

**Assessing and managing
interactions of protected and listed
marine species with commercial
fisheries in Western Australia**

FRDC Report – Project 2007/059

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1.0 Non technical summary

2007/059 Assessing and managing interactions of protected and listed marine species with commercial fisheries in Western Australia

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Objectives

1. Development of a risk-based management system using evidence-based science to assess the impact of incidental capture of protected and threatened species in the demersal gillnet fishery.
2. Analysis and interpretation of the interaction between demersal gillnetting and pinnipeds based on fishing effort and pinniped foraging behaviour.
3. Analysis of the factors influencing the rate of entanglement of large cetaceans in ropes of the Western Australia fishing industry and development of future interaction rate scenarios

Outcomes achieved to date

Bycatch of Australian sea lions (ASL) in demersal gillnet fisheries has been identified as a key threat to the species based on its assessment as threatened under the Environment Protection and Biodiversity Conservation Act (1999). This project has identified the areas where ASL are most likely to interact with the temperate shark fisheries (TSF) in Western Australia. It has also identified the vulnerability of many of the small colonies of ASL throughout WA to low levels of incidental mortality and developed a methodology to rank the level of risk to individual ASL colonies given hypothetical scenarios of incidental bycatch. Whilst the spatial scale of assessment was very broad in this report, these findings show that more robust estimates of incidental mortality of ASL across the range are needed. Modelled rates of entanglement of humpback whales in the West Coast Rock Lobster Fishery (WCRLF) suggest that increases in population size of humpback whales will not result in any appreciable increase in this rate across the fishery.

The management of interactions between protected species and commercial fishing operations has become a focus for management authorities over the past decade. Increasing concern from an ecological and public perspective has raised awareness about the need for determining where and how these interactions are occurring, and if necessary, what management actions are needed to address them. Assessments of the impacts of commercial fisheries on non-target species in Western Australia are provided annually by the Department of Fisheries in the *State of the Fisheries* report. This statutory reporting had highlighted two issues of interactions with protected species that warranted further investigation; A-Interaction between Australian sea lions (ASL) and demersal gillnet fisheries and B-Interaction between the West Coast Rock Lobster Fishery (WCRLF) and humpback whales.

Demersal gillnets have the potential to catch a variety of non-target species. Bycatch of marine mammals, and in particular pinnipeds (seals), in demersal gillnets is documented worldwide. The ASL is currently listed as a threatened species under the *EPBC Act*, and the draft Recovery Plan lists bycatch in demersal gillnet fisheries as a threatening process. Recent research on the concurrent issue in South Australia (SA) stated that “...bycatch models suggest that the majority of ASL subpopulations in SA are exposed to unsustainable levels of bycatch mortality” (p. 7, FRDC 2007/041, Goldsworthy et al. 2010). There are limited data to determine the level of threat posed to ASL from demersal gillnet fisheries in Western Australia.

This project approached the issue by determining the likelihood of interaction (i.e. being in the vicinity of a gillnet) between demersal gillnet fishing and ASL based on the spatial patterns of fishing effort and sea lion foraging effort. This approach results in a relative probability of interaction across the range of the fishery, but is not to be interpreted as a real level of interaction or incidental mortality. This showed us that there were two areas of highest probability of interaction, both centred on areas of the highest density of ASL. Based on our current level of understanding about ASL life history traits, many individual colonies in WA are susceptible to very low levels of on going, incidental mortality and could be threatened by bycatch in the gillnet sector of the Temperate Shark Fisheries (TSF) if indeed there is some level of capture. The patterns of likely interaction suggested that several of the ASL colonies on the easternmost part of the range on the south coast of WA and the largest colony in WA, Beagle Is, on the west coast could be the most likely to be affected by the inferred patterns of incidental bycatch in the demersal gillnet fisheries. Whilst this study did not aim to estimate current levels of incidental mortality of ASL in the TSF, it has highlighted the importance of obtaining some robust estimates of incidental mortality in lieu of the current uncertainty. The results from this study are important in the further management of this issue as they inform us of where we are likely to observe interactions between the TSF and ASL if this were indeed occurring. This will help in designing effective and robust independent observer programmes. It also informs us of where the relative threat exists among ASL colonies, and not just the areas of greatest likelihood of interaction with ASL. This will help in determining where mitigative action, if required, should best be implemented to reduce the threat to relevant ASL populations if this is found to be warranted.

A better understanding of ASL foraging patterns and demersal gillnet fishing effort on a finer spatial scale is also required to better determine the relative level of threat to ASL populations. The spatial reporting of fishery effort used in this report (60 x 60 nautical miles) is too coarse to accurately assess the threat to ASL populations that display variable patterns in foraging behaviour. The current reporting by fishers is now more fine scale. Additionally, the limited number of ASL tagged to determine foraging patterns reduces the accuracy and confidence of determining the threat to the specific colonies and age groups within each colony. The use of uniform estimates of ASL foraging behaviour in this study acts to inflate the relative risk of incidental mortality. Refined estimates of these two variables are needed to gain a better understanding of this issue.

There have been over 40 recorded entanglements of large whales in the ropes of the marine industries of Western Australia during the past 20 years. Whilst this issue does not constitute a large ecological pressure on large baleen whale stocks, it is considered to be a significant issue due to the high level of public interest. Over 90% of these entanglements could be sourced to the fishing gear of the West Coast Rock Lobster Fishery (WCRLF). The incidence of large whale entanglement in the WCRLF over the past 20 years was investigated to determine what factors, if any, could explain the rate of interaction. It was thought that population abundance

of humpback whales, the predominant species involved in entanglements in Western Australia, was a major factor in the rate of interaction. Recent estimates of an annual growth rate of approximately 10% of the group D humpback whale population (breeding stock defined as migrating along the western coast of Western Australia to calving and breeding grounds from sub-antarctic foraging area) suggested that the rate of entanglement could double approximately every 7 years. Analysis of these data showed a very moderate annual rate of increase of entanglement, much lower than expected given the rate of humpback whale population change. A raft of mitigative actions undertaken by the WCRLF including, changes to pot setting practises and length of ropes, as well as significant reductions in fishing effort in recent years are the most likely reasons for the very weak relationship between whale abundance and entanglement rate. In view of these factors it is unlikely that entanglement rate will increase at any greater rate than has been recorded over the past 5-10 years

Keywords

WA temperate demersal gillnet fisheries, West Coast Rock Lobster Fishery, Australian sea lion, Humpback whale, incidental bycatch.

2.0 Acknowledgements

I thank FRDC, DOFWA and the Australian Centre for Marine Mammal Science (ACAMMS) for their financial support in this project. I must also thank the Professional Shark Fisheries President Neville Mansted and elected representative Geoff Campbell in supporting the development of the grant proposal and participating in the discussions and project development. The Western Australian Fishing Industry Council, and in particular, Felicity Horne, were very supportive of the development of the project and assisted in delivering the project's aims and outcomes to the industry members. Carl Bevilaqua, SeaNet Extension Officer, was also supportive and integral in developing the project and encouraging industry involvement. All of the above individuals, as well as representatives of the Conservation Council of WA (Nic Dunlop), Department of Fisheries Shark Research Scientist (Rory McAuley) and Departmental Management Officers were members of the Sea Lion and Shark Fishing Interaction Advisory Group (SLSFIAG), which provided advice on the formulation of the project and feedback on the results. I am indebted to their willingness to be involved and commitment to the process that ensured all participants and stakeholders were provided the opportunity to contribute. Doug Coughran (DEC) was the source of data on the entanglements of whales in marine gear across the State and I am indebted to his advice and understanding of the issues involved in large whale entanglements and disentanglements and the success of mitigation strategies. Consultation with representatives of the WCRLF was also invaluable in understanding the factors involved in entanglements and the implementation of mitigation strategies across the fishery that have resulted in a successful management of the issue.

Many thanks to Brett Molony (DOF) for numerous critical reviews of the report prior to submission and to Carolyn Stewardson (FRDC) for her patience and input in finalising the report. I am extremely grateful to Simon Goldsworthy (SARDI) for his assistance in development of the spatial probability model and its implementation. Discussions with Peter Shaughnessy (CSIRO), Nick Gales (AAD) and Derek Hamer (SARDI) also greatly informed my understanding of the issues surrounding the interaction between ASL and demersal gillnets.

3.0 Background

The interaction of commercial fishing activities with protected species has become an increasingly significant issue in Australia, both ecologically and socially, over the past decade. The development of the *Environmental Protection and Biodiversity Conservation Act* (EPBC Act, 1999) and the associated requirement for all export fisheries to undergo a full ecological assessment includes managing and mitigating impacts on protected species. There is also strong public opinion about the need to minimise such interactions and concern about tolerating even low levels of incidental mortality of key protected species. Whilst such opinions may be based on social concerns and not ecological sustainability principles, they can still impact upon public policy. In the absence of well researched and formulated management strategies, it is possible that long term access of some commercial fishing operations may largely be determined by their impacts on protected species.

The shift to a more holistic approach in natural resource management of commercial fishing requires a more comprehensive approach to meet the principles of ecosystem-based fishery management (EBFM). This process has begun for the management of commercial fisheries in Western Australia with the issue of protected species interactions having already been addressed for some fisheries (e.g. SLEDs in the West Coast Rock Lobster Fishery; dolphin exclusion grids in the Pilbara Trawl Fishery).

This project targeted two specific interaction issues that have been identified in WA commercial fisheries. The most recent assessment in 2009 of the TSF in WA by the Commonwealth under the EPBC Act (1999) stipulates that the management authority (DoF) must undertake a study to estimate the probability of interaction between fishing activity and the ASL and determine a scientifically robust level of coverage for an effective independent observer programme. Implementation of this observer programme should be achieved subject to the outcome of the previous stage. This is applicable to both the Joint Authority Southern Demersal Gillnet and Demersal Longline Fishery (JASDGDLF) along the south coast of WA and the West Coast Demersal Gillnet and Demersal Longline Fishery (WCDGDLF) along the southern half of the west coast of WA. These two fisheries will be referred to collectively in this document as the TSF.

Independent risk assessment of ecological impacts of the WCRLF as part of the fishery's Marine Stewardship Council certification stipulated that whilst the entanglement of large whales did not represent a serious ecological threat to the population, it was nevertheless a significant social issue due to its high visibility, the inherent social value of whales in western society and the likelihood that the population recovery of large whales would lead to a continued increase in entanglements (DoF 2004). Determining the likely effects of an increasing abundance of humpback whales on the entanglement rate was seen as an important step in the management of this issue.

3.1 Background to the Temperate Shark Fisheries interaction with Australian sea lions (ASL)

The TSF are demersal-set gillnet and demersal-set longline fisheries which operate on the south and south-west coasts of WA respectively targeting shark and scalefish. These fisheries landed a combined total of 1300 tonnes of shark and 230 tonnes of scalefish in 2005/06 to the value of over \$6M (Fletcher & Santoro 2009). Both of these fisheries have undergone a series of management measures since 2004 in order to maintain target stock sustainability. The latest raft of changes implemented from 2006/07 onwards have been designed to to reduce fishing

effort capacity to 2001/02 levels through the use of an explicit hourly fishing effort system. This has led to an approximate 40% reduction in the maximum allowable fishing effort by removing latent effort and a restructuring of the measurement of fishing effort to ensure a more accurate assessment. Assessment of the current levels of fishing effort from the new daily logbook system is still being performed and unfortunately were unavailable for this study. For this reason data from 2005/06 are the latest used in this report. Other changes to the fisheries regulation in recent years have led to an effective cessation of longline fishing in these two fisheries in order to reduce mortality of mature dusky and sandbar sharks in an effort to promote the recovery of these species.

Demersal set gillnets have one of the highest rates of incidental bycatch as a fishing technique, especially for pinnipeds (Woodley & Lavigne 1991, Reijnders et al. 1993). There has been only one independent study of the composition of incidental bycatch in the TSF, conducted between 1994-1999 (McAuley & Simpfendorfer 2003). This study observed 2-18% of fishing effort across the entire range of the two TSF and only observed a single incidental mortality of an ASL, a New Zealand fur seal and a bottlenose dolphin during the entire study. The very low frequency of observed incidental mortality events makes it hard to extrapolate these figures to any meaningful estimate of overall incidental mortality rate in the TSF. In addition, observer effort was not consistent across the fisheries range and in some cases a lower than average level of fishing effort was observed in areas of high ASL abundance. This will have reduced the probability of observing entanglements of ASLs, but perhaps not of other marine mammals such as bottlenose dolphins that may be more uniform in distribution.

Whilst there has been a significant reduction in the fishing effort in the two gillnet fisheries in recent times, there may still be a significant issue with regards to the impact of incidental mortality upon the ASL. A review of pinniped interactions with commercial fisheries in Australia found that ASL had a level of probability of capture in demersal-set gillnets and anecdotal evidence suggested that captures were of higher probability in some areas such as around Kangaroo Is (Shaughnessy et al. 2003). Recent independent observer studies in the Commonwealth South-East Shark and Scalefish Fishery (SESSF) in South Australia has shown a higher than expected level of ASL incidental mortality and an associated risk of extinction of many colonies (Goldsworthy 2008, Goldsworthy et al. 2010). In line with the recent recommendations of the Commonwealth strategic assessment of the two TSF, it has become necessary to further investigate the issue of TEPS interactions and in particular the interaction with the recently listed *Endangered* species, the ASL.

The ASL is Australia's only endemic pinniped species and was recently listed as a threatened species ("Vulnerable" category) under the *Environmental Protection and Biodiversity Act* (1999), based on the likelihood of further population declines and a limited number of breeding adults. Amongst the key threatening processes determined in the draft recovery plan was the interaction with demersal gillnet fisheries across its range (Goldsworthy et al. 2009). Anecdotal evidence suggests that ASLs are vulnerable to capture in demersal set gillnets (Shaughnessy et al. 2003) and their life history traits make them vulnerable to even low levels of incidental mortality (Goldsworthy & Page 2007, Campbell et al. 2008a). Analysis of the spatial characteristics of demersal gillnet fishing and ASL foraging effort in South Australia showed that fishing effort varied considerably around colonies and that colonies with limited pup production (< 40 pups) would be at risk of going extinct in the face of low levels of ongoing incidental mortality (Goldsworthy & Page 2007, Goldsworthy et al. 2010).

ASLs are almost exclusively benthic foragers and the research to date shows that animals spend

between 40-50% of their time at sea on the benthos (Costa & Gales 2003, Fowler et al. 2006, Campbell & Holley 2007). Demersal set gillnets are set just on the sea bottom to capture sharks and benthic scalefish and the mesh size of 6.5-7.0 inches is large enough to entangle sea lions. ASLs also exhibit one of the highest recorded rates of entanglement in marine debris, including demersal gillnet fishing net (Page et al. 2004). Spatial foraging patterns of tagged ASLs to date have shown that they range from shallow coastal waters (<10m) to the continental shelf edge, with adult females foraging up to 70 kilometres away from their breeding sites (Goldsworthy & Page 2007, Campbell 2008). This means that ASLs have the capacity to forage over the entire continental shelf, ensuring a complete overlap with the area of operation of the demersal gillnet shark fisheries in WA. Site specific foraging patterns could strongly influence the probability of interaction with the demersal gillnet fisheries and the corresponding level of risk (Goldsworthy & Page 2007).

