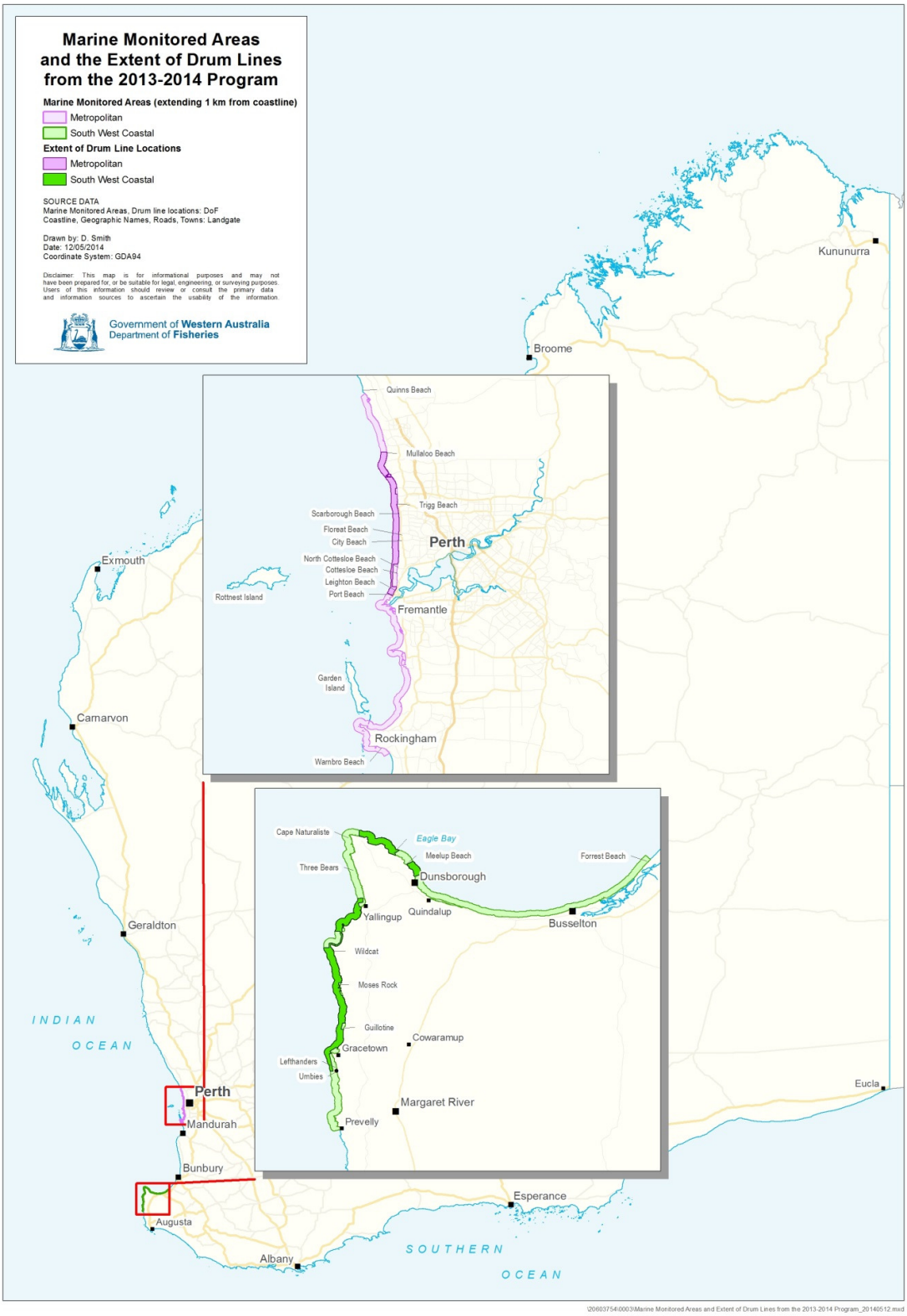

Figure 1. Map of Western Australia indicating the size and location of the two Marine Monitored Areas (Metropolitan and South West Coastal), along with the areas of drum line deployment for the January – April 2014 trial program.

MATERIALS AND METHODS

Drum line operations

Locations and Time Periods

Baited drum lines were routinely deployed within specific regions of the two MMAs (see Fig. 1) in coastal waters about one kilometre off the specified beaches. The lines were targeting the capture of, to the extent possible, large (≥300 cm Total Length) white sharks, tiger sharks and bull sharks. Contractors were required to bait, maintain and patrol the drum lines from 0600 hours to 1800 hours. In addition, vessels were able to rapidly respond by deploying some of the total available drum lines if large sharks were identified as a threat within these areas, which happened on two occasions in this period.

Drum lines were first deployed in the south west coastal MMA within the Geographe Bay region on 25 January 2014. They were deployed daily at specified beaches in this location until 10 February 2014. As planned, the operations of the contractor for this region were subsequently moved to the Capes region on 11 February 2014 and deployed at specified beaches in this region until 30 April 2014. In the Metro region, drum lines were deployed daily at specified beaches from 31 January 2014 until 30 April 2014.

During the initial stages of the trial (25 January – 6 March), the number of drum lines set in each MMA varied from 10 – 29 per day. From 6 March onwards, 30 drum lines were set daily at specified beaches in each MMA usually in groups of two to four depending on the number of specified locations within MMAs.

Daily Operations and Data Recording

Any white, tiger or bull sharks greater than or equal to 300 cm TL captured by the contractors were to be humanely destroyed using a firearm. Other captured animals that were either less than 300 cm TL or not one of the three target species and were considered to have some chance of survival were released as swiftly and carefully as possible. If the drum lines caught animals which were not in a condition considered likely to survive they were humanely destroyed.

In cases where it was not considered to unreasonably compromise their chances of survival, sharks to be released were first tagged with conventional fin tags (see image below showing a fin tag attached to a tiger shark). On three occasions, released sharks had internal acoustic tags inserted.

Daily records were kept of all drum line deployments, noting the species and lengths of all sharks captured. The vast majority of captured sharks were photographed for subsequent species validation. Deceased sharks (whether destroyed or killed by their capture) were fitted with uniquely-identified disposal tags and removed a distance offshore for disposal. Any protected species of mammals, birds or reptiles (i.e. non-fish wildlife) that were deceased were to be retained for the Department of Parks and Wildlife, but none were captured in the trial period.

There were some considerations during the trial period regarding what additional research data could be undertaken during the trial period. This included discussions about instigating a program to collect genetic samples from captured sharks. It was determined that detailed considerations of the potential impacts of conducting additional research activities on both the staff involved in completing these operations and the welfare of released sharks was required before suitable decisions could be made. Consequently, the potential to include additional research activities in future drum line programs is discussed later in this report.

