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Shark Action Plan Policy Report

Michelle R Heupel, Peter M Kyne, William T White, Colin A Simpfendorfer

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Australian Institute of Marine Science

CSIRO

James Cook University Australia

Charles Darwin University

Enquiries should be addressed to:
Michelle Heupel
m.heupel@aims.gov.au

Project Leader's Distribution List

Department of the Environment and Energy, Biodiversity Conservation Division	
Department of the Environment and Energy, Biodiversity Conservation Division	
Great Barrier Reef Marine Park Authority	Darren Cameron

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Important Disclaimer

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EXECUTIVE SUMMARY

Conservation of chondrichthyan species (sharks, rays and ghost sharks) is an increasing priority globally as evidence of overexploitation of many species becomes increasingly apparent. While there are a range of potential stressors to chondrichthyan species, their primary threat comes from interactions with fisheries. Therefore, to improve the status of these species on national and international scales requires effective fisheries management. However, management and conservation of chondrichthyan species is complicated. A number of chondrichthyans are fishery targets and as such subjected to directed fishing effort, while others are encountered as bycatch in fisheries targeting other high value species (e.g. tuna). Species taken as bycatch are often retained as byproduct if they can be sold. The type of management applied, and amount of data collected vary depending on whether the species is target or byproduct. Finally, some species interact with fisheries but are discarded with little or no data are recorded on the number of interactions or condition of individuals. These differences in the amount and type of data available complicate management decisions and the situation is made even more complex by the broad distributions of some species which span national and international boundaries. As such, concerted efforts to understand population status and trends are required to facilitate management and conservation of chondrichthyan species.

Here we examined the status of chondrichthyan species within Australian waters in an effort to understand how well current protections are working. This work is placed in the context of national and international conservation measures. We also explore additional threats such as climate change, shark control programs and habitat loss relative to the current and future status of these species. Finally, we explore a framework for managing information and responses to international obligations for at-risk species.

Overall, the status of Australian chondrichthyan species is good. The majority of assessed Australian chondrichthyans were determined not to be in a threatened category and were assess as Near Threatened (9.8%) or Least Concern (69.4%). A further 9.2% are currently Data Deficient (insufficient information to assess their status). Thus 11.6% of assessed species fell within a threatened category. This is one of the lowest threat rates when compared to other regional or national level assessments for chondrichthyans. Of the 22 species identified as Critically Endangered or Endangered, all but five of these species are already protected in Australia or previously considered for protection. Five of 17 species considered Vulnerable are already protected in Australia. However, some of the Vulnerable species qualify for listing based on small distributions rather than as a result of an immediate direct threat. The national analysis confirmed the main threat to Australian chondrichthyan species is commercial fishing pressure through targeted harvest or bycatch mortality.

Based on the assessments and research conducted here we make the following recommendations:

Recommendations

- Prioritise assessment and potential EPBC listing of Endangered and Critically Endangered chondrichthyan species that are not currently listed.
- Improve data recording to species-level for target, bycatch and discard species, including information on their condition and fate.

- Undertake research to define the biology and life history of threatened and at-risk species to better inform their management.
- Explore and develop methods for assessing the status of species and their population trajectories independent of fishery catch data (which may be unreliable and retrospective in nature).
- Regularly update Ecological Risk Assessments of species that interact with fisheries relative to the capacity to collect data and assess the status of these species; including interactions of threatened species, or those of conservation concern.
- Consider the potential implications of cumulative threats, primarily in relation to coastal species, where climate change, habitat loss, pollution, exposure to multiple fisheries, etc. can play a compounding role in species status and population viability.

1. INTRODUCTION

Conservation of chondrichthyans (sharks, skates, rays and ghost sharks – hereafter referred to as 'sharks') is an increasing priority globally, including in Australia, as evidence of declines of some species becomes apparent. Current global estimates indicate approximately 25% of shark species are threatened with extinction (Dulvy et al. 2014a). The most pervasive threat to these species is fishing. This includes targeted fisheries as well as those in which they are taken as byproduct and bycatch. As markets for shark products have increased in the last several decades (Clarke and Dent 2015) so has pressure on their populations and incentive for fishers to harvest or retain them. This market demand, combined with globally pervasive fishing, has been a major driver of decline for many shark populations (Dulvy et al. 2017). The implications of fishing pressure are apparent at local, regional and global scales causing complications in how to best manage and conserve shark species. Australia is not immune to these issues with a number of nationally threatened species. This Shark Action Plan Policy Report explores areas for improved management including a summary of the current status of sharks, guidelines for reducing impacts and improving management, and identification of key knowledge gaps impeding conservation and management. A separate report, The Action Plan for Australian Sharks, contains species assessments for all Australian sharks.

Designing effective conservation and management processes for shark species is a complex issue due to a wide array of factors. With increasing numbers of shark species nearing or crossing thresholds where they require national and international protection, a broader perspective on their status and our national approach to their management is required. Species reaching threat categories are considered for protection under the *Environment Protection and Biodiversity Conservation Act* (*EPBC Act*) to recover populations. Here we examine the status of Australian shark species relative to current national protections. Compilation and synthesis of existing data and knowledge is required for application to national level decisions around the management and protection of shark species. In addition to national concerns, Australia is also a signatory to several international agreements including the Convention on International Trade in Endangered Species (CITES) and the Convention for the Conservation of Migratory Species (CMS) that include shark species on their Appendices. Australia is a Signatory to both of these instruments and as such has obligations set out in these agreements, including to work with other countries to improve the status of populations that are subject to global protections.

Finally, Australia has a National Plan of Action (NPOA) for sharks (http://www.agriculture.gov.au/fisheries/environment/sharks/sharkplan-2) which outlines 15 issues for shark conservation and management. The NPOA provides a roadmap for improved management and conservation of shark species in Australian waters. Many of the issues identified in the NPOA relate to data collection, management assessment, understanding effects of fishing and completing risk assessments. Although compiled in 2012, many of these issues are still relevant and require further action. The scope of the NPOA is broad-reaching and as such recommendations are for high level actions. This Shark Action Plan Policy Report takes a more detailed look at species status and threats relative to existing policy to help formulate more detailed guidance for managers and policymakers. Recommendations compiled here are intended to supplement those listed in the NPOA.

2. OVERVIEW OF STATUS OF SPECIES WITHIN AUSTRALIAN WATERS

Until now, the most recent compilation of IUCN Red List Assessment of sharks in this region was conducted in 2003 when approximately 175 Australasian chondrichthyans were assessed and reported on (Cavanagh et al. 2003). The 2003 assessments revealed 34 species (19%) listed in threat categories, but the majority of species were Least Concern. Here the IUCN Red List of Threatened Species Categories and Criteria were applied at the national level to assess the extinction risk of all species of sharks, rays, and ghost sharks occurring in Australian waters. Therefore, this assessment differs from the one conducted in 2003 which included the broader Oceania region. Methods and results of 328 species assessment are provided in the accompanying *The Action Plan for Australian Sharks*. The majority of species are in the Least Concern category (69% of the Australian fauna) suggesting a large number of healthy populations within Australian waters, although there are a number of species without enough data to make an accurate status assessment (Data Deficient; 9%) and an almost equal number of species considered Near Threatened (10%) as in all threatened categories (Vulnerable, Endangered, Critically Endangered; 12%; Table 1). Thus, consideration of ongoing pressures and threats should be part of forward planning to prevent currently Near Threatened species moving into threatened categories.

Table 1. Classification of Australian chondrichthyans into IUCN categories based on assessment of species in Australian waters only in 2018. These classifications may differ from global listings that include other regions.

IUCN category	
Critically Endangered	5 (1.5%)
Endangered	16 (4.9%)
Vulnerable	17 (5.2%)
Near Threatened	32 (9.8%)
Least Concern	227 (69.4%)
Data Deficient	30 (9.2%)

2.1 Critically Endangered species (IUCN)

Three species assessed as Critically Endangered under IUCN Red List Categories and Criteria are currently listed on the *EPBC Act* or have previously been considered for listing. The other two species (*Cephaloscyllium albipinnum* and *Dentiraja confusus*) have shown evidence of significant decline based on fisheries observer data (Table 2) and should be considered for further protection.

2.2 Endangered species (IUCN)

Examination of Endangered species revealed that 11 of 16 species are currently protected under the *EPBC Act.* In addition, two species (*Sphyrna mokarran* and *Urolophus orarius*) have been previously considered but not listed under the *EPBC Act*. The remaining three Endangered species not included or previously considered for *EPBC* listing are *Alopias pelagicus*, *Dipturus canutus* and *Squalus chloroculus.* The Pelagic Thresher (*Alopias pelagicus*) is listed on CMS and as such was considered for listing as Migratory under the

EPBC Act. In 2014, Australia took a reservation on listing this species to avoid impacts on recreational fishers and therefore is not listed under the *EPBC Act* as Migratory. Declines of *Dipturus canutus* and *Squalus chloroculus* are related to fishing pressure on a suite of demersal species off south-eastern Australia, including several sharks and skates.

2.3 Vulnerable Species (IUCN)

Seventeen species were assessed as Vulnerable applying the IUCN Red List Categories and Criteria. Five of these species are already listed as threatened or Migratory under the *EPBC Act*. The Bigeye Thresher (*Alopias superciliosus*) was included in the reservation for CMS described above for Pelagic Thresher and as such is not listed under the *EPBC Act*. Some of the remaining species have small home ranges which contribute to their Red List status. A number of Vulnerable species likely lack sufficient species-specific data to be considered for *EPBC* listing, but warrant additional research to better understand their status.

2.4 Other status assessments

Status information for the remaining IUCN Red List categories (Near Threatened, Least Concern and Data Deficient) can be found in the accompanying *The Action Plan for Australian Sharks*.

In addition to IUCN Red List assessments, a recent review of the status of Australia's fished shark stocks has been completed as a Shark Report Card (SRP) to The Fisheries Research and Development Corporation (Simpfendorfer et al. 2018). This assessment of 194 Australian shark species revealed the majority (n = 126) of Australia's fished shark populations are sustainable and 11 populations are recovering from past overexploitation. However, 16 populations are overfished and 4 are declining and of concern (Table 2). Most of the overfished species are assessed as Critically Endangered or Endangered and receive protection from listing on the *EPBC Act*. Of note are *C. albipinnum* and *Anoxypristis cuspidata* which are overfished, but not listed in a threatened category on the *EPBC Act*. Some of the species identified as overfished are pelagic species that are not heavily fished by Australian fleets (e.g. *Carcharhinus longimanus* and *Isurus oxyrinchus*). An additional 39 species are currently undefined. While these results suggest Australia has a good track record in managing fisheries that take sharks, including several target shark fisheries, it reveals there is capacity for improvement.

Table 2. List of species considered threatened under IUCN Red List Categories, any associated listing on the *Environment Protection Biodiversity Conservation* (EPBC) *Act* and their fishery status as defined in the Shark Report Card.

Species	Common name	IUCN	EPBC	Fishery status
Pristis pristis	Largetooth Sawfish	CR	VU	O
Pristis zijsron	Green Sawfish	CR	VU	O
Carcharhinus longimanus	Oceanic Whitetip Shark	CR		O
Cephaloscyllium albipinnum	Whitefin Swellshark	CR		O

Species	Common name	IUCN	EPBC	Fishery status
Dentiraja confusus	Australian Longnose Skate	CR		
Centrophorus harrissoni	Harrisson's Dogfish	EN	CD	O
Centrophorus zeehaani	Southern Dogfish	EN	CD	
Squalus chloroculus	Greeneye Spurdog	EN		TR
Rhincodon typus	Whale Shark	EN	VU, M	O
Alopias pelagicus	Pelagic Thresher	EN		
Cetorhinus maximus	Basking Shark	EN	M	
Galeorhinus galeus	School Shark	EN	CD	TR
Glyphis glyphis	Speartooth Shark	EN	CR	O
Glyphis garricki	Northern River Shark	EN	EN	O
Sphyrna lewini	Scalloped Hammerhead	EN	CD	O
Sphyrna mokarran	Great Hammerhead	EN		O
Pristis clavata	Dwarf Sawfish	EN	VU	O
Zearaja maugeana	Maugean Skate	EN	EN	
Dipturus canutus	Grey Skate	EN		
Urolophus orarius	Coastal Stingaree	EN		
Mobula birostris	Giant Manta Ray	EN	M	
Carcharodon carcharias	White Shark	VU	VU, M	TR
Squatina albipunctata	Eastern Angelshark	VU		TD
Alopias superciliosus	Bigeye Thresher	VU		
Carcharias taurus (Australia)	Grey Nurse Shark	VU	CR (east) VU (west)	O
Isurus oxyrinchus	Shortfin Mako	VU	M	TD
Isurus paucus	Longfin Mako	VU	M	
Brachaelurus colcloughi	Colclough's Shark	VU		O
Eusphyra blochii	Winghead Shark	VU		
Anoxypristis cuspidata	Narrow Sawfish	VU	M	O
Aptychotrema timorensis	Spotted Shovelnose Ray	VU		
Dentiraja australis	Sydney Skate	VU		
Spiniraja whitleyi	Melbourne Skate	VU		
Hemitrygon fluviorum	Estuary Stingray	VU		
Urolophus bucculentus	Sandyback Stingaree	VU		
Urolophus sufflavus	Yellowback Stingaree	VU		
Urolophus viridis	Greenback Stingaree	VU		
Myliobatis hamlyni	Purple Eagle Ray	VU		

CR: Critically Endangered, EN: Endangered, VU: Vulnerable, CD: Conservation Dependent, M: Migratory, O: Overfished, TD: Transitional Depleting, TR: Transitional Recovering

Although there is good alignment between species listed as threatened based on IUCN Red List Categories and Criteria and their identification as being overfished, there are a number of species that have previously declined based on fishing pressure, or are currently in decline, that are not listed on the *EPBC Act* (Table 3). Some consideration should be given to whether management interventions for species in decline need adjustment prior to these species reaching a state requiring assessment for listing under the *EPBC Act*. Most of these species were not assessed as threatened applying the IUCN Red List Categories and Criteria because the declines occurred over only part of their Australian range.

Table 3. Australian shark stocks with evidence of population declines (Overfished, Transitional Depleting, Transitional Recovering) as defined by Simpfendorfer et al. 2018 that are not listed on the *EPBC Act* and the type of management arrangements in place (if any). Fishery rules – species-specific rules in place in main fisheries; Protected species – protected under Commonwealth/state/Territory legislation; Rebuilding plan – species with a rebuilding plan under the Commonwealth Harvest Strategy Policy. Modified from Simpfendorfer et al. 2018.

Species	**Common name**	**Aust. management**
Overfished		
Centrophorus granulosus	Gulper Shark	Rebuilding plan
Odontaspis ferox	Sand Tiger Shark	Protected species (NSW)
Transitional Depleting		
Cephaloscyllium variegatum	Saddled Swellshark	None
Galeocerdo cuvier	Tiger Shark	None
Transitional Recovering		
Squalus chloroculus	Greeneye Spurdog	Fishery rules
Squalus grahami	Eastern Longnose Spurdog	Fishery rules
Squalus montalbani	Philippine Spurdog	Fishery rules
Centrophorus moluccensis (Eastern Australian stock)	Endeavour Dogfish	Fishery rules
Deania quadrispinosa	Longsnout Dogfish	Fishery rules
Carcharhinus amblyrhynchos	Grey Reef Shark	Fishery rules
Carcharhinus obscurus	Dusky Shark	Fishery rules
Carcharhinus plumbeus	Sandbar Shark	Fishery rules
Triaenodon obesus	Whitetip Reef Shark	Fishery rules

3. DATA GAPS AND DATA NEEDS FOR AUSTRALIAN SHARKS

There are significant data gaps for Australian shark species, with many, especially the rays, largely understudied. The 2003 IUCN assessment of 175 Australasian sharks revealed 34% (approximately 59 species) were Data Deficient (Cavanagh et al. 2003) indicating not enough was known about their populations to determine if they were under threat of extinction. Global statistics indicate as many as 47% of sharks could not be accurately assessed due to limited data (Dulvy et al. 2014a). In the current assessment of 327 species within Australian waters the proportion of Data Deficient species improved with only 9.2% of species listed in this category, but this still includes 30 species highlighting that considerable data-gaps remain. In addition, some of these species are of concern based on their interactions with fisheries. To ensure effective management and conservation, improved data collection is required for these data-poor species.