The most recent IUCN assessment of status of pinniped species worldwide upgraded the status of ASL to *Endangered* based on the reported decline in abundance at some populations, the threat of incidental mortality from commercial fisheries and the projected viability of populations based on these scenarios (IUCN 2008). This recent listing adds further weight to the need to determine the nature of the interaction with demersal-set gillnet fisheries across its range.

3.2 West Coast Rock Lobster Fishery (WCRLF) and large whale entanglement

The high numbers of pots (traps) with floats and lines in commercial fisheries worldwide has led to an increasing rate of entanglement of large marine life including large baleen whales and sea turtles (Robbins & Mattila 2004). In Western Australia a total of 41 large whales were recorded as entangled in marine debris between 1990-2009, 33 of which were in pot ropes of the WCRLF. Of this portion, 95% were humpback whales, making the entanglement of humpback whales in the pot ropes of the WCRLF the most significant fishery-whale interaction issue. This fishery is the highest user of pots in the state with in excess of 60,000 individual pots in the water during fishing seasons, not to mention the volume of recreational fishing pots. Over the last 20 years there has been an increase in the numbers of reported entanglements, in part, due to the increased abundance of humpback whales in the Group IV region (Johnston & Butterworth 2006). With this population undergoing an estimated annual increase of nearly 10%, the potential for considerably higher rates of entanglement to occur is apparent. This issue does not represent a threat to the population recovery as the entanglement rate is very low in relation to the estimated population size (<0.01%), but does represent a considerable social issue as there is strong public sentiment regarding the protection of once endangered species of whales. This is reflected in Federal Government policy and the general approach to whale conservation. Even though the Humpback whale was recently removed from the IUCN *Vulnerable* status list, it is still protected under the *EPBC Act* as a migratory species. The Southern Right whale is also prone to entanglement in marine ropes and debris and is currently listed as *endangered* under the *EPBC Act* (1999), though its range overlaps to a much lesser degree with the WCRLF.

A large whale disentanglement team established by the Department of Environment and Conservation (DEC) in WA has a very high rate of success of freeing whales of encumbering entanglements. This has been especially successful for instances involving the WCRLF due to the high level of co-operation between industry, DEC and Department of Fisheries (DoF). The adoption of a Code of Practice in 2007 (developed in conjunction by WRLC, DEC & SeaNet) to address and mitigate the issue has been of enormous benefit in not only ensuring successful outcomes when entanglements occur but also in developing fishing practices to minimise its occurrence.

4.0 Need

Incidental mortality in commercial fishing activities is acknowledged as an issue for many protected and endangered species throughout the world. Whilst Australia is considered a world leader in managing these interactions, further improvements in management and greater research are still required to meet the expectations of the community. Within WA, to address the variety of interactions with protected and listed marine species across all our commercial fisheries in a cost effective manner, an holistic and integrated approach needs to be taken. Several protected species issues have already been identified through existing research projects and management processes, including entanglement of whales in fishing ropes and interactions between seals and demersal gillnets. These two issues involve protected species on the Commonwealth threatened list (i.e the ASL, Humpback and Southern Right Whale) which generates attention from both an ecological and a social perspective. A greater understanding of the factors involved in these interactions will be needed to design mitigation programs. Assessments at both the individual fishery and bioregional level will be required to input into the ecosystem-based fisheries management (EBFM) frameworks that are being developed for each WA bioregion. There is also the ongoing requirement for all fisheries to satisfy the protected species criteria under the *EPBC Act* (1999) which for some is vital to maintain their export certification. The most recent assessment of the demersal gillnet fisheries in WA outlined the need for a specific programme to determine the nature and extent of the interaction and impact on ASL populations. Moreover, there is the potential for significant pressure from advocacy groups to press for regulation of fishing effort or methods unless well-formulated management systems to address these pressing issues are developed.

5.0 Objectives

1. Development of a risk-based management system using evidence-based science to assess the impact of incidental capture of protected and threatened species in the demersal gillnet fishery.
2. Analysis and interpretation of the interaction between demersal gillnetting and pinnipeds based on fishing effort and pinniped foraging behaviour.
3. Analysis of the factors influencing the rate of entanglement of large cetaceans in ropes of the Western Australia fishing industry and development of future interaction rate scenarios

This report was structured such that the in achieving the first two objectives were combined to form Chapter 6 and that the research methodologies, results and discussion of results in achieving the third objective was presented in Chapter 7.

6.0 Interaction between the demersal gillnet fisheries and australian sea lions in Western Australia

6.1 Methods

Assessment of the spatial overlap between fishing effort and ASL foraging effort was performed to characterise the probabilities of interaction at individual management units (breeding colonies) of ASL. To determine a risk-based approach to the issue of the impact of incidental bycatch of ASLs in the demersal gillnet fisheries a range of scenarios within a Population Viability Analysis (PVA) were undertaken and the outputs of the spatial interaction index used to produce a hierarchical index of potential risk for the ASL colonies in WA.

6.1.1 Spatial model of ASL foraging and demersal gillnet fishing effort and the probability of interaction

Estimates were made of the spatial extent of foraging for five age/gender classes, pups, juveniles, sub-adult males (SAMS), adult females and adult males (bulls), as defined by Gales et al. (1994). These were produced using the normal probability density function with a mean and standard deviation of distance travelled from the breeding colony, as this species is a central-placed forager (Goldsworthy & Page (2007)). The direction of foraging effort was not constrained, but foraging effort was constrained by the coast and continental shelf edge (200m). Foraging ranges of the age/gender class of animals were adapted from Goldsworthy & Page (2007) with empirical data from this and other studies where applicable. A list of the mean and standard deviations of foraging ranges used in the calculation of the distribution of foraging effort is presented in Table 6.1.

The proportion of foraging effort for each age/gender group at each colony was calculated for each point on a 10 x 10km grid that overlaid the distribution of the ASL population in WA across the continental shelf. This was done using the normal probability density function, the mean and standard deviations of foraging range and the distance between each node point and the respective breeding colony. To apportion foraging effort on the same spatial scale as the CAES (Catch And Effort Statistics) blocks of reported fishing effort (60 x 60 nautical mile), the relative proportions of foraging effort for all points that fell within the confines of a CAES block were summed. This produced a matrix of proportional foraging effort for each age/gender class for each breeding colony within each CAES block (see Appendix 1).

To calculate the relative foraging effort of each different sex/age class, the normal probability proportions were adjusted for proportion of time spent at sea. This adjusts for the different length of foraging trips and time ashore undertaken by different age classes. Mean proportions of time at sea were determined from empirical data from this study (see Table 6.2) and other studies of ASL. Adjusting for the number of each different sex/age class was also performed. The proportion of each age class in the population was calculated by creating a stable age-structured population based on survival curves in Goldsworthy & Page (2007) using mean values of pup production (P), which were created with data from ASL and other otariid species. The relative proportion of each sex/age class was used to multiply each of the matrices of foraging effort probability, these were summed and made proportional so as to represent the spatial foraging effort of the entire population. In effect, the spatial foraging effort is a probability of occurrence of sea lions from an individual colony within each CAES block.

Nominal foraging effort at each node point was expressed as the number of seal foraging days/year

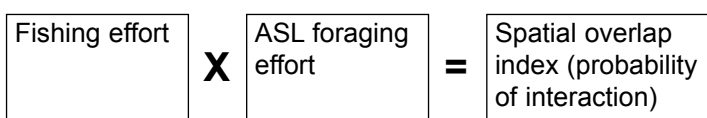
based on the relative distribution of foraging effort, the relative proportion of time at sea and the number of each age/gender group at each colony based on the age-structured population and mean pup production numbers. The values of seal foraging days/year at all node points were interpolated using the inverse distance weighting method in the Spatial Analysis programme within the GIS Arcview v3.2 programme to visually demonstrate the distribution of ASL foraging effort.

There are two fisheries that permit demersal gillnetting over the range of the ASL in Western Australia. These are the West Coast Demersal Gillnet and Demersal Longline Fishery (WCDGDLF) that extends from Cape Leeuwin to Shark Bay, and the Joint Authority Southern Demersal Gillnet and Demersal Longline Fishery (JASDGDLF), that extends from Cape Leeuwin to the SA-WA border (Fig. 6.1). The compulsory reporting of fishing effort for these two fisheries includes the length of net set and hours fished, allowing a measure of kilometre gillnet hours (km net hrs) set per month for each CAES block. Verified data on this scale exists from 1992/93-2005/06. Mean fishing effort (averaged over 4-5 year blocks) was plotted against ASL distribution to examine changes in the intensity and distribution of fishing around ASL colonies over this period. A set of management changes were introduced in the 2006/07 season to reduce the fishing capacity and measure fishing effort on a finer spatial and temporal scale, however verified levels of fishing effort have not been calculated since this point (Fletcher & Santoro 2009). Whilst the fishery effort data for the 2006/07 remains unverified, it represents the most up to date, relative level of effort across CAES blocks, if not the absolute measure of effort needed for fishery management purposes (R McAuley pers comm.). Based on this qualification, these data were used in calculating the probability of interaction between ASL and gillnet fishing effort to reflect the most contemporary estimate of relative probability of risk of incidental mortality. The level of fishing effort across all blocks was made proportional to create a probability matrix to match with the representation of ASL foraging probability and produce the interaction probability (spatial overlap index).

The probability of interaction is a representation of the spatial overlap of foraging effort and the fishing effort. This interaction probability is an adaptation from Schoener (1968). This assumes that interaction occurs based on the probability of ASL foraging effort and gillnet fishing effort occurring at the same space in time (see Box 1).

A proportional interaction rate for each colony x CAES block was calculated as the product of the spatial foraging effort for each colony x CAES block and the fishing effort per CAES block of the most recent season (2006/07). The interaction probabilities can then be used to apportion a nominal level of mortality among the different colonies based on a hypothetical scenario of total incidental mortalities (F) due to interaction with demersal gillnet fisheries.

Box 1. Spatial overlap indices and probability matrices



Diagrammatic representation of the approach used to determine the likelihoods of interaction between demersal fishing effort and foraging sea lions. The two spatial probability matrices of fishing effort and foraging effort at a number of xy node points are multiplied to produce a spatial overlap index. This spatial overlap probability does not imply that every interaction equals an incidental mortality event, but does imply that the relative level of interaction across the area is directly related to the index of spatial overlap. Because the fishing and foraging matrices are probabilistic, they cannot produce a measure of the change in intensity of the spatial overlap index.

The level of mortality for each colony can then be broken down into the different age/gender groups based on the proportions of each age/gender group that make up the spatial foraging effort of the relevant subpopulation. This was calculated using the stable age-structured population and corrected for the proportion of time at sea based on empirical satellite tracking and dive data. The number of females (F_f) subject to incidental mortality in any hypothetical value of F was calculated by summing the number of female pups ($N/2$), the number of female juveniles (based on the sex specific survival curve in Goldsworthy & Page 2007) and the number of adult females in the population. This measure of the incidental mortality rate was used in the PVA as the analysis was structured as separate populations of breeding females based on the extreme philopatry of females (Campbell et al. 2008a). This approach has been used for ASL in a number of other studies of anthropogenic mortality (Goldsworthy & Page 2007, Campbell et al. 2008b).

6.1.2 Population viability analysis (PVA) and impact of incidental mortality

Location of ASL colonies within Western Australia was taken from Gales et al. (1994). Estimates of pup production (P) were taken from Gales et al. (1994) and modified by recent surveys (R. Campbell, unpublished data). Pup production numbers were used to determine age-structured population abundance for each individual colony using the gender specific survival curves for ASL in Goldsworthy & Page (2007). Survival was calculated for each 1.5 year interval based on data from other species as well as the limited information available for ASL. Maximum age of females was estimated at 25 years based on tooth analysis (R. McIntosh, unpublished data) and 15 years for males. The survival curves ($a=1.5$ yrs) used were; females ($S=0.627-0.048a + 0.001a^2-(0.159 \times 10^{-4})a^3$), and males ($S=0.627-0.082a + 0.005a^2 -(0.962 \times 10^{-4})a^3$). All colonies were assumed to have the same demographic parameters.

Models were developed for the female part of the population only and for each colony separately due to the extreme natal site fidelity of female ASL (Campbell et al. 2008a). A Leslie matrix of female population based on pup production estimates (Assuming 1:1 sex ratio at birth, no. female pups = $P/2$) was created to simulate ASL population trajectories for 100 breeding cycles (Table 6.1).

Density-independent models were used as the current population abundance is well below that of estimated pristine levels (Ling 1999, Campbell 2005), and there is limited evidence of density-dependent effects on ASL demographic traits (McKenzie et al. 2005). There was no inclusion of potential Allee effects (Allee et al. 1949) or genetic effects (e.g. inbreeding co-efficients, reduced heritable fitness) as there were insufficient data to quantify these effects.

Stochastic models can simulate population growth and probabilities of extinction and population reduction. The PVA in this study was performed using the RAMAS® Metapop software (v1.1, Akcakaya 1998) based on the Leslie matrix of female ASL. Quantifying the potential risk to individual ASL populations due to varying levels of incidental mortality was measured by the rate of decline of population abundance and the probability of extinction (or quasi-extinction). Quasi-extinction was defined as when a population fell below a threshold of 10 females. Demographic stochasticity was simulated by sampling the numbers of survivors from a binomial distribution and young from a Poisson distribution in the RAMAS Metapop programme (Akcakaya 1998).

PVAs were performed on two baseline population trajectories, a stable population trajectory ($r=0$) and an increasing population trajectory ($r=0.01$). For most colonies of ASL there were

insufficient data to assess trends in abundance, however those with medium term datasets suggest that colonies were either stable or decreasing (McKenzie et al. 2005). The stable population trajectory represents the majority of WA colonies based on present knowledge and the increasing population trajectory scenario was used to determine if a positive value of r affected the outcome. The use of extant population trajectories, which includes all potential sources of anthropogenic mortality, may underestimate the baseline trajectories of ASL population growth. The increasing population trajectory was created by adjusting relative survival of all age classes (1.01) to produce a 1% per season growth rate, where $(e^r - 1) \times 100$.

PVAs were simulated using 1000 replicates for 100 breeding cycles (100 x 1.5yrs). The exponential growth rate (r) and probability of extinction was recorded and assessed against the current conservation status criteria E from the IUCN red list (version 3.1).

Vulnerable-10% probability of extinction within 100 years

Endangered-20% probability of extinction within 20 years or five generations, whichever is longer (62 years)

Critically Endangered-50% probability of extinction within 10 years or 3 generations (35 yrs, see below), whichever is longer

Terminal and/or Quasi Extinction-Defined here as < 10 females.

