On-the-water management solutions to halt the decline and support the recovery of Australia's endemic elasmobranchs

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1. Key Findings

1. Multiple indicators show several species of endemic elasmobranchs occurring in southeastern Australia have undergone major population declines (up to 80%) as a direct result of fisheries activities over the past 30 years or longer. These indicators include fishery-independent survey data and fishery-dependent observer data.

2. Ten species of endemic elasmobranchs (4 shark, 3 skate, 3 stingaree) with restricted geographic and/or bathymetric distributions and identified as of immediate conservation concern (listed as at least Threatened on the IUCN Red List) were examined to assess more current fishery-interactions and potential solutions to mitigate further fisheries-induced population declines. A key consideration for endemic species is that local depletions are equivalent to global depletions for population status.

3. Based on the current AFMA observer data, nine of the ten endemic elasmobranch species examined should be managed as bycatch/discard species because they were nearly all discarded across all commonwealth fishery sectors. The notable exception being angelsharks, which should be managed as a target or byproduct species as they were almost entirely retained in the southeast trawl and mostly retained (> 50%) in the Bight trawl sectors.

4. The global lack of basic biological, ecological and available recent fishery-interaction data (levels of catches, bycatches and discarding and discard mortality levels) was a major and reoccurring impediment to quantifying species-specific fishery impacts and identifying on-the-water solutions to redress historic population declines of endemic sharks and rays. This was especially the case for stingarees and skates and with the state-managed trawl fisheries in New South Wales.

5. Ecological risk assessments identified that four of the ten species have been at ongoing risk of extinction since 2010 due to the cumulative effects of Commonwealth demersal fisheries. The identified fisheries-induced risks to endemics are ongoing and increasing.

6. Bycatch Reduction devices (BRD's), improved catch handling practices, spatial fishing closures, and for some species, further commercial catch (output) controls are likely to be most effective for mitigating fishery impacts on endemic sharks and rays. No single management measure is likely to be effective on its own. All three of these management measures are used in commonwealth and/or state fisheries. Most of these arrangements are in place for management of other species but provide mainly incidental benefits for endemic elasmobranchs.

7. Up-to-date independent observer and/or survey data are essential to demonstrating population trajectories, impacts of fishing and future conservation of endemic species. For state fisheries in particular, such recent data were lacking. Recent observer data obtained from AFMA for the Commonwealth fisheries was of a high standard, except for the mostly discarded stingarees and skates.

8. Management implementation will require strong cross-jurisdictional arrangements as geographic and bathymetric ranges of all but two species extend across jurisdictional boundaries. This is particularly the case for inshore species that often cross state boundaries. Only two of the

ten species are likely to be managed effectively by one agency. Some offshore species occur mainly in Commonwealth waters, potentially simplifying implementation.

9. Spatial closures are likely to be the most difficult measure to implement. Commonwealth managed Australian Marine Parks alone are not adequate because of location and/or zoning that allows fishing. In the absence of recent observer data candidate locations could be informed by future analysis historical data. Suitable locations are likely to include fishing locations that have substantial economic value for commercially harvested target species.

10. The key barriers to implementation are the trade-offs between continued resource use and conservation, the uncertainty associated with inadequate data, and most importantly, the extent that managers treat that uncertainty with precaution. The ongoing fisheries-driven extinction risks of endemic elasmobranchs are clear and need to be a priority and strongly addressed by fisheries management agencies.

11. Overcoming barriers requires a strong commitment by all agencies and resource stakeholders to reveal and analyse all existing and current data and to finance the collection of new and ongoing ecological and fisheries data that will reduce uncertainties in risk and population assessments so that robust conservation measures can be implemented for sustainable population recovery and viable fisheries.

12. The stark reality that fishing activities have historically and continue to drive endemic elasmobranchs towards extinction needs to be acknowledged in fisheries management plans and afforded immediate management intervention to redress current population trajectories.

2. Recommendations

1. Immediately implement and where necessary further develop appropriate bycatch reduction devices (BRDs) in State and Commonwealth fish and prawn trawl fisheries to exclude capture and reduce mortalities of non-retained endemic skates, stingarees and rays as well as endemic sharks. Of immediate attention for implementation of appropriate BRDs are the New South Wales and South Australian prawn trawl fisheries, and for further development in the impending research program concerning the fish trawl component of the Commonwealth South Eastern Shark and Scalefish Fishery.

2. Prevent fishing effort expansion in relevant commonwealth or state managed fisheries that interact with the endemic sharks and rays discussed in this paper until thorough independent investigation of direct threats to endemic sharks and rays is completed and subsequently published. Carefully monitor the distribution if fishing effort, not just in terms of its perimeter, but also by terms of area of occupancy fished.

3. Implement world's best practice catch handling techniques across all fisheries to help improve survivorship of discards. This potentially could have immediate benefits but substantial benefits will require broad education, further development and monitoring programs with performance measures.

4. Maintain the annual/biannual observer programs already in place within the SESSF and mandate robust observer programs be undertaken at least every 5 years across all smaller-scale state fisheries that interact with endemic elasmobranchs throughout southeast Australia. Improve robustness by training observers in shark and ray identification. The data from such surveys need to be published and made publicly available (with respect to fisher confidentiality and commercial interests etc.) within 1 year of collection for independent scientific scrutiny and enactment in fisheries management plans. Mandate that fisheries agencies publish and disseminate fishery interaction observer data for scientific scrutiny and resource management and conservation purposes.

5. Maximise the scientific capacities, efficiencies and resourcing of observer programs, including the training of observers, to pursue improvements in observer data that specifically include species identification of skates, rays and stingarees and quantification of the numbers and sizes of each species retained and discarded across finer spatial scales for incorporation in population and risk assessments, and determination of potential protective areas for conservation purposes.

6. Provide conditions in Commonwealth Wildlife Trade Operation approvals that risk assessments of threatened endemic elasmobranchs, including cumulative risks, be undertaken across all relevant fisheries at least every 5 years. Develop prior decision rules to ensure appropriate fisheries management actions are taken to reduce mortality of high-risk species within 1 year of assessments. Publish results for public and scientific scrutiny.

7. Broaden the scope of AFMAs Upper Slope Dogfish Management strategy during its review phase in conjunction with the Commonwealth Department of Environment, to become an upper-slope shark and ray management strategy. This would increase conservation and recovery support especially to whitefin swellshark and grey skate that breed within existing closed areas for gulper sharks (*Centrophorus* species), whilst maintaining continued protection for greeneye spurdog that survey data shows are migrating into these areas.

8. Analyse all existing fisheries catch data and review commercial catch limits for greeneye spurdog and eastern angel shark taking greater account of stock status uncertainty and urgent conservation needs. Analyse existing electronic and conventional tagging data for greeneye spurdog and whitefin swellshark.

9. Determine and quantify the conservation benefits of existing inshore fishing closures in state waters to coastal stingaree (South Australia) (Appendix B), Colclough's shark (Queensland) and longnose skate (Tasmanian shark nursery areas).

10. Determine and quantify the conservation benefits of providing new spatial protection areas (fishing closures) on the continental shelf of southeastern Australia to endemic skates (particularly the Sydney skate), rays and stingarees. As part of this process, a priority is to immediately analyse and map species-specific baseline survey data from historical Southern Surveyor cruises and recent catches from AFMA observer data to identify candidate closure locations on the continental shelf of southeastern Australia and determine overlap with existing State and Commonwealth fishery closures and Commonwealth Marine Parks.

11. Elevate, prioritise and drive to the highest level increases in funding and research programs to undertake fisheries-relevant biological and ecological studies of threatened endemic elasmobranchs, particularly skates, rays and stingarees. Prioritise studies that will reduce uncertainty in risk and population assessment. Biological studies should be integrated with observer programs where possible to maximise cost-benefits of sample collections. A key priority of future stock and risk assessments of endemic elasmobranchs is the collation and analyses of all current fisheries interaction data from state and commonwealth fisheries.

12. Scope the feasibility (costings and logistics) of undertaking regular (e.g. every 5 years) standardised fishery-independent surveys of continental shelf- and slope-inhabiting endemic elasmobranch species not exceeding every 5 to 10 years. These data are to directly feed risk and population assessments and drive future management and conservation plans.

13. Ensure the science, scientific standards and protocols of elasmobranch research encompass world's best practice so that robust and sound assessments and advice concerning the management and conservation of Australia's endemic elasmobranchs can be made at the highest level of certainty.

14. Prioritise and enforce management measures that provide conservation benefits to endemic elasmobranchs with low biological productivity in fisheries management plans. This will not only enhance the conservation measures of endemics, but will ensure the sustainability and credibility of Australian fisheries. Australian fisheries management needs to strive to be the world leaders in elasmobranch conservation.

3. Background and objectives

Australia's oceans are characterised by high endemism of elasmobranchs (hereafter referred to as 'endemics') and as a consequence, a global conservation priority to protect the evolutionary diversity of elasmobranchs (Davidson and Dulvy 2017). Endemic species only occur within Australia's Exclusive Economic Zone (EEZ). Australia is one of 21 regions in the world containing 'triple threat hotspots'. These hotspots are characterised by the presence of threatened species in high levels of richness, endemicity, and evolutionary distinctiveness (Stein *et al.* 2018).

The most recent report card for Australia's sharks and shark-like rays identified that most species examined are being effectively managed and are considered sustainable (Simpfendorfer *et al.* 2018). However, this assessment did not include the majority of the broad taxonomic group of 'rays' (i.e. skates, stingrays, stingarees and devil rays) that collectively total about 125 species (Simpfendorfer *et al.* 2018). Like sharks, fishing pressure through target and incidental catch is a major threat to rays worldwide (Dulvy *et al*. 2014, Davidson *et al*. 2015). Thus, the conservation status of many endemics remains a concern. Notably, at least nineteen Australian elasmobranch species are classified as either Endangered or Critically Endangered on the IUCN Red List (Heupel *et al.* 2018). Further, concomitant with improved data, the threat level for some species has increased over the past decade despite management interventions. For example, the whitefin swellshark (*Cephaloscyllium albipinnum*) was reclassified from 'Near Threatened' to 'Critically Endangered' over eight years (Pardo *et al*. 2019), and likewise, the greeneye spurdog (*Squalus chloroculus*), from 'Near Threatened' to 'Endangered' over ten years (Walker *et al*. 2019).

Although protection for such species can be legislated under Australia's national environmental laws, the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), only one threatened endemic species, the Maugean skate (*Zearaja maugeana*), is currently listed under the Act. It should be noted that at the time of writing, three threatened endemic elasmobranch species (whitefin swellshark, longnose and grey skate) identified by the National Environmental Science Program's (NESP) Shark Action Plan (Heupel *et al*. 2018), that were nominated in 2019 (Finalised Priority Assessment List 2019), are currently being considered by the federal government for protection under Australia's Environment Protection and Biodiversity Conservation (EPBC) Act. This process can take several years (species assessment completions due 30 October 2022) and consequently, more immediate management intervention may be required to prevent further depletions of these endemics whilst listing deliberations are taking place.

The management and conservation of many endemics is complicated by virtue of their distributions and the multitude of fisheries in which they interact. Not only can the geographic ranges of endemics cross state boundaries, but the depth distribution of the majority of endemics extends from coastal waters managed by states, to offshore waters extending beyond three nautical miles which are typically managed by the commonwealth government (Last and White 2011). The recent NESP Shark Action Plan identified that south-eastern Australia (southern Queensland through to eastern Victoria) is a region containing a high level of incidence of threatened elasmobranch species, as a direct result from fishing (Heupel *et al*. 2018). Within this region, there are several state-managed fisheries as well as the commonwealth-managed Southern and Eastern Scalefish and Shark Fishery (SESSF). The SESSF operates across an area (Appendix B, Fig. 3) where the endemicity rate of shark and ray species ranges from 42-77% (Last and White 2011). New South Wales warrants particular focus given the interaction of its diverse ocean fisheries with numerous shelf- and slope-inhabiting endemic species of significant conservation concern (Heupel *et al*. 2018), and the recent transitioning process of its Southern Fish Trawl Fishery from state to federal management. Differences in jurisdictional resources, legislation, and fisheries management could be causes for inconsistent and potentially ineffective means to conserve endemic populations.

The conservation needs for Australian endemic sharks and rays are urgent, globally recognised, and forecasted to be successful if appropriate actions are implemented (Davidson and Dulvy 2017). An evaluation of fisheries that pose a high conservation risk to threatened Australian endemic sharks and rays, particularly in south-eastern Australia, is required so that effective conservation management tools can be-developed and implemented where necessary. Enactment of appropriate management measures may prevent escalation of the conservation status of endemics into higher threat categories in the future, and more broadly it could also prevent some species that are not currently threatened from becoming threatened (Heupel *et al*. 2018). This should provide a model for other areas in Australia to follow where the extinction-risk to endemics is currently lower. Such actions will not only further promote the sustainability of Australian fisheries, but help conserve the evolutionary diversity of elasmobranchs within Australian waters.

In this report we review the status of ten endemic elasmobranch species that are considered Vulnerable or Endangered (based on IUCN Red List criteria) as a consequence of fishery impacts in south-eastern Australia (Heupel *et al*. 2018). We specifically synthesised published information and available data concerning each species' biology and fishery-interactions to identify potential conservation impacts, and concomitant on-water solutions to mitigate such impacts. We also consider barriers to implementing such solutions and recommend ways to overcome these impediments.

Project Objectives

1. Identify "on the water" solutions that can be implemented to deliver immediate and long-term benefits for the conservation of specific endemic sharks and rays in Australia.

2. Identify barriers to implementing proposed management solutions, and make recommendations to overcome them.

4. Species and data sources

The Australian Marine Conservation Society (AMCS) selected ten Australian endemic elasmobranch species from the 'Red List' of the International Union for the Conservation of Nature (IUCN) in the categories of Critically Endangered, Endangered or Vulnerable (IUCN 2020) (Table 1) for examination. Each species is entirely restricted to the territorial waters of Australia's Exclusive Economic Zone (EEZ).

The ten species examined were:

whitefin swellshark (*Cephaloscyllium albipinnum*),
longnose skate (*Dentiraja confusus*),
Sydney skate (*Dentiraja australis*),
grey skate (*Dipturus canutus*),
eastern angelshark (*Squatina albipunctata*),
greenback stingaree (*Urolophus viridis*),
yellowback stingaree (*Urolophis sufflavus*),
coastal stingaree (*Urolophus orarius*),
Colclough's shark (*Brachaelurus colcloughi*),
greeneye spurdog (*Squalus chloroculus*).

Species synopses

A synopsis of available biological and fisheries-related data was prepared for each species (Appendix A). Each synopsis summarised key species attributes including: distribution, biological characteristics, population status, population trends, fishery interactions and current management arrangements, catch mitigation options and future data needs. These data were used to gain insights into the magnitude of fishery impacts, the key impacting fisheries, and to identify potential solutions to mitigate fisheries captures and potentially reduce mortalities of each of the ten study species.

Data sources

The sources of these data were primarily from published scientific articles and fisheries technical reports. The most comprehensive data sets concerning historical time series data were from: (1) the Integrated Scientific Monitoring Program from 1994–2006 for the Commonwealth fisheries (Walker and Gason 2007, 2009), and (2) a fisheries-independent survey of shark and ray catch rates across the outer continental shelf and slope off southern New South Wales for the periods 1976–77 and 1996–1997 (Graham *et al.* 2001). For species from the upper continental slope (200–600 m), some survey data were obtained on automatic-longline survey catch rates before and after the implementation of fishing closures to protect gulper sharks Centrophoridae (Williams *et al.* 2012).

Historical observer-based data were available for several pertinent fisheries, including the NSW Ocean Fish Trawl Fishery (1993-1995; Liggins 1996), Ocean Prawn Trawl Fishery (1990-1992; Kennelly *et al*. 1998) and Ocean Trap and Line Fishery (2007-2009; Macbeth and Gray 2016, 2008-2009; Macbeth *et al*. 2009), and the Queensland Offshore Prawn Trawl Fishery (2000s; Courtney *et al.* 2007). For South Australia, the results from research trawl surveys done in the Spencer Gulf (South Australia) in 2007 and 2013 were available (Burnell *et al.* 2015).

The Australian Fisheries Management Authority (AFMA) provided up to date observer and logbook data covering relevant Commonwealth managed Southern and Eastern Scalefish and Shark Fishery (SESSF) covering the years 2003 to 2019. The supplied data covered several fishing sectors within the SESSF; the South East Trawl sector, Great Australian Bight Trawl Sector (GABTF), Danish seine sector, Scalefish Hook sector, Shark Hook and Gillnet sector, and the Trap sector. The years with available observer data varied between fishing sectors. The observer data did not include levels of observer coverage, limiting analyses to unstandardized catches and could not be extrapolated to fishery-wide catches. These data were provided after the first draft of the report was submitted.

The New South Wales Department of Primary Industries (NSW DPI Fisheries), provided relevant summated fisher logbook data (i.e. reported landed catch and effort data) for the period 1997/98 to 2019/20. These data were also provided after the first draft of the report was submitted. Despite requests, NSW DPI were not forthcoming with supplying recent observer data covering the relevant NSW ocean fish and prawn trawl fisheries.

The provided AFMA observer and logbook data and the NSW DPI reported landed catch and effort data were used to identify and quantify (where possible) historic and current levels of endemic-fishery interactions.

As only limited (unstandardized) AFMA observer data could be obtained, we also examined the ongoing risk to the species of interest using published ecological risk assessments based on productivity, susceptibility assessment (PSA) and Sustainability Assessment of Fishing Effects (SAFE) methods (Wayte *et al.* 2007, Zhou *et al.* 2007, Zhou *et al.* 2012).

5. Results

It is recommended that readers familarise themselves with the species synopses (Appendix A) prior to, or in conjunction with, reading sections 5 and 6 of this report. These species synopses provided greater species specific details.

5.1 Fishery interactions, species abundance and monitoring

Historical trends in species abundance and impact of fishing methods

Historical survey data summarised in the species synopses (Appendix A) showed historical population declines (up to 80%) in all the species considered as a direct consequence of commercial overfishing (Table 1) (Graham *et al.* 2001, Walker and Gason 2007). Currently the main threats are fishing by trawl and longline methods. Previously deep set (> 200 m) gillnets had a major impact on various species of greeneye dogfishes (*Squalus* species) and gulper sharks (*Centrophorus* species) (Daley, Stevens and Graham, 2002). This method has since been eliminated from continental slope waters in Australia, providing substantial conservation benefits.

Later the Upper Slope Dogfish Management Strategy (USDMS) was implemented to conserve gulper sharks (*Centrophorus* spp) and greeneye spurdog (Squalus chloroculus) (AFMA 2012). This strategy provides an example of a comprehensive approach to conservation management. The strategy includes a series of areas closed to fishing, coupled with a code of practice for safer handling and live release and other management measures. The effectiveness of areas closed to fishing is often difficult to measure. In the case of the USDMS, Tagging data indicates that greeneye spurdogs have migrated into closures on the upper slope thereby reducing mortality in fished areas (Williams *et al.* 2012). Appendix 1.

Table 1. Historical impacts of fishing on endemic sharks and rays

Common name	Species	IUCN Redlist	Ecological Risks
Whitefin swellshark	*Cephaloscyllium albipinnum*	Critically endangered, decreasing	SESSF: trawl, longline (previously gillnet)
Longnose Skate	*Dentiraja confuses* (sp. A)	Critically endangered, decreasing	SESSF: trawl, Danish seine, longline
Sydney Skate	*Dentiraja australis*	Vulnerable	SESSF: trawl; NSW: trawl
Grey Skate	*Dipturus canutus* (sp. B)	Near threatened	SESSF: trawl, longline
Eastern Angelshark,	*Squatina albipunctata*	Vulnerable	SESSF: trawl; NSW: trawl
Greenback Stingaree	*Urolophus viridis*	Vulnerable	SESSF: trawl; NSW: trawl
Yellowback Stingaree	*Urolophis sufflavus*	Vulnerable	SESSF: trawl; NSW: trawl
Coastal Stingaree	*Urolophus Orarius*	Endangered	SA: Prawn Trawl
Colclough's Shark,	*Brachaelurus colcloughi*	Vulnerable	QLD: prawn trawl; NSW: trawl
Greeneye spurdog	*Squalus chloroculus*	Endangered	SESSF: trawl, longline (previously gillnet)

* SESSF = Southern and Eastern Scalefish and Shark Fishery managed by the Australian Fisheries Management Authority.
* IUCN Redlist = International Union for the Conservation of Nature Redlist of Threatened Species

Ecological risk assessments

In fisheries with high species diversity, the cost of species by species assessment is problematic because, the time series data sets needed to estimate mortality of non-target species are generally not of sufficient quality, in terms of spatial coverage, and reliable species identifications. The potential use of ecological risk assessment (ERA) methods is attractive because they can estimate mortality without time series data. It is important to note however that results will only be approximate and are likely to contain both false negative and false positive results.

Understanding the likelihood of errors in ERA requires a basic understanding of quantities and methods used. Methods are often specific to a particular analysis as methods continue to evolve. Commonwealth fisheries in particular have come to rely on a method known as the Sustainability of Australian Fisheries Effects for Ecological Risk Assessment of fish species (SAFE) (Zhou *et al*. 2012). This method calculates a sustainable level of fishing mortality for a given species, based on life history parameters, such as age at maturity and number of young. For species where these parameters are not known, mortality is estimated by comparison to species with known parameters. The estimated level of fishing mortality is calculated for each species by first calculating the proportion of overlap between fishing effort and species distribution. The mortality estimate is then calculated taking into account catchability in the area where species and fisheries overlap. Catchability is straightforward to estimate for trawl fisheries, using the area swept by the net, and the selectivity of the net. For some other methods, catchability is more difficult to assess. For example baited hooks attract sharks but the range of attraction is poorly understood.

Reliable application of the SAFE method requires both cumulative assessments and repeated measures. Assessing only one fishery at a time, can give false positives by highlighting areas where a species has potential refuge outside one fishery, without assessing that area.

Summarised below are the only published SAFE repeated cumulative risk assessments for the Commonwealth Managed Southern and Eastern Scalefish and Shark (SESSF) Fishery (Zhou *et al.* 2012) (Table 2). Importantly this assesses the combination of both hook and net methods that can capture endemic sharks and rays on both clear sediments and reefs, limiting habitat refuge. The results showed that for four endemics, the estimated cumulative fishing mortality in the SESSF exceeds the sustainable mortality to the extent that populations are predicted to crash, that is fall to such low numbers that they may never recover. These species are whitefin swellshark, Sydney skate, grey skate and greeneye spurdog (Table 2) (Zhou *et al.* 2012). These species are mainly from the upper continental slope; the Sydney skate is an exception as it mostly occurs in shelf waters (see Appendix 1). These results do not consider the additional cumulative effects of State and Commonwealth Fisheries, which are likely to impact the Sydney skate.

A recent case study shows that cumulative risks can be comprehensively assessed across Commonwealth – State boundaries if data can be shared. This has previously been hampered by the lack of spatial resolution in capture locations for many State fisheries. More recently a study assessed the cumulative risks of Commonwealth and NSW Fisheries to one endemic shark and one endemic ray. These results included both an inshore species: draughtboard shark (*Cephaloscyllium laticeps*) –low risk; and an offshore species: the Bight skate (*Dipturus gudgeri*) – medium risk (Zhou *et al.* 2019).

Table 2. Cumulative risk assessment scores for the Southern and Eastern Scalefish and Shark Fishery sectors (trawl, gillnet, longline and Danish seine methods) based on the SAFE method (Zhou *et al.* 2012).