3.1 Species Data Gaps

An expert workshop held in 2016 identified 3 species with a medium priority for data collection and potential conservation action (Table 4; see Heupel et al. 2016 for detailed methods). These species were prioritised for data collection due to their common interaction with fisheries and restrictive life history parameters. The remaining Data Deficient species were considered lower priority for research because of low interactions with fisheries, and hence a low likelihood of threat or capacity to manage any existing threat. No species were considered to be of high priority for data collection. It is worth noting, however, that this review focused on 77 of the 175 species assessed in 2003 in threat categories or considered Data Deficient (excluding Least Concern species). The review therefore did not include all Australian species and as such other priority research species may emerge.

Table 4. Data Deficient species considered medium priorities for data collection.

Species	Common name	IUCN	Priority
Dentiraja flindersi	Pygmy Thornback Skate	DD	Medium
Cirrhigaleus australis	Mandarin Shark	DD	Medium
Mustelus walkeri	Eastern Spotted Gummy Shark	DD	Medium

The majority of Data Deficient species are deepwater inhabitants which are difficult to study and can be cost-prohibitive. However, should fishing pressure change within Australian waters (e.g. fishing below 700m [the current max depth of most Australian fishing]) these species will have increased exposure to risk. A lack of clear understanding of their life history and current abundance will hamper any ability to determine effects of fishing on these populations. Thus, any expansion of deepwater fisheries should take these little known species into account including directed data collection and research.

3.2 Data Needs

In addition to identification of species that require further study, the 2016 expert workshop identified several topic areas where data are lacking for species in several IUCN categories. Parameters relating to biology and ecology of species in Vulnerable, Near Threatened and Data Deficient categories were common data gaps. Expert assessment also revealed considerable differences in knowledge among species. Vulnerable and Near Threatened species require additional data on population trends, life history characteristics and pressures. In contrast, for many of the Data Deficient species taxonomy is the only known information indicating significant data gaps in all aspects of their life history, population trend and pressures. Over 80% of Data Deficient species require data on nearly every category to assess their conservation status. This result highlights the need for better species-specific data on shark biology, abundance and fishery interactions in Australian waters.

A brief examination of the currently known distribution patterns of species was also conducted to determine patterns in where species in each category occur in Australia. The majority of Vulnerable and Near Threatened species were located on the east coast of Australia and may be linked to the longstanding fisheries and high human population density in this part of the country. The majority of Data Deficient species were from deepwater regions in Western Australia and Queensland where there is limited fishing pressure and so limited fishery interactions and knowledge of these species.

3.3 Threats

The predominant threat to Vulnerable and Near Threatened species is fisheries. Experts conducted an assessment to provide an indication of which fishing gears Vulnerable and Near Threatened species interacted with most. Results indicated the majority of Vulnerable and Near Threatened species interacted with trawl and longline fisheries with fewer species interacting with gillnet and recreational fisheries. This in part reflects the distribution of these species and bias toward deepwater species comprising the majority of Data Deficient species. Where possible, data collection on captured sharks should be increased in fisheries. It should be noted that this assessment did not include Endangered or Critically Endangered species since their listing status should have resulted in policy to reduce their interactions with fisheries. Habitat loss was also considered a possible threat for at least one species. Climate change was not considered in this assessment and is explored in section 8 of this report.

4. PRIORITY ACTIONS FOR THE DEPARTMENT OF THE ENVIRONMENT AND ENERGY

4.1 National Species Assessment and Listing

Based on the results of IUCN Red List assessments it is suggested that DoEE investigate the possibility of listing several species for protection under the *EPBC Act*. Two of these species are considered high priorities and should be assessed immediately (Table 5). An additional five species are considered medium priorities and should be investigated within the next 12-18 months to determine if they meet evidentiary standards for *EPBC Act* listing.

Table 5. Species assessed as Threatened based on IUCN Red List Assessments and associated *EPBC* listing and management action priority. Species listed as NA priority are already listed in similar levels on the *EPBC Act* and IUCN Red List Assessments.

Species	Common name	IUCN	EPBC	Comment	Priority
Carcharias taurus (East coast)	Grey Nurse Shark	CR	CR		NA
Pristis pristis	Largetooth Sawfish	CR	VU	Consider up-listing	Medium
Pristis zijsron	Green Sawfish	CR	VU	Consider up-listing	Medium
Carcharhinus longimanus	Oceanic Whitetip Shark	CR		Previously considered, threats mostly outside Australia	
Cephaloscyllium albipinnum	Whitefin Swellshark	CR		Consider listing	High
Dentiraja confusus	Australian Longnose Skate	CR		Consider listing	High
Centrophorus harrissoni	Harrisson's Dogfish	EN	CD		NA
Centrophorus zeehaani	Southern Dogfish	EN	CD		NA
Squalus chloroculus	Greeneye Spurdog	EN		Subject to fisheries management and indicated as recovering	
Rhincodon typus	Whale Shark	EN	VU	Listed and also Migratory. Threats mostly outside Australia	NA
Galeorhinus galeus	School Shark	EN	CD		NA
Glyphis glyphis	Speartooth Shark	EN	CR		NA
Glyphis garricki	Northern River Shark	EN	EN		NA
Sphyrna lewini	Scalloped Hammerhead	EN	CD		NA

Species	Common name	IUCN	EPBC	Comment	Priority
Sphyrna mokarran	Great Hammerhead	EN		Previously considered. Lacks species specific data for listing. Possible lookalike issue with *S. lewini*	
Alopias pelagicus	Pelagic Thresher	EN		Threats mostly outside Australia	
Cetorhinus maximus	Basking Shark	EN		Threats mostly outside Australia	
Pristis clavata	Dwarf Sawfish	EN	VU	Consider up-listing	Medium
Zearaja maugeana	Maugean Skate	EN	EN		NA
Dipturus canutus	Grey Skate	EN		Lacks species specific data for listing	
Urolophus orarius	Coastal Stingaree	EN		Previously considered, not prioritised. Small range	
Mobula birostris	Giant Manta	EN		Listed as Migratory	
Carcharias taurus	Grey Nurse Shark	VU	CR		NA
Carcharodon carcharias	White Shark	VU	VU		NA
Squatina albipunctata	Eastern Angelshark	VU		Consider listing	Medium
Alopias superciliosus	Bigeye Thresher	VU		Threats mostly outside Australia	
Isurus oxyrinchus	Shortfin Mako	VU		Threats mostly outside Australia	
Isurus paucus	Longfin Mako	VU		Threats mostly outside Australia	
Brachaelurus colcloughi	Colclough's Shark	VU		DoEE has on a watching brief	
Eusphyra blochii	Winghead Shark	VU		Possible look-a-like issue with *S. lewini*	
Anoxypristis cuspidata	Narrow Sawfish	VU		Listed as migratory. Consider threat listing	Medium
Aptychotrema timorensis	Spotted Shovelnose Ray	VU		Small range	
Dentiraja australis	Sydney Skate	VU		Not enough species-specific data	
Spiniraja whitleyi	Melbourne Skate	VU		Not enough species-specific data	
Hemitrygon fluviorum	Estuary Stingray	VU		Limited recent data	
Urolophus bucculentus	Sandyback Stingaree	VU		Not enough species-specific data	

Species	Common name	IUCN	EPBC	Comment	Priority
Urolophus sufflavus	Yellowback Stingaree	VU		Not enough species-specific data	
Urolophus viridis	Greenback Stingaree	VU		Not enough species-specific data	
Myliobatis hamlyni	Purple Eagle Ray	VU		Small range	

4.2 International Obligations

In conjunction with priorities established for Australian species, international nominations to CITES and CMS are likely to continue and include additional species in the future. These listings have implications for the protection, regulation and monitoring of species in Australian waters. At least a portion of nominated species will occur in Australian waters and interact with Australian fisheries (including shark control programs). Monitoring and management may be required to satisfy Non-Detriment Finding requirements for CITES and reporting to CMS. Mechanisms for collecting these data on a national scale and a process for collating and reporting the data are needed.

Given the high value of their fins and growing global concern for their status, it is likely that the wedgefishes (*Rhina, Rhynchobatus*) and giant guitarfish *(Glaucostegus*) will be listed under both CMS and CITES in the next 1-3 years. To improve our ability to meet and support international listings as well as develop adequate national policy around management and conservation of wedgefishes they should be an **immediate priority for research and data collection**.

5. RESEARCH PRIORITIES AND FUTURE NEEDS

A number of actions are required to better define the status of Australian sharks, and understand the implications of current fishing pressure and management regimes. Future research and data priorities should include:

- Conduct meta-analyses of current spatial protections (e.g. dogfish closures, GBRMP, AMP, etc) and their capacity to protect at-risk but not listed species.
- Use research and data collection to define the status of high risk species such as wedgefish/guitarfish and Narrow Sawfish, as well as species with potential lookalike issues in fisheries such as Smooth and Great Hammerheads and Winghead Sharks.
- Improve data collection to define the biology, life history and identification of biologically important areas for at-risk species.
- Update Ecological Risk Assessments of fishery species relative to the capacity to collect data and assess the status of these species (tractability). This would identify species of high concern and high potential to improve the status of the population. Flow on analyses could consider the tractability and efficacy of mitigation and management processes.
- Conduct qualitative risk assessments for deepwater species (which comprise the majority of Data Deficient species) and identification of future threats to these populations.
- Explore and develop methods for assessing the status of species and their population trajectories independent of fishery catch data (which may be unreliable and retrospective in nature).
- Estimate levels of capture and handling stress, and post-release mortality, especially for at risk species, and develop methods to reduce mortality associated with capture and handling.
- Consider the potential implications of cumulative threats, primarily in relation to coastal species, where climate change, habitat loss, pollution, exposure to multiple fisheries, etc can play a compounding role in species status and population viability.

Research and data needs for Near Threatened species should be prioritised to allow intervention prior to these species moving into threatened categories. Including, but not limited to:

- Meta-analysis of the life history parameters and fisheries interactions of NT species to provide an indication which are at greatest risk of becoming threatened and are priorities for data collection.
- Direct surveys and sampling to:
    - Define distribution, habitat preference, fisheries interactions
    - Apply non-extractive methods such as baited underwater video or towed video systems to estimate abundance
    - Collect tissue samples for genetic and life history analyses
- Improve identification of deepwater or difficult to discern species

6. REVIEW OF COMMON THREATS AND POTENTIALLY SIGNIFICANT IMPACTS TO LISTED SHARK SPECIES

6.1 Introduction

Shark populations in Australia face a series of threats ranging from direct impacts of extractive use of species, to indirect effects of habitat loss and climate change. Anthropogenic activities can produce significant threats to shark species, including damage of key habitats or impacts to critical life stages. Interactions with shark species can occur with a variety of industries including, but not limited to: fisheries, oil and gas development and port development.

There are currently 10 species of shark listed as threatened and 4 listed as Conservation Dependent under the EPBC Act. A further 11 are protected migratory species and as such are also Matters of National Environmental Significance (MNES). It is anticipated that the number of threatened and/or migratory shark species will increase in coming years as the global status of many populations continue to decline. Global, or regional declines often result in species protection under international treaties such as the Convention on International Trade in Endangered Species (CITES) and the Convention for the Conservation of Migratory Species (CMS). Australia is a Signatory to both of these instruments.

All listed threatened and MNES species are protected under the EPBC Act and actions that will have, or are likely to have, a significant impact to the species requires approval from the Federal Environment Minister. The Matters of National Environmental Significance Significant Impact Guidelines (2013) defines a significant impact as follows:

> *A 'significant impact' is an impact that is important, notable, or of consequence, having regard to its context or intensity. Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the environment which is affected, and upon the intensity, duration, magnitude and geographic extent of the impacts. All of these factors must be considered when determining whether an action is likely to have a significant impact on matters of national environmental significance.*

The purpose of this section is to help identify threats that are relevant to the conservation of shark species and could potentially produce significant impacts on EPBC listed species.

6.2 What species does this apply to?

Chondrichthyans (sharks, skates, rays and chimaeras) are found throughout Australian waters and include an array of diverse and endemic species. This section outlines potential threats to currently listed elasmobranch species and those which may be listed in the future. Due to the diversity of elasmobranch species and the habitats they use, this document will be structured by habitat type rather than species groupings. See below for a table of current listed threatened and migratory species (Table 6).

Table 6. List of EPBC listed threatened species and species considered MNES based on CITES and/or CMS listings.

Species	Common name	EPBC status	CMS	CITES
Anoxypristis cuspidata	Narrow Sawfish	M	CMS App I & II	CITES App I
Carcharodon carcharias	White Shark	V, M	CMS App I & II	CITES App II
Manta alfredi	Reef Manta	M	CMS App I & II	CITES App II
Manta birostris	Giant Manta Ray	M	CMS App I & II	CITES App II
Pristis pristis	Largetooth Sawfish	V, M	CMS App I & II	CITES App I
Pristis zijsron	Green Sawfish	V, M	CMS App I & II	CITES App I
Pristis clavata	Dwarf Sawfish	V, M	CMS App I & II	CITES App I
Rhincodon typus	Whale Shark	V, M	CMS App I & II	CITES App II
Cetorhinus maximus	Basking Shark	M	CMS App I & II	CITES App II
Carcharhinus falciformis	Silky Shark	M	CMS App II	CITES App II
Carcharhinus longimanus	Oceanic Whitetip Shark			CITES App II
Lamna nasus	Porbeagle Shark	M	CMS App II	CITES App II
*Mobula eregoodootenkee**	Pygmy Devil Ray	M	CMS App II	CITES App II
Mobula japonica	Spinetail Devil Ray	M	CMS App II	CITES App II
Mobula thurstoni	Bentfin Devil Ray	M	CMS App II	CITES App II
Sphyrna lewini	Scalloped Hammerhead	CD	CMS App II	CITES App II
Sphyrna mokarran	Great Hammerhead		CMS App II	CITES App II
Sphyrna zygaena	Smooth Hammerhead			CITES App II
Alopias pelagicus	Pelagic Thresher		CMS App II	CITES App II
Alopias superciliosus	Bigeye Thresher		CMS App II	CITES App II
Alopias vulpinus	Common Thresher		CMS App II	CITES App II
Carcharhinus obscurus	Dusky shark		CMS App II	
Isurus oxyrinchus	Shortfin Mako	M	CMS App II	
Isurus paucus	Longfin Mako	M	CMS App II	
Prionace glauca	Blue shark		CMS App II	
Rhynchobatus australiae	White-spotted Wedgefish		CMS App II	
Squalus acanthias	Spiny Dogfish		CMS App II	
Carcharias taurus	Grey Nurse Shark (east coast)	CR		
Glyphis glyphis	Speartooth Shark	CR		

Species	Common name	EPBC status	CMS	CITES
Glyphis garricki	Northern River Shark	E		
Zearaja maugeana	Maugean Skate	E		
Carcharias taurus	Grey Nurse Shark (west coast)	V		
Centrophorus harrissoni	Harrisson's Dogfish	CD		
Centrophorus zeehaani	Southern Dogfish	CD		
Galeorhinus galeus	School Shark	CD		

CD = Conservation Dependent, CR = Critically Endangered, E = Endangered, M = Migratory, V = Vulnerable
*Note: the taxonomy of mobulids is currently being revised and this species name is likely to change. This name has been retained for now because it matches the CMS and CITES listings.

6.3 Threats

For many elasmobranch species the key threats are extractive use. This is primarily through interactions with fisheries where species are landed as target and/or bycatch. Harvesting of elasmobranchs in itself is not necessarily detrimental, as long as fishery targets and management can maintain populations within sustainable levels. Activities that cause direct mortality, particularly to mature females of highly threatened species require consideration for their effects on susceptible populations. Although there are a variety of direct and indirect threats to marine populations, they can largely be divided into four categories: fisheries, shark control programs, climate change and habitat loss.

6.3.1 Fisheries

The primary threat to elasmobranch populations globally is overfishing. In Australia, elasmobranchs are caught as target species and bycatch in a variety of fisheries. Elasmobranchs are also captured in recreational fisheries. Although elasmobranch species are released and/or discarded from both commercial and recreational fisheries, little information is available regarding post-release survival. Therefore, cryptic morality may also occur post-release increasing the effects of fisheries. Common fisheries threats are listed below.

1. **Gillnet fisheries.** The primary effort relevant to elasmobranchs in Australia is via demersal gillnet fisheries in southern Australia and inshore gillnet fisheries in northern Australia.