Generation time for ASL was estimated to be 12.4 yrs, based on the Leslie matrix of mature females created from the age-specific survival curves (Goldsworthy & Page (2007). Projections for each colony were run with simulated removal of increasing numbers of juvenile females until populations reached the categories of criteria E. It should be noted that the removal of juvenile females is a conservative estimate of the impact on population viability. Removal of mature females versus juvenile females would result in a greater probability of extinction and reduced estimates of r .

Table 6.1. Mean pup production values (P) and mean (\pm sd) foraging distance for age/gender groups for each Australian sea lion breeding colony.

Colony	Pup Production (P)	Bulls	Cows	SAMS	Juvs	Pups
Abrolhos	20	80 (55)	20 (10)	24 (15)	12 (5)	8 (4)
Beagle	79	80 (55)	20 (10)	24 (15)	12 (5)	8 (4)
Nth Fish	63	80 (55)	20 (10)	24 (15)	12 (5)	8 (4)
Buller	39	80 (55)	20 (10)	24 (15)	12 (5)	8 (4)
Hauloff	35	80 (55)	20 (10)	24 (15)	12 (5)	8 (4)
Doubtful	20	80 (55)	20 (10)	24 (15)	12 (5)	8 (4)
Red Islet	40	80 (55)	20 (10)	24 (15)	12 (5)	8 (4)
West Is	25	80 (55)	30 (20)	24 (15)	18 (10)	8 (4)
Investigator	25	80 (55)	30 (20)	24 (15)	18 (10)	8 (4)
Termination	10	80 (55)	20 (10)	24 (15)	18 (10)	8 (4)
McKenzie	10	80 (55)	20 (10)	24 (15)	18 (10)	8 (4)
Kimberley	50	80 (55)	20 (10)	24 (15)	18 (10)	8 (4)
Kermadec	5	80 (55)	20 (10)	24 (15)	18 (10)	8 (4)
Taylor Is	10	80 (55)	20 (10)	24 (15)	18 (10)	8 (4)
Glennie	30	80 (55)	20 (10)	24 (15)	18 (10)	8 (4)
George	5	80 (55)	20 (10)	24 (15)	18 (10)	8 (4)
Wickham	20	80 (55)	20 (10)	24 (15)	18 (10)	8 (4)
Salisbury	25	80 (55)	20 (10)	24 (15)	18 (10)	8 (4)
Cooper	5	80 (55)	20 (10)	24 (15)	18 (10)	8 (4)
Round	25	80 (55)	20 (10)	24 (15)	18 (10)	8 (4)
Six Mile	50	80 (55)	20 (10)	24 (15)	18 (10)	8 (4)
Ford Is	30	80 (55)	30 (20)	24 (15)	18 (10)	8 (4)
Spindle	60	80 (55)	30 (20)	24 (15)	18 (10)	8 (4)
Twilight Cove	5	80 (55)	20 (10)	24 (15)	18 (10)	8 (4)

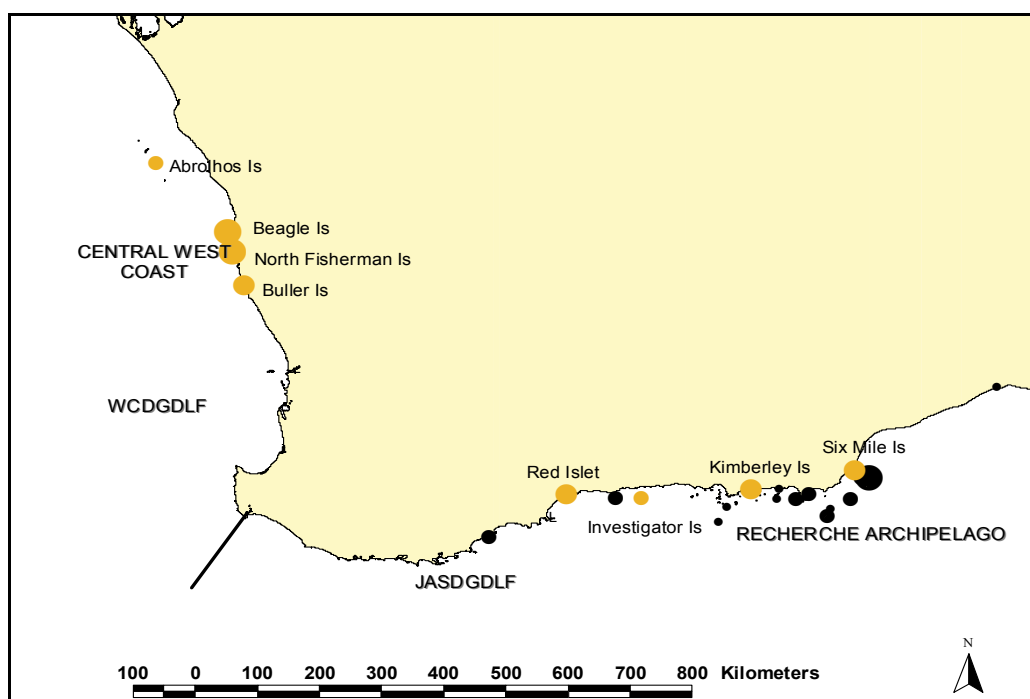


Figure 6.1. Distribution of Australian sea lion colonies and areas referred to in the text. The size of ASL breeding colonies symbols (●) are relative to the value of pup production and the tagging locations are shown in yellow. The boundaries of the two relevant demersal gillnet fisheries, WCDGDLF & JASDGLF, are effectively defined by the line extending from the south-west corner of the WA coast and the northern and eastern boundaries, respectively, of the map.

6.2 Results

6.2.1 Spatial model of ASL foraging and demersal fishing effort and the probability of interaction

A summary of characteristics of foraging range for each age/gender group at each colony is presented in Table 6.1. There was general concurrence between studies of foraging range of pup, juvenile and adult females in Western Australia and South Australia. The resulting map of foraging effort across WA generally mirrors the distribution of pup production, with a slightly greater density of foraging effort on the west coast than the south coast due to the smaller foraging ranges (Figs. 6.2 & 6.3).

The overlay of the at sea locations on the modelled range of spatial foraging effort provides an interesting comparison and measure of the representation of the model (Fig. 6.3). In some cases it appears that the modelled foraging range extends well beyond the empirical at-sea data, especially in its range toward the continental shelf. However, the limited number of ASLs that have been tagged at each location for a short period of time (2-4 weeks) means that the total ASL foraging effort will be grossly under-represented by these data.

The level of demersal gillnet fishing effort has decreased over time on both the west coast and south coast centred fisheries. Historically, the fishing effort has been concentrated on the south coast within CAES blocks that contain the majority of ASL breeding colonies (Figs. 6.4-6.6). There has been a significant reduction in the amount of fishing effort in most CAES blocks that are adjacent to ASL breeding colonies over time. In some cases, there has been an 80% reduction in the level of effort in specific CAES blocks. One notable exception has been the relative increase in fishing effort in block 29142, just to the north of Beagle Island in the past ten years. The most recent management measures have further reduced fishing effort, however there is still a relatively high level of fishing effort in CAES blocks adjacent to the majority of breeding colonies (Fig. 6.7). The spatial scale of fishing effort reported is very coarse and does not distinguish between nearshore and continental shelf edge within a fishing block. Due to the different distribution and abundance of commercial shark species, relative fishing effort across depth within a fishing block changes considerably over space and time. As such it is difficult to make direct comparisons between the levels of fishing effort across space and time and the associated rate of interaction with ASL.

The patterns of relative interaction probability are fairly uniform across the south coast with the highest levels occurring in proximity to the easternmost breeding colonies (Fig. 6.8). Virtually all colonies are expected to exhibit moderate levels of interaction with demersal gillnet fishing effort. On the west coast, the majority of the interaction is predicted to be centred on the Beagle Island population with low levels expected at the three other breeding colonies. The rate of interaction at the Abrolhos Islands is probably an overestimate as there is an exclusion of gillnet fishing effort within three nautical miles of the islands, which includes a large proportion of the foraging effort of ASL at this site based on tagging studies.

Whilst there has been no estimate of historical interaction probabilities, it is assumed that the rate of interaction is directly proportional to the level of fishing effort, assuming a constant foraging effort. Given that TSF management has targeted an approximate 40% reduction in fishing effort to 2001/02 levels, this suggests that the probability of interaction has been significantly reduced at the majority of breeding colonies across WA since the inception of effort reduction measures.

6.2.2 Population Viability Analysis

PVA outputs show that many of the breeding colonies of ASL are vulnerable to very low levels of incidental mortality assuming a stable or increasing population trajectory (Figs. 6.9a&b). Due to the stochasticity in the model, all colonies that produce less than 10 pups were likely to qualify for *endangered* or *critically endangered* status under simulations without any additional incidental mortality. Under the stable trajectory, 1-2 mortalities per breeding cycle was sufficient to drive every colony into the *endangered* or *critically endangered* category, and only 3 mortalities was enough to push over half of the colonies to *extinct* status. Similarly for the increasing population scenario, 2-3 mortalities per breeding cycle was enough to drive all colonies into the *endangered* or *critically endangered* category, and 6 mortalities per cycle would result in over half of all colonies going *extinct*.

Distribution of the hypothetical incidental mortalities based on the interaction probabilities suggests that at a rate of 40 mortalities per breeding cycle (approx. 27 per annual fishing season), nearly 80% of breeding colonies would be reclassified as *endangered* under both the stable and increasing population model (Figs. 6.10a&b). This is an equivalent rate of 1.8×10^{-4} seals /km net hour/year, or 1 seal every 5,500 km net hours. The first incident of a colony going *extinct* (Spindle Is) started at a relatively low total of just 51 incidental mortalities per breeding cycle. At a rate of 100 incidental mortalities per breeding cycle there may be as many as 8 colonies that would qualify for *extinct* under the stable population trajectory, but it is estimated that over 100 mortalities are required to push the first colony into these categories under the nominal 1% population growth rate trajectory.

The PVA suggests that Spindle Is, in the eastern end of the range on the south coast, would be the most potentially at risk colony. The next group of potentially at risk populations included a number of colonies in the same area (i.e Spindle and Ford Iss.) and the largest colony in WA, Beagle Is, on the central west coast. Many of the inshore colonies on the south coast were deemed to be at a relatively low potential risk, and this also applied to the three other breeding colonies on the west coast of WA (North Fisherman Is, Buller Is and Abrolhos Is.).

These results show that the small, isolated colonies of ASL in Western Australia are under threat from even low levels of additional, human-sourced mortality. Secondly, the underlying population growth rate or trajectory can have a strong bearing on a population reaching *extinct* (or quasi-extinct) status, but not so much on the classification of populations as *endangered* or *critically endangered*.

The sensitivity of the model to determine impacts on varying sizes of colonies was determined by looking at the regression between the number of additional mortalities required to shift individual colonies between conservation categories (i.e. *Critically Endangered* to *extinct*) and the size of the colony (pup production). This relationship was non-linear (Fig. 6.11) indicating a bias of greater impact upon relatively larger colonies.

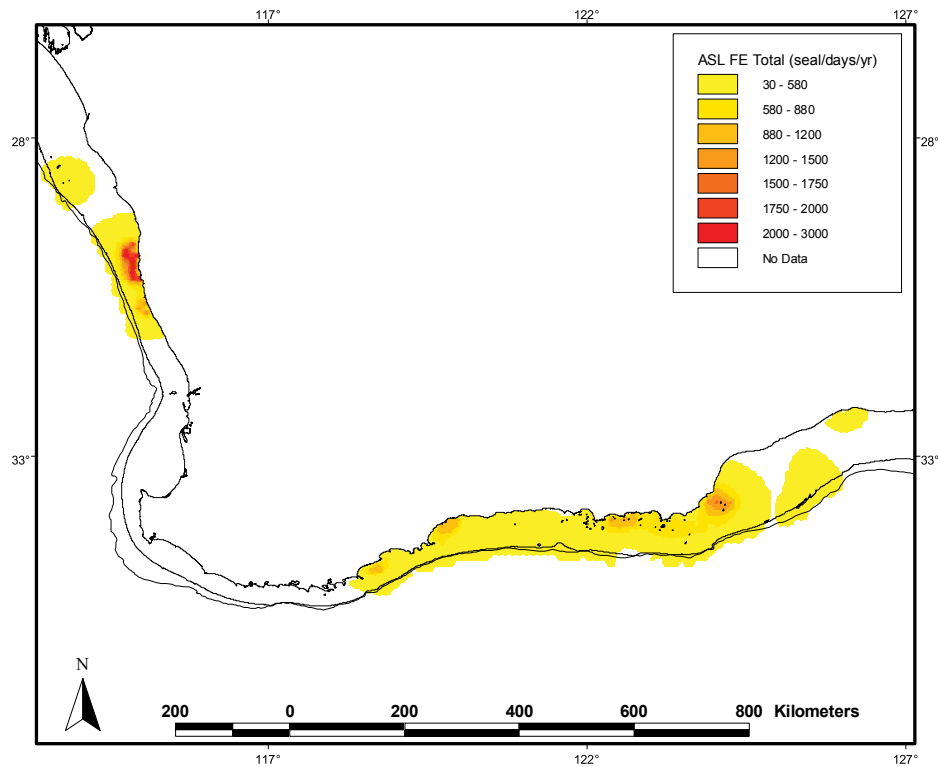


Figure 6.2. Spatial model of the total foraging effort (FE) of the Australian sea lion population in WA expressed as the number of seal foraging days per year.

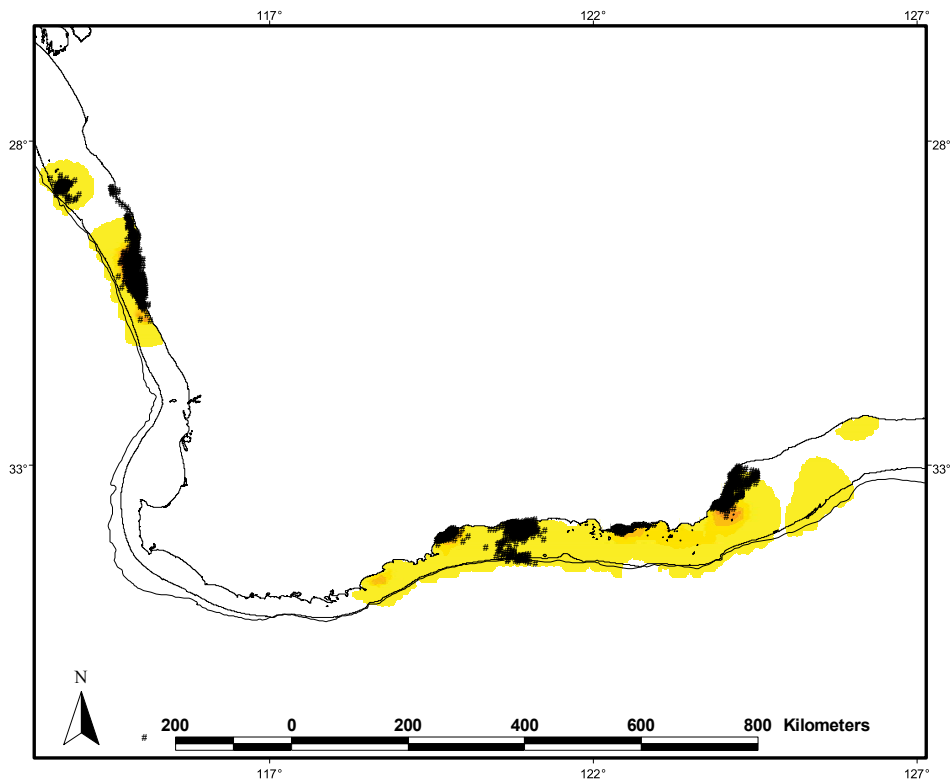


Figure 6.3. Model of spatial foraging effort of ASL with the overlay of all PTT derived at sea locations from (Figures 2-8) from the seven tagging locations. All at-sea locations are from adult female, juvenile and pup age classes. The majority of locations provided fitted well within the bounds of the model.

