What could Australia's total sustainable wild fisheries production be?

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1 Acknowledgments

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2 Executive Summary

2.1 Background

Australian fisheries occur over a large ecological area, and are economically, socially and politically important. Wild fisheries production averaged around 160,000 tonnes per annum between 2010-11 and 2012-13. However, it has been reported in recent years that there is little scope for an overall increase in wild fisheries production. For example, Working Together: The National Fishing and Aquaculture RD&E Strategy 2010 states 'little opportunity exists to increase the volume from wild-catch fisheries". Such statements have never been formally tested and could, if they are believed, constrain future investment by government and industry.

The aim of this project was to provide a first attempt at an approximate estimate of total potential maximum sustainable yield from Australia's commercial fisheries. The project considered only key commercial species and selected by-product species.

The focus of the project was on equilibrium biological productivity and estimating Maximum Sustainable Yield (MSY) for commercial fisheries. With the cooperation and contributions of stock assessment staff in all jurisdictions, it was possible to complete this project covering the enormous diversity of fisheries and the large number of species/stocks included.

In choosing MSY for the species-stocks examined in this project, it is important to note that we are not advocating MSY as a reference point or target catch. It is also important to note that many MSY estimates were derived specifically for this project and represent only commercial catches based on assumed sectoral catch shares. Results assume each sector and jurisdiction MSY based on proportional share of current catches.

It is not suggested that such estimates, particularly those determined using catch-only data-poor methods, be used directly for management purposes without further work being undertaken. The MSY's are, however, indicative of a potential sustainable production for assessed stocks if they were at the biomass that delivered MSY.

Other factors, such as whether an increase in production would be met with an increased market demand or would produce maximised economic returns, are clearly important; along with other market and economic issues, as well as any impacts on ecosystem sustainability and bycatch species. However, these were beyond the scope of the current project and were not considered. In addition, the potential impacts of climate change on fishery productivity, which may become considerable, were also beyond the scope of the current project. The results presented here should be seen as a snapshot of potential production, and very much a first stage, and would need to be considered within each jurisdiction's management framework and settings.

2.2 Aims/objectives

There were four objectives to this work:

1. Develop a nationally agreed framework of methods to estimate sustainable yields;
2. Review and identify species that may have potential for significant growth in catches;
3. Application of methods to determine potential total sustainable yield from Australian fisheries; and
4. Identify next steps if a large potential increase in production is possible.

2.3 Methods

All jurisdictions contributed to this project, providing both data and the results of analyses regarding equilibrium MSY estimates and recent average catches. The project team included a fisheries scientist, nominated by each jurisdiction, who was to be the point of contact for the project and are co-authors of this report. André Punt and Malcolm Haddon, who provided high-level stock assessment support and advice, developed the overall assessment framework. The National Research Providers Network oversaw the project.

The focus of the project was on biological productivity and estimating equilibrium Maximum Sustainable Yield (MSY). This also had the advantage of enabling a level of consistency across species and jurisdictions in which different reference points (*e.g.* Maximum Economic Yield) might be used in practice. Importantly, the results presented are only for species and/or stocks where there were some data on which an assessment to determine MSY could be based. Expert judgement alone was not deemed sufficient. While the results presented here should be treated cautiously, the project results still provide insights into biologically sustainable catches and the potential for increased production.

Workshops were held to agree on approaches and review results. A complementary project was undertaken from February – August 2018 in which data-poor assessment methods were developed for application to the Status of Australian Fish Stocks (SAFS). For that project, training workshops were held in each jurisdiction. These data-poor assessment workshops, coupled with repeated direct contact with assessment scientists in each jurisdiction, provided an efficient way to undertake the current project so that additional workshops were not required.

Each jurisdiction was responsible for selecting species to be included. Most SAFS species were included together with other key species (no discard species were assessed due to the lack of adequate data to conduct an assessment).

For species with significant recreational catches, if the MSY estimates included data from both commercial and recreational sectors, then any potential increase in catch was apportioned to each sector based on the ratio of current catches. Similarly, potential increases in catches were allocated across jurisdictions in the same manner for species that were assessed across jurisdictions. Therefore, any potential increase in catch was allocated to each sector or jurisdiction based on their proportional share of current catches (generally 2015 to 2017). The aim here was to ensure that no additional complexity or potential controversy was introduced through a change in hypothetical “allocation”.

Estimating equilibrium MSY for species/stocks where there was a formal stock assessment was relatively easy, as the assessment models provide this information. Also, where existing MSY estimates were available, these were used. For others, a multi-level assessment framework for estimating MSY was developed and related software addressed data-rich to data-poor assessment methods. MSY estimates were then compared to recent 3-year average catches.

Trends in historic catches were considered to place potential increased production in context. Consequently, trends in the catches of each jurisdiction were described qualitatively with a narrative explaining changes in overall catch and catch composition.

2.5 Results

Total Australian wild fisheries production between 2000/01 and 2016/17 peaked at 236,151 t in 2004/05. Total catch declined to around 152,000 t in 2013/14 and 2014/15 but increased in 2015/16 and 2016/17 to around 170,000 t pa. The decline was evident in all the main groups; fish and sharks, crustacea and molluscs. The explanations for the decline in catches are complex and vary among fisheries and jurisdictions. Numerous factors have been identified including management measures to deal with previous overfishing, fishery restructuring, changed reference points, greater emphasis on profitability rather than volume of production, stock fluctuations due to environmental conditions, changing markets, re-allocation of resources, habitat loss, and disease. In addition, there have been significant changes to fisheries management in Australia over the last decade. Formal harvest strategies have been adopted by the Commonwealth and several other jurisdictions, and the advent of the Status of Australian Fish Stocks reports has also seen a greater focus on ensuring and reporting sustainability.

An open source R package named *simpleSA* (as in "simple stock assessment") was developed to facilitate the estimation of MSY for relatively data-poor fisheries across Australia and was used extensively during the project. The Catch-MSY method for estimating MSY was used extensively. As a data-poor method, delivering highly uncertain estimates compared to other assessment methods, the limitations of this method were described in depth.

MSY was estimated for 290 species/stocks comprising 138,975 t, 84% of average total landings for the period 2014/15 to 2016/17. Overall, over 75% of estimates of MSY were produced as a direct result of this project. The remainder were based on existing assessments or from their outputs. Assessment methods used varied among jurisdictions.

The total commercial MSY for the species assessed across all jurisdictions was 344,634 t, compared to the current average commercial catch of 138,975 t of the assessed species. Adding the non-assessed species average commercial catch of just over 26,741 t gives a total annual potential production of just over 371,000 t. This is more than double the current national catch (136%). Potential increases in production varied considerably among jurisdictions.

The potential difference in production, in commercial terms, was particularly high for Australian Commonwealth (federal), South Australian and Western Australian managed fisheries. This, in part, reflects the influence of highly productive small pelagic species that also occur in New South Wales waters. Conservative reference points for small pelagic species are often set to reflect the ecosystem services these species provide. This is the case in Australia.

Consequently, we looked at the implications of small pelagic fisheries on overall potential production based on the three jurisdictions above. We looked at potential commercial production excluding MSY estimates for small pelagic species and when current TACs were taken as measures of catch potential. Nationally, excluding small pelagic species/stocks gives a potential increase in other species of about 80,000 t or 48% of current average catches. Including TACs for the small pelagic species sees a potential increase of 127,500 t or 77% of current catches.

In most cases the commercial MSY was greater than the current commercial catch. However, it is not suggested that this catch could or should be taken under current operating conditions. Whether this is the case or not, depends on the current biomass level of each species/stock and given that some stocks are depleted or at biomass levels below that which sustains MSY, rebuilding of some species/stocks would be required. It also depends on the target reference point adopted for management, for example using B_{MEY} for Commonwealth managed fisheries.

Overall there were caveats and assumptions that should be considered when interpreting the results. Technical interactions between and within fisheries were not considered. For example, such interactions may imply that fishing some economically important species in a sustainable manner would lead to under-utilizing some other species. Data-poor assessment methods, in particular catch-MSY, were used to estimate MSY for many species and these methods have increased uncertainty. Regardless, the overall results generally indicate Australian fisheries operate below maximum production levels.

2.4 Implications and Further Development

The results of this study indicate the potential for increased production from Australia's commercial fisheries. However, many of the assessments included in this report require further data to improve estimates, may be subject to change and have not been independently reviewed.

Other factors such as whether an increase in production has market demand or maximised economic returns are clearly important, along with other market and economic issues, as well as any impacts on ecosystem sustainability and bycatch species, but were beyond the scope of the current project and were not considered. In addition, the potential impacts of climate change on fishery productivity, were also beyond the scope of the current project.

Importantly, the MSY estimates do not provide a quantitative basis for assessing the past declines in overall catches. The latter need to be analysed separately for each species/stock and each jurisdiction. Such an analysis, together with the results of the current study, would make it possible to identify constraints to increasing fishery production and determine whether such increases are practical or even desirable.

2.5 Keywords

Total catches, Maximum Sustainable Yield (MSY), Australian Fisheries, Status of Australian Fish Stocks (SAFS)

3 Introduction

By world standards, Australian fisheries are small in terms of production, but they have a large geographic, ecological, social and political footprint. Wild fisheries production averaged around 160,000 tonnes per annum between 2010-11 and 2012-13. The National Marine Science Plan (https://www.marinescience.net.au/nationalmarinescienceplan) notes that Australia needs to address its current and potential future gaps in food self-sufficiency and improve production as part of reducing its reliance on imports; Australia currently imports 72% of its seafood. However, it has been reported in recent years that there is little practical scope for an overall increase in wild fisheries production. For example, Working Together: the National Fishing and Aquaculture RD&E Strategy 2010 (FRDC, 2010) states 'little opportunity exists to increase the volume from wild-catch fisheries'. The scale of such statements needs to be measured to guide future investment in fisheries by government and industry.

The aim of this project was to provide a first attempt at estimating total annual potential yield from Australia's commercial fisheries. The project only considered key commercial species and selected by-product species. All jurisdictions contributed to the project. It was agreed that the focus of the project should be on equilibrium biological productivity and estimating Maximum Sustainable Yield (MSY). This also had the advantage of enabling a level of consistency among species and jurisdictions in which different reference points (*e.g.* Maximum Economic Yield) are used. Importantly, the results presented are only for species and/or stocks where there was some data (at least some catches) on which an assessment to determine MSY could be based. Expert judgement was considered subjective and not appropriate for such determinations. While the results presented here should be treated cautiously, the project results provide insights into biologically sustainable catches and the potential for increased production.

In choosing MSY as a level of yield for stocks for this project, it is important to note that we are not advocating MSY as a reference point or target catch, although it is widely used as such. It is also important to note that many of the MSY estimates were derived specifically for this project. It is not suggested that such estimates, particularly those computed using catch-only data-poor methods, should be used directly for management purposes without further assessment work and review being undertaken. They are, however, indicative of potential maximum production for stocks if they were at the biomass level that delivered MSY.

Other factors, such as whether an increase in production has a corresponding market demand or leads to maximised economic returns are clearly important; along with other market and economic issues, as well as any impacts on ecosystem sustainability and bycatch species. However, these were beyond the scope of the current project and were not considered. In addition, the potential impacts of climate change on fishery productivity, which may be considerable, were also beyond the scope of the current project. The results presented here should be seen as a snapshot of potential production and very much a first stage. A second stage project (if required) would look at species interactions within fisheries (that could prevent all species being fished at their MSY catch levels simultaneously), implications of an increased fishery footprint required to achieve the extra catch, and market issues.