2. **Demersal longline.** Demersal longline fishing occurs Australia-wide with at least some of this effort targeting sharks (e.g. gummy, whiskery, dusky, blacktip sharks).

3. **Pelagic longline**. Although pelagic longlines primarily target tuna species, there is bycatch of pelagic sharks. Shark catch limits reduce retention, but post-release survival of discards is not well known.

4. **Trap and/or line.** Trap and/or line fisheries target teleost fish with minor catches of elasmobranchs.

5. **Prawn trawl**. A wide range of elasmobranchs are caught as bycatch in prawn trawl fisheries. Bycatch reduction devices help exclude larger individuals, but smaller species are caught and primarily discarded. As with other gear types, post-release survival is largely unknown for discarded individuals.

6. **Fish trawl.** These fisheries operate in shelf and slope waters and although they do not target elasmobranchs, there is elasmobranch bycatch. This bycatch includes species that are not resilient to fishing pressure such as gulper sharks.

7. **Recreational.** There is some targeting of elasmobranchs by recreational fishers, but they are more commonly encountered as incidental catch and released. Implications of catch and release are not well known.

6.3.2 Shark Control Programs

Shark Control Programs (SCPs) have been deployed to control populations of large, potentially dangerous sharks with programs currently in place in Queensland and New South Wales. A trial program was run in Western Australia but was discontinued. Australian SCPs rely on two main fishing techniques: gillnet and drum line. Gillnets are highly effective at catching a variety of elasmobranch species, including harmless species such as mobulid rays. Drum line installations are more selective in the species captured due to the use of large baited hooks and individuals can be released outside the possible impact area, although their survivorship is not known. This approach reduces unwanted bycatch of harmless species, but still has the potential to catch non-target sharks and individuals too small to be a threat to humans. SCP installations are a continuous and non-discriminatory source of mortality for elasmobranch species along the east coast of Australia.

6.3.3 Climate Change

Climate change is one of the most ubiquitous threats in marine communities. Changes in oceanic conditions are resulting in habitat loss, species range shifts, alteration of prey communities and other alterations potentially yet unrecognised. The major changes to ocean ecosystems will come from increased water temperature, increased tropical storm activity, changes in pH and changes in sea level (see climate change section of this document). One current implication of climate change can be observed in back-to-back bleaching events on the Great Barrier Reef. This damage to coral communities is likely to have flow on effects to the species that rely on these habitats, including elasmobranchs. Loss of coral is also being documented through tropical storm damage and crown of thorn starfish outbreaks. These cumulative threats will degrade coral reef habitats and the implications for elasmobranch populations are yet to be determined.

6.3.4 Habitat loss

Degradation and loss of habitat causes substantial risk to maintaining populations of threatened species. For marine species, coastal development in response to population growth, mangrove removal, alteration of rivers and runoff of pollutants can all have direct effects on critical habitats (e.g. nursery areas). Although the implications of habitat degradation and loss are not well-studied, heavy reliance on coastal habitats by juvenile elasmobranch species may ultimately result in population-level effects.

There are a variety of mechanisms which produce habitat loss. Examples are listed below, noting this is not an exhaustive list.

- **Mangrove degradation/loss.** Primary threats to mangroves include deforestation and implications of land-clearing and intensive agriculture (e.g. sedimentation, pollutant runoff from catchments). Mangrove habitats provide an array of ecosystem services and provide key resources for a variety of marine and estuarine species. Loss of these habitats will have flow on effects through marine communities. Mangroves are important habitat for many juvenile shark and ray species. The high productivity of mangrove ecosystems provides a source of prey for various elasmobranchs, while mangrove structure provides refuge for juveniles and small species as protection from larger predators.
- **Seagrass loss.** Similar to mangrove ecosystems, seagrass habitats provide multiple ecosystem services, support prey populations and provide refugia for elasmobranch species. Loss of seagrass will have similar effects to elasmobranch communities as those described for mangrove loss. A variety of natural and anthropogenic sources can result in loss of seagrass habitats including sedimentation, freshwater flow, etc.
- **River alteration.** Construction of dams and weirs alter the flow regime of river systems, but also block passage of species that rely on these habitats. Altered flow regimes can displace individuals that rely on estuarine or river conditions. Heavy river flows can force species to move into estuarine areas occupied by additional predators, and weir structures can restrict return to preferred habitats.
- **Coastal development.** Human population increases often result in coastal development which can have detrimental effects on marine ecosystems. Expansion of port facilities result in alteration of natural habitats and dredging causes habitat disturbance both at the site of extraction and the site of dumping. These direct effects on habitat are often coupled with increased levels of chemicals and pollutants occurring in coastal waters. These changes can work to displace species and/or produce physiological changes such as endocrine disruption of reproduction. Thus, the effects of coastal development are

diverse and broad, with currently limited information on their long-term effects on elasmobranch populations.

As conditions and ecosystems continue to be altered and climate change effects become more prevalent in marine ecosystems, consideration should be given to cumulative impacts. Activities that result in damage or loss of critical habitat must be considered in conjunction with existing pressures, including fishing. In isolation each of these factors may not cause a significant impact to elasmobranch populations, but the combination of habitat loss and fishing pressure might produce adverse outcomes for populations. Careful consideration of the individual impact, the importance of the habitat and other current stressors should be applied.

6.4 Ecology of species and reliance on habitat

Elasmobranch species are particularly susceptible to exploitation and population decline based on their typically long life spans, late age at maturity and low fecundity. Although some species can grow quickly and produce numerous young (e.g. sharpnose sharks), at the other extreme some species live for several decades and will produce less than 10 offspring during their lifetime (e.g. gulper sharks). Most species fall somewhere between these two ends of the spectrum with females producing 4-6 young every two years after a period of up to 10 years required to reach sexual maturity. These demographic parameters require careful management of elasmobranch populations to ensure sustainability.

Elasmobranch species can be found in almost every aquatic environment around Australia ranging from freshwater rivers to the open ocean. Use of habitat varies by species and often by life stage, with many species highly dependent on specific habitats or conditions. Below some of the major habitat types are discussed relative to potential habitat-specific threats to species.

6.4.1 River

A number of elasmobranch species inhabit rivers in Australia, including some of the world’s most threatened species – the sawfishes. Elasmobranch species that inhabit rivers are specialists adapted to living in these conditions and as such rarely occur in marine conditions (although some species may undergo ontogenetic shifts from use of freshwater habitats as nurseries to using marine habitats as adults). A variety of activities can threaten riverine elasmobranchs. Fishing (net and line) is one of the principal threats to elasmobranch populations and rivers are no exception. Species such as sawfishes are extremely susceptible to entanglement in fishing gear posing an increased risk of mortality. Habitat alteration through construction of weirs can prevent individuals from moving up river to preferred habitats or conditions and/or preventing avoidance of predators that occur in estuarine reaches of rivers. Alteration of river flow regimes via dams or other structures can alter conditions and force individuals to move to less optimal habitats. Introduction of pollutants into river habitats can also have physiological implications. For example, pollutants in rivers in Florida, USA have resulted in endocrine disruption of reproductive cycles of resident sharks and rays. Therefore a suite of human activities can directly and indirectly effect riverine elasmobranchs. Activities that have the potential to significantly alter these habitats or affect river inhabitants should be examined in relation to effects on threatened species.

6.4.2 Estuary

Estuarine habitats include most coastal bays and function as critical habitat for an array of species including elasmobranchs. Their close proximity to and influence from rivers make species that rely on these habitats susceptible to some of the same influences as river species. Construction of weirs and alteration of freshwater flows can have profound impacts on estuarine habitats and species. For example, heavy freshwater flows associated with rainfall events can force species to move due to reduced salinity, can remove seagrass beds that provide habitat and prey and can wash pollutants downstream into estuarine and coastal habitats. Estuaries are inhabited by a suite of small- and medium-bodied sharks and a number of ray species. Ray species of note in estuarine habitats include narrow sawfish, wedgefish and stingrays. Although many of the small- and medium-bodied sharks that inhabit estuaries are reasonably productive, these habitats are often heavily fished meaning resident populations are already under pressure from at least one industry. Extraction of estuarine species through fishing should be considered in the context of other threats in the region and new developments should also consider the ongoing effects of fishing and the potential implications of further stressors on estuarine communities.

6.4.3 Coastal

Coastal species are often exposed to greater threats than many other populations due to their proximity to human development and activities. These areas are often adjacent to or overlap with estuarine habitats and as such have similar threats. Similar to estuarine habitats, a wide variety of shark and ray species occur in these areas. Coastal habitats often serve as nursery areas for juveniles of a number of large-bodied shark species. These highly productive inshore habitats provide ample prey while also providing shelter from large predators which are more likely to occur further offshore. Therefore, coastal habitats tend to serve as critical habitat for the survival of juvenile sharks and rays. These regions also host a variety of small-bodied, productive species that form the basis of coastal shark fisheries. This combination means that coastal areas are highly important to a number of species with varying life history strategies and that they are also regularly targeted for extraction of sharks for human consumption. Additional threats to these systems come from loss of key habitat features that provide food and structure such as seagrass beds and mangrove forests. Anthropogenic activities that damage or remove these habitats are likely to have flow on impacts to elasmobranch populations that rely on these features for survival.

6.4.4 Coral Reef

Coral reef ecosystems are subject to a variety of disturbances including those produced by climate change. While a number of elasmobranch species use coral reef habitats, their dependence varies. Some species (e.g. Grey Reef Sharks) are highly dependent and only found in coral reef habitat, while others move extensively between reefs and coastal habitats (e.g. Tiger Sharks). Fishing remains one of the greatest threats for all reef-associated species. Reef-attached species are subject to fishing pressure, but many reef habitats are designated as marine protected areas excluding fishing to protect resident species. Sharks that live on a single reef that is closed to fishing have much greater protection than individuals living on reefs open to fishing. Depending on reef protection levels, reef residents in some areas may be more affected by changes in habitat than fishing pressure. Their direct reliance on reef habitats makes them less able to adapt to new conditions or other habitats, thus loss of reef habitats may lead to significant declines in these species. Activities that directly reduce coral cover and or degrade coral reef habitats should be considered a potential threat to reef-associated elasmobranchs. Highly mobile species that move between reefs have increased risk levels because their movement patterns may produce higher interaction rates with fishing vessels. However, they are less dependent on coral reef habitats and as such will be less affected by declines in reef health.

6.4.5 Pelagic

Pelagic elasmobranchs are known to move broad distances including across international boundaries. This movement, coupled with population declines, has resulted in a number of these species being listed on international treaties and subsequently as MNES. Based on their open ocean habitat use and movement patterns the greatest threat to these populations is through fisheries. The majority of fishing pressure on pelagic species is from open ocean fisheries in international waters.

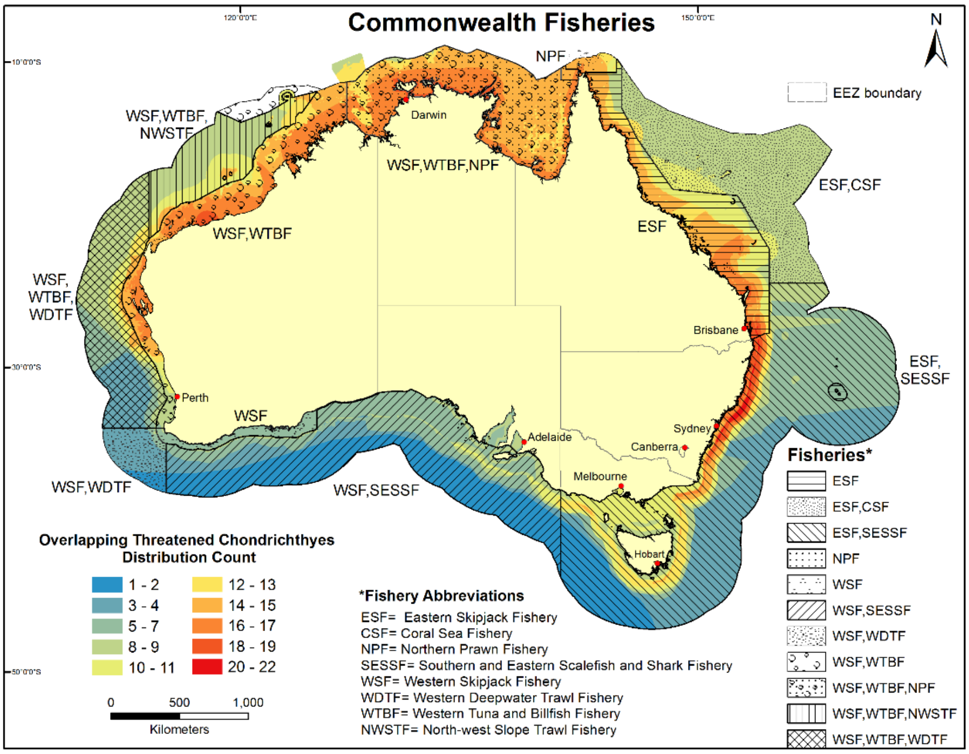
6.4.6 Deepwater

Deepwater elasmobranchs are some of the slowest growing, longest lived and least fecund of all elasmobranch species. Due to their deepwater distribution they are immune to many of the factors that affect coastal species. However, oil and gas exploration, drilling and other activities may have implications for these species. If these activities alter key habitats such as seamounts they may have implications for these species. Fishing pressure is likely the greatest current threat to these species due to their life history characteristics. Any new fishing and/or extractive activities that occur in the range of deepwater elasmobranchs should be examined for potential impacts on these vulnerable populations.

7. DISTRIBUTION OF THREATENED SPECIES

7.1 National-scale distributions

Based on current IUCN Red List assessments of Australian elasmobranchs, 40 species are listed as threatened (Vulnerable, Endangered or Critically Endangered; Table 1). The distributions of threatened elasmobranchs span the entire Australian coastline and EEZ (Figure 1). The greatest numbers of threatened species occur along the east coast of Australia, primarily offshore of New South Wales. Similar numbers of threatened species can be seen throughout the north, especially in Northern Territory. These areas likely represent longstanding fishing effort (NSW) and the distribution of highly vulnerable species (e.g. sawfishes). Breaking distribution data down by IUCN Red List category (Figure 2) reflects the larger numbers of species in the Vulnerable category compared to Endangered and Critically Endangered, but further highlights the common distribution of individuals in these categories. This information provides context for where future threat management may be required.



Data provided by Commonwealth Fisheries 2006 Dataset

Figure 1. Distribution of 40 threatened elasmobranch species (Vulnerable, Endangered or Critically Endangered) based on IUCN Red List assessments. Colours indicate overlapping numbers of species in a location.