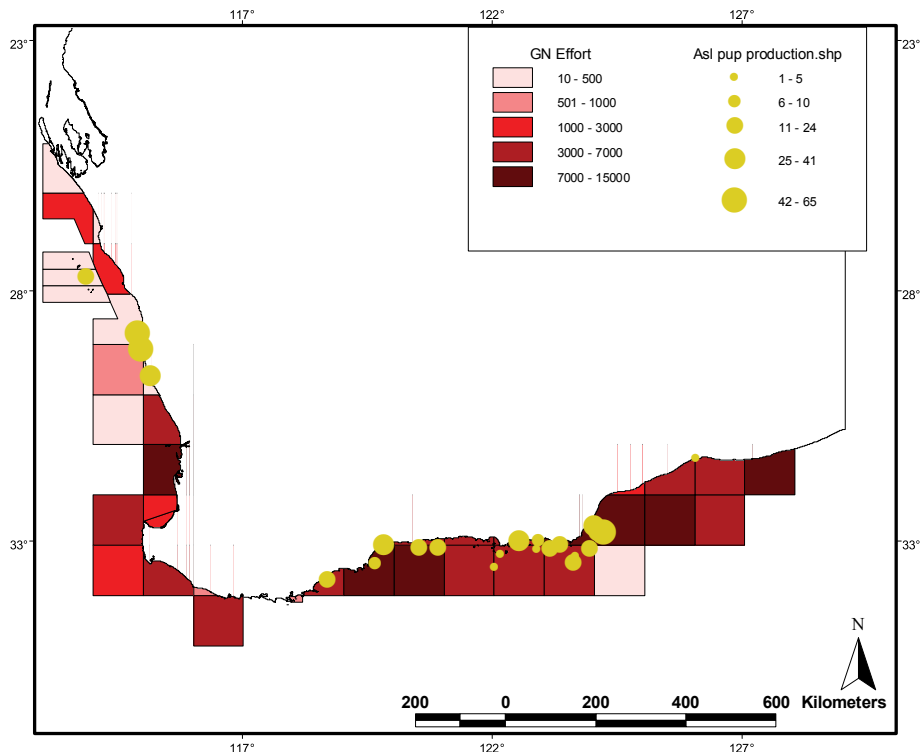


Figure 6.4. Mean distribution of gillnet (GN) fishing effort ('000s km gn hours) per CAES block between 1992/93 and 1995/96 fishing seasons in the WCDGDLF and JASDGLF. Relative distribution and abundance of Australian sea lion pup production is shown by the graduated symbols.

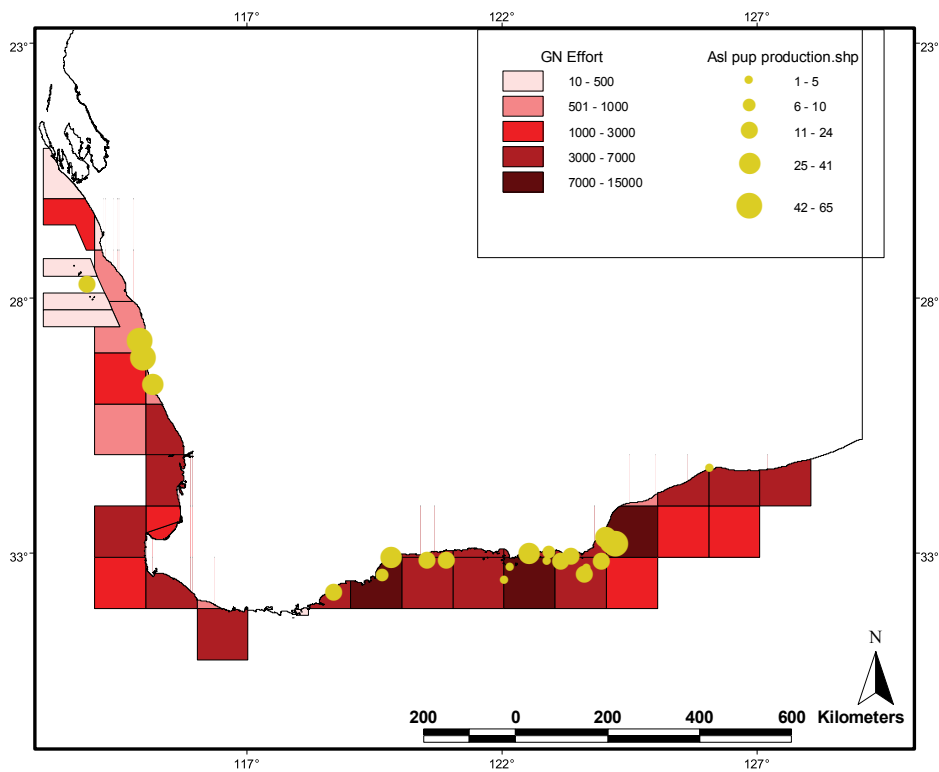


Figure 6.5. Mean distribution of gillnet (GN) fishing effort ('000s km gn hours) per CAES block between 1996/97 and 2000/01 fishing seasons in the WCDGDLF and JASDGLF. Relative distribution and abundance of Australian sea lion pup production is shown by the graduated symbols.

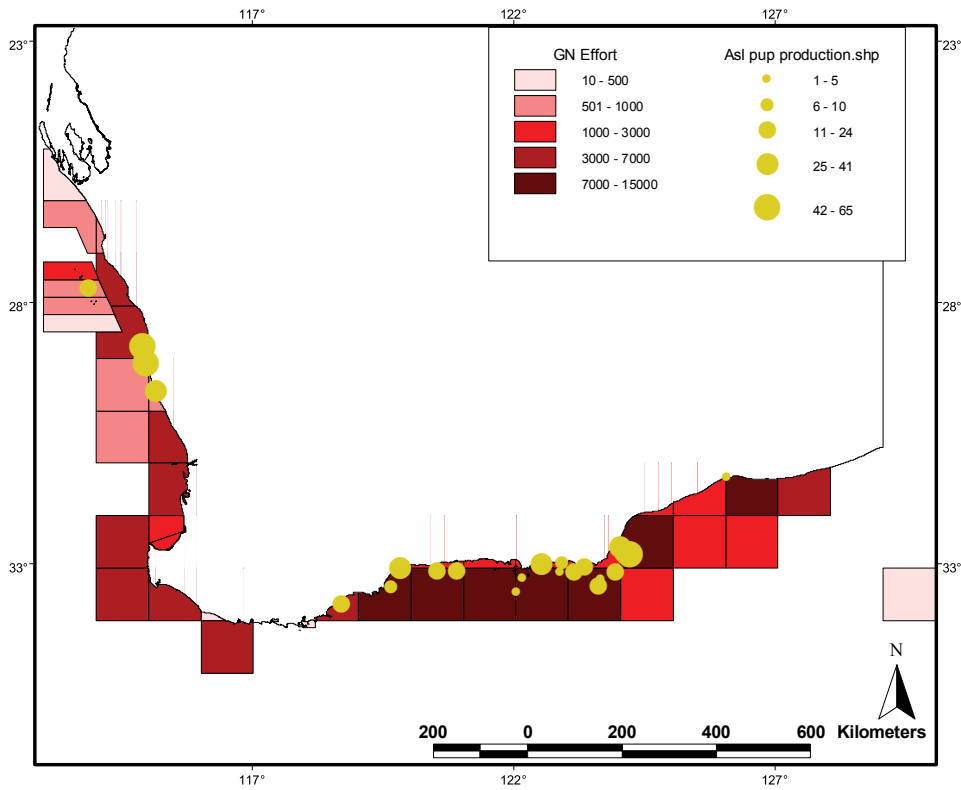


Figure 6.6. Mean distribution of GN fishing effort ('000s km gn hours) per CAES block between 2001/02 and 2005/06 fishing seasons in the WCDGDLF and JASDGLF. Relative distribution and abundance of Australian sea lion pup production is shown by the graduated symbols.

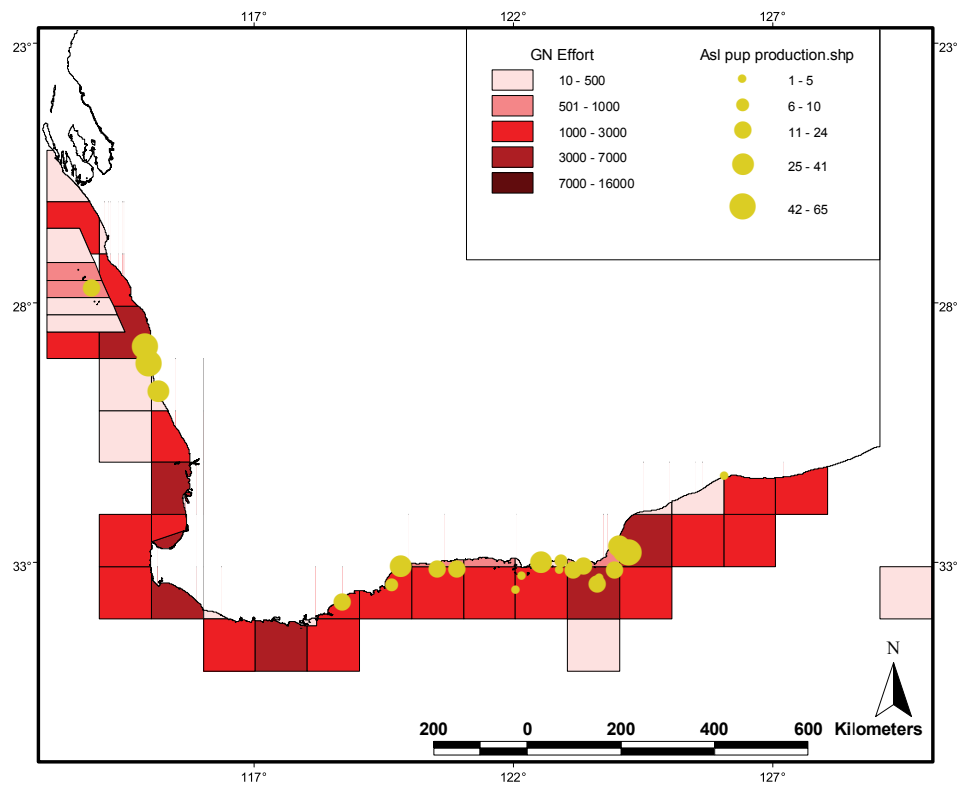


Figure 6.7. Distribution of gillnet (GN) fishing effort ('000s km gn hours) per CAES block for the most recent (2006/07) fishing season in the WCDGDLF and JASDGLF. These data reflect the most recent management measures to restrict fishing effort and were used in the calculation of the interaction probabilities.

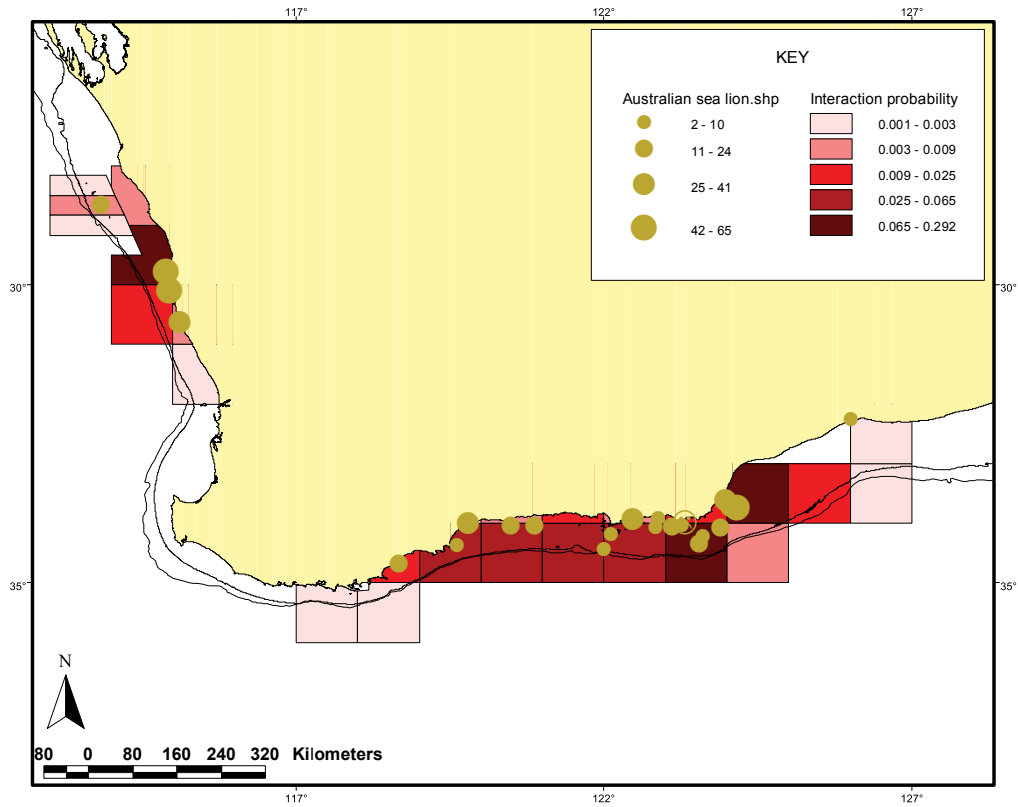


Figure 6.8. Interaction probabilities between fishing and foraging effort based on spatial overlap for individual CAES blocks. The relative abundance of ASL populations are indicated by the level of pup production. The darker the colour the higher the relative probability of interaction. One area of relatively high interaction occurred within each fishery, mid-west coast for the WCDGDLF and the eastern end of the south coast for the JASDGLF, adjacent to the areas of highest pup production.