Species	2007 Conservation risk	2010 Conservation risk	Risk Trend
whitefin swellshark	potentially extreme	Extreme	Increased
longnose skate	Not assessed	Not assessed	ID issues
Sydney skate	Extreme	Extreme	steady
grey skate	Potentially extreme	Extreme	Increased
eastern angelshark	Not assessed	Not assessed	ID issues
greenback stingaree	Not assessed ...	Not assessed	ID issues
yellowback stingaree	Not assessed	Potentially extreme	ID issues
coastal stingaree	Not assessed	Not assessed	Not assessed
Colclough's shark	Not assessed	Not assessed	Not assessed
greeneye spurdog	Extreme	Extreme	Steady

* Extreme risk indicates possible extinction in three years if mortality is not reduced
* Potentially extreme risk indicates possible reduction to very low numbers if mortality is not reduced in three years
* ID = identification

A key consideration in the development of various ERA methods has been determining the most informative way to measure exposure (overlap between fishing effort and species distribution). On face value a high overlap suggests high risk. For example in a previous ERA for the southeast trawl sector of the SESSF, overlaps for endemics range between 18.3% for greenback stingaree and 87.8% for whitefin swellshark (Table 3) (Wayte *et al.* 2007). The complex life histories of sharks and rays however mean that simple exposure metrics can be problematic. What is more informative is the extent that the fishing overlaps with, what can be relatively small, mating and pupping/egg-laying locations that are possible for sharks and rays with internal fertilization. Unfortunately these locations are poorly known for many endemics. By contrast where these areas are well known and managed, populations are likely to be sustainable even if overlaps are high. The best example of this is gulper sharks (*Centrophorus* species). Even though there is up to 90% of population ranges within the SESSF trawl fished for these species, populations are expected to recover because key breeding locations have been protected by the Upper Slope Dogfish Management Strategy (Wayte *et al.* 2007, AFMA 2012, Daley *et al*. 2019). This case study is discussed further below (Section 5.5) as an example how management responses to high-risk species require more detailed studies that ERA results alone can provide.

Table 3. Spatial overlap between species distribution within the fishery boundary and Commonwealth trawl fishing effort 2001–2004 (Wayte *et al.* 2007).

Species	Core bathymetric (seafloor) depth (m)	Proportion of core species range trawled (%)
whitefin swellshark	240–550	87.8%
longnose skate	20–120	19.5%
Sydney skate	50–180	80.7%
grey skate	450–600	87.5%
eastern angelshark,	?	?
greenback stingaree	80–180	18.3%
yellowback stingaree	not assessed	not assessed
greeneye spurdog	180–600	86.5%

? possible confusion with Australian angel shark (*Squatina australis*)
* Colclough's shark and the coastal stingaree do not overlap with Commonwealth trawl fishing.
* the yellowback stingaree was not included in assessment of 2001– 2004 catches
* Core range is defined as the estimated range that contains 90% of mature adults
* Methods including observer data and tracking data were used to calculate core range.

Fishery data quality

Three sets of catch history data were obtained for analysis in the sections that follow: Observer data for the Commonwealth Southern and Eastern Scalefish and Shark fishery, Logbook (at sea) data for the SESSF, and NSW reported landed catch and effort data. Before examining these data in detail, a preliminary review was used to classify the identification level (family/genus/species) that could be interpreted with confidence (Table 4). Confidence was highest where catches were reported to species level and these matched the published geographic and depth ranges.

In Commonwealth observer data, catches were considered likely to be reported to at least genus level and mainly to species level. Some records were out of range, suggesting misidentifications. Most of the misidentification matched just a few common patterns that could be easily addressed in one or two observer training workshops. These patterns are discussed in the catch analysis sections that follow. This training could also benefit NSW observers if NSW observer data could be obtained.

The Commonwealth logbook data for endemic sharks was generally resolved to at least genus level but the skates and stingarees were not. The data for dogfish catches was confused by various common names that suggest several possible families. This problem could be substantially and almost immediately by redistributing shark identification sheets already prepared by CSIRO and AFMA (Daley et al .2002).

The New South Wales landings data also had more reliable identifications for sharks than rays. For dogfishes their data was resolved to genus level and species groups (discussed below), which is a commendable for these species that are similar in appearance

Table 4. Data quality scores for species of interest to Commonwealth fisheries management. Scores indicate the level at which identifications are reliable
Data quality scores: 0=not resolved to family, 1=family, 2= genus, 3=species level id, 4= species identification consistently matches published geographic and depth range

Common Name	SESSF Observer	SESSF Logbook	NSW Landings
whitefin swellshark	4	3	4
skates	3	1	0
angelsharks	3	2	3/4
stingarees	2/3	1	0
greeneye spurdog	2/3	0	2

* Although NSW State observer data was requested it was not provided in time for this report.

5.2 Analysis of observer-based Commonwealth fishery catch data

In order to estimate the magnitude of fishery impacts from Commonwealth fisheries, total catch estimates were based on observer data scaled up by the fraction of fishing observed. For example, if the observed catch in a year was x and the rate of observer coverage was 10%, then the estimated catch was estimated as 10 x the observed catch. The observer coverage was estimated as the observed effort/logbook effort. Different measures of effort were used for different gear types: Trawl – hours fished; longline – number of hooks; seine – number of shots. The total estimates were only obtained when the logbook and observer data could be matched. If there was no observer coverage or logbook reporting and collation practices were not consistent then data were excluded (Table 5).

Key species
When catches were estimated for Commonwealth fishery sectors, the results highlighted substantial estimated combined catches of three species from the upper slope and six species from the continental shelf (Table 5). The largest estimated minimum catch weights for upper slope species were whitefin swellshark - 1,319 t, greeneye Spurdog – 997.3 t and grey skate 260.6 t. The fishery sectors that contributed most to these catches were the autoline sector, and the southeast trawl. The largest estimated catches for contintental shelf species were all rays: Sydney skate – 154.8t, longnose skate – 345.3 t, Melbourne skate – 763.9 t, sandyback stingaree – 288.4 t and yellowback stingaree – 257.6 t and greenback stingaree – 798 t. The sectors with the greatest impact on these continental shelf species were the southeast trawl and the Danish seine. Of particular concern was an estimated 3,184 t of unidentified sharks and rays were taken. These include 997 t of mixed Spurdog (Genus *Squalus*), 437 t of mixed skates and 1,166 t of mixed stingaree. The largest of these unidentified estimated catches, mixed stingarees, was

attributed to the Danish seine method. As the gillnet sector recorded only low estimated catches (< 13 t) of each of the species considered here, that sector was excluded from further detailed analysis.

Discard rates
Unstandardised observer data (not scaled up by observer coverage rates) were used to distinguish between byproduct and bycatch species. The results indicate, nine of the ten endemic elasmobranch species examined should be managed as bycatch species because they were nearly all discarded (Table 6). The exception being angelsharks, which were almost entirely retained in the southeast trawl (only 1–2% discarded) and substantially retained in the Bight trawl (33% discarded). Some Melbourne and mixed skate (66-72% discarded) were also retained across fisheries, except in the Bight trawl fishery (Table 6).

Sector specific trends in scaled estimated catches
The scaled estimated total catches were examined for inter-annual trends (Table 7). When these catches were plotted (Figures 1–4), it was possible to classify general patterns to one of four types using visual inspection: 1) rising trend, 2) declining trend, 3) rise-peak-decline trend, and 4) no trend (Table 7). Some of the patterns suggest identification problems. There are several possible explanations for the other patterns. These include change in the spatial distribution of effort, sequential depletion, decreased abundance in some cases and increased abundance in others. Some discussion of the patterns follows but further analysis, including standardisation by fishing zone, are needed to conclusively interpret patterns.

Table 5. Minimum estimates of total catches (2003 to 2019) of endemic sharks and rays in various sectors and fishing methods of the Commonwealth managed Southern and Eastern Scalefish and Shark Fishery (SESSF) (tonnes). Catches > 100 t in bold.

Species	Danish Seine 2012 - 2019	GHAT Gillnett 2007 – 2015, 2018	GHAT Automatic longline 2001 – 2015, 2017 - 2019	Southeast Trawl 2010 – 2019	Great Australian Bight Trawl 2001 – 2008, 2010 , 2012, 2014, 2016, 2018	Minimum estimated total
whitefin swellshark	2.9	2.9	**841.1**	**397.1**	74.6	1318.6
Sydney skate	17.0	0.1	1.6	**136.0**	0.1	154.8
grey skate	14.1	0.9	**122.7**	**105.1**	17.8	260.6
longnose skate	82.5	3.1	7.0	**243.8**	8.9	345.3
mixed skates	18.0	10.5	23.4	9.0	**376.0**	436.9
Melbourne skate	**268.7**	12.7	13.6	**263.9**	**205.0**	763.9
greeneye spurdog	**105.1**	0.3	**273.8**	**593.1**	25.0	997.3
mixed spurdog	67.7	0.3	59.0	**133.0**	**580.3**	840.3
eastern angel shark	4.4	0.0	0.0	4	0.0	8.4
mixed angel shark	2.6	2.9	0.0	2	98.7	106.2
mixed stingaree	**1166.6**	0.6	0.7	5	**735.1**	**1908.0**
(sandyback stingaree)	6	2.4	0.3	8	**271.7**	288.4
yellowback stingaree	**255**	0.0	0.0	2	0.6	257.6
greenback stingaree	**798**	0.0	0.0	**19**	**175.1**	992.1

* GHAT = Gillnet Hook and trap sector of the Southern and Eastern Scalefish and Shark Fishery

Table 6. Observed discard rates of endemic sharks and rays in Commonwealth fisheries (% unstandardised observed catch discarded). Discard rates< 75% in bold

Species	Danish Seine	Autoline	SETrawl	Bight trawl
whitefin swellshark	100	99	86	86
Sydney skate	100	100	100	100
grey skate	100	100	85	100
longnose skate	100	100	99	100
mixed skates	100	100	**72**	100
Melbourne skate	82	**66**	**71**	97
greeneye spurdog	100	95	91	95
mixed spurdog	100	98	98	99
eastern angel shark	0	not recorded	1	not recorded
mixed angel shark	0	not recorded	**2**	**33**
mixed stingaree	96	100	100	100
sandyback stingaree	100	100	94	100
yellowback stingaree	98	not recorded	97	100
greenback stingaree	100	100	100	100

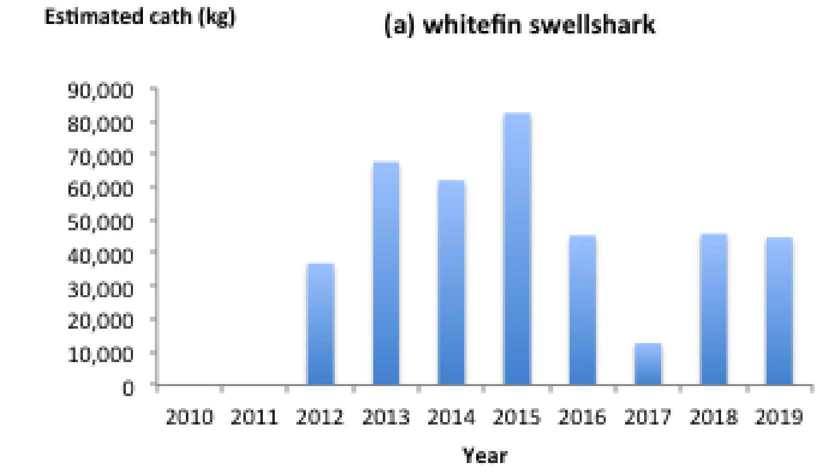
Table 7. Patterns in the estimated total catches of endemic sharks and rays estimated from observer data scaled by coverage in various sectors and fishing methods of the Commonwealth managed Southern and Eastern Scalefish and Shark Fishery (SESSF)

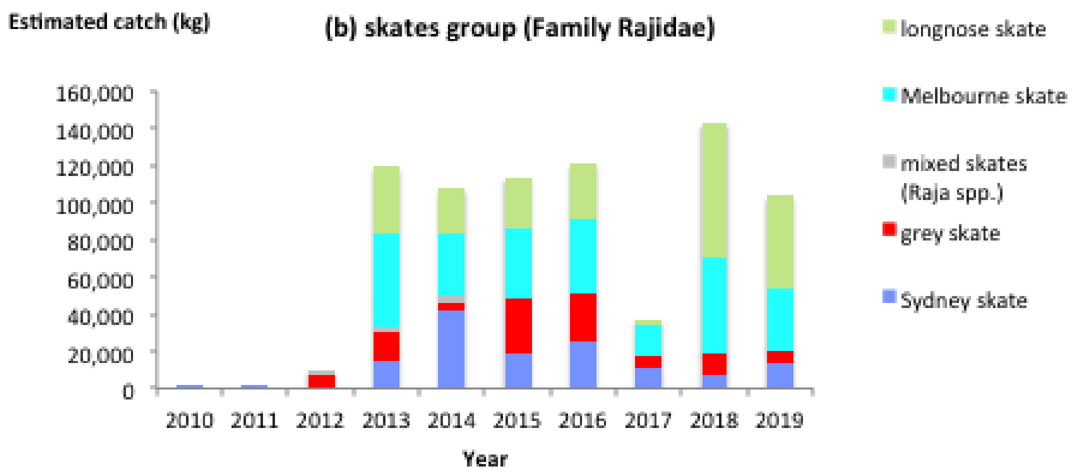
Species	Southeast Trawl	Bight Trawl	Danish Seine	Autoline
whitefin swellshark	Rise-peak-decline	Decline	Out of depth range	Triple rise-peak-decline
Sydney skate	Rise-peak-decline	No pattern	No pattern	No pattern
grey skate	Rise-peak-decline	No pattern	Out of depth range	No pattern
longnose skate	Rise	Not observed	Rise	No pattern
mixed skates	Rise	No pattern	Rise	No pattern
Melbourne skate	No pattern	decline	Rise-peak-decline	No pattern
greeneye spurdog	Rise	Rise	Rise – out of range	Rise peak decline
mixed spurdog	decline	No pattern	rise	Decline
eastern angelshark	Rise-peak-decline	Not observed	No pattern	Not observed
mixed angel shark	Rise-peak-decline	No pattern	No pattern	Not observed
mixed stingaree	Decline	Rise peak decline	Decline	Not observed
sandyback stingaree	No pattern	Rise peak decline	No pattern	Not observed
yellowback stingaree	Rise-peak-decline	No pattern	No pattern	Not observed
greenback stingaree	Rise	No pattern	No pattern	Not observed

Southeast Trawl Sector

While the estimated catches for the southeast trawl sector showed some patterns between years, these unstandardized data provided little evidence of change in abundance over time (Figure 1). There was some evidence of improved reporting. The Spurdog group (genus *Squalus*) showed an increase in the proportion of the catch identified as greeneye Spurdog (Figure 1c) with a corresponding decline in mixed Spurdog. Similarly the stingaree group (Family Urolophidae) showed an increase in the proportion of catch identified to species (Figure 1e)

Figure 1. Trends in estimated annual catches of endemic shark and ray species in the Commonwealth Southeast Trawl Sector





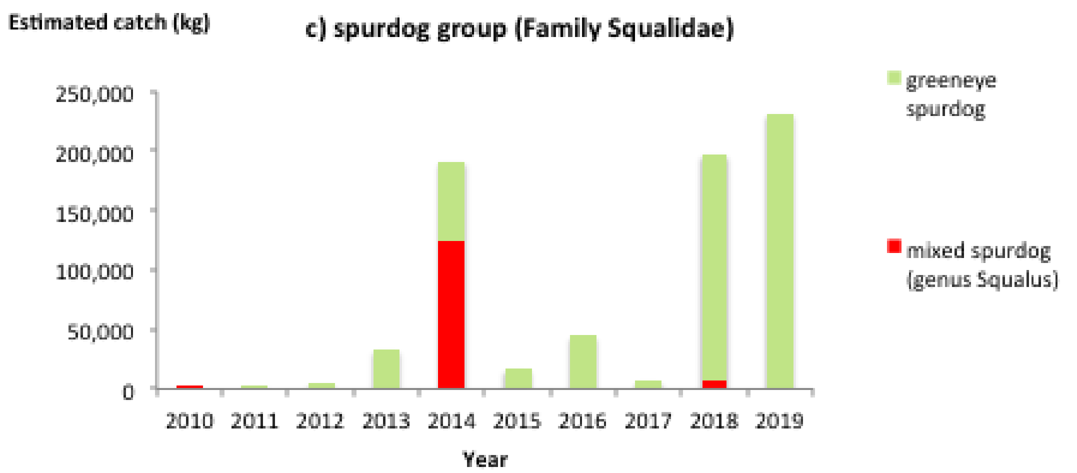
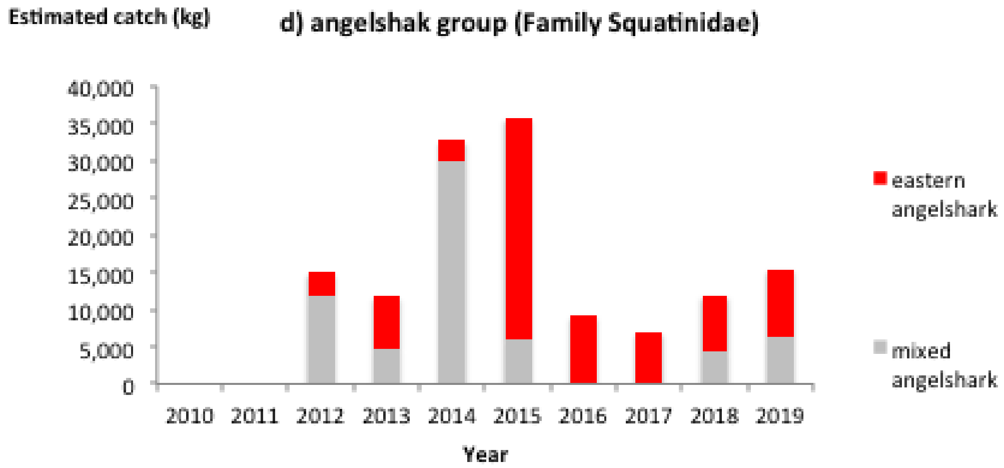
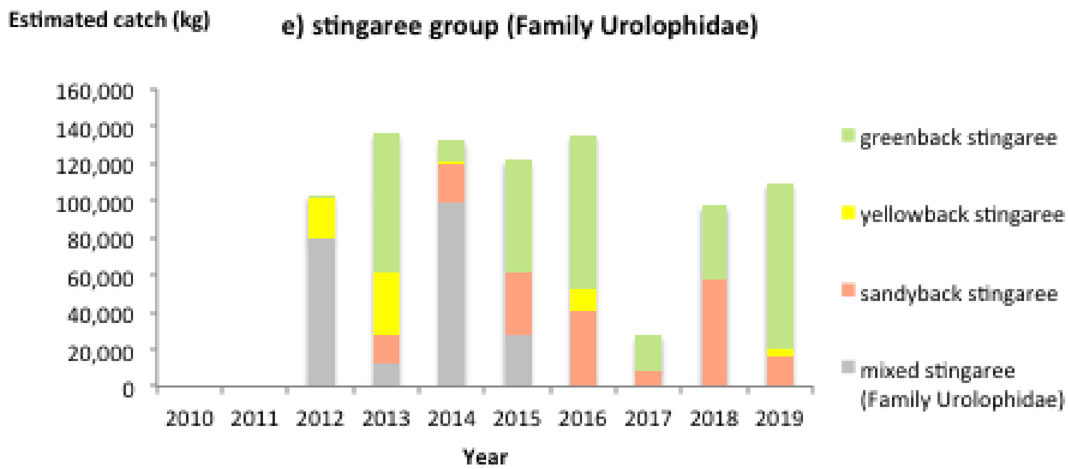


Figure 1 continued. Trends in estimated annual catches of endemic shark and ray species in the Commonwealth Southeast Trawl Sector





Great Australian Bight Trawl Sector
Whitefin swellshark, showed catches of 20 – 25 t in 2003, 2004 and 2006 (Figure 2a). All subsequent catches were much lower.

Interpretation of the observed skate catch was confounded by species identification problems (Figure 2b). Up to 2005, the skate catch was reported almost entirely as Melbourne skate. Between 2007 and 2012, the proportion of Melbourne skate in observed catches fell to near zero and the proportion of 'mixed skate' in catches rose to 100%. Very few skates were reported subsequently.

High catches of mixed spurdog were estimated for two years: 2008 and 2014 (Figure 2c)

Angelshark estimated catches were low in most years but a very large catch of 80 t was istimated for 2014. The eastern angelshark was not reported, as it does not occur in the Great Australian Bight (Last and Stevens 2009).

Stingaree records suggest inaccurate species identification. In 2005 and 2006, substantial catches of sandyback stingaree of up to 200 t were estimated. This appears to be out of range because the species has a southeastern distribution from Queensland to Beachport (South Australia). In 2012 and 2014, most of the observed stingaree catch was reported as mixed stingaree. In 2014 and 2018, substantial catches of greenback stingaree were recorded. This species has not previously been reported west of Portland (Victoria) and these records are almost certainly misidentifications of the sparsely-spotted stingaree (*Urolophus paucimaculatus*) which is widely distributed across southern Australia, including the Great Australian Bight. This result highlights the need for adequate observer training and resourcing for correct and consistent species identifications within and across fisheries.

Figure 2. Estimated catches of endemic shark and ray species in the Great Australian Bight trawl sector.

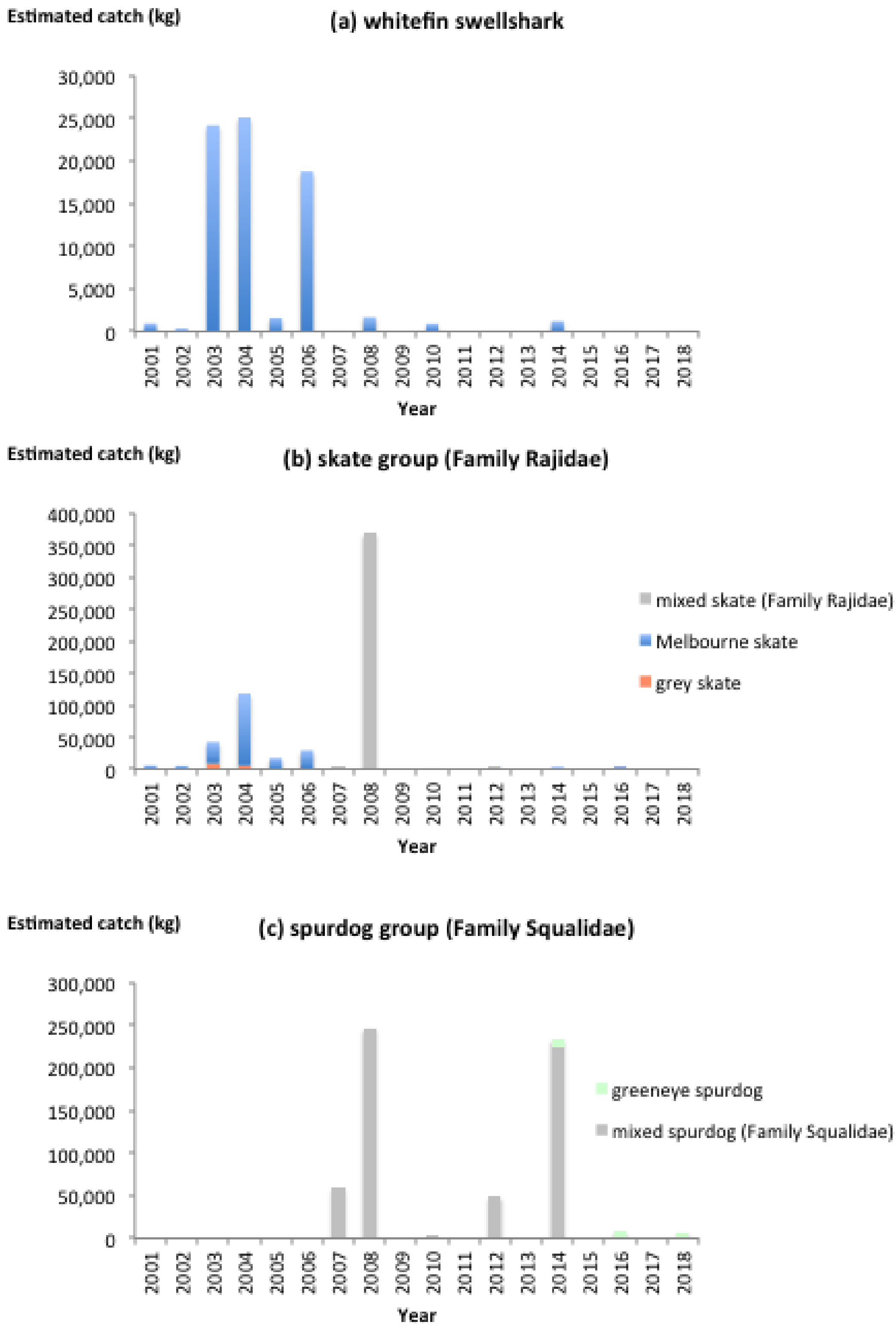
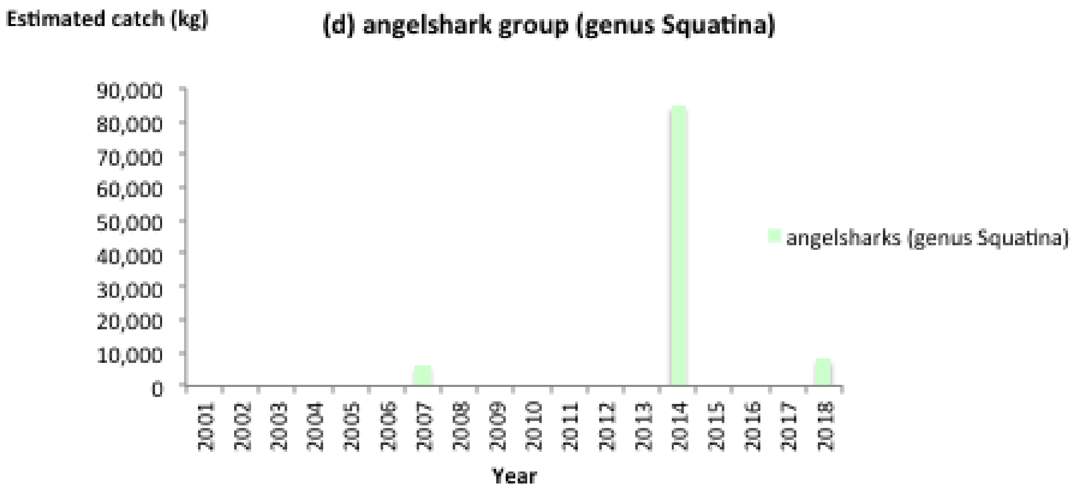
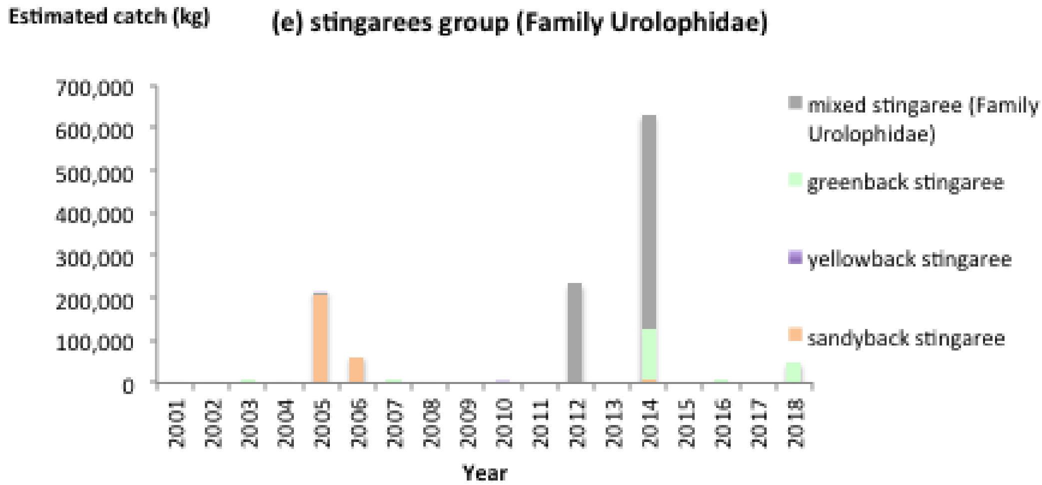


Figure 2 (continued). Estimated catches of endemic shark and ray species in the Great Australian Bight trawl sector.