Australian wild fisheries production peaked at 236,151 t in 2004/05 but declined to around 152,000 t in 2013/14 and 2014/15. It has since increased in 2015/16 and 2016/17 to around 170,000 t pa. This overall decline is attributed primarily to management constraints on activity due to previous overfishing and the use of controls on fishing methods (Productivity Commission, 2016). Although, alternatively, Edgar et al., (2018) advocated that it is due to continuing excessive fishing, however there are other environmental, economic and fishery management reasons that this may not exclusively be the case (Little et al 2019; Gaughan et al 2019). Nevertheless, it is necessary to consider trends in current catches to place potential increased production in context. Consequently, trends in the catches of each jurisdiction are described together with a narrative qualitatively addressing changes in overall catch and catch composition.

The project was overseen by the National Research Providers Network (RPN). This committee was established in response to the National Fishing and Aquaculture RD&E Strategy in 2010 (FRDC, 2010). Membership includes fisheries and aquaculture research heads or their delegates from each State jurisdiction, CSIRO, ABARES, AFMA, FRDC, Universities, Oceanwatch, Indigenous Reference Group (IRG) and IMOS (Appendix 1).

3.1 Project Objectives

1. Develop a nationally agreed framework of methods to estimate sustainable yields;
2. Review and identify species that may have potential for significant growth in catches;
3. Apply the methods to determine potential total sustainable yield from Australian fisheries; and
4. Identify next steps if a large potential increase in production is possible.

4 Methods

4.1 Approach

All jurisdictions contributed to this project, providing both data and the results of analyses regarding equilibrium MSY estimates and recent average catches. The project team included a fisheries scientist, nominated by each jurisdiction, to be the point of contact for the project and are co-authors of this report. In addition, other scientists who contributed directly to undertaking assessments to estimate MSY are also listed in Appendix 1. They were assisted by André Punt and Malcolm Haddon, who provided high-level stock assessment support and advice, and developed the overall assessment framework. The project was overseen by the RPN.

A national workshop was held in August 2017 (Appendix 2). The objectives of the project were outlined; the specific aims of the workshop were to:

- agree on selection criteria for species/stocks to be included and begin the development of an agreed species list;
- develop an agreed assessment approach and framework; and
- develop a workplan.

Presentations, from participating jurisdictions, included:

- likely species/fisheries for inclusion and reasons for selection;
- available data and assessment approaches used; and
- an assessment framework using the Southern and Eastern Scalefish and Shark Fishery (SESSF) as an example. A presentation on this framework is included as Appendix 3.

It was agreed across all jurisdictions present that the focus of the project should be on biological productivity and yield (Maximum Sustainable Yield, MSY) and that species only caught by recreational fishers would not be included. The selection of MSY had the advantage of enabling a level of consistency across jurisdictions and species where different reference points (*e.g.* Maximum Economic Yield) might be used. Importantly, it was also agreed that the project should take a conservative approach when attempting to estimate MSY to avoid over-estimating production. There were three reasons behind this decision:

- it was the first time a national analysis had been undertaken;
- many of the species selected were regarded as relatively data-poor; and
- species/fisheries interactions were not being considered.

More detailed outputs from this workshop are given in the sections below. The primary objective of the project was, therefore, to compare average current catches with the MSY estimates to determine the potential for increased production.

4.1.1 Next Steps and Communication

Initially it was considered that regional workshops would be held to apply the agreed methods to species and/or fisheries within each region. However, a complementary project was undertaken from February to August 2018, whereby data-poor assessment methods were developed for application to the Status of Australian Fish Stocks (SAFS) (FRDC Project 2017/102, Haddon et al., 2019). As part of that project, training workshops were held in each jurisdiction on the assessment of data-poor stocks. These data-poor assessment workshops, as well as repeated direct contact with assessment scientists in each jurisdiction, provided an efficient way to undertake the current project so that additional workshops were not required.

A final synthesis workshop was held in Melbourne in May 2019 to aggregate and synthesize the results across jurisdictions and to identify and record key assumptions and areas of uncertainty particular to each jurisdiction. In addition, future developments were also considered where these were deemed warranted.

The RPN was regularly updated on project progress. Following the final workshop, an RPN meeting was held to go briefly through results, implications and next steps.

4.2 Species Selection

The key criterion for selecting species to be assessed was that there were adequate data available on which estimation of MSY could be based (at least a regular time-series of catches). Expert judgement alone concerning potential maximum yields was not considered to be sufficient to provide usable estimates of productivity.

It was agreed at the first workshop that most SAFS species (SAFS, 2019) would be included in the evaluation of MSY together with selected byproduct species (no discard species were considered due to the lack of adequate data upon which an assessment could be made).

Each jurisdiction was responsible for selecting species to be included. It was agreed that there should be consistency with SAFS at the stock level. However, in some cases species complexes could be considered if defensible reasons were documented, such when species were caught together, but not recorded separately in catch statistics, e.g. basket quota.

For species with significant recreational catches, if the MSY estimates included data from both commercial and recreational sectors, then any potential increase in catch was apportioned to each sector based on the ratio of current catches. Similarly, potential increases in catches were allocated across jurisdictions in the same manner for species that were assessed across jurisdictions. Southern bluefin tuna was dealt with in the same way. Therefore, in all cases, apart from the tropical tunas, any potential increase in catch was allocated to each sector or jurisdiction based on their proportional share of current catches; the aim being to ensure that no additional complexity or potential controversy was introduced through a change in hypothetical “allocation”.

The tropical tunas and billfish were dealt with differently. Tuna fisheries in the Indian and Pacific Oceans are among the world’s largest tuna fisheries (FAO 2018). Australian catches of Pacific tunas and billfishes are relatively small and almost non-existent from the Indian Ocean. The Western and Central Pacific Fisheries Commission and the Indian Ocean Tuna Commission do have extensive stock assessments estimates (e.g. WCPFC 2018, IOTC-SC21 2018) but given the minor scale of the current Australian catches, particularly in the Indian Ocean, it was decided that any pro-rata increase in potential catch would be biased. Consequently, current Australian TACs were used as a proxy for an “Australian MSY”.

Australia has many data-limited or data-poor species/fisheries where data, if it exists, is only available from the commercial sector. Consequently, the analyses for many species were based on commercial catches only using the catch-MSY method (Martell and Froese, 2013). However, it has been shown that the resulting MSY estimate can be applied to just the commercial component (Rudd and Branch 2017; Haddon 2018; Haddon et al., 2019). Even if such species had a significant recreational component, with or without a trend in the recreational catches, this was found to introduce only minor biases (see the *Significant Unknown Recreational Catches* section in Haddon, 2018, or Haddon et al., 2019).

4.3 Estimating MSY

Estimating sustainable yields for target species where there is a formal stock assessment was relatively easy, as the associated assessment models were developed and published. For example, Dichmont et al., (2016) identified 76 Australian stocks with model-based assessments. These made up 37% of the 2013 catch recorded in the 2013 SAFS report (Dichmont et al., 2016).

A multi-level assessment framework for estimating MSY was presented at the first workshop (Appendices 2 & 3). This was used as the basis for the simplified framework presented here. In broad terms the approaches available depend on the available data (and its quality):

- data-rich - well sampled biological and fishery data leading to a full assessment;
- data-moderate - includes catch time series, CPUE or one estimate of biomass, biological data (growth, maturity, natural mortality, *M*), limited age- or length-composition data, equilibrium *F* estimate; and
- data-poor - only catch time-series.

Consequently, the assessment framework (consisting of five levels) and resulting software addressing data-rich to data-poor assessment methods is outlined in Table 1. Further details of some of these methods are given in the following appendices:

- Appendix 4 – Computing MSY using the results of an age-structured model
- Appendix 5 – Computing MSY using data-moderate Bayesian methods (age and sex structure model, delay difference model and Schaefer production model)
- Appendix 6 – Corrected average catch
- Appendix 7 – The *simpleSA* R Package

Table 1. Multi-level stock assessment framework

Data Availability	Level	Assessment Type	Data used	Example References
Data-rich	1	Age-structured models	Multiple types, usually index and composition	Method and Wetzel (2013)
Data-moderate	2	Biomass dynamics model Age-structured production model Delay-difference model Stochastic stock reduction analysis	Catch and an index or one estimate of abundance	Method and Wetzel (2013) Rudd and Thorson (2018) Prager (1992, 1994) Lombardi and Walters 2011) This report
Data-poor	3	Catch-MSY, OCOM	Catch	Martell and Froese (2013)
	4	Depletion corrected average catch	Catch	MacCall (2009)
	5	Recent average catches	Catch	Restrepo et al. (1999)

Two open source R (R Core Team, 2017) packages, *simpleSA* and *cede*, were produced to facilitate the analysis of relatively data-poor fisheries across Australia:

1. *simpleSA* contains the three main data-poor stock assessment techniques (catch-MSY, surplus-production modelling, and age-structured surplus production modelling) in addition to functions to assist with catch-curve analysis (refer to section 4.3.1); and
2. *cede* contains R software to assist with data exploration (simple mapping and data summary functions) and with illustrating and comparing different catch-effort standardization techniques (refer to section 4.3.2).

Both R packages are freely available. Currently they are available in a shared DropBox folder although this will likely change to a publicly open BitBucket or GitHub directory hosted by CSIRO. Eventually at least *simpleSA* may be put onto the CRAN (Comprehensive R Archive Network), which, along with GitHub, is the standard repository for R packages. The *simpleSA* package continues to be developed with a new branch being formed, now called *datalowSA*, and is available for download and/or installation from https://github.com/haddonm/datalowSA

4.3.1 The *simpleSA* R Package

An open source R package named *simpleSA* (as in "simple stock assessment"; Haddon et al., 2019) was developed to facilitate the estimation of MSY for relatively data-poor fisheries across Australia. This was designed to contain three stock assessment methods suitable for Australian conditions plus other additional routines or functions for conducting analyses for stock assessments. The three main methods considered were:

1. the catch-MSY method (Martell and Froese, 2013);
2. surplus-production modelling (Prager, 1994; Haddon, 2011); and
3. age-structured production modelling (Punt, 1994; Punt et al., 1995)

Also included in *simpleSA* were some utility functions for conducting catch-curves. The three main methods are listed with the least robust method (catch-MSY) first and, assuming the availability of representative data, the more robust assessment last (age-structured production modelling). This package was used extensively to provide MSY estimates. Further details on *simpleSA* R are given in Appendix 7.

4.3.2 The *cede* R Package

The *cede* R package (as in "catch effort and data exploration"; Haddon, 2018a), was developed to provide tools to assist the jurisdictions with data exploration to aid in understanding the factors influencing the fishery data they work with (e.g. by simple mapping of their data, and plotting their data subdivided by years or areas or some other factor). It also attempted to simplify the process of CPUE standardization.

4.3.3 What was Reported

For each species / stock selected, each jurisdiction completed a common template that had the following fields:

- species (common and scientific names);
- jurisdiction;
- stock;
- data period (first and last year);
- MSY estimate (and range);
- 3-year average catch;
- estimation method; and

- key contact and reference for the assessment (if available).

Where an estimate of MSY and or 3-year average catches were given as a range only, midpoints were used in subsequent analyses. For each jurisdiction, the total catch of assessed species was compared to the average total catch of all species. The latter was for the years 2014/15 to 2016/17 and obtained from the ABARES fisheries and aquaculture statistics 2017 (Mobsby, 2018).

Many fisheries have catches of individual species that are relatively low. In reporting these results, care has been taken to avoid issues around confidentiality. In such cases, results are only reported at an aggregate level based on advice from each jurisdiction.