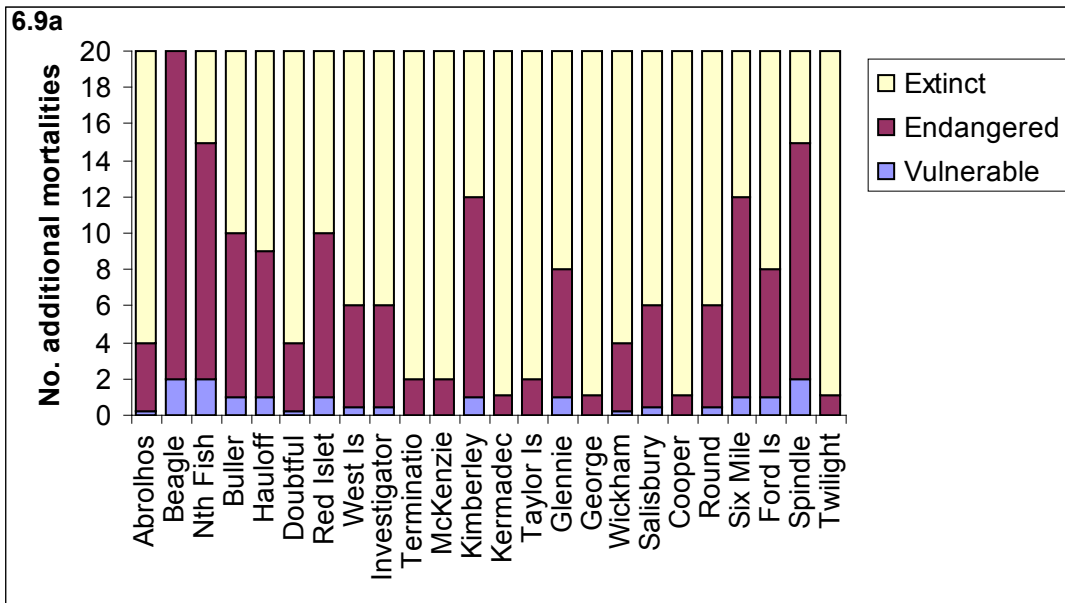


Figure 6.9a. The nominal number of additional mortalities of Australian sea lions pre breeding cycle (1.5 yrs) of pre-recruit females under a stable population trajectory ($r=0$) for each breeding colony to qualify it for different risk categories.

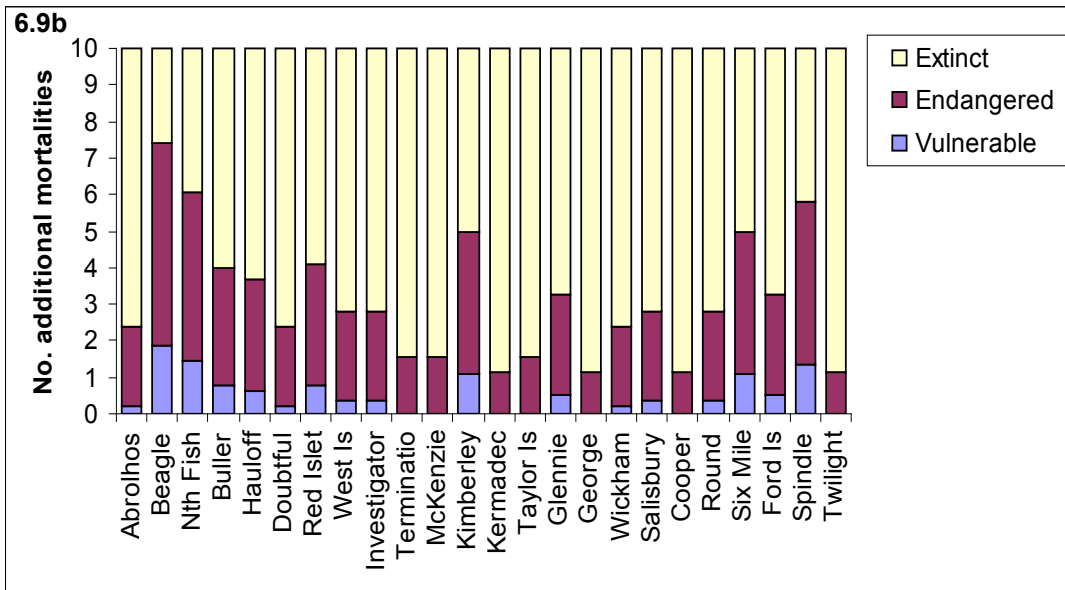


Figure 6.9b. The number of additional mortalities required under the increasing population ($r=0.01$) scenario.

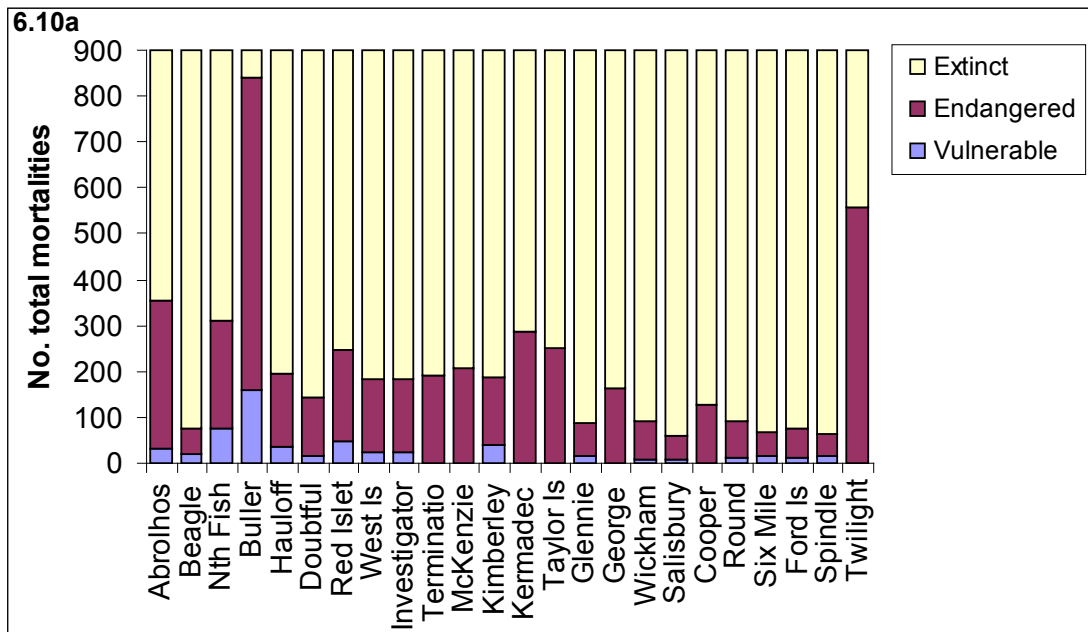


Figure 6.10a. The total number of additional mortalities of Australian sea lions pre breeding cycle (~1.5 yrs) of pre-recruit females per breeding season under the stable population trajectory ($r=0$) required to qualify each colony for the various risk categories. Mortalities were apportioned to individual breeding colonies according to the probability of interaction.

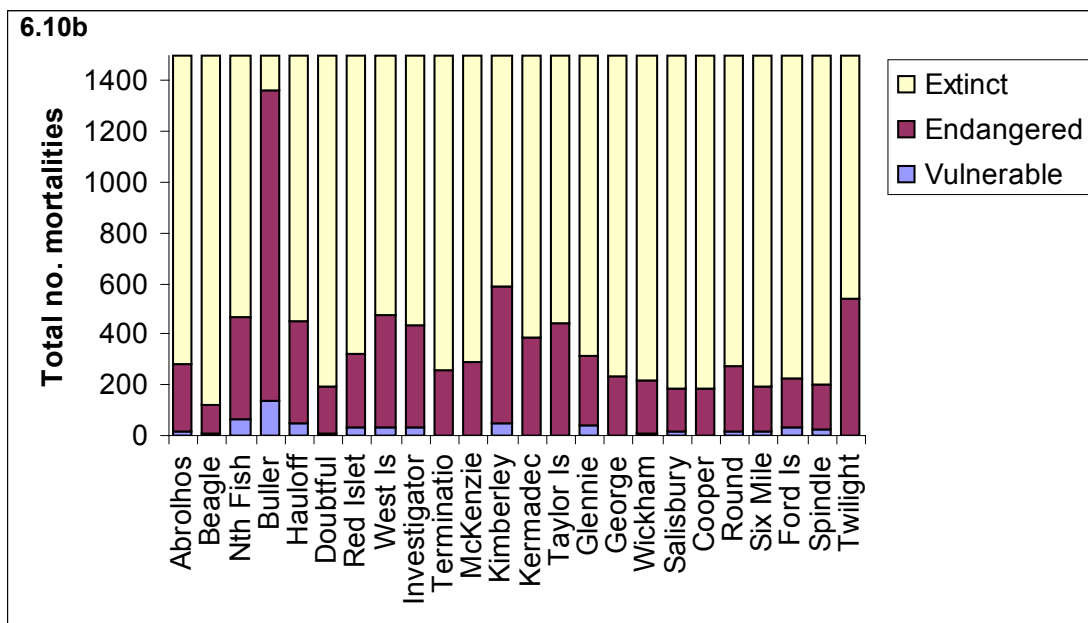


Figure 6.10b. The total number of mortalities required for the increasing population trajectory scenario ($r=0.01$).

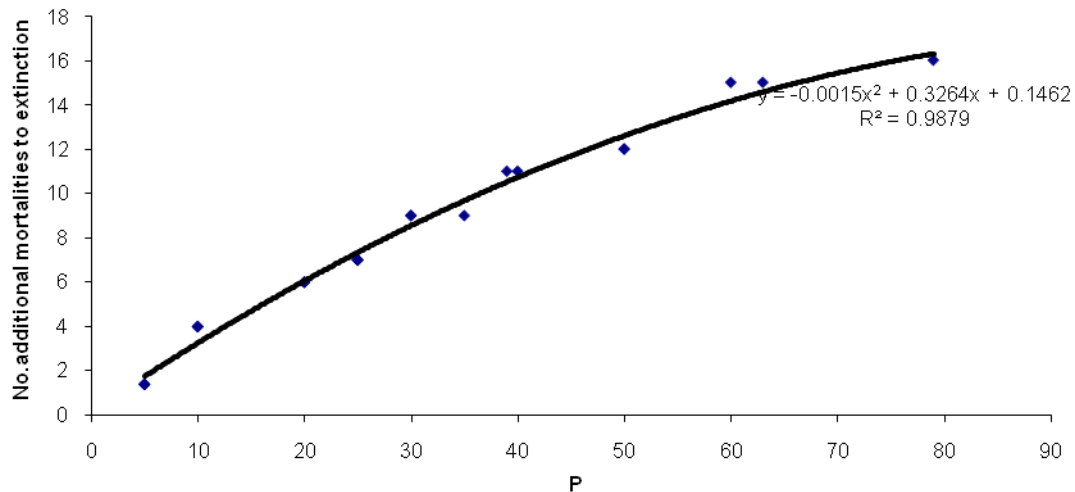


Figure 6.11 Regression of the number of additional mortalities to shift individual colonies from critically endangered to quasi extinct on population size as indicated by pup production (P). The non-linear relationship showed that the spatial overlap model apportioned relatively greater impact of incidental mortality onto the larger populations.

6.3 Discussion

6.3.1 Sea lion spatial foraging model

This study suggests that ASLs forage throughout the continental shelf waters from shallow nearshore environments to the continental shelf edge. Tracking of individual sea lions has shown considerable differences between colonies and among individuals within the same cohort at the same colony. Preferences for directional foraging travel were consistent among age groups at one colony, Beagle Is, in particular. This study adds to the weight of data showing that ASL are very individualistic foragers, and that they show faithfulness to particular foraging sites over short time periods (4-6 weeks, Goldsworthy et al. 2007). In general, animals from colonies on the west coast of WA were predominantly shallow water foragers with restricted foraging ranges. Sea lions from the one offshore site on the west coast, Abrolhos Is, showed the most restricted foraging ranges and diving behaviour. Sea lions tagged at the one offshore site on the south coast, Investigator Is, showed the most extensive foraging ranges and were the deepest divers studied. Whilst there were considerable differences in the bathymetry adjacent to these two sites, this was a remarkable difference. Animals tagged at nearshore sites on the south coast displayed intermediate foraging ranges and there was some evidence to suggest that animals were either foraging in shallow (0-20m) or deeper water.

It is presumed that these differences in foraging strategies among and within colonies are driven by available habitat, patchiness of prey distribution and possible prey preferences among animals. The limited spatial overlap of foraging areas among animals from the same colony may be an adaptation to reduce resource competition among individuals and maximize individual reproductive success through an optimal foraging strategy. This pattern has many implications for the assessment of spatial overlap and incidental mortality with the demersal gillnet fisheries and for the assessment of ecosystem impacts with human activities.

The model of ASL spatial foraging patterns demonstrates the general use of the continental

shelf waters by ASL, however there are considerable differences in foraging ranges between locations. The greatest concentration of foraging effort is on the central-west coast where there are three relatively large populations with restricted foraging ranges. Foraging effort on the south coast is more broadly distributed due to the extensive foraging ranges of sea lions from these colonies. The area of greatest foraging effort is around the easternmost group of breeding colonies which produce approximately 10% of the pup numbers in WA.

The model of predicted foraging effort is based on central place foraging from breeding colonies and does not incorporate spatially discrete haulout populations, such as those of sub-adult and adult males present in the Perth metropolitan area (Gales et al. 1992), and does not take into account the dispersal of animals away from the breeding colonies outside of the breeding season. During several visits to the breeding colony of Kimberley Island in the breeding season interval, there were very few animals observed (2-10), whereas during the breeding season there were upwards of 100-120 animals present (Gales et al. 1994). Based on the limited spatial foraging data, adult females used many other islands in the area, up to 40 kilometres away, as haulouts during the breeding season. It is assumed that animals from all age groups disperse to many of the islands in the area outside of the breeding season and visits to some of these islands confirmed the presence of mother-pup pairs and juvenile animals. This will act to distribute the foraging effort even wider than the model suggests for certain populations and potentially increasing or lessening the interaction rate dependent on fishing effort distribution. This pattern of dispersal was not evident at all breeding colonies visited outside of the breeding season. In most cases, sea lions of nearly all age groups remain resident at the majority of breeding colonies visited throughout the breeding cycle. It is thought that the proximity of Kimberley Island to a large number of suitable islands may facilitate dispersal of animals of all age groups. It is expected that similar patterns of dispersal occur for breeding colonies within the Recherche Archipelago, but are not expected at most other sites. Observations of consistent numbers of animals representative of all age groups at Investigator Island and Red Islet both within and outside of the breeding season show that there is limited dispersal, most likely due to the lack of suitable island sites in the vicinity.

This pattern of dispersal within the Recherche Archipelago may also be driven by limited resource availability and could represent an optimal foraging strategy to exploit prey resources in a variety of habitats throughout the 17.5 month breeding cycle. Long term satellite tagging of individuals may provide some answers to these questions and discern patterns over longer time periods. These extended foraging patterns will also have a bearing on the likely interaction rate with demersal fishing activities.