Danish seine fishery

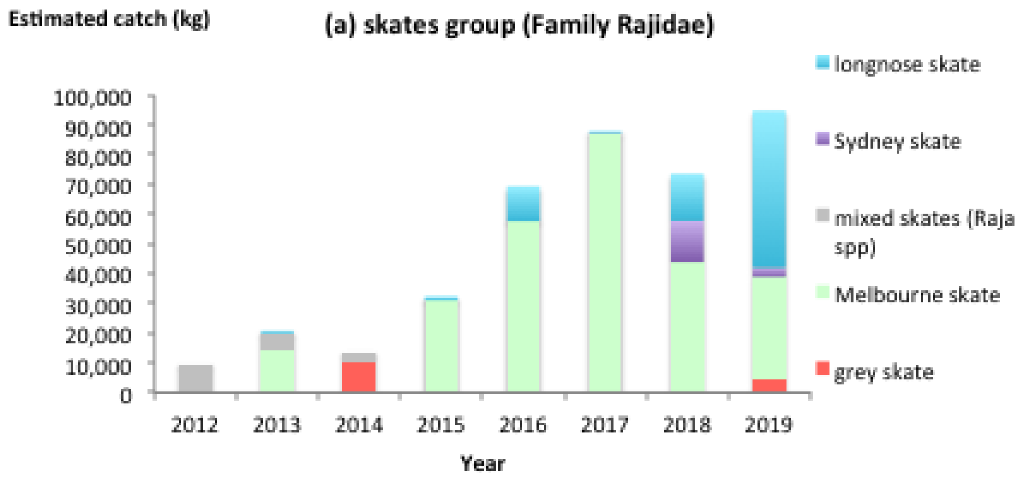
Three groups were examined further for the Danish Seine sector: skates, spurdogs and stingarees (Figure 3). The skate group showed an increasing trend in estimated catch and a change in species composition that suggests some improvements to reporting practices (Figure 3a). For most years catch was reported mainly as Melbourne skate. This seems unlikely as daily port sampling reported that the longnose skate was far more abundant in inshore waters where Danish Seine vessels operate (Treloar 2008). By 2019 the proportion of longnose skate increases to dominate the observed catch, which is more realistic. Reports of grey skate in this inshore sector could be errors as this species occurs on the continental slope (see Appendix A).

The Spurdog group showed and increase in catches and an increase in the proportion of the catch identified to species (Figure 3b). The increase in the reported catch of greeneye is probably erroneous as this species occurs mainly on the continental slope but seine fishing is undertaken on the shelf. These records are more likely whitespotted dogfish (*Squalus acanthias*) and piked Spurdog (*Squalus megalops*) (RKD personal observations during port visits).

The reported stingaree catches also displayed changes in species composition that appear to be due to inaccurate species identification (Figure 3c). In 2012, almost the entire observed catch

(99%) of was reported as mixed stingaree. A substantial catch of yellowback stingaree was reported in 2013 alone. From 2014 to 2019, most of the stingaree catch was reported as either sandyback stingaree or greenback stingaree. The greenback stingaree could have been confused with the sparsely spotted stingaree in catch reports. The greenback stingaree occurs mainly in waters deeper that 65 m, whereas the sparsely spotted stingaree is much more common inshore (Last and Stevens 2009).

Figure 3. Observed unstandardized catches of endemic shark and ray species in the Commonwealth Danish Seine sector.



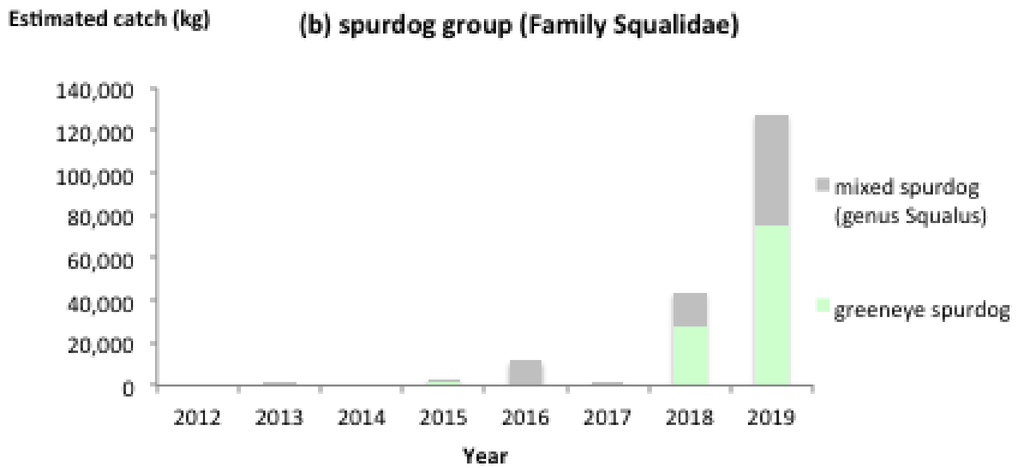
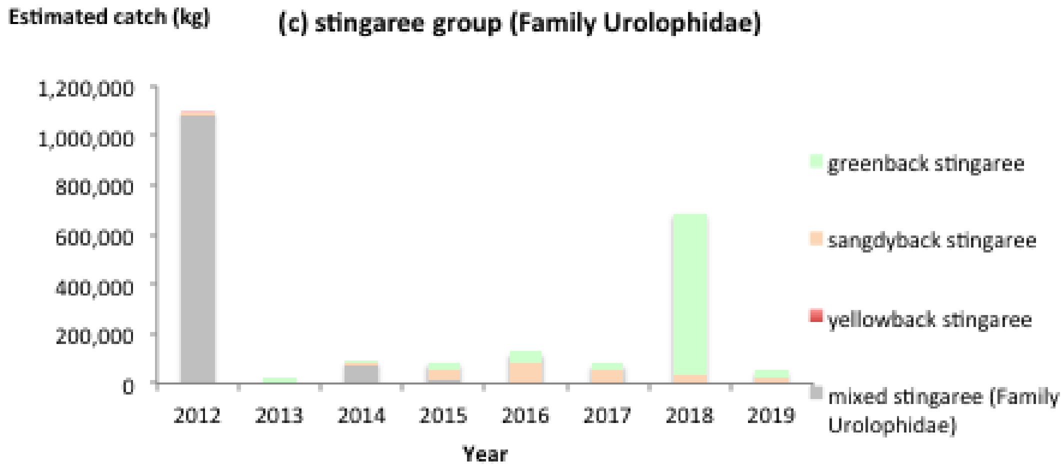


Figure 3 continued. Observed unstandardized catches of endemic shark and ray species in the Commonwealth Danish Seine sector.



Automatic longline

The whitefin swellshark had a distinctive and triple rise-peak-decline pattern (Figure 4 a). The skate catch was dominated by the grey skate Figure 4b). The Spurdog catch showed an increase in estimated catch and in increase in the proportion of the catch attributed to Greeneye Spurdog (Figure 4c).

Figure 4. Estimated total catches of endemic shark and ray species by automatic longline method in the Commonwealth Gillnet, Hook and Trap Sector of the Southern and Eastern Scalefish and Shark Fishery.

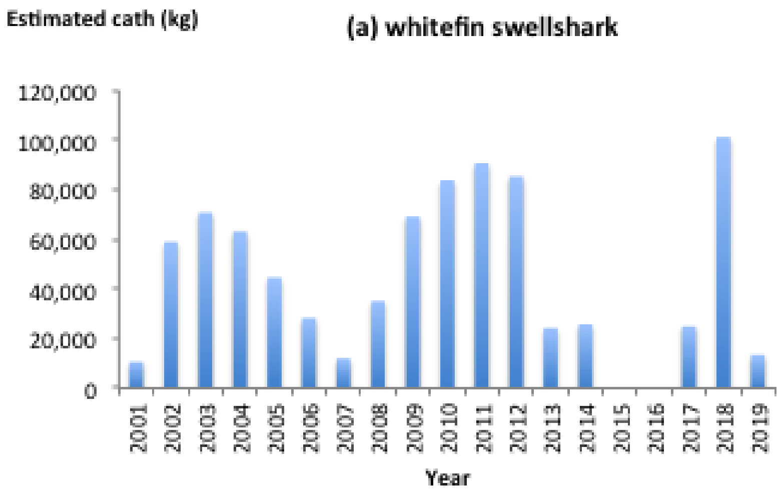
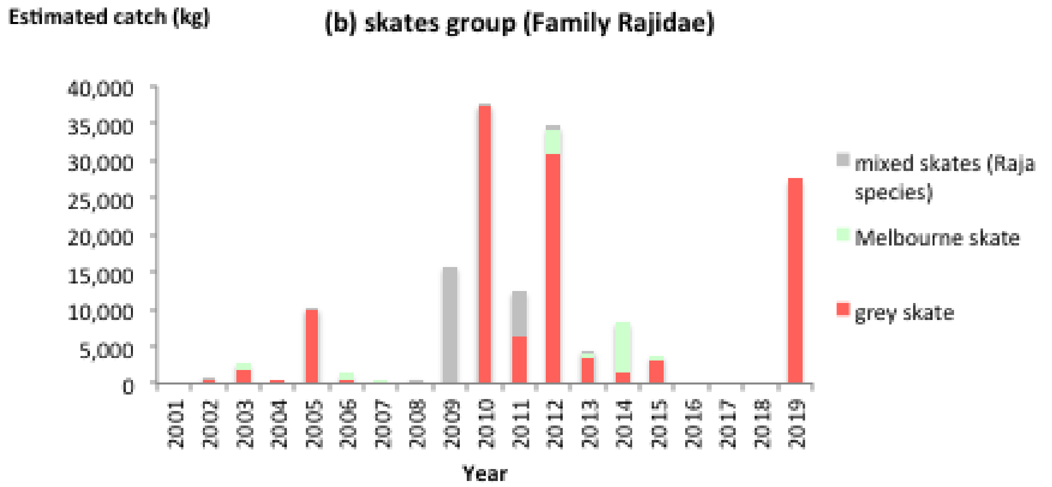
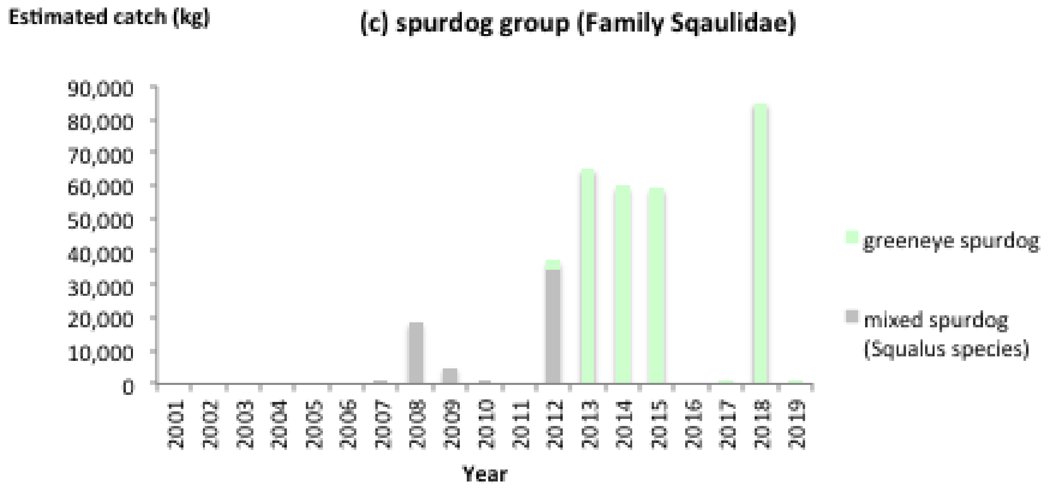


Figure 4 continued. Estimated total catches of endemic shark and ray species by automatic longline method in the Commonwealth Gillnet, Hook and Trap Sector of the Southern and Eastern Scalefish and Shark Fishery.





5.3 Analysis of Commonwealth logbook data

The utility of the AFMA logbook catch data as a means of quantifying endemic-fishery interactions was assessed by firstly examining the 2002–2018 pooled data by reported name and gear type. Only the whitefin swellshark could be evaluated as a single species. Because of mixed identifications, catches of all other endemics were considered in broad taxonomic groups; notably angelsharks, skates and dogfishes. Catches of stingarees were not recorded in logbooks and therefore this data stream was deemed worthless for assessment for this group. Following this broad examination, annual catches of angelsharks were examined.

Overall, these broad results point to some utility of the logbook data for angelsharks, but data quality issues resulting from poor species identification, make the logbook data unreliable for other endemic species catch assessments. For these species the observer data were more reliable for interpreting endemic-fishery interactions (Section 5.2).

Pooled data
The pooled catch data identified that angelshark data had some potential for assessment of catches across years for trawl fisheries. A total of 2,628 t of angel shark was reportedly caught between 2002 and 2018, with 97.6% being taken in the trawl fisheries (Table 8). Notably, 82.3% of the catch was reported at the level of species.

The skate group had the second largest combined catch for the period of 1,541 t, with 80.8% being taken by trawling and 14.2% by hook gear (Table 8). Species composition was poorly resolved; fishers only attempted to identify 4.6% of the catch to species.

The dogfish group had the most taxonomic confusion as catches were variously reported in one of six categories: 1. Dogfishes, 2. Mixed dogfishes, 3. Greeneye dogfish, 4. Greeneye dogfishes mixed, 5. greeneye Spurdog, and 6. gulper shark/sleeper shark /dogfishes. The combined catch for these groups during the period was 308 t, of which only 1% was identified to species.

Although reported to the level of species, the whitefin swellshark data was also problematic. The total catch across all years was small, only 61 t, with 35.5 t taken in trawl and 23.9 t in gillnet sectors. The breakdown of the catch by gear type indicated potential species misidentification in the gillnet sector. The setting of gillnets is restricted by regulation to waters inshore of the 200 m bathymetric contour, but the whitefin swellshark is primarily distributed beyond 200 m.

Table 8. Total combined logbook catches (t) by gear type of endemic sharks and rays in Commonwealth fisheries for the period 2002–2018.

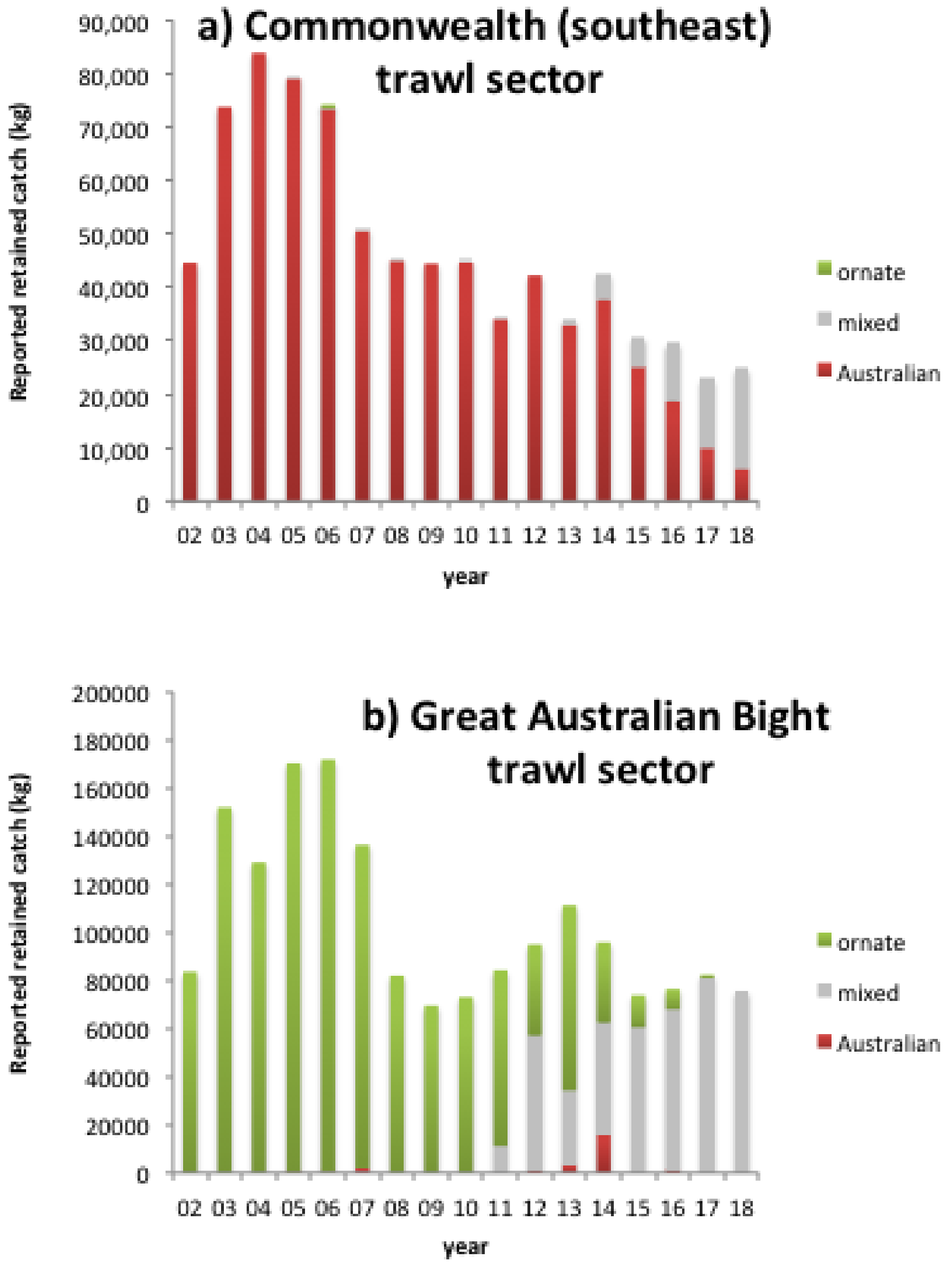
Fishing gear	Angelshark group	skates group	whitefin swellshark	dogfishes groups	stingarees
Danish seine	36	71	1	3	0
Hooks	0	219	0	13	0
Pots and traps	0	0	0	0	0
Purse seine	0	0	0	0	0
Set gillnet	26	5	24	3	0
Trawl	2,566	1,246	36	290	0
Total	2,628	1,541	61	308	0

Angelshark annual catch trends
Annual logbook catch data for angelsharks were considered separately for the Commonwealth (southeast) Trawl Sector (CTS) and the Great Australian Bight Trawl Sector (GAB). In the CTS, catches showed a rise-peak-decline pattern rising from 44.6 t in 2002 to 83.8 t in 2005, then falling to 23–25 t in 2017–2018 (Figure 5a). The logbook reported species composition was dominated by Australian angelshark. This contradicts the observer data for the same fishery that indicated the main species captured by the CTS was eastern angelshark (Figure 1d, section 5.2). The CTS logbook data shows a decrease in the proportion of angelshark catch reported to species level since 2014. While this is a loss in precision, it more accurately reflects low confidence in the species identification in logbook records.

The annual catches of angelsharks reported in the GAB were much higher than for the CTS. The GAB catches showed a double rise peak decline pattern, rising from 83.6 t in 2002 to 136 t in

2007, then falling to 70 t in 2009, then rising again to 110 t in 2013 and again falling to 76 t in 2018 (Figure 5b). The species composition changes from entirely ornate angelshark in 2010 to entirely mixed angel shark by 2018. Again, this is probably a more accurate reflection of low confidence in the species identification in logbook records.

Figure 5. AFMA logbook recorded annual catches of angelsharks between 2002 and 2018 in a). Commonwealth southeast trawl sector, and b) the Great Australian Bight trawl sector.



5.4 Analysis of NSW reported landed catch and effort data

The summated fisher-reported landed catch data supplied by NSW DPI were examined for trends in reported landed catches of endemics between 1997/98 and 2019/20. There was a notable change in the reporting format of data in 2009/10 from monthly summaries to daily catch reporting. This change in format also included greater emphasis on individual species identification, but impacted continuity and compatibility of fishing effort data. The earlier catch returns summarised total catches (species kg) and total fishing effort (number of days fished) by fishing sector/method per month. Since 2009/10 the reported catches (species kg) by fishing sector/method are reported for each fishing day; so, the only effort information obtained is the number of fishing days that a species was actually retained, and not the number of days fishing occurred but a species was not retained. This change in reporting did not allow compatible CPUE information to be determined across both data sets (i.e. pre- and post-2009/10; as per the data supplied).

Angelshark
Both the Australian and eastern angelshark are captured in the NSW Ocean Trawl and Ocean Trap and Line fisheries. Prior to 2009/10, angelshark was reported as a mixed species, after which the two species were reported as separate species.

Since 2009/10, angelshark catches have comprised about 66% Australian and 34% eastern (Figure 6). Both species are predominantly taken in the ocean trawl fishery; Australian angelshark in fish trawls (~94% of catch), and eastern angelshark in fish trawls (~72% of catch) and prawn trawls (27% of catch) (Tables 9 and 10). Small quantities of both species have been taken in trap and line fishery (mostly in fish traps) and the Danish seine fishery.

Combined angelshark catches peaked in 2009/10, but since then there has been a general decline in catches of both species. This was most evident for the Australian angelshark, with catches declining from around 40,500 kg in 2009/10 to 9,500 kg in 2017/18, after which catches rose slightly to 14,500 kg in 2019/20. Catches of eastern angelshark also display a lesser decline since 2012/13, with catches between 2014/15 and 2019/20 being lower than those between 2009/10 and 2013/14 (Figure 6).