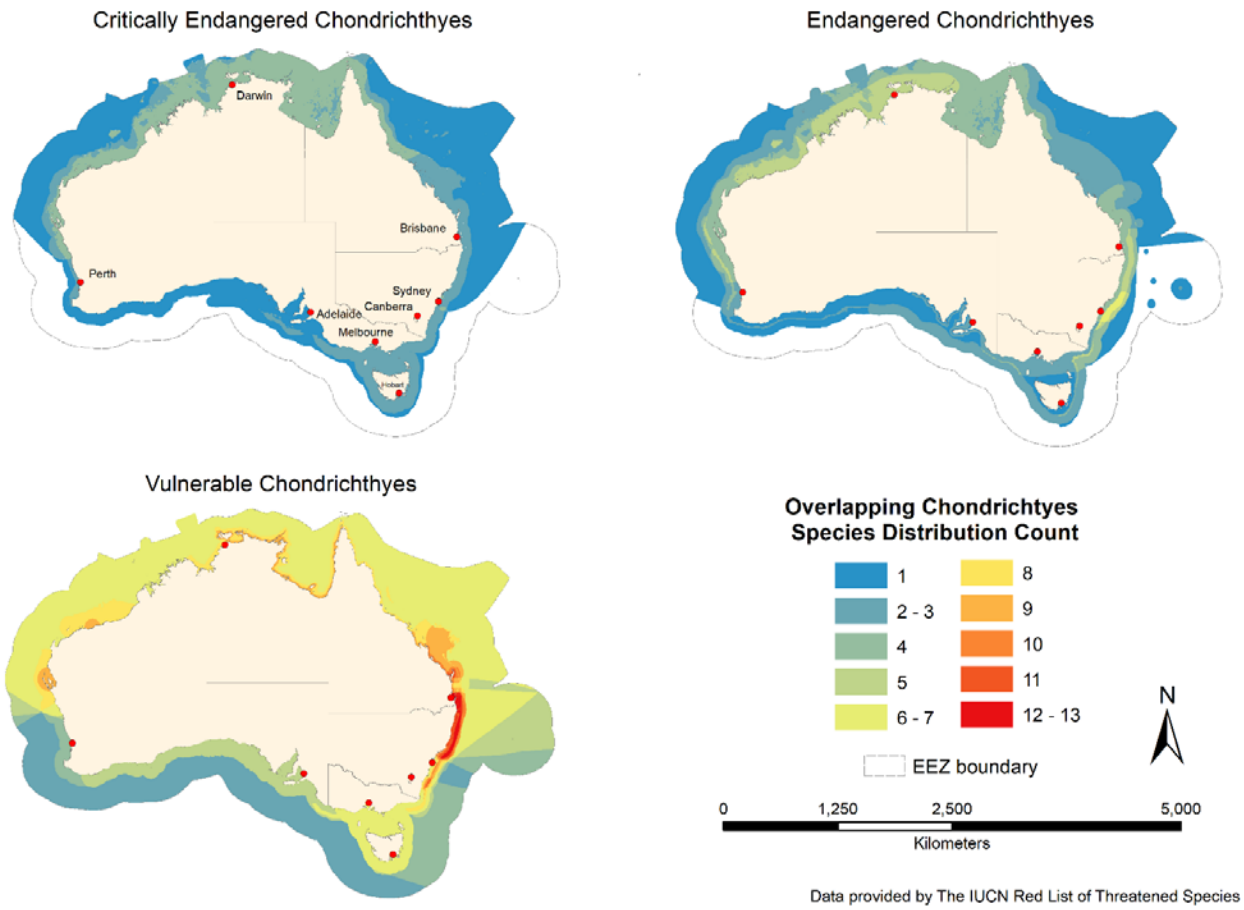
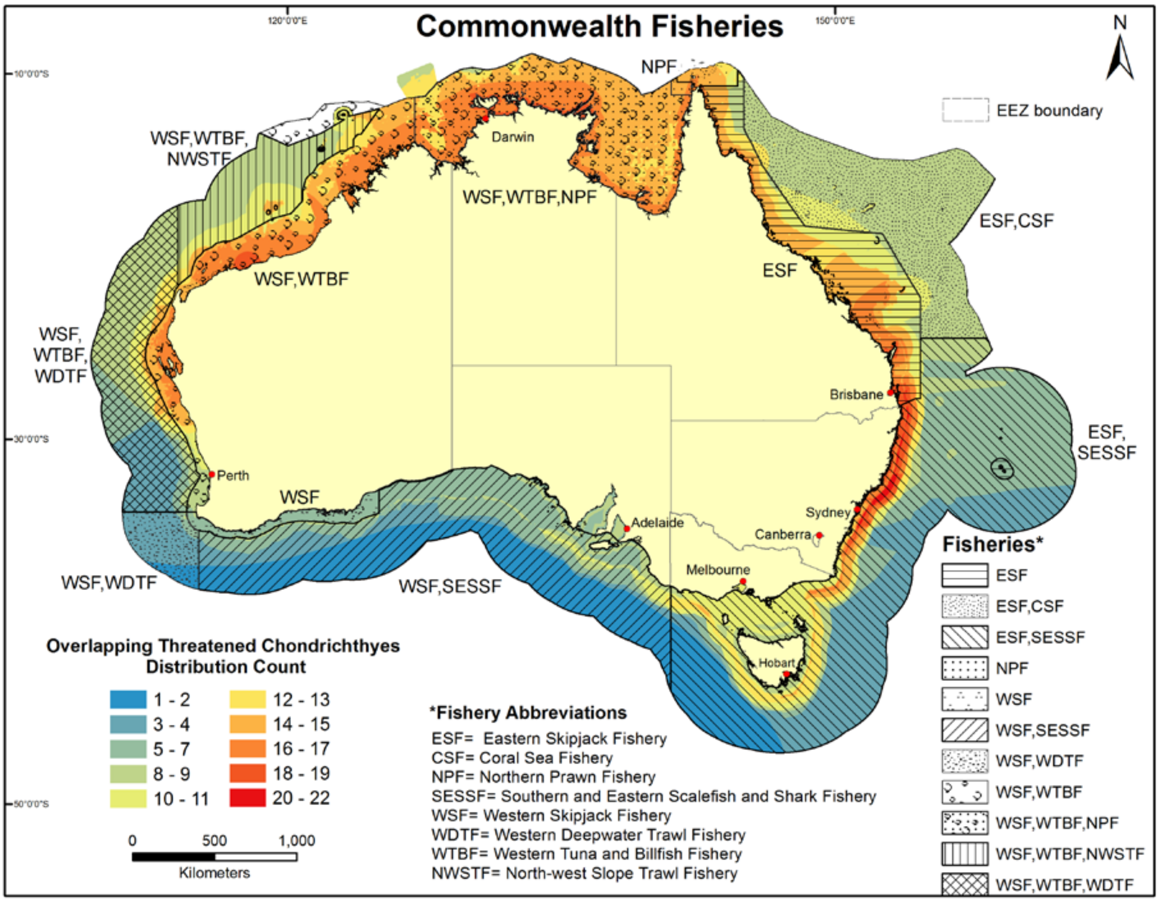


Figure 2. Distribution of 40 threatened elasmobranch species by IUCN Red List category. Colours indicate overlapping numbers of species in a location.

7.2 Overlap with fisheries

The primary threat to these species is fishing pressure in the form of targeted fishing or harvested bycatch. Like the distribution of species, Australia’s fishing fleets span the entire coastline and to the edge of the Exclusive Economic Zone. The vast majority of threatened elasmobranch species overlap with one or more fishery. Commonwealth fisheries often operate in offshore waters outside state boundaries, but can overlap with state fisheries. Figure 3 displays a suite of Commonwealth fisheries that are known to harvest or interact with elasmobranch species overlaid with threatened species distributions. Fisheries names are defined on figures, but also listed in Table 7. While this map indicates extensive overlap with threatened species distribution, it should be noted that fisheries regulations are in place to prohibit retention of some species and to limit harvest of others. Therefore, overlap of fisheries should be considered in the context of fishery targets, regulations and level of effort. Not all of the depicted fisheries will exert the same amount of pressure on elasmobranch populations.



Data provided by Commonwealth Fisheries 2006 Dataset

Figure 3. Distribution of Commonwealth fisheries relative to the distribution of threatened elasmobranch species.

Like Commonwealth fisheries, there is extensive overlap between threatened elasmobranch species and state and territory fisheries. Figures 4 – 9 are indicative of the location of state and territory fisheries that harvest or interact with elasmobranchs relative to threatened species distributions. Information was not included from Tasmania, based on limitations regarding availability of commercial fisheries data. Future research should explore this region more fully also taking recreational gillnet activity into consideration. The number and type of active fisheries vary around the country with South Australia and Victoria appearing to have the least direct interaction with threatened elasmobranchs based on the extent of fisheries. As with Commonwealth fisheries, overlap of fisheries should be considered in the context of fishery targets, regulations and level of effort. Not all of the depicted fisheries will exert the same amount of pressure on elasmobranch populations. Future research should consider catch and effort of threatened species, especially those in the Vulnerable category. Reduction of pressure on these species now could allow stabilisation and recovery of species which would negate the need to list them in higher threat categories in the future.

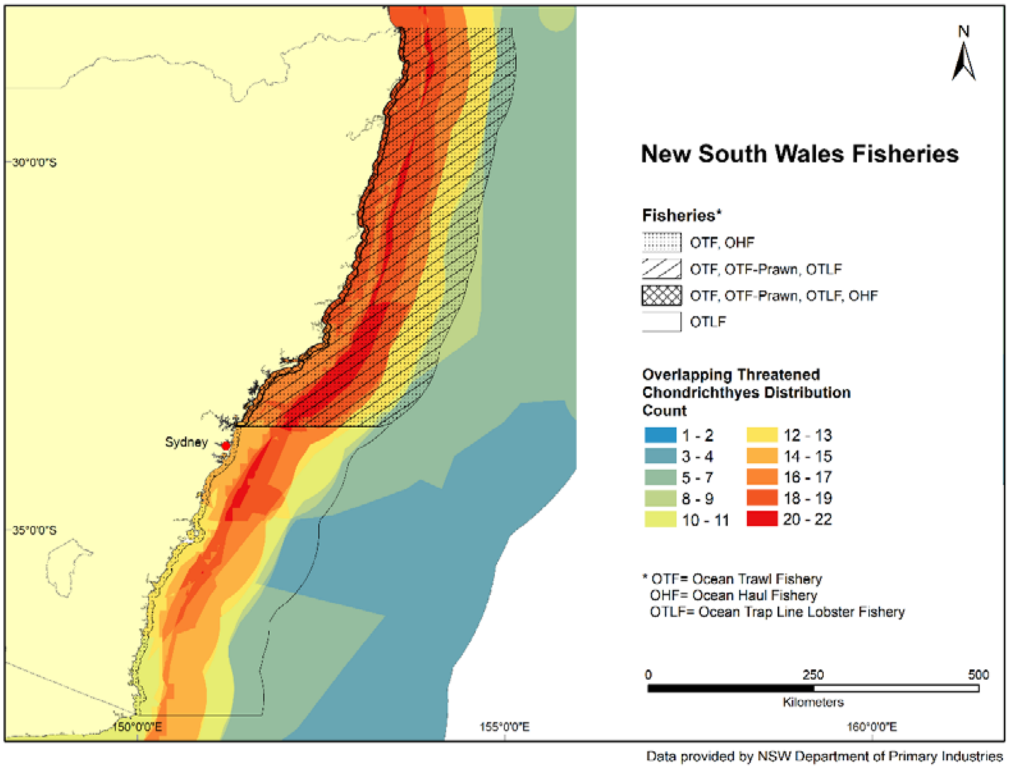


Figure 4. Distribution of New South Wales Fisheries relative to the distribution of threatened elasmobranch species.

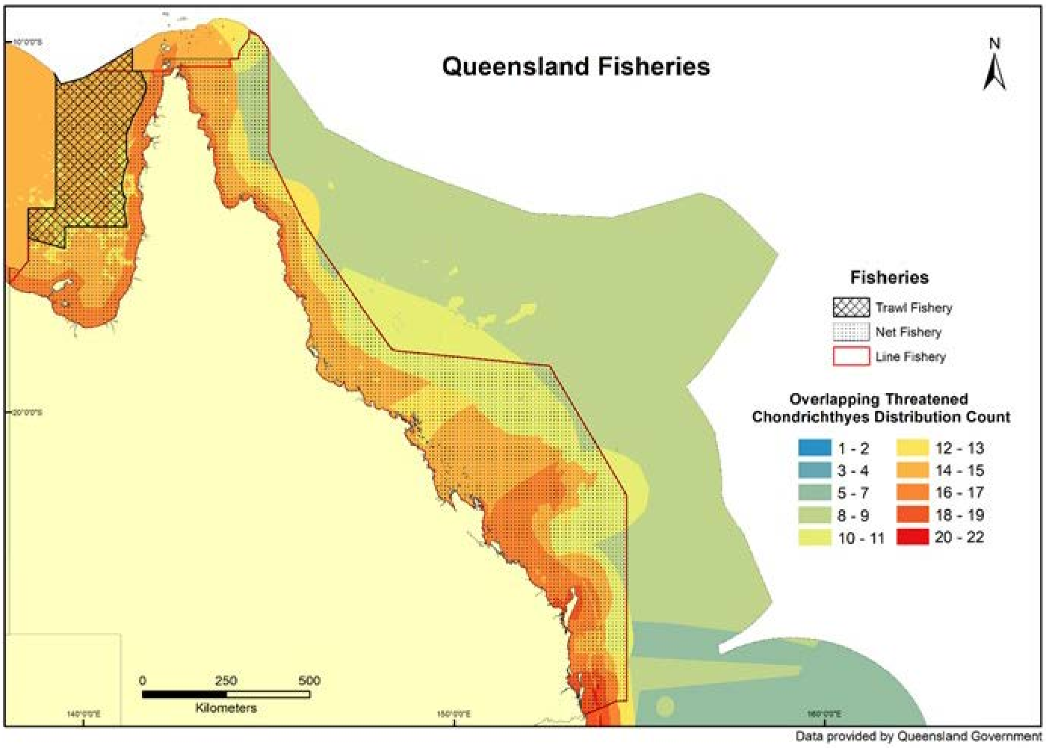


Figure 5. Distribution of Queensland fisheries relative to the distribution of threatened elasmobranch species. Note the east coast boundary includes the extent of trawl and gillnet activities.

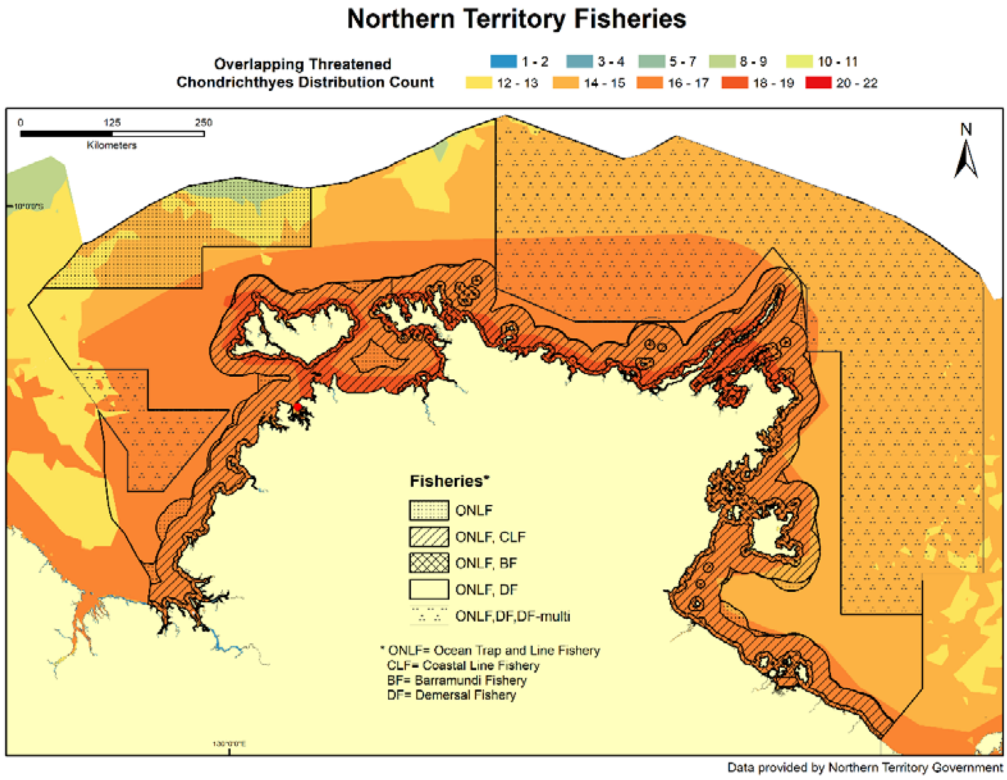


Figure 6. Distribution of Northern Territory fisheries relative to the distribution of threatened elasmobranch species.

