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Western Australian Shark Hazard Mitigation Drum Line Program 2014 – 2017

Peer review report

July 2014

Client: Government of Western Australia - Environmental Protection Authority

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Contents

Scope of the review

This document provides a peer review of the Western Australian Shark Hazard Mitigation Drum Line Program 2014–17 (the drum line program) as commissioned by the Western Australian Environmental Protection Authority (EPA). The review specifically considers the information provided by the Department of Premier and Cabinet (DPC), identified herein as 'the proponent', within the Western Australian Shark Hazard Mitigation Drum Line Program 2014–17: Public Environmental Review document, identified herein as the 'PER'.

The three year program was referred to the EPA for assessment under section 38(1) of the *Environment Protection Act 1986* (EP Act) and to the Commonwealth Department of the Environment (DotE) for assessment under Part 3 of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Under the Terms of Reference, this review provides advice to the EPA on the findings, conclusions and proposed management for the implementation of the Western Australian Shark Hazard Mitigation Drum Line Program 2014–2017, specifically with respect to points 1 and 2 as identified in the Work and Output required as stated in Table 1 of the Environmental Scoping Document (ESD).

Specific review points:

The following provides specific comments based on the review of the proponent's information as provided in the Public Environmental Review (PER), against the Environmental Scoping Document (ESD). The comments are identified against specific points of reference listed in Table 1 of the ESD where appropriate.

Establish clear measurable objectives and performance measures, including trigger points and corresponding management actions

This is a requirement under the Environmental Scoping Document (ESD 2a + b[1]) and is poorly addressed by the proponent. The drum line program has the potential to be a long-term program, continuing for an unspecified timeframe (after the initial three-year period) if it is approved. It is very important that the management plan has clear and measurable objectives to identify what constitutes success along with a well-specified monitoring program that includes performance indicators and reference points (preferably target and limit) to determine when or whether success is achieved. These reference points should also be designed to determine if the program is not achieving its objectives and thus requires adjustment or cancellation.

There remains a need to establish clear maximum levels of catch (trigger-points) for each species (these are not set out in the management plan) and to identify actions that will be taken if these maximum levels are reached or exceeded. Such actions might include a reduction in effort (reducing the number of drum lines in operation) or an increase in offsets. A 'review' of catches at the end of the program or at the end of each year, while an important part of monitoring may be too late for any effective management response.

An agreed process to develop maximum catch levels for each species is required. These maximum levels should be linked to the overall objectives and subject to revision as additional information becomes available.

The management of the program would be greatly improved by establishing a management advisory committee similar to those operating under fisheries management. Such a committee would be responsible for overseeing the management and reporting of the program including the establishment of objectives, reference points and corresponding management actions. Such committees usually have an independent chairperson, an expert with the specific scientific expertise required to support the committee, and stakeholder representatives as appropriate. In this case a DPC representative, a Department of Fisheries – Western Australia (DoF) research member, an independent research member, an environment/conservation member and other relevant stakeholders would be appropriate.

Operational data

Summary data provided in the PER document from the trial program are not sufficient to adequately monitor and assess the program. A lack of suitable data collection would limit the ability of the proponent to undertake robust assessments of population-level impacts on all species captured and would prevent an overall population assessment of white sharks in particular – (ESD 2c).

[1]Refers to identified points in the 'Work and Output Required' section of Table 1 in the Environmental Scoping Document

The type of information required to improve monitoring and guide management in both the static and rapid response components of the program, should include but not be restricted to:

- number of drumlines active each day (time of deploy/retrieval for each)
- location of each drumline (latitude/longitude) and catch recorded (including zero catch)
- frequency + time of checking + time of baiting/rebaiting
- type of bait used on each drumline
- catch depredation rates
- bait loss or indication of shark interaction with baits noted for each
- species caught (including photo validation of all sharks taken)
- length, sex of all species taken
- activity/viability status of captured sharks
- reporting the capture of tagged sharks

Biological sampling of captured sharks

Any future assessment of the program, if it proceeds, would be compromised if sufficient data were not collected from the start. Failure to do so is one of the significant issues limiting an overall understanding of the initial impact of the NSW shark program, as data collected in the early part of the program were incomplete (Reid and Krogh 1992). The capture of sharks targeted by the WA program represents an opportunity for those animals to contribute to an assessment of population size and trends as well as provide information that will reduce uncertainty in demographic parameters used in population modelling. This would in turn inform future management decisions. Sampling of white sharks in particular would be vital. It is important to recognize that contributing samples to research should not be seen as a reason for endorsing the proponent's program but, that not collecting such samples where it is possible to do so would not comply with best practice (ESD 2e) and limit the ability to adequately monitor and improve the program. It is important that such data collection is established as a standard part of the program rather than being introduced on an 'as per request basis'.

It is extremely important that all dead or euthanized white sharks and other listed species (e.g. mako and grey nurse) be landed and returned to the DoF for examination by trained staff. Important samples would include:

- tissue sampling for genetic analyses;
- a full biological examination (e.g. morphormetrics, tissue sampling for genetics, vertebral samples for aging, reproductive state, stomach contents)
- other samples to be provided for specialist value adding research programs on request.

A tissue sample should be retained from all released white sharks for genetic assessment and to contribute to estimates of population size.

It is critical that these data and samples be collected by DoF to ensure consistency in data collection and longevity in data management. Specific samples such as vertebrae and tissue (for genetic analysis) should be submitted to a central long-term repository (e.g. CSIRO, museum).