Data analysis

All catch data from record sheets submitted by the contractor vessels were provided to the Department of Fisheries (Department) and species identifications were validated by cross-referencing against photographs. The catch data for each MMA were then tabulated and checked for completeness and errors (such as transcription mistakes) prior to undertaking analyses and reporting of all captures in each MMA. The level of analysis that could be undertaken for individual species was determined by the relative number caught. For those species that were caught rarely, only the number caught was assessed. Because tiger sharks (*Galeocerdo cuvier*) were caught on a more frequent basis, more detailed analyses such as examination of catch rates and size frequencies were completed.

Given the significant difference in the oceanographic and habitat characteristics of the northward-facing, relatively protected waters of waters of Geographe Bay (Forrest Beach to Cape Naturaliste) compared to those of the more exposed waters off the westward-facing Capes coast (Cape Naturaliste to Prevelly) these two sub-areas of the southern MMA (see Fig. 1) were assessed separately.

RESULTS

Catches (all species)

Catches by the WA drum lines during the period January 25 – 30 April 2014 mostly comprised tiger sharks (91% of the total numerical catch; Table 1). These captures are therefore considered in detail. The very small number of individuals for the other species caught by the drum lines (0–7 individuals per species) did not allow more detailed analyses to be completed.

Table 1. Numbers of animals caught on Western Australian drum lines. The "dead" category includes target species of sharks that were killed based on their size (≥300 cm TL) and all shark species that were dead upon retrieval or killed due to a very low likelihood of surviving.

	Total catch		Metro		Geographe Bay		Capes	
Common name	**Dead**	**Released alive**	**Dead**	**Released alive**	**Dead**	**Released alive**	**Dead**	**Released alive**
Tiger shark	64	99	34	75	15	5	15	19
Shortfin mako	4	1	0	0	2	0	2	1
Dusky shark	0	1	0	1	0	0	0	0
Spinner shark	0	1	0	0	0	1	0	0
Bull shark	0	1	0	1	0	0	0	0
Unidentified shark	0	1	0	0	0	0	0	1
Ray	0	7	0	7	0	0	0	0
North-west blowfish	0	1	0	1	0	0	0	0

Non-target species

Sharks

In total, 9 individuals of non-targeted sharks species were caught (Table 1). This included five shortfin mako sharks (*Isurus oxyrinchus*) which were caught in the south west (ranging from 170 – 264 cm TL), one of which was tagged and released, three of which were dead upon gear retrieval and one which was destroyed because it was unlikely to survive release. A single dusky shark (290 cm TL) and a single spinner shark (180 cm TL) were caught and each was tagged and released. One unidentified shark removed itself from the hook and swam off before it could be identified.

Non-shark

Seven rays (species unknown) were caught in the Metro region, all of which were released alive. Two of the rays were identified as sting rays (Family Dasyatidae). A single north-west blowfish (*Lagocephalus sceleratus*) was caught and released alive.

Target species

White Sharks

No white sharks were caught during the trial drum line program.

Bull Sharks

A single bull shark (197 cm TL) was caught in the Metro region. It was tagged and released alive.

Tiger sharks

In total, 163 tiger sharks were caught (67% in the Metro; 12% in Geographe Bay and 21% in the Capes). Ninety-nine (61%) were released alive with a greater proportion of these in the Metro region (Table 1; Figure 2).

A total of 17 (10%) were dead upon gear retrieval. These were distributed across all regions and occurred throughout the duration of the trial. The remainder (29%) of the captured tiger sharks were destroyed either because they were 300 cm or greater in total length (TL) or in three instances because the individual shark was considered unable to survive.

The tiger sharks captured in this trial period ranged in size from 153 – 450 cm TL (mean size = 270 cm TL, SD = 63 cm, n = 155; Figure 3) with a larger range of sizes captured in the Metro region (Figure 4). The overall sex ratio significantly differed from parity ($\chi^2 = 34.1$, $p < 0.0001$) with more females being caught at all three locations (Figure 4). Released sharks ranged in size from 153 – 299 cm TL while those that died (either because they were dead upon gear retrieval or due to their size) were from 182 – 450 cm TL (Figure 5).

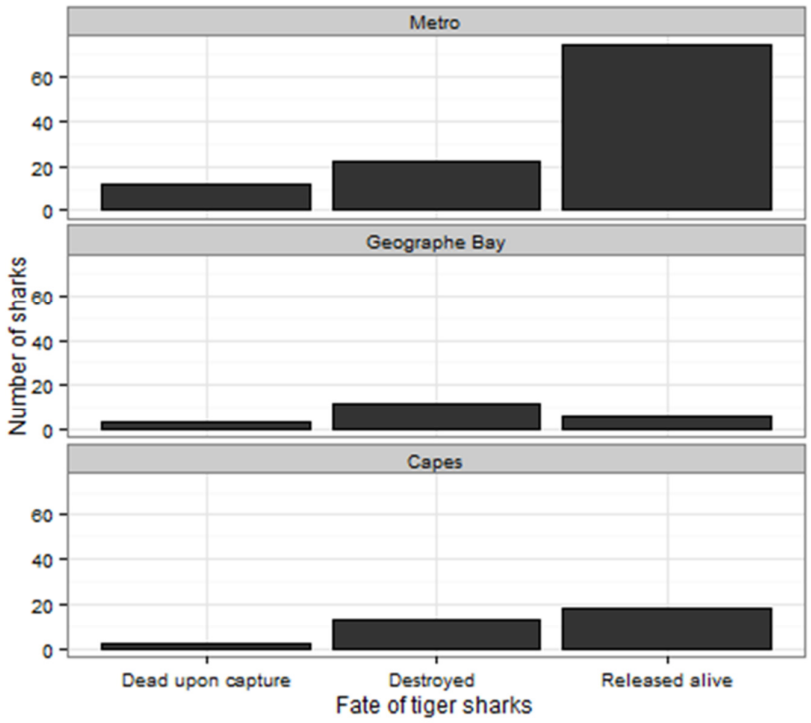

Figure 2. Fate of tiger sharks caught on Western Australian drum lines by region. Destroyed sharks were generally those 300 cm TL or greater.