An alternative method to the use of satellite tracking instruments to estimating foraging range of ASL has been suggested in Goldsworthy et al. (2010). This involves the use of stable isotope analysis of sea lion whiskers to stratify offshore versus nearshore foraging. Preliminary data show that animals that forage offshore (in water depths 80-100m) have higher $^{15}\text{N}/^{14}\text{N}$ ratios to inshore foragers and that the spatial patterns inferred are relatively constant over the course of 12-18 months (Lowther et al. 2010). The use of stable isotope analysis of whiskers could be used to screen among colonies for the proportion of offshore versus inshore foraging animals in each age/gender class. This approach needs to be verified with some accompanying satellite tracking data but would be a far more cost-effective solution to determining the proportion of foraging types at targeted sites. This discrimination is important as the fine scale overlap of fishing and foraging effort will determine the real probability of risk of capture of sea lions in gillnets.

6.3.2 Demersal gillnet fishing effort

There has been a marked reduction in the level of gillnet fishing across the range of the ASL over the past 25 years. The present levels are at an historic low within this period. The distribution of fishing effort has been broadly consistent over this time with a considerable proportion persisting along the south coast in proximity to many ASL breeding colonies, in particular the eastern end of the species range. This is consistent with the targeting of gummy sharks (R. McAuley pers. comm.). There has been a significant reduction in effort on the west coast, but consequently a greater concentration of this effort in the foraging areas of the Beagle Is colony.

The effect of further management measures (post 2006/07) to reduce fishing effort and sustain stocks of commercial shark species means that there has probably been a greater reduction in the probability of incidental mortality of ASL due to demersal gillnet fishing than implied here. Whilst the measures of fishing effort presented in this study are not proven as reliable and comparable over the time frame, there may have been at least a 2-3 fold reduction in the threat of incidental mortality over most of the range of the ASL. However, it is possible given the generation time and longevity of ASL that the effects of historically higher levels of fishing effort and associated incidental mortality would still be impacting on population size and trends in abundance today.

It should be noted that demersal gillnet effort is targeted to specific areas in different zones and not distributed uniformly across a CAES block. In the WCDGDLF, the majority of fishing effort is concentrated between 40 and 100 metres. This would mean that the real rate of interaction may be lower than that estimated by the model due to the high level of juvenile and adult female foraging effort in waters less than 40 metres. Generally, fishers exploit stock in 0-80 metres in zone 1 of the JASDGDLF and in waters less than 40 metres in zone 2. This may result in a greater probability of interaction than estimated by the model due to a concentration of fishing effort in preferred areas of ASL foraging effort.

6.3.3 Spatial overlap of ASL foraging and demersal gillnet fisheries

The probability of interaction between gillnetting activity and the ASL is concentrated at the areas of highest ASL distribution, in particular the eastern end of the Recherche Archipelago and the central west coast area. Moderate levels of interaction were evident at the remainder of breeding colonies along the south coast and there was a low probability of interaction for the Abrolhos Island population, which is still an overestimate due to the restriction of demersal gillnetting within 3 nautical miles of the islands.

The coarse scale of the fishing effort data is a limitation on assessing the probability of interaction with ASL. In most cases the CAES blocks range from the coast to the continental shelf and do not distinguish the fishing effort across depth. As was evident from the at-sea positions and diving data, the tagged sea lions foraged in a range of habitats from nearshore to continental shelf edge, which may markedly reduce the rate of spatial overlap with the fishing effort in some areas. To make more accurate estimates of threat and associated potential risk to the ASL, a greater resolution of fishing effort should be estimated from the compulsory daily logbook data. At present these data are unavailable for use. Greater resolution of sea lion foraging behaviour and alternative methods of modeling the ASL spatial foraging effort (i.e Aarts et al. 2008) based on the factors that influence the foraging behaviour, such as bathymetry, proximity of haulout islands, should be attempted to resolve the fine-scale patterns between locations. Resolution of these two datasets would produce a more accurate probability of

interaction and may show a considerable reduction of potential risk to many of the populations of sea lions that have restricted foraging ranges in shallow coastal areas.

However, the relative spatial overlap or probability of interaction does not inform us of any actual rate of incidental mortality. Whilst there may be a relatively greater potential risk for one colony versus another based on these modelled data, there is a pressing need for more empirical data on the actual rates of incidental capture. These data could be used to provide an index of interaction which may be applied across the range to quantify the probability of incidental capture associated with an interaction probability.

6.3.4 PVA outcomes and risk assessment

The ASL colonies in WA are extremely vulnerable to low levels of ongoing additional mortality, as demonstrated by the viability analysis. Natural variation and uncertainty in some parameters of ASL life history result in declines in abundance and potential extinction for many small colonies. In nearly all cases for stable population trajectories, the addition of any ongoing incidental mortality resulted in population decline and an increased the risk of extinction. It is conceivable that many of the colonies of ASL in WA are undergoing a low level decline in abundance. This possibility was raised for the ASL colonies in South Australia (Goldsworthy & Page 2007), and may be even more appropriate in WA given the smaller size of most colonies. The results from the two scenarios of population trajectory, stable and increasing, showed that a moderate rate of population growth would make small populations more robust to ongoing low levels of incidental mortality, but that most colonies in WA are at risk of extinction at fairly low levels of additional mortality. The results presented here reflect the results seen in the risk analysis of demersal gillnetting to ASL viability in South Australia. This confirms that the ASL population is extremely vulnerable to human activities, and that the population structure has a very strong influence on the viability of the many colonies. There may be a case for reclassifying the entire population at a higher probability category, i.e. *Endangered* under the *EPBC Act* (1999), as the metapopulation structure of isolated populations means that the risk of extinction is possibly higher than previously understood. Many of the colonies qualified for this category under the stable or increasing population trajectories with the addition of 1-2 incidental mortalities per breeding season. Based on the spatial overlap index of interaction and the PVA outcomes, a hierarchy of vulnerability to the effects of incidental mortality in demersal gillnetting showed that relatively large colonies in the eastern group of the Recherche Archipelago (Spindle Is, Ford Is and Six Mile Is), a number of smaller colonies in the central portion of the Recherche Archipelago and the largest colony, Beagle Is, on the central west coast were classified at the most critical category of criteria E (*extinct or quasi-extinct*) at hypothetical levels of combined incidental mortality of around 80 animals. The next tier of colonies affected by incidental mortality were a number of colonies on the south coast immediately to the west of the Recherche Archipelago (West Is, Investigator Is, Doubtful Is) and Kimberley Is in the Recherche Archipelago. The least affected colonies were those remaining on the west coast (Abrolhos Is, Buler Is, North Fisherman Is) and the remote Twilight Cove colony in the Great Australian Bight. There is a tendency for the PVA model to have greater impact on large colonies as the relationship between additional number of mortalities required to change conservation categories and pup production is curvi-linear.

There is also a need for better estimates of many ASL life history parameters if PVA methodologies are to inform management authorities. At present, there is still a high degree of uncertainty in some parameters and the current PVA analysis suggests that many small ASL populations are most likely to be undergoing population declines. There is limited empirical

data on ASL abundance at most colonies in WA to support or refute this. Alternatively, the current levels of abundance of ASL may be a remnant of the population size 30 years ago due to the impacts of all forms of anthropogenic mortality.

6.3.5 Limitations of study and future directions

Whilst the general spatial pattern of probability is reflective of the patterns of fishing effort, some care must be taken in interpreting these findings due to the coarse scale of the fishing effort data and the potential overestimate of spatial ASL foraging effort proposed by the simple normal distribution model. Fishing effort is not distributed evenly across a CAES block. Depending upon the region and target species, fishing may extend into shallow waters or may be more concentrated in waters deeper than 50 metres. It is apparent that this lack of discrimination combined with the potential shallow water foraging specialization of some ASL colonies could lead to a significant over-estimate of probability based on the methods employed in this study. Greater refinement of the spatial patterns and models of fishing and foraging effort would provide a more reliable estimate of potential risk posed to the sea lion population.

In addition, there is some suggestion that sea lions and the gillnet fishery are separated on micro-geographic scales due to their different target or prey species. ASLs are targeting small cryptic, benthic prey predominantly on reef structure (McKenzie et al. 2005) whereas the commercial demersal gillnet fishers prefer to keep their nets away from habitats such as these (Dr. R. McAuley, pers. comm.). In effect they may occupy slightly different niches in benthic communities and not directly interact. Conversely, there may be an element of attraction of sea lions to the gillnets to depredate small sharks and scalefish. Many commercial gillnetters have noticed depredation of catch by New Zealand fur seals in areas sympatric with ASL (R. McAuley, pers. comm.). ASL are also known to target scalefish and shark from nets (McKenzie et al. 2005) but it is not known if this is a general pattern across areas and across age groups or a specific behaviour, such as the removal of bait from rock lobster pots by ASL on the west coast of WA (Campbell unpublished data). The attraction of sea lions to demersal gillnets may reduce the accuracy of the spatial probability model, as attraction could vary greatly from region to region, be related to local prey density and could be age class dependent. Additionally, there may be a component of naivety in the probability of ASL incidental capture in demersal gillnets, producing a bias in younger age classes being vulnerable to incidental capture.

There is limited empirical data on the bycatch rate of ASL in demersal gillnets. McAuley and Simpfendorfer (2003) observed a single mortality of an ASL in zone 2 of the JASDLDFG during the observation of approximately 2% of fishing effort in that region during the period 1994-1999. Extrapolation of this result suggests a number of sea lions may be caught every fishing season, however the observation of only a single incidental mortality is not a reliable measure for extrapolation. The PVA suggests that annual bycatch rates of up to tens of ASLs could result in many of the sea lion colonies being in decline and classified as *endangered*, *critically endangered* or *extinct*. An observation of a single mortality could also be a rare, one-off event, and not representative of the general rate. These data highlight the need for a more robust estimate of incidental mortality.

Based on these figures a much higher level of observer effort would be required to ensure a robust estimate of the incidental mortality rate. It is recommended that a one-off independent observer programme be developed that would include monitoring of bycatch for a minimum of 20% of fishing effort, preferably in areas of high probability of interaction. The candidate areas

would be north of Beagle Is and the eastern end of the Recherche Archipelago. Observed rates of bycatch could be expressed in terms of the level of sea lion foraging effort and fishing effort and extrapolated to estimate a rate of incidental mortality across the whole population. This approach was recently used by Goldsworthy et al (2010a) to produce an estimate of potentially more than 250 ASL being caught every year in the gillnet sector of SESSF in South Australia and approximately 370 being caught every breeding cycle. They observed 2.4% of the gillnet fishing effort between 2006-2009, and encountered 12 ASL mortalities on ten individual trips. They found that the observed bycatch rate was linearly correlated to the likelihood of encountering a foraging sea lion. This supports the use of a probabilistic model of determining the relative potential risk that demersal gillnet fisheries poses to the benthic foraging ASL.

There is a considerable difference in the encounter rate of incidental capture of ASL between the two independent observer studies in South Australia (Goldsworthy et al. 2010a) and Western Australia (McCauley & Simpfendorfer 2003). The overall estimate of incidental mortality from all observed data in Goldsworthy et al. (2010a) was 0.0021 seals/km.hr or 1 sea lion every 476 km.hrs of gillnet fishing effort. This is markedly different from the observed rate in McCauley & Simpfendorfer (2003) of 1 sea lion every 30,000 km.hrs of gillnet effort. This 6 fold difference in observation rates may be explained by the difference in intensity of seal foraging effort in the areas of observation, as the Goldsworthy et al. (2010a) study targeted areas of known ASL distribution whereas McCauley & Simpfendorfer (2003) were investigating target stocks of shark which did not necessarily coincide with areas of high ASL abundance. Further analysis of these data may allow a comparison of the relative seal foraging effort in these two studies which may explain the variance in observed bycatch rate.

Further examination of the fine-scale foraging behaviour of ASL and patterns of fishing effort would also provide some benefit in accurately determining the probability of interaction. The incorporation of daily logbook fishing data with accurate GPS positions of nets is essential to provide a finer scale representation of fishing effort than the current 60 x 60 nautical mile grids. The use of GPS satellite trackers with a resolution of 5-15 metres would provide extremely accurate foraging tracks of sea lions and provide estimates of time spent in areas when foraging. This would help formulate more accurate models than the relatively simple normal distribution of spatial foraging effort based on a limited number of tagging studies and animals for this study. This research could also examine habitat preferences of ASL for areas where extensive marine habitat mapping has been performed. One candidate area for this kind of study would be in the eastern end of the Recherche Archipelago where habitat mapping has been done in proximity to several breeding colonies. This would help elucidate whether sea lions prefer habitats that are utilised by the commercial gillnet fisheries and determine a more accurate probability of incidental mortality.

The PVA models are based on relatively simple interpretations of the likely ASL demography parameters. The parameter estimates for ASL were based on some empirical data for this species but also included estimates of survival and relative fecundity from other species (Northern and Antarctic fur seals in Goldsworthy & Page 2007). It is also likely that demographic rates vary greatly among populations of ASL, especially given the high level of genetic population subdivision and the variation in marine habitat across the range. It is not known how the variation in these traits will affect the outcomes of the PVA. The density independent nature of the analysis may have a strong bearing on the outputs. Essentially, it means that as populations become depleted there is no provision for an increase in vital demographic rates to respond to the population pressure (i.e. incidental mortality). This results in the reduction in abundance and increased threat classification of many of the small colonies of ASL in this study, especially for the stable

population trajectory scenario. Whilst there may be some justification for this parameterization based on the low density of most colonies and the likelihood that ASL populations are still well below the pristine abundance, this trait has a strong bearing on population responses to anthropogenic impacts. Assessment of the impact of incidental mortality on the New Zealand sea lion population from one study suggested that density-dependent responses in reproductive rate, survival and age of primiparity could alleviate the impact of increased human-sourced mortality (Breen et al. 2003). Density-dependent rates of pup mortality have been observed in some species of pinniped (Doidge et al. 1984, Campagna & Le Beouf 1988) and there is some evidence to suggest that ASL pup mortality is positively density-dependent on the central west coast breeding colonies (Campbell 2003). It is not known whether a reduction in pup mortality rates would occur in response to a reduction in population abundance at these colonies and whether it would be sufficient to prevent a continued population decline. Trend analysis of pup production at Beagle Island suggests that there has been a 1% decline in pup numbers per year over the past 15 breeding seasons, though this decline was not significant (Campbell et al. unpublished data). Comprehensive research would be required to determine the important demographic rates at a range of localities, and may need to incorporate seasonal and environmental factors in lieu of potential climate change impacts.

Sufficient evidence exists to support further research into determining the rate of bycatch of ASL in demersal set gillnet fisheries. Anecdotal evidence provided in the literature (Shaughnessy et al. 2003), empirical data from observer programmes in other demersal gillnet fisheries (Goldsworthy et al. 2010) and the extreme vulnerability of the many small, isolated colonies of ASL in Western Australian suggests that demersal gillnetting may pose a potential risk to the viability of the ASL population in WA.

