# A risk-based, weight of evidence approach to determine the range of plausible estimates for the southwestern Australian population of white sharks. (Working Draft)

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## Executive Summary

Following the significant increase in the rate of shark attacks within Western Australia (WA) over the past decade, the WA government funded a study to examine the potential impact on white shark numbers that may have resulted from changes to fisheries and other management arrangements over the past 30 years. This study has resulted in the range of plausible population estimates and trajectories for the white shark population that occur off the WA coast to be generated for use in the development of appropriate human safety and associated risk mitigation strategies.

Data on white sharks from southwestern Australia (SWA) is relatively sparse. To develop estimates of population size a highly innovative weight of evidence, risk based approach designed for use in data poor situations was adopted. The main inputs included a re-construction of the catch levels that would have been removed from the SWA population of white sharks since 1938. This estimated catch history was used in combination with a demographic model to generate a series of possible population scenarios. A total of sixteen scenarios were generated using 4 different initial population sizes (2-10 thousand females), two alternative life history characteristics (standard and conservative) and two post release survival rates (0 or 50%). The resultant trajectories describe how the estimated levels of capture over the past 70 years could have affected each of the 16 alternative scenarios.

The plausibility of each scenario was determined by their level of consistency with each of other available lines of evidence. These included the catch rates of white sharks by commercial fishers across periods before, during and after the highest levels of white shark captures occurred, trends in the rate of attacks per head of WA population for the past twenty years, observed sighting rates by WA abalone divers for the past decade and sightings at South Australian (SA) cage diving sites for the last 20 years. Additional lines of evidence include comparisons with population estimates of white sharks from other regions and relative catch rates and stock estimates for co-occurring non-white shark populations in this region.

Importantly, there were no lines of evidence that were consistent with a decline in the population size of SWA white sharks over the past decade. All of the lines of evidence that potentially reflect white shark relative abundance were consistent with there being either some increase in their population or, at worst, no decline. This suggests that the current SWA white shark population is, at worst stable, but more possibly it has been very slowly increasing over the past decade. A stabilisation would have been generated from the significant reduction fishing effort for all shark species in this region reducing the bycatch of white sharks. An increasing trend is, however, more likely if since formal protection of white sharks was introduced in 1997, some proportion of individuals still captured now survives their release, combined with the cessation of all targeted fishing by all sectors.

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 to several 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.

# Contents

## Introduction

Following the relatively large number of shark related attacks and fatalities that have occurred in Western Australia (WA) over the past decade, the WA Government initiated a number of programs designed to reduce the risks of further significant shark related injuries and fatalities (WA Govt., 2012). These programs include a series of research studies, enhancements to the level of shark monitoring, aerial patrols and most recently the deployment of drum-lines to specifically reduce risks to aquatic users within two Marine Management Areas (MMAs) located on the lower west coast over the summer period (Nov-April) (WA Govt. 2013).

To assist in the ongoing development of appropriate policies for human risk mitigation strategies within WA, identifying the range of plausible estimates for the current population size and trajectory of the white shark population that occurs off the WA coast is required. This includes the degree to which the recent high level of attacks could potentially be associated with increases in the numbers of white sharks off the WA coast during this period. Consequently, one of the research projects funded by the WA government was an examination of the potential impact on white shark numbers that may have followed the series of changes in fisheries management and other associated arrangements implemented over the past 30 years, including their protection across Australia between 1996-99.

In examining the potential effects, it is recognised that the data available on white sharks is relatively sparse, especially for the relevant region of the Australian coast (southwestern Australia- SWA). Accordingly, to develop these population estimates a suite of inventive methods had to be adopted. This included gathering the available data from a diverse range of sources and to most effectively utilize the variety of quantitative and qualitative information that was gathered, a highly innovative weight of evidence, risk based approach was utilised (Fletcher 2014).

The main inputs used to investigate the potential for management actions to have affected the population of white sharks in this region have come from an integrated series of studies being undertaken by the Department of Fisheries. These included generating a re-construction of the likely annual catch levels of white sharks that have affected the SWA population across WA and other relevant parts of southern Australia over the past 70 years (Taylor et al., in prep). It also involved the development of a series of population scenarios using demographic and risk analysis modelling which used a range of likely life history characteristics and post-release mortality rates for white sharks (Braccini, et al., in prep).

The preliminary outcomes from these investigations have been used within this present study in conjunction with other available lines of evidence (LoE) to determine a plausible range of population estimates and trends for the SWA population of white sharks. It is important to emphasise that the population estimates and trajectories generated by this study are based on the current available information and are primarily being generated for use in the development of human safety and associated risk mitigation strategies. Consequently, for this purpose, the appropriate focus for applying the precautionary approach has been towards human safety such that if there are potential threats to human safety, the lack of full scientific certainty should not be used to postpone measures to prevent further harm. Finally, as this is still a working draft, some details may change in final editing but it is not expected that the fundamental conclusions will be materially altered.

## Background

White sharks are relatively rare in all locations where this species is found throughout the world, with each population having a relatively large spatial distribution that can extend across both coastal and oceanic waters (Last & Stevens, 2009). They are a wide-ranging species with significant movements having been documented for many individual white sharks (e.g. Bruce et al., 2006).

Concerns about their status worldwide (e.g. Murphy, 1996), have resulted in many countries implementing high levels of protection for this species over the past few decades (e.g. CITES listing). In Australia, the white shark was initially declared a protected species under various state legislation between 1996 and 1999 and the Commonwealth Endangered Species Protection (ESP) Act (Malcolm et al. 2001). In 1999, the ESP Act was replaced by the Environment Protection and Biodiversity Conservation (EPBC) Act, and white sharks were listed under this new Act as a 'vulnerable' species due to evidence of continued population decline, its conservative life history characteristics (longevity and low reproductive capacity), limited local distribution and relative abundance (EA, 2002).

The majority of the information used to support their listing in Australia came from eastern Australia and at this point it was considered to be a single population that included Australia and New Zealand. Following their listing, the Commonwealth Government developed and released a White Shark Recovery Plan (EA, 2002). More recent reports by DEWHA (2008, 2009) SEWPaC (2013a) and the revised national Recovery Plan (SEWPaC, 2013b) found insufficient evidence to confirm an increase in species abundance. However, each of these reports were developed assuming a single population with the majority of the conclusions still largely based on data relevant to eastern regions (i.e. eastern Australia).

It has recently been determined that there are effectively two subpopulations of white sharks in Australia. Recent tracking data and a genetic study (Blower et al. 2012; Bruce & Bradford 2012) both indicate that the two subpopulations of white sharks that occur in Australian waters are separated at Bass Strait. There is an Eastern population comprising Eastern Australia and New Zealand and a southwestern population which extends from western Bass Strait in Victoria across the southern ocean in South Australia and Western Australia up the west coast of WA to approximately North West Cape (Last and Stevens, 2009).