Spurdog
Changes in reporting requirements in 2009/10 resulted in different reports of spurdog catches. Before 2009/10, a mixture of endeavour/toughskin (interpreted as gulper sharks, *Centrophorus* species), greeneye (interpreted as mixed *Squalus* species) and mixed unspecified species (interpreted as mixed Squalidae, Centrophoridae and possibly other Squaliformes) were reported, but after 2009/10 this was changed to only dark- and white-tailed spurdog (Figure 7). Here dark tailed Spurdog is interpreted as *Squalus chloroculus* and closely related species, whereas white-tailed Spurdog is interpreted as other closely related species of Squalus that are not Squalus chloroculus. This distinction is a useful innovation in field based technique for Squalus species that are arguably very similar in appearance.

Between 1997/98 and 2008/09 catches of both endeavour and greeneye spurdog starkly declined; endeavour from 19,500 to 3,800 kg, and greeneye from 16,000 to 800 kg per annum. Both species were predominantly taken (~50%) in the fish trawls, and also dropline for endeavour and deepwater royal red prawn trawl for greeneye (Table 9). CPUE of both species over this time period also displayed strong declines (Figure 6). Since 2009/10 very few spurdog have been reported as being retained (5,000 kg over 11 years) with most catches occurring in the trap and line fishery (Table 10).

Figure 6. a). Reported total landed catches of angelshark by species composition in NSW ocean fisheries between 1997/98 and 2019/20; b). Reported total landed catches of Australian angelshark by ocean fishery sector between 2009/10 and 2019/20; c). Reported total landed catches of eastern angelshark by ocean fishery sector between 2009/10 and 2019/20. Note there was a change in species reporting format in 2009/10.

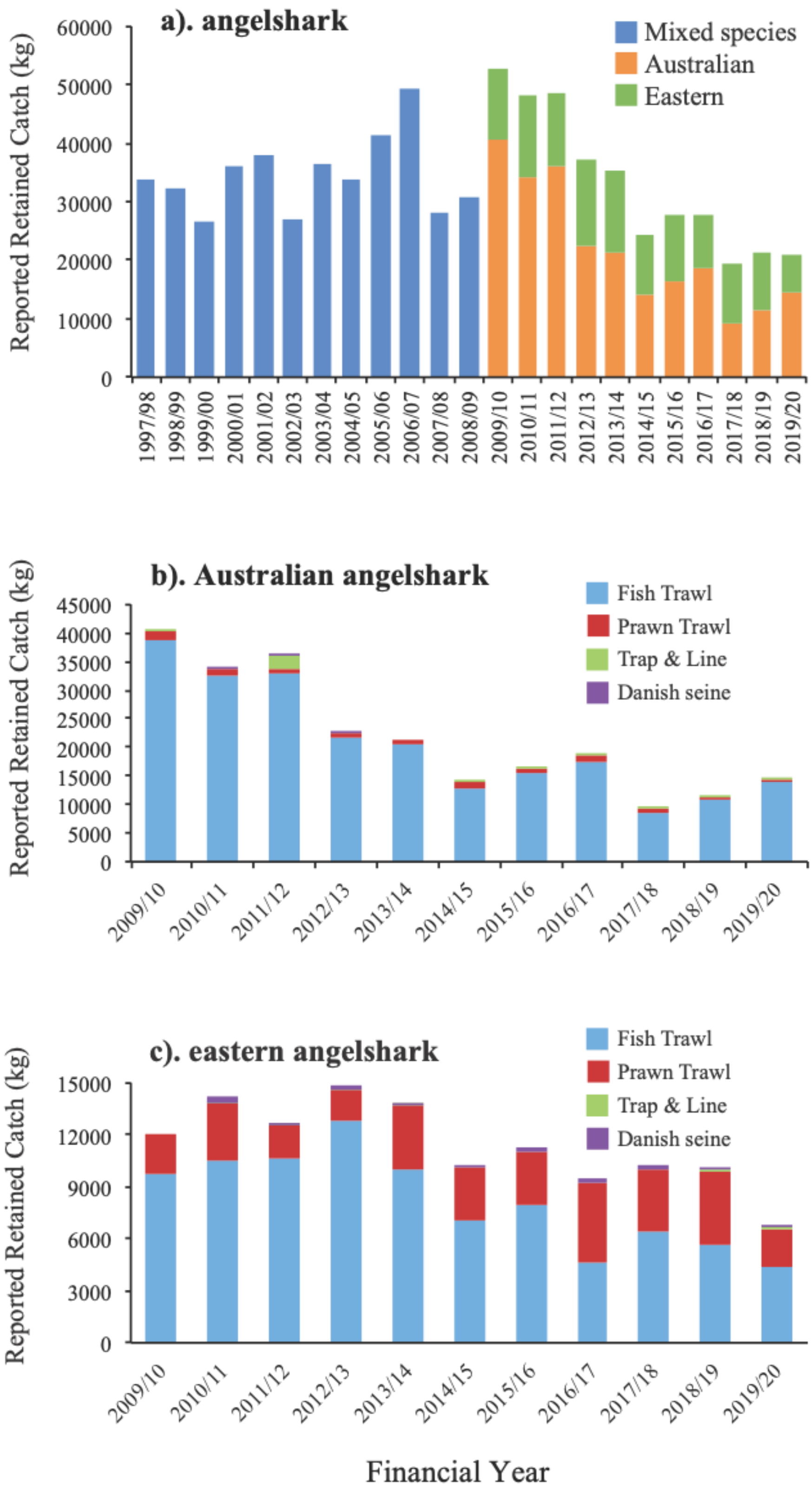


Figure 7. a). Reported total landed catches of spurdog in NSW ocean fisheries between 1997/98 and 2019/20; b). Reported catch-per-unit-effort (CPUE) of Endeavour/toughskin and greeneye spurdog in the ocean fish trawl fishery between 1997/98 and 2008/09. Note there was a change in fishing effort reporting format in 2009/10 which prevented CPUE being determined after that year.

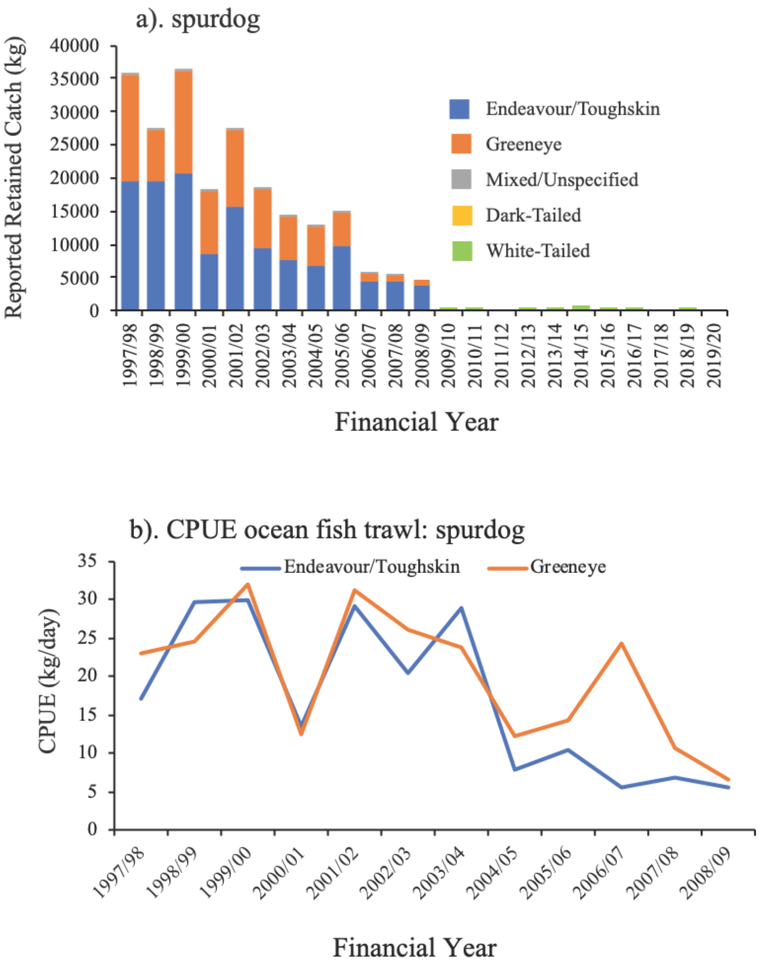


Table 9. The total reported landed catch in New South Wales between 1997/98 and 2008/09 for each endemic group and the percentage contribution of each ocean fishery and gear type to total catches. Bold identifies greatest contribution. Based on NSW DPI catch return data.

				Ocean Trawl Fishery			Ocean Trap & Line Fishery									
	Total Catch (kg) 1997/98 to 2008/09	Ocean Trawl Fishery Total %	Ocean Trap & Line Fishery Total %	Fish trawl %	Prawn trawl %	Prawn trawl royal red %	Fish trap %	Handline %	Dropline %	Setline %	Longline %	Trotline %	Driftline %	Jigging %	Trolling %	Other or ambiguous %
Angelshark unspecified	413,680	**97.3**	2.7	**78.6**	18.5	0.2	2.6	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Endeavour/ Toughskin spurdog	130,015	**54.3**	45.7	**49.0**	0.8	4.4	2.5	0.8	37.8	1.3	0.0	3.0	0.0	0.0	0.0	0.1
Greeneye spurdog	89,650	**83.3**	16.7	**50.8**	10.3	22.2	1.8	0.3	13.9	0.4	0.0	0.2	0.0	0.1	0.0	0.0
Unspecified spurdog	957	44.4	**55.6**	37.1	5.3	2.0	**39.4**	2.0	4.1	7.8	0.0	2.3	0.0	0.0	0.0	0.0
Unspecified stingray & stingaree	277,744	**92.6**	7.4	**86.5**	6.0	0.0	0.3	0.4	1.0	1.6	0.1	3.4	0.0	0.0	0.2	0.5

Table 10. The total reported landed catch in New South Wales between 2009/10 and 2019/20 for each endemic group and the percentage contribution of each ocean fishery and gear type to total catches. Bold identifies greatest contribution.

	Total Catch (kg) 2009/10 to 2019/20	Ocean Trawl Fishery Total %	Ocean Trap & Line Fishery Total %	Ocean Trawl Fishery			Ocean Trap & Line Fishery								
				Fish Trawl %	Prawn trawl %	Danish Seine %	Fish trap %	Handline %	Dropline %	Setline %	Longline %	Trotline %	Driftline %	Jigging %	Trolling %
Australian angelshark	238,707	**98.8**	1.2	**94.2**	4.4	0.2	0.1	0.0	0.0	0.1	1.0	0.0	0.0	0.0	0.0
Eastern angelshark	125,212	**99.8**	0.2	**71.7**	27.1	1.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Dark-tailed spurdog	1,306	18.9	**81.1**	16.2	2.7	0.0	8.6	13.1	5.7	**43.4**	7.9	2.3	0.0	0.1	0.0
White-tailed spurdog	3,501	5.0	**95.0**	2.9	2.1	0.0	0.1	21.7	33.1	**29.7**	0.5	9.4	0.6	0.0	0.0
Unspecified stingrays & stingarees	285,692	**87.6**	12.4	**82.2**	5.2	0.1	0.1	0.6	0.2	10.7	0.3	0.4	0.0	0.0	0.1
Whitefin swellshark	5,393	1.3	**98.7**	1.0	0.3	0.0	0.4	0.0	7.4	**90.0**	0.0	0.9	0.0	0.0	0.0

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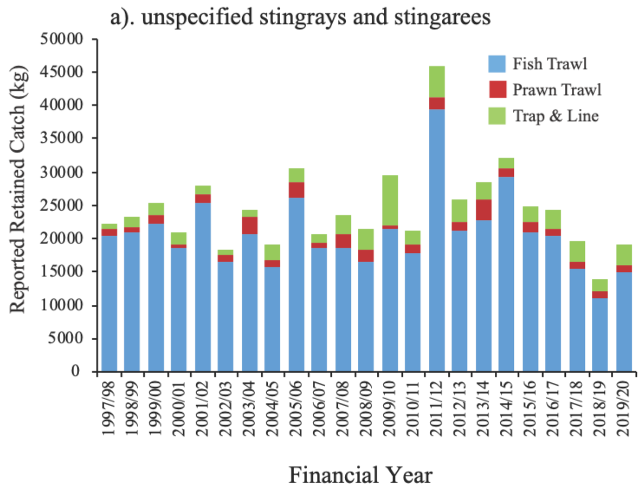
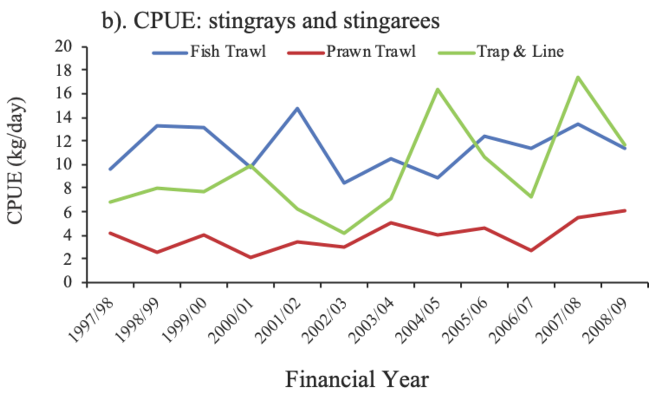
Stingrays and stingarees

Stingrays and stingarees are not reported by species, but binned into a category of unspecified mixed species. This is even after the NSW Department of Primary Industries introduced a new reporting format in 2009/10, so the species composition of catches remains unquantified.

Reported landed catches since 1997/98 to current have been relatively stable displaying no global increases or decreases (Figure 8). There was a notable peak catch of ~46,000 kg in 2011/12, and least catch of ~14,000 kg in 2018/19. Between 1997/98 and 2008/09, approximately 86 and 6% of the reported catch was taken in fish trawls and prawn trawls, respectively (Table 9). Between 2009/10 and 2019/20, approximately 82 and 10% of catches were taken in fish trawls and setlines, respectively (Table 10). This could represent a trend for greater retention and less discarding of stingrays and stingarees in the line fishery in recent years. CPUE between 1997/98 and 2008/09 was relatively flat for both the fish and prawn trawl fisheries, whereas CPUE displayed greater fluctuation and an increase after 2003/04 in the trap and line fishery.

Figure 8. a). Reported total landed catches of unspecified stingrays and stingarees in each NSW ocean fishery sector between 1997/98 and 2019/20; b). Reported catch-per-unit-effort (CPUE) of unspecified stingrays and stingarees in the NSW ocean fish trawl, prawn trawl and ocean trap and line fishery between 1997/98 and 2008/09. Note there was a change in fishing effort reporting format in 2009/10 which prevented CPUE being determined after that year.

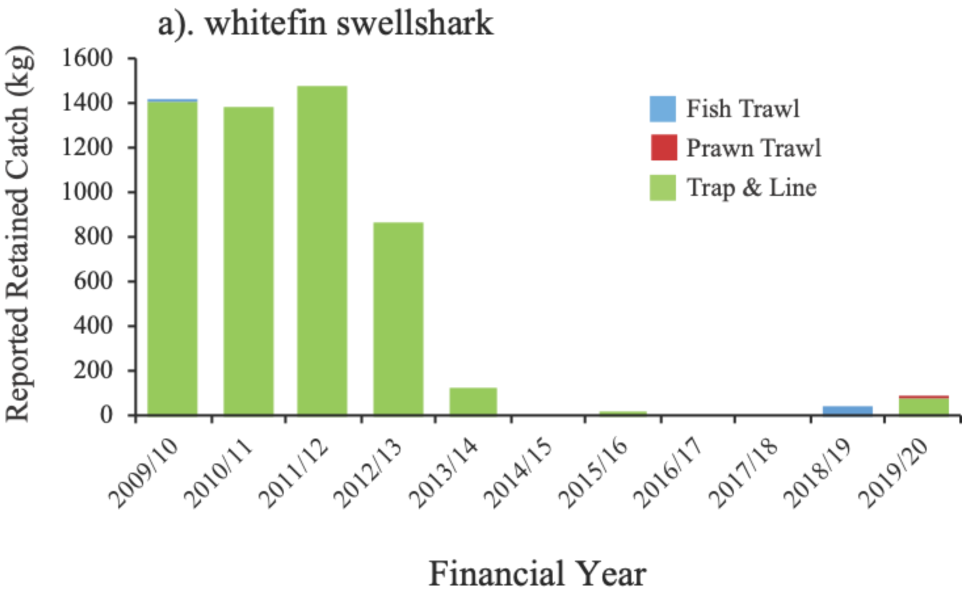




Whitefin swellshark

Whitefin swellshark was not reported as being captured before 2009/10 when a new reporting system was introduced. Since then catches have been low, and most recently only sporadic (Figure 9). Greatest catches occurred between 2009/10 and 2012/13 in the Trap and Line Fishery, predominantly by the methods of setline and dropline (Table 10).

Figure 9. a). Reported total landed catches of whitefin swellshark in each NSW ocean fishery sector between 1997/98 and 2019/20.



5.5 Management options and barriers to implementation

Five key management options were identified: restrict expansion of each fisheries footprint, introduce best-practice catch handling practices, implement and further develop bycatch reduction devices, commercial catch (output) controls, and closing areas to fishing (Table 11). The first two of these should be implemented immediately and applied across all fisheries. The other three will require short- and longer-term development. The identified primary barriers to implementation were lost earning capacity and inadequate species-specific fishery and biological data. These are discussed below.

Option 1. Restrict fisheries footprint and impacts
Above all, there should be no expansion in fishing area or fishing effort in any commonwealth or state managed fisheries that interact with endemic elasmobranchs without a thorough independent investigation and subsequent publication of direct threats to each specific species. For conservation purposes, fishery-induced impacts on endemics need to be reduced, not increased.

Most commonwealth and state managed fisheries are currently restricted, so there should be few management impediments to achieving this option. Effort footprints still require monitoring. While it is relatively straightforward to ensure that the perimeter of fishing effort does not expand, it can be difficult to determine if the total area fished has increased. This occurs by expanding into new habitat or locations as fishing gear and electronics improve. A solution is to map fishing effort by square km grid cell each year and check for increases. This is a relatively straight forward mapping technique already applied to Commonwealth Fisheries. For some State fisheries this would require improvements to the spatial resolution of catch data.

Option 2. Introduction of world's best practice catch handling techniques
The immediate introduction of proven best practice catch handling techniques across all fisheries could help reduce discard mortalities of endemic elasmobranchs (and other species) and have instantaneous conservation benefits. Recent studies have identified that some relatively simple and inexpensive changes to the ways that catches are handled can improve immediate survivorship of released individuals (Zollett and Swimmer 2019). Some examples for sharks and rays include reduced setting and tow times of fishing gears, releasing larger animals in the water and not landing them on-board, avoid dehooking and the use of dehooking devices, and the use of hoppers to sort catches on deck (Poisson et al. 2014, Gallagher et al. 2014, Zollett and Swimmer 2019). In general, catch handling techniques should aim to reduce: (1) immediate mortality, (2) injuries that result in delayed mortality, and (3) physiological stress that can lead to death. Quantification of the effectiveness of such endeavors on improving the survivorship of different species will require novel research.

It is particularly noted that AFMA has developed and promoted (via print and video publications) best catch handling practices of elasmobranchs across fisheries (AFMA 2016, 2018). Development of best handling practices is an iterative process and the introduction of further specific catch handling practices across fisheries will require industry-wide education and promotion (outreach) programs, as well as further research and development and monitoring programs (Poisson et al. 2014).

Whilst such codes are relatively easy to develop at management level, they must be practical and flexible for fishers to adapt to different situations. Impediments to their success primarily fall on impracticalities and fishers failing to comply with identified practices. Notably, there is generally no in-situ enforcement of catch handling practices. Nevertheless, the inclusion of electronic monitoring (e.g. cameras) aboard vessels may improve take up rates and compliance of best handling practices across vessels and fisheries. Recent implementation by AFMA of electronic monitoring aboard vessels operating in the CTS and GAB has seen an increase in reporting of discarded catches in logbooks, suggesting fishers under-reported discards in the past (Emery et al. 2019). Observers could also be used to monitor handling practices aboard different vessels.

Table 11. Possible management options for endemic shark and ray species

Species	Spatial management option	Other options
coastal stingaree	Area closure – inshore, SA	BRDs and handling
Colclough's Shark	Area closure – inshore, QLD	
longnose Skate	Area closures – inshore, TAS+	BRDs and handling
Sydney Skate	Area closures – Continental shelf	BRDs and handling
eastern Angel shark	Area closures – Continental shelf	Additional output controls
greenback Stingaree	Area closures – Continental shelf	BRDs and handling
yellowback Stingaree	Area closures – Continental shelf	BRDs and handling
whitefin swellshark	Area closures – upper slope	handling
greeneye Spurdog	Area closures – upper slope	handling
grey Skate	Area closures – upper slope	handling

BRD = bycatch reduction device

Option 3. Development and implementation of alternate trawl configurations including bycatch reduction devices (BRDs).

The abatement of catches and bycatches of several endemic species in the identified trawl fisheries could be achieved using bycatch reduction devices (BRDs), such as the Nordmore grid and turtle excluder devices (TEDs). Such devices and other trawl modifications have been shown to be successful in reducing sharks, large-sized stingarees, rays and skates, as well as other endangered organisms, from capture in prawn trawl fisheries in Australia (e.g. Northern Territory – Brewer et al. 2006, Griffiths et al. 2006; Western Australia –Wakefield *et al.* 2017; South Australia - Kennelly and Broadhurst 2014; Noell et al. 2018;) and elsewhere throughout the world (e.g. Brazil – *Silva et al.* 2011 ; Guyana – Garstin and Oxenford 2018; Suriname – Willems *et al.* 2016). Nevertheless, bycatch animal size and morphology relative to target and byproduct species together with actual BRD configuration will affect the success and benefits of BRDs in reducing catches and mortalities of each specific species.

BRDs would be most suitable and applicable for direct implementation in the NSW Ocean Trawl Fishery (Inshore and Offshore Prawn) to reduce bycatches (and potential discard mortality) of the greenback and yellowback stingarees, Sydney and longnose skates and the eastern angelshark, and likewise throughout the South Australian Prawn Trawl Fisheries to minimise bycatches of the endangered coastal stingaree. Specific BRDs that reduce turtle capture (TEDS) are used throughout the Queensland offshore prawn trawl fisheries, but their effectiveness in reducing endemic elasmobranchs requires further monitoring (Griffiths *et al*. 2006).

The use of BRDs is mandated in the NSW inshore and offshore prawn trawl fisheries, but the specific use of separator grids is optional. Grids (to reduce cuttlefish and crab bycatches) have been developed for use in the Spencer Gulf Prawn Trawl Fishery in South Australia. Some relatively simple modifications to grids already developed and utilized in prawn trawl fisheries may be required to determine the most beneficial grid design to eliminate or significantly reduce bycatches of each identified endemic, whilst minimising impacts on the quantities and sizes of target and byproduct species. Novel alternative gear designs and anterior-gear modifications in trawls may also facilitate greater reductions in unwanted bycatches of endemics (McHugh et al. 2017).

The development and implementation of grids is more problematic in the identified demersal fish trawl fisheries, notably the Southeast Fish Trawl Fishery (SETF) and the Southern Fish Trawl component of the NSW Ocean Trawl Fishery (current management migration to SESSF), that negatively interact with elasmobranch endemics. Many of the target and byproduct species are similar sized and shaped to some endemics, thus making it difficult to separate such species in-situ. Some endemics (e.g. the longnose skate, eastern angel shark) are themselves valuable byproduct in these fisheries. Nevertheless, appropriate trawl configurations and grid designs could be further developed that reduce catches of endemics in these (and other) fish trawl fisheries with potentially minimal (acceptable) impacts on catches of targeted and other economically valuable byproduct species.

Notably, at the time of compiling this report, the Fisheries Research and Development Corporation had recently granted a project to address sustainability issues in the commonwealth trawl fisheries. *FRDC Project 2019-027: Improving and promoting fish-trawl selectivity in the Southern and Eastern Shark and Scalefish Fishery (SESSF) and Great Australian Bight Trawl Sector (GABTS).* This project is timely for addressing the conservation issues concerning elasmobranch endemics in these commonwealth fisheries. A priority of this project should be endemic elasmobranchs.