Ideally all sharks (including tiger sharks) should be sampled to provide adequate data on all species impacted. Where possible, all dead and euthanized sharks should be landed and a full biological examination performed. Where this is not possible, sampling should be undertaken onboard the capture vessel prior to disposal of the carcass. Sampling and data collection should include:

- an accurate measure of total or fork length
- sex and reproductive state

- tissue sampling (genetics)
- vertebrae (aging)
- an assessment of injuries sustained during capture (e.g. hook damage)

Investigation of post-release survival for all species – priority for white sharks

Post release mortality is unknown for the sharks caught in the program but as indicated by the proponent, it may be high. Research on post-release mortality would improve the proponent's overall ability to assess and monitor impacts. Such data combined with catch depredation rates are likely to provide information on whether sharks suffering short-term post release mortality may be attracting other sharks to the local area and changing the rate of catch.

Improve the accuracy of data collection from commercial fisheries within WA regarding white shark bycatch

Understanding the overall impact of the program would be greatly improved by gaining a better estimate of cumulative impacts on white sharks across the range of the south western population. This would require a dedicated program to provide more robust estimates of the current level, regional and interannual variability and trend in white shark catches for fisheries in WA and other jurisdictions across the population's range, including where possible, the collection of biological samples from sharks taken in these fisheries (ESD 1d).

Avoid targeting tagged sharks

The detection of tagged sharks provides immediate opportunities for actions to mitigate risk other than setting additional drumlines in an attempt to capture. It is important that the detection of tagged sharks not automatically initiate the rapid response component of the program. Such an exemption would be consistent with the ESD mitigation hierarchy of – avoid, minimise, rectify and offset (ESD 3). A decision tree listing the alternative actions that could be taken on detection of a tagged shark, and when each option would be used, should be developed to support rapid decision making.

Avoid areas of known white shark aggregations

The conclusion of negligible risk posed by the program to white sharks in particular is based on the proponent's estimate of shark capture rates in similar programs elsewhere and capture rates by DoF research staff when previously operating in the Marine Monitored Areas (MMAs). The rapid response component of the program (RR), however, is not restricted to the MMAs and may occur anywhere in WA waters. Setting of RR drumlines in areas where white sharks are known to aggregate (e.g. in the vicinity of finfish schools [e.g. snapper - *Pagrus auratus*], around whale carcasses [floating or stranded], or around seal colonies) could rapidly elevate catch levels and increase the risk of population impact. These areas should be exempt from RR deployments.

Gear configuration

The proponent's identifies the use of extremely large hooks in the program (25-O cited). If the rate of significant injury or post-release mortality is high in non-target animals, the proponent should consider using more conventional hook sizes. This may require an assessment that balances a higher catch rate of non-target animals with the benefit of releasing these in better condition.

Detailed comments pertaining to the PER document

Clear, measurable objectives and performance measures, including trigger points and corresponding management actions

The stated aims of the proponent's drum line program are variously described as being to "*provide additional protection from the risk of shark interactions to water users at a select number of swimming beaches and surf spots in the metropolitan and southwest regions of the State*" or more simply to capture "*potentially dangerous sharks which come into close proximity of popular swimming beaches and surf breaks during the high use summer months*". The proponent further states that the proposed program is designed to have a localised impact on the abundance of target sharks and is not designed to significantly affect the total size of these species. These aims by themselves have no clear measures of what would constitute success. However, their implicit goal is to improve public safety.

The proponent indicates that the drum line program is not considered to be a permanent shark hazard mitigation strategy and that "..*it is hoped that at some time in the future, drum lines may be able to be replaced with alternative mitigation strategies*". This suggests it will be the success in developing these alternative strategies, as opposed to any measured success of the drumline program per se, which will dictate the period over which the drumline program may eventually be run. However effective monitoring against agreed criteria will be essential to estimating the value of the program.

The proponent clearly indicates that the scope of the assessment "*does not include an examination of the degree to which the use of drum-lines would reduce risks associated with human-shark interactions"*. Such an assessment is not a requirement under the ESD or the referral process under the EPBC Act. However, the management of the program would be improved by such an assessment given that reducing such risks is the implicit goal of the program.

A review of the QLD Shark Control Program recommended that a series of formal reference-points be determined (QDPI&F 2006), although that review failed to recommend what such reference points might be based around, or what actions might be taken should a (limit) reference point be reached. For the proponent, a simple reference point might be reaching or exceeding the anticipated annual catch, or another specified catch point, of any target species (e.g. 10 individuals in the case of white sharks). Reference points are, however, of little value unless reaching or exceeding them instigates a predetermined and agreed management response or action, such as a redirection or reduction in effort. An open-ended, no limit catch of target species (particularly listed/migratory species) would be a demonstrably poor management arrangement for the program and could not be considered as being environmentally sensitive, compliant with the EPBC Act or meeting Australia's obligations under international treaties (e.g. CMS[2]). Ensuring there are clearly defined and measurable objectives ensures that agreed triggers and ensuing actions can support those objectives and that management decisions are rational, defensible and transparent. Such management frameworks are standard in fisheries and environmental management and should be applied here.