4.3.4 Non-Assessed Species

The species for which MSY estimates were obtained made up a considerable proportion of reported total landings in each jurisdiction (see below). The aim was for the species/stock from which MSY were obtained would make the majority of the reported landings. However, there were likely to be species that could not be assessed due to inadequate data. Therefore, the average recent catch from these non-assessed species was only added to the assessed MSY estimates to give “total” production. The catches from these non-assessed species were not adjusted or corrected in any way.

Some jurisdictions provided estimates of potential maximum sustainable catches based on expert opinion; such “estimates” are not included in the totals but are reported separately.

5 Results

5.1 Current Australian Catches

Total Australian wild fisheries production between 2000/01 and 2016/17 peaked at 236,151 t in 2004/05. Total catch declined to around 152,000 t in 2013/14 and 2014/15 but increased in 2015/16 and 2016/17 to around 170,000 t pa (Figure 1). The decline was evident in all the main groups; fish and sharks, crustacea and molluscs.

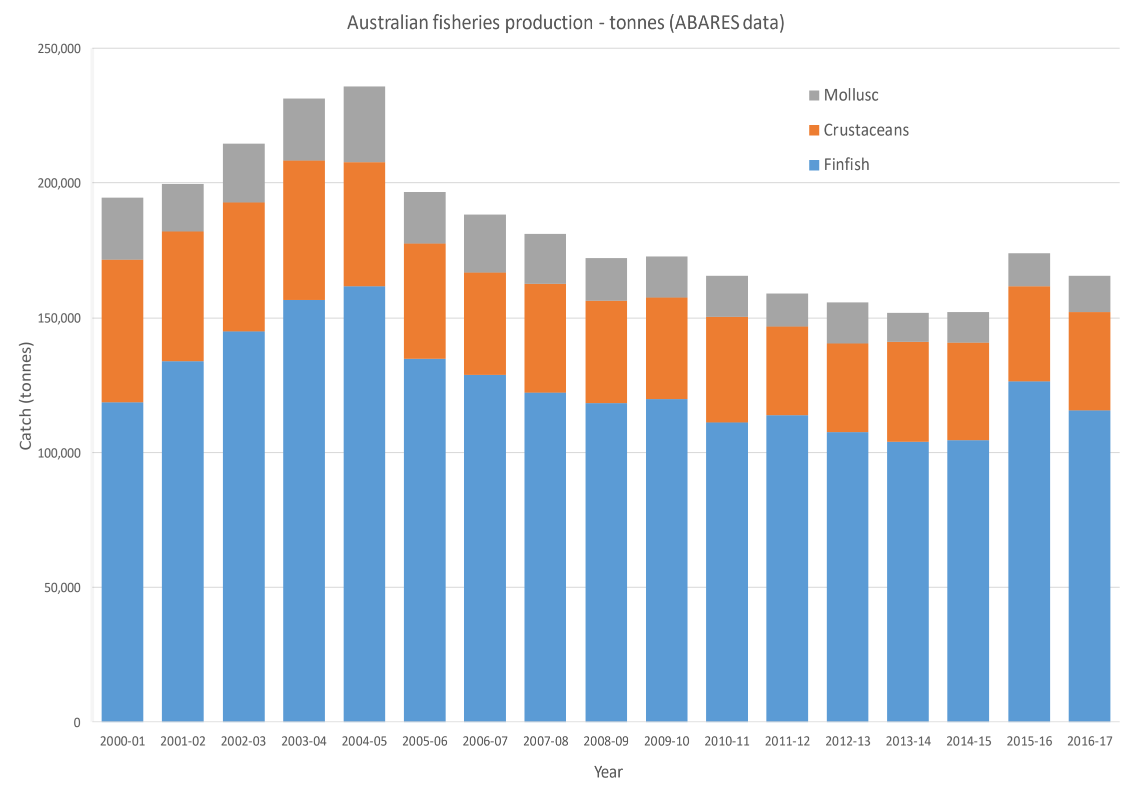

Figure 1. Total Australian fisheries production, 2000/01 to 2016/17 (Source: Australian Fisheries Statistics, ABARES).

The Productivity Commission attributed the reason of the decline in catches to management constraints on activity due to previous overfishing and the use of controls on fishing methods (Productivity Commission, 2016). Edgar et al. (2018) argued that while changing climate and more precautionary management contributed to the declines, excessive fishing has played the major role. The contention by Edgar et al (2018) that fish stocks are rapidly declining has been rebutted by Little et al. (2019) and Gaughan et al. (2019) citing a more complex combination of factors that have attributed to trends in catches.

Nationally, there have been notable declines in shark catches and those of rock lobsters, abalone,scallops and "other" fish species. However, the reasons for the decline in catches are complex and vary across fisheries and jurisdictions (Figures 2 - 9). Numerous factors have been identified including management measures to deal with previous overfishing (such as the implementation of HSs), fishery restructuring, changed reference points, greater emphasis on profitability rather than volume of production, stock fluctuations due to environmental conditions, changing markets, re-allocation of resources, habitat loss, and disease. In addition, there have been significant changes to fisheries management in Australia over the last decade. Formal harvest strategies have been adopted by the Commonwealth and several other jurisdictions. The advent of the Status of Australian Fish Stocks reports (SAFS, 2019) has also seen a greater focus on ensuring and reporting sustainability.

Comments were obtained from the jurisdictions regarding their catches, through the RPN. These are briefly summarised below:

5.1.1 Commonwealth

Catches have declined from a peak of around 75,000 t during the early 2000s to a low of under 40,000 t in 2012/13 but have increased to around 50,000 t in recent years (Figure 2). Commonwealth fisheries have undergone significant management changes during this period. The Commonwealth fisheries Harvest Strategy Policy was introduced in 2007 and fully implemented in 2008 (DAFF, 2007; Smith et al., 2008). The policy specified the biomass corresponding to Maximum Economic Yield (B_{MEY}) as the explicit target. It was preceded by a structural adjustment package in 2006 to reduce fleet numbers in several fisheries with the aim of removing excess capacity, improving the profitability of the remaining fleet, and to assist in the implementation of a network of marine protected areas (Rayns, 2007; Vieira et al., 2010). This Government buy out of licences, from Nov 2005 – Nov 2006, removed vessels from the Commonwealth fishing fleet and, it is argued, reduced effort and lowered catches, particularly of minor species.

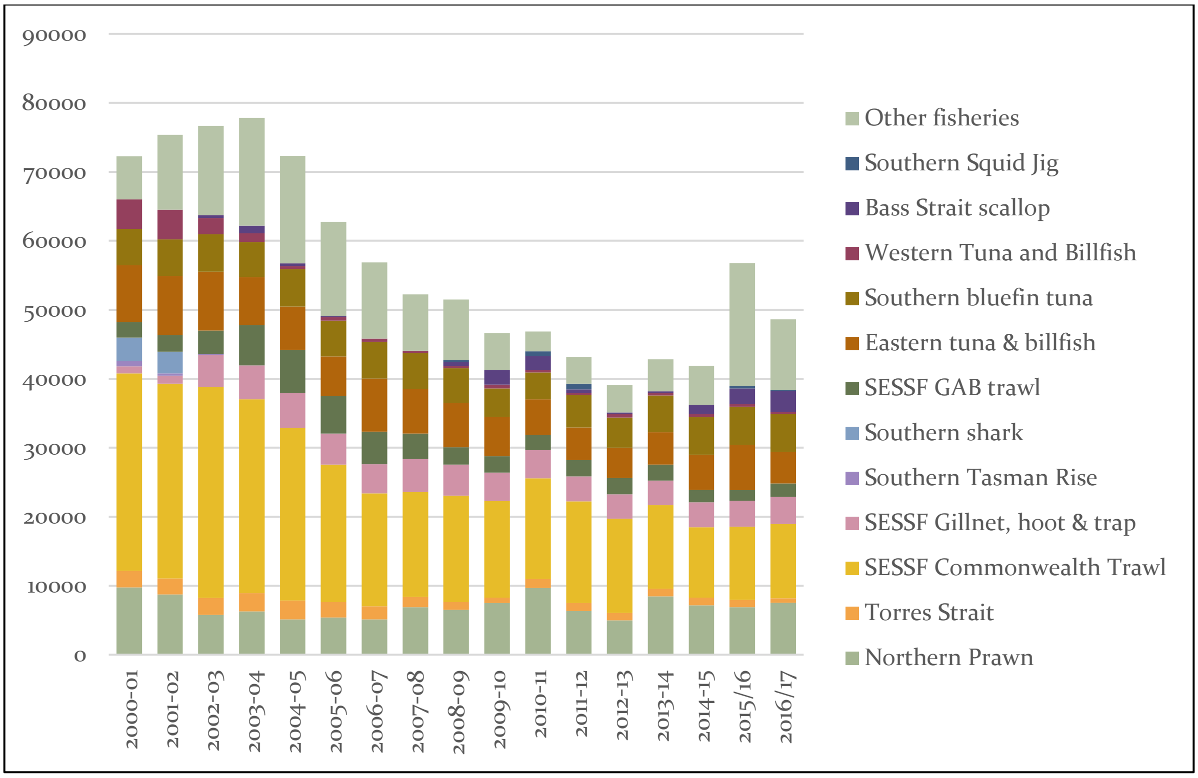

Figure 2. Commonwealth fisheries production (tonnes) by major fishery (Source: ABARES Fisheries Statistics).

The catches in the Western Tuna and Billfish Fishery (WTBF) and the South Eastern Scalefish and Shark Fishery (SESSF) declined substantially from 2000/01 to 2016/17 (Figure 2). Declines in the WTBF are primarily due to reduced effort. In the SESSF, catches of orange roughy and school shark declined due to a major management response to previous overfishing (the cessation of targeted fishing), while catches of blue grenadier declined due to changed fleet dynamics. Reasons for the catch reductions for other species are less clear. Under-caught TACs have become a significant issue in the Commonwealth. For example, 23 of 34 species groups under quota management were caught less than 50% of their TACs during 2015/16. Knuckey et al., (2018) investigated the reasons for this and identified the following seven factors:

- legislative / management impediments;
- fleet capacity and characteristics;
- fisher behaviour and vessel operation;
- climate change and oceanographic conditions;
- costs of production and markets;
- quota ownership and trading; and
- the assessment processes.

It was found that under-caught TACs could not be attributed to a single factor but there was a complex interplay of all.

5.1.2 South Australia

Overall catches have been relatively stable apart from a peak in 2004/05, and a slight increase in recent years (Figure 3). Total production is dominated by Australian Sardines. The catch of sardines increased from 12,000 t in 2001/02 to between 30 – 40,000 t across the years 2005/06 and 2016/17. Excluding sardines, production by South Australia declined by 31% (approximately 3,850 t) between 2001/02 and 2013/14 (from 12,450 t to 8,600 t). Production was higher in 2014/15 and 2015/16 (9,700 t – 12% higher than 2013/14).