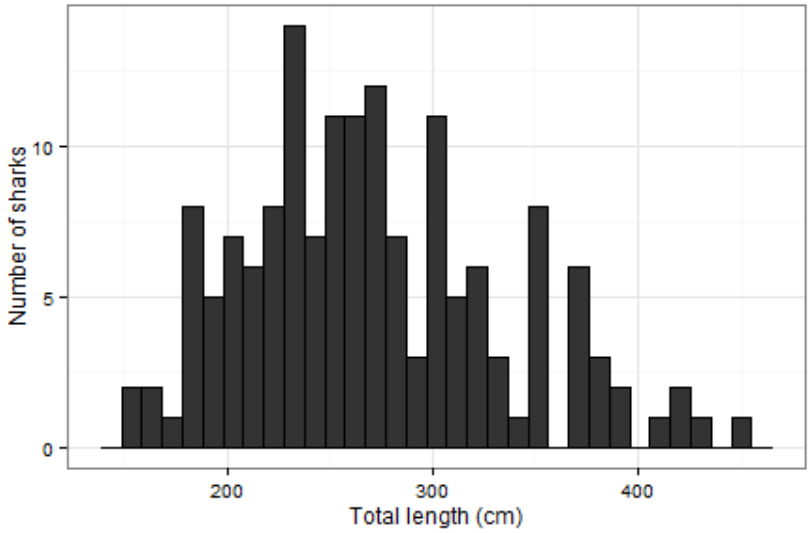

Figure 3. Size frequency of tiger sharks caught in all regions.

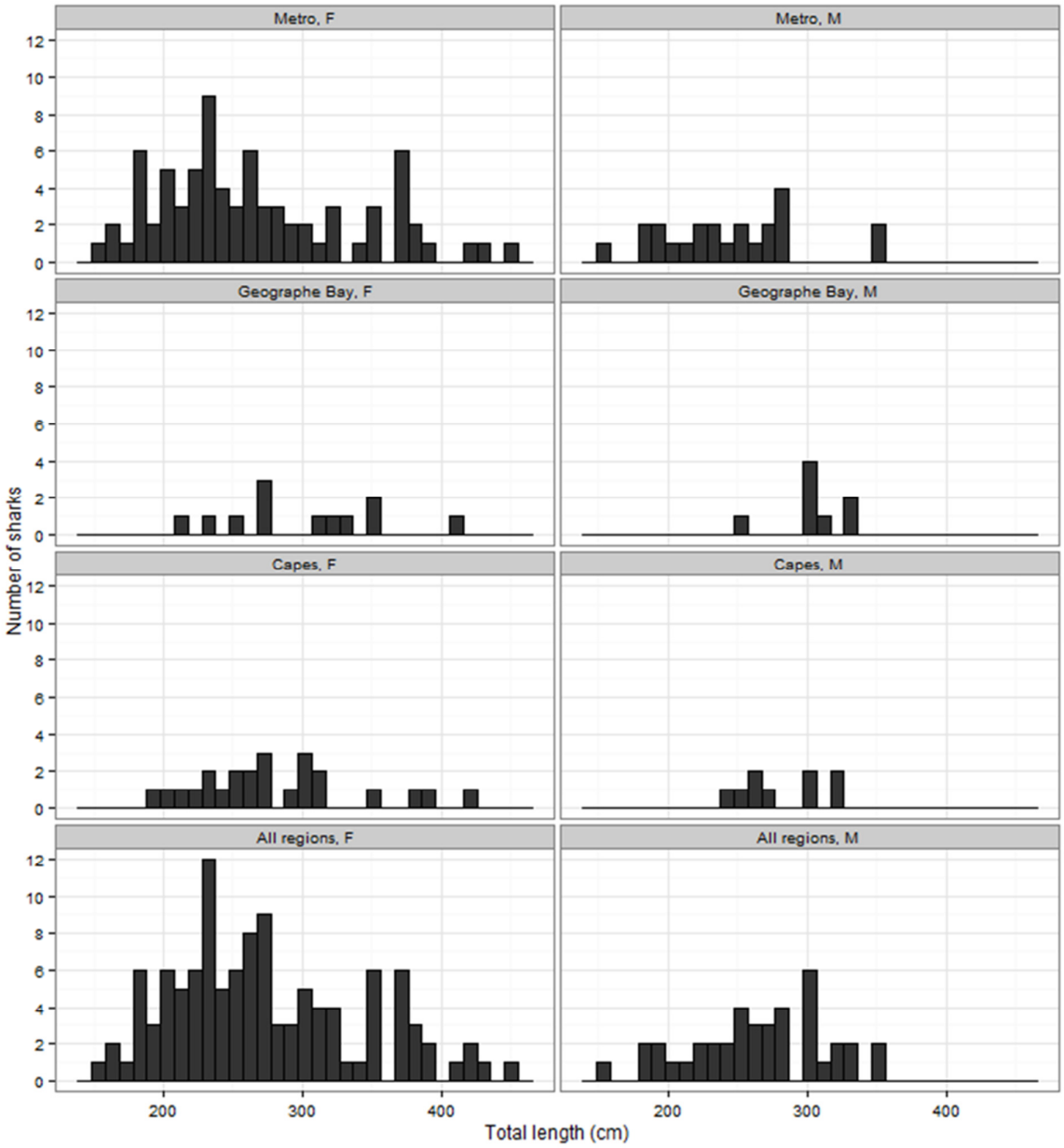

Figure 4. Size frequency and sex (F = females, M = males) of tiger sharks caught by region.