Within the geographical distribution of this southwestern subpopulation, white sharks have not been directly targeted by commercial activities and relatively minor levels of recreational activities and they have now been protected for nearly 20 years. These features have meant there is not a long history of fishery dependent or fishery independent data collected on their level of captures (Malcolm et al, 2001; Taylor et al., in prep). Despite these limitations, it is imperative for the development of future government policies and decision making processes associated with risk mitigation strategies that a plausible range for the current size and trajectory of the SWA white shark population is estimated. This study therefore makes use of the currently available information to calculate the range of plausible estimates.

## Methodology

Using the current understanding of the population structure of white sharks in Australia, the assessment for white sharks off WA has been completed at the regional level that includes South Australia, Western Australia waters and associated Commonwealth waters off western Bass Strait. Determining the impact of management changes on white shark numbers in this region is not simple and it is recognised that there is a paucity of quantitative data even for basic factors such as the annual number of captures (Taylor et al. in prep).

Risk based assessments are designed to assist in making the most informed decisions possible in situations where data are limited (SA, 2012). This approach was therefore considered the most appropriate to generate estimates of plausible population sizes given the information currently available. The specific assessment techniques applied combine standard risk assessment methodologies (e.g. Fletcher 2005; ISO 31000, 2009) with a 'weight of evidence' approach which is being increasingly adopted for data limited assessments (e.g. Wise et al., 2007; Linkov, et al., 2009). This recently developed method (as proposed in Fletcher, 2014) can therefore make use of all available lines of evidence for white sharks in this region within a structured risk framework to transparently determine the most appropriate likelihoods for each plausible population scenario.

One of the more common methods of estimating the stock size of populations with minimal quantitative information, but especially those that have relatively large distributions, long life expectancy and low fecundities, is to develop demographic population models based on their life history characteristics and exploitation rates (e.g. Cortes, 1998; McAuley et al., 2005). Such analyses integrate a number of aspects and can be used to infer the minimum population sizes that must be, or must have been present, to estimate the levels of mortality they have been subjected to while still being extant (e.g. Tompson in Malcom et al., 2001). This approach is most applicable if captures occur across a reasonable proportion of their distribution because this avoids potential issues associated with localised depletions biasing the results.

A primary input used in this population assessment was the estimates of the re-constructed annual catch levels of white sharks that occurred in WA, SA and other waters to western Bass Strait over the past 70 years. The main method used to calculate these estimates was a comprehensive survey of commercial fishers and other groups that had a long history operating in these waters (Taylor et al., in preparation).

The results of this catch re-construction study were used to generate a series of possible population scenarios for the SWA population of white sharks using a demographic population model. The scenarios were based using one of two alternative life history characteristics, one of a series of potential initial population sizes and one of two post release survival rates (Braccini et al., in preparation). This resulted in 16 population trajectories being generated, one for each of the 16 different population scenarios. These trajectories describe how the estimated levels of white shark mortality over the past 70 years could have affected each of the SWA white shark population scenarios.

To determine which of these scenarios was plausible and their relative likelihood, each of the different scenarios was compared against patterns identified or information contained in other available lines of evidence. This compared the trajectories in relation to (i) any predicted changes in their abundance (ii) past and current trajectories (iii) current population estimates. The lines of evidence that were examined included:

(1) The estimated bycatch rates of white sharks by WA commercial shark fishers
(2) WA Commercial Abalone Divers Observations.
(3) Neptune Islands Sightings.
(4) WA Shark Attack Rate.
(5) WA Public Reporting of Shark Sightings
(6) Other White Shark Population Estimates
(7) Comparative catch rate estimates using dusky shark numbers
(8) SA & WA Tagging records

Each of these information sources was explicitly considered on its merit within an overall narrative that transparently discusses how these factors are thought to relate to the level of consistency with the different scenarios (Fletcher, 2014). The more each of the independent lines of evidence are considered consistent with a specific scenario, the greater the level of confidence that can be placed on the plausibility of the scenario being a more likely reflection of the real situation. By contrast, the more the different lines of evidence are inconsistent with a specific scenario, the more unlikely it is that this scenario is plausible. Using basic statistical theory it possible to determine when it becomes improbable that a scenario is plausible based on the relative number of relevant lines of evidence that are considered inconsistent with the scenario.

# Results

## Estimated Re-construction of White Shark Captures

The study by Taylor et al (in prep.) provides the first detailed reconstruction specifically for the catch of white sharks for the SWA population. It includes estimates of the incidental catch (bycatch) from commercial shark fisheries in WA, SA and Commonwealth waters across to western Bass Strait, plus the additional mortalities arising from gamefishing and other recreational captures in SA and WA including those associated with the Albany whaling station in WA.

Prior to the study by Taylor et al. (in prep.), the historical number of white sharks caught was largely unknown because fishers for many years were not obliged to report their white shark bycatch in fisheries catch and effort returns or logbooks. Consequently, to provide the estimates to enable the reconstruction of the white shark catch in WA demersal gillnet and demersal longline fisheries, licensed fishers from this fishery were interviewed during face-to-face confidential interviews. Similar interviews were held with other fishers from the recreational sector and also those that were associated with the Albany whaling station.

Catch estimates derived from these interviews with WA fishers were then linked with effort data reported in fishery logbooks and a linear modelling approach was used to reconstruct the total white shark catch for these WA fisheries. Shark fisheries across southern Australia used the same fishing methods as the WA fisheries therefore the approach was extrapolated to also generate the estimated catch in these waters across to western Bass Strait by using the fishing effort applied by these fisheries.

Taylor et al. (in prep) found that the majority of the white shark captures in WA comes from their incidental capture by the West Coast and Joint Authority demersal gillnet and demersal longline fisheries (WCDGDLF, JADGDLF). This differs from the pattern found for the eastern population of white sharks where their capture in bather protection programs and from recreational gamefishing was estimated to comprise a larger proportion of mortality (Pepperell, 1992; Reid et al. 2011; Sumpton et al. 2011). The estimated captures of white sharks associated with the Albany whaling station in the 1960s-70s were found to be far less than previously postulated (Malcom et al., 1991). It is unlikely that annual mortality of white sharks in this region was more than 10 white sharks a year even during the period of whaling operations (whaling ceased in 1978).

The annual estimated number of white shark captures across the WA to western Bass Strait region (see Fig. 1) has decreased substantially from a maximum estimate level in 1988 of 261 per year (182-357 95% CI) to the current annual estimate across the entire population of 92 (71-115, 95% CI). The reduction in catch level has largely been due to the reductions in fishing effort in the two main fisheries which were aimed at improving the sustainability of target shark species (e.g. school and gummy sharks).