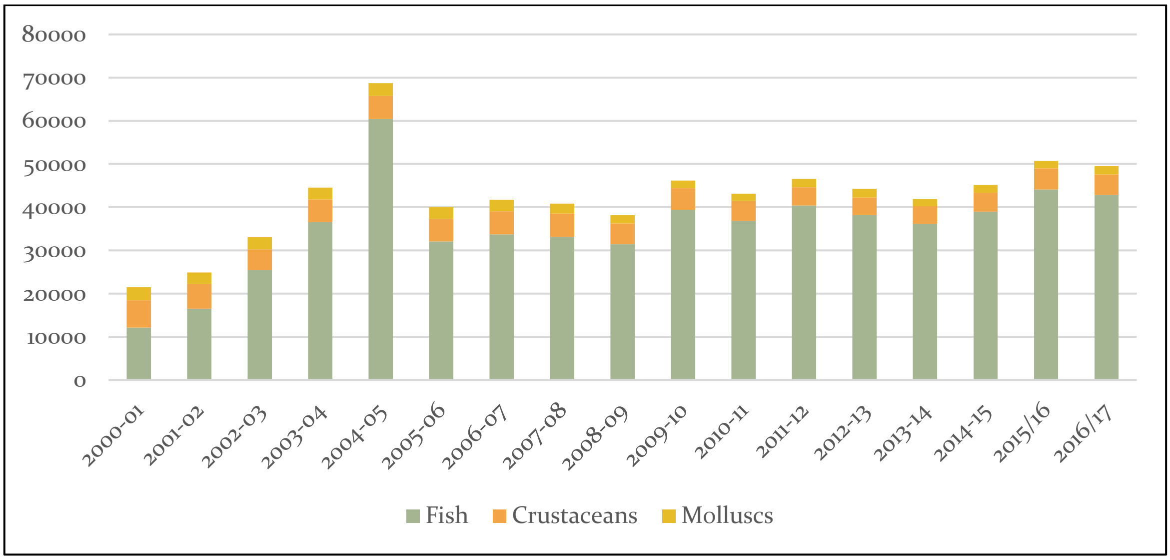

Figure 3. South Australia fisheries production (tonnes) by major fishery (Source: ABARES Fisheries Statistics).

Catches of some species off South Australia, including southern rock lobsters, abalone, prawns in the Gulf of St Vincent, southern garfish and snapper, have declined due to management measures in response to reduced harvestable biomass. Catches of Australian salmon and Australian herring have declined due to declining markets. The commercial catch of King George whiting has declined, reflecting increased recreational catches.

5.1.3 Western Australia

Catches declined from around 40,000 t in the early 2000s to under 19,000 t in 2011/12 and 2012/13, but have increased to 22,000 t in 2016/17 (Figure 4).

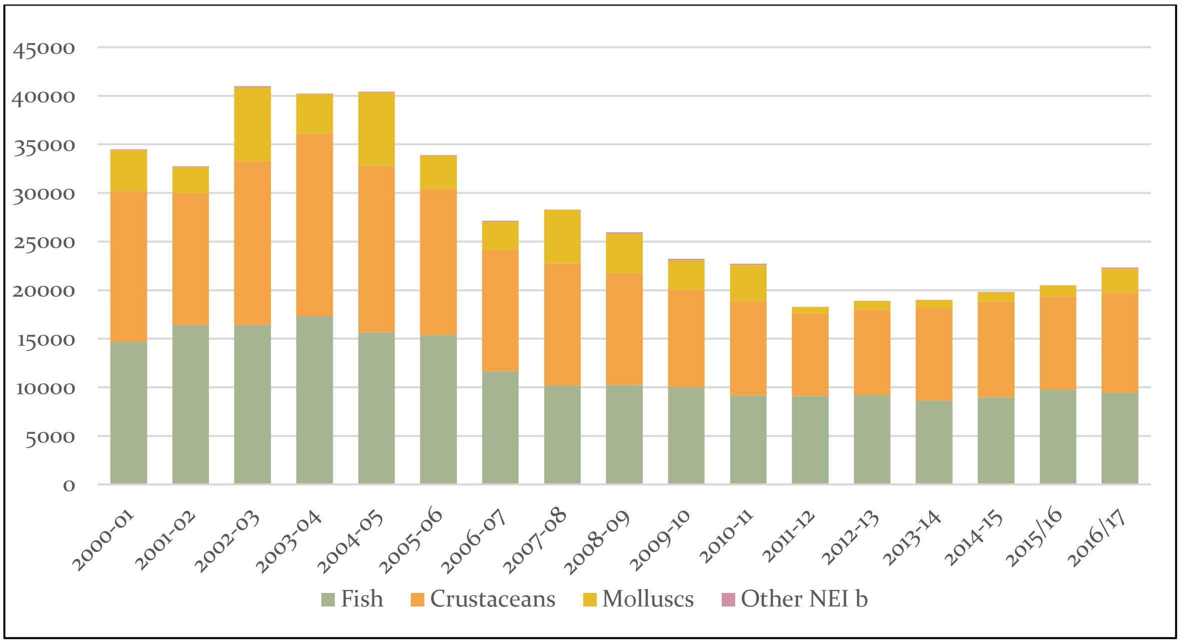

Figure 4. Western Australia fisheries production (tonnes) by major fishery. Other NEI – not elsewhere included. (Source: ABARES Fisheries Statistics).

Catches of western rock lobster declined from an average of around 11,000 t in the early 2000s to 5,500 t in 2011/12. Initially, this was due to management-driven effort reductions in response to a period of low recruitment. A subsequent shift from effort controls based on achieving MSY, to transferable quota allocations based on MEY has resulted in the catch returning to 6,000 t given improved recruitment and record levels of egg production. The extreme marine heatwave in 2010/11 in the Gascoyne, and upper West Coast regions caused almost total loss of the stock of Roe's abalone in the region (Caputi et al., 2019). The 2011 marine heatwave also led to major declines in blue swimmer crabs and saucer scallop stocks in Shark Bay and scallops in Abrolhos Islands, resulting in the closure of these scallop fisheries in 2012 for three and five years respectively. Current catches of these stocks have not fully recovered to previous levels. Environmental changes also resulted in a 10-year decline in the fisheries for crab in Cockburn Sound, resulting in their closure to fishing in 2014/15. Management changes to the West Coast Demersal and Tropical Demersal fisheries have led to major reductions in effort and catches of up to 50%. In addition, there have been reductions in the demand and markets for Australian salmon and Australian herring, together with management changes (Gaughan et al. 2019).

5.1.4 Queensland

Annual commercial catches have steadily declined from about 30,000 t to 20,000 t during 2000–2017 (Figure 5). Explanations for the general decline relate to reduced fishing effort and/or catch rates. The causes have been generally qualitatively related to:

- changes in availability of product;
- fishery management in response to past fishing pressures (e.g. new quota allocations and procedures);
- changed patterns of fishing between fisheries and species to adjust to market demands, product prices and economics;
- increased competition between commercial, charter and recreational fishing sectors;
- cross jurisdictional linkages;

- environmental influences on biological processes such as fish recruitment, growth and mortality, and habitat productivity;
- area of fishing, for example via marine park zonings reducing the fished area; and
- fewer licences; for example, the licence buy-backs as part of the Representative Areas Program (Great Barrier Reef Marine Park RAP) introduced in 2004. License buy-backs occurred over the following three years in the lead up to the 2007 election. About $250 million was paid by the Australian Government to businesses affected by RAP in Queensland.

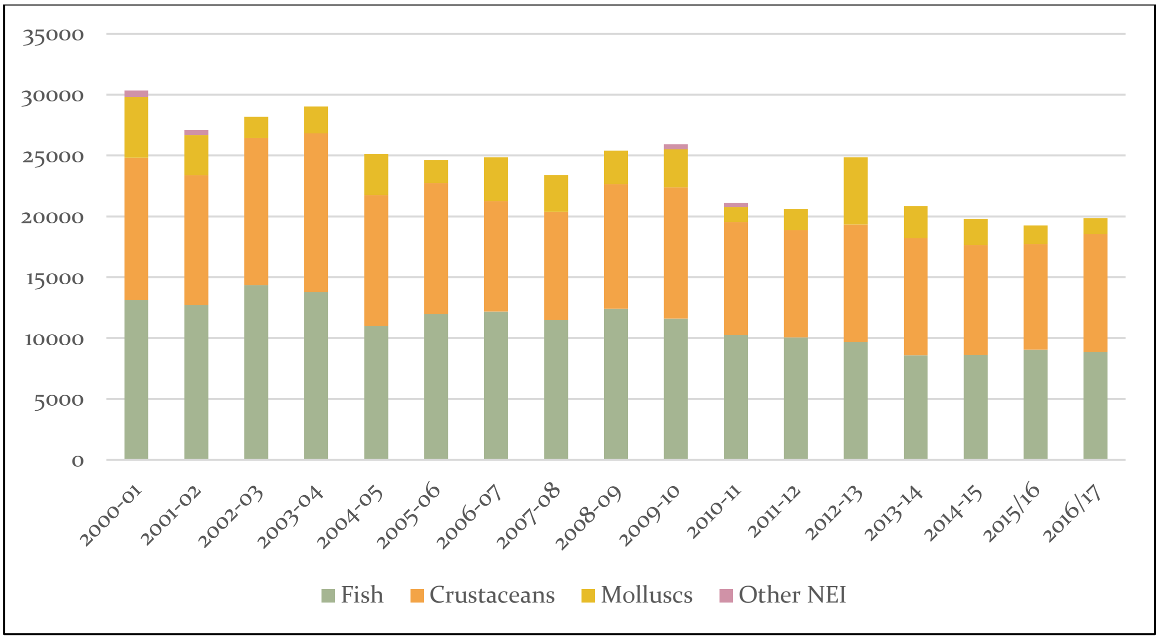

Figure 5. Queensland commercial fisheries production (t) Other NEI – not elsewhere included. (Source: ABARES Fisheries Statistics).

These general hypotheses and in combination, vary among fisheries and species. The following are some species-specific considerations:

- ***Saucer scallop*** harvests and catch rates have declined to historical lows of less than 200 t meat weight during 2016–2017. Management procedures are in place with new spatial and seasonal closures to reduce the likelihood of over-fishing.
- ***Barramundi*** are relatively long-lived reaching 20 to 35 years. They mature (mostly) as males before changing into females and move between salt and freshwater. Barramundi populations and harvests tend to vary regionally, with river-flows affecting their growth, survival, and catchability. Annual harvests have been steady, with 839 t taken during 2017. Wild caught barramundi harvests may change with the supply of aquaculture product and associated market price.
- ***Yellowfin bream, sand whiting and dusky flathead*** are part of the inshore net fishery. They are also vital to recreational fishing. Over the last five years (2013 to 2017), the total harvest off south east Queensland averaged 242,272 and 121 t per year for yellowfin bream, sand whiting and dusky flathead respectively, with catches split 54% commercial versus 46% recreational for bream, 77% commercial versus 23% recreational for whiting and 36% commercial versus 64% recreational for flathead. Harvests of bream

and whiting have declined from peak fishing pressures during the 1980s to 2000s. Commercially, harvests have remained steady over the last decade.