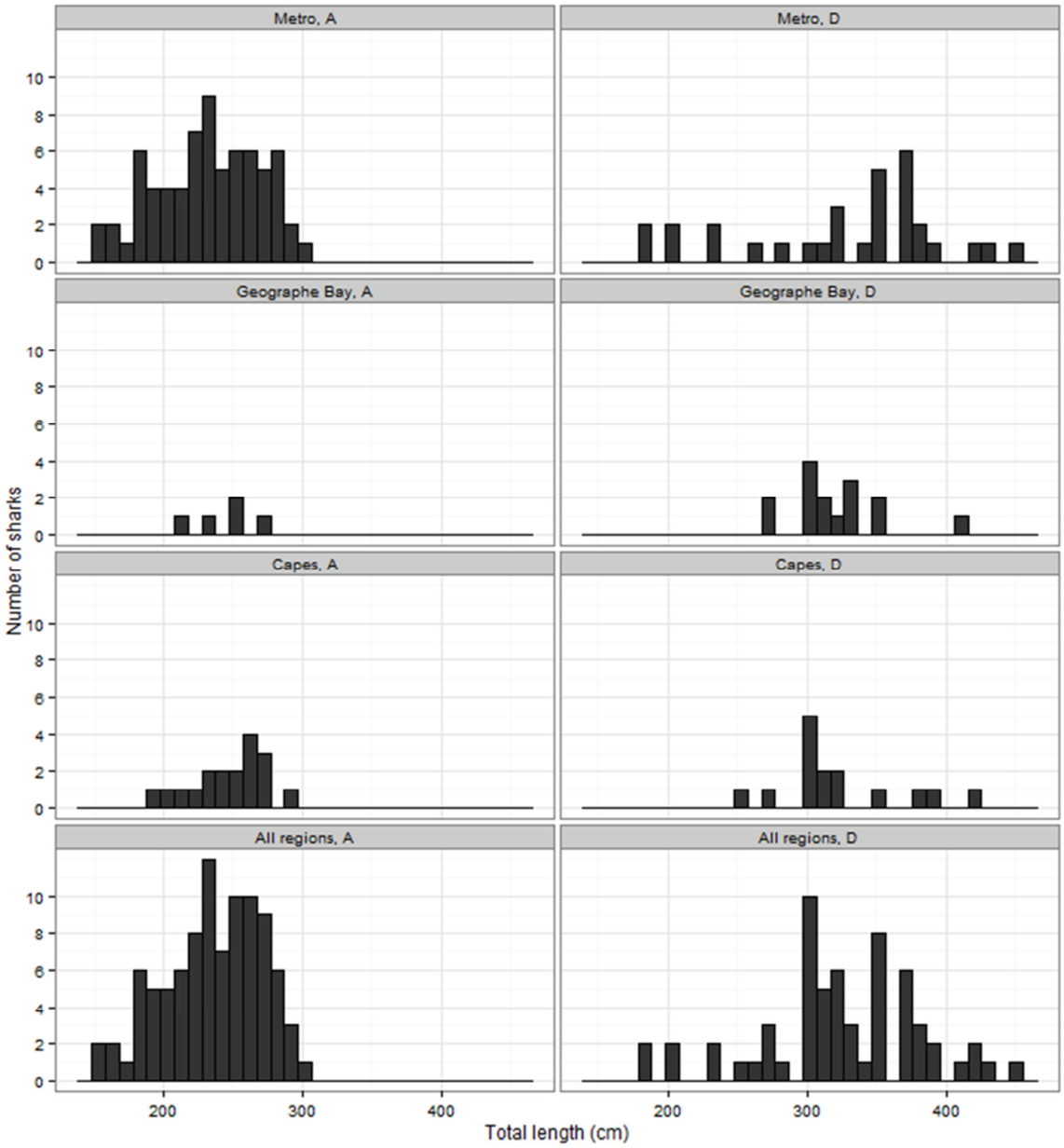

Figure 5. Size frequency and fate (A = alive/released, D = dead) of tiger sharks caught by region. The dead category includes sharks that were dead upon gear retrieval and those killed due to their size.

Of the 99 tiger sharks that were released, 90% were tagged with a dorsal fin tag. To date, none of these tagged sharks has been recaptured. Of the three tiger sharks that were fitted with internal acoustic tags, one (230 cm TL female) is confirmed to have died immediately after release; one (251 cm TL female) was detected by a VR4G receiver approximately 2 km from its release site 30 minutes after release and the third (173 cm TL female) has not been detected following her release (noting no data from the more widely spread VR2 receivers are available for this time period).

Based on length-weight conversions from northern Australia (Stevens and McLoughlin, 1991), the estimated weight of tiger sharks killed during this program (assuming 100% survival of released sharks) is approximately 17 tonnes. More than half of this was taken in the Metro region (Table 2).

Given the potential for at least some released sharks to have died post-release, total mortality is likely to be higher than this estimate. The maximum amount, assuming no survival of released sharks, is approximately 25 tonnes (Table 2).

Table 2. Estimated total weight of tiger sharks killed by Western Australian drum lines. The lower limit and upper limit assume 100% and 0% survival of released sharks, respectively. Length-weight conversions are based on tiger shark data from northern Australia (Stevens and McLoughlin, 1991).

Region	Lower limit (tonnes)	Upper limit (tonnes)
Metro	9.5	15.3
Geographe Bay	3.5	4.0
Capes	3.9	5.5
Total	16.9	24.8

Catch rates (tiger sharks only)

The catch per day at each of the three sites was variable with many of the days having no captures, particularly in the Capes region (Figure 6). The overall rate of capture (sharks captured per day) in the Metro region was very similar to that in Geographe Bay (1.2 tiger sharks per day) with catch rates for both of these areas being higher than for the Capes region (0.4 tiger sharks per day). The lower average catch rates in the Capes region may reflect either distributional differences (lower abundance in the southern region) and or differences in susceptibly in this region. Furthermore the different geography of each of these two south west sub-regions (e.g. sheltered waters at Geographe Bay vs. more exposed waters off the Capes) may also have influenced the relative catch rates of this species.

In the Metro Region, the daily catch rates for all captured tiger sharks were highest in early-mid February (e.g. 9 captured on 14 February; Figure 6a) which was followed by lower, more stable daily catches of tiger sharks for the remainder of the trial program. The daily catch data for both locations in the south west showed no trends across time (Figure 6b,c).

The decline in catch levels observed in the Metro after February may reflect some level of depletion of tiger sharks in this region but their continued capture up to the last day of the program indicated tiger sharks were still present within the region. There was no evidence of any depletion within the two south west areas with the catch level remaining at consistent levels for the duration of drum line deployment at both Geographe Bay and the Capes (Figure 6).

The catch rate of tiger sharks 300 cm TL or greater (all of which were destroyed) however showed no pattern at any of the sites (Figure 7). This may be an indication of different distribution and residency patterns for small compared to larger tiger sharks but the data are too few to be conclusive.

More detailed analyses may subsequently be able to explore the extent to which the observed spatial and daily differences in catches may have been influenced by differences in local oceanographic and benthic conditions and hook density (i.e. Gear competition/saturation effects) or bait type.