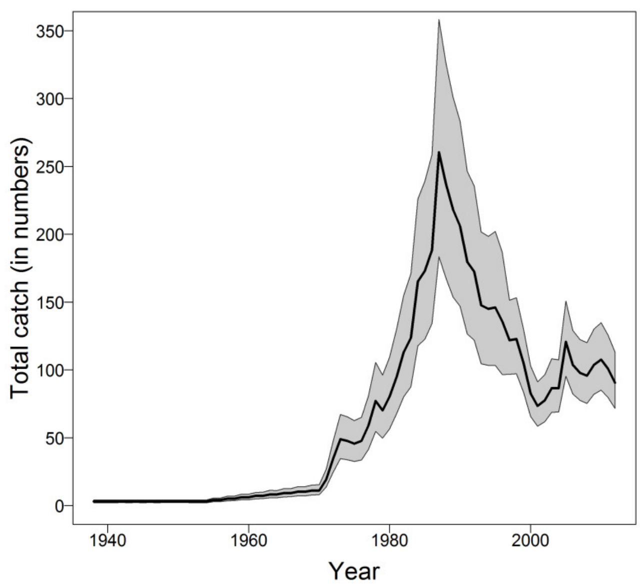



**Figure 1** – Estimated numbers of white sharks captured each year from commercial shark fisheries in WA, SA, eastern Victoria, plus the additional mortalities arising from game fishing and other recreational captures in SA and WA including those associated with the Albany whaling station.

The formal protection of white sharks after 1997 may have also reduced the mortality of white sharks found alive in commercial gear. Their listing also resulted in other fishing arrangements being affected through the prohibition of the use of large hooks and wire traces in 2005 – 2006 for other commercial fisheries. These actions will therefore have reduced mortality as white sharks which were previously caught incidentally using these methods would probably all have been killed. The level to which the release of captured white sharks ultimately results in their death (i.e. post release mortality) is not clear. A study on other species captured in this type of gear in eastern Australia suggests that the post release mortality may be high (Braccini, et al. 2012). However, there have been at least some records of recaptures from sharks released from commercial longline and gillnet (Malcolm et al., 2001) and from gillnets in other locations (Cliff et al., 1996).

## Population Scenarios using Estimated Captures

### Summary of Methods

To determine population productivity and the probability of population increase and recovery, Braccini et al. (in prep) used a multi-analytical approach considering two plausible scenarios of life history (LH1 -standard and LH2 more conservative), different unexploited population sizes ($N_0$), fishing mortalities (*F*) and different post release survival (PRS) in the period after protection occurred in 1997 (0% or 50%).

Population productivity was estimated using demographic analyses considering uncertainty in life history. For LH1 and LH2, a probability distribution was defined for each life history parameter and samples from these distributions were used in a Monte Carlo procedure to construct probability distributions of population productivity.

The productivity information was combined with scenarios of $N_0$ and F based on the best available information to recreate the likely population trajectories between 1938 (the assumed first year that white sharks were taken in commercial and recreational fisheries) and 2012. Estimates of white shark populations in the North Eastern Pacific, South Africa, and Australia were used to inform the $N_0$ scenarios. Though biased low, these estimates provide the order of magnitude for white shark populations, which, as a top predator, are naturally low in abundance. Once the order of magnitude was obtained Braccini et al. (in prep) built 10 $N_0$ scenarios, between 2,000 and 10,000 females in steps of 1,000, and one larger $N_0$ scenario of 20,000 females. A starting option of just 1000 females was not presented because this option did not allow the stocks of the LH2 strategy to survive until the end of the time series given the removals from the population determined from the catch reconstruction.

Interactions of white sharks with commercial fishing gear in WA and across to western Bass Strait mostly occurs in shark gillnet fisheries. White shark catches in commercial gillnet fisheries targeted at sharks in Western Australia (WA), South Australia (SA) and western Victoria were reconstructed (as outlined above) based on interviews of commercial fishers. Other quantifiable historic sources of mortality included the recreational catch of white sharks in Albany, WA, next to the whaling station and the game fishing catch in South Australia (SA). The *F* scenarios were then derived from the reconstructed white shark catches and the $N_0$ scenarios. The post release survival (PRS) options either assumed that all captured sharks die (based on the high levels recorded for some species Braccini et al., 2012), or that since protection was introduced in 1996, 50% of these released sharks now survive based on the evidence that at least some white sharks are known to survive capture and release (Malcolm et al., 2001).

The productivity, $N_{0,}$ F and PRS information was used in 1,000 simulations to obtain a sample of population trajectories for each scenario which permitted the calculation of the relative probability of population increase/recovery between 1998 and 2012 (Braccini et al., in prep). From this suite of population scenarios, 16 were selected for detailed assessment. This included four starting population levels and for each of these, the 2 life history patterns and 2 post survival rates (0% or

50%). The starting population scenarios chosen included the two lowest population scenarios that did not crash prior to 2012 (initial population sizes of 2,000 and 3,000 females). In addition, starting values of 5,000 and 10,000 females were also examined. There were no discernable differences in the patterns of scenarios with starting population sizes greater than 10,000 females (Braccini, et al., in prep) starting values higher than this were not included in this assessment.

### Scenarios Assuming 0% survival upon release after protection.

For the population scenarios based on a starting number of 2,000 females, the LH1-0 scenario population would have declined to approximately 80% of the unexploited level in the late eighties coinciding with the major increase in catch levels (Figure 2a). Since that time it would have remained at approximately this level to 2012. For the LH2-0 scenario, the population would have declined rapidly to be less than 50% of the unexploited level by the late eighties (Figure 2a). It would have continued to decline steeply even after the reductions in effort would still be declining now.

For the scenarios based on starting populations of 3,000 females (Figure 2b) the LH1-0 the population would have declined to less than 85% of the unexploited level by the late eighties but with a slow increase over the past 20 years to be about 87% of the unexploited level. For LH2-0, the population would have noticeably declined by the end of the 1980s and would still be clearly declining to about 65% of the unexploited level in 2012.

For an initial population of 5,000 females, the LH1-0 scenario shows only a minor decline would have occurred to the end of the eighties with the subsequent trend up to the current time slowly increasing with the current level back above 90% of the unexploited level (Figure 2c). For LH2-0 there was a more pronounced decline in the eighties compared to LH1 with some evidence of a decline occurring until the end of the series with the population at about 80% of the unexploited level.

At starting female populations of 10,000 (Figure 2d), there would have been minimal changes to the population at any time for the LH1-0 scenario which shows minimal effects with the 2012 population at >96% of the unexploited level. The LH2-0 scenarios shows a slightly greater decline to be 90 % of unexploited levels but neither scenario indicates there would be any trends observable in the last 20 years.

### Scenarios assuming 50% Release Survival Post 1996 protection.

These scenarios assume some level of post release survival (50%) following the introduction of protection to this species in the late 1990s. As for the LH1-0 scenario, for the 2,000 female starting population, the LH1-50 scenario population declined by approximately 20% to be 80% of the unexploited level in the late eighties coinciding with the major increase in catch levels (Figure 2e). Since then, however, the combination of substantially lower effort post 1990 and a 50% level of post-release survival post protection in 1997, would have enabled an increase to now be back above 85% of the unexploited level (Figure 2e). For the LH2-50 scenario, the population declined rapidly to be less than 60% of the unexploited level by the late eighties and has continued to trend down, but not as rapidly as the LH2-0 scenario.

For the 3,000 female starting population, the patterns are generally similar to the 2,000 female scenarios for both LH1-50 and LH2-50 (Figure 2f). The LH 1-50 scenario declined in the eighties to about 85% of the unexploited level but this has recovered over the past decade to about 90% of the unexploited level. For LH2-50 it would still be declining, albeit more gradually, to 70% of the unexploited level by the end of the time series.