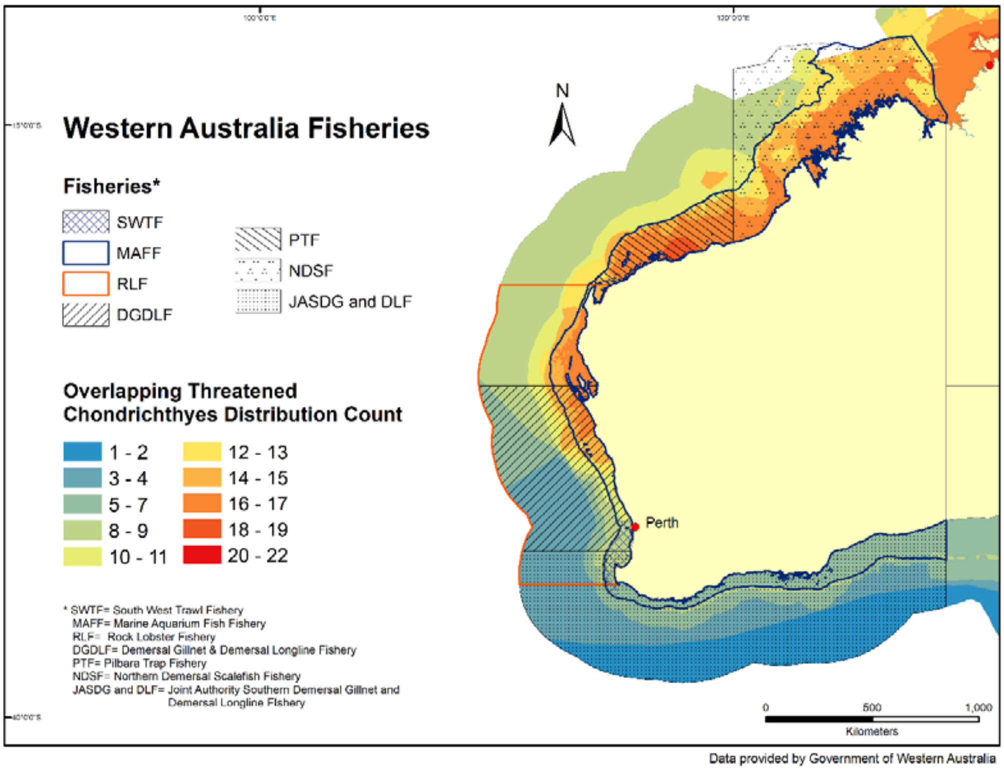


Figure 7. Distribution of Western Australian fisheries relative to the distribution of threatened elasmobranch species.

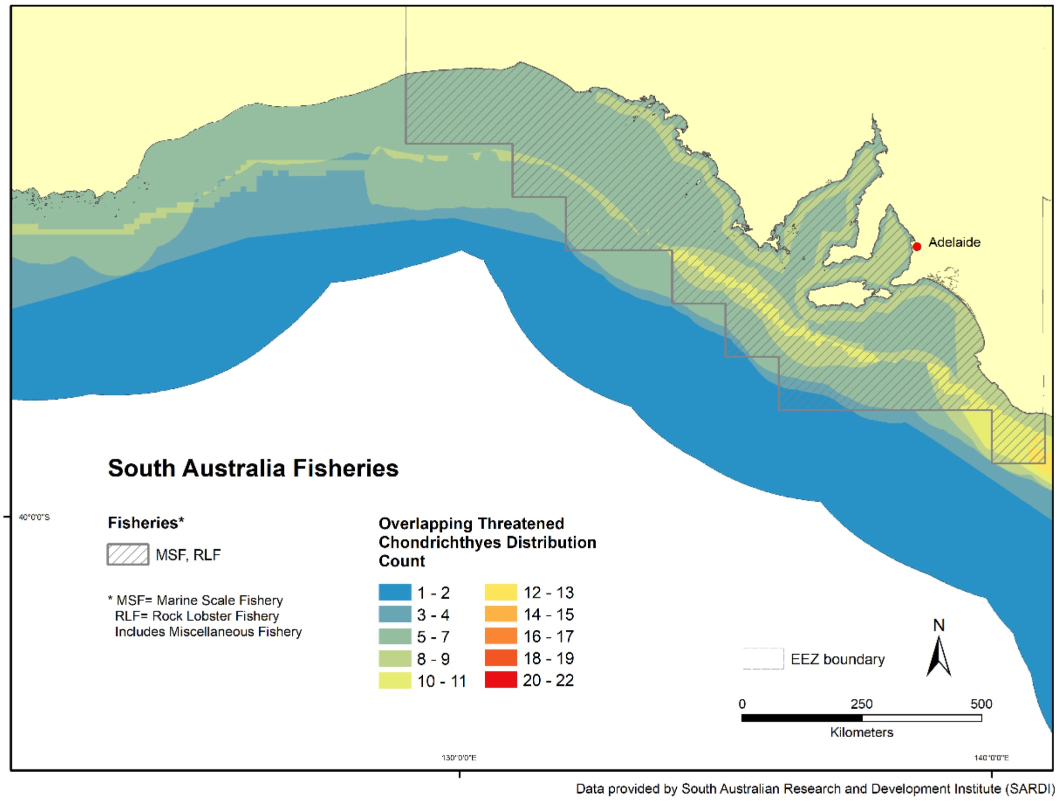
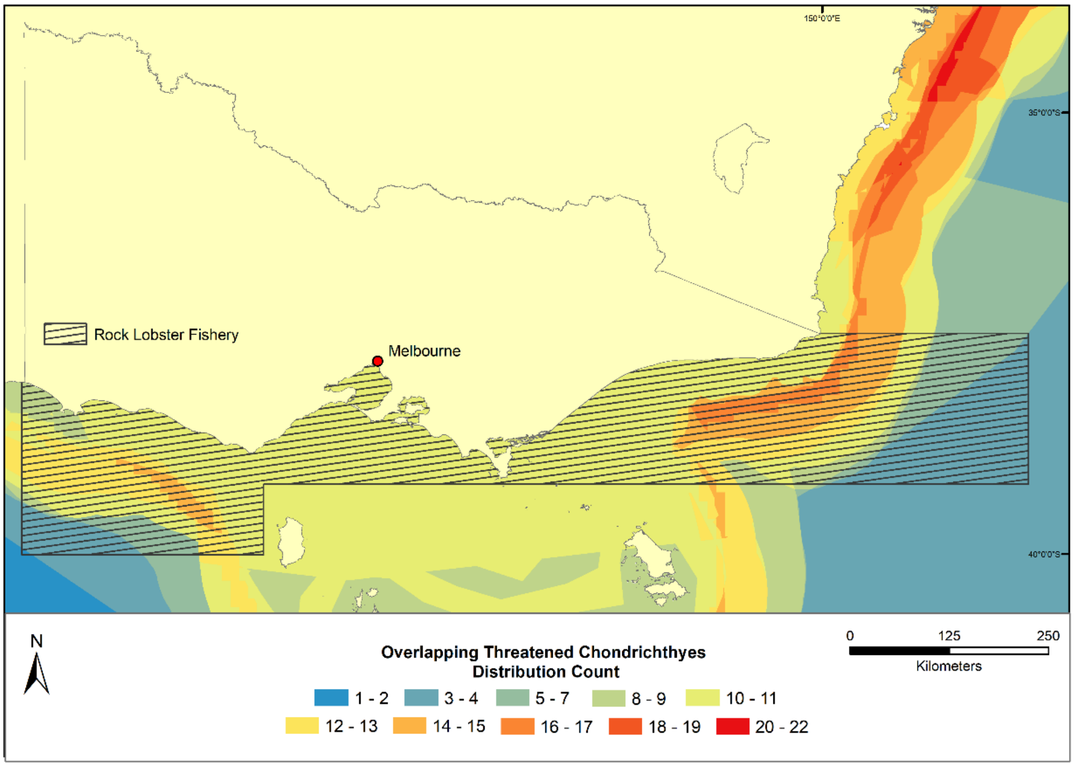


Figure 8. Distribution of South Australian fisheries relative to the distribution of threatened elasmobranch species.

Victoria Fisheries



Data provided by Victorian Fisheries Authority (VFA)

Figure 9. Distribution of Victorian fisheries relative to the distribution of threatened elasmobranch species.

Table 7. Listing of fisheries indicated in mapping distributions including the abbreviation used and area of operation.

Abbreviation	Fishery name	Location
ESF	Eastern Skipjack Fishery	Commonwealth
CSF	Coral Sea Fishery	Commonwealth
NPF	Northern Prawn Fishery	Commonwealth
SESSF	Southern and Eastern Scalefish and Shark Fishery	Commonwealth
WSF	Western Skipjack Fishery	Commonwealth
WDTF	Western Deepwater Trawl Fishery	Commonwealth
WTBF	Western Tuna and Billfish Fishery	Commonwealth
MWSTF	Northwest Slope Trawl Fishery	Commonwealth
OTF	Ocean Trawl Fishery	New South Wales
OHF	Ocean Haul Fishery	New South Wales
OTLF	Ocean Trap Line Fishery	New South Wales
	Queensland Trawl Fisheries	Queensland
	Queensland Net Fisheries	Queensland
	Queensland Line Fishery	Queensland
ONLF	Ocean Trap and Line Fishery	Northern Territory
CLF	Coastal Line Fishery	Northern Territory
BF	Barramundi Fishery	Northern Territory

Abbreviation	Fishery name	Location
DF	Demersal Fishery	Northern Territory
SWTF	South West Trawl Fishery	Western Australia
MAFF	Marine Aquarium Fish Fishery	Western Australia
RLF	Rock Lobster Fishery	Western Australia
DGDLF	Demersal Gillnet & Demersal Longline Fishery	Western Australia
PTF	Pilbara Trap Fishery	Western Australia
NDSF	Northern Demersal Scalefish Fishery	Western Australia
JASDG & DLF	Joint Authority Southern Demersal Gillnet & Demersal Longline Fishery	Western Australia
MSF	Marine Scalefish Fishery	South Australia
RLF	Rock Lobster Fishery	South Australia
RLF	Rock Lobster Fishery	Victoria

As overlap of species distributions with fisheries boundaries would suggest, a large number of sharks interact with Australian fisheries. The 2018 Shark Assessment Report (SAR; Woodhams and Harte 2018) summarises catch data by jurisdiction to provide an indication of the harvest of shark species. Table 8 taken from the SAR indicates the proportions of catch of the top 10 species by volume. As indicated by highlighted text, in most jurisdictions the top species by volume include species listed under the EPBC Act. The SAR also reports on catch and release of sharks by recreational fishers, however, recording interaction rates with recreational fishers is difficult (Table 9). Although sharks and rays are recognised as an importance resource for Indigenous Australians, there are no recent assessments of interactions or harvest of these species by Indigenous fishers.

Table 8. Listing of commercial shark catch by volume, by jurisdiction as summarised in the 2018 Shark Assessment Report (Woodhams and Harte 2018).

Table 2 Top 10 shark species caught by jurisdiction, 2006–07 to 2014–15

Jurisdiction	Top 10 species by catch volume	Proportion of total catch (%)
Commonwealth	Gummy, school, sawshark (*Pristiophorus spp.*), ornate angelshark (*Squatina tergocellata*), common sawshark (*Ristiophorus cirratus*), elephantfish (*Callorhinchus milii*), shortfin mako (*Isurus oxyrinchus*), Australian angelshark (*Squatina australis*), platypus (mixed species) and broadnose shark (*Notorynchus cepedianus*).	85
New South Wales	Shovelnose rays (family Rhinobatidae), unspecified shark, gummy, fiddler rays (Trygonorrhina), angel shark (*Squatina spp)*, blacktip (Carcharhinus spp), sandbar (*C. plumbeus*), sawshark (*Pristiophorus spp.*), wobbegong (Orectolobidae) and bronze whaler (*C. brachyurus*).	78
Victoria	Gummy, skate, southern eagle ray (*Myliobatis australis*), elephantfish, angelshark, blue (*Prionace glauca*), school, bronze, seven gilled and unspecified shark.	97
Queensland	Unspecified whaler (Carcharhinus spp), Australian blacktip, hammerhead, blacktip, unspecified shark, spot-tail, scalloped hammerhead (*Sphyrna lewini*), pigeye and bullshark (grouped) and spinner shark (*Carcharhinus brevipinna*).	91
South Australia	Gummy, school, bronze and dusky whaler, wobbegong, port jackson (*Heterodontus portusjacksoni*), elephantfish, saw shark and other.	100
Western Australia	Gummy, bronze, whiskery (*Furgaleus macki*), sandbar, hammerhead, copper whaler, spinner, wobbegong, blacktip and pigeye.	94
Tasmania	Gummy, elephantfish, draughtboard (*Cephaloscyllium laticeps*), school, seven gilled (Hexanchidae), sawshark, thresher (Alopias spp.), mako (Isurus spp.), unspecified shark and wobbegong.	99
Northern Territory	Australian blacktip (*C. tilstoni*), hammerhead (Sphyrna spp.), spottail (*C. sorrah*), pigeye (*C. amboinensis)*, bull (*C. leucas*), lemon (*Negaprion acutidens*), tiger (*Galeocerdo cuvier*), winghead (*Eusphyra blochii*), dusky and milk shark (*Rhizoprionodon acutus*).	99

Source: Data supplied by jurisdictions

Table 9. Listing of number of sharks caught and released by recreational fishers by jurisdiction as summarised in the 2018 Shark Assessment Report (Woodhams and Harte 2018).

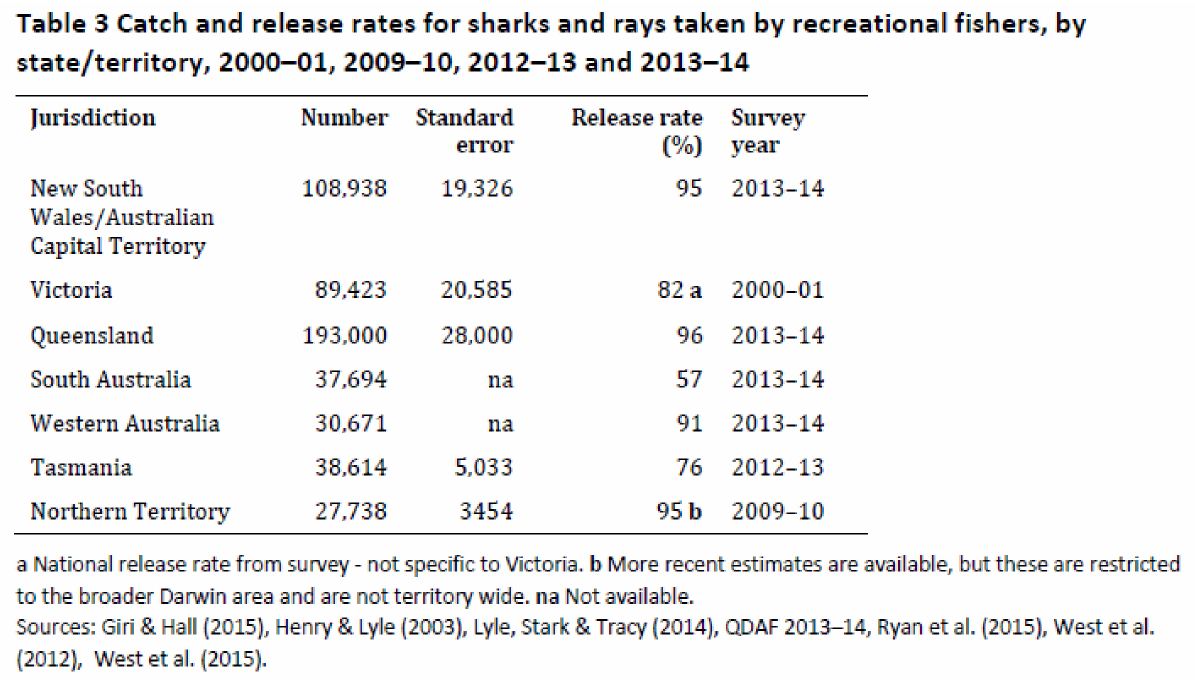


Table 3 Catch and release rates for sharks and rays taken by recreational fishers, by state/territory, 2000–01, 2009–10, 2012–13 and 2013–14

Jurisdiction	Number	Standard error	Release rate (%)	Survey year
New South Wales/Australian Capital Territory	108,938	19,326	95	2013–14
Victoria	89,423	20,585	82 **a**	2000–01
Queensland	193,000	28,000	96	2013–14
South Australia	37,694	na	57	2013–14
Western Australia	30,671	na	91	2013–14
Tasmania	38,614	5,033	76	2012–13
Northern Territory	27,738	3454	95 **b**	2009–10

a National release rate from survey - not specific to Victoria. **b** More recent estimates are available, but these are restricted to the broader Darwin area and are not territory wide. **na** Not available.
Sources: Giri & Hall (2015), Henry & Lyle (2003), Lyle, Stark & Tracy (2014), QDAF 2013–14, Ryan et al. (2015), West et al. (2012), West et al. (2015).