While it may be possible, over time, to monitor the local and total biological impacts of the drum-line program on different shark populations, it will be much harder to evaluate the program's success in the context of its implicit, overarching goal of improving public safety. Given the higher than expected capture rate of tiger sharks in the trial period of the program (including 50 over the target 3m TL)[3], it is clear that

[2] Convention on Migratory Species

[3] The proponent's report does not specifically state the number of tiger sharks over 3m TL that were caught during the trial drum-line program. This number was calculated based in the information in Figure 3 of Appendix 7.

the number of sharks within the MMAs (at least for that species) is higher than previously considered. It is therefore reasonable to assume that the presence of tiger sharks in the vicinity of beaches within these MMAs, and hence the encounter frequency between tiger sharks and waters-users, is also much higher than previously considered. It is thus notable that no attacks in either MMA have been attributed to tiger sharks despite their obvious presence during periods of high in-water use and their demonstrated capability to injure humans[4]. This suggests, as noted in other areas, that the presence of sharks alone is a poor indicator of attack risk and that the variability in the number of attacks recorded is a poor indicator of the overall status of shark populations. This conclusion concurs with some statements within the proponent's document (e.g. Appendix 9) but is at odds with other sections of that same document and other areas of the proponent's report in general that imply a more direct relationship. It also presents a challenge for the proponent's implementation of an 'imminent threat/rapid response' as the sighting or detection[5] of a shark > 3 m TL does not, by itself, indicate that shark poses an imminent threat of attack. Sharks, even those over 3 m TL, are natural and likely frequent visitors to near-shore waters along areas of the WA coast including within the MMAs. Detections of tagged sharks are likely to constitute only a small proportion of the total number of visitors.

The numbers of sharks in the MMAs are likely to be more tightly correlated with the number of human-shark encounters (the occurrence of sharks and people in close proximity). However, these data are not recorded and many - if not the majority, of such encounters likely go unnoticed because few result in incident (= attack). The relationship between encounters and incidents is likely complex, time-variant, spatially variable and non-linear[6]. The removal of any shark that has the potential by nature of its size and identity (species) to bite a person no doubt reduces the risk of such an incident occurring. What is unclear is whether that particular shark would have posed an imminent threat to public safety, or to what extent the overall level of risk within a region is reduced by its removal. Shark control programs work best when they reduce the population size of sharks within the area in which they cover (i.e. the MMAs) and specifically along the beaches that such programs operate. This occurs as a consequence of either localised depletion, continuing interception of sharks entering these areas, or as a result of creating a more widespread overall population decline. The extent of the localised depletion or population-wide decline required to reduce risk to an 'acceptable' level is much more difficult to identify, particularly when an acceptable level has not been identified. A zero risk of shark attack is an unattainable goal without local extinction.

The implementation of long-running shark control programs in NSW, Qld and South Africa based either primarily on large-mesh gillnets or a mix of drumline and mesh nets have seen a parallel reduction of shark-related fatalities within their footprint. However, they have not eliminated shark attacks within their footprint. The NSW shark control program operates at 51 beaches, spanning 200 km out of the approximate 1100 km of the NSW coast (Green *et al.* 2009). Despite the notable statistic of having seen only one fatality at a beach covered by the NSW shark control program, 29 shark attacks resulting in injury (approximately 20% of all attacks in NSW) have occurred at meshed beaches since the program's inception, including five attributed to white sharks. The single fatality was one of those attributed to a white shark. It is unknown how many shark attacks might have occurred if the NSW shark control program was not in operation or how many of those that have occurred may have resulted in fatality if concurrent improvements in rescue procedures and medical response times had not occurred over the same period.

There are a number of behaviours in white sharks that can lead to conflicting interpretations of the likely effect of a localised fishing activity such as the proponent's drumline program. White sharks are highly mobile and migratory, spending long periods travelling between sites of temporary residency. Satellite and acoustic tagging of white sharks have revealed long distance movements for individuals in the south-western Australian population.

[4] Identifying the species involved in shark attacks can be difficult unless tooth fragments are found or the wound/bite pattern provides clear evidence. There are scientific reports that that discuss and address these difficulties (e.g. Lowry *et al*. 2009).

[5] Refers to the detection of an acoustic tagged shark by an acoustic receiver or location data from a shark tagged with a satellite tracking tag

[6] The non-linear relationship between the incidence of shark attack and numbers of sharks is correctly noted in Appendix 4.

Examples include multiple individuals tracked moving between the Neptune Islands in South Australia, west through the Great Australian Bight, past Perth to the Exmouth region of northwest Western Australia and return (Bruce *et al*. 2006, Bruce and Bradford 2013).

Similar long distance movements are commonly reported for white sharks in eastern Australia (Bruce and Bradford 2012) and other areas of the world (Boustany *et al.* 2002, Bonfil *et al.* 2005, Weng et al. 2007, Jorgensen et al 2009, Duffy et al 2012, Domeier and Nasby-Lucas 2013). This behaviour involving long distance movements is similar to tiger sharks in Hawaii (Holland *et al*. 1999) where drum line-based shark control programs were variously trialled between 1956 and 1976 to reduce the incidence of attacks by that species. These programs failed to reduce the incidence of shark attack and were terminated (Wetherbee *et al*. 1994). It was also noted that the localised fishing for such wide-ranging sharks after an attack was of limited use if the objective was to catch the shark responsible (Holland *et al*. 1999). The proponent's rapid response policy to deploy drum lines after a shark attack incident might similarly meet with a low rate of success.