For the 5,000 female scenarios, the LH1-50 scenario shows only a slight decline up to the end of the eighties and the subsequent trend up to the current time is stable or slightly increasing to be > 95% of the unexploited level (Figure 2g). For LH2-50 there was a slightly more pronounced decline in the eighties compared to LH1-50, resulting in a 20% decline to be 80% of the unexploited level with a very slow decline to the end of the run.

At 10,000, there is again minimal difference among scenarios; no effective depletion from the unexploited level would have occurred over time for LH1 and only minimal depletion from the unexploited level for LH2 (Figure 2h).

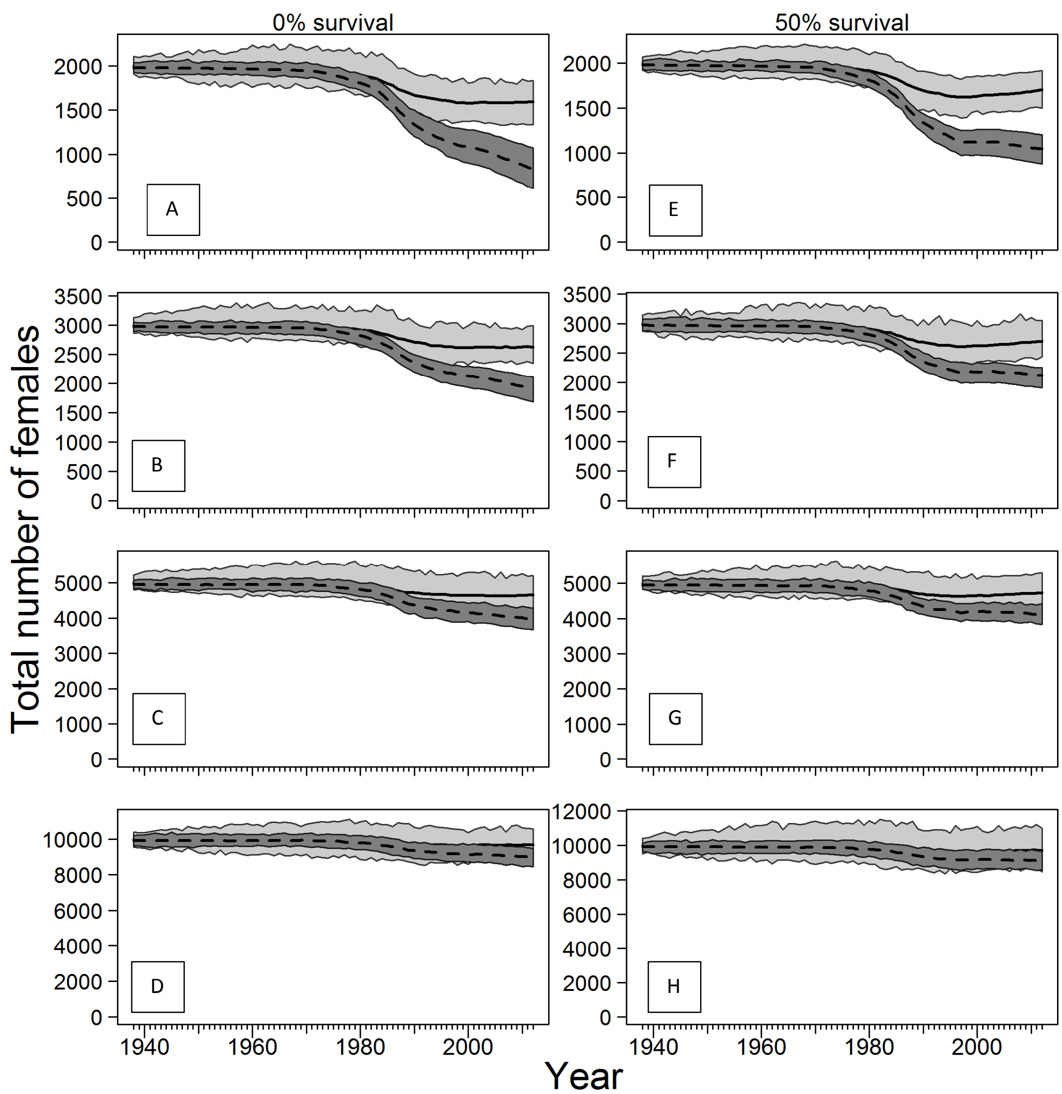



**Figure 2 –** Population trajectories for number of female white sharks (double to get total population of males and females) assuming all captures lead to mortality (0%) or fifty per cent survival (50%) . Solid line and lighter error range LH1; Dashed line and darker range LH2.

## Additional Lines of Evidence

### Catch Rate of Commercial WA fishers

The estimated catch rates of white sharks as determined from the interviews with commercial fishers were used to generate reconstructed catch history in each of the three time periods; (i) from the beginning of formalised shark fishing operations in the late 1980s until the listing of white sharks occurred in 1996; (ii) 1997 to 2004 ; and (iii) 2005- 2012 following the major reduction in effort. The catch rate estimates were determined for the three main fishing zones in WA zones; West Coast, Zone 1 and Zone 2 (see Figure 3). These catch rates provided a line of evidence on the potential changes in the relative population size of white sharks over this thirty year period.

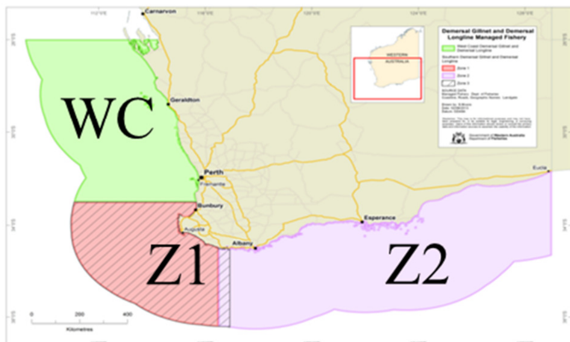



**Figure 3** – Location of zones for estimating white shark catch levels

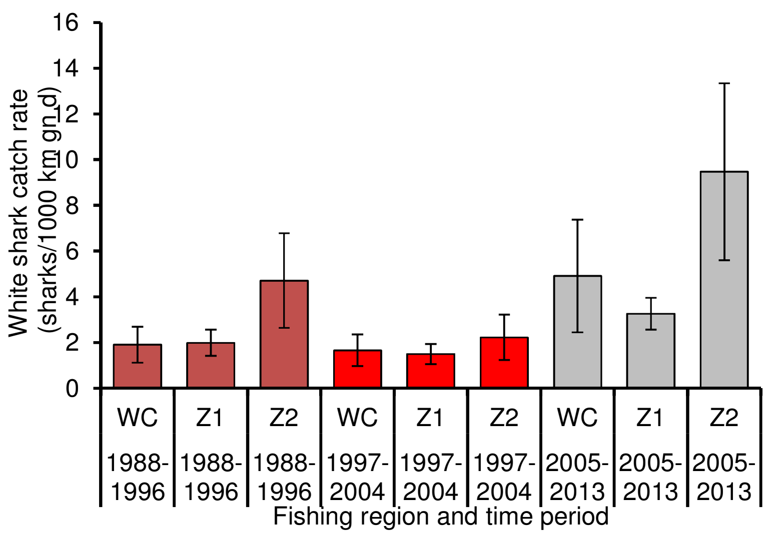



**Figure 4** – White shark catch rates for the three time periods – prior to listing (1988-1996), after listing before major reduction in fishing effort (1997-2004) , after major reduction in fishing effort (2005-2013).