7.2.1 Bycatch

Sharks and rays are often captured as bycatch in fisheries that are targeting higher value species (e.g. tuna). The fate of captured sharks and rays varies by species, with unwanted species discarded while others are retained due to the value of their parts (flesh, fins, etc.). Historical fisheries management relied on data collection focused on target species, with data on bycatch species limited or non-existent. Recent recognition of the implications of bycatch effects on populations (e.g. post-release mortality, retention of bycatch) has led to increased reporting of bycatch species, as well as increased regulation of the fate of bycatch (e.g. the Northern Prawn Fishery does not allow the retention of shark and ray bycatch). Some reporting is occurring, particularly for bycatch species that are of conservation concern, such as those listed on the *EPBC Act.* Information compiled for the State of the Environment Report reflects some of the available data on bycatch of *EPBC Act* listed species (Table 10). These data indicate high interaction of listed sharks with line (tuna and billfish fisheries) and net (scalefish and shark fishery) fisheries. There is also evidence of interaction between sawfishes and the Northern Prawn Trawl fishery. While these data reveal important interactions with listed shark and ray species, data were only compiled for Commonwealth fisheries. Interaction rates with the numerous State and Territory fisheries outlined above are not captured in these numbers. States and territories are required to report catches of listed threatened species to the Commonwealth, but to date these data have not been investigated.

To fully determine the effects of fishing on shark and ray populations, accurate data must be collected on the numbers of individuals harvested as target catch in fisheries, retained as byproduct in fisheries and the number of individuals discarded and their condition at release. Observer programs in Commonwealth, State and Territory fisheries collect some of these data, allowing increased understanding. A full understanding of the interaction of sharks and rays with fishing operations needs to include an understanding of the capacity of species and populations to survive these interactions. This requires data on harvest rates and potential cryptic mortality (i.e. post-release mortality). As fisheries management evolves and improves, more comprehensive consideration of effects on non-target species should be a priority to ensure ecological roles and ecosystem functions remain intact. Better data recording and reporting will help inform whether current catch and interaction rates are sustainable for potentially vulnerable shark and ray species.

Table 10. Interactions of EPBC listed species, including sawfish and sharks, compiled as part of the 2016 State of the Environment Report (Evans et al. 2016).

Table MAR1 Number of reported interactions of AFMA-managed fisheries with species listed under the EPBC Act, 2012–15

Fishery	Year	Turtle	Sea snake	Dolphin	Whale	Fur seal/ sea lion	Seabird	Sawfish	Shark	Seahorse/ pipefish
Eastern Tuna and Billfish Fishery	2012	10	0	0	0	0	0	0	1683	0
	2013	15	0	1	0	1	0	0	2015	0
	2014	7	0	0	0	0	0	0	1125	0
	2015	30	0	7	3	0	14	0	2093	0
Northern Prawn Fishery	2012	72	8977	2	0	0	0	476	0	74
	2013	72	8150	2	0	0	0	507	0	140
	2014	36	4787	1	0	0	0	343	0	140
	2015	63	7527	0	0	0	7	307	0	140
Small Pelagic Fishery	2012	0	0	0	0	0	0	0	0	0
	2013	0	0	0	0	0	1	0	0	0
	2014	0	0	0	0	0	1	0	0	0
	2015	0	0	9	0	15	2	0	23	0
Southern and Eastern Scalefish and Shark Fishery	2012	1	0	19	0	217	196	0	288	405
	2013	0	0	9	0	259	94	0	157	0
	2014	0	0	14	0	133	18	0	157	0
	2015	0	0	29	0	128	66	0	166	0
Torres Strait Prawn Fishery	2012	0	242	0	0	0	0	0	0	0
	2013	4	771	0	0	0	0	1	0	0
	2014	4	1091	0	0	0	0	1	0	0
	2015	3	669	0	0	0	0	1	0	0
Western Tuna and Billfish Fishery	2012	6	0	0	0	0	0	0	764	0
	2013	2	0	0	0	0	0	0	325	0
	2014	2	0	0	0	0	0	0	263	0
	2015	3	0	0	0	0	0	0	87	0

AFMA = Australian Fisheries Management Authority; EPBC Act = *Environment Protection and Biodiversity Conservation Act 1999*
Note: Interactions include those with animals that are reported as alive, injured, dead or unknown. Values presented are the total of all categories across all commercial fisheries managed by the Australian Government. All interactions are reported as per reporting requirements under the EPBC Act. Interactions listed are derived from commercial fisheries logbooks and may not include all interactions listed in fishery observer logbooks. Logbook data are not routinely verified, and therefore AFMA cannot attest to the accuracy of these data or authenticate that records are complete. Values are numbers reported and do not account for variability in effort across fisheries.
Source: Protected species interaction reports, Australian Fisheries Management Authority

7.3 Shark Control Programs

Shark Control Programs (SCPs) pose an additional threat to elasmobranch species. The level of threat is directly related to the type of gear used in the program (nets or drum lines) and the amount of equipment deployed. Currently New South Wales and Queensland have SCPs which include gillnet and drum line installations (Figure 10). There have been numerous discussions regarding potential expansion of SCPs in Western Australia and Queensland after incidences of shark attack. Future deployment of SCPs should consider potential impacts on threatened species that occur in the area. Additional information about SCPs is available via program web sites and reports. A brief summary is included below to provide some of the most recent data from QLD and NSW SCPs.

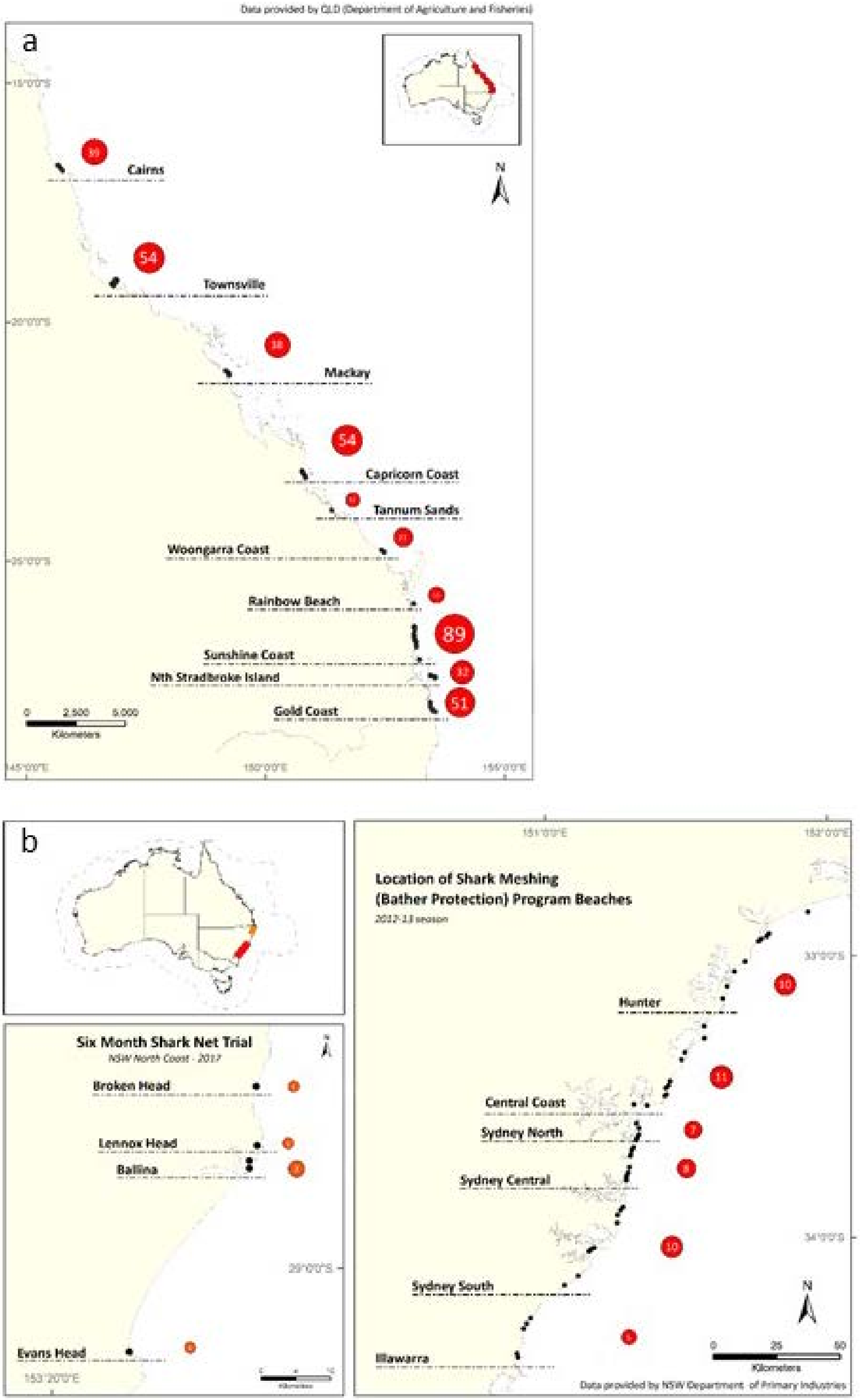


Figure 10. Location of a) QLD and b) NSW Shark Control Program deployments. Size of circles and numbers indicate the number of installations in that location. Orange coloured circles in NSW represent the northern NSW trial.

7.3.1 Queensland Shark Control

During the calendar year of 2017 (the most recent data available) a total of 510 sharks were captured in Queensland shark control net and drum line installations (Figure 11). This included individuals from 28 shark species of varying size and age classes. Across the captured species, sizes ranged from a minimum of 60 cm (Australian Sharpnose Shark) to 525 cm total length (Tiger Shark). Captured individuals were recorded in one of three fate categories with the majority (74%) recorded as dead, 22% recorded as euthanised and 4% released alive.

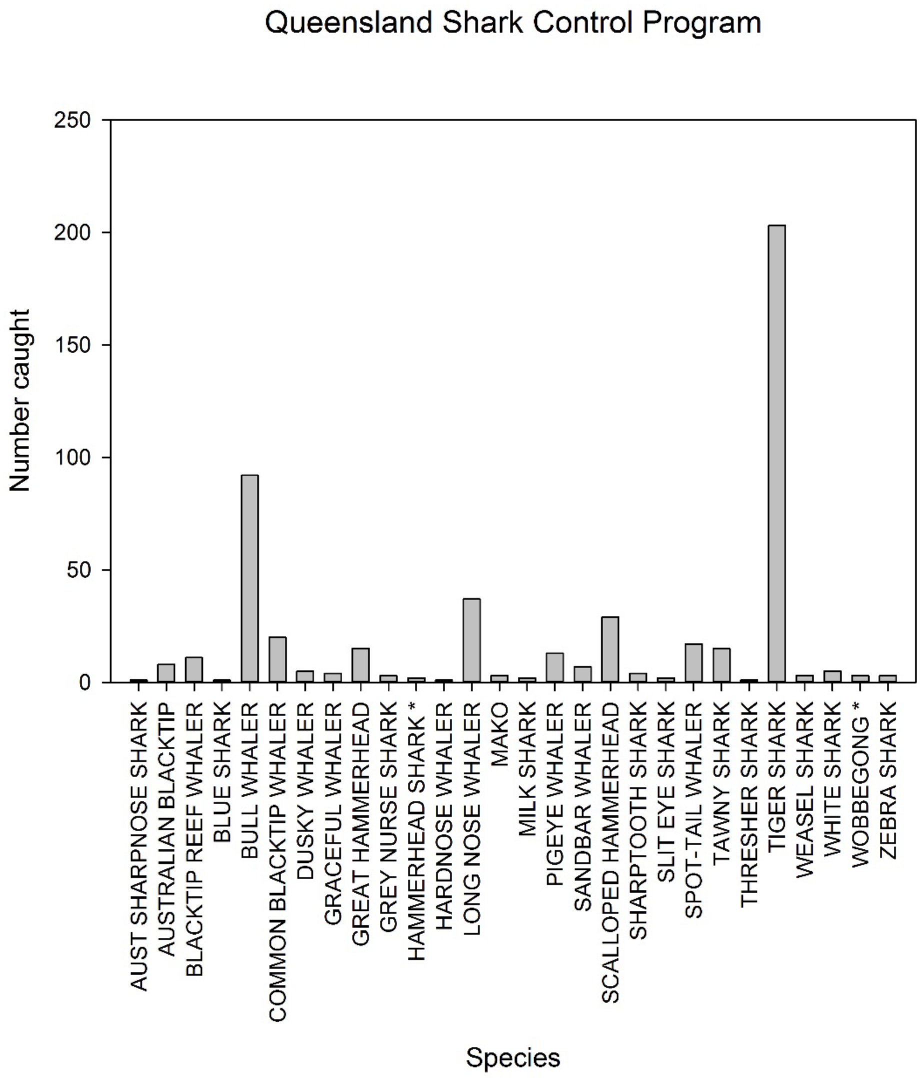


Figure 11. Number and species of shark captured in Queensland Shark Control Program installations in 2017.

7.3.2 New South Wales Shark Control

During the 2017-2018 meshing season (1 Sept – 30 Apr) a total of 381 elasmobranchs were captured in New South Wales shark control net and drum line installations (Figure 12). This included individuals from 23 species (17 shark species, 6 ray species) of varying size and age classes. Across the captured species, sizes ranged from a minimum of 50 cm (Australian Cownose Ray) to 362 cm total length (Great Hammerhead). Captured individuals were recorded in one of two fate categories with approximately half (54%) recorded as dead and 46% released alive.

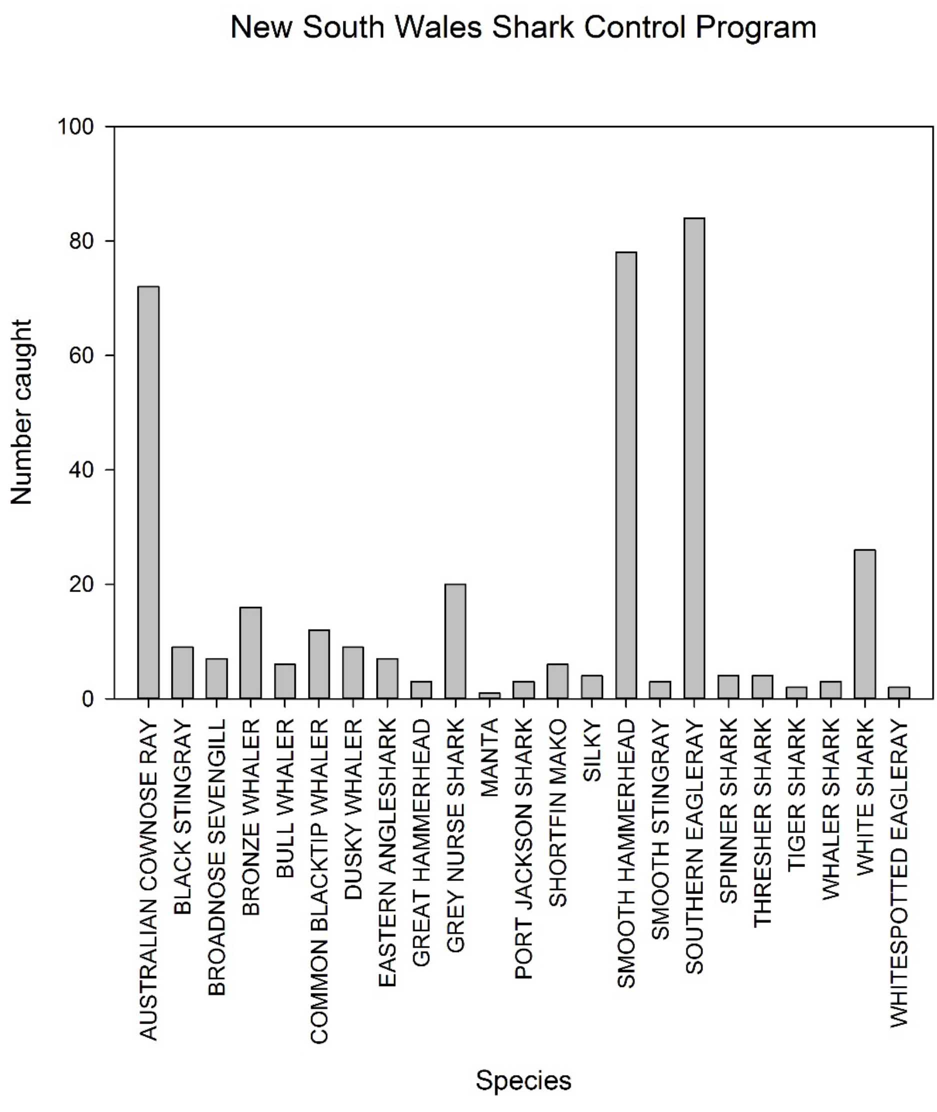


Figure 12. Number and species of elasmobranch captured in New South Wales Shark Control Program installations in 2017-2018.