The use of BRDs assumes that mortality to endemics (and other excluded organisms) released via such devices would be low. Although this assumption requires novel testing for the endemics in question, mortality should be significantly lower than current practices of hauling organisms from depth, sorting them onboard and subsequently discarding them at the surface. Research elsewhere has identified greater survival of BRD released organisms on the seafloor rather than via normal fishing operations (Broadhurst *et al.* 2006).

Impediments to BRD implementation.
A foremost impediment (from industry and management) to the immediate implementation of BRDs and alternative trawl configurations is the potential and unquantified loss of target and retained byproduct species, and hence economic returns. This would particularly be the case in the fish trawl fisheries. Potential reductions in retained catches and concomitant economic losses would be fishery- and gear-specific.

Because there is no generic BRD that will immediately solve all endemic bycatch problems, further research and testing of alternative gears will be required to determine optimal and economically viable outcomes that have industry and government acceptance.

Another major (and reoccurring) impediment is the lack of available and current observer data that quantifies the levels of bycatches and discarding (and discard mortality levels) of endemic sharks and rays across the identified fisheries. This is particularly the case for the prawn trawl fisheries in New South Wales (current data not made available) and South Australia (no current program).

Option 4. Output controls
A second option would be to implement species-specific catch quotas for those species that are retained, and potentially, bycatch (or discard) quotas and trigger limits for those endemics not

retained. Specifically, discard trigger limits could be used to change fishing practices, such as stop fishing or move-on provisions in areas where discard limits are exceeded. Total allowable catches (TACs) already exist for several quota and non-quota species in the commonwealth managed SESSF, and in some state-based fisheries. TACs do not currently exist for the grey skate or the eastern angelshark even though they are important byproduct in some fisheries at least. TACs could be developed and implemented for such species in the SESSF (where they are predominantly taken) as per the current AFMA process. Catch quotas for these species could also be applied to state fisheries as per the commonwealth-state processes and agreements for gulper sharks (*Centrophorus* spp). Rules and contingencies such as secondary fishery, gear and spatial closures would need to be developed and incorporated into fisheries management plans for implementation once quotas are reached.

Impediments to Output controls
A key impediment to the implementation of further output controls is the direct loss of revenue. This will particularly affect fishing operations with marginal profitability. For these operations, the entire value of the targeted catch may be needed to pay the fixed annual operating cost. Byproduct species such as angelshark and skate can be an economic break point for marginal operations.

Another major impediment concerns the problematic logistics and costs of quota determination, implementation and enforcement. Bycatch or discard quotas and trigger limits would be less preferred by management and industry as they are potentially a more complex logistic option that will most likely require independent on-board observations (human or electronic) of bycatches and discards and rely on real-time monitoring, reporting and management intervention. This would incur additional logistic arrangements and costs to the current TAC process undertaken in the SESSF.

Option 5. Implementation of spatial fishing closures
Adequate and successful protective areas for long-term species conservation need to be based on robust science. It is therefore imperative that appropriate research be funded as a priority to firstly identify suitable areas, and secondly to assess their benefits as part of an adaptive management strategy.

Closed fishing areas are widely advocated as a conservation management tool for elasmobranchs across the globe (Davidson and Dulvy 2018). In Australia, there are networks of commonwealth and State-based marine parks that contain areas closed to fishing that provide some protection to a whole assortment of marine species, including elasmobranchs (Table 12). It is important to note that only a fraction of marine parks are protected zones that exclude all methods of fishing. When protected zones are considered there is little protection for most of the species considered in this report. Exceptions are the eastern angel shark and Colclough's shark that have 12.6% and 24.1% of their range protected. There are also a number of fishery specific smaller-scale spatial and temporal fishing closures allocated for particular species, such as those that encompass critical habitat for the east coast grey nurse shark, and for the gulper shark.

Overall, fishery and species-specific closures are much more effective at conserving endemic sharks and rays than Commonwealth/State Marine Parks that are implemented to protect biodiversity more generally. This is the case even for smaller fishery closures (Table 12). A leading example is the Commonwealth deep water closed fishing areas implemented to protect Harrison's dogfish, southern dogfish and greeneye Spurdog (Upper Slope Dogfish Management

Strategy) (Table 13). Analysis of tagging data from the closed areas shows that these areas are likely to be effective, although recovery will take tens of years (Daley *et al.* 2019). These closures are also likely to provide some protection to the whitefin swellshark and the grey skate. By contrast the Commonwealth Marine parks provide little overlap (0-3.5%; Table 3) or protection to most of the species considered here. Exceptions are the Colclough's shark and the eastern angle shark. Even where the overlap between closures and species range is demonstrated, the direct conservation benefits of these closures on endemics are difficult to quantify without measurements of residency and movement extent. There are some movement data available for whitefin swellshark and greeneye spurdog, but it is yet to be analysed in detail (Williams *et al.* 2012).

The specific creation of additional strategically located and sized fishing closures has the potential to achieve synergies of such closures across species. This is especially the case for the shallow-water stingarees and skates that co-occur across similar habitats (bare substrata < 200m) and are primarily captured across the same demersal trawl fisheries off south-eastern Australia (especially NSW). Specific area closures could also potentially benefit the coastal stingaree population in South Australia. It is noted however, that both New South Wales and South Australia already have inshore fishing (trawling) closures (Appendix B), and in NSW there are several areas prohibited to fishing (including bare substrata) within its network of marine parks. However, it is not documented whether these closed areas currently provide any refuge or direct or indirect conservation benefits to the identified shallow water endemics. Such an assessment is required prior to instigating any additional spatial fishing closures. It is further noted that not all species are harvested, nor interact with fisheries, across their entire distribution.

Impediments to implementation of spatial fishing closures.
The main impediment to implementing spatial closures is understanding the trade-offs between resource use and conservation and limiting lost earnings. Demonstrating the potential benefits of closed areas is difficult. It is an extremely difficult and complex process to determine how much area and habitat is actually required to be closed. A range of data types are needed that are often difficult and expensive to collect. In deeper waters of the continental slope these research costs escalate to hundreds of thousands, or even millions, of dollars.

When considering any management measure, managers are bound to consider the economic objectives of fishery management plans. In most cases fishery-species specific closures are required, and in the absence of any cumulative protective benefits across several species, this could potentially result in many areas being closed to fishing within a region. There is need and an opportunity to implement and develop economic analyses to support more informed and open discussion of the trade-offs between resource use and conservation. Although economics are essentially outside the scope of this report, the type of input needed from economists is briefly described in the following section.

Table 12. Overlap (%) between existing Commonwealth Marine Parks and Protected Zones and geographic range of Australian endemic sharks and rays. Data after Heupel *et al.* (2018).

Species	Australian Marine Park	Protected Zone
Whitefin swellshark	19.8	3.5
Longnose Skate	10.5	1.9
Sydney Skate	9.6	0
Grey Skate	19.1	3
Eastern Angelshark,	**75.3**	12.6
Greenback Stingaree	11.8	1.5
Yellowback Stingaree	7.4	0
Coastal Stingaree	8.4	0
Colclough's Shark,	**79**	24.1
Greeneye Spurdog	19.1	3

Table 13. Existing fishery based spatial management arrangements with potential benefits for endemic Australian sharks and rays.

Species	Commonwealth	New South Wales	Tasmania	South Australia
Whitefin swellshark	USDMS	offshore closure	out of range	out of range
Longnose Skate	none identified	Inshore prawn trawl closures	Shark nursery areas	out of range
Sydney Skate	none identified	offshore closure	out of range	out of range
grey Skate	USDMS	offshore closure	out of range	out of range
eastern Angelshark,	none identified	offshore closure	out of range	out of range
greenback stingaree	none identified	Inshore prawn trawl closures	Shark nursery areas	out of range
yellowback stingaree	none identified	Inshore prawn trawl closures	out of range	out of range
coastal stingaree	SA Closures (Appendix B)	out of range	out of range	Inshore prawn trawl closures
Colclough's Shark,	Australian Marine Park	out of range	out of range	out of range
greeneye spurdog	USDMS	offshore closure	out of range	out of range

USDMS = upper slope dogfish management strategy

5.6 Solutions to barriers

The two key barriers identified were lack of biological and fishery-interaction data and reduced earnings. A lack of data is the greatest barrier to achieving conservation benefits. In fact, these two interact strongly with data collection impeded by the potential for lost earnings. Given this, there is a real need for independent and validated fisheries data to ensure that the science concerning the harvesting and conservation of endemics is sound to inform robust management recommendations. Nevertheless, all research needs to be done in collaboration with fishers and managers to ensure acceptability of results and outcomes. This has been shown to be especially the case with developing BRDs (Broadhurst 2000)

The cost of fisheries and marine data collection is often high (millions of dollars), particularly in deep oceanic waters. Moreover, sharks and rays are difficult to observe or obtain data until they are caught. Fishers observe sharks and rays every day on a cost-effective basis and have the capacity to meet some of the additional data needs, aiding cost-effective research. Fishers can be trained to collect appropriate data in standardised and systematic ways that can be useful in resource management (Lordan *et al*. 2011, Uhlmann et al. 2011). Nevertheless, because a powerful disincentive is the perception that data drives management actions that could impede profit, any fisher-derived data program requires proper quality control and validation protocols (Kraan *et al*. 2013, Ewell *et al*. 2020).

Understanding and limiting lost earnings

It is important to note that management measures most likely to achieve conservation outcomes for most of the species considered here are fishery-species specific small-scale closures and other measures including BRDs. Such measures have the ability to impact fishers' incomes. Thus, it is imperative to identify and quantify such economic impacts as part of research programs and deliberations with industry. Designing effective conservation measures is expensive. Surveys from fishing vessels carrying independent observers are an effective way to collect key data without the cost of running much larger survey vessels.

In most of the fisheries considered here, conservation research is user pays by the fishing Industry. The research time and effort needed to inform spatial protection for just one species is illustrated by the gulper shark (*Centrophorus* species) example in Australia (Daley *et al.* 2019). Obtaining the required baseline data on aging for gulper sharks took an entire MSc thesis. Mapping the distribution of gulper sharks, including remnant populations and breeding areas took 20 sea voyages including specific mapping surveys on chartered vessels from Hobart to Brisbane and across the Great Australian Bight. Developing the electronic tagging methods to understand home range residency and movements took 8 months. A research vessel was needed to map the seafloor in sufficient detail to set listening stations ready for electronic tracking. Collecting the electronic tagging data took 15 months and several sea voyages on chartered vessels. Developing models to integrate data types took a PhD thesis over seven years.

Limiting trade-offs is particularly difficult for spatial management. Fisher 'lore' identifies areas where the seafloor interacts with ocean currents to produce ecological features, or 'hotspots' (Prince 2001). These can be highly productive for both target species and endemic sharks and rays, leading to high trade-offs if these are entirely closed. The locations of these hotspots are generally much better known among fishers than managers. Without up to date independent observer programs and detailed logbook data, these areas and other areas of suitable habitat cannot be located, understood, or managed effectively. Conservation benefit requires part of these productive and actively fished areas to be closed, with inevitable costs to fishers. These costs can be substantial both individually and collectively as an industry. The economic impacts on industry would be specific to each proposed fishing closure.

There is a need to measure and understand economic trade-offs before fishery closures can be implemented in an informed manner. As a minimum the gross value of production of an area that will potentially be closed should be measured. Estimates of lost profit are more time consuming but can be obtained using existing methods. What is particularly challenging is estimating what fraction of commercial species catch quota for target species can be caught in alternative areas, once closures are implemented, and what the corresponding loss of profit will be. There is a need for further input from economists concerning such deliberations.

Baseline life-history and population dynamic data

Fisheries-related biological and ecological research needs be a priority area for endemic sharks and rays as there is a dearth of such information for many species. Whilst in recent years there has been much effort both worldwide and in Australia on improving our ecological and fisheries impact knowledge of elasmobranchs, much of this research has been focused on sharks. A priority area for future biological and fisheries impact assessment research needs to be that of endemic rays (i.e. stingarees, skates, stingrays and devil rays) because they have been less studied than sharks. This is especially required for southeastern Australia, a region that contains many threatened endemic elasmobranch species at threat from fishing (Heupel *et al*. 2018), particularly the skates, rays and stingarees.

Life history underpins assessment of productivity risks and ability to recover. The basic biological (longevity, growth, reproduction) and ecological (habitat associations, movement and migrations, population linkages, trophic interactions) parameters are little studied for many elasmobranchs, and for most endemics examined here, they were either unknown or unreported. Residency and movement data are particularly required for both determining and assessing protective areas.

Moreover, the scope of existing historical studies has often been constricted either spatially (regional) or temporally and thus may not be relevant across broad (distribution-wide) scales. Some data may be outdated and not currently relevant for heavily-impacted threatened species. This may especially be the case in southeastern Australia, a region acknowledged as a climate change hot-spot. The cumulative impacts of fishing and climate change on the demography and life history characteristics of endemics need to be considered in risk assessments for future management and conservation actions of each species.

Ongoing observer data

A refocus of priority in data collection to endemics is required across observer programs. This is especially the case for those species that are primarily discarded, such as the rays and stingarees. Both the numbers and sizes of endemics retained and discarded need to be determined across space and time for all state and commonwealth managed fisheries. Such data need to be obtained at the species level, and not binned into higher taxonomic categories. The assessment of discard mortality of endemics also needs to be a priority research area.

The most recent AFMA observer data for the Great Australian Bight Trawl Fishery (GAB) highlight the problems concerning species-specific identification and reporting of stingarees and skates. Notably, the sandyback stingaree (*U. bucculentus*) was the sole species reported in GAB catches in 2005 and 2006, and the greenback stingaree (*U. viridus*) in 2014 and 2018 (sole species). However, neither species apparently occurs within the GAB. In 2012 and 2014, the majority of stingarees were reported as unidentified. Greater training and resourcing of observers and industry (commercial fishers) in species identification of threatened endemics is required to redress this problem that currently plagues the quality of the data in the AFMA observer and logbook programs.

On-going fisheries observer data (human and electronic) are heavily relied on for assessing and managing many species and fisheries. In particular, for discarded species this is the only fishery-interaction data available. Yet, there is no overall coordination or integration of such programs across fisheries and management jurisdictions; the methodologies, data procedures, standards and reporting of programs are not standardized, nor the data systematically accessible or available. Not all programs are on-going, but are often temporally or spatially constrained as a result of limited costs and resourcing, and the need to prioritise programs across fisheries and over time. Moreover, data collected are also prioritised across species, with endemic bycatch (discard) species not always obtained. There is an urgent need to redress this situation.

There is also a need for agencies to provide wider, more open and timely dissemination of observer data, for greater scrutiny and use by the broader scientific, management and fishing industry communities as well as the general public. This would be achieved by the creation of a national fisheries observer database and reporting system. National databases exist for other marine research streams, such as the Integrated Monitoring Observer System (IMOS). A national fisheries observer database would provide for the deposition, storage and reporting of data across all species and fisheries and allow the appropriate access to data (with caveats that cover commercial and privacy issues and intellectual property etc.) for nominated interest groups.

A national reporting and assessment system of bycatches and discarding, not just retained catches, across fisheries is also required for the holistic assessments and management of species and fisheries across Australia (Kennelly 2020).

6. Conclusions

This project synthesised available biological and fisheries-interaction information of ten endemic elasmobranchs (3 stingaree, 3 ray, 4 shark) in southeastern Australia, a region of high threatened elasmobranch diversity and fisheries importance. Each individual species summary provided a synopsis of the status, distribution, biology and fisheries, and management for conservation. These summaries informed an assessment of fishery impacts, management options, barriers to implementation, and solutions for addressing barriers.

All ten species examined have undergone demonstrable fisheries-driven population declines that have increased their risks of extinction. Analysis of the Commonwealth and New South Wales data sets indicates cumulative effects of fisheries are likely to contribute to declines. Substantial and immediate actions, including further implementation of BRDs, output controls and closed areas will be required to support the recovery of each species. Whilst, endemic elasmobranchs are likely to be afforded some protection by each of these measures, the extent and nature of protection is not clear because of gaps in fishery data and knowledge of each species biology and ecology. Key gaps in baseline knowledge are particularly evident for the skates and stingarees

Key barriers to immediate conservation implementation are measurements of the trade-offs between economic losses, the uncertainty associated with inadequate data, and importantly, the extent that managers treat that uncertainty with precautionary actions. The fisheries-driven extinction risks of endemic elasmobranchs are clear and need to be a priority and strongly addressed by fisheries management agencies.

A commitment to implement management actions based on sound and robust science is required to provide suitable and measured conservation benefits to endemics. All fisheries agencies and resource stakeholders must work together to commit to reveal and analyse all existing and current data and to finance the collection of new and on-going ecological and independently-validated fisheries data that will quantifiably reduce uncertainties in risk and population assessments of endemics.

Lastly, legislation is required that mandates governments and management agencies implement and enforce management measures that allow population recovery and long-term conservation of endemic elasmobranchs.

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Appendix A. Species Synopses

Whitefin swellshark - *Cephaloscyllium albipinnum*

Listed as Critically Endangered on the IUCN Red List. Nominated for protection under the Australian Environment Protection Biodiversity Conservation (EPBC) Act.

- **Distribution and Biology**
  The whitefin swellshark (*C. albipinnum*) is endemic to Australian waters with a geographic distribution around southeastern Australia, from Batemans Bay NSW to Eucla WA including Tasmania, south to at least Maria Island (Last and Stevens, 2009). The bathymetric (seafloor) range of is restricted to the outer continental shelf and upper slope (126–800 m) (Last and Stevens, 2009). Observer data shows peak abundance between the 400 m and 600 m contours within the southeast fishery (Walker and Gason 2007). Electronic tagging data shows peak abundance between 400 m and 700 m in the Great Australian Bight (Williams *et al*. 2012). This narrow bathymetric distribution provides for only a narrow strip of habitat that is only 15 km wide in some parts of southeastern Australia.

  The whitefin swellshark attains a maximum size of approximately 110 cm total length (TL) with a maximum age of 27 years (Bell 2012). Females reach sexual maturity at approximately 98 cm TL (13 years) and males at 70 cm TL (8 years) (Bell 2012).

  Reproduction mode is oviparous producing large egg cases, approximately 10–12 cm long (Bell, 2012). The reproductive cycle is likely to be continuous with egg capsules being produced as frequently as physiological conditions allow, with seasonal peaks in egg bearing females (Bell, 2012). Fecundity is not known. Egg cases have long coiled tendrils that are normally associated with attachment to structures (Ebert *et al.* 2006).

  Diet and tagging data indicate that the whitefin swellshark is an ambush predator (Bell 2012, Williams *et al*. 2012). Habitat varies from sediments with few reef patches to steep terraces on the upper slope (Williams *et al*. 2012).

- **Population Estimates**
  There are no population estimates for the whitefin swellshark.

  Declines in the abundance been observed in waters off southern NSW (Graham *et al.* 2001), Victoria and Tasmania (Walker and Gason 2007).
  Standardised fishery catch rates declined by 75% off Victoria and Tasmania from 1994–2006 (Walker and Gason, 2007). In independent trawl surveys of the South-East trawl grounds, catch rates declined by 30% in some areas between 1976 and 1997 (Graham *et al*. 2001). In 2010, this species was assessed as "extreme high risk" in the cumulative risk assessment for the Southern and Eastern Scalefish and Shark Fishery (Zou *et al.* 2007, 2011). This assessment predicted that the species would be at risk of extinction within three years if fishing mortality was not reduced.

  Survey data indicates localised increases in abundance due to migration following fishery closures as part of the Upper Slope Dogfish Management Strategy. Catch rates for whitefin swellshark in the '60 mile' closure south of Coffin Bay increased from 0.26% of hooks set in 2005 to 2.37% of hooks set in 2008 (Williams *et al*. 2012).

- **Fishery Interactions**
  The main fishery impacts on the whitefin swellshark are from demersal trawling and automatic longline fishing in the Southern and Eastern Scalefish and Shark fishery and the Great Australian Bight Trawl Fishery. This combination of gear types accesses both sediments with few reef patches (trawl) and steep terraces (longline).

  Electronic and conventional tagging data indicate that post capture survivorship of this species can benefit from careful handling (Williams *et al.* 2012). This species can survive longer than most species of sharks in air (Daley *et al.* 2007).

- **Management Arrangements**
  While not intended specifically for the purpose, the Upper Slope Dogfish Management Strategy is the key management arrangement currently mitigating the effects of fishing on the whitefin swellshark. The AFMA has implemented seven targeted spatial closures that cover an approximate area of 4738 km2 between the depths of 200 m and 650 m (AFMA, 2012). The Flinders Research Zone, Port MacDonnell and Murray Closures all fall within the area of occupancy of the whitefin swellshark and provide protection from all forms of fishing in the case of the Flinders and MacDonnell closures and from trawling within the Murray closure (AFMA, 2012). Restricting gillnetting to waters shallower than 183 m also provided substantial benefits for upper-slope species.

- **Catch Mitigation and Conservation/Protection Options**
  Maintaining the USDMS will have substantial benefit for the whitefin swellshark. Careful handling and release practices of the incidentally captured sharks has the potential to increase post capture survivorship.

- **Data Deficiencies and Future Needs**
  Independent survey data that includes demographic information for the whitefin swellshark were collected from at least five voyages completed to map the distribution of gulper sharks (Williams et al. 2012). Examination of these data would inform the location and scale of breeding populations that could be used to refine spatial management arrangements.

  Ten whitefin swellshark were fitted with acoustic transmitters with depth and temperature sensors and another 40 were fitted with conventional tags during surveys by CSIRO (Williams *et al.* 2012). The acoustic data should be analysed to examine daily and seasonal movement patterns associated with breeding and feeding, and temperature limits. A further 40 individuals were fitted with conventional tags during the same surveys and some have been recaptured by fishers. These conventional tags have the potential to give insights to movements into and out of closures and post capture survivorship.

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Longnose Skate - *Dentiraja confusus*

Listed as Critically Endangered on the IUCN Red List. Nominated for protection under the Australian Environment Protection Biodiversity Conservation (EPBC) Act.

- **Distribution and Biology**
  The longnose skate (*Dentiraja confusus*) occurs in waters between 10 and 400 m around southeastern Australia from Sydney (NSW) to Portland (Victoria), and including Tasmania (Last and Stevens 2009). It is most abundant on the continental shelf between 20 and 120 m (Walker and Gason 2007). Its distribution overlaps that of many other skates and rays (Last and Stevens 2009).

  The longnose skate attains a maximum size of approximately 70 cm total length (TL) with a maximum observed age of 12 years (Treloar 2008). Females reach sexual maturity at approximately 53 cm TL (7 years) and males at 48 cm TL (6 years). This equates to a generation length is 9.5 years (Treloar 2008). Preliminary estimates of annual rates of natural mortality were 0.42 for females and 0.38 for males (Treloar 2008; Walker et al. 2008).

  Reproduction of the longnose skate is believed to occur on a continuous cycle with pregnant females, and males carrying spermatocytes, present year-round with the potential for a seasonal peak in winter (Last and Stevens 2009, Treloar 2008). The longnose skate is oviparous, laying egg cases that are 6 to 7 cm long and approximately 5 cm wide (Treloar *et al.* 2006). Incubation period for captive reared eggs ranged from 96 to 180 days and was largely dependent on mean ambient water temperatures (Treloar 2008). Size at birth for captive reared neonates ranged from 9.5 to 10.2 cm TL. The diet of the longnose skate was examined by Treloar *et al.* (2007).

- **Population Estimates**
  There are no population estimates for the longnose skate.

  Declines in the abundance of the longnose skate have been observed in waters off southern NSW (Graham et al. 2001), Victoria and Tasmania (Walker and Gason 2007).

  Fishery-independent scientific trawl surveys conducted on the upper continental slope (220 to 605 m) trawl grounds between Newcastle (NSW) and the NSW/Victorian border on the NSW coast recorded significant declines in the abundance (catch per unit of effort – CPUE) of skate species between 1976-77 and 1996-97 (Graham et al., 2001). Eight skate species were identified in catches and combined for analyses, with the global decline in skate CPUE being 32.7 to 5.5 kg/hour between 1976 and 1996 (Graham *et al*. 2001). According to HSI (2019), the longnose skate (*Dentiraja confusus*) and the Melbourne skate (*Spiniraja whitleyi*) were the most common skates caught in the survey regions adjacent to Ulladulla and Eden, where declines in skate CPUE were most pronounced (92.8 and 84.8%, respectively) (Graham *et al.*, 2001). Overall, skate catches were greatest in the 440 to 495 m depth zone.