The WA area closest to South Australia (Z2), and therefore the presumed centre of distribution of this white shark population, had the highest estimated catch rates in WA waters for all three time periods (Figure 4). The changes in the estimated catch rate for the different time periods within this zone suggest there may have been some level of decline in abundance of white sharks from the first period (when catch levels were relatively high) compared to the second period, with an increase during the last decade. For the more westerly zones (Z1 and West coast zones), there was only a minor decline in catch rates between the first and second time periods but an increase during the last period.

*Consistency* – For this line of evidence, the estimated decline in catch rates for Z2 after the late 1980s would be most consistent with those scenarios that predict there was some material level of depletion of this population generated by the relatively high level of mortality that occurred in the 1980s. The estimated catch rates during the last decade in all three regions would be most consistent with the scenarios that predict some level of increase in the population during the last decade following the reductions in the estimated level of annual captures and the implementation of protection.

It would not be consistent with a significant decline during this the last decade or with no decline in the period around the end of the 1980s.

### Commercial Abalone Diver Observations

Since 2007 the daily logbook for abalone divers has included a specific category for reporting white sharks and other protected species. As encounters do not involve the mortality of a protected species, there is no obvious incentive for under-reporting. Anecdotal reports and interviews with several long-term abalone fishers suggest that recent logbook data on white sharks observations for this fishery are fairly accurate.

White sharks were identified in 12 out of the 111 spatial grid-cells for which fishing effort was recorded for this fishery. Many of the sightings occurred close to the Recherché Archipelago with most sharks sighted from May to August (Taylor et al., in prep). In the eastern regions of WA, sightings have corresponded to areas where fishing effort was highest (**Figure** 5). However, no white sharks were reported by divers west of Albany despite high levels of effort at locations such as Windy Harbour and Augusta. A higher number of sightings in eastern WA is expected as this area is closest to South Australia, the presumed centre of distribution of this white shark population.

The annual number of white sharks observed per 1,000 hours of diving effort was low in all years (<2 white sharks) although in both 2012 and 2013 the number of white sharks observed was slightly higher than other years (Figure 6). While there is a high degree of variability among years there is possibly the start of slight increasing trend over the latter period.

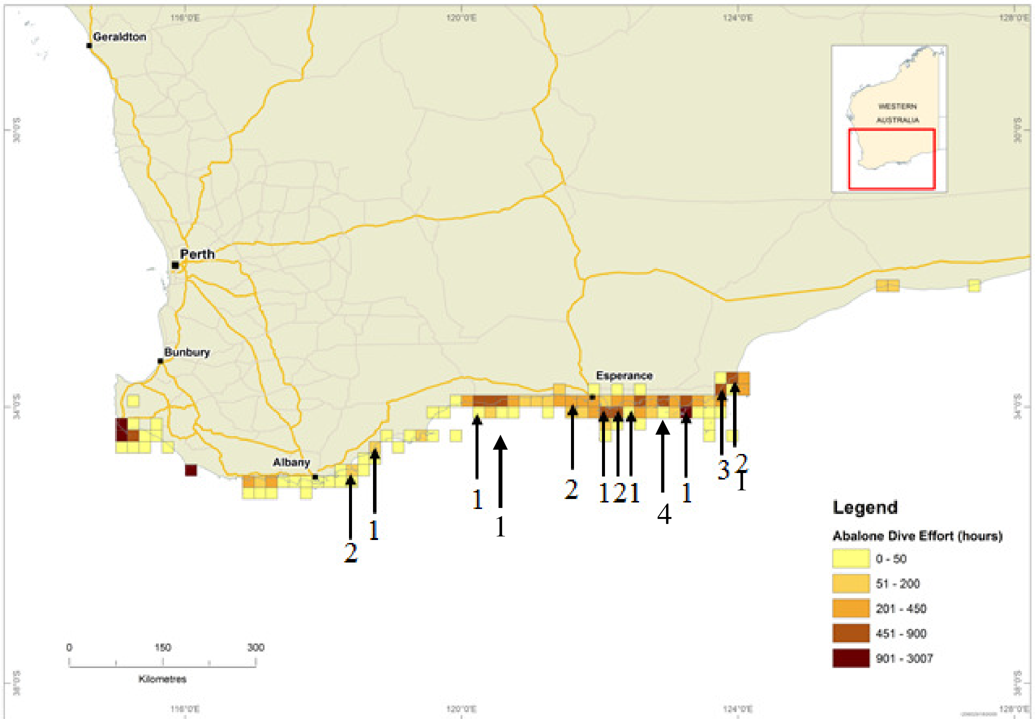



**Figure 5** Distribution of dive effort in the Greenlip/Brownlip abalone diver fishery from 2007–2013 and the locations where white sharks were seen by divers. The numbers represent the number of times a white shark was observed in each grid-cell over this period.

Phone interviews with seven long-term abalone divers (mean = 20.9 years' experience, SD = 9.6 years) suggest that through time, the number of white sharks sighted has been small. All interviewed divers perceived the abundance of white sharks in Western Australia in 2013 to be greater than when they started diving but only one of these divers based this perception on an increase in the number of white sharks he had seen while diving.

*Consistency* - This line of evidence is, therefore, most consistent with scenarios that indicate either no change in the past decade or potentially a slight increase. It would not be consistent with a significant decline during this period.

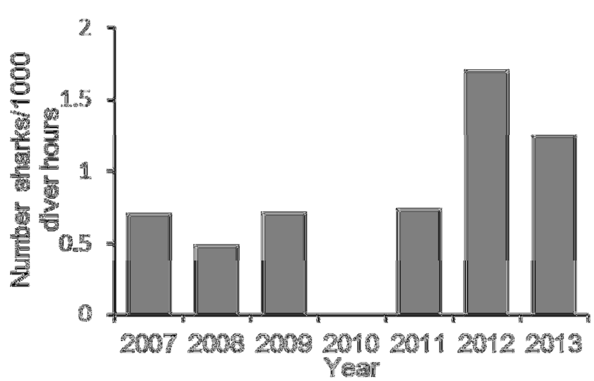



**Figure 6** – The number of sharks observed by commercial abalone divers per 1,000 hrs diving.

## Neptune Islands Sightings

Utilising the information collected on shark sightings within the daily logbooks completed by the cage diving operators, Bruce and Bradford (2012) reported that the long term trend for the number of sharks sighted per day off the Neptune Islands in South Australia has increased since 1999 and specifically since 2007. They concluded that while the observed increase in sightings could be in response to increased abundance following the protection of the this species in Australian waters, the results they obtained comparing behaviours of acoustically tagged sharks from different regions in these islands suggested that at least some of the increase was associated with increased number of cage diving excursions that occurred each year after 2007. The increased baiting from these operations may have increased the residency time of individual white sharks within this area.