However, even comparisons to the Hawaiian shark control program may not be appropriate. White sharks can also show patterns of site and movement pathway fidelity, where some individuals may revisit certain locations, or follow similar pathways during travel periods over different years (Domeier and Nasby-Lucas 2008, Anderson *et al*. 2011, Bruce and Bradford 2012). If such cases of fidelity to the MMA regions were apparent, then sharks that followed such behaviour may be at a higher risk of capture than those that do not, with their capture resulting in an overall localised depletion (of returning animals) and hence a reduction in shark-people encounters. What is unknown is how many white sharks move through the MMAs, how many may temporarily reside in these areas (if any), of these animals - how many are likely to return over multiple years and, if a shark is removed, how long it will be before another shark adopts similar behaviour. What is also unknown, and unlikely to be known, is what percentage of sharks that occur in MMAs end up presenting a true threat to public safety by nature of their encounter circumstance.

The failure to catch any white sharks in the trial (January to April) period of the static drumline program does not necessarily reflect the limited capacity of the program do so. White sharks are more commonly encountered during the winter to early summer period in waters off the designated MMAs and a low level of capture would be expected during the time of year the trial was undertaken. The low level of catch of white sharks does not necessarily indicate that captures during the full period of the program (if implemented) can also be expected to be low. There are few data to guide what an expected level of catch might be. However, the proponent's decision to exclude static drumline fishing from the majority of the winter-spring period will no doubt reduce the level of potential impact on the species.

These uncertainties in shark behaviour make the proposed drum-line program a quite uncertain management response to the threat of white shark attacks. It is important that this aspect of the program be recognised by the managers and the public so that sufficient data are collected to test program effectiveness and that unrealistic expectations are not raised in the public using the beaches.

Operational details and draft management plan

The draft management plan contains no performance indicators that relate to the catch of target species. Thus the efficacy of the program in meeting its objectives and the risks of exceeding acceptable catch levels are not identified performance measures. This is not 'best practice'. The experimental nature of this management response suggests that this program, if approved, be trialled as a strict adaptive management approach.

Further provisions need to be established by the proponent to meet monitoring requirements of adaptive management including standard data collection and the landing for biological examination of animals caught and killed by the program.

The definition of a shark posing an '*imminent threat*' requires further clarity. It appears to have been applied to the confirmed sighting of a shark, as opposed to that shark's behaviour. Although the wording of Appendix 3: *Guidelines for fishing for sharks posing an imminent threat to public safety* suggests that sighting a shark by itself may not necessarily constitute an imminent threat, the application of this policy during at least the trial program, as identified by the proponent, appears to have been based on sightings alone. Sharks are normal visitors to inshore environments and the sighting of a shark or the ability to observe its path (e.g. from the air) provides alternative mitigation opportunities by way of beach closures, to attempts at catching and removing it.

Alternatives are also specifically available when the situation involves a shark tagged with either an acoustic tag which can be monitored by one of the proponent's VR4G iridium/GSM-linked acoustic receivers, or a satellite tracking tag. Such sharks are tagged for research purposes and provide key information on shark movements that will likely assist the proponent in understanding shark behaviour, population status and the impacts of the proposed program. If the opportunities are used well, the independent detection of acoustically tagged sharks will also provide information on the proportion of sharks entering that MMA that are being detected. The detection of tagged sharks, particularly acoustic-tagged sharks, provides immediate opportunities for actions to mitigate risk other than setting additional drumlines in an attempt to capture. The proponent should clearly identify that the detection of tagged sharks will be exempt from the rapid response component of the program. Such an exemption would be consistent with the ESD mitigation hierarchy of – avoid, minimise, rectify and offset (ESD 3).

The conclusion of 'negligible risk' posed by the program to white sharks in particular is based on the proponent's estimate of shark capture rates in similar programs elsewhere and capture rates to-date by DoF research staff in the MMA areas. The rapid response component of the program (RR), however, is not restricted to the MMAs and may occur anywhere in WA waters. Setting of RR drumlines in areas where white sharks are known to aggregate (e.g. in the vicinity of finfish schools such as seasonal snapper *Pagrus auratus* aggregations, whale carcasses - floating or stranded, or seal colonies) could rapidly elevate catch levels and increase overall population impact. These areas should be exempt from RR deployments.

The description and configuration of gear used under the program identifies circle hooks of size described as 25-O but provides no details of the dimensions of these hooks. There are no standard size definitions for hooks, and hook sizes are not comparable between manufacturers or between different hook types. Thus a 25-O hook by itself provides little information. Media images and reporting of the hook size used indicates that it is particularly large. Although the proponent identifies that this hook type was chosen to reduce the take of non-target animals, it is clear that it is reasonably effective at taking non-target sized sharks. What is not reported by the proponent is the extent of injury sustained by non-target animals when caught using this gear. The literature cited by the proponent on the benefit in using circle hooks (Godin *et al.* 2012) refers to commercially available and considerably smaller hooks. The results of Godin *et al.* (2012) would not be applicable to the proponent's gear type.

If the rate of significant injury or post-release mortality is high in non-target animals, the proponent might consider using more conventional hook sizes. This may require an assessment that balances a higher catch rate of non-target animals with the potential for releasing them in better condition.

Comments on overall risk assessment

The proponent recommends the development of a range of 'acceptable catch levels' for target species but does not identify actions to be taken if these acceptable levels are reached or exceeded. A review of catch rates at the end of each year or at the end of the program is not a 'best practice' management strategy. The setting of catch reference points and established actions to be undertaken should these be reached is a clear directive in the ESD – see also comments above on the Draft Management Plan.