  Observer-based data in the Southern and Eastern Shark and Scalefish Fishery (SESSF) identified a 96% decline in standardised catch rates (standardised CPUE 0.689 to 0.029 kg/km) of the longnose skate in the South-East Trawl Fishery component between 1998 and 2004 (Walker and Gason 2007). The longnose skate was not recorded in catches in 2005 and 2006.

It was deemed that the longnose skate population had declined > 80% as part of the nomination for listing the longnose skate as Critically Endangered (under criterion 1) to the Australian Government Department of Environment and Energy in 2019 (Humane Society International 2019).

- **Fishery Interactions**

The longnose skate is taken as bycatch, with the majority of catches retained and utilised as byproduct, in demersal fish trawl fisheries that operate across a large proportion of its range. The longnose skate has been assessed as having a high encounter level and selectivity in otter trawl fishing methods in the SESSF (Walker et al. 2008).

The annual catch of the longnose skate in the SESSF between 2000 and 2006 was estimated to be approximately 24675 (± 2522) kg, with 16582 kg (67%) of this being retained as byproduct (Walker and Gason 2007). The longnose skate is the only skate species caught in great numbers in the SESSF where the majority of the catch is retained. The majority (22715 kg, 92%) of this catch was taken in the SETF otter trawl fishery, with small amounts taken in the SETF Danish seine (725 kg) GHAT longline fishery (595 kg) and GABTF otter trawl fisheries (528 kg) (Walker and Gason 2007). Further, 20832 kg (92%) of the SETF catch was taken in depths < 199 m.

Between 2010 and 2019 a total of 10,100 kg of longnose skate were observed to be caught (85% discarded) in the SETF and 300 kg (all discarded) in the GAB trawl fishery. This equated to 32% of all trawl-caught skates observed in SETF and 40% in GAB catches. Between 2012 and 2019 a total of 950kg (all discarded) of longnose skate were observed in seine catches in the SSESF. The data could not be scaled to estimate fishery wide catches, as the proportion of observed versus total fishing trips was not reported.

In NSW, rates and levels of catch (retained and discarded components) of the longnose skate (and skates in general) in the ocean fish trawl fishery are unknown, despite observer surveys being done between 1993 and 1995 (Liggins 1996) and again between 2014 and 2016 (NSW DPI unpublished study). In the early survey, catch and retain/discard data were not collected as skates were not deemed commercially important. Results from the most recent survey have not been made public, despite requests to the NSW Department of Primary Industries (Fisheries).

Discard survival rates of the longnose skate are not known, but for skates in general they are species- and gear-specific, and potentially low in demersal trawl fisheries (Enever et al. 2009).

- **Management Arrangements**

  There are no specific current or historic fishery or conservation management arrangements for the longnose skate. Management of bycatch species within the SESSF is outlined in the Southern and Eastern Scalefish and Shark Management Plan 2003, the Commonwealth Policy on Fisheries Bycatch 2000. The overall objectives of these plans are to: 1. reduce the discarding of target and non-target species to as close to zero as practically possible, 2. minimise overall bycatch in the fishery over the long-term, 3. avoid interactions with EPBC listed species, and 4. reduce the number of high risks assessed through AFMA's Ecological Risk Assessment process.

  The fisheries in which the species is taken are managed by traditional measures such as limited entry, vessel and gear restrictions, species-specific catch quotas and spatial closures.

  The Commonwealth Marine Park Network provides some protection for the longnose skate; however, the majority of marine park areas are located deeper than the optimal depth range (20 m -120 m) of the species. Heupel *et al*. (2018) reported that 10.5% of the longnose skate's distribution falls within Australian Marine Parks, with 1.9% in waters closed to fishing.

- **Catch Mitigation and Conservation/Protection Options**

  Immediate: No expansion in fishing area or effort in the SESSF (especially in waters < 200m) should be permitted without a thorough investigation of direct threats to the longnose skate population.

  Medium-term: Although not a target species, the longnose skate is a valuable byproduct species in the SETF. Potentially, catches (and mortality levels) of the species could be capped (or even prohibited) via a catch quota. However, the conservation benefits of such a scheme is dependent on the survival rates of discards, which could be problematic and are unmeasured at present. It is likely that trawl-induced mortality is high and probability of survival of discards low.

  Bycatch reduction devices have the potential to limit catches of skate (and other organisms), especially larger sized individuals, providing potential conservation benefits (Broadhurst et al. 2006, Kynoch et al. 2015, Garcés-García et al. 2020). The use of such devices may even increase the survival of unwanted individuals in trawl codends, by reducing the quantities of organisms captured (Enever et al. 2009, 2010). Shortened tow times may also be a mechanism to increase survival rates of discarded organisms (Ellis et al. 2018). Tow durations could be monitored using VMS technology. Specific experiments are required to test the suitability of excluder devices and tow-times on reducing total catches of skates and mortalities of discards.

  If BRDs and improved handling measures do not reduce catches and mortalities of skate, then substantial shallow water (< 200 m depth) protective closed fishing areas may be required to abate the threat of otter trawling on the longnose skate. Potentially, fine-scale analyses of observer data in the SETF and NSW ocean fish trawl fisheries may provide appropriate areas of protection.

- **Data Deficiencies and Future Needs**

  There is limited (and potentially outdated) information concerning (a) the species biology and population demographic parameters, and (b) the magnitude and locations of fishery catches and discarding across appropriate spatial and temporal scales. Distribution-wide information concerning its biology and ecology, along with more recent finer-scale information on fishery interactions is vital for assessing the potential impacts of fishing on populations and for determining long-term solutions for the management and protection of the species.

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Sydney Skate - *Dentiraja australis*

Listed as Vulnerable on the IUCN Red List. It is not listed on the Australian Environment Protection Biodiversity Conservation Act (EPBC).

- **Distribution and Biology**
  The Sydney skate (*Dentiraja australis*) has a limited geographic distribution on the east Australian continental shelf between Moreton Bay (Queensland) and Jervis Bay (NSW) (Last and Stevens 2009). It occurs at depths between 20 and 200 m.

  The Sydney skate is a relatively common and medium sized skate reaching 50 cm total length (TL), with males maturing from 43 to 48 cm TL (Last and Stevens 2009). There are no published studies concerning the biology and demographic characteristics of the Sydney skate. A recent study examined its diet (Reis and Figueira 2020).

- **Population Estimates**
  There are no population estimates for the Sydney skate.

  Fishery-independent scientific trawl surveys conducted on the upper continental slope (220 to 605 m) trawl grounds between Newcastle (NSW) and the NSW/Victorian border on the NSW coast recorded significant declines in the abundance (catch per unit of effort – CPUE) of skate species between 1976-77 and 1996-97 (Graham et al., 2001). Eight skate species were identified in catches and combined for analyses, with the global decline in skate CPUE being 32.7 to 5.5 kg/hour between 1976 and 1996 (Graham et al. 2001). The Sydney skate was the most abundant species taken in the shallowest depth range (220 to 275 m) (Graham et al. 2001).

  No global decline or increase in standardised CPUE of the Sydney skate was evident between 1998 and 2006 based on observer catch data collected in the Southern and Eastern Shark and Scalefish Fishery (SESSF) (Walker and Gason 2007). Standardised CPUE of Sydney skate caught in the SETF increased from 0.476 to 1.509 kg/hr between 1998 and 2003, after which it declined to 0.463 kg/hr in 2006 (Walker and Gason 2007).

- **Fishery Interactions**
  The Sydney skate is a non-utilised bycatch species taken in the SESSF that is solely discarded (Walker and Gason 2007). Between 2000 and 2006 it was estimated that an average of 157239 (± 5683) kg of Sydney skate were caught and discarded annually in the SESSF, of which 99% (156227 ± 5666 kg) were taken in the SETF. Notably, 91% (141724 ± 5149 kg) were captured at depths < 199 m.

  Between 2010 and 2019 a total of 5,970 kg of Sydney skate were observed to be caught (99.7% discarded) in the SETF. This equated to 18% of all skates observed in SETF catches. A total of 200kg of Sydney skate were observed in seine catches between 2012 and 2019. These data could not be scaled to estimate fishery wide catches, as the proportion of observed versus total fishing trips was not reported.

  There is no quantitative information on catches (retained or discarded) of the Sydney skate taken in the NSW ocean fish and prawn trawl fisheries. Observer surveys in these fisheries in the 1990s did not collect data on skates as they were not deemed important (Kennelly et al. 2008, Liggins 2006). The results of recent observer-based studies in these fisheries (fish trawl: 2014 to 2016; prawn trawl: 2017 to 2019) have not been released publicly. They were not made available for this report despite AMCS requests to the NSW Department of Primary Industries (Fisheries).

In NSW, commercial fishers are not required to record catches of skate and thus the species is not recorded in the NSW DPI commercial catch database.

Discard survival rates of the Sydney skate are not known, but for skates in general they are often low in demersal trawl fisheries (Enever et al. 2009).

- **Management Arrangements**
  There are no specific current or historic fishery or conservation management arrangements for the Sydney skate. Management of bycatch species within the SESSF is outlined in the Commonwealth Fisheries Bycatch Policy (2018). The overall objectives of these plans are to: 1. reduce the discarding of target and non-target species to as close to zero as practicably possible, 2. minimise overall bycatch in the fishery over the long-term, 3. avoid interactions with EPBC listed species, and 4. reduce the number of high risks assessed through AFMA's Ecological Risk Assessment process.

  The NSW ocean trawl fisheries in which the species is potentially taken are managed by traditional measures such as limited entry, vessel and gear restrictions, species-specific catch quotas and spatial closures.

  The Commonwealth Marine Park Network provides little protection for the Sydney skate as the majority of marine park areas are located deeper than the species depth range (< 200 m). Heupel *et al*. (2018) reported that although 9.6% of the Sydney skate's distribution falls within Australian Marine Parks, the species does not occur within areas closed to fishing.

- **Catch Mitigation and Conservation/Protection Options**
  Immediate: As an immediate precautionary measure, no expansion in fishing area or effort in the SETF (especially in waters < 200m) or the NSW ocean fish and prawn trawl fisheries should be permitted without a thorough investigation of direct threats to the Sydney skate population.

  Since the Sydney skate is not utilised and 100% discarded in commonwealth trawl fisheries (based on available AFMA observer data), it would be most beneficial to eliminate (or at least minimise) capture of the species in trawl nets. It is not known, however, whether the Sydney skate is harvested by NSW fishers as the species is not recorded in logbooks. Regardless, bycatch reduction devices such as grids inserted in trawls (especially in prawn trawls) have the potential to eliminate or at least minimise catches of skate (and other similar shaped and sized organisms), especially larger sized individuals, providing potential conservation benefits (Broadhurst et al. 2006, Kynoch et al. 2015, Garcés-García et al. 2020). The use of such devices may even increase the survival of unwanted individuals in trawl codends, by reducing the quantities of organisms captured (Enever et al. 2009, 2010). Shortened tow times may also be a mechanism to increase survival rates of discarded organisms (Ellis et al. 2018). Tow durations could be monitored using VMS technology. Specific experiments are required to test the suitability of excluder devices and tow-times on reducing total catches of skates and mortalities of discards.

Medium-term: If discard reduction methods do not reduce catches and mortalities of skate, then substantial shallow water (< 200 m depth) protective closed fishing areas may be required to abate the threat of otter trawling on the Sydney skate. At present there is not enough fishery-interaction information to determine the scale and potential benefits of such closures across the species distribution. Fine-scale analyses of recent observer data in the SESSF may provide appropriate areas of protection. Similar information is required for the NSW ocean fishing sectors, especially the fish and prawn trawl. At present there is no quantitative information on the scale of fishery interactions and the overlap of NSW fishing grounds and the species distribution. Moreover, data on the species habitat preferences, residency and movements would greatly assist designing suitable protective areas.

- **Data Deficiencies and Future Needs**

  There is no information concerning (a) the species biology, population demographic parameters and movements, and (b) the magnitude and locations of ocean fishery catches (prawn and fish trawl) in NSW which overlap with most of the species distribution and where the species may be most prevalent. Obtaining this information is vital for assessing the potential impacts of fishing on populations and for determining long-term solutions for the management and protection of the species across its distribution.

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Grey Skate *Dipturus canutus*

Previously known as *Dipturus* sp. B
Listed as Endangered on the IUCN Red List. Nominated for protections under Australian Environment Protection Biodiversity Conservation (EPBC) Act.

- **Distribution and Biology**

  The grey skate is distributed along the south-eastern Australia from Crowdy Head (New South Wales) to Eucla (Western Australia) (Last and Stevens 2009). It inhabits hard and soft substrates between the 155 and 1050 m bathymetric contours (Last and Stevens 2009, Williams *et al.* 2012). Observer data shows this species is caught most frequently on the seafloor between the 400 m and 600 m Bathymetric contours (Walker and Gason 2007). The habitat includes both trawled sediments with few reef patches and steep terraces with canyons and seamounts (Williams *et al.* 2010, 2012).

  The grey skate attains a maximum size of approximately 93 cm total length (TL) (Treloar 2008). Females reach sexual maturity at approximately 84 cm TL (7 years) and males at 71 cm TL (6 years) (Treloar 2008). Female reproduction mode is oviparous, but fecundity is unknown.

- **Population Estimates**

  There are no population estimates for the grey skate.

  Independent trawl surveys off southern New South Wales suggest declines between 1976 and 1996 but identification issues make it difficult to distinguish between grey skate and closely related species (Graham *et al.* 2001).

  In 2005, longline surveys identified areas of high abundance of grey skate in the Great Australian Bight (Williams *et al.* 2012). This area south of Coffin Bay was subsequently closed to fishing

- **Fishery Interactions**

  The main fishery impacts on the grey skate are from demersal trawling and automatic longline fishing on the upper continental slope in the Southern and Eastern Scalefish and Shark fishery and the Great Australian Bight Trawl Fishery. This combination of gear types accesses both sediments with few reef patches (trawl) and steep terraces (longline). Capture survivorship in trawl and longline fishing is low (Williams *et al.* 2012).

- **Management Arrangements**

  The Upper Slope Dogfish Management Strategy is almost certainly providing some protection for the grey skate. AFMA has implemented seven targeted spatial closures that cover an approximate area of 4738 km^2 between the depths of 200 m and 650 m (AFMA 2012).

- **Catch Mitigation and Conservation/Protection Options**

  Retaining the USDMS will maintain substantial benefit for the grey skate.

- **Data Deficiencies and Future Needs**

  Independent survey data that includes demographic information for the grey skate were collected from at least five voyages completed to map the distribution of gulper sharks

(Williams *et al.* 2012). Examination of these data would inform the location and scale of breeding populations that could be used to refine spatial management arrangements.

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Eastern Angel Shark - *Squatina albipunctata*

Listed as Vulnerable on the IUCN Red List. It is not listed on the Australian Environment Protection Biodiversity Conservation Act (EPBC).

The IUCN Shark Specialist Group determined that the angel shark family (Squatinidae) was the second most threatened of all the world's sharks and rays (Chondrichthyes) (Dulvy et al. 2014).

- **Distribution and Biology**
  The eastern angel shark (*Squatina albipunctata*) is distributed from around Cairns (Queensland) to Lakes Entrance (Victoria). It is a demersal species that inhabits soft substrates and has been recorded between 10 and 500 m depth. It reportedly mostly occurs in deeper depths on the outer continental shelf and upper slope (200 to 400 m) (Last and Stevens 2009, Raoult 2016). Based on research surveys undertaken in the 1970s and 1990s, the species may be most abundant at depths between 250 to 350 m in NSW (Raoult 2016).

  The spatial distribution of the eastern angel shark overlaps with the sympatric Australian angel shark (*Squatina australis*), which primarily occurs along the continental shelf between 10 and 150 m from Newcastle (NSW) south around Tasmania and west to Rottnest Island (Western Australia) (Last and Stevens 2009).

  There is limited biological information concerning the eastern angel shark. It attains at least 130 cm total length (TL), with females attaining larger maximum lengths than males (Raoult 2016). Males mature by 80 cm TL and females at around 107 cm TL, with length at birth being about 27 to 30 cm TL (Last and Stevens 2009, Raoult 2016).

  Although not specifically documented, angel sharks generally bear live offspring with litters mostly < 10 but potentially up to 20 pups, with litter size in some species related to female TL (Bridge et al. 1998; Colonello et al. 2007, Baremore 2010). Gestation period and generation length are also unknown for the species but other angel sharks are known to have reproductive cycles of 3 years and gestation periods of up to 12 months (Colonello *et al.* 2007, Baremore 2010), and generation lengths of up to 23 years (Cailliet et al. 1992). The longevity (maximum age) of the eastern angel shark is also unknown, but other species have attained longevities of 35 years (Cailliet *et al*. 1992).

  Raoult (2016) hypothesised potential movements/migrations of individuals between depths that may be linked with parturition and pupping, which may take place in shallower inshore waters. Smaller (juveniles) may then reside in shallower waters (< 50 m) (nursery grounds) and move to deeper waters with attainment of sexual maturity. Similar scenarios have been suggested for other angel sharks (Colonello et al. 2007).

- **Population Estimates**
  There are no population estimates for the eastern angel shark, however the available data indicate the population is depleted by approximately 60% from initial stock size (Raoult 2016; Raoult et al. 2019). The IUCN Red List states population declines of 90% (typically across three generation lengths) across the southern half of the species distribution (Pogonoski et al. 2016).

Fishery-independent scientific trawl surveys of the upper continental slope (220 to 605 m) trawling grounds between Newcastle (NSW) and the NSW/Victorian border identified a global 96% decline in CPUE of eastern angel shark (*Squatina* species A) from 32.6 to 1.3 kg/hour between 1976 and 1996 (Andrew et al. 1997; Graham et al. 2001). Specific declines in CPUE ranged between 73 and 98% across different spatial zones. Mean catch rates during the first survey (when abundances were high) were also greater between 200 and 400 m compared to between 440 and 605 m. There was also a concomitant (and significant) truncation in the average lengths of captured eastern angel sharks during the two survey periods; the average TL of females and males declined from 88.9 to 77.7 cm TL and 82.8 to 71.5 cm, respectively (Raoult 2016). Graham et al (2001) concluded that the eastern angel shark population in south-eastern Australia was significantly depleted, and the combined impacts of the NSW and Commonwealth fish trawl fisheries have primarily driven this depletion. The area of these observed declines represents about a quarter of the total range of the eastern angel shark (Pogonoski et al. 2016).

Catch information from the NSW Shark Meshing (bather protection) Program (SMP) also showed a decline in catches of angel sharks (previously assumed to be solely the Australian angel shark based on depth delineation – Raoult 2016) from 1950 to 2010 of 92% (Reid et al. 2011, Raoult 2016). However, catches between 1990 and 2010 were stable at around levels of 25% of catches from 1950 to 1970 (Raoult 2016). Recent (since 2010) catches of the eastern angel shark in the SMP have been confirmed, but their numbers and proportions of total angel sharks (combined species) in recent catches have not been reported (Raoult 2016).

The species is assessed as ‘Transitional Depleting’ according to the Australian Shark Report Card and the Status of Australian Fish Stocks (2018). In NSW, the angel shark complex (combined species) is assessed as ‘fully fished’ (2013-2105, NSW DPI 2016).

- **Fishery Interactions**
  Fisheries catch data for the eastern and Australian angel sharks have historically been combined as ‘angel sharks’ (i.e. unspecified species), which is problematic for assessing species-specific fishery impacts. Since 2009, attempts to distinguish and report on each species separately in NSW have been implemented, but this still poses problems due to difficulties in distinguishing each species as they have similar morphologies and colorations and can co-occur in the same catch (Raoult 2016).

  Angel sharks have been incidentally caught in commercial trawl fisheries off south-eastern Australia for around 100 years. Historically, the eastern angel shark has mostly been caught in the southern half of its range (where it is most abundant), primarily as bycatch in the NSW prawn trawl fishery, the NSW fish trawl fishery and the Commonwealth managed southeast trawl component of the Southern and Eastern Scalefish and Shark Fishery (SESSF) (Raoult 2016). Angel sharks taken in these fisheries are marketed and utilised as trawl byproduct. The eastern angel shark has been rarely captured in the northern half of its range where it is taken as bycatch and mostly discarded in low numbers in the Queensland deep water prawn trawl fishery (Queensland East Coast Otter Trawl Fishery – ECOTF) (Rigby *et al.* 2016) and it has not been reported as a bycatch in any other sectors of the ECOTF.

Minimal numbers of angel sharks are taken in the commonwealth gillnet fishery and none in the demersal longline fishery (Raoult 2016). Angel sharks were also not observed in any catches in the NSW commercial demersal longline and dropline fisheries (2007-2009) (Macbeth and Gray 2016). Angel sharks may therefore not be particularly susceptible to the hook and line fisheries in southeastern Australia.

A recent examination of reported angel shark (combined species) catches (AFMA fisheries catch data 1992 to 2012; NSW DPI commercial catch returns 1990 to 2008) across southeastern Australia has been undertaken by Raoult (2016). These data are based on commercial fishers' logbooks and refer to landed catches only. Pertinent results are synthesised below.

Since 2000, retained catches of angel sharks (combined species) combined across the Commonwealth and NSW fisheries have averaged more than 100 tons (processed trunk weight) per year, equating to a monetary value of over AUD $400,000 per annum at point of first sale across the NSW and Victorian fish markets (based on AFMA and NSW collated data reported in Raoult 2016). The species contribution and the number of individuals this harvested tonnage equated to was not determined. Total catches of angel sharks for the combined AFMA and NSW fisheries datasets showed yearly variations with no significant decline in total weight landed across the years analysed (Raoult 2016). However, when analysed separately, the CPUE of angel sharks taken in the commonwealth sector displayed a significant decline across the 20-year time period.

Raoult (2016) reported some trends in analyses of the NSW DPI commercial catch records of reported retained catches (1990 to 2008). Notably, during this period there were no significant declines in the CPUE of angel sharks (combined species), and that the size composition of sampled catches included a 'reasonable proportion' of reproductively mature individuals (but no actual size composition data were presented). Seasonal variations in catch rates were evident, with retained catches being greatest in winter and spring that may be linked to water temperatures and animal movements. Raoult (2016) suggested angel sharks may be sustainably harvested at current rates.

Raoult (2016) acknowledged that whilst angel shark populations in south eastern Australia have been subject to substantial overfishing and are currently depleted, retained catches of eastern angel shark over the past decade appear to have stabilised at substantially lower numbers, and that at current harvest levels appear sustainable. Raoult further suggested that the intensity of fishing across south-eastern Australia may not have reached levels to drive the angel shark populations to dire levels as reported for other angle shark species in other regions of the world (e.g. the North Sea - Bom et al. 2020). Accordingly, Raoult (2016) ascribed the eastern angel shark as currently being 'sustainably overfished'.

Raoult (2016) also noted that the majority of trawling effort in south-eastern Australia prior to the 1990s occurred between 50 and 200 meters (based on Larcombe et al. 2001), suggesting that not all of the total angel shark habitat has or is being fished. Bathymetry, and in some cases legislation, may have limited fishing at depths < 50m, whereas limited productivity and resource levels may have reduced the amount of fishing at depths > 250 meters, where the angel shark is reportedly most prevalent.

Large areas of the eastern angel shark habitat (particularly the northern half) appear to have been historically lightly fished (Raoult 2016). Indeed, Heupel et al. (2018) report that 75.3% of the eastern angel shark's distribution falls with Australian Marine Parks, and 12.6% within closed fishing areas.

Raoult (2016) did not analyse any observer data, and thus potential levels and locations of discarding of (eastern) angel sharks in these (and other) fisheries across southeastern Australia have not been assessed.

There have not been any reports of discarding of angel sharks across the NSW fish and prawn trawl fisheries. An observer survey of the NSW ocean fish trawl fishery estimated that 93 (± 7) tonne of angel shark (combined species) were captured and retained (100%) per annum between 1993 and 1995, of which 60% were captured on the Sydney fishing grounds (Liggins 1996). The results from a recent (2014 to 2016) observer survey in this fishery have not been made public. Angel sharks were recorded as being present in the bycatch in the NSW ocean prawn trawl fishery (1993 to 1996) but their numbers were not quantified nor was it reported whether they were retained or discarded (Kennelly et al. 1998). Again, the results from a recent (2017 to 2019) observer survey in this fishery have not been made public. Despite requests by the AMCS to the NSW Department of Primary Industries (Fisheries) for these data for this report, at the time of writing this report the data were not forthcoming.