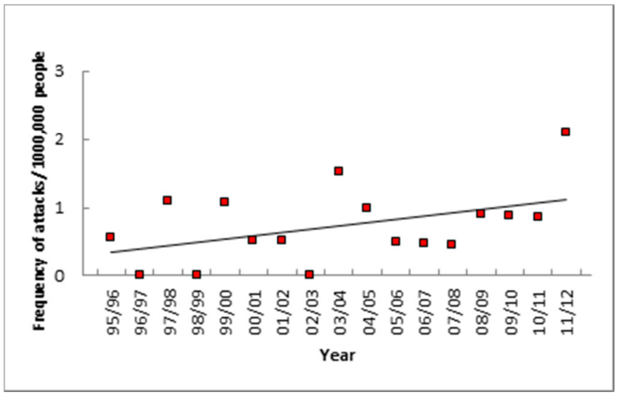
*Consistency* - This line of evidence would, therefore, be fully consistent with scenarios that indicate no change in population size over this period or a slight increase. It would not be consistent with scenarios that predict significant declines in the population of white sharks over this period.

## WA Shark Attack Data

A recent study of rate of white shark attacks in Western Australia, found a statistically significant increase in the rate of incidents even after the data had been adjusted to account for human population growth in the State (DoF, 2012; Figure 7). Unlike the study by West (2011) which found no increase in the adjusted rate of attacks by all sharks across Australia, the WA study found that the average annual rate of attacks from white sharks in WA has increased from 0.4 per million in 1995/96 to over 1 per million in 2010/11. Importantly, this increasing rate per resident was unlikely to have been generated by increased participation rates in water related activities given that the rate for all recreational activities in WA has fallen slightly over the past 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 (ABS, 2013).

One of the potential causes for this increasing rate of white shark incidents per head of population is an increase in the total abundance of white sharks in the SWA population. This could have occurred as a result of this species being protected under Commonwealth/WA and SA legislation in 1997/1998 but also from the significant reductions in effort levels for the main fisheries that captured this species as bycatch which began in 1990. Alternatively (or in addition), the relative distribution of the SWA population of white sharks may have shifted over this period with higher proportion of this population now occurring off the Western Australian coast.

It is plausible that the increased rate observed in white shark interactions off WA may be related to increased population size of white sharks. The magnitude of the suggested increase based on rates of incidents per head of population (a doubling over twenty years) is, however, unlikely to be linearly related to changes in the total white shark population size. A doubling in numbers for this type of population in this time period is not biologically feasible (see above).

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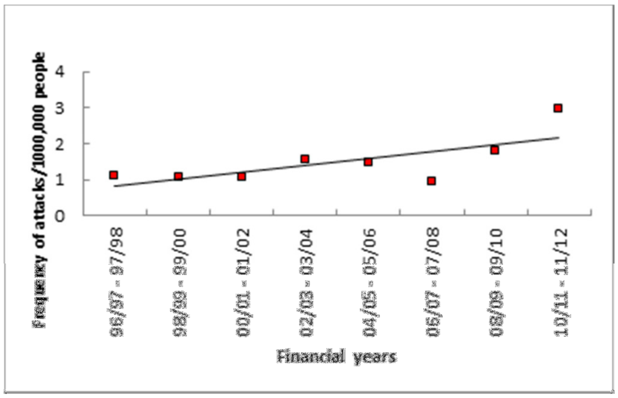


(b)

**Figure 7.** Frequency of attacks per 1,000,000 Western Australian residents by (a) financial year, (b) pooled by two calendar years (DoF, 2012).

*Consistency* - The observed trend for an increase in the rate of attacks in WA would be most consistent with the population scenarios that predict there has been some level of increase in the white shark population during the last twenty years. It would not be consistent with scenarios that predict significant declines in the population of white sharks over this period.

### Public Reported Sightings

The available time series of data on reported public sightings in WA only extends for three years (Taylor et al., in prep). This period is too short to provide a comparative line of evidence for the time scales relevant to the population scenarios. This dataset, however, may provide valuable information on this issue at some point in the future if it is maintained in a consistent manner.

### Other White Shark Population Estimates

A small number of population estimates of white sharks have been calculated. A minimum population estimate for white sharks in Australia was calculated by Tompson (in Malcolm et al., 2001) using a deterministic model with inputs that were largely based on annual capture data from what is now recognised as the eastern population. This study calculated that a minimum population size of 5000-26,000 was required to maintain the estimated annual catch level, which at that time was estimated to be 200 individuals.

A number of estimates of white shark population sizes have been generated by mark recapture studies. These have all been undertaken at just one or a few specific locations within the distribution of the different populations and are therefore highly likely to underestimate the total population size due to many of the assumptions required for such methods not being met. A tag based study for an area of South Africa (Kwazulu) estimated a population size for this region of 1,300 (Cliff et al., 1996). A photo-based recapture study undertaken at another location in South Africa generated estimates of approximately 900 for the Western Cape region (Towner et al., 2013). Similarly, a study by Chapelle et al., (2012) also using photograph based methods at two islands in central California calculated only a few hundred sharks. However, using a Bayesian demographic model, Burgess et al., (in review) concluded that to obtain the recapture results presented in Chappelle et al. (2010) at least 2,000 individuals must have been present in this part of the Central Californian region. Consequently, the population size of white sharks across the greater North East Pacific is expected to be significantly greater.

*Consistent Pattern* - Using the more holistic population estimation methods, the numbers of white sharks in SWA Australia would be expected to be in the order of several thousand. It would not be consistent with estimates at the whole population level that exceed 15000 or are less than 1000.

### *Comparative Dusky Shark Estimates*

Based on gillnet fishing mortality rates estimated for cohorts born in 1994 and 1995 (McAuley et al, 2005 ), the application of multiple age-dependent and independent natural mortality estimates and an estimate of the number of 0+ dusky sharks caught by gillnets in 1994/95, the total population size of dusky sharks in WA was calculated. This estimated that the minimum numbers at that time could have been between 750, 000 and 4 million. Given the relatively low catch rate of white sharks compared to dusky sharks (2 – 3 orders lower depending upon the zone; McAuley & Simpfendorfer, 2003) this suggests that their population estimates should also be in the order of two-three orders of magnitude lower.

*Consistency* - Using this catch rate relationship would make total population estimates for white sharks in the order of several thousand to be not inconsistent with the estimates of the population size of the dusky sharks and their relative vulnerability to capture. It would not be consistent with estimates of white sharks of less than 1,000 or much greater than 10,000 individuals.

### *Tagging*

Over 100 white sharks have been tagged across both South Australia and Western Australia over the past decade but especially in the last five years. The vast majority of these have been tagged at Neptune Islands in SA and therefore the problems outlined above in terms of biases associated with any mark recapture estimates are relevant here. The concentrated distribution of tagging activities and other concerns over the potential level of tag shedding all need to be addressed before this method is likely to generate a robust estimate of population size. The adoption of genetic based tagging methods in the coming years is, however, a distinct possibility for use of this species.