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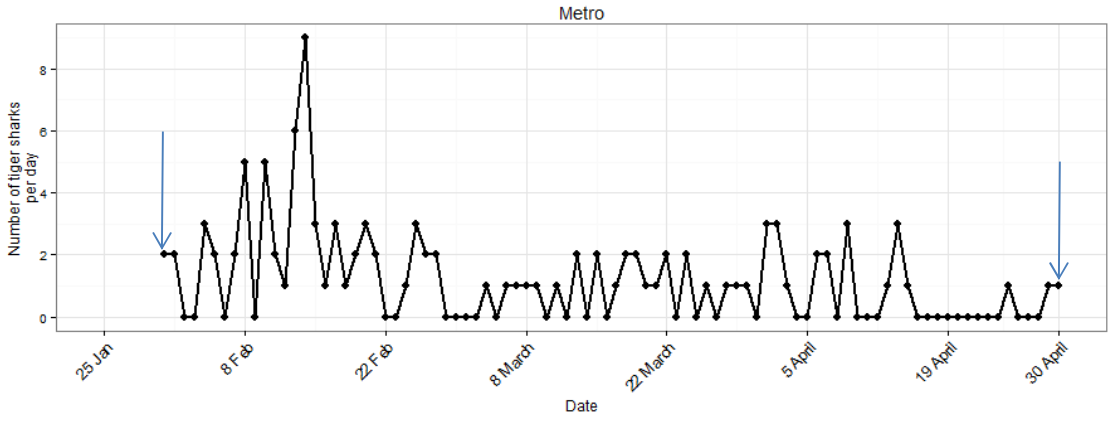

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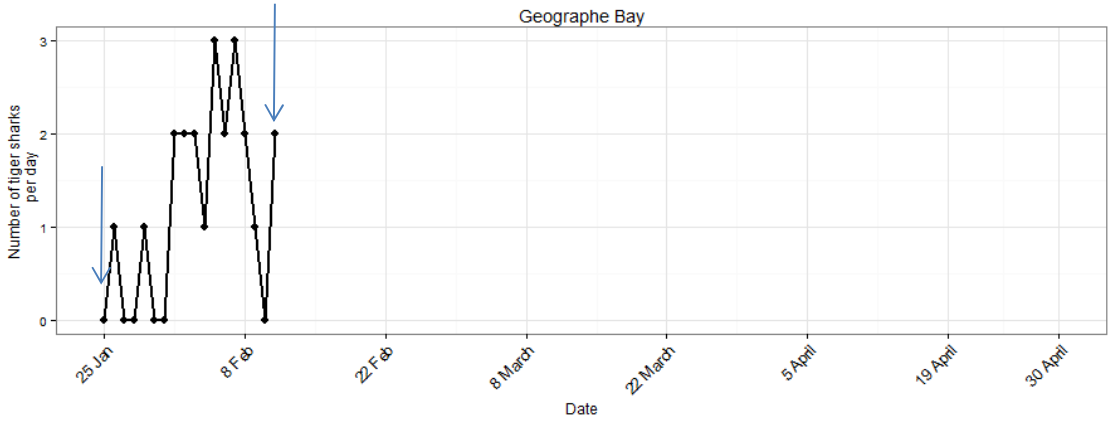


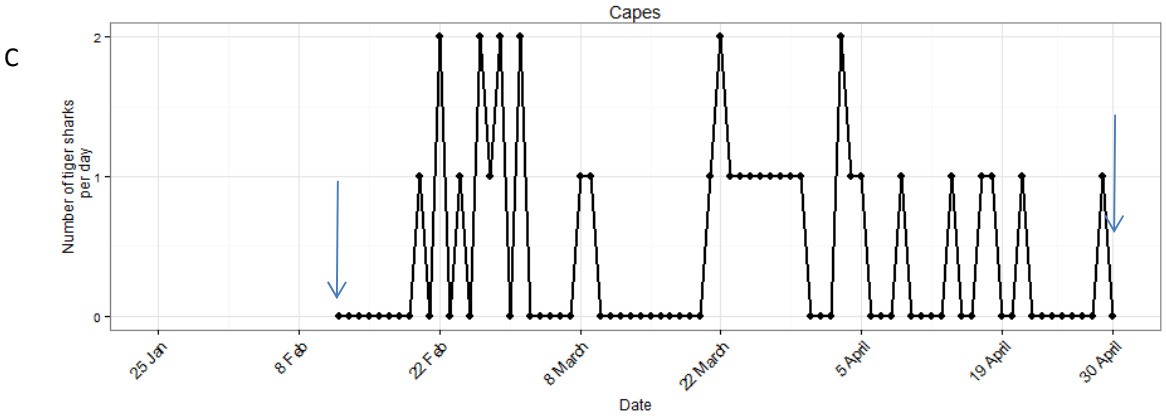
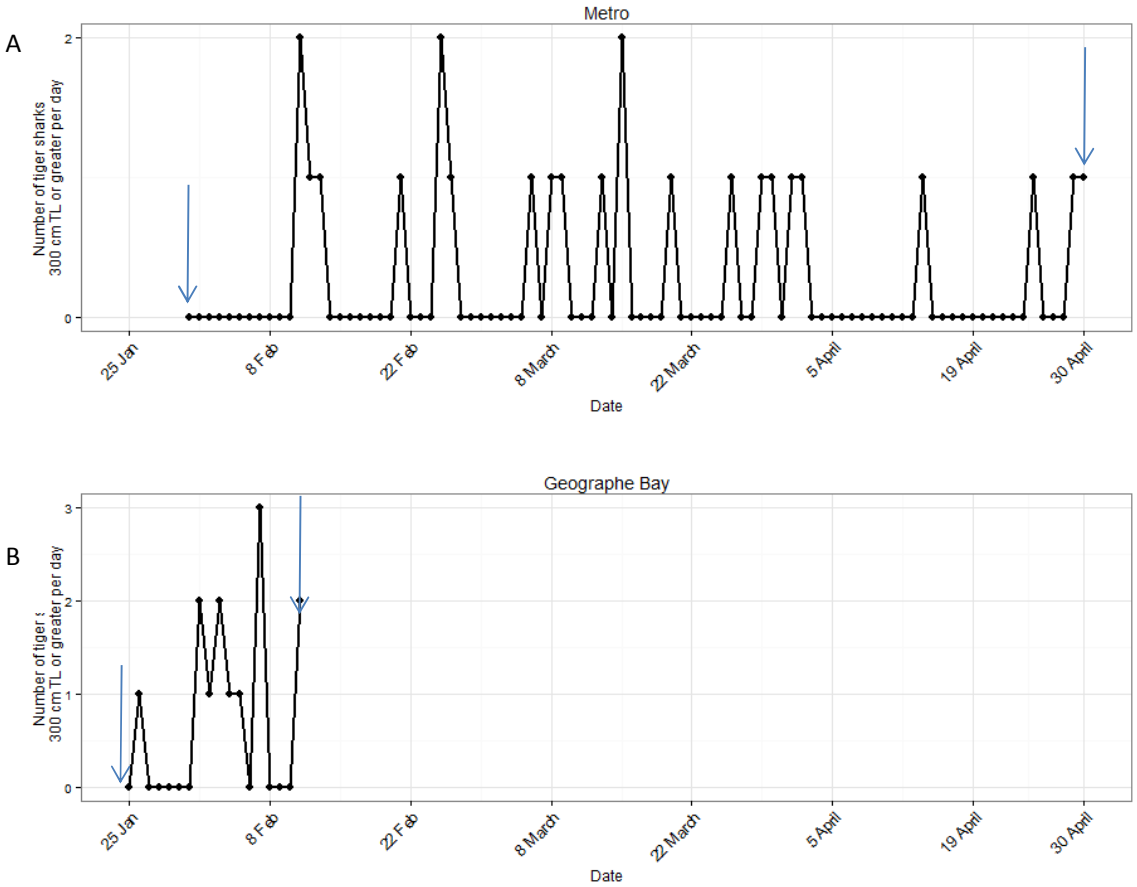


Figure 6. Daily catch of all tiger sharks captured in the (A) Metro, (B) Geographe Bay and (c) Capes regions. Blue arrows represent the start and finish of fishing within each region. Note the different scales of the y-axis for each region.