Similarly, recent observer data covering the SESSF were not made available for this report despite requests by the AMCS to AFMA.

The survival rates of discarded angel sharks (across fisheries/depths etc) are unknown. Nevertheless, sharks and rays are known to be subject to capture-induced parturition (either premature birth or abortion of pups), and can incur barotrauma-induced mortalities (Adams et al. 2018, Raoult 2016). Such information on levels and survival rates of discards is vital for developing catch mitigation plans for the eastern angel shark.

The capture of eastern angel sharks in recreational fisheries have not been identified, but it is most likely that catches are few and sporadic.

- **Management Arrangements**

  There are no specific current or historic fishery or conservation management arrangements for the eastern angel shark (or angel sharks in general across eastern Australia). No individual or fleet-wide quotas or catch/bycatch restrictions exist for the eastern angel shark across the fisheries in which it is caught. Management of bycatch species within the SESSF is outlined in the Commonwealth Fisheries Bycatch Policy 2018. The overall objectives of these plans are to: 1. reduce the discarding of target and non-target species to as close to zero as practicably possible, 2. minimise overall bycatch in the fishery over the long-term, 3. avoid interactions with EPBC listed species, and 4. reduce the number of high risks assessed through AFMA's Ecological Risk Assessment process.

  Recent management changes (particularly fishing fleet reductions and spatial closures) in the south-east trawl fishery component of the Southern and Eastern Scalefish and Shark Fishery may preclude future increases in effort and catch across the southern distribution and habitat of the eastern angel shark. This could potentially cap catches and provide some protective measures to the species.

The migration of the management of the NSW fish trawl fishery to the Commonwealth as part of the Southern and Eastern Scalefish and Shark Fishery may provide fewer obstacles to developing and implementing catch mitigation and conservation strategies for the eastern angel shark (and other species) in these fisheries.

The eastern angel shark is currently protected to some degree by spatial fishing closures. Heupel et al. (2018) estimated that 12.6% of the species distribution fell within areas closed to fishing, and that 75.3% occurred within waters declared marine parks. This amount of protection from closed fishing areas was the second highest for any elasmobranch examined by Heupel et al. (2018).

- **Catch Mitigation and Conservation/Protection Options**
  Because the current population/harvest assessment for the eastern angel shark is 'sustainable, fully fished, or transitional depleting' – it would be very hard convincing management and industry (and fisheries assessment scientists) that immediate and drastic management initiatives must be implemented to protect the species. It is common for population levels of harvested species to be reduced (even depleted), and for such populations to be length and age truncated, but still be 'sustainably' harvested at low levels. It could also be argued there are many areas where the population appears to be lightly fished (and therefore protected), especially in the north. The species is also potentially afforded some protection via the commonwealth closed fishing areas (Heupel et al. 2018).

Nevertheless, catch mitigation must be a required goal to protect the eastern angel shark from further overfishing and population declines, and to help conserve and potentially rebuild populations. Potential medium- and long-term options include, introductions of catch (and discard) quotas, development of alternative trawl gears and best practice onboard handling of discards, and extending closed fishing areas.

Since the eastern angel shark is a retained byproduct species, it would be most appropriate as a first step to introduce catch quotas for the species across its distribution. These would need to be specific for each fishery and require coordination between commonwealth and state-based fisheries management agencies. An understanding of discard mortality would be required for determining quotas.

The development of appropriate bycatch reduction devices (potentially simpler in prawn than fish trawl fisheries) could also benefit species conservation and be a further option to reduce total mortalities of the eastern angel shark.

At present at least 12.6% of the population area of the species occurs within commonwealth closed fishing areas (Heupel *et al.* 2018) and this area could be higher given state waters areas closed to fishing. Before opting for more closed fishing areas, there is a need to understand the benefits of the current closures on the population, as well as greater detail on the species critical habitat use and finer scale fisheries interaction data.

- **Data Deficiencies and Future Needs**
  Whilst some recent research in NSW has shed some light on the biology of the eastern angel shark, there remains a dearth of knowledge concerning its demographic and ecological characteristics across its distribution, especially in Queensland waters, for management. Specifically, directed studies of the age, growth and longevity determination and reproductive characteristics, including length and age at maturity, gestation period, litter sizes and areas of pupping are required. The potential movements and migrations and population linkages between depths and along coasts should also be investigated.

  A directed and appropriately funded research program is required to quantify the necessary demographic and ecological characteristics of the eastern angel shark across its distributional range for stock assessments and population estimations for the robust management of the species.

  Finer scale information from observer surveys of catch locations (depth, habitat, longitude), and levels and survival of discarding are required.

  Implement a project to develop (1) novel bycatch reduction devices for eastern angel shark in the fish and prawn trawl fisheries, and (2) best in-situ handling and discarding practices to maximize survival of discarded angel sharks across depths, fishing gears and fisheries. On-water solutions to catch mitigation via bycatch reduction devices development for eastern angel sharks. Determine survival rates and best practices to maximise the survival of discarded catch across depths and fishing gears.

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Greenback Stingaree - *Urolophus viridis*

Listed as Vulnerable on the IUCN Red List. It is not listed on the Australian Environment Protection Biodiversity Conservation Act (EPBC).

- **Distribution and Biology**
  The greenback stingaree (*Urolophus viridis*) is distributed along the south-eastern continental shelf in depths between 20 and 200 m (but mostly from 80 to 180 m) from around Stradbroke Island (Queensland) to Portland (Victoria), including Tasmania (Last and Stevens 2009). It's distribution overlaps in part with the yellowback stingaree, which occurs at similar depths between Stradbroke Island (Queensland) to Green Cape (NSW) (Last and Stevens 2009).

  The greenback stingaree reaches a maximum total length (TL) of 51 cm (female) and 42 cm (male) and it has the lowest productivity of any stingaree in southeast Australia (Trinnie et al. 2015). This makes the species particularly vulnerable to the impacts of fishing. Aspects of its reproductive biology in the southern area of its distribution (Lakes Entrance, Victoria and Western Bass Strait) have been studied by Trinnie et al. (2015). Female length at maturity and maternity varied regionally, but occurred between 26 and 31 cm (maturity) and 23 and 34 cm (maternity), with males attaining maturity at 27 to 28 cm TL. Females mostly produce only 1 or 2 pups each year, the number dependent on maternal TL, with mean size at birth being 16 to 18 cm TL dependent on region. Reproductive period is non-seasonal.

  The regional differences in reproductive biology of the greenback stingaree could potentially be an effect of fishing (Trinnie et al. 2015); the observed smaller maximum TLs and smaller length-at-maturity and -maternity observed at Lakes Entrance compared to the Western Bass Strait potentially being the result of greater fishing effort and mortalities on the species at Lakes Entrance (Trinnie et al. 2015). The reproductive biology in the northern region of its distribution (NSW) where the species is most abundant, and has had intense historic fishing, has not been studied.

  There are no published studies concerning age and growth, longevity and population demographic characteristics of the greenback stingaree. Stingarees can attain 10 to 15 years of age (White et al. 2001, 2002).

- **Population Estimates**
  There are no population estimates for the greenback stingaree.

  It is proposed that the greenback stingaree population has been depleted by at least 30% since the 1980s as a result of trawling activity across much of its range (Kyne et al. 2019a). The results of fishery-independent scientific trawl surveys identified localised declines of 66% (between 45 and to 91% depending on the spatial zone) in the abundance of urolophids between 1976 and 1996 on the upper continental slope (220 to 605 m) trawl grounds between Newcastle (NSW) and the NSW/Victorian border (Graham et al. 2001). The global decline in CPUE was from 19.5 to 6.7 kg/hour between 1976 and 1996 (Graham et al. 2001). Over 70% of the total stingaree catch during both survey periods was taken off Sydney. The greenback stingaree was a major component of the total urolophid catch across all grounds and both surveys.

Although these declines were documented partially prior to the last three generation period (30 years), fishing pressure has been ongoing in the region and there is no reason to suspect that declines have ceased since the 1996-97 surveys (Kyne et al. 2019a).

Declines in greenback stingaree catches of 33% were observed in the Southern and Eastern Shark and Scale-fish Fishery (SESSF) between 2000 and 2006, but this may have been the result of shifting fishing effort (Walker and Gason 2007).

Despite these declines, Kyne et al. (2019a) noted that some refuge may be provided to the species where fishing pressure is lower, notably northern NSW and the Bass Strait. Heupel et al. (2018) reported that 11.8% of the greenback stingaree distribution falls with Australian Marine Parks, and 1.5% within closed fishing areas.

- **Fishery Interactions**
  The greenback stingaree is a bycatch species that is not utilised and thus discarded at sea. It has been recorded as bycatch in observer programs in the Commonwealth managed Southern and Eastern Shark and Scale-fish Fishery (SESSF), and observed in catches in the NSW ocean fish trawl fishery, NSW ocean prawn trawl fishery, and potentially the NSW ocean trap and line fishery, and the Queensland East Coast Trawl fishery.

  Because the greenback stingaree is not retained, it does not feature in the Australian Fisheries Management Authority (AFMA) or NSW catch records that only collect and report data on landed catches.

  Walker and Gason (2007) estimated that 454,679 (± 31,128) kg of greenback stingaree were caught and discarded per annum between 2000 and 2006 in the SESSF. This was the greatest quantity for any ray species and accounted for 17% of all rays captured (and discarded) in the fishery. The majority of these catches (448,537 kg; 98.6% of total) occurred in the SETF otter fish trawl component with 82.8% of these catches being taken in depths < 200m at an average rate of 24.22 (±1.58) kg caught per tow (Walker and Gason 2007). At this depth, there was an observed decline in catches of 0.337 post 2000. No greenback stingarees were observed in the SESSF demersal dropline and longline fisheries or the scale-fish gillnet fishery. More recent catch data for the SESSF were not available from AFMA at the time of report preparation.

  Between 2010 and 2019 a total of 18575 kg of greenback stingaree were observed to be caught (and 100% discarded) in the SETF and 10,930 kg in the GAB. For the SETF, this represented 56% of all trawl-observed stingarees captured across years. Between 2012 and 2019 a total of 1665 kg of greenback stingaree were observed to be caught (and 100% discarded) in seine component of the SETF and 7,711 kg in the GAB. This represented 27% and 46% of all seine-observed urolophids captured across years in the SETF and GAB fisheries. The data could not be scaled to estimate fishery wide catches, as the proportion of observed versus total fishing trips was not reported. The quantity of greenback stingaree increased in observed trawl catches between 2013 and 2019, and was especially high in 2019 (6000+ kg). The stingaree catch data for the GAB in particular demonstrates the problems observers have with identifying and reporting urolophids, as the greenback stingaree was reported in the GAB in 2014 and 2018 (sole species) but the species does not occur in the GAB.

In NSW, rates and levels of discarding of the greenback stingaree (and urolophids in general) are unknown, despite historic observer surveys having occurred in the ocean fish trawl (1993 to 1995; Liggins 1996) and prawn trawl (1990 to 1992, Kennelly et al. 1998) fisheries. Catch and discard data were not collected for stingarees as both studies were focused solely on species of commercial and recreational importance. The data from more recent observer surveys in the NSW ocean fish trawl (2014 to 2016) and ocean prawn trawl (2017 to 2019) fisheries have not been released publicly, nor were they forthcoming following requests by the Australian Marine Conservation Society to NSW Department of Primary Industries (Fisheries) for this report.

Only a couple of stingarees (unidentified species) were observed (2007 to 2009) in the NSW commercial line (dropline and longline) fisheries (Macbeth et al. 2009, Macbeth and Gray 2016).

Greenback stingaree catch rates of up to 1.3 individuals per hour of trawling were observed during experimental comparisons of different prawn trawl configurations on eastern king prawn trawl grounds off northern NSW (Macbeth et al. 2018), which provide some estimates of their potential catch rates in the NSW ocean prawn trawl fishery.

The occurrence of the greenback stingaree in the Queensland East Coast Trawl fishery has not been quantified (Courtney et al. 2007)

Discard survival rates of the greenback stingaree are not known, but could potentially be low based on the findings for other trawl caught stingaree species (Heard et al. 2014, Campbell et al. 2018). Stingarees are known to abort their pups upon capture and handling (Adams et al. 2018), and are particularly susceptible to crowding and the effects of within net and onboard handling (Heard et al. 2014, Campbell et al. 2018), all which can impact post-release survival rates and population reproductive output.

In conclusion, historical catch and discarding levels in the SESSF are relatively well documented and monitored via the current observer programs, but there is a lack of similar information for the NSW fish and prawn trawl fisheries that operate over a significant portion of the species distribution. Discard survival rates for the species are lacking.

- **Management Arrangements**

  There are no specific current or historic fishery or conservation management arrangements for the greenback stingaree (or stingarees in general) across eastern Australia. Since all caught individuals are typically discarded, there are no individual or fleet-wide species catch/bycatch quotas or restrictions. Management of bycatch species within the SESSF is outlined in the Commonwealth Fisheries Bycatch Policy 2018. The overall objectives of these plans are to: 1. reduce the discarding of target and non-target species to as close to zero as practicably possible, 2. minimise overall bycatch in the fishery over the long-term, 3. avoid interactions with EPBC listed species, and 4. reduce the number of high risks assessed through AFMA’s Ecological Risk Assessment process.

  There are no specific spatial fishing closures for the greenback stingaree. Heupel et al. (2018) reported that 11.8% of the greenback stingaree distribution falls with Australian

Marine Parks, but only 1.5% within closed fishing areas. The species may occur in some state-based inshore marine parks and other general spatial fishing closure areas (e.g. inshore closures in NSW ocean prawn trawl fishery) that may provide some refuge from fisheries capture.

- **Catch Mitigation and Conservation/Protection Options**
  Immediate: The best and potentially most parsimonious on-water solution to overcome the potential high mortality levels of trawl-caught greenback stingarees (and other stingarees) is to eliminate as many stingarees as possible from actual capture (i.e. stop them from entering trawl nets, or facilitate their escape upon entry, directly on the sea floor). This could be potentially achieved using relatively simple separator grids, such as the Nordmore grid and turtle excluder devices (TEDS), that are used in prawn trawl fisheries throughout the world (Broadhurst et al. 2002, Brewer et al. 2006, Kuhnert et al. 2011).

  Specifically, grids (with vertical bars) physically exclude organisms broader than the bar spaces from entering the codend of a net by directing the larger organisms either upwards or downwards and out via an escape chute (Broadhurst 2000). Such devices have been successful in eliminating stingarees and similar shaped and sized rays (and other elasmobranchs and endangered organisms) from capture in prawn trawl fisheries (Brewer et al. 2011, Kennelly and Broadhurst 2014, Wakefield et al. 2017). In the specific fisheries here, some simple development would be required to determine the most beneficial bar spacing to eliminate stingarees, but still retain target and by-product species.

  This strategy would still allow fishing to take place across all current grounds. The major impediment from industry (and hence management) is that there would be some loss of currently retained product (target and by-product species) and hence economic losses, particularly in the fish trawl fisheries. Potential losses and costs would be fishery and gear specific that will require further research and development and industry input. This option also assumes that mortality to stingarees (and other excluded organisms) would be low. This latter assumption would require novel testing, but mortality should be significantly lower than current practices of hauling organisms from depth, sorting them onboard and subsequently discarding them at the surface.

  Medium-term: If BRDs prove to be unsuccessful in mitigating catches, an alternative, and less conducive, solution is to implement entire fishing closures or specific wide-spread fishing closures throughout the species distribution (in addition to any current marine park or fishing closures). This option would be problematic for industry and management and would require much public consultation and potential economic losses to industry. Such measures would require more precise and finer-scale data on catch and discarding rates and levels of stingarees (and potential hot-spots) across all fisheries than presently available.

  A third and more complex logistic option would be to implement species-specific bycatch (or discard) quotas, that once attained, the fishery is closed. This would be logistically difficult to manage and potentially costly. It would require on-board observations (human or electronic) of catch and discards, and rely on real-time monitoring and reporting and management intervention. This option would not be preferred by industry or management.

- **Data Deficiencies and Future Needs**

  Biology. Whilst some recent research has shed some light on the reproductive biology of the species, a directed and appropriately funded program is required to quantify the necessary demographic characteristics of the species across its distributional range for stock assessments and population estimations. Specifically, age, growth and longevity determination, as well as potential movements and migrations between depths and along coast require investigation. This research is warranted for all urolophid species and a general research program could cover this.

  Fishery. The quantification of catches and discards is currently limited to the SESSF, but ongoing identification problems of stingarees impact the quality and usefulness of the data. The observer programs in NSW need to include all species (as opposed to just commercial/recreational important species) in their data collection and reporting systems. Greater knowledge of survivorship of discarded urolpohids is required.

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Yellowback Stingaree - *Urolophus sufflavus*

Listed as Vulnerable on the IUCN Red List. It is not listed on the Australian Environment Protection Biodiversity Conservation Act (EPBC).

- **Distribution and Biology**

  The yellowback stingaree (*Urolophus sufflavus*) is distributed along the south-eastern continental shelf from around Stradbroke Island (Queensland) to Green Cape (NSW) (Last and Stevens 2009). It inhabits soft substrata between 40 and 300m, but mostly between 100 and 160 m. It's entire distribution overlaps with the greenback stingaree.

  The yellowback stingaree reaches a maximum total length (TL) of at least 43 cm, with males attaining sexual maturity by 23 cm TL (Last and Stevens 2009). There are no published studies concerning the biology and demographic characteristics of the yellowback stingaree.

  Stingarees generally have low productivity, producing only 1 to 3 pups either annually or biannually (Trinnie et al. 2015). Some species can attain longevities of 15 years (White et al. 2001). Their life-history characteristic make them particularly susceptible to the impacts of fishing (Dulvy et al. 2014)

- **Population Estimates**

  There are no population estimates for the yellowback stingaree.

  It is proposed that the yellowback stingaree population has been depleted by at least 30% since the 1980s as a result of trawling activity across much of its range (Kyne et al. 2019b). This was primarily driven by the results of fishery-independent scientific trawl surveys that identified localised declines of 66% (between 45 and to 91% depending on the spatial zone) in the abundance of urolophids between 1976-77 and 1996-97 on the upper continental slope (220 to 605 m) trawl grounds between Newcastle (NSW) and the NSW/Victorian border (Graham et al. 2001). The global decline in CPUE was from 19.5 to 6.7 kg/hour between 1976 and 1996 (Graham et al. 2001). Over 70% of the total stingaree catch during both survey periods was taken off Sydney. The yellowback stingaree was one of four urolophid species taken in these surveys, but occurred in lower quantities than the greenback and sandyback stingarees. Although these declines were documented partially prior to the last three generation period (30 years), fishing pressure has been ongoing in the region and there is no reason to suspect that declines have ceased since the 1996-97 surveys (Kyne et al. 2019b).

- **Fishery Interactions**

  The yellowback stingaree is a bycatch species that is not utilised and thus discarded at sea. It has been recorded as bycatch in the Commonwealth managed Southern and Eastern Shark and Scale-fish Fishery (SESSF), and observed in the NSW ocean fish trawl fishery, NSW ocean prawn trawl fishery, and the Queensland East Coast Trawl fishery.

  Because the yellowback stingaree is not retained, it does not feature in the Australian Fisheries Management Authority (AFMA) or NSW catch records that only collect and report data on landed catches.

Walker and Gason (2007) estimated that 4,776 (± 1,134) kg of yellowback stingaree were caught and discarded per annum between 2000 and 2006 in the SESSF. The majority of these catches (4014 kg; 84% of total) were taken by the method of Danish seining in waters < 200m in the SETF component (Walker and Gason 2007). No yellowback stingarees were observed in the SESSF demersal dropline and longline fisheries or the scale-fish gillnet fishery.

Between 2010 and 2019 a total of 2,310 kg of yellowback stingaree were observed to be caught (97% discarded) in the trawl and 740 kg (81% discarded) in the seine component of the SETF. This represented 7% and 12% of all observed urolophids captured in the trawl and seine sectors, respectively. The data could not be scaled to estimate fishery wide catches, as the proportion of observed versus total fishing trips was not reported.

In NSW, rates and levels of discarding of the yellowback stingaree (and urolophids in general) are unknown, despite historic observer surveys having occurred in the ocean fish trawl (1993 to 1995; Liggins 1996) and prawn trawl (1990 to 1992, Kennelly 1993, Kennelly et al. 1998) fisheries. Catch and discard data were not collected for stingarees as both studies were focused solely on species of commercial and recreational importance. The data from more recent observer surveys in the NSW ocean fish trawl (2014 to 2016) and ocean prawn trawl (2017 to 2019) fisheries have not been released publicly, nor were they forthcoming following requests by the Australian Marine Conservation Society to NSW Department of Primary Industries (Fisheries) for this report.

Only a couple of stingarees (unidentified species) were observed (2007 to 2009) in the NSW commercial line (dropline and longline) fisheries (Macbeth et al. 2009, Macbeth and Gray 2015).

The species is rarely taken in the Queensland East Coast Prawn Trawl Fishery (Courtney et al. 2007, Kyne et al. 2016 JFB).

Discard survival rates of the yellowback stingaree are not known, but could potentially be low based on the findings for other trawl caught stingaree species (Campbell et al. 2018). Stingarees are known to abort their pups upon capture and handling (Adams et al. 2018), and are particularly susceptible to crowding and the effects of within net and onboard handling (Campbell et al. 2018), all which can impact post-release survival rates and population reproductive output.

- **Management Arrangements**
  There are no specific current or historic fishery or conservation management arrangements for the yellowback stingaree (or stingarees in general) across eastern Australia. Since all caught individuals are typically discarded, there are no individual or fleet-wide species catch/bycatch quotas or restrictions. Management of bycatch species within the SESSF is outlined in the Commonwealth Fisheries Bycatch Policy 2018. The overall objectives of these plans are to: 1. reduce the discarding of target and non-target species to as close to zero as practicably possible, 2. minimise overall bycatch in the fishery over the long-term, 3. avoid interactions with EPBC listed species, and 4. reduce the number of high risks assessed through AFMA’s Ecological Risk Assessment process.

Heupel et al. (2018) report 7.4% of its distribution falls with Australian Marine Parks, but none within areas closed to fishing. The species may be afforded some protection in NSW based marine parks and the NSW ocean prawn trawl inshore fishing closures.

- **Catch Mitigation and Conservation/Protection Options**
  Immediate: The most strategic solution to overcome the potential high mortality levels of trawl-caught yellowback stingarees (and other stingarees) is to eliminate as many stingarees as possible from actual capture (i.e. stop them from entering trawl nets, or facilitate their escape upon entry, directly on the sea floor). This could be potentially achieved using relatively simple separator grids, such as the Nordmore grid and turtle excluder devices (TEDS), that are used in prawn trawl fisheries throughout the world (Broadhurst et al. 2002, Brewer et al. 2006, Kuhnert et al. 2011).

  Specifically, grids (with vertical bars) physically exclude organisms broader than the bar spaces from entering the codend of a net by directing the larger organisms either upwards or downwards and out via an escape chute (Broadhurst 2000). Such devices have been successful in eliminating stingarees and similar shaped and sized rays (and other elasmobranchs and endangered organisms) from capture in prawn trawl fisheries (Brewer et al. 2011, Kennelly and Broadhurst 2014, Wakefield et al. 2017). In the specific fisheries here, experimental development would be required to determine the most beneficial bar spacing to eliminate stingarees, but still retain target and by-product species. In the local situation, the development of appropriate grids would be more problematic in fish trawl than prawn trawl fisheries.

  This strategy would still allow fishing to take place across current grounds. The major impediment from industry (and hence management) is that there would be some loss of currently retained product (target and by-product species) and hence economic losses, particularly in the fish trawl fisheries. Potential losses and costs would be fishery and gear specific that will require further research and development and industry input. This option also assumes that mortality to stingarees would be low. This latter assumption would require novel testing, but mortality should be significantly lower than current practices of hauling organisms from depth, sorting them onboard and subsequently discarding them at the surface.

  Medium-term: Given the low magnitude of fishery interaction in the SETF, but noting no data are available for NSW fisheries, the proposition of specific closed fishing areas to protect yellowback stingaree would be problematic. Such measures would require more precise and finer-scale data on discarding rates and mortalities of yellowback stingarees across all fisheries than presently available. Despite this, no expansion in SETF and NSW ocean fish and prawn trawl fisheries should occur until a risk assessment of their impacts on stingaree (and other endemics) populations is undertaken.