The risk assessment, specifically as it relates to white sharks, draws heavily on the analyses presented in Appendix 9: *A risk-based, weight of evidence approach to determine the range of plausible estimates for the south-western Australian population of white sharks - Working Draft*. It specifically draws on estimates of population size provided in that document and the conclusion that white shark numbers are increasing. However, there are significant flaws in the conclusions presented in Appendix 9 and the lack of information provided in that document on how historical catch scenarios were developed diminishes confidence in the proponent's risk assessment for this species (see below for specific comments on Appendix 9). This does not necessarily mean that the conclusion of *negligible risk* is incorrect, but the information provided is inadequate to judge that level of risk.

It is, however, possible that white shark numbers have increased. What is most likely to have been significant for the white shark population west of Bass Strait (including WA waters) since the species protection is the reduction in effort within fisheries previously identified by Malcolm *et al.* (2001) as responsible for the highest bycatch of the species. The reduction in effort in target shark fisheries in the Southern and Eastern Scalefish and Shark Fishery (SESSF) as well as a reduction in effort in Western Australian shark fisheries (including spatial closures) have been directed at sustaining commercial species and reducing impacts on marine mammals vulnerable to the gears used. The reduction in effort has likely resulted in a reduced impact on the white shark population by means of reduced bycatch and the survival through the release of some that are caught. There is some evidence that white shark populations in other areas of the world have benefited from a combination of their protection and fisheries management actions designed to improve the status of commercial shark species (Burgess *et al*. 2014; Curtis *et al*. 2014). Thus it is also plausible that white shark populations have benefited from these similar actions in Australia, but there is little empirical data to confirm this.

The risk assessment provided by the proponent indicates that the catch of 163 tiger sharks in the January to April trial program of which at least 64 were dead or euthanized and actual mortalities likely to be significantly more was "*not considered to have exceeded those outlined within the initial risk assessment which would generate a negligible impact*". The proponent then identifies that the 'annual' catch levels of the extended program (November to April) is expected to be 300. The original risk assessment estimated that only 10-20 tiger sharks would be killed by the trial program and that the number required to induce a measurable change in the tiger shark population would be in the order of 100s. This suggests that the extended program has the capacity to create a measurable change in the population of tiger sharks, particularly if post release mortality is high. Whilst this level of impact may be sustainable, it would again be good practice for the proponent to have a clearly defined upper catch limit under the program to reduce the risk of adverse population and ecosystem level impacts.

Review of key advice documents included in the PER

Two documents listed in the Appendices contribute key information to the proponent's risk assessment and conclusions. One of these documents is a published DoF report the other is an unpublished working draft also produced by the DoF. These two documents are reviewed below.

Comments on Appendix 4: A correlation study of the potential risk factors associated with white shark attacks in western Australian waters. DoF Occasional Publication 109 (2012)

This document compares data on white shark attacks in Western Australian waters to a series of other data sets in the form of linear correlations. The report concludes that the incidence of white shark attacks in WA waters has '*slowly increased over the past two decades*' and that this has occurred at '*a rate faster than human population growth*'. This finding is similar to that reported by Curtis *et al*. (2012) in their world-wide analyses of white shark attacks, but is not consistent with the study of West (2011) who reported that the increase in incidence of shark attacks (albeit referring to incidents from all species combined) was similar to human population growth across Australia as a whole. Irrespective of these comparisons, all such studies have concluded a steady increase in the incidence of white sharks over time.

There are many difficulties when simply comparing the incidence of shark attacks to human population growth. The simple statistic of human population growth does not take into account variations in regional demographics, changes in human population distribution and variations in lifestyle and behaviour of people over time. Specifically, it does not take into account changes in recreational water use which no doubt has varied over time in WA waters.

The proponent concludes statistical or graphical support for significant or plausible correlations between shark attacks and eight out of 17 data series examined. The statistical tests used to achieve these results are not described, a quantitative level of significance is quoted in only three cases and there is no rigorous definition of how 'plausibility' was assessed when it was concluded. The report does not provide sufficient information to permit a thorough assessment of its scientific rigor.

The report, however, makes two useful observations– these are that available data in WA suggest:

a) the incidence and annual regularity of white shark attacks has slowly increased since 1995/96 and,
b) attacks by white sharks tend to occur more frequently during winter and spring.

The remaining correlations provide little useful information and, in general, are more likely to be heavily biased by hidden factors that influence the behaviour of water users and the areas that they use, rather than a relationship with shark attack.

Correlation data can be a useful method for developing hypotheses about what causes something to happen. However, the greatest limitation of such analyses is interpreting any observed correlations in a useful way. Although a causal relationship between two data sets leads to a correlation between them, a correlation may occur between two sets of data even when there is no causal relationship. A commonly expressed summary of this is the phrase '*correlation does not imply causation*' (Aldrich 1995). The report thus establishes that correlations exist between various data series and shark attacks but fails to test the validity of any of these correlations.

The proponent makes somewhat of an over-use of data in the figures of Appendix 4 with five showing different correlations defined by aggregating the same data in five different ways. The use of these multiple figures for the same data does not materially increase the significance of the results.

It is notable that the main theme implied by the findings in Appendix 4 is that the rate of white shark attacks in WA cannot be explained by human population growth. This theme is also mentioned in other sections of the PER document. Yet the proponent does not examine a direct correlation between shark attack and human population size. Notwithstanding the above caveats, when these data are examined there is a significant positive linear correlation between these two variables for the greater Perth area where the majority of attacks have occurred (Figure 1) although this relationship only explains 34% of the variability in the data.