- ***Coral trout*** extend north from the Great Barrier Reef (GBR) into the eastern Torres Strait where it is under Commonwealth jurisdiction. Queensland accounted for around 90% of the total harvest during 2017/18. The total harvest by Queensland averaged 983 t during 2013-14 to 2017-18. Sectoral shares were 82% commercial (806 t) and 18% recreational (177 t). Commercial harvests have been steady during the last decade under quota management. Potential harvest increase is possible based on stock assessment results but doing so could reduce commercial profitability. Marine park zoning restricts fishing from certain GBR areas.
- ***Sea mullet*** support Queensland's largest finfish fishery. There is considerable beach seine and gill netting for this species, which spawns in ocean waters, and movements and catchability relate to river flows. Some estuarine and freshwater habitats may not be as productive as in the past. The 2016 assessment is expecting a decline as the biomass and recruitment are on a declining component of a cycle. The overall trend for harvest is a steady decline. Harvests in recent times are below the long-term average. In the last few years, harvest is consistently the lowest reported in the time series and catch rates have levelled off.
- **Shark** harvests are rigorously quota controlled. Quota changes are unlikely without improved monitoring and data. Without improved data, conclusions about trends in harvest or catch rates cannot be made.
- ***Spanish mackerel*** harvests taken by commercial fishing steadily increased during the 1970's. Harvests were around 600–800 t before 2003. A commercial quota was implemented in 2004 at 619.5 t. Commercial harvests are currently around 300t with lower catch rates and latent quota. An overall decline in spawning stock aggregations has been reported.
- ***Mud crab*** reported commercial harvest (2017/18) was around 890 t for the east coast and 144 t for the Gulf of Carpentaria. Population densities and abundance are spatially variable and genetically separated between the east coast and the Gulf of Carpentaria. Annual harvests increased until 2015 but have dropped marginally in recent years. High prices and demand maintain fishing pressure.
- ***Prawn*** commercial harvests were 6,000–8,000 t each year until 2003. This harvest reduced to 4,000–6,000 each year during 2004–2017. Annual harvests vary with species, but relate to their abundance and profitability, leading to fishing operations changing their targeted fishing effort. Eastern king prawns have the most sustained harvests. In general, prawns have a long-term increasing trend in catch rates, partially related to increases in fishing power. In addition, prawn harvests in far north Queensland relate to the frequency of barge and service vessels in this remote region. The global financial crisis may have affected economics 2007–2009.
- ***Bugs*** caught using trawls have increased due to price/demand. Annual harvests are now around 700-800 t.
- ***Stout whiting*** harvest (~ 1,000 t) varies annually with catch rates, export prices and demand, offshore processing costs, and quota settings across east coast jurisdictions.

5.1.5 New South Wales

Catches have declined from around 18,000 t in the early 2000s to around 11,000 t in recent years (Figure 6). Much of this decline has been attributed to fishery restructures and changing markets.

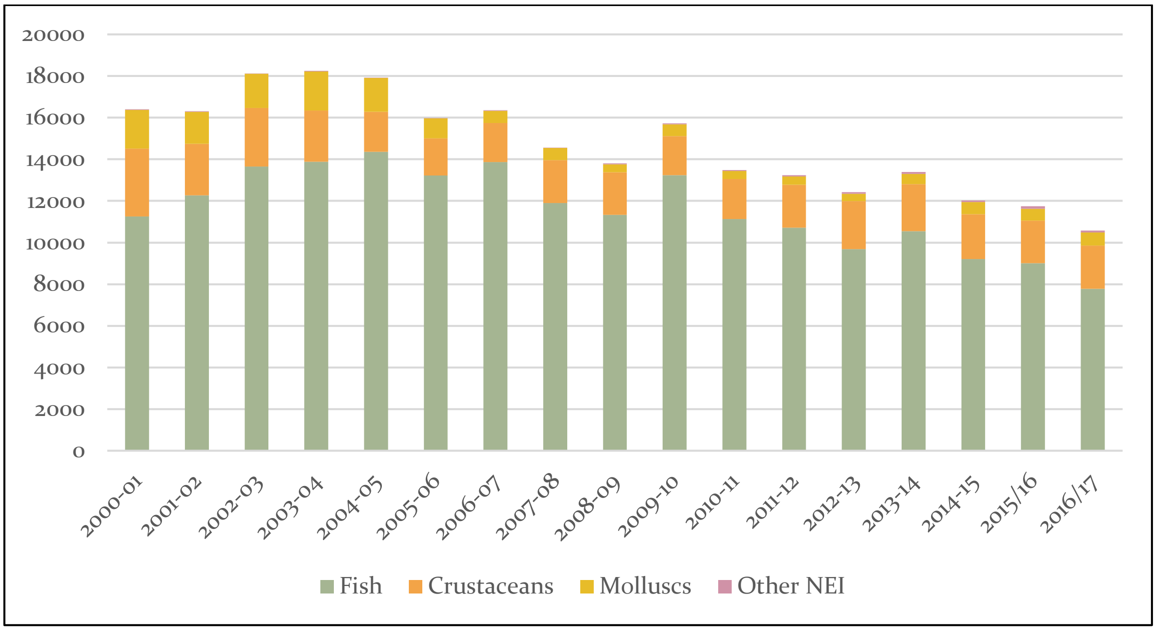

Figure 6. New South Wales fisheries production (tonnes) by major fishery. Other NEI – not elsewhere included. (Source: ABARES Fisheries Statistics).

There has been a 75% reduction in fishing effort by the offshore prawn trawl fishery since 2000/01 following industry restructures. This has led to reductions in the catches of eastern king prawn, cuttlefish, squid and octopus. Similarly, landings of school prawns have declined due to a 70% reduction in fishing effort by the estuary prawn trawl fishery since 2000/01. Catches of common estuarine species (sand whiting, yellowfin bream, luderick, dusky flathead) have dropped due to an approximate 65% reduction in mesh net fishing effort since 2000/01. NSW's largest fishery by volume, sea mullet, has been relatively stable, although catches during the last five years or so are somewhat less than those in the early 2000s. Australian salmon, as with other jurisdictions, has seen an overall decline driven by variable and changing markets.

5.1.6 Tasmania

Catches peaked in the mid-2000s around 10,000 t, but have subsequently declined to around 4,000 t (Figure 7). There are declines in catches of most species but the most significant include scallops, southern rock lobsters, abalone and unspecified "fish others".

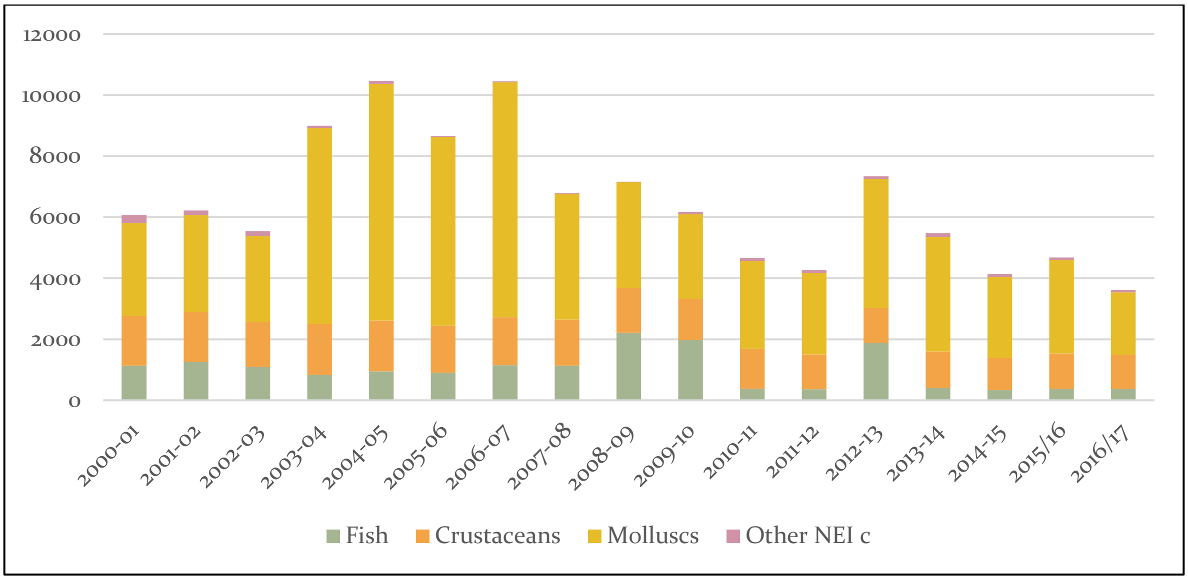

Figure 7. Tasmania fisheries production (tonnes) by major fishery. Other NEI – not elsewhere included. (Source: ABARES Fisheries Statistics).

Declines in catches off Tasmania are attributed to various factors. The decline in catches of scallops is a combination of exploitation and subsequent management response, and natural variability. Management shift to an MEY target rather than MSY have led to reductions in the catches of southern rock lobsters, plus the need to rebuild stocks in some areas. Abalone catches on the east coast has been reduced with lower TACs in response to overfishing plus declining productivity from marine heat waves and the invasion of the spiny sea urchin *Centrostephanus* (Mundy and McAllister, 2018). Total fish and shark catches have declined so that they are now only a relatively small portion of the total catch. A typical example is trends in the catch of Australian salmon which has declined from almost 500 t to around 50 t. Declining beach price of most scalefish species indicates, this decline in catch is in response to markets and competition from aquaculture (Atlantic salmon) rather than depleted stocks.

5.1.7 Northern Territory

While catches have remained relatively stable at approximately 5,500 t, the composition of catches have changed substantially since 2000 (Figure 8). Effectively, reductions in catch in the Barramundi, Mud Crab, Offshore Net and Line, and Trepang fisheries have been offset by substantial increases in the Demersal Fishery and to a lesser extent the Timor Reef Fishery.

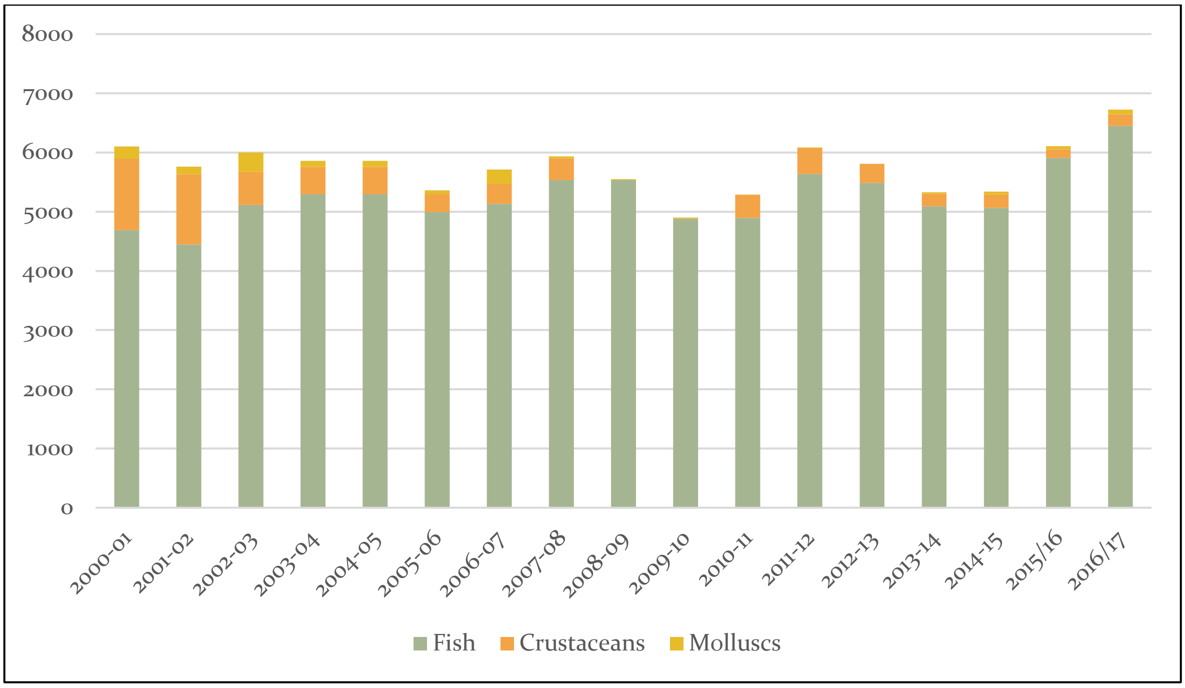

Figure 8. Northern Territory fisheries production (tonnes) by major fishery (Source: ABARES Fisheries Statistics)

Detailed comment on some specific fisheries are as follows.