- **Data Deficiencies and Future Needs**
  There is no information concerning the species biology, population demographic parameters and movements. There is also a dearth of information on the magnitude and locations of fishery catches and discarding especially in NSW. Such information is vital for assessing the potential impacts of fishing on populations and for determining long-term solutions for the management and protection of the species. The commonwealth

observer data are limited due to ongoing identification problems of stingarees that impact the quality and usefulness of the data. Greater accuracies in species identification and subsequent reporting of stingarees are required.

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Coastal Stingaree - *Urolophus orarius*

Listed as Endangered on the IUCN Red List. This species was previously assessed, but it is not listed on the Australian Environment Protection Biodiversity Conservation Act (EPBC).

- **Distribution and Biology**
  The coastal stingaree (*Urolophus orarius*) has a limited geographic distribution within the eastern Great Australian Bight including the Gulfs, occurring at depths < 50 m between Ceduna and Beachport (South Australia) (Last and Stevens 2009). This corresponds to an area of approximately 40,000 km^2 (Kyne et al. 2019c).

  The coastal stingaree is a small ray that attains a maximum length of 31 cm total length (TL), with males reaching maturity by 28 cm TL (Last and Stevens 2009). There are no published studies concerning the biology and demographic characteristics of the coastal stingaree.

  In general, stingarees are viviparous, have a gestation period of about 3 months and produce litters between 1 and 4 individuals either annually or biannually (Trinnie et al. 2014, White et al. 2001). Based on the known biology of other stingarees, it is assumed that the coastal stingaree has low productivity.

- **Population Estimates**
  There are no population estimates for the coastal stingaree.

  The coastal stingaree is considered sparsely-distributed with low abundance. This is based on its low occurrences in research trawl surveys done in the Spencer Gulf in 2007 and 2013, in which it was only captured in areas of low fishing intensity (Burnell et al. 2015). It is assumed that the species has undergone a population reduction of > 50% over the last three generations (27 years) (Kyne et al. 2019c).

- **Fishery Interactions**
  The coastal stingaree is a non-utilised and discarded bycatch species taken in the South Australian Prawn Trawl Fisheries; the Spencer Gulf Prawn Fishery (30 licences), Gulf St. Vincent Prawn Fishery (10 licences), and West Coast Prawn Fishery (3 licences) (Kyne et al. 2019c). These fisheries, which commenced in the 1960s, operate over about half of the known range of the coastal stingaree. There are no published estimates of the quantities of coastal stingaree taken (and discarded) across these fisheries. The species has not been reported in observed catches in the commonwealth trawl and seine fishery in the Great Australian Bight.

  Discard survival rates of the coastal stingaree are not known, but could potentially be low based on the findings for other trawl caught stingaree species (Heard et al. 2014, Campbell et al. 2018). Stingarees are known to abort their pups upon capture and handling (Adams et al. 2018), and are particularly susceptible to crowding and the effects of within net and onboard handling (Heard et al. 2014, Campbell et al. 2018), all which can impact post-release survival rates and population reproductive output.

- **Management Arrangements**
  There are no specific current or historic fishery or conservation management arrangements for the coastal stingaree in South Australia. South Australian prawn trawl fisheries are managed by traditional measures such as limited entry, vessel and gear restrictions as well as seasonal closures and rotation of trawling grounds. The species probably occurs in some areas within the inshore prawn trawling closures (< 10 m depth), the state's inshore marine park network and other marine parks, that may provide some refuge from commercial prawn trawling.

  Heupel et al. (2018) reported that 8.4% of the coastal stingaree's distribution falls with Australian Marine Parks, but none within closed fishing areas.

- **Catch Mitigation and Conservation/Protection Options**
  Immediate: Among other management tools, bycatch reduction devices (Nordmore grids) have recently been designed for use in the Spencer Gulf Prawn Trawl Fishery to reduce the capture of the endangered giant cuttlefish (Kennelly and Broadhurst 2014). These grids should also reduce (and potentially eliminate larger sized individuals) catches of the coastal stingaree (Broadhurst personal communications). Such grids should be mandated for immediate use in all prawn trawl vessels (total of 43 licences ??) that operate in the Great Australian Bight to minimize the capture and potential catch- and discard-induced mortalities of the coastal stingaree across its distribution. This is in addition to the current use of onboard hoppers and the industry separator panels to minimize crab catches. This should be done as a priority conservation measure even though there is little data concerning the magnitude of the stingaree catch (i.e. scale of problem) across the prawn trawl fisheries.

  No expansion in fishing area or effort in the prawn trawl fisheries should be permitted, even if new fishing grounds may be economically productive, without an exhaustive investigation of the coastal stingaree population in the area and appropriate protective measures mandated. At present significant areas of the coastal stingarees distribution are trawl free, thus potentially providing a refuge to the impacts of fishing. The benefits of these closed areas to the coastal stingaree need to be quantified

  Long-term: Obtain fine-scale catch and discard information via an independent observer program across the prawn trawl fisheries to determine the scale and locations of coastal stingaree fishery interactions. Undertake appropriate research to assess critical life-history biological and ecological (reproduction, productivity, age, longevity, habitat requirements, movements) information for the species for more informed management measures.

- **Data Deficiencies and Future Needs**

  There is no information concerning (a) the species biology, population demographic parameters and movements, and (b) the magnitude and locations of fishery catches and discarding. Such information is vital for assessing the potential impacts of fishing on populations and for determining long-term solutions for the management and protection of the species.

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Colclough's Shark, *Brachaelurus colcloughi*

Listed as Endangered on the IUCN Red List. Nominated for assessment in 2021 under the Australian Environment Protection Biodiversity Conservation (EPBC) Act.

- **Distribution and Biology**
  This rare species is restricted to waters off southern New South Wales and southern Queensland; It occurs primarily shoreward of the 100 m bathymetric contour (Last and Stevens 2009, IUCN 2020).

  Maximum size is 85 cm total length with males maturing at 61 cm and females at 55 cm; Size at birth is around 18 cm (Kyne et al. 2011)

  Age and growth are not known.

  The species shelters in rocky reefs during the day and forages on surrounding sediments during the night (Kyne *et al.* 2011).

- **Population Estimates**
  < 10,000 mature individuals (IUCN 2020)

- **Fishery Interactions**
  Trawl, gillnet and tunnel net fisheries.

- **Management Arrangements**
  No known fishery management arrangements specifically for this species, but the species does occur in some marine parks (e.g. Great Sandy Marine Park and Great Barrier Reef Marine Park) that potentially offer some (unquantified) protection from fishing.

- **Catch Mitigation and Conservation/Protection Options**
  A total of 79% of this species range is within Australian Marine Parks, including 24.1% inside protected zone. The most straightforward approach to reducing the conservation risk to this species would be to modify zoning of part of the relevant Australian Marine Parks to include more of the species range within the protected zone. The Moreton Bay Marine Park is the most important conservation instrument for this species. In New South Wales the Cape Byron Marine Park is important refuge.

- **Data Deficiencies and Future Needs**
  More details on the distribution and life history of this species would help inform the suitable location and potential value of increase protected zone to the conservation of this species.

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Greeneye Spurdog - *Squalus chloroculus*

Listed as Endangered on the IUCN Red List. Nominated for assessment in 2021 under the Australian Environment Protection Biodiversity Conservation (EPBC) Act.

- **Distribution and Biology**
  The Greeneye Spurdog distributed along the south-eastern Australia from Jervis bay (Queensland) to Eucla (Western Australia) (Last and Stevens 2009). It inhabits hard and soft substrates of the upper slope between the 200 and 1400 m bathymetric contours (Last and Stevens 2009, Williams *et al.* 2012). Electronic tagging found most individuals mainly inhabit the narrow upper continental slope between the 200 and 600 m contours (Williams *et al.* 2012). Conventional tag recaptures from 11 individuals showed three individuals moved at least 550 km from their release point in 800 days. Most of the remainder moved less than 275 km from their release points in 950 days.

  The Greeneye Spurdog attains a maximum size of approximately 99 cm total length (TL) with a maximum age of 26 years (Rochowski *et al.* 2015.). Females reach sexual maturity at approximately 80 cm TL (9–12years) and males at 63 cm TL (16 years) (Rochowski *et al.* 2015). Female reproduction mode is viviparous, giving birth to 4–15 pups every three years during the breeding season from September to December (Rochowski *et al.* 2015). Diet consists of a range of benthic and demersal fishes and invertebrates (Bracini *et al.* 2005).

- **Population Estimates**
  There are no population estimates for the greeneye gpurdog.

  Independent trawl surveys off southern New South Wales suggest declines between 1976 and 1996 but identification issues make it difficult to disdinguish between greeneye spurdog and closely related species (Graham *et al.* 2001). There is compelling evidence of declines in abundance off Victoria and South Australia from standardized observer catch and effort data from the Southeast Trawl Sector of the Southern and Eastern Scalefish and Shark Fishery. These data show a 95% decline in catch rates from 1996 to 2004 (Walker and Gason 2007).

  In 2005, longline surveys identified areas of high abundance of Greeneye Spurdog in the Great Austalian Bight. Greeneye spurdog were caught on 3.0% of hooks set south off Coffin Bay whereas the commercially valuable pink ling were only caught on 0.55% of hooks set. Further west near Ceduna, greenyeye spurdog were even more abundant, caught on 3.5% of hooks where ling were only caught on 0.62% of hooks set.

  The area south of Coffin Bay was subsequently closed to fishing and by 2008 further surveys showed numbers of greeneye spurdog had increased three-fold to a catch rate of 9.4%. This is interpreted as migration as breeding could not account for this increase in numbers. During the same interval the catch rate for pink ling also increased from 0.55% to 2.2% indicating this closure is beneficial for commercial species as well as greeneye spurdog (Williams et al. 2012). The high ratio of sharks to Scalefish in this survey is interpreted as pre-fishery abundance for the longline sub-fishery as at that time automatic longline fishing had been excluded from expanding into new areas and the steep terraces limited trawl access.

- **Fishery Interactions**
  The main fishery impacts on the greeneye spurdog are from demersal trawling and automatic longline fishing on the upper continental slope in the Southern and Eastern Scalefish and Shark fishery and the Great Australian Bight Trawl Fishery. This combination of gear types accesses both sediments with few reef patches (trawl) and steep terraces (longline).

- **Management Arrangements**
  The USDMS is the key management arrangement currently mitigating the effects of fishing on the greeneye spurdog. AFMA has implemented seven targeted spatial closures that cover an approximate area of 4738 km2 between the depths of 200 m and 650 m (AFMA, 2012).

- **Catch Mitigation and Conservation/Protection Options**
  Retaining the USDMS will maintain substantial benefit for the Greeneye Spurdog. Tagging data indicates Careful handling of the incidentally captured sharks has the potential to increase post capture survivorship from line caught vessels. The seasonal breeding patterns of this species offer the potential for seasonal closures but these would have major economic impact on fisheries. In the autolongline sector of the SESSF, dehookers will reduce release survivorship

- **Data Deficiencies and Future Needs**
  Independent survey data that includes demographic information for the greeneye spurdog were collected from at least five voyages completed to map the distribution of gulper sharks (Williams *et al.* 2012). Examination of these data would inform the location and scale of breeding populations that could be used to refine spatial management arrangements. Eighteen greeneye spurdog were fitted with acoustic transmitters with depth and temperature sensors and others were fitted with conventional tags during surveys by CSIRO (Williams *et al.* 2012). The acoustic data should be analysed to examine daily and seasonal movement patterns associated with breeding and feeding, and temperature limits. Further conventional tag recaptures by fishers are likely. These conventional tags have the potential to give insights to movements into and out of closures and post capture survivorship.

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Appendix B. Examples of closed areas with the potential for benefits for endemic sharks and rays.

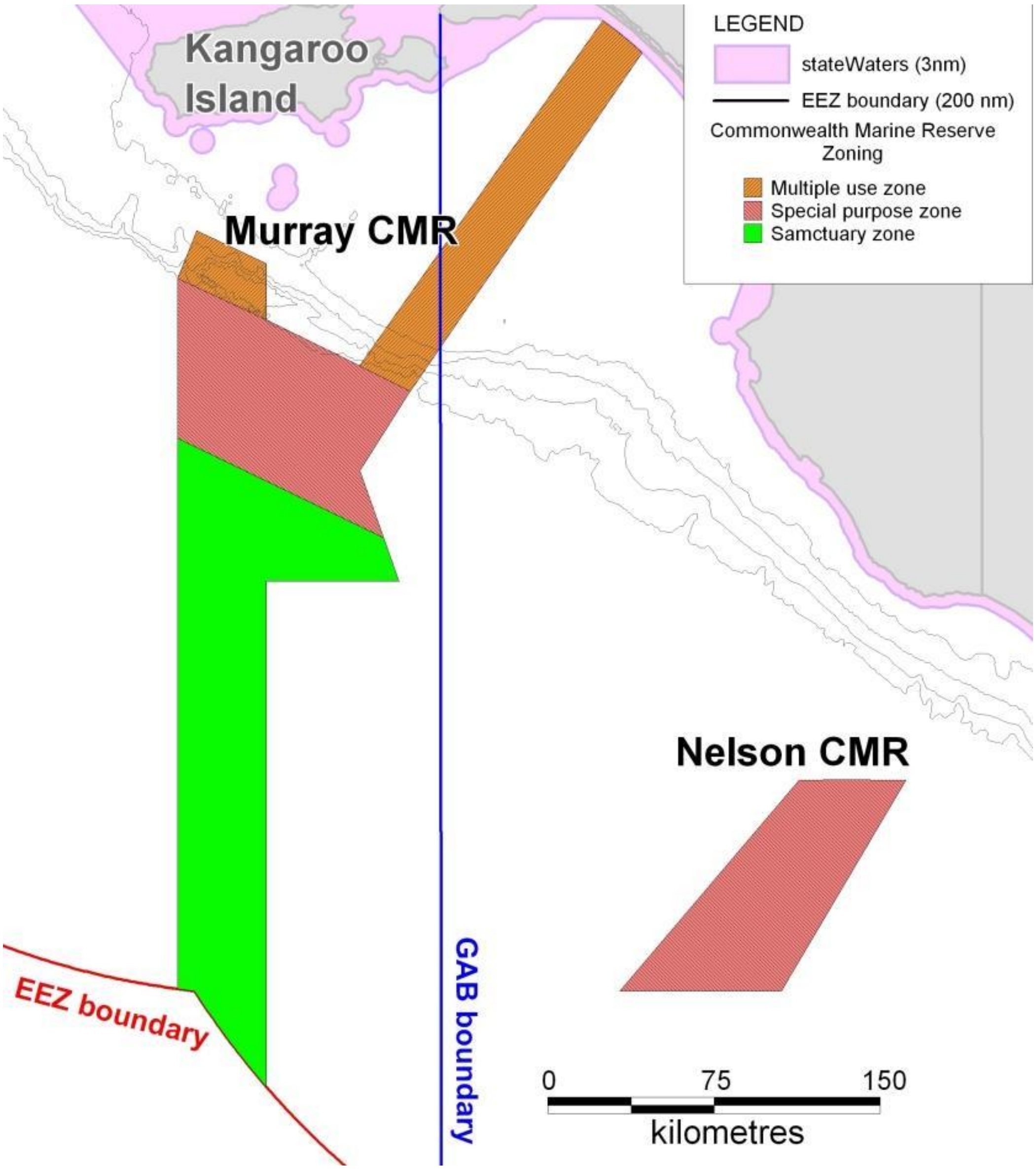
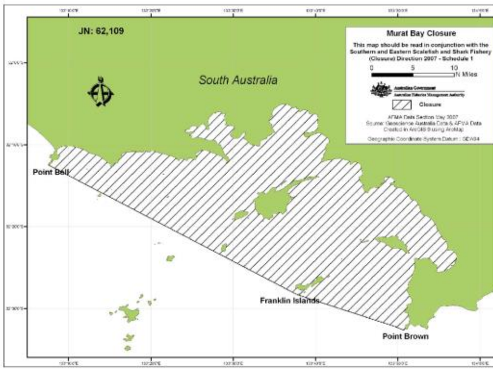
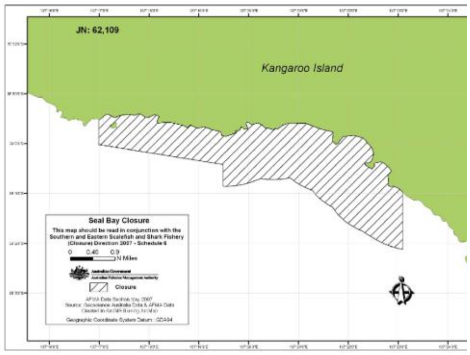


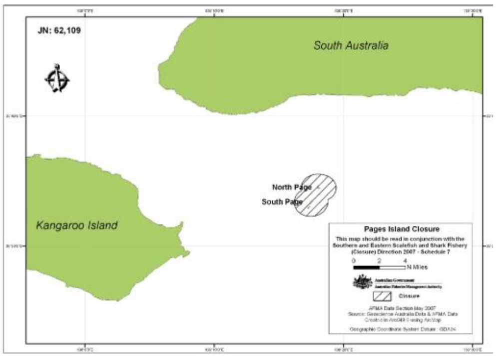
Figure 1. Location of the Murray Commonwealth Marine Reserve
An area with the potential to mitigate fishery impacts on Greeneye Spurdog if changes to zoning were made. Grey contour lines: 100 m, 20 m, 700 m, 1300 m. (Modified after Williams *et. al* 2012)



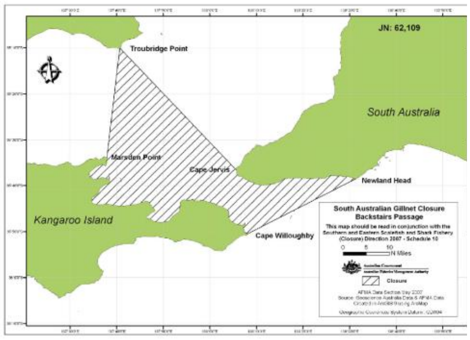
A. Murat Bay



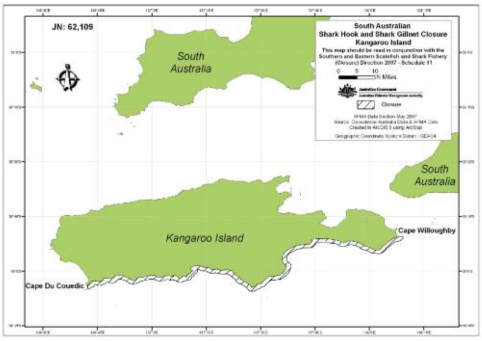
B. Seal Bay



C. Pages Island



D. Backstairs Passage



E. Kangaroo Island

Figure 2. Five Commonwealth Fishery Area Closures with potential to mitigate fishery impacts on the Coastal Stingaree

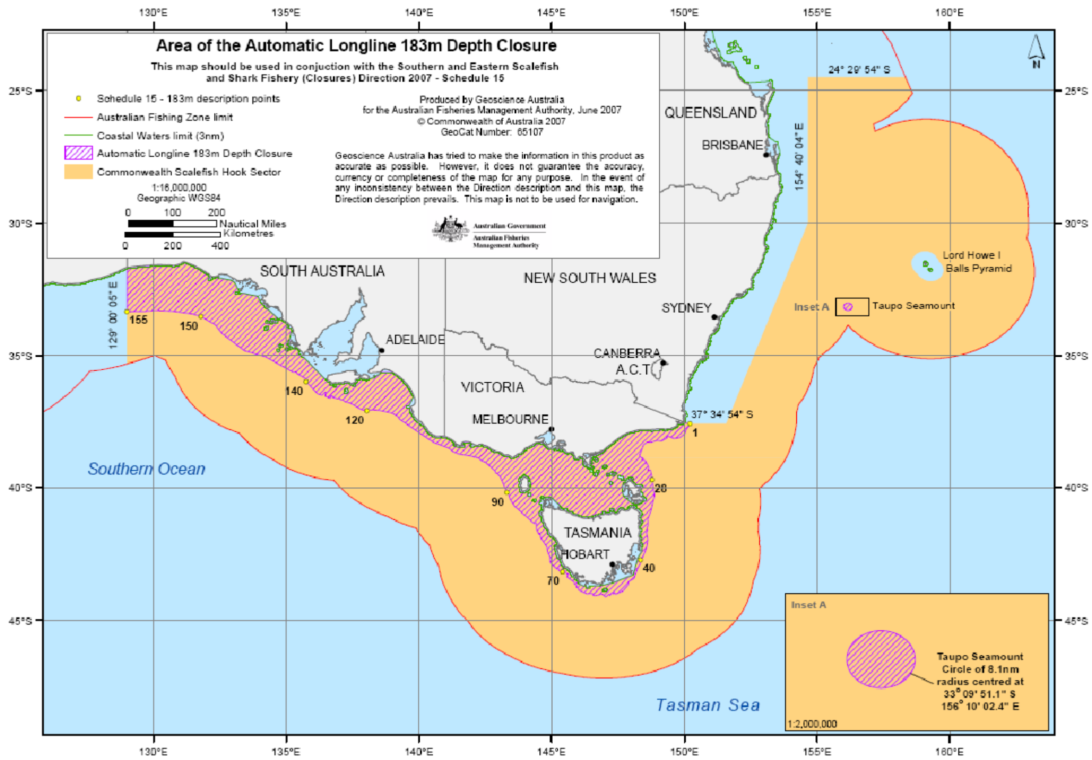


Figure 3a. Area of the Commonwealth Automatic longline closure with the potential to partly mitigate fishery impacts on inshore endemic species

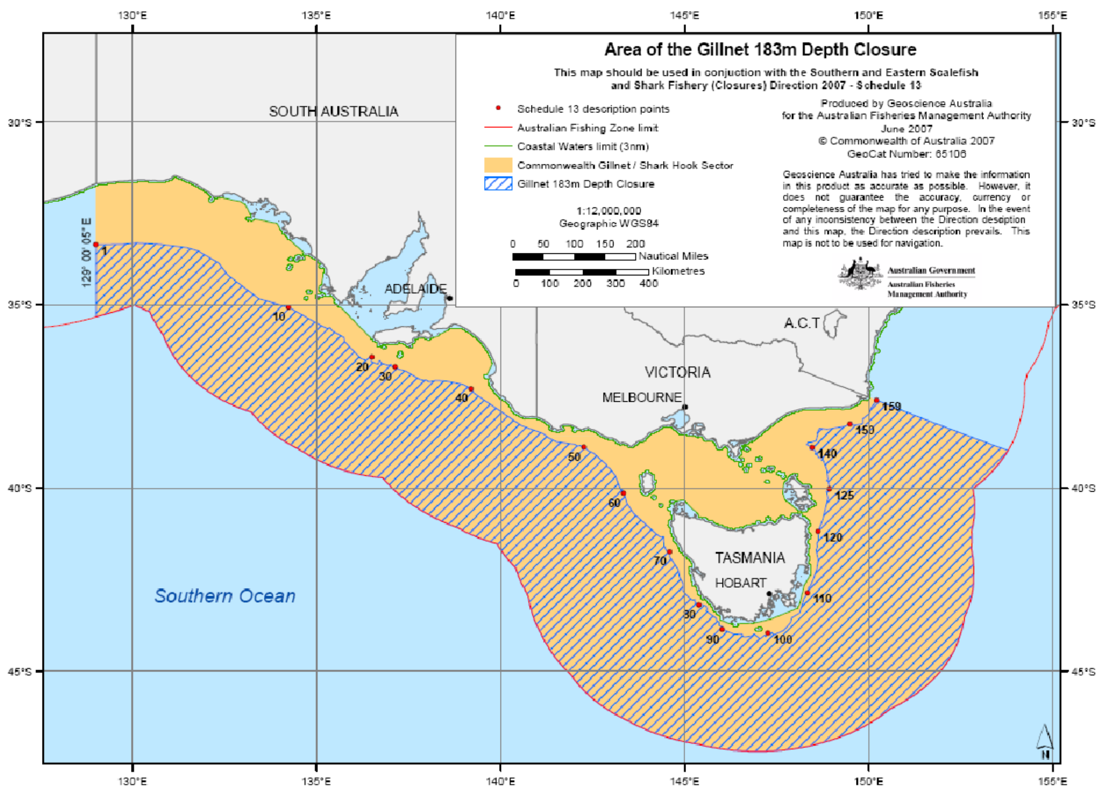


Figure 3b. Area of the Commonwealth Gillnet Depth closure with the potential to partly mitigate fishery impacts on offshore endemic species