**Table 1 –** Summary of patterns consistent with each of the lines of evidence

| Line of Evidence | Most Consistent Pattern | Not Inconsistent | Inconsistent |
|---|---|---|---|
| Commercial catch rates of white sharks in WA | A decline from 1998-1996 with an increase during the past decade | Some early decline and then stable | No decline in late 80s and/or a decline during past decade |
| Abalone Diver sightings | Either no change in the past decade or potentially a slight increase | Stable during past decade | A decline in past decade |
| Neptune Island sightings | Either no change since 1999 or a slight increase | near stable during past 15 years | A clear decline in past 15 years |
| WA white shark attack rate | Some level of increase in the white shark population during the last twenty years. | Stable over last 20 years period | A decline in past 20 years |
| Other white shark estimates | The numbers of white sharks in the order of a few to several thousand. | Estimates above 1,000 or below 10,000 | Estimates > 15,000 or < 1,000 |
| Comparative Estimates from Dusky Sharks | | White shark population should be 2-3 orders of magnitude lower than Dusky Shark numbers (750,000-4 million) i.e. - several thousands | Estimates < 750 or > 40000 |

## Population Abundance Estimates

This risk based population abundance estimation method first establishes if a scenario was plausible or not. This required that the population under a particular scenario was able to 'survive' to the end of the time series (i.e. did not drive the population to zero as this would mean white sharks would now be absent in southwestern Australia). It also required that a scenario was not inconsistent with four or more of the six lines of evidence that were applicable.

If a scenario was considered plausible, based on the relative levels of consistency with each of the various lines of evidence, a relative level of likelihood for that scenario was calculated. The working estimate for the current size for the SWA population of white sharks was calculated using the combined estimates from each of the plausible scenarios that had a moderate to high level of relative likelihood (Table 2).

### Consistency of Scenarios with Different Lines of Evidence

### Estimates of Plausible Population Range

Each of these 16 scenarios (Figure 2) was then individually examined for their consistency with each of the lines of evidence (Table 1). The level of consistency varied both within and between each life history strategy group and between the different levels of release mortality (Table 3). The three scenarios that had the highest level of consistency across all of the various lines of evidence and therefore scored a High likelihood rating were LH1 2,000-50, LH1-3,000-50 and LH1 3,000-0 (Table 3). These scenarios were fully consistent with most of the estimated changes in commercial catch rates, the pattern of abalone diver sightings, sightings at the Neptune Islands, shark attack rate and other estimates of white shark relative abundance. Importantly, they were not inconsistent with any other line of evidence. The median estimates of current population size (which includes both males and females) associated with these three scenarios ranged from 3,400 – 5,400 individuals.

**Table 2**: Criteria used for determining plausibility and relative likelihoods for plausible scenarios based on the level of consistency with the various lines of evidence (LoE).

| Category | Criteria |
|---|---|
| Not Plausible | ≥4 LoE are Inconsistent |
| Plausible | < 4 LoE Inconsistent |
| Low | < 3 LoE Consistent and >2 Inconsistent |
| Moderate | < 3 LoE Consistent and ≤ 2 Inconsistent |
| High | >3 LoE Consistent and none Inconsistent |

The four scenarios that had moderate levels of consistency with the various lines of evidence covered a larger range of estimated population numbers (Table 3). For the LH1 scenarios with moderate likelihoods, the estimates varied from 3,200 (LH1 2000-0) up to 9,500 (LH1 5000-50) individuals. For the more conservative LH2 scenarios, the only one with a moderate likelihood level generated an estimated current population size of 8,200 individuals.

Of the scenarios examined, only three were considered not plausible. Both of the LH2-2000 scenarios and the LH2 3000-0 scenario were not consistent with at least four of the lines of evidence.

### Potential impact of Proposed Drum line Program

To assess the potential impacts of the current drum line program proposal (WA Govt. 2013) the relative effects that may be generated to each of the plausible scenarios from the additional capture of 20 individuals/year for three years were assessed (see Table A2). This level of capture is twice the maximum level that is anticipated to occur during this program (DoF, 2014).

Even at this exaggerated rate of capture for most of the scenarios the estimated population after this period was either the same or higher than it would have been in 2012. The only scenarios that would be lower are those that already had a declining trend and these additional captures did not materially affect any trend. Moreover, all of the estimates of population sizes for these scenarios indicate that the population is well above the level where risks to population viability and longer term sustainability would be of concern. Thus the minimum population scenario still about 70% of the unexploited level.

**Table 3 - Assessment of each line of evidence against each of the different population scenarios generating a likelihood function.**

√ - Fully Consistent; O – Either Part Consistent or Not Inconsistent; X - Inconsistent. Colour coding: Green = High likelihood; Yellow = moderate likelihood; Blue = low likelihood; Not Plausible = Clear.

| Life-History, Starting Population and Post Release Survival Scenario | Current Total Popln Size | Comm Catch Rates | Abalone Diver Sightings | Neptune Islands Sightings | WA White Shark Attack Rate | Other White Shark Estimates | Other Species Catch Rate Comparison | Plausible | Likelihood |
|---|---|---|---|---|---|---|---|---|---|
| LH1 0% | | | | | | | | | |
| LH1-2,000- 0 | 3188 | O | O | √ | O | √ | O | Yes | Mod |
| LH1-3,000-0 | 5238 | √ | √ | √ | √ | √ | O | Yes | High |
| LH1- 5,000-0 | 9300 | O | √ | √ | O | O | O | Yes | Mod |
| LH1- 10,000 -0 | 19340 | X | O | √ | O | X | O | Yes | Low |
| LH1 50% | | | | | | | | | |
| LH1- 2,000- 50 | 3412 | √ | √ | √ | √ | √ | O | Yes | High |
| LH1- 3,000- 50 | 5400 | √ | √ | √ | √ | √ | O | Yes | High |
| LH1- 5,000- 50 | 9460 | O | O | √ | O | O | O | Yes | Mod |
| LH1-10,000-50 | 19400 | X | O | √ | O | X | O | Yes | Low |
| LH2 0% | | | | | | | | | |
| LH2-2,000-0 | 1668 | X | X | X | X | √ | O | No | - |
| LH2-3,000-0 | 3828 | X | X | X | X | √ | O | No | - |
| LH2-5,000-0 | 7950 | X | X | O | X | O | O | Yes | Low |
| LH2-10,000-0 | 17980 | X | O | √ | O | X | O | Yes | Low |
| LH2 50% | | | | | | | | | |
| LH2-2,000-50 | 2092 | X | X | X | X | O | O | No | - |
| LH2-3,000-50 | 4230 | O | X | O | X | √ | O | Yes | Low |
| LH2-5,000-50 | 8250 | O | O | √ | O | O | O | Yes | Mod |
| LH2-10,000-50 | 18280 | X | O | √ | O | X | O | Yes | Low |

## Discussion

In determining the range of plausible population size of the white shark population off Western Australia it is acknowledged that there are uncertainties associated with each of the available lines of evidence and life history parameters. If used by themselves, none is unlikely to be sufficient to discern current plausible population levels and trajectories for the southwestern Australian population of white sharks. The clear advantage of using a risk based weight of evidence approach is that while each line of evidence may have issues, their collective use substantially increases the overall robustness of the conclusions that can be made. The more each of the different lines of evidence are consistent with one or more of the scenarios, the greater the likelihood of the population being within this range. By contrast, the more the different lines of evidence are inconsistent with a specific scenario, the lower the likelihood that this is a reasonable reflection of reality. This type of approach is rapidly becoming the standard technique for dealing with low or limited data situations in fisheries and other environmental assessments (e.g. Wise et al., 2007; Linkov, 2012; Fletcher 2014).