- **The Barramundi and Mud Crab** catches are known to have a strong positive correlation between recent year's rainfall and population size (Robins et al., 2005; Meynecke et al., 2012). Contemporary catches, as a proportion of the NT total, by these fisheries have been much lower than historic levels due to successive poor wet seasons and a halving of effort through a reduction in the number of licences in the Barramundi Fishery.
- **The Timor Reef and Demersal fisheries** target tropical snappers. In 2012, these fisheries introduced new management arrangements, including the setting of TACCs that have allowed these fisheries to expand.
- **The Offshore Net and Line Fishery** targets sharks and Grey Mackerel. The proportion of sharks landed by this fishery has reduced over time due to the increasing value of Grey Mackerel. Additionally, a reduction in shark fin prices has meant that the long line vessel in the fleet has not operated since 2012. Total catches in this fishery have reduced commensurable with the shift in prices and effort.
- **The Trepang Fishery** has substantially reduced in catch as the single licence holder has been exploring ranching rather than focusing on wild capture.

5.1.8 Victoria

Catches were between 5,000 to 6,000 t during the 2000s but have declined to just under 5,000 t in recent years (Figure 9). The bulk of the reduction was due to reduced catches of scallops, abalone and southern rock lobsters, whereas fish catches have been variable but relatively stable.

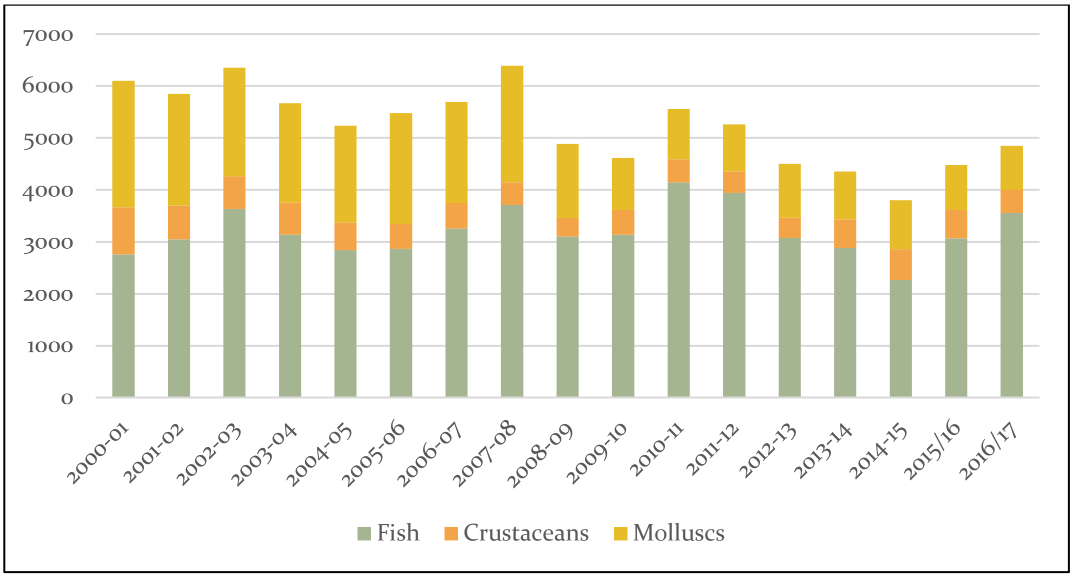

Figure 9. Victoria fisheries production (tonnes) by major fishery (Source ABARES: Fisheries Statistics)

The decline in scallop catches is a combination of exploitation and subsequent management response, and natural variability. Abalone catches are about half of what they were. Much of that decline was due to the disease that impacted the fishery and the subsequent management response, particularly in the Western Zone. Catches of southern rock lobsters have declined primarily due to management response to exploitation levels.

5.2 Methods to estimate MSY

The total Australian annual catch (averaged over 2014/15-2016/17) was 165,715 t. MSY estimates were obtained for 290 species/stocks that comprised 84% of current landings (Table 2). The number of species/stocks assessed, and the proportion of catch these made up of the total catch varied among jurisdictions, from 17 (Northern Territory) to 62 (Commonwealth) species and 70.5 to 95.4% of annual catches, respectively (Table 2).

Table 2. Catch (t) of species with MSY estimates (and number of assessed species/stocks) compared to total production for each jurisdiction – average catch 2014/15-2016/17.

Jurisdiction	Total catch (t)	Catch for species with MSY estimates (t)	Species with MSY estimates	Non-assessed catch (t)	% total catch with MSY estimates
Commonwealth	49,077	38,106	62	10,971	77.6
South Australia	50,085	47,765	37	2,320	95.4
Western Australia	20,878	17,522	58	3,356	83.9
Queensland	19,650	13,862	31	5,788	70.5
NSW	11,447	8,926	29	2,521	78.0
Tasmania	4,146	3,547	34	599	85.6
Northern territory	6,058	5,666	17	392	93.5
Victoria	4,374	3,581	22	793	81.9

Total	165,715	138,975	290	26,740	83.9

In this section we describe the methods used to estimate MSY and the number of species (and their tonnage) for which estimates were obtained. Overall, approximately 75% of estimates of MSY were produced as a direct result of this project. The remainder were based on existing assessments or from their outputs. However, assessment methods used varied considerably among jurisdictions. Results are summarised in Table 3 and for key species plus the remainder aggregated, are tabulated for each jurisdiction in Tables 4 to 11. MSY estimates and implications for production are also described in the next section. Further details for each jurisdiction (considering confidentiality issues) are given in Appendices 8 to 15.

5.2.1 Commonwealth

MSY was estimated for 62 species/stocks comprising 38,106 t, 77.6% of the total annual catch (Table 2). As indicated above, current Australian TACs were used as proxies for MSY for the nine tropical tunas and billfish (Table 4). Of the remaining 53 species/stocks, 22 estimates of MSY were calculated as a part of this project. Catch-MSY (Appendix 7) was used to estimate MSY for 15 species in the SESSF. These were the Tier 3&4 species for which model-based assessment are not available (e.g. Tuck, 2016). MSY was estimated for small pelagic species using the method outlined in Appendix 5. For the remaining species, MSY was obtained from existing assessments using the approach outlined in Appendix 4. The Commonwealth target is B_{MEY}, but MSY estimates were calculated for stocks with B_{MEY} targets. The majority of such stocks were data-rich, with MSY estimates based on data-rich assessments, referred to as Tier 1-type assessments in the SESSF (e.g. Tuck, 2016a), (Table 4, Appendix 8).

Assessments for three species were cross-jurisdictional, southern bluefin tuna (SBT), eastern school whiting and tiger flathead. For SBT, MSY was estimated for the whole stock and the estimate presented in Table 4 was derived from the proportion that the Australian catch made up of the total catch. Here it is assumed that the potential increase in the Australian catch follows the same proportion. A similar approach was taken for whiting and flathead between the Commonwealth and NSW.

5.2.2 South Australia

MSY was estimated for 37 species/stocks comprising 47,765 t (or 95.6%) of the total annual catch (Table 2). Catch-MSY was used to estimate MSY for 30 species. A range of other methods, from surplus production to Stock Synthesis, were used to estimate MSY for the other seven species/stocks (Table 5, Appendix 9).

Recreational catches were included in the assessments for 21 species. A commercial MSY was calculated by applying the ratio of the commercial catch to the total catch to the overall MSY estimate. The recreational catch data were estimated based on four recreational fishing surveys conducted in South Australia in 1995/96, 2000/01, 2007/08 and 2013/14 (McGlennon and Kinloch, 1997; Jones and Doonan, 2005; Jones, 2009; Giri and Hall, 2015). Linear interpolation was conducted between two successive surveys to estimate recreational harvest in years between the surveys. Recreational catch estimates for the years prior the first survey in 1995/96 were calculated by scaling catches to match changes in South Australian human population over time. Recreational catches by weight were then summed with commercial catches to determine total annual catch (t) for each species. Total annual catch was used as a single series in catch-MSY, while catches by each sector (commercial and recreational) were fitted individually for southern rock lobster, garfish and King George whiting in their respective integrated models.

5.2.3 Western Australia

MSY was estimated for 58 species/stocks comprising 17,522 t (or 83.9%) of the total annual catch (Table 2). Catch-MSY was used to estimate MSY for 57 species/stocks using commercial data only (Table 6, Appendix 10).

For western rock lobster, a biomass dynamics model was fitted to the following time series: catch (commercial and recreational) for 1944 until 2017; commercial catch-rate for 1950 – 2017; independent index of abundance for 1991 – 2017; and water temperature spanning 1991 – 2017 (de Lestang et al., 2016).

5.2.4 Queensland

MSY was estimated for 31 species/stocks comprising 13,862 t (or 70.5%) of the total annual catch (Table 2). Several stock assessment models were used to estimate MSY including age-, length- and/or sex-structured models, monthly length-/age-models, and monthly delay-difference models (Table 7, Appendix 11). In addition, regional age structured models were used for three species and catch-MSY for two species.

For 12 species/stocks, MSY estimates were for multiple jurisdictions: NSW (7 species), Northern Territory (3 species), QLD/NT/NSW (1 species) and QLD/NSW/Vic (1 species). Recreational catches were included in the assessments for 14 species. In all cases, MSY was calculated for the Queensland commercial catch based on the current cross-jurisdictional and recreational catch components. Only differences between the Queensland "commercial" MSY estimate and the current 3-year average commercial catch are reported. The other commercial components were included in the appropriate State sections. The assessment for grey mackerel in the Gulf of Carpentaria was undertaken by NT Fisheries and the NT and Queensland catches were apportioned accordingly.

5.2.5 New South Wales

MSY was estimated for 29 species/stocks comprising 8,926 t (or 78%) of the total annual catch (Table 2). Catch-MSY was used to estimate MSY for 19 species/stocks (Table 8, Appendix 12). A population model that accounts for recreational and unreported catches (NSW DPI 2018, G Liggins, Pers comm) was used for eastern rock lobster. The "commercial" MSY for eastern rock lobster has been adjusted to account for non-commercial catches. MSY estimates for seven species were obtained from assessments undertaken by Queensland and two from assessments for Commonwealth species (Table 8, Appendix 12). MSY estimates for east-coast blue mackerel and Australian sardine were included under the Commonwealth, acknowledging that these are shared stocks with NSW.

5.2.6 Tasmania

MSY was estimated for 34 species/stocks comprising 3,547 t (or 85.6%) of the total annual catch (Table 2). Catch-MSY was used to estimate MSY for 31 species. The estimate for Australian sardines was derived from daily egg production surveys (Ward et al., 2015). For banded morwong, MSY was estimated using an age-structured model implemented using CASAL (Moore et al., 2018) (Table 9, Appendix 13).

5.2.7 Northern Territory

MSY was estimated for 17 species/stocks comprising 5,666t (or 93.5%) of the total annual catch (Table 2). Stochastic stock reduction analysis (Lombardi and Walters, 2011) was used to assess 12 stocks and catch-MSY 4 stocks. Mud crabs were assessed using a Deriso delay-difference model (Grubert et al., 2019) (Table 10, Appendix 14). The estimate of MSY for grey mackerel in the Gulf of Carpentaria included NT and Queensland catches and was apportioned accordingly.

Recreational fishing and charter vessel catches were used in the assessment of 16 stocks and the "commercial" MSY calculated from the MSY estimate based on the ratio of the commercial catch to the total catch by stock.