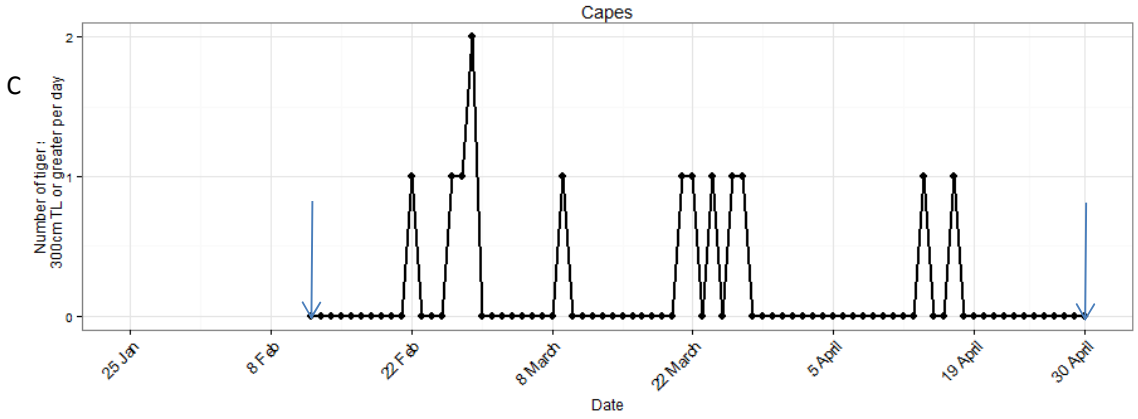


Figure 7. Daily catch of tiger sharks ≥ 300 cm TL in the (A) Metro, (B) Geographe Bay and (c) Capes regions. Blue arrows represent the start and finish of fishing within each region. Note the different scales of the y-axis for each region.

Acoustic detections

The Shark Monitoring Network (SMN) was established to collect data on acoustically tagged sharks using arrays of acoustic receivers which can provide data on the presence of acoustically-tagged sharks detected within the MMAs. These data were examined for the period of drum line deployment in 2014 compared with the same period in 2013 to assess the hypotheses that (i) drum lines capture all sharks in their vicinity and/or (ii) attract more sharks to the area than would otherwise have been the case. To reduce confounding by recent captures, this analysis did not include the sharks that had acoustic tags inserted during the drum line operations.

At the time of generating this report, a full set of validated acoustic data was only available from the remotely-accessible satellite-linked VR4G receiver data (Table 3). The data from sub-surface (VR2W) receivers will also be examined in the latter half of 2014 after these units are retrieved for data-download and servicing.

Table 3. Shark detection data for satellite-linked (VR4G) receivers within MMAs.

Species/name	Tag release date	Size (cm FL)	Number of detection days (Jan-Apr 2013)*	Number of detection days (Jan-Apr 2014)
Tiger shark (*G. cuvier*)	13/11/2012	211	4	1 (Metro)
Bronze whaler (*Carcharhinus brachyurus*)	5/10/2013	226	-	4 (Metro)
Bronze whaler (*C. brachyurus*)	4/11/2013	242	-	1 (Geographe Bay)

*These detections are restricted to receivers deployed within MMAs.

Three sharks (acoustically tagged prior to the drum line program) were detected during the trial program in 2014 at receivers in close proximity to baits. Despite their proximity to baited drum lines, none of these were caught. This demonstrates that drum lines do not catch all sharks that come into the vicinity of the drum lines.

Given the small number of observations in each year, the data are not sufficient to address the hypothesis concerning the level of attraction of sharks to these areas through the deployment of drum lines.

DISCUSSION

Ecological impacts and observed versus expected catches

For most species or species groups, the observed levels of catch by the drum line program were consistent with the predictions (low for most species) that were presented in the initial risk assessment (DoF, 2014, Table 4). For one species the actual level of capture was lower than predicted (dusky sharks), only the actual catch of tiger sharks was higher than expected. The comparison of the actual versus predicted capture levels of each of the main species or groups are considered below.

Table 4. Summary comparison of actual catch levels versus predictions presented in the risk assessment (DoF, 2014).

Species/Group	Level of capture consistent with predictions?	Comments
White Sharks	Yes	-
Bull Sharks	Yes	-
Tiger Sharks	No - Higher	Possible effect of increased water temperatures in recent years.
Dusky Sharks	No - Lower	Drum lines inshore of migration route
Grey Nurse	Yes	-
Demersal Scalefish	Yes	-
Dolphins	Yes	-
Seals/Sea Lions	Yes	-
Whales	Yes	-
Turtles	Yes	-

Targeted species

Tiger sharks

Tiger sharks are a relatively abundant, tropical and subtropical shark species with a geographic distribution that extends from the west coast of WA over the northern half of Australia to southern NSW. The drum lines deployed for the trial were only located in small areas at the southern end of the tiger shark range on the west coast of Australia (compare Figure 8 with Figure 1). This species is currently subjected to only minor levels of exploitation elsewhere along the WA coast.

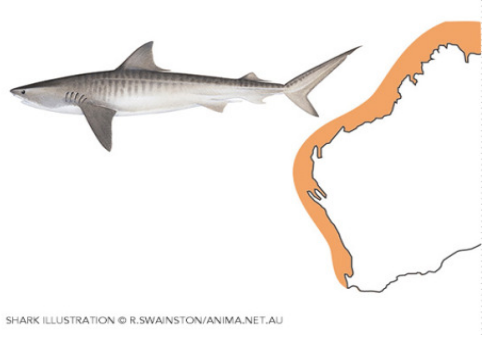


Figure 8. Distribution of the tiger shark in WA.