7.0 Large whale entanglement in the WCRLF

7.1 Methods

7.1.1 Factors affecting rate of entanglement

Reported rates of entanglement of large whales in pot ropes of the WCRLF and other marine sources were maintained by the DEC and DoF based on reports from the WCRLF industry and other marine users. This report collates the reported entanglements since 1990 to the conclusion of the 2008/09 WCRLF fishing season. Confirmed sightings with locations of original entanglement (where possible) or first sightings were plotted on GIS maps using Arcview 3.2. Distribution of entanglements were initially examined by eye to determine any obvious patterns. Examination of the temporal distribution of entanglement events was done using frequency histograms of captures per calendar month. The predominant time for entanglements in the WCRLF occurs during the latter stages of the “reds” fishery, in particular during the month of July. To determine if there was any relationship between the entanglement rate and levels of fishing effort, the mean level of seasonal fishing effort (May-July) for the last 5 years in fishing blocks (1 degree latitude by 10 fathoms depth) was estimated and overlain on the known entanglement positions. This relatively large spatial scale of fishing effort was used as the limited number of entanglement incidents did not warrant examining finer spatial scale fishing effort. Correlation of fishing effort with entanglement rate (with correction for block size heterogeneity) was performed to determine if fishing effort affected entanglement rates.

The fine-scale path of the northward humpback whale migration in relation to its proximity to the coast may have some affect on the year to year variation in entanglement rates. This migration coincides with the timing of the greatest flow strength of the southward bound Leeuwin Current (LC) and years of high LC strength may result in the whales migration path being closer to shore to avoid the current and thus increasing the rate of interaction with the WCRLF. Leeuwin Current strength is related to the conditions of the SOI (Southern Oscillation Index) in the Pacific Ocean. El Niño conditions are responsible for years of weak LC flow and La Niña conditions represent strong LC flows. Anomalies in monthly averages of the Fremantle mean sea level (FMSL), a proxy of LC strength, were plotted against the annual entanglement rate to determine if this environmental factor plays a role in the level of humpback whale entanglement.

7.1.2 Future scenarios

To estimate the potential increase in whale interaction with the WCRLF it was assumed that the entanglement rate (Re) was directly proportional to the product of three parameters; the abundance of humpback whales (N), the level of fishing effort (FE) across the area of interaction and the number of days (D) of potential entanglement between the fishery and the whale migration; such that

$$Re \propto N \times E \times D \quad Eq. 1$$

These parameters were set at baseline levels at T_0 determined by the value at 1999/2000. This year was chosen as it allows for some validation of the potential factors which may be influencing the entanglement rate (i.e fishing effort, population trajectory of humpback whales) from 1999/2000 to the last recorded season (2007/08). Values for these three variables were estimated for the period 2007/08 to the 2019/2020 fishing season to determine the potential increase in entanglement rates.

This population of humpback whales has been increasing at approximately 10% per annum for a number of years and is expected to continue increasing (DEH 2005). However, recent data suggests that calf mortality rates are increasing, indicative of a population that may be nearing its carrying capacity (Doug Coughran, Senior Wildlife Officer, Dept. of Environment & Conservation-pers. comm.). Calculation of likely rates of population increase were also developed for this study using a discrete time, non-age structure logistic model of population dynamics, as used in generalized reconstructions of historical whale abundance (IWC 1999).

$$P_{t+1} = P_t + r_{\max} P_t (1 - (P_t / K)^z) - C_t \quad Eqn. 2$$

where P_t is the total population size during year t , r_{\max} is the maximum intrinsic net rate of population growth, K is the carrying capacity which is assumed to equal pristine abundance, z is the exponent setting the maximum sustainable yield level (MSYL, assumed to be 2.39 for large baleen whales) and C_t is the total catch in terms of numbers of whales during year t . This model was modified to remove the C_t term assuming a zero catch rate of Group IV humpback whales in the modelled time series. The starting point for this exercise was 1999, the time of the last population survey estimate of 8,000-14,000 (Bannister & Hedley 2001, DEH 2005) and using parameters of $r_{\max} = 0.1$ and $K = 20,000$ based on a review of Group IV population dynamics (Johnston & Butterworth 2002).

The relative level of fishing effort was measured as the number of potlifts in the “reds” period

of the fishery in the depths where entanglements occurred. The level of effort in 1999/2000 was used as the baseline measure and all years subsequent were measured as a proportion of that effort to represent the relative increase or decrease in the number of pots present. This technique should account for factors such as multi-day pot pulling as it is assumed that this will be relatively consistent from year to year.

There is no established understanding of the spatial and temporal dynamics of humpback whale migration and their relationship with increased abundance (Dr Nick Gales pers. comm.). For the purposes of this study we will assume two scenarios; A-that the migration period remains constant with increasing N and B;- that the migration period (time of entanglement risk) through the WCRLF grounds extends by 1 month (a relative increase of 50%) at both the start and end of the fishing season over the time frame of this study (20 years). This means that in scenario A, D is a constant and removed from the equation. In scenario B, the change in migration period was modelled as a linear increase of 2.5% per year, resulting in a relative increase of FE from 1 at 1999/2000 to 1.5 in 2019/2020. The corresponding increase of the migration period at the end of the migration will not increase D as the fishing season is finished at the end of June, prior to the end of the migration period. The start of the potential entanglement period of whales in the waters of the WCRLF was determined by the start of the month in which the first entanglement (May) was recorded.

All three parameters were given equal weighting in the calculation of Re in this instance. There may be a strong case for variable weighting of these factors, however based on the available knowledge at present we were unable to determine a methodology for weighting these factors in calculating the rate of entanglement.

7.2 Results/discussion

7.2.1 Factors affecting rate of entanglement

The distribution of entanglements of large baleen whales occurred throughout the state from the south coast to the tropical northern waters (Fig. 7.1). Whales were reported to have been entangled in a variety of fishing gear, including ropes of the WCRLF as well as ropes from fisheries operating in international waters, as well as pearling lease lines. The predominant species of whale entangled was the humpback whale (88%), with southern right whales (10%) the second most numerous. The vast majority of entanglements over the study period was reported to be from the WCRLF (80%), and June was by far the most common month for entanglements in the WCRLF with over 50% of the reported incidents. Over a quarter of all incidents in the WCRLF occurred out of the fishing season in August-October. It is assumed that these events consisted of animals that became entangled in the latter part of the fishing season (May-June) during the northward migration. Based on this assumption over 75% of entanglements in the WCRLF occur in the latter of the “reds” part of the fishery during the northward migration of the humpback whale stock. A single entanglement occurred in March 2008 of a Brydes whale, a species which does not have the same migration pattern as the Humpback whale and so does not relate to the spatial and temporal dynamics of entanglement rate examined in this study.

There were a small number of entanglements ($n=5$) occurring in the first two months of the fishery (November-December) during the southern migration of the humpback whale. Due to the limited number of these events, it is not possible to determine any relationship between fishing patterns and entanglements at this time of the year.

There does not appear to be any relationship between the mean level of fishing effort in the “reds” part of the fishery and the rate of entanglement of whales (Fig. 7.1). A cluster of entanglements occurred in the waters around Perth and Rottnest Is., possibly due to the concentration of the migration path either side of Rottnest Is. The entanglement rate and fishery data do not fit the assumption of normal distribution and homoscedascity for a correlation (Gotelli & Ellison 2004) as there are too many missing data blocks (fishing blocks with no recorded captures). Whilst the two time series are not equivalent, it is likely that the rate of entanglement events were not affected by the density of pots on such broad spatial scales as the measure of fishing effort in this scenario (60 x 60 nautical miles). Given that thousands of pots are set each day in each CAES fishing block, there is likely to be a saturation of pots and ropes to enable entanglement of whales in all fishing blocks. It is more likely that the fine-scale migration path parameters and fine spatial scales of pot density are measures that will dictate the entanglement rate. There are no data on these two parameters at present.

There does not appear to be any relationship between the strength of the Leeuwin Current (FMSL as proxy) and the entanglement rate observed (Fig. 7.2). It may be reasonably argued that seasons with increased LC strength may act to push the northward migrating humpback whales closer to the coast to avoid swimming against the current.

7.2.2 Future scenarios

The derived model of entanglement rate suggests that entanglement rate will increase over the next 10 years, mostly driven by the continued increase in whale abundance (Fig. 7.3). The model under scenario A provides a good fit for the increased trend in entanglement rate over the past ten years, taking into account the increases in whale abundance and reduction in fishing effort. An increased overlap of the fishery activity and whale migration due to the hypothesized lengthening of the migration period (scenario B) would more than double the entanglement rate to an average of approximately 4 per season, however this scenario does not fit the trend in observed data over the last ten years. It appears that with the group IV humpback whale population nearing its carrying capacity within 10-12 years, the entanglement rate should plateau.

There is no obvious determinant for the high interannual variability rate in entanglement rate, which appears to be a factor of probability and the low incident rate. No obvious connection was found between the activity of the Leeuwin Current and the rate of entanglement, though a better understanding of the actual spatial interaction of the WCRLF fleet and the humpback population migrating through the fishing grounds would help explain the patterns observed. Extensive sampling of environmental conditions and the fine-scale parameters of the migration path is a logistically difficult and expensive process and would probably not provide any greater outcome for the management of this interaction.

This second variable is limited due to constraints on the onset of the migration event from the Antarctic feeding waters to the northern breeding grounds. Large baleen whales require enough time feeding in the austral summer period to gain sufficient energy stores to make the long northern migration and return every year. It is possible that increased large whale abundance in the foraging areas of Antarctica may actually increase competition and delay the migration start time. Other contributing factors to this will be the unknown effects of climate change and associated regime shifts in oceanic ecosystems. The timing of gray whale migration events changed by 7 days over 20 years in the northern hemisphere in response to the regime shift in the North Pacific Ocean (Rugh et al. 2001). There has been no analysis of change in the

timing of migration events of the eastern and western humpback whale populations in relation to climate change effects to date. There is some possibility that the timing of humpback whale migration has changed or will change in the future to reflect changing environmental conditions but there may also be consequent changes in many other marine processes including the timing of life stages of the western rock lobster and subsequent changes to the fishery. At present there is insufficient data to comment on the likelihood of change to the entanglement rate of large whales due to global warming and oceanographic changes.

The other strong contributing factor in this issue is the introduction and use of the Code of Practice for reducing whale entanglements (DEC 2005) for the WCRLF, developed by the DEC, SeaNet and the Western Rock Lobster Council. This was formally introduced into the fishery in 2005/06 season and is undoubtedly responsible for the good working relationships between the fishery and DEC and the quick and positive outcomes in disentangling whales (Doug Coughran-pers. comm.). However, it is not known how the implementation of the code impacts on the numbers of whales entangled in the first place, nor is it recorded what degree of implementation of the code there is across the fishery. The major mitigative practices to reduce the rate of entanglement in the code is to shorten pot ropes as much as is practical and to minimize the setting of pots in clumps or high densities on fine-spatial scales such as around particular reefs or habitats during the “reds” part of the fishery. The shortening of ropes on pots reduces the amount of rope floating on the surface that can become entangled around a whale and a reduction in the amount of entangling material on the surface will reduce the risk of entanglement. The practice of setting pots in clumps is hard to control as the main driver for fishers is to maximize catch rates of lobsters and this may involve heavy potting around suitable habitat.

Without a further understanding of all factors at play, from the biological and environmental to the practices of the fishery, it is hard to predict how all the relevant factors will combine and what the trend in entanglement rate will be. The most relevant factor will be what the maximum rate of entanglement, as opposed to the mean rate, is likely to become. Due to the high level of yearly variation, the maximum level may be 2-3 times the mean, and will be important to have existing management practises that can respond to the likely changes. It seems that an increase of 20-30% in the mean rate of entanglement over the next decade would still be a sufficiently low number to not require additional management arrangements. However the likelihood of these changes in entanglement rate should be incorporated into the management strategies of the WCRLF, which presently has as a performance measure that there should be no increase in the rate of entanglement of large whales (DoF 2009). It appears that despite the implementation of the CoP, the increasing whale abundance and potential increased overlap of fishery activity and whale migration will act to increase the rate of entanglement over the next ten years. Monitoring of the uptake of the CoP and very specific details and analysis of each entanglement such as the fine-scale pot densities and weather patterns may help in determining the factors involved in entanglement and help refine the effectiveness of the CoP.

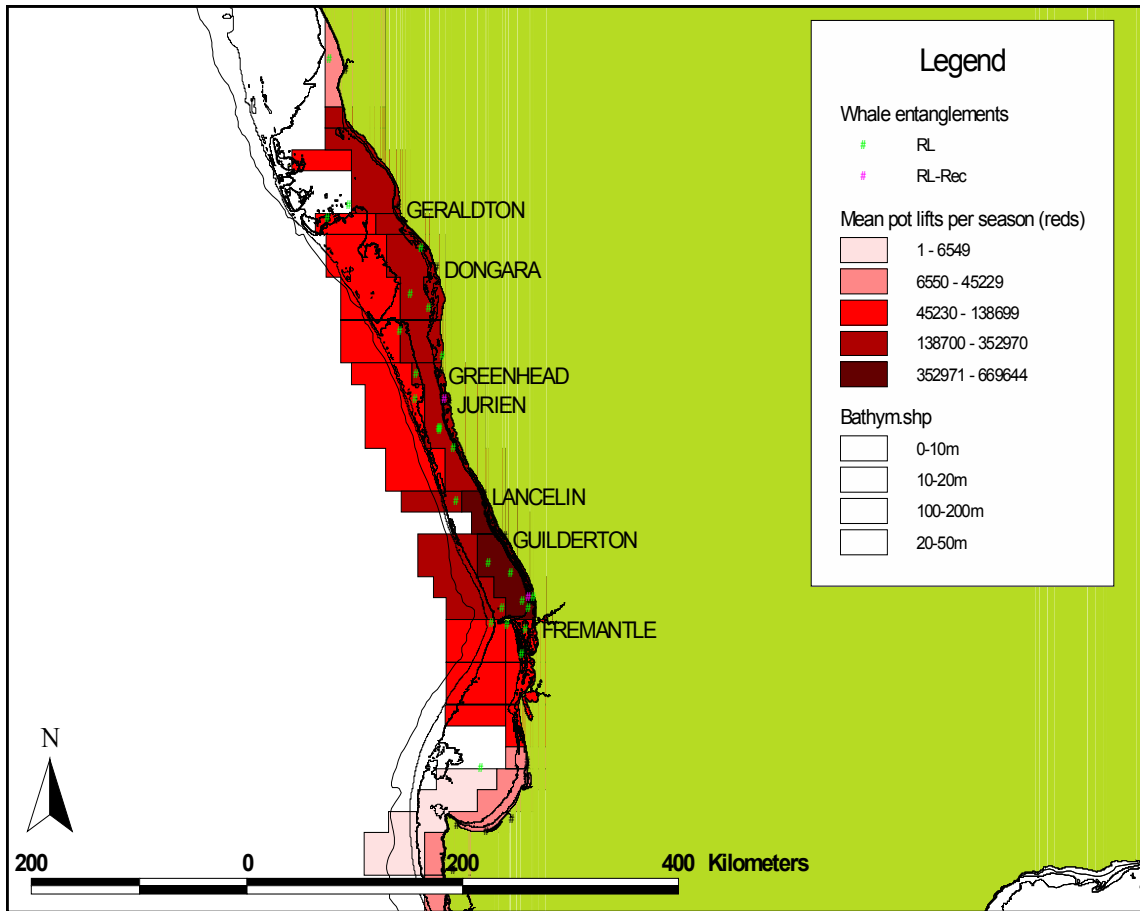


Figure 7.1. The distribution of entanglements of humpback whales (green) against the mean fishing effort (pot lifts) during the entanglement risk period in the WCRLF for the fishing seasons (2003/04 to 2007/08). The two recorded entanglements in recreational rock lobster gear are also shown (pink).