5.2.7 Victoria

MSY was estimated for 22 species/stocks comprising 3,581 t (or 81.9%) of the total annual catch (Table 2). Catch-MSY was used to estimate MSY for all species/stocks (Table 11, Appendix 15).

5.3 MSY Estimates and Potential Production

The total MSY for the species assessed across all jurisdictions was 344,634 t (Table 3). This represents a potential increased production of almost 206,000 t relative to the current average catch of 138,975 t of the assessed species. Adding the non-assessed species average catch of just over 26,741 t gives a total potential production of just over 371,000 t. This is more than double the current national catch.

However, potential increases in production varied considerably among jurisdictions (Table 3). The potential for increased production, in absolute terms, was particularly high for Commonwealth and South Australian, and, to a lesser extent, Western Australian commercial fisheries. This, in part, reflects the influence of highly productive small pelagic fisheries. The implications of this are dealt with in more detail below.

Results for key species plus the remainder aggregated are tabulated for each jurisdiction in Tables 4 to 11. These tables present the MSY estimate, the average 3-year catch, the assessment method used and a key reference for each assessed species. These MSY estimates are for the commercial fisheries for that species in each jurisdiction. As described in the Methods section, they account for commercial catches in other jurisdictions and recreational catches where they were used in the assessments. Further details, including additional species, the data period, and total MSY estimates (e.g. including recreational/charter boat catches, for each jurisdiction are given in Appendices 8-15). Some species are aggregated for confidentiality reasons (e.g. x).

The difference between MSY and the current catch for each species/stock has to be interpreted carefully. Where MSY is greater than current catch, it is not suggested that this catch could be taken directly. It depends on the current biomass level of a particular species/stock and the target reference point adopted for management of that species, for example B_{MEY} for Commonwealth fisheries.

When the current catch is greater than MSY for a species/stock, potential reasons are dealt with individually in the different jurisdictional sections. In addition, Section 5.3.9, "Current catches versus MSY estimates", presents a comparative analysis of species/stocks where current average catches are greater than MSY estimates and discusses the implications of the assessment methods used.

Table 3. Comparison of total estimated MSY with current catch (2014/15-2016/17) and estimated total potential production by jurisdiction.

Jurisdiction	Current average catch (t)	MSY	Difference	Non-assessed	Total potential
	MSY species	estimate (t)	(t)	catch (t)	production (t)
Commonwealth	38,106	158,287	120,181	10,971	169,258
South Australia	47,765	89,132	41,367	2,320	91,452
Western Australia	17,522	37,485	19,963	3,357	40,842
Queensland	13,862	20,568	6,706	5,788	26,356
NSW	8,926	13,218	4,292	2,521	15,739
Tasmania	3,547	9,198	5,651	599	9,797
Northern Territory	5,666	11,883	6,217	392	12,275
Victoria	3,581	4,863	1,282	793	5,656
Total	138,975	344,634	205,659	26,741	371,375

Table 4 Commercial MSY estimate and average 3 year catch for selected Commonwealth species/stocks. Other species include minor species/stocks and those aggregated for confidentiality reasons. APP4 and APP5 refers to Appendix 4 and 5, this report. MI is... Hi is…

Species name	Common name	MSY (t)	Av 3 yr catch (t)	Method	Reference
Centroberyx gerrardi	Bight Redfish	625	267	SS3 App4	Haddon (2016)
Platycephalus conatus	Deepwater Flathead	1,200	695	SS3 App4	Haddon (2016)
Metapenaeus endeavouri, M. ensis	Prawn Endeavour	2,080	896	delay difference	Hutton et al (2018), Turnbull et al (2009)
Penaeus esculentus, Penaeus semisulcatus	Prawn Tiger	3,337	2,242	size-age structured	Hutton et al (2018), O'Neill et al (2006)
Penaeus indicus	Prawn Red-Leg Banana	750	142	statistical popn dynamics	Hutton et al (2018)
Macruronus novaezelandiae	Blue Grenadier	4,492	1,461	SS3 App4	Tuck (2014)
Seriolella brama	Blue Warehou	1,833	10	SS3 App4	Punt (2008)
Hyperoglyphe antarctica	Blue-Eye Trevalla	588	309	Catch-MSY	This report
Various	Deepwater Sharks	259	80	Catch-MSY	This report
Rexea solandri	Gemfish Eastern	1,219	74	SS3 App4	Little and Rowling (2009)
Rexea solandri	Gemfish Western	761	59	SS3 App4	
Sillago flindersi	Eastern School Whiting	973	729	SS3 App4	Day (2017)
Mustelus antarcticus	Gummy Shark	4,375	2,347	statistical popn dynamics	Punt and Thompson (in prep)
Nemadactylus macropterus	Jackass Morwong	654	174	SS3 App4	Tuck et al (2016a,b)
Hoplostethus atlanticus	Orange Roughy, Eastern Zone	2,315	380	SS3 App4	Haddon (2017)
Hoplostethus atlanticus	Orange Roughy, Other	681	25	SS3 App4, ASPM	Wayte This report
Oreosomatidae	Oreo	248	122	Catch-MSY	This report
Genypterus blacodes	Pink Ling	1,578	869	SS3 App4	Whitten and Punt (2014)

Species name	Common name	MSY (t)	Av 3 yr catch (t)	Method	Reference
Centroberyx affinis	Redfish, Eastern	913	66	SS3 App4	Day (2017)
Seriolella punctata	Silver Warehou	2,064	342	SS3 App4	Burch et al (2019)
Platycephalus richardsoni	Tiger Flathead	2,854	2,850	SS3 App4	Day et al (2016)
Dissostichus eleginoides	Patagonian Toothfish MI	588	440	SS3	Day and Hilary (2017)
Dissostichus eleginoides	Patagonian Toothfish HIMI	3,405	2,967	SS3	Ziegler and Welsford (2015)
Panulirus ornatus	Torres Strait Rock Lobster	680	570	statistical popn dynamics	Plaganyi et al (2017)
Scomberomorus commerson	Spanish Mackerel	111	75	age-structured	Hutton et al (2019)
Plectropomus leopardus	Coral Trout	141	40	age-structured	Hutton et al (2019)
Thunnus maccoyii	Southern Bluefin Tuna	11,530	5,489	statistical popn dynamics	Hilary et al (2017)
Sardinops sagax	Australian Sardine	38,536	127	App5	This report
Scomber australasicus	Blue Mackerel	26,723	2,500	App5	This report
Trachurus declivis	Jack Mackerel	17,730	5,062	App5	This report
Emmelichthys nitidus	Redbait East	5197	121	App5	This report
	Tuna and billfish, east	7,592	5,058	TAC	
	Tuna and billfish, west	10,125	357	TAC	
	Other species	2,129	1,161	Catch-MSY	This report
	Total	**158287**	**38106**		

Table 5 Commercial MSY estimate and average 3 year catch for selected South Australian species/stocks. Other species include minor species/stocks and those aggregated for confidentiality reasons. APP5 refers to Appendix 5, this report. SG is Spencer Gulf, GSV, Gulf of St Vincent.

Scientific Name	**Common name**	**MSY**	**Av 3 yr Catch (t)**	**Method**	**Reference**
Haliotis rubra	Abalone Blacklip	452	353	Catch-MSY	This report
Haliotis laevigata	Abalone Greenlip	501	349	Catch-MSY	This report
Arripis truttaceus	Australian Herring	155	86	Catch-MSY	This report
Arripis georgiana	Australian Salmon	686	365	Catch-MSY	This report
Sardinops sagax	Australian Sardine	79,000	39,548	SS3	Ward et al (2017)
Potunus armatus	Blue Crab	722	655	catchMSY	This report
Hyporhamphus melanochir	Garfish	117	167	length-age structured	McGarvey et al (2007).
Sillaginodes punctatus	King George Whiting	835	274	length-age structured	McGarvey et al. in prep
Monacanthidae	Leather Jackets	36	25	Catch-MSY	This report
Nelusetta ayraudi	Ocean Jackets	433	163	Catch-MSY	This report
Octopus spp.	Octopus	14	12	Catch-MSY	This report
Donax deltoides	Pipi	921	536	SimpleSA surplus prod	This report
Ovalipes australiensis	Sand Crab	84	52	Catch-MSY	This report
Chrysophrys auratus	Snapper - SG	143	60	DEPM/App5	McGarvey et al (2018)
Chrysophrys auratus	Snapper - GSV	125	325	DEPM/App5	McGarvey et al (2018)
Sphyraena novaehollandiae	Snook	55	46	Catch-MSY	This report
Sepioteuthis australia	Southern Calamari	450	394	Catch-MSY	This report
Jasus edwardsii	Southern Rock Lobster	1,408	1,575	Length structured	McGarvey et al (2016).
Katelysia spp.	Vongole	158	65	Catch-MSY	This report
Panaeus (Melicertus) latisulcatus	Western King Prawns	2,609	2,528	Catch-MSY	This report

Aldrichetta forsteri	Yellow Eye Mullet	55	17	Catch-MSY	This report
Sillago schomburgkii	Yellowfin Whiting	123	119	Catch-MSY	This report
	Other species	51	51	Catch-MSY	This report
	Total	**89,132**	**47,765**		

Table 6 Commercial MSY estimate and average 3 year catch for selected Western Australian species/stocks. Other species include minor species/stocks and those aggregated for confidentiality reasons.

Scientific Name	Common name	MSY	Av 3-yr Catch (t)	Method	Reference
Arripis georgianus	Australian Herring	743	81	Catch-MSY	This report
Sardinops sagax	Australian Sardine	8,314	1,990	Catch-MSY	This report
Ylistrum balloti	Ballot's Saucer Scallop	4,600	1,127	Catch-MSY	This report
Penaeus merguiensis	Banana Prawn	457	321	Catch-MSY	This report
Lates calcarifer	Barramundi	51	51	Catch-MSY	This report
Carcharhinus, Loxodon & Rhizoprionodon spp.	Blacktip Shark	46	0	Catch-MSY	This report
Metapenaeus endeavouri	Blue Endeavour Prawn	368	298	Catch-MSY	This report
Portunus armatus	Blue Swimmer Crab	677	544	Catch-MSY	This report
Lethrinus punctulatus	Bluespotted Emperor	537	354	Catch-MSY	This report
Lutjanus erythropterus	Crimson Snapper	252	215	Catch-MSY	This report
Carcharhinus obscurus	Dusky Whaler	302	148	Catch--MSY	This report
Cnidoglanis macrocephalus	Estuary Cobbler	123	63	Catch-MSY	This report
Pristipomoides multidens	Goldband Snapper	677	709	Catch-MSY	This report
Haliotis laevigata	Greenlip Abalone	174	106	Catch-MSY	This report

Scientific Name	Common name	MSY	Av 3-yr Catch (t)	Method	Reference
Mustelus antarcticus	Gummy Shark	429	406	Catch-MSY	This report
Chrysophrys auratus	Pink Snapper	692	275	Catch-MSY	This report
Lutjanus sebae	Red Emperor	306	292	Catch-MSY	This report
Lethrinus miniatus	Redthroat Emperor	66	52	Catch-MSY	This report
Haliotis roei	Roe's Abalone	107	52	Catch-MSY	This report
Carcharhinus plumbeus	Sandbar Shark	158	33	Catch-MSY	This report
Mugil cephalus	Sea Mullet	459	208	Catch-MSY	This report
Pinctada maxima	Silverlip Pearl Oyster	212	186	Catch-MSY	This report
Jasus edwardsii	Southern Rock Lobster	56	40	Catch-MSY	This report
Lethrinus nebulosus	Spangled Emperor	201	100	Catch-MSY	This report
Scomberomorus commerson	Spanish Mackerel	324	287	Catch-MSY	This report
Penaeus esculentus & P. monodon	Tiger Prawn	1,003	855	Catch-MSY	This report
Glaucosoma hebraicum	West Australian Dhufish	161	45	Catch-MSY	This report
Arripis truttaceus	West Australian Salmon	1,652	138	Catch-MSY	This report
Melicertus latisulcatus	Western King Prawn	1,749	1,450	Catch-MSY	This report
Panulirus cygnus	Western Rock Lobster*	11,115	6,193	Biomass dynamic	de Lestang et al. (2016)
Aldrichetta forsteri	Yelloweye Mullet	317	16	Catch-MSY	This report
Sillago schomburgkii	Yellowfin Whiting	181	86	Catch-MSY	This report

Scientific Name	Common name	MSY	Av 3-yr Catch (t)	Method	Reference
	Other species	622	393	Catch-MSY	This report
	Total	**37,485**	**17,522**		

Table 7 Commercial MSY estimate and average 3 year catch for selected Queensland species/stocks.