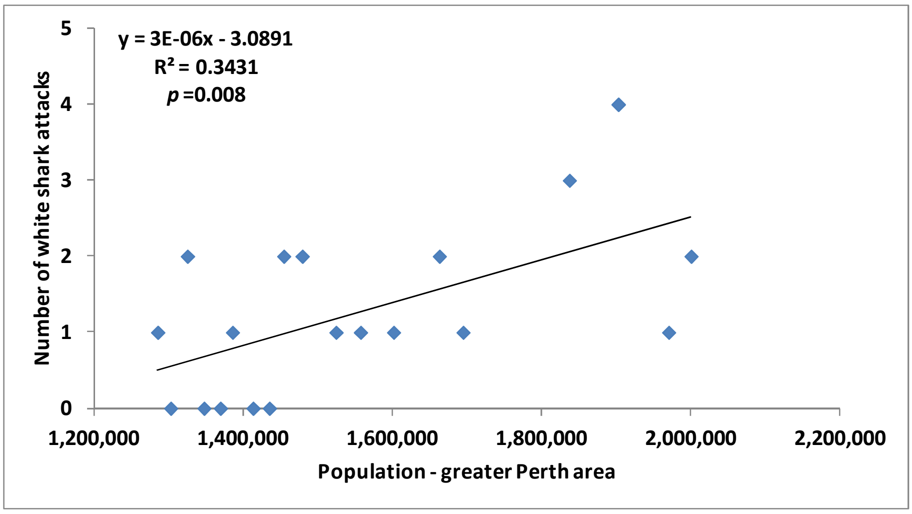

Figure 1: Correlation between the annual (financial year) incidence of white shark attacks in WA and the Greater Perth population (1995/96 to 2013/14); Shark attack data sourced from the Australian Shark Attack File; Population data sourced via the Australian Bureau of Statistics. The equation provides the details of the plotted regression line, its defined R^2 value and statistical significance (*p*).

Thus an equally plausible contributing factor to the slow increase in shark attacks over time is an increase in the human population size in Western Australia. This factor is ignored in Appendix 4. The actual correlation between the incidence of shark attack and population growth may be even higher as population growth and recreational water use are unlikely to have been constant over time as a result of changing patterns of wealth, demographics and lifestyle choices.

It is, however, unlikely that human population growth alone can account for all patterns observed. This suggests that there are other factors contributing to the pattern of shark attacks in Western Australian waters which may include variations in the distribution of sharks due to responses in biological and/or environmental variables and changes in their population levels. Disentangling these factors will not be easy to achieve.

It is also important to note that despite its high profile and profoundly tragic consequences, shark attack is rare in WA relative to the number of water users and the difference between no attacks and a few attacks in any one year may be random chance.

Comments on Appendix 9: A risk-based, weight of evidence approach to determine the range of plausible estimates for the south-western Australian population of white sharks (Working Draft)

This is one of the main supporting documents in the PER assessment. This document and the '*in preparation*' report from which it appears to draw significant information (Taylor *et al*. in prep) are cited by all of the proponent's other assessment documents. Appendix 9 refers to demographic modelling of white shark populations matched with a 'weight-of-evidence' approach to conclude that Australia's (south) western white shark population is either stable in number, or has been slowly increasing over the last decade and is likely to have a current level of 70-85% of virgin biomass.

The primary finding of this document states:

"The range of population estimates generated from the more plausible scenarios all indicate that the SWA population of white sharks is at least in the order of at least a few thousand individuals (>3000 for all plausible scenarios). Further, the population numbers are still > 70% of their unexploited levels with the highest likelihood scenarios all above 85% of unexploited levels. Consequently, the additional removal of a relatively small number of white sharks (<10/year – which is < 10% of current capture rates) for public safety purposes was found to have no material effect on the population numbers and therefore the viability/status of the SWA population of white sharks".

Demographic modelling is a useful exercise and, when coupled with verified data on the requisite biological parameters, can provide estimates of the vulnerability of a population to the combined effects of fishing and other non-natural sources of mortality. Such analyses have generally provided similar results for populations of white sharks where this method has previously been applied and include other examples for Australian waters (Malcolm *et al*. 2001, Hillary *et al*. 2012) and off the west coast of the US (Burgess *et al*. 2014). The results of these approaches are highly sensitive to assumptions regarding the parameters used. All of these approaches (including the proponent's) have used either the same or similar parameters and thus it is entirely unsurprising that each has reached similar population level conclusions. However, as stated by Cortes (2007) in his review of demographic modelling as applied to shark populations: "..*it is impossible to gauge the accuracy of any of these estimates without comparison with empirically derived estimates, which rarely exist*".

Appendix 9 provides few details on how key parameters were estimated. Two of the significant parameters that dictate the predicted trajectories and current population estimates are the initial population size from which the model is run and the catch history of white sharks across the population. Modelling minimum viable population levels and population trajectories for white sharks via demographic models as used by the proponent are scientifically useful exploratory exercises but highlight the critical uncertainties and lack of information available to adequately assess current population size, population status and hence the likely impacts of any additional removals from the population. The outcomes of such modelling are heavily dependent on underlying assumptions relating to: biological parameters, initial population size (which is unknown), current/historical catches across the populations range (which are poorly documented) and either explicitly or implicitly assuming that some catches or trajectories are sustainable or more plausible compared to others (for which there are few data to adjudicate). It is important to note that such exercises are not stock assessments and they do not provide estimates of actual population size.