There was a high level of consistency in the patterns seen among independent lines of evidence (Table 3). Importantly, there were no lines of evidence that were consistent with a decline in the population of white sharks over the past decade. Each of the lines of evidence that potentially reflect white shark relative abundance was consistent with there being either some level of increase over the past decade, or at worst no decline. An increasing trend is considered more likely if there were some benefits from their listing as protected species nearly two decades ago through the survival of some of the individuals that are released after their incidental capture by all sectors.

Most of these lines of evidence are independent of one another in terms of what is being measured and they cover wide or different parts of the spatial distribution this population of white shark. Thus, while the commercial catch rates and sightings abalone by abalone divers are both from southern WA, Neptune Islands is in SA and the shark attack data mostly emanate from the West Coast of WA. If the patterns only reflected a general shift in abundance from one location to another, then an increase in one location should be balanced by a decrease somewhere else.

Based on the currently available lines of evidence, the SWA white shark population is currently, at worst, stable but more possibly very slowly increasing. A stabilisation could be generated from just the reduced mortality occurring over the past twenty years from the significant reduction in commercial shark fishing effort across this entire south western region of Australia. A possible increase in population size would, however, appear to require the survival of at least some proportion of individuals that are still captured but are now released since their protection was introduced in 1997.

Based on the patterns and information contained within each of the lines of evidence, the overall number of scenarios that were considered plausible was reduced from 16 to 13. Furthermore, the comparative assessments identified a small number (3) of plausible scenarios that had a high level of consistency across all the different lines of evidence, all of which show an increasing trend in population numbers. Consequently, in terms of the assessment of the potential risks to human safety, this series of analyses provides sufficient evidence to conclude that it is at least plausible that there may have been some (albeit small) increase in white shark numbers since their protection. It is important to reflect that the inverse of this situation (similar types of evidence, mostly from eastern

Australia, which were indicative of population declines) was used in the 1990s as the basis to list this species as vulnerable (EA, 2002).

The range of population estimates that have been developed in this study from the more plausible scenarios may be considered preliminary. From a public safety perspective, however, they all indicate that the SWA population of white sharks is in the order of a few to several thousand with the high likelihood range being from 3400-5400. Moreover, the current estimated levels of depletion are not considered problematic for the ongoing effective population viability of this population. The current (2012) population levels for the plausible scenarios are at least 70% or above of their pre-exploitation levels with the most plausible scenarios having estimates of current population sizes that are above 85% of pre-1938 levels.

All of these estimates indicate that the population size is well above the level where risks to population viability and longer term sustainability would be of concern. Consequently, the proposed additional removal of a relatively small number of white sharks (< 10/year – less than 10% of the current estimated level of annual capture) for public safety purposes in the two MMAs is highly unlikely to make any material effect on this population. The modelling of the potential impact of even an additional 20 white shark mortalities per year (double the maximum estimated for the MMA program) for three years made no material change to the population size and the trajectory of any of the plausible scenarios with the most conservative still approximately 70% of the unexploited level. Thus the proposed drum line program operating in WA for three years will pose a negligible risk to the effective population viability/ sustainability of the SWA population of white sharks.

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## Appendix 1 – Output Tables from the population simulations

**Table A1. Population trajectories under the different scenarios of life history (LH), unexploited female population size ($N_0$), and fishing mortality. Depletion ratio (D.R.) is the female population size in 2012 ($N_{2012}$) relative to $N_0$. Simulations run under the assumption of 0% and 50% survival of sharks caught after protection between 1998 and 2012.**

| LH | $N_0$ | D.R. | $N_{2012}$ |
|---|---|---|---|
| 0% Survival | | | |
| **1** | 2,000 | 0.797 | 1,594 |
| | 3,000 | 0.873 | 2,619 |
| | 5,000 | 0.930 | 4,650 |
| | 10,000 | 0.967 | 9,670 |
| **2** | 2,000 | 0.417 | 834 |
| | 3,000 | 0.638 | 1,914 |
| | 5,000 | 0.795 | 3,975 |
| | 10,000 | 0.899 | 8,990 |
| 50% Survival | | | |
| 1 | 2,000 | 0.853 | 1,706 |
| | 3,000 | 0.900 | 2,700 |
| | 5,000 | 0.946 | 4,730 |
| | 10,000 | 0.970 | 9,700 |
| 2 | 2,000 | 0.523 | 1,046 |
| | 3,000 | 0.705 | 2,115 |
| | 5,000 | 0.825 | 4,125 |
| | 10,000 | 0.914 | 9,140 |

**Table A2. Future projections for testing the effect of white shark drum-line catches (DL catch) for three years under different scenarios of life history (LH), unexploited female population size ($N_0$), and fishing mortality. Depletion ratio (D.R.) is the female population size in 2016 ($N_{2016}$) relative to $N_0$. Drum-line catches were assumed at 10 females per year which is double maximum expected. Catch in commercial gillnet fisheries was set at the average catch of the last 5 years of data. Simulations run under the assumption of 0% and 50% survival of sharks caught between 1998 and 2012. Only plausible scenarios included. Note the majority of decline observed in the LH2 scenarios (indicated in brackets) were due to the underlying trends – see Figure 2 above.**

| LH | DL catch | $N_0$ | D.R. | $N_{2016}$ | *Total Popln after 3 years of DL Program* | *Population in 2012* |
|---|---|---|---|---|---|---|
| | | | **0% PRS** | | | |
| **1** | 10 | 2,000 | 0.792 | 1,585 | 3170 | 3188 |
| | | 3,000 | 0.872 | 2,615 | 5230 | 5238 |
| | | 5,000 | 0.932 | 4,658 | 9316 | 9300 |
| | | 10,000 | 0.967 | 9,674 | 19348 | 19340 |
| **2** | | 5,000 | 0.773 | 3,867 | 7734 | (7950) |
| | | 10,000 | 0.891 | 8,908 | 17816 | 17980 |
| | | | **50% PRS** | | | |
| **1** | 10 | 2,000 | 0.865 | 1,731 | 3462 | 3412 |
| | | 3,000 | 0.910 | 2,729 | 5458 | 5400 |
| | | 5,000 | 0.949 | 4,745 | 9490 | 9460 |
| | | 10,000 | 0.982 | 9,820 | 19640 | 19400 |
| **2** | | 3,000 | 0.681 | 2,042 | 4084 | (4230) |
| | | 5,000 | 0.815 | 4,077 | 8154 | (8250) |
| | | 10,000 | 0.913 | 9,133 | 18266 | 18280 |