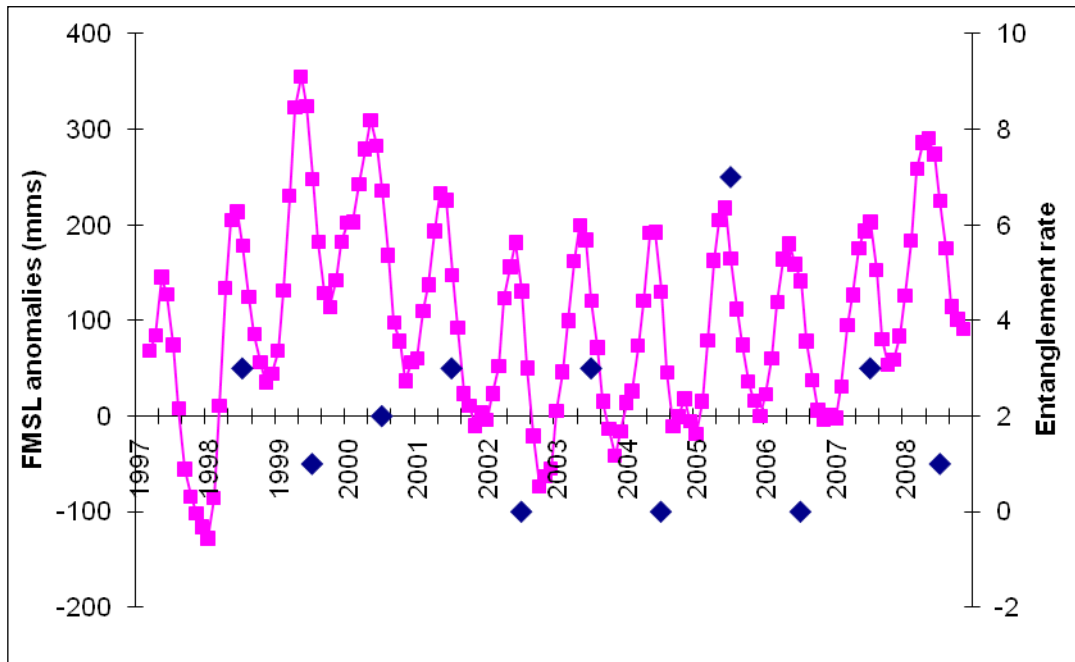


Figure 7.2. Plot of the anomalies of the mean Fremantle sea level (FMSL – Pink) against the seasonal entanglement rate (Blue) over the past ten fishing seasons. There was no apparent pattern between the activity of the Leeuwin Current and entanglement rate.

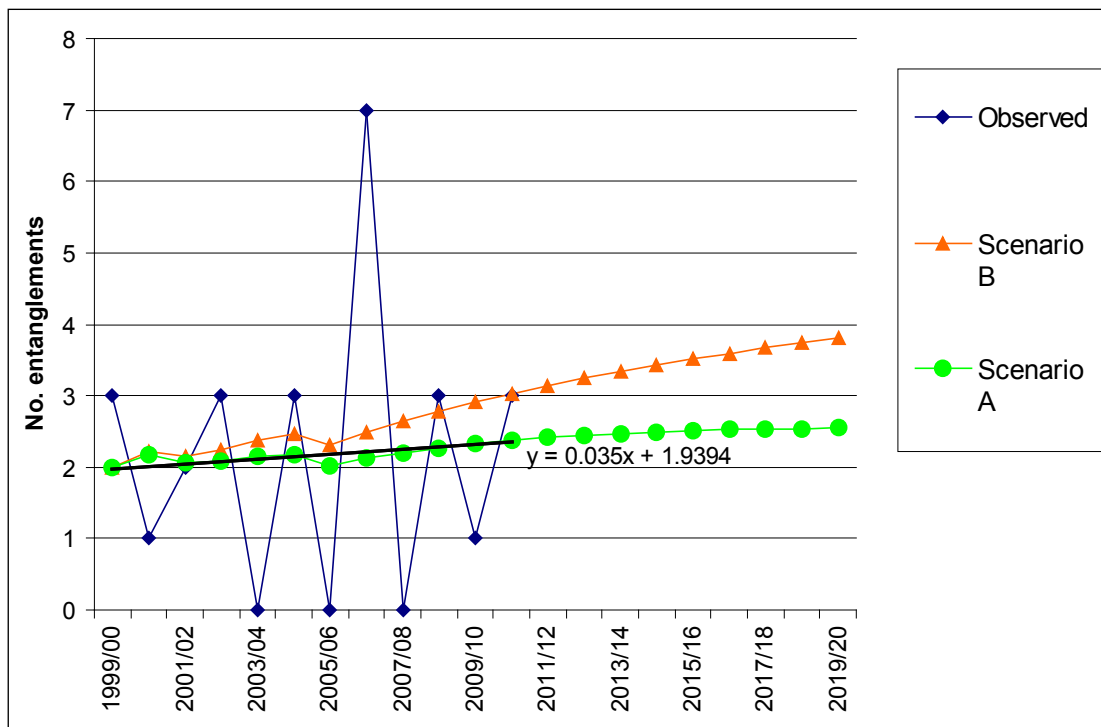


Figure 7.3. Trend in observed large whale entanglements (blue) plotted against the estimated trends in entanglement rate forecast by scenario A and scenario B. The plotline in scenario A shows a better fit to the trendline of observed whale entanglements than scenario B.

8.0 Benefits

This project forms a pilot study to primarily focus on defining the relative overlap of ASL foraging and demersal gillnetting fishing activity and the potential impact of incidental mortality of ASLs in the demersal gillnet fishing sector in WA. This report has led to the development of a Sea Lion-Shark Fishing Interaction Advisory Group (SLSFIAG), consisting of fishery personnel, industry representatives, NGOs and fishery scientists and managers. This group has supported the recommendations of this project, particularly that an independent observer programme be designed and implemented based on the spatial patterns of potential interaction and potential risk to ASL populations. Preliminary discussions about potential mitigation strategies were deferred until further empirical evidence on the nature of the interactions was determined by the independent observer programme. Other benefits of this project have been to:

- develop a ubiquitous spatial management tool in TEPS/fishery interactions
- highlight concerns of industry in relation to trends in seal/ sea lion populations
- raise awareness among the fishing industry of the legislative requirements for maintaining WTO exemption

The benefits of this research to the WCRLF has been to quantify the risk of whale entanglement associated with changes to the level of fishing effort, changes in whale abundance and potential changes due to environmental factors. Some of the factors are beyond the control of the fishing industry but this report has also highlighted the importance of monitoring the industry's uptake of the Code of Practice and its strong role in mitigating large whale entanglement. This report will contribute to further studies of large whale entanglement both for this specific issue and for other instances throughout the work. These data are also useful when considering changes to the timing of the WCRLF, such as extending the season into August to take advantage of market opportunities. The report demonstrates the strong influence that increasing the temporal overlap of the fishery and the whale migration can have on entanglement rate.

9.0 Further development

The SLSFIAG has endorsed the recommendation of the current study to develop and implement as quickly as possible a robust independent observer programme that can also be used to monitor and collect relevant data for the target species of the TSF. This has been listed as one of the requirements for the ongoing WTO certification of the fishery by the Commonwealth government under the *EPBC Act* (1999). The Professional Shark Fishers Association along with the Western Australian Fishing Industry Council (WAFIC) has also independently endorsed this recommendation. Alternative funding sources have been identified by the SLSFIAG and funding applications have been drafted for submission if required.

Alternative methods to examine the interaction rate between sea lions and gillnets could be investigated. One such way would be to spatially model foraging tracks using correlated random walks (e.g. grey seals in Austin et al. 2004) and randomly select gillnet fishing effort from the daily logbook data to simulate the chances of physical interaction between the two groups. The advantage of this method is that it is relatively easy to model the effects of spatial closures on the interaction rate, and may provide a more accurate measure than the simple normal distribution of foraging effort model. This is an important distinction as the only

proposed mitigation strategy for the incidental mortality of sea lions in demersal gillnets is to reduce fishing effort with spatial or temporal closures. In this scenario it would be essential to be able to quantify the benefit of the closure in terms of reducing the threat of incidental mortality as well as determining the potential loss of catch for the fishing industry.

No further development of modelling large whale interactions with the WCRLF or determining uptake of the Code of Practice has been planned or undertaken. The last EMS for the WCRLF in relation to the Marine Stewardship Certification rated this issue a low ecological risk as it does not represent a threatening process to the group D humpback whale population.

10.0 Planned outcomes

The planned outcomes in the project proposal were:

- An understanding of the determining factors involved in the rate of large whale entanglements in the ropes of the west coast lobster fishery and the efficacy of potential mitigation strategies. This will give fishery managers an understanding as to what affects the rate of entanglement of large whales and what potential mitigation strategies could be employed and their respective cost-benefit analyses. This has great public and fishery benefit as there is significant public concern over this issue, and;
- An assessment of the spatial and temporal overlap of pinniped foraging effort and demersal gillnet fisheries effort. This outcome will help define the areas of concern regarding the probability of interaction between protected pinniped species and the two demersal gillnet fisheries in WA. These data will provide fishery managers with the information needed to assess spatial/temporal options of management of fishing effort to mitigate incidental bycatch of threatened/protected species.

The project has delivered an assessment of the likely impact of increasing humpback whale abundance on the entanglement rate in ropes of the WCRLF and suggests that there is likely to be a minimal increase in the rate given the current fishery management arrangements and mitigation strategies involved. The spatial assessment of the overlap between ASL foraging range and demersal gillnet fishing effort has highlighted the areas where the greatest likelihood of interaction would occur. The report has also developed a risk ranking for impacts of hypothetical levels of interaction on the viability of sub-populations of ASL based on the distribution of the most recently available demersal gillnet fishing effort (2005/06).

11.0 Conclusion

ASLs display very distinct and individualistic foraging patterns, which may be related to habitat variation, patch quality and prey preferences. There are also regional and ontogenetic patterns evident in the size of the foraging range and depths to which animals can dive. This makes the construction of a generalized foraging model for this species difficult. There appears to be almost complete spatial overlap of demersal gillnetting activity and ASL foraging range, however the probability of interaction between ASL and demersal gillnet fisheries in WA has probably reduced over the past 5 years due to the reduction in fishing effort. Regular re-assessment of the likely spatial overlap of fishing effort and foraging effort may be required as the redistribution of fishing effort in response to management measures and target stock

distribution and fishery returns could greatly affect the probability of interaction. The viability of many colonies of ASL may still be affected due to the lag effects of this recent interaction rate and any ongoing incidental mortality. Alternative models of determining the interaction rate would also be valuable. There is still considerable uncertainty in the PVA model of ASL demography, especially in the understanding of underlying population trajectories and the possibility of density-dependent rates of demographic traits. Knowledge of the population trajectories of ASL at some of the colonies identified as being at risk from the impact of potential incidental mortality as well as greater information on key demographic parameters would greatly enhance our ability to assess the probability of interaction and its likely impact.

ASL populations in WA are particularly vulnerable to very low levels of additional mortality and a better understanding of the real rate of bycatch in demersal gillnetting is required to accurately determine the threat. Estimates of the incidental mortality rate in a number of areas from an independent observer programme may provide information to fully assess the potential risk to this threatened species. A more refined spatial scale of the fishing effort is required to better understand the issue and further refinement of the sea lion foraging model is also needed, especially if mitigative action (i.e spatial closures) was proposed and its potential effect to be quantified. This is a priority action in understanding the interaction between ASL and the gillnet fisheries and fulfilling the requirements for the continued WTO approval of the fisheries, as well as enacting the Federal Threatened Species Recovery Plan for the ASL.

The project was able to partially fulfil the first two objectives. Limitations in the spatial scale and extent of ASL foraging data and gillnet fishing effort has reduced the accuracy of the model to provide empirical estimates of the spatial overlap between the two resource groups. This means that a coarse scale interpretation of the probability of interaction posed to ASL by the two TSF could be over-estimated. This has obvious consequences with regards to using these data to formulate a management response to the perceived issue of incidental mortality of ASL. The use of a PVA model to determine the impact of potential bycatch on ASL colonies is also limited by the accuracy of the estimates of demographic parameters and the underlying population trajectory. This project did not intend to determine a method of estimating the actual rate of incidental mortality of ASL in demersal gillnet fisheries from the existing data but to provide a method of determining where the extent of the interaction was expected to occur and assess the vulnerability of ASL colonies to ongoing anthropogenic mortality.

The entanglement rate of large whales in the WCRLF is likely to increase over the next 10-15 years as the Humpback whale population increases before plateauing at its projected carrying capacity of approximately 30,000. This increase may be quite modest though as reductions in fishing effort, uptake of mitigative actions in the WCRLF and a potentially reduced carrying capacity for humpback whales all act to reduce the rate of entanglement. At a maximum forecast level, the entanglement rate may more than double from its current average of about 2 per fishing season. The potential lengthening or changing in timing of the migration period due to increasing population size and climate change effects has the potential to increase the entanglement rate due to greater temporal overlap of the two events. The likelihood of an increase in entanglement rate due to ecological effects should be reflected in the performance measures of the fishery's Environmental Management Strategy. Encouragement of the uptake of the Code of Practice within the fishery and some measurement of the participation of the fishery in the code will facilitate a better understanding of the factors controlling the rate of entanglement. This component of the project was able to determine the relative contribution of increasing humpback whale abundance on the entanglement rate of large whales in WCRLF and estimate the change in entanglement rate in the future.

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Appendix 2 – Intellectual property

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Appendix 4 – Acronyms

AAD	Australian Antarctic Division
ACAMMS	Australian Centre for Marine Mammal Science
ASL	Australian sea lion
CAES	Catch And Effort Statistics
CSIRO	Commonwealth Scientific and Industry Research Organisation
DEC	Department of Environment and Conservation
DOF	Department of Fisheries, Western Australia
EPBC	Environment Protection and Biodiversity Conservation Act
IUCN	International Union for the Conservation of Nature
JASDGDLF	Joint Authority Southern Demersal Gillnet and Demersal Longline Fishery
PVA	Population Viability Analysis
SAMS	Sub-adult males
SARDI	South Australian Research and Development Institute
SLSFIAG	Sea Lion Shark Fishing Interaction Advisory Group
TEPS	Threatened and Protected Species
TSF	Temperate Shark Fishery
WCDGDLF	West Coast Demersal Gillnet and Demersal Longline Fishery
WCRLF	West Coast Rock Lobster Fishery