The predictions were that most of the captures of this species were expected to be released, with the number expected to be killed in the order of 10-20 individuals. The level of catch of tiger sharks in the drum line trial program was higher than expected. Thus, while the proportion that was released alive was consistent with predictions (being over 60%), the actual number killed was 64.

Having a higher than expected number of tiger sharks off the west coast of WA is, however, consistent with the observed trend in warming water temperatures occurring off this part of the coast and, moreover, in the past 4-5 years this region has experienced marine heat wave events (Pearce et al., 2011). These have been associated with major effects on a number of species including affecting their distributions (Caputi et al., 2014), which could have also led to increased numbers of this mainly tropical species being located towards the southern extent of their distribution off WA. Additional monitoring of this species would be required to determine whether the catch rates experienced in 2014 are now typical or not.

Despite higher numbers encountered in the trial program than was anticipated, the initial risk assessment indicated that the number of tiger sharks that would need to be killed before even a measurable change in their total population would occur was likely to be in the order of 100s. The number known to have died during the trial (see Table 1), while higher than expected, was still less than the levels considered necessary to potentially make a material effect on total stock size.

The levels of mortality generated from the trial period are not considered to have exceeded those outlined within the risk assessment which would generate more than a negligible risk. However, the higher than expected level of captures obtained in the trial period and the possibility of high-levels of post-release mortality has prompted a more detailed examination of the risks associated with this level of capture should this same level be maintained for a number of years.

Bull sharks

All available information that has been obtained by the Department's shark research program over the past two decades suggested that within the MMAs this species' distribution is largely confined to the Swan/Canning system. Consequently, given their apparent scarcity in near-shore marine waters off south-western WA, the expected number of bull sharks caught in this program was considered to be negligible. Consistent with this prediction, only bull shark was caught in the trial period.

White sharks

Based on the low rates of capture of white sharks during the targeted fishing operations (which have been designed to enable tagging of these sharks) completed off WA in the past few years, especially during this time of the year, it was expected that the capture of white sharks would be small (< 10). The lack of any white shark captures in the trial period within the MMA locations is consistent with this prediction and that white sharks are more common in winter and spring when water temperatures are lower (DoF, 2012).

Non-targeted Species

Dusky shark

One of the most important and economically valuable species that was considered to be a potential bycatch of this drum line program was the dusky shark (*Carcharhinus obscurus*). There were initial concerns that the level of captures of this species may be relatively high and if it were to exceed 30 this would represent a moderate risk to the stock. Only one was caught in the trial period, which was much less than predicted.

It is likely this lower than predicted catch is due to the drum line gear being set well inshore of what emerging data suggests is this species' offshore migratory pathway.

Shortfin mako

Due to concerns for populations of shortfin mako (*Isurus oxyrinchus*) elsewhere in the world this species was included in Appendix II of the *Convention on Migratory Species* and therefore must be listed as a migratory species under the EPBC Act. Accordingly, it has been considered separately in this report.

There are no particular concerns about anthropogenic impacts on shortfin mako in Australian waters with continued recreational and commercial catches still allowed after listing. Moreover the very small number caught in the trial program (5) would have negligible impacts on this species' Australian population.

Grey Nurse

The number of captures of this species was expected to be very low and their survival prior to release should be high given their ability to buccally ventilate and maintain neutral buoyancy.

Consistent with the predictions, no individual of this species of shark was caught in the trial program, supporting the initial assessment that the risk to this population is negligible.

Demersal scalefish

The design of the gear (e.g. size and design of hooks) made it highly unlikely that any demersal scalefish species would be caught in the drum line program. As no demersal scalefish were caught on drum lines in the trial program this is consistent with the prediction.

Seals and Sea lions

The size and design of the hooks made it a remote likelihood that any individual pinniped would be captured in the program.

Consistent with the predictions, none of these species were caught during the program.

Turtles

Turtles are not common in the more temperate regions where the MMAs are located. Individuals of most turtle species are therefore highly unlikely to be in the vicinity of the MMAs and therefore even interact with the drum lines. The size and design of the hooks make it a remote likelihood that any turtle would be captured on the drum lines.

Consistent with the predictions, none were captured in the trial period.

Whales

The trial period (January–April) occurred outside the typical migration seasons for the whale species that migrate along the WA coast, reducing the likelihood of encountering drum line ropes. In addition, the positioning of the lines well inshore of where the majority of whale movements occur also reduced the likelihood of entanglements if they are encountered.

Consistent with the predictions, no interactions with whales occurred during the trial period.

Dolphins

Given the size and design of the hooks used, it was highly unlikely that dolphins would be captured by the drum line gear.

Consistent with the predictions, no dolphins were captured during the trial period.

Broader ecosystem effects

The footprint of the operation is extremely small compared to the distribution of the species most likely to be directly affected, with only very small numbers of species other than tiger sharks captured and/or killed. As outlined above, the program has therefore generated only negligible impacts on each of the affected species.

There was nothing captured in the trial drum line program that would significantly affect the original assessment that this program would have negligible impacts on the ecosystem. Consistent with this prediction, no effects to other species have been identified.

The removal of up to 25 tonnes of a common species of shark (i.e. tiger shark) in one year distributed across effectively three small areas of the west coast bioregion by this trial program is still unlikely to have had any measurable effect on the functioning of the broader mesoscale, Leeuwin-Naturaliste ecosystem (which extends across this part of the West Coast

bioregion). Nonetheless the potential effects of this level of capture extending over a number of years will be assessed in more detail in the revised risk assessment.

Comparison with shark control measures used elsewhere

Drum lines, long lines and gillnets have been used to target potentially dangerous sharks in other locations including Queensland, New South Wales, South Africa, Brazil and Hawaii (McPhee, 2012; Table 1). Direct comparisons between the operations of different shark control measures are complicated by a number of factors. These include differences in oceanographic conditions and therefore regional species composition, background abundance levels and movements of different shark species, histories of commercial fishing effort, fishery management and marine conservation measures plus differences in available data series and how long after initiation of the programs that the data were started to be collected. In addition, gear types, hooks sizes and bait types also vary among these programs.

In terms of the number of hooks used, the trial WA program was similar in scope to the drum line program coordinated by the Natal Sharks Board in KwaZulu-Natal, South Africa but much smaller than the number used in the Queensland drum line program. The hook size used in WA was much larger than used elsewhere. Importantly, the customized hook-design featured a point that was strongly recurved back towards the shank, analogous to the design found on circle hooks. This design closes the gape of the hook compared to the standard J hooks. As was predicted in the initial risk assessment (DOF, 2014), the combination of a larger hook size and closed-gape used in WA appears likely to have contributed to the very low numbers of non-shark bycatch species captured compared to other locations. Essentially the catch was dominated by tiger sharks, which was a target species, with minimal other species captured and effectively no non shark bycatch.