The proponent has arbitrarily defined a range of initial population sizes, arbitrarily defined a 'starting point' equating to a time of virgin biomass, modelled various trajectories based on assumed historical catch scenarios - the basis for which are not defined in Appendix 9, selectively culled trajectories and used the resulting model output to estimate population sizes relative to their assumed virgin biomass. These choices provide the basis for useful exploratory analyses. However, very few of the key parameters used have robust empirical measures and this is the challenge for interpreting such model outputs. Although it is possible that the actual population and even the trajectory of the current population may fall within the boundaries of the proponent's model outputs, without empirically derived estimates it is impossible to adjudicate their veracity. There is some evidence that white shark populations in other areas of the world are increasing and have benefited from a combination of protection and fisheries management actions designed to improve the status of commercial shark species (Burgess *et al*. 2014; Curtis *et al*. 2014). Thus it is also plausible that white shark populations have benefited from similar actions in Australia. However, conclusions of possible population increases by these other studies are based on empirical data in the form of verified catch or observation rates (e.g. Lowe *et al*. 2012). The proponent provides no useful empirical data in similar to support.

The proponent then argues that they have assessed the "*plausibility*" of their demographic modelling scenarios based on the consistency of model output with "*other lines of evidence*". The document draws information from five[7] other lines of evidence to support the conclusions of the demographic modelling, hence resulting in their "*highly innovative weight-of-evidence*" approach.

However, the data in these lines of evidence are highly ambiguous and in all cases there are either alternative plausible interpretations, caveats on the use of these data at their source have been ignored or the data have been used out of context. There is thus insufficient information within the lines of evidence to support or refute the 'plausibility' of the proponent's modelling and the support concluded in each case is highly subjective and cannot be substantiated. Thus these assessments of plausibility lack credibility.

These lines of evidence are examined in turn below.

1. WA ABALONE DIVERS OBSERVATIONS

The document refers to sightings logged by abalone divers since a specific category for reporting white shark sightings was introduced in 2007. The data are extremely sparse, primarily dealing with zero observations. When white shark sightings were aggregated over the entire 2007-2013 period, observations were limited to within 13 out of approximately 100 blocks of unspecified size (but assumed to each be 100 nm^2 based on Hart *et al*. 2013). Cumulative shark sightings over this entire seven-year period within each of the 13 blocks where sharks were reported ranged from 1 to 4. When these data were standardized for diving effort, the range within these years was approximately 0.5 to 1.7 sharks sighted per 1000 hrs of diving. Given the low numbers, the high level of zero sightings and the unstated level of reliability in reporting, it is highly unlikely that these data provide a useful index at this stage. However, the concept is a good one and abalone divers should be encouraged to report sightings over time. It will be important, however, to examine ways of verifying the extent and variability in reporting, as changes in reporting rate or motivation to report can severely bias such data, particularly when observed numbers are so low and data are examined over short time periods. Such low numbers of sightings can also be influenced by repeat observations of the same shark when diving in one area.

The document also refers to a phone survey of seven 'long-term' abalone fishers who all reported that white sharks were more abundant in 2013 compared to when they commenced diving (reported average years of diving = 20.9). Notably, however, six of the seven divers surveyed admitted that their conclusion was not based on observing more sharks, but on their perception that more sharks were present.

Given that reported observations of white sharks are so low over the time period and that comments on sharks numbers were, in the majority, not based on any increase in the number of sharks actually sighted – the conclusion by the proponent that these data are "*most consistent*" with no change or a slight increase in shark population size cannot be supported.

[7]Appendix 9 cites eight line of additional evidence. However, one of these – '*Catch Rate of Commercial WA Fishers'* forms the basis for calculating population scenarios by the demographic modelling and thus is not an 'additional line' of evidence. Two lines of evidence – 'Public reported sightings' and 'Tagging' data were judged too inconclusive to provide support.

2. NEPTUNE ISLAND SIGHTINGS

The document refers to the long-term (12 year) frequency of white shark sightings at the North Neptune Islands, South Australia reported by Bruce and Bradford (2013). This study examined the number of sharks sighted over the period 2000 to 2011, specifically focusing on the impact of changes in shark cage-diving operations before and after a sustained increase in effort in 2007. While the Bruce and Bradford study found that the number of sharks sighted per day by cage-dive operators had significantly increased after 2007, this was concluded to be caused by an increase in residency times in response to shark cage-diving operations, hence resulting in sharks temporarily accumulating at this site. The study found no similar changes at the South Neptune Islands, 12 km away, where the frequency of shark cage-diving was significantly less. The study reports no evidence of an increase in population size and states that:

"*The lack of available measures of population size combined with these* [observed] *interannual variations [*in the number of sharks sighted] *makes it difficult to conclude population-level changes in abundance from these data*."

White sharks are temporary residents at the Neptune Islands (which holds Australia's largest aggregation of seals) with a median residency period of 9 days (Bruce and Bradford 2013).

The proponent's conclusion that data from the Bruce and Bradford study are "*fully consistent*" with either no change or a slight increase in population size cannot be supported.

3. WA SHARK ATTACK DATA

The document refers to an increasing rate of white shark attacks in Western Australian waters since 1996 that exceeds the rate of the State's population increase, citing analyses in a Department of Fisheries Report which is included as Appendix 4 (see above for a review of Appendix 4). Notwithstanding the shortcomings of analyses presented in Appendix 4, the proponent argues that an increase in the rate of shark attack in WA could not be attributed to an increase in participation rates in water related activities, stating:

"..*given that the rate for all recreational* [water] *activities in WA has fallen slightly over the last decade and, specifically, for surf related sports (which is one of the main categories of activities involved in the attacks), it has fallen from 2.1% in 2005/06 to 1.2% for 2011/12"* citing ABS (2013).