7.4 Overlap with Australian Marine Parks

Australia has a wide array of Marine Park areas or Australian Marine Parks (AMP) (Figure 11). The size and location of AMPs vary as do the restrictions associated with zoning within them. Zones are used to regulate activities within AMPs and as such provide varying levels of protection for elasmobranch species. Only National Park Zones are closed to all forms of commercial and recreational fishing and as such provide complete protection from fishing for elasmobranchs that use these areas. In addition to the AMPS are two World Heritage Areas (Great Barrier Reef, Ningaloo) which also include protected area designations.

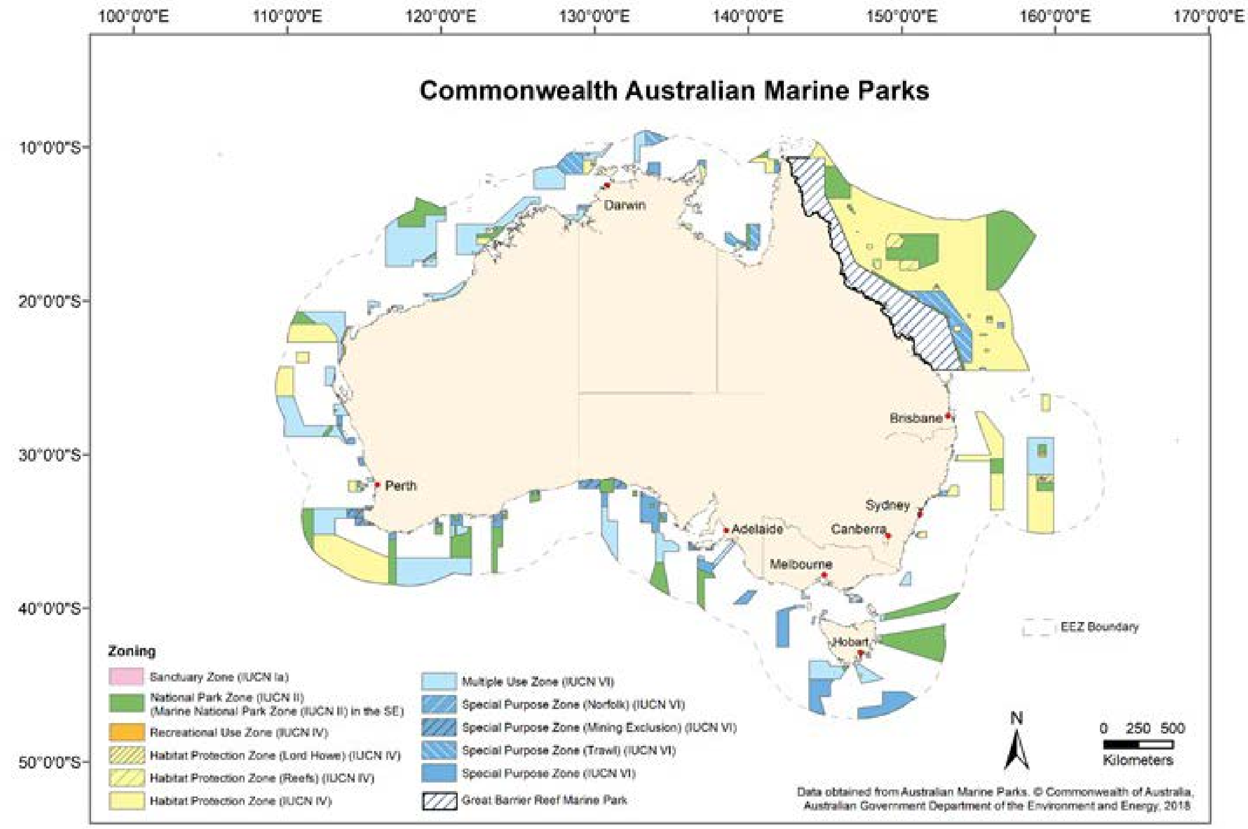


Figure 13. Location of Australian Marine Parks and indicative zoning where green areas indicate those closed to all forms of commercial and recreational fishing.

Examination of the distribution of threatened elasmobranch species relative to AMPs reveals that all but one species (*Zearaja maugeana*) occur within at least one AMP (Table 11). The amount of threatened elasmobranch range which overlaps with the AMPs ranges from 1.6-79.0%. However, this overlap includes areas where various forms of commercial and recreational fishing are allowed. When examining only the overlap with protected zones closed to fishing seven species show overlaps of < 1% (*Zearaja maugeana* – 0%, *Urolophus sufflavus* – 0%, *Dentiraja australis* – 0%, *Urolophus orarius* 0.1%, *Glyphis glyphis* – 0.1%, *Anoxypristis cuspidata* – 0.6%, *Urolophus bucculentus* – 0.9%). The maximum overlap with closed areas by any species was 24.1% for *Brachaelurus colcloughi*, the second highest was *Squatina albipunctata* with 12.6% overlap. Thirty-one of the threatened species examined had overlap percentages less than 10% (inclusive of those with <1%). This suggests that threatened elasmobranch species are gaining limited protection from fishing based on protections within AMPs. However, a number of other protected areas are in place that were not considered in this analysis, including those managed by state and territory governments. As such this is a conservative estimate of potential protected area benefits.

Table 11. List of species considered threatened under IUCN categories, associated listing on the Environment Protection Biodiversity Conservation Act (EPBC) and the percentage of their range which occurs in Australian Marine Parks (% in AMP) and the percent of their range which occurs in protected (closed to fishing) zones within the AMP (% in PZ).

Species	**Common name**	**IUCN**	**EPBC**	**% in AMP**	**% in PZ**
Carcharias taurus (East coast)	Grey Nurse Shark	CR	CR	29.8	5.4
Pristis pristis	Largetooth Sawfish	CR	VU	29.0	4.1
Pristis zijsron	Green Sawfish	CR	VU	34.5	6.2
Carcharhinus longimanus	Oceanic Whitetip Shark	CR		50.1	10.3
Cephaloscyllium albipinnum	Whitefin Swellshark	CR		19.8	3.5
Dentiraja confusa	Australian Longnose Skate	CR		10.5	1.9
Centrophorus harrissoni	Harrisson's Dogfish	EN	CD	19.5	5.3
Centrophorus zeehaani	Southern Dogfish	EN	CD	14.9	1.1
Squalus chloroculus	Greeneye Spurdog	EN		19.1	3.0
Rhincodon typus	Whale Shark	EN	VU, M	46.3	9.9
Galeorhinus galeus	School Shark	EN	CD	25.1	4.3
Glyphis glyphis	Speartooth Shark	EN	CR	1.6	0.1
Glyphis garricki	Northern River Shark	EN	EN	24.1	1.8
Sphyrna lewini	Scalloped Hammerhead	EN	CD	37.4	6.2
Sphyrna mokarran	Great Hammerhead	EN		34.1	5.6
Pristis clavata	Dwarf Sawfish	EN	VU	26.3	3.3
Zearaja maugeana	Maugean Skate	EN	EN	0.0	0.0
Dipturus canutus	Grey Skate	EN		19.1	3.0
Urolophus orarius	Coastal Stingaree	EN		8.4	0.0
Carcharodon carcharias	White Shark	VU	VU, M	40.0	9.2
Squatina albipunctata	Eastern Angelshark	VU		75.3	12.6
Cetorhinus maximus	Basking Shark	VU	M	21.6	5.6
Alopias pelagicus	Pelagic Thresher	VU		54.6	12.0
Alopias superciliosus	Bigeye Thresher	VU		48.0	9.9
Isurus oxyrinchus	Shortfin Mako	VU	M	40.8	9.5
Isurus paucus	Longfin Mako	VU	M	50.1	10.9
Lamna nasus	Porbeagle	VU	M	26.8	7.2
Brachaelurus colcloughi	Colclough's Shark	VU		79.0	24.1

Species	Common name	IUCN	EPBC	% in AMP	% in PZ
Eusphyra blochii	Winghead Shark	VU		36.0	6.4
Anoxypristis cuspidata	Narrow Sawfish	VU	M	10.4	0.6
Aptychotrema timorensis	Spotted Shovelnose Ray	VU		44.0	7.0
Dentiraja australis	Sydney Skate	VU		9.6	0.0
Spiniraja whitleyi	Melbourne Skate	VU		18.9	4.7
Hemitrygon fluviorum	Estuary Stingray	VU		33.3	7.0
Urolophus bucculentus	Sandyback Stingaree	VU		14.5	0.9
Urolophus sufflavus	Yellowback Stingaree	VU		7.4	0.0
Urolophus viridis	Greenback Stingaree	VU		11.8	1.5
Myliobatis hamlyni	Purple Eagle Ray	VU		45.4	11.8
Mobula birostris	Giant Manta	VU	M	48.9	10.3

7.5 Summary

This assessment reveals that there is a high degree of overlap between the boundaries of Australian fisheries and the known distribution of threatened Australian elasmobranchs. This is an initial examination of the potential for interaction between fisheries and threatened elasmobranchs. The degree of overlap between fisheries' areas of activity is not necessarily indicative of level of risk because the amount of fishing effort varies by time and location. Therefore future studies should examine the location and amount of effort in fisheries to better understand levels of risk. Interaction with threatened species or those of conservation concern should be a part of Ecological Risk Assessments associated with fisheries. Research should also examine what is being caught and how often threatened species are encountered. Like most fisheries around the world, data on bycatch are limited in Australia. Failure to fully characterise the species that interact with fisheries and their fate (harvested as bycatch, released live, released dead) hampers our ability to define the effects of fishing on populations and ensure adequate management is in place to maintain sustainable population levels. Better recording of bycatch species is needed, including information on their condition and fate. The levels of interaction with various gear types should be explored to determine whether any mitigation measures can be employed. If mitigation could be implemented, especially for Vulnerable species, this may provide an opportunity to recover species and prevent escalation of species into higher threat categories. The location, amount and type of shark control program measures should also be considered in relation to the location and status of threatened elasmobranchs that could be impacted by those installations. Finally, it seems apparent that threatened elasmobranchs obtain limited protection from fishing pressure via Australian Marine Park zoning. Future research should focus on the occurrence and residency of threatened species within these areas to further refine our understanding of how to use these areas as a means of supporting population recovery.

8. REVIEW OF RESEARCH RELATED TO CLIMATE CHANGE EFFECTS ON ELASMOBRANCHS

8.1 Introduction

Climate change is one of the greatest and most pervasive threats to aquatic and terrestrial populations (Hoegh-Guldberg and Bruno 2010, Last et al. 2011). Significant changes in habitats and populations are anticipated under projected future climate scenarios and many have already begun, especially in the marine environment (e.g. Harley et al. 2006, Cheung et al. 2009, Poloczanska et al. 2013). It is worth noting, however, that most extant vertebrates have survived past changes in climate (e.g. Bowen and Karl 2007). Extant Chondrichthyan fishes have survived all five previous mass extinctions (Kriwet et al. 2008, Lighten et al. 2016) suggesting populations have at least some capacity to adapt or resist change. Based on the somewhat recent and rapid progression of current environmental changes there are few studies directly focused on defining responses of marine species to climate change impacts in the wild. Most current research is based on directed, lab-based studies. Elasmobranchs are no exception, with the majority of current field research focused on movement ecology or presence with limited understanding of species or population level thresholds for persistence under various environmental factors beyond laboratory studies.

The range and distribution of species are already changing due to climate-based changes in conditions, particularly in relation to changes in water temperature (Last et al. 2010, Poloczanska et al. 2013). Cheung et al. (2009) examined global patterns of biodiversity of 1066 exploited marine fish and determined turnovers in biodiversity will be as high as 60% which will cause ecological disturbances. Harley et al. (2006) similarly suggest that impacts on a small number of ‘leverage species’ could produce community level changes in marine ecosystems. Several targeted studies by Perry (2005), Dell (2015) and Robinson (2015) indicate that sea surface temperature and changes in ocean currents are likely drivers for redistribution of marine fishes (including elasmobranchs). Changes in distribution of pelagic fish have already occurred within and beyond Australia. The SW Pacific and Tasman Sea are noted as areas of increasing ocean temperature which is redistributing fish populations and altering abundance in various locations (Dell et al. 2015, Robinson et al. 2015). Changes have been most apparent close to shore due to the strong influence of the East Australian Current and its capacity to alter water temperature (Robinson et al. 2015). The trailing edges of pelagic fish distributions are speculated to change faster than leading edges suggesting the overall range of some species may contract (Robinson et al. 2015). Understanding the redistribution and range changes of threatened and exploited species (and their changing overlap with fisheries and other threats) is crucial to effective management and conservation of these populations.

While climate change is likely to drive species ranges toward the poles, some species may alter their distributions in other ways. Studies in the North Sea indicate that while many species undertook latitudinal and depth shifts, some species only exhibited changes in depth to avoid warming waters (Perry et al. 2005, Sguotti 2016). The need to avoid warm water has the potential to limit dispersal of some species where access to adjacent cooler water may be limited. Habitat restrictions will also likely be an issue. For example, species that are highly site attached or habitat dependent such as coral reef species may not be able to move to another reef to seek cooler temperatures (e.g. Hoegh-Guldberg and Bruno 2010, Schlaff et al. 2014). Inability to move to more preferable conditions may be more dramatic in species with long life spans that are less able to compensate for warming based on their life history characteristics (Perry et al. 2005). Many elasmobranchs, especially skates and rays, have no pelagic life history stages so may be effectively isolated and unable to react to a changing environment. Alternatively, warming conditions may be advantageous for some species by expanding their ranges and increasing growth and survival (Fuentes et al. 2016, Sguotti 2016).

8.2 Research gaps

Much of the current research directly testing climate change effects on elasmobranchs is based on laboratory studies of biology and physiology. This is in part because future climate conditions can only be replicated in laboratory settings, and also due to the difficulty in separating multiple environmental factors and stressors to define field-based effects of climate. Laboratory based research has most commonly focussed on potential effects of ocean acidification. Interestingly, several studies show limited effects of elevated CO_2 on growth and survival of young sharks inside egg capsules (Rosa et al. 2014, Heinrich et al. 2016, Johnson et al. 2016). These results suggest some level of tolerance to elevated CO_2. However, physiological impairment has been noted post-hatching such as decreased growth and body condition and reduced brain and muscle aerobic potential (Rosa et al. 2016, 2017). These contrasting results suggest effects of elevated CO_2 may vary and require further study. The combination of increased temperature and CO_2 also requires further study. For example, Pistevos et al. (2015) found Port Jackson shark embryos developed faster under warmer conditions, but when coupled with elevated CO_2, energetic demands increased in conjunction with decreased metabolic efficiency and capacity to locate prey via olfaction. In this case sharks developed faster, which may benefit the species through reduced exposure to predators at a vulnerable size, but if the ability to find prey is decreased survival may ultimately be reduced. Further exploration of physiological effects of climate change are required, including exploration of cumulative impacts. It should also be noted that studies to date have focused on small, egg-laying species which are easily maintained in captivity. Ocean acidification effects on more mobile species are yet to be explored.

The capacity for adaptation in sharks and rays should be explored in future research. For example, environmental stressors have been reported to cause rapid epigenetic changes (Lighten et al. 2016) which might allow species to persist and adapt to altered environmental conditions. Epigenetic changes facilitate the ability to switch select genes on and off to adapt to environmental change such as increases in water temperature. The capacity to regulate gene expression can help species adapt to new conditions. While sharks and rays are long-lived with conservative genetic lineages, and therefore exhibit slow evolutionary change, epigenetic changes can occur more rapidly and may provide the ability to cope as species evolve over longer time scales. Recent research by Lighten et al. (2016) revealed that skates exposed to increased water temperature exhibited epigenetic regulation which may help buffer these species from climate change impacts. Further research is needed to determine the scale and scope of epigenetic change to offset climate change effects. However, despite the complexity and potential long-term impacts of climate change, research should not focus on this aspect of Chondrichthyan biology at the expense of currently more significant impacts of fishing.