Similar to WA, tiger sharks form a major component of the Queensland drum line catch, and to a lesser extent the long line catch in Brazil and to an even lesser extent South Africa (Table 5). This pattern probably reflects the susceptibility of tiger sharks to static baits (i.e. they are recognized as scavengers, as well as being active predators) along with differences in average water temperatures and the tropical/subtropical distribution of this species. Most of the other programs capture a wider range of species including non-shark bycatch.

Table 5. Examples of shark control measures using drum lines, long lines or gillnets

Location	Time scale	Gear used	Fishing duration	Target species	Main shark species	Non-shark bycatch
Western Australia	January to April 2014	Drum lines - 72 hooks (25/0 Customised – Closed Gape – circle like). initially baited with Bonito, Mackerel and since with miscellaneous fish heads and frames. Set approx. 1 km offshore.	24 hours a day. Hooks are baited or checked at least once a day.	White shark, tiger shark, bull shark. Those < 3m are released	Tiger shark (>90%)	1 north-west blowfish (silver toadfish, *Lagocephalus sceleratus*). 7 rays
Queensland[1]	Ongoing from 1962	Drum lines - 352 hooks (14/0 Mustad J design) baited with sea mullet and set in water 8 – 10 m depth. 35 hooks set off south east Queensland beaches. Hooks are checked 20 days a month. Gillnets – Approx. 35 surface large-mesh nets (186 m TL, 6 m drop, stretched mesh size of 50 cm) set in water 8 – 10 m depth.	24 hours a day. Hooks are baited and checked 20 days a month. 24 hours a day. Nets are checked 20 days a month.	Bull shark, tiger shark, white shark Most killed	Tiger shark, bull shark	Drum lines and Gillnets- Mostly loggerhead turtle (approx.10 per year at Gold Coast, Sunshine Coast and Rainbow Beach). Also small number of green turtle, leatherback turtle, common dolphin, bottlenose dolphin, white-spot eagle ray, *Manta* spp . and other rays.
New South Wales[2]	Ongoing from 1937	Gillnets – Bottom-set large-mesh nets used at 51 beaches (150 m TL, 6 m drop, stretched mesh size of 50 – 60 cm) set in water 10 – 12 m depth.	Soak time varies from 12 – 96 hours. Nets are set every weekend day and nine week days per month from September to April.	White shark, bull shark Most are found dead	Hammerhead shark, whaler shark (*Carcharhinus*. Spp), angel shark	Currently around 5 bottlenose dolphins a year.
South Africa[3]	Ongoing from 2005	Drum lines – 79 hooks (14/0 Mustad J design) baited with Southern Rover or Jacobever species. Gillnets – 23.4 km of netting used along a 320 km stretch of coast (most nets are 214 m long, 6.3 m deep and 300 – 500 m offshore).	24 hours a day (although hooks and nets are sometimes removed in winter during the 'sardine run'). Hooks and nets are checked daily from Monday – Friday.	Bull Shark, white Shark Alive sharks are towed as far offshore as possible, tagged and released.	Dusky Shark, scalloped hammerhead	Drum lines - Less than 10 animals a year consisting of *Manta* spp., loggerhead turtles, leatherback turtle, other turtles, long-beaked and common dolphins.
Brazil[4]	2004 to 2011	Drum lines – 23 lines with two different hook types and sizes (9/0 J-style and 17/0 circle) baited with Moray Eels or Oilfish. Long lines – Two lines (100 hooks per line, same hooks size and bait as drum lines).	Drum lines fished 24 hours a day and hooks baited and checked daily at dawn. Long line hooks had an average soak time of 15 hours.	Tiger Shark, bull shark Live animals were relocated, tagged and released.	Nurse Shark, Tiger Shark	Less than 100 teleosts a year (mostly Ariidae). Eight turtles Cheloniidae) in total.
Hawaii[5]	1959 to 1976	Long lines – various configurations with up to 100 hooks at any one time. Skipjack tuna was the main bait. Light long lines and hand lines were also fished sporadically between 18 – 118 m depth).	Not reported for each gear type.	Tiger Shark, Most were killed.	Sandbar Shark, Tiger Shark	None reported in the Wetherbee et al. 1994 publication.

1 = Sumpton et al. (2011); 2 = Reid et al. (2011); 3 = Cliff and Dudley (2011); 4 = Hazin and Afonso (2013); 5 = Wetherbee et al. (1994). Other drum line shark mitigation measures may have been deployed elsewhere. Note that the shank length and gape diameter of hooks varies among models making direct comparisons of hook size difficult.

Program improvements

The activities associated with the deployment and monitoring of the drum lines generally worked well. There were, however, a number of improvements that could be made.

- There appeared to be clear advantages in the handling of the captured individuals for the vessel that had access to a deck ramp. This made the removal of hooks and undertaking other activities on the captured animals much safer for the crew and more likely to be less injurious to the captured animal.
- The methods used to capture and transmit the data could be made more efficient. Like all new programs, the logistics involved and especially determining what information is most important to collect are frequently not clear until a program is underway. Modifications could therefore be made to the drum line program to improve the efficiency/consistency of operations and streamline data delivery and validation.
- The collection of environmental data such as water temperature and habitat type and the routine recording of damage to gear and bait usage could help in the interpretation of catch rate information.
- A program of training of field staff in shark identification, data collection and data recording will continue.
- It would also be appropriate to consider the feasibility of trialling alternative gear set ups for the drum lines that could potentially reduce the catch of sharks less than 300 cm TL.

Future research opportunities

Due to the start-up nature of this trial program, there were a number of logistical challenges during this period which meant it was not possible to develop and implement a full program of research to utilise the drum line activities. Thus, while tags were fitted to most released sharks, there was no opportunity to systematically collect data other than the core information on the lengths and sex of captured sharks.

Future options would still require careful consideration of how collecting other biological data (including genetic samples, tags, reproductive, dietary, age and growth, etc.) could be built into the daily drum line routine to help assess potential impacts on effected shark populations. The collection of additional biological samples and data will therefore depend on dealing with the logistical constraints such as drum line vessels' type, size, capabilities and storage facilities; distance from and type of port facilities; operator training requirements; protocols and appropriate exemptions for scientific research of protected species, etc..

Experiences from the shark control programs undertaken in Queensland, New South Wales and South Africa, suggest that providing opportunities for the collection of biological data could lead to useful collaborations with Universities and other research institutes. This would

lead to improved ecological and biological knowledge on the large sharks located in these regions of the WA coast.

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