The ABS (2013) report, however, clearly states with respect to the 2011/12 data on participation in surfing that the "*estimate has a relative standard error of 25% to 50% and should be used with caution*". This warning appears not to have been considered by the proponent in their analyses. Furthermore, although the participation rate reported by the ABS for other water activities such as swimming/diving[8] in 2011/12 was also less at 9.6% than that reported in 2005/06 (9.9%), the values over the period were not reported by the ABS to be significantly different. In addition, the proponent's comparison uses the ABS participation rate rather than the numbers of people engaged in the activity. Given the increase in WA's population over the period, the ABS data translates into an increase by approximately 31,000 in the number of people participating in swimming and diving activities over since 2005/06, not a slight decrease as the proponent concludes.

An increase in the number of people participating in marine-based water activities in Western Australia is also predicted by surveys of beach use by Eliot *et al.* (2005) who concluded that there was a general increase in beach use between 1994 and 2004 by approximately 4% per annum and at some Perth beaches of up to 10% per annum over this period. The WA has consistently experienced the highest population growth rate of any Australian State over recent years (e.g. 2.9% in 2012/13) and the population of the greater Perth region has increased from 1,286,000 in 1996 by nearly 700,000 to 1,970,000 in 2013 (ABS

[8]The ABS report does not defined swimming and diving as being exclusively marine in nature

2013, DPI 2009). It would seem more plausible that WA in general, and the greater Perth region in particular, have experienced a significant increase in the number of people using marine waters for recreational purposes rather than less as the proponent's document concludes.

Despite these statistics, the number of shark attacks over the period August 2010 to July 2012 was unusually high compared to any similar period previous or since in the State and this cannot be fully accounted for by increases in water use or increases in the population size of white sharks, should the latter have occurred. The proponent reasonably concludes that the increase in the rate of attacks by white sharks relative to the WA (human) population size cannot be fully explained by an increase in the white shark population alone, as under their own calculations it would require a biologically impossible rate of increase since the species protection and specifically for the 2010 - 2012 period. This statement is in agreement with general findings on white sharks in particular by South African researchers and research on the species in eastern Australia that has concluding that the frequency of attack is poorly correlated to the local abundance of the species (Bruce and Bradford 2012, Dicken and Booth 2013). The proponent reasonably concludes that the relationship between abundance and frequency of attack is not linear.

Thus the proponent's conclusion that the observed trend in shark attacks (relative to population growth) "*would be most consistent*" with some level of increase in the white shark population also cannot be supported.

4. OTHER WHITE SHARK POPULATION ESTIMATES

The proponent compares their estimate of 'population size' with other calculations for white shark populations world-wide (including other Australian-based research). The proponent's document incorrectly states that a previous Australian study (Thomson *in* Malcolm *et al*. 2001) "..*used inputs that were largely based on annual capture data from what is now known as the eastern population*". In fact, the dominant catch data in that study (over 75%) came from what is now known as the western population and that study's conclusions are thus readily applicable within the bounds of the caveats provided.

As stated above, demographic modelling approaches (including the proponent's) to investigate white shark populations have each used either the same or similar parameters and thus it is entirely unsurprising that they have each reached similar conclusions regarding population levels. What remains unknown is how the model outputs in each case reflect the actual status and trajectory of the individual populations to which they have been applied. Comparing populations of white sharks between vastly different world regions is unlikely to be biologically sound as such simple comparisons fail to take into account differences in historical population processes and ecosystem characteristics that can result in different base level population sizes and trajectories.

Other estimates of 'population size' for Australian waters are not referred to by the proponent including those by Blower *et al*. (2012) who estimated the effective population size (N_e) for the southwest population to be approximately 700. However, this was not an estimate of all life history stages combined, had very wide confidence limits and noted that the relationship between effective population size and actual abundance (i.e. population census size or N_c) is often complex and unclear.

Given the uncertainties and biases in the population estimates from the other Australian studies and those world-wide, it is difficult to adequately compare such results between different populations and their veracity with respect to actual population sizes within the regions is unclear. It is thus unclear to what extent these data can be used to support or refute the proponent's modelled population estimates.

5. COMPARATIVE DUSKY SHARK ESTIMATES

This section provides no useful information on white sharks. The demographics of dusky sharks, as well as their ecology and fishery status, are sufficiently different to white sharks that such simple comparisons are not biologically meaningful. These comparisons give no measure of support.

6. CONCLUSION

Overall, there is little support for a "*high level of consistency in the patterns seen among independent lines of evidence*" with the model output as stated by the proponent. The problem with the 'weight-of-evidence' based approach used in this case is that it is open to significant bias depending on the qualitative 'lens' used to adjudicate the level of support provided. When used appropriately, a weight-of-evidence approach must consider all available lines of evidence, including an assessment of the veracity of 'supporting' as well as alternative interpretations of the data used. This does not appear to have been the case in the proponent's document and it correspondingly lacks credibility.

The proponent clearly identifies that Appendix 9 is a 'Working draft'. However, the findings in Appendix 9 form a substantial input to the proponent's overall risk assessment and guides their conclusions. Appendix 9 contains examples of selective use of information and cites non peer-reviewed Departmental reports that would fail the test of good science and scientific reporting. It would thus be prudent for the Department to engage one or more independent reviews of this document before it is finalized and adjust the overall risk assessment accordingly.

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