8.3 Types of climate change impacts

Climate change is having direct and indirect effects on elasmobranch populations and these effects vary based on the habitats where these species occur. Direct effects are mainly attributed to changes in water temperature, freshwater input and ocean acidification. Indirect effects relate to ocean circulation, sea level rise, severe weather, and light and UV radiation (Chin et al. 2010). Indirect effects will also be seen through impacts to habitat or prey abundance. Shallow habitats are heavily affected by several of these factors such as freshwater input, damage from severe weather, increased temperature and sea level rise. In contrast, pelagic systems are less affected with temperature and ocean circulation likely to be the most influential factors (Chin et al. 2010). An assessment of climate change risks for elasmobranchs within the Great Barrier Reef revealed freshwater/estuarine and reef species are most vulnerable to climate change, largely based on projected changes in temperature, ocean circulation and freshwater input (Chin et al. 2010). Interestingly, while coastal and inshore species showed moderate to high exposure to climate change factors, two-thirds of these species had low sensitivity to these changes indicating they could cope with altered environmental conditions. This result provides further evidence that responses to climate change may be species-specific and difficult to generalise.

Elasmobranch populations are likely to show an array of responses to changes in environmental conditions. Table 12 lists environmental parameters and their potential effect on shark and ray populations. Here, several of the potential responses to climate change are discussed based on categories of species groups (coastal, estuarine, pelagic, reef).

Table 12. List of environmental variable that may change under future climate scenarios and their potential implications for elasmobranch populations.

Temperature	As most elasmobranchs are ectothermic, surrounding water temperature affects the rate of important physiological and metabolic functions (e.g. digestion, somatic growth, reproduction). Increases in ocean temperature associated with global warming may cause: • **Range shifts/contractions/expansions** as individuals move to exploit/avoid certain temperatures; indirect effects of resource competition and/or predation when using new areas • **Effects on the timing of seasonal activities** (e.g. mating, parturition) **and migration patterns** which may affect species interactions, reproductive capabilities and recruitment • **Increased rate of embryonic development/decrease in gestation period** which may give females of a species more time to replenish energy reserves following parturition before the onset of winter and the next reproductive cycle • **Increased size of offspring at birth** which may enhance neonate survival rates

	• **Increased somatic growth rates** which may affect the timing of reproductive maturity • **Habitat loss** – critically important for coral reef species, due to mass coral bleaching/mortality events • **Changes in abundance/distribution of prey** due to effects on migration/spawning of prey with changes in currents or through a decrease in productivity in response to changes in upwelling
Salinity	Changing precipitation (i.e. increase in heavy rainfall/freshwater run-off events alter hydrological systems, affecting quantity and quality of water resources. Given that most elasmobranchs are stenohaline and occupy a narrow salinity range, changes in salinity may affect elasmobranch species through: • **Range shifts/contractions/expansions** as animals move to exploit/avoid certain salinities; indirect effects of resource competition and/or predation when using new areas • **Decreased fitness/mortality** if animals are unable to re-locate due to the increased physiological costs of osmoregulation • **Habitat loss** through an inability to access important habitats during periods of high freshwater flow (e.g. mangrove, shallow water) • **Effects on productivity and prey abundance** due to runoff
Dissolved oxygen	Expansion of oxygen minimum zones and anoxic "dead zones" may affect elasmobranchs through: • **Constraining habitat** • **Range shifts** as animals move to avoid hypoxic zones; indirect effects of resource competition and/or predation when using new areas
Sea level rise	Coastal systems will increasingly experience flooding and erosion due to projected sea level rise causing: • **Habitat loss** – critically important for coastal and estuarine species or for species that use coastal habitats at certain life history stages (e.g. pupping, nursery ground)
Tropical storms	Increases in the frequency and magnitude of tropical storms may affect elasmobranchs through: • **Habitat destruction** – particularly important for site-attached species (e.g. reef sharks) **or loss of habitat for prey** (e.g. seagrass beds) • **Short- or long-term changes in abundance and/or distribution** associated with drops in barometric pressure
pH	Ocean acidification poses substantial risks to polar and coral reef ecosystems with current global average CO_2 levels likely the highest in the past 2 million years. This may affect elasmobranch species through: • **Habitat loss** as reef-building corals degrade or growth is significantly inhibited • **Decreased growth rates** through an increase in energetic demands along with a concurrent decrease in metabolic efficiency and reduced ability to locate food through olfaction

8.3.1 Changes in distribution

Changes in distribution or range shifts already evident in some marine communities are likely to continue as conditions continue to change. For example, Last et al. (2011) reported climate and non-climate based range shifts in Tasmanian waters which included representatives from six elasmobranch families. One of the primary drivers of range shifts is water temperature. Due to the widespread and pervasive nature of temperature change this factor is altering distribution of species in all habitat categories (coastal, estuarine, pelagic, reef). As most elasmobranchs are ectothermic, surrounding water temperature affects the rate of important physiological and metabolic functions (e.g. digestion, somatic growth, reproduction). Range shifts based on temperature are likely to be long-term and/or permanent. Other factors which are less persistent may also cause short-term displacement of populations. Events such as freshwater floods or severe storm events or marine heatwaves may cause individuals or populations to be temporarily displaced from a location (e.g. Heupel et al. 2003, Ubeda et al. 2009, Udyawer et al. 2013, Wernberg et al. 2013). If these events intensify or become more common they could result in longer-term effects on populations, especially coastal and estuarine species.

Despite the mobility of sharks and their potential to move to areas with more suitable environmental conditions, habitat specialists and those with restricted dispersal may be somewhat restricted. For example, species dependent on habitats such as coral reefs can only shift their range if there is additional reef habitat with suitable environmental conditions. For these species movements to deeper water adjacent to reefs or deeper non-emergent reefs (if available) may be the preferred response. Moving away from a reef with limited information about available habitat in a new location is a risky behaviour which may lead some species to remain at a home site despite sub-optimal environmental conditions.

8.3.2 Changes in prey abundance

Climate associated changes in environmental conditions also have implications for resources that predators rely on such as prey communities. Modelling of ocean warming indicates decreases in primary productivity can cause changes in populations. For example, reduction of micronekton fish and cephalopods caused trophic cascades in pelagic systems (Griffiths 2010). This suggests mid trophic levels may be key drivers in pelagic systems which are required to maintain predator populations. Loss or alteration of prey groups due to effects of climate change such as reduced survival based on ocean acidification or changes in ocean circulation ultimately effect the survival and persistence of elasmobranch populations. Changes in prey abundance and distribution affect species in all habitat categories (coastal, estuarine, pelagic, reef).

8.4 Physiological effects

Changes in environmental conditions can have positive or negative effects on populations. Increased water temperature, for example, can speed gestation and reduce energy demands on pregnant females. In fact, sharks have been shown to selectively use warm water habitats when pregnant (behavioural thermoregulation) for this purpose (e.g. thermal maxima, the condition of individuals will decline as their metabolic rate increases Economakis and Lobel 1998, Hight and Lowe 2007). In contrast, if temperatures exceed and potentially exceeds their capacity to consume enough food to support their energetic needs. Data are still limited on the overall impacts of increasing temperature for elasmobranchs with some species potentially gaining from increased water temperature and others losing. Other persistent changes such as ocean acidification are hard to quantify as described earlier. Effects on mobile species can only be speculated due to lack of direct study. Other acute factors such as freshwater input and severe weather are typically short-lived, but can have physiological effects. Most elasmobranchs are stenohaline and occupy a narrow salinity range, therefore conditions outside their physiological limits will lead to mortality if individuals remain within these conditions. Changes in salinity are most likely to affect coastal and estuarine species, but can extend to some reef habitats. Therefore physiological effects of climate change vary and require further study, especially in pelagic species.

8.5 Effects by habitat type

Sharks and rays occupy a wide range of habitat types and have a variety of life history characteristics which will result in differing resilience and responses to stressors such as climate change. Any climate change effects must be considered within the context of direct human alteration of habitats (e.g. mangrove removal, dredging) since overall impacts will be compounded and cumulative. However, here we consider climate change effects on habitat types as an indicator of which changes are having the greatest effect on species that occur in different areas in isolation of direct human impacts. The habitat types can be grouped into: coastal, estuarine, pelagic, reef.

8.5.1 Coastal

Coastal habitats are some of the most exposed and vulnerable to climate change impacts (e.g. Klein and Nicholls 1999). Due to their typically shallow depths coastal habitats are affected by a number of climate change factors. Habitats adjacent to the coast are subject to changes in sea level rise which will alter habitats. In some cases this will create new habitat that is usable for species such as inundation of mangroves, in other places habitat is decreased. For example, if sea grass beds no longer receive enough light to persist due to increased water depth, critical habitat will be lost. Coastal regions are also highly susceptible to damage associated with severe weather such as tropical storms. Proximity to rivers mean that coastal habitats are also exposed to increased runoff and freshwater input if rainfall increases associated with storm events. Finally, water temperature changes are pervasive in all habitat types, but may be exacerbated in shallow coastal areas which are subject to heating due to sun exposure. The combination of increased ambient temperature with solar heating may cause significant changes in coastal habitats and ecosystems.

8.5.2 Estuarine

Like coastal habitats, estuarine areas are often shallow and adjacent to land. Therefore many of the factors that affect coastal habitats also apply to estuarine areas including sea level rise, storm damage and water temperature. However, due to the reduced salinity in these regions and natural connection to freshwater sources increased or altered rainfall patterns will have a greater effect on estuarine systems than most other habitat types. High freshwater input can cause salt wedges (picnocline) where a lens of freshwater sits on top of more marine water. Picnoclines have the potential to produce hypoxic zones where dissolved oxygen levels are decreased (e.g. Justić et al. 1996) causing "dead zones" where only specialist or highly adaptive species can survive. This scenario has the potential to displace individuals or cause mortality.

8.5.3 Pelagic

Pelagic habitats are likely to be the most stable due to the inertia of large water masses and distance from coastal influences such as freshwater input. Temperature is the most relevant factor in pelagic habitats. However, changes in ocean circulation may occur which can exacerbate temperature changes or distribution of prey. Changes in pH associated with ocean acidification may also play a role in the health of pelagic ecosystems through effects on primary producers and prey species (e.g. zooplankton). Therefore, climate change effects for elasmobranchs in pelagic environments are mainly via indirect effects produced by decreased productivity or availability of prey.

8.5.4 Reef

Climate change effects on reef habitats will vary depending on the location of reef habitats. Reefs close to shore will be exposed to similar stressors to those of coastal habitats via freshwater input and storm damage. All reef habitats are affected by sea level rise through increases in depth which can alter coral survival or community composition. Temperature is having similar effects with some coral species capable of withstanding increased temperatures and others suffering mortality. Thermal stress on coral reefs is already evident through recent bleaching events on the Great Barrier Reef. The long-term implications of severe bleaching are yet to be determined, but are likely to result in different coral communities than in the past. Corals may also be affected by changes in pH through ocean acidification. Increased acidification and increased water temperature may have confounding effects on a variety of reef dependent species (e.g. Pistevos et al. 2015). Whether changes in coral communities will affect predators such as sharks are largely unknown, but likely to depend on changes in prey community composition and abundance. Therefore effects on reef systems encompass a series of complex relationships which may result in a variety of outcomes.

8.6 Climate change and survival

The distribution, abundance and survival of marine fish is heavily influenced by changes in growth and reproduction (Perry 2005). If the capacity of a species to grow is reduced based on limited access to prey or increased physiological demands, their overall fitness will decline. This decline can impact reproductive capacity and survival of offspring. Although some species of elasmobranch may be able to relocate to avoid adverse conditions under climate change, not all will be able to move. Species are then required to adapt to new conditions, or new habitats assuming there is adequate prey to support their populations. All of these factors are also confounded by human impacts such as fishing. If a population is already depleted due to fishing they may not have capacity to withstand or recover from the additional stressors produced by climate changes. It is currently unclear whether elasmobranch populations can adapt fast enough to deal with current and future changes in climate, or how much populations will have to rely on re-distribution or range shifts to survive. It is likely, however, that coastal, estuarine and reef species will be most heavily impacted by a range of stressors including fishing, coastal development and climate change. A study of threats to species in the Spencer Gulf revealed that climate change was rated as the highest exposure threat due to widespread overlap with species distributions (Robbins et al. 2017). However, there was a high level of uncertainty regarding the status and effects on elasmobranchs which resulted in low expert confidence. Lack of even basic biology for some species precludes understanding how climate change will affect reproduction or other biological processes (e.g. growth) (Robbins et al. 2017). Although limited to the Spencer Gulf, this analysis is indicative of the scenario relating to elasmobranchs on a national scale. Effects are likely to occur, but our ability to predict the scale and scope of those effects is currently limited.

8.7 Management considerations

The major threat to elasmobranchs globally and nationally is overfishing. Climate change is increasing stress on exploited and threatened species (Table 13), but research on climate impacts should not come at the expense of dealing with the existing well-established impacts of fishing. The most pervasive climate-based risk to elasmobranchs is likely to be changes in water temperature which have the capacity to redistribute species (e.g. Last et al. 2011). Current research has already revealed movement of species both horizontally and vertically (Perry et al. 2005, Sguotti 2016) as they seek more preferable conditions. Understanding the potential for species redistribution is crucial to effective management and sustainable fisheries (Dell 2015). Redistribution has the capacity to increase or decrease vulnerability to fisheries and will vary by species and location. For example, if species currently resident within Australian Marine Parks or other protected areas move to an area open to fishing, their vulnerability to this threat increases substantially. In contrast, if species in fished areas are displaced into protected areas their vulnerability will decrease. The capacity for change, and implicit variability of effects, mean changes in management that reflect the new distributions of species are crucial to helping maintain threatened and exploited elasmobranch populations.

Species displacement and the need for altered management arrangements is likely to extend across national and international boundaries. Therefore cross-jurisdictional or region-scale management may be required. Since human population growth and resulting overfishing are major drivers in ocean degradation (e.g. Butler 2014), these impacts need to be managed and ameliorated to reduce impacts of climate change. Protection of biodiversity and prioritised and updated management based on an ongoing (quantitative) risk assessment are needed to meet multiple future needs. For example, changes in species distribution may disrupt ecosystem processes causing flow-on problems that effect biodiversity and food security (Rice 2011). Increased biodiversity protection may improve overall ecosystem health providing a buffer against climate change impacts. Marine biodiversity is influenced by a suite of stressors, climate change being just one, but it is a pervasive and persistent stressor. Species and population resilience to climate change impacts might be improved if effects of other pressures can be limited (Rice 2011).

Ultimately, reducing human impacts on populations may increase resilience of species and increase their capacity to adapt to changing climate conditions (Butler 2014, Rice 2011). Increased data collection and improved data sharing are also important to understanding climate change impacts. Current management is often hampered by lack of data on population status and trends, therefore improved data collection can inform managers about changes in populations which are integral to an adaptive management approach and provide the basis for a quantitative risk-based approach to prioritising management actions. This is crucial as climate change impacts could confound the impacts of fishing. Directed and adaptive management programs should focus on reducing impacts of fishing on at-risk species and consider applicability of closed areas to protect biodiversity and maintain ecosystems that support elasmobranch populations.

Table 13. List of environmental variables associated with future climate change, their potential impacts on elasmobranch species and which habitat types (and associated species) are most likely to be affected.

Environmental variable	Potential impact on species	Species group affected
Water temperature	• Range shifts/contractions/expansions as individuals move to exploit/avoid certain temperatures • Effects on the timing of seasonal activities (e.g. mating, parturition) and migration patterns which may affect reproductive capabilities and recruitment • Physiological effects such as decreased gestation period, increased growth rate, shorter time to maturity, etc • Habitat loss • Changes in abundance/distribution of prey	Coastal Estuarine Pelagic Reef
Freshwater input (increased rainfall)	• Range shifts/contractions/expansions as animals move to exploit/avoid certain salinities • Physiological effects/mortality if animals are unable to relocate to avoid adverse conditions • Habitat loss • Changes in abundance/distribution of prey	Coastal Estuarine
Sea level rise	• Habitat loss • Changes in abundance/distribution of prey	Coastal Estuarine Reef
Severe weather (tropical storms)	• Short- or long-term changes in abundance and/or distribution associated with severe weather • Habitat damage/loss • Changes in abundance/distribution of prey	Coastal Estuarine Reef
Ocean acidification (increased pH)	• Physiological effects on growth and survival • Habitat loss • Changes in abundance/distribution of prey	Coastal Estuarine Pelagic Reef
Dissolved oxygen	• Range shifts as animals move to avoid hypoxic zones • Changes in abundance/distribution of prey	Coastal Estuarine

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www.nespmarine.edu.au

Contact:

Michelle Heupel
Australian Institute of Marine Science

PMB No 3, Townsville, QLD 4810
m.heupel@aims.gov.au
tel | +61 07 4753 4205