Species name	Common name	MSY (t)	Av 3 yr catch (t)	Method	Reference
Ylistrum balloti	Ballot Saucer Scallop	500	212	Monthly-age-structured	Yang et al 2016
Penaeus merguiensis, P. indicus	Banana Prawn	802	634	Age-structured	Tanimoto et al (2006)
Portunus armatus	Blue Swimmer Crab	499	427	Monthly length-structured	Sumpton et al (2017)
Platycephalus fuscus	Dusky Flathead	39	44	Sex, age and length structured	Leigh et al (2019)
Carcharhinus spp. & *Sphyrnidae* spp.	Whaler & Hammerhead shark	1,272	410	Regional-age-structured	Leigh (2016)
Plectropomus leopardus	Common Coral Trout	1,648	806	Regional-age-structured	Campbell et al (2019)
Lutjanus erythropterus	Crimson Snapper	155	36	Age-structured	O'Neill et al (2011)
Melicertus plebejus	Eastern King Prawn	2,478	2,661	Population dynamic model	O'Neill et al (2014)
Metapenaeus endeavouri, M. ensis	Endeavour Prawn	1,112	491	Weekly delay-difference	Wang et al (2015)
Lutjanus johnii	Golden Snapper	55	2	Age-structured	O'Neill et al (2011)
Scomberomorus semifasciatus	Grey Mackerel	2,014	807	Sex age-structured, stochastic SRA	Bessell-Browne et al (2019)
Lutjanus argentimaculatus	Mangrove Jack	24	5	Age-structured	O'Neill et al (2011)
Glaucosoma scapulare	Pearl Perch	61	29	Age length structured	Sumpton et al (2017)
Lutjanus sebae	Red Emperor	23	1	Age-structured	O'Neill et al (2011)
Lethrinus miniatus	Redthroat Emperor	431	230	Regional-age-structured	Leigh et al (2006)
Melicertus longistylus	Redspot King Prawn	716	191	Weekly delay-difference	Wang et al (2015)

Species name	Common name	MSY (t)	Av 3 yr catch (t)	Method	Reference
Lutjanus malabaricus	Saddletail Snapper	164	24	Age-structured	O'Neill et al (2011)
Sillago ciliata	Sand whiting	348	209	Age length structured	Leigh et al (2019)
Mugil cephalus	Sea Mullet	2,134	1,599	Sex and age-structured	Lovett et al (2018)
Chrysophrys auratus	Snapper	81	63	Age-structured	Wortmann et al (2018)
Scomberomorus commerson	Spanish Mackerel	246	293	Age-structured	O'Neill et al (2018)
Ranina ranina	Spanner Crab	1,138	1,063	multiple	O'Neill (unpublished results)
Scomberomorus munroi	Spotted Mackerel	92	138	Sex and age-structured	Bessell-Browne et al (2018)
Sillago robusta	Stout Whiting	1,097	805	Age-structured	O'Neill and Leigh (2016)
Pomatomus saltatrix	Tailor	351	65	Age length structured	Leigh et al (2017)
Penaeus esculentus, Penaeus semisulcatus	Tiger Prawns	1,836	1,482	Weekly delay-difference	Wang et al (2015)
Acanthopagrus australis	Yellowfin Bream	227	131	Age- and length-structured	Leigh et al (2019)
Scylla serrata	Mud crab	1,025	1,006	Catch-MSY	This report(Northrop et al., 2019)
	Total	**20,568**	**13,862**		

Table 8 Commercial MSY estimate and average 3 year catch for selected New South Wales species/stocks. Other species include minor species/stocks and those aggregated for confidentiality reasons.

Species name	Common name	MSY (t)	Av 3 yr catch (t)	Method	Reference
Portunus armatus	Blue Swimmer Crab	164	176	Catch-MSY	This report
Platycephalus caeruleopunctatus	Bluespotted Flathead	221	91	Catch-MSY	This report
Ibacus spp.	Bugs	59	24	Catch-MSY	This report
Platycephalus fuscus	Dusky Flathead	189	140	Catch-MSY	This report
Arripis trutta	East Australian Salmon	1,015	757	Catch-MSY	This report

Metapenaeus macleayi	Eastern School Prawn	972	649	Catch-MSY	This report
Hyporhamphus autralis	Eastern Sea Garfish	99	37	Catch-MSY	This report
Nemadactylus douglasii	Grey Morwong	199	23	Catch-MSY	This report
Girella tricuspidata	Luderick	538	290	Catch-MSY	This report
Scylla serrata	Giant Mud Crab	146	185	Catch-MSY	This report
Argyrosomus japonicus	Mulloway	142	77	Catch-MSY	This report
Nelusetta ayraudi	Ocean Jacket	405	288	Catch-MSY	This report
Donax deltoides	Pipi	257	158	Catch-MSY	This report
Sillago ciliata	Sand Whiting	143	99	Catch-MSY	This report
Mugil cephalus	Sea Mullet	4,216	2,742	Age structured	Lovett et al (2018)
Sepioteuthis australis	Southern Calamari	70	45	Catch-MSY	This report
Acanthopagrus australis	Yellowfin Bream	419	279	Catch-MSY	This report
Seriola lalandi	Yellowtail Kingfish	276	95	Catch-MSY	This report
Trachurus novaezelandiae	Yellowtail Scad	404	407	Catch-MSY	This report
Sagmariasus verreauxi	Eastern Rock Lobster	171	157	Population model	G. Liggins unpublished
Haliotis rubra	Blacklip Abalone	382	129	Catch-MSY	This report
Pagrus auratus	Snapper	223	174	age-length structured	Wortmann et al (2018)
Melicertus plebejus	Eastern King Prawn	622	668	Population model	O'Neill et al (2014)
Sillago robusta	Stout Whiting	261	195	age structured	O'Neill unpublished
Pomatomus saltatrix	Tailor	335	62	age length structured	Leigh et al (2017)
Sillago flindersi	Eastern School Whiting	1,097	805	Stock Synthesis 4	Tuck
	Other species	192	175	various	
	Total	**13,218**	**8,926**		

Table 9 Commercial MSY estimate and average 3 year catch for selected Tasmanian species/stocks. Other species include minor species/stocks and those aggregated for confidentiality reasons.

Species name	Common name	MSY (t)	Av 3 yr catch (t)	Method	Reference
Haliotis rubra	Abalone Blacklip	2,163	1,613	Catch-MSY	This report
Haliotis laevigata	Abalone Greenlip	164	148	Catch-MSY	This report
Arripis trutta	Australian Salmon	599	50	Catch-MSY	This report
Sardinops sagax	Australian Sardine	3,000	11	DEPM	Ward et al 2015
Thyrsites atun	Barracouta	140	1	Catch-MSY	This report
Cheilodactylus spectabilis	Banded Morwong	31	32	age-structured	Moore et al 2018
Latridopsis forsteri	Bastard Trumpeter	37	7	Catch-MSY	This report
Platycephalidae	All flathead species	81	62	Catch-MSY	This report
Nototodarus gouldi	Gould's Squid	309	209	Catch-MSY	This report
Trachurus declivis	Jack Mackerel	321	2	Catch-MSY	This report
Octopus spp.	Octopus species	96	80	Catch-MSY	This report
Sepioteuthis australis	Southern Calamari	93	100	Catch-MSY	This report
Hyporhamphus melanochir	Southern Garfish	70	24	Catch-MSY	This report
Jasus edwardsii	Southern Rock Lobster	1,635	1,087	Catch-MSY	This report
Latris lineata	Striped Trumpeter	45	11	Catch-MSY	This report
Notalabrus spp.	Wrasse	85	78	Catch-MSY	This report
	Other species	329	32	Catch-MSY	This report
	Total	**9,198**	**3,547**		

Table 10 Commercial MSY estimate and average 3 year catch for selected Northern Territory species/stocks.

Species name	Common name	MSY (t)	Av 3 yr catch (t)	Method	Reference
Lates calcarifer	Barramundi	1,741	361	Stochastic SRA	Unpublished
Scylla serrata	Mud Crab	618	195	Delay Difference	Grubert et al (2019)
Lutjanus malabaricus	Saddletail Snapper	1,286	1,971	Stochastic SRA	Martin (2018)
Lutjanus erythropterus	Crimson Snapper	687	731	Stochastic SRA	Unpublished paper
Pristipomoides multidens	Goldband Snapper	749	527	Stochastic SRA	Unpublished paper
Scomberomorus semifasciatus	Grey Mackerel	1,819	412	Stochastic SRA	Grubert et al (2013)
Carcharinus tilstoni/limbatus	Blacktip Shark	1,264	58	Stochastic SRA	Grubert et al (2013)
Scomberomorus commerson	Spanish Mackerel	2,173	419	Stochastic SRA	Grubert et al (2013)
Carcharinus sorrah	Spottail Shark	630	9	Stochastic SRA	Grubert et al (2013)
Protonibea diacanthus	Black Jewfish	179	197	Stochastic SRA	Grubert et al (2013)
Lutjanus sebae	Red Emperor	91	89	Stochastic SRA	Unpublished
Lutjanus johnii	Golden Snapper	17	53	Stochastic SRA	Penny et al (2018)
Eleutheronema tetradactylum	Blue Threadfin	15	10	Catch-MSY	This report
Polydactylus macrochir	King Threadfin	310	262	Catch-MSY	This report
Lutjanus argentimaculatus	Mangrove Jack	14	66	Catch-MSY	This report
Unspeciated	Trevally	290	306	Catch-MSY	This report
	Total	**11,883**	**5,666**		

Table 11 Commercial MSY estimate and average 3 year catch for selected Victorian species/stocks. Other species include minor species/stocks and those aggregated for confidentiality reasons.

Species name	Common name	MSY (t)	Average 3 yr catch (t)	Method	Reference
Arripis georgiana	Australian Salmon	354	303	Catch-MSY	This report
Sardinops Sagax	Australian Sardine	1,543	1,683	Catch-MSY	This report
Haliotis rubra	Blacklip Abalone	1,366	717	Catch-MSY	This report
Acanthopagrus butcheri	Bream, Black	161	22	Catch-MSY	This report
Platycephalidae	Flathead Species	106	76	Catch-MSY	This report
Hyporhamphus melanochir	Garfish, Southern (Sea)	107	45	Catch-MSY	This report
Jasus edwardsii	Rock Lobster, Southern	445	279	Catch-MSY	This report
Chrysophrys auratus	Snapper	162	74	Catch-MSY	This report
Sillaginodes punctatus	Whiting, King George	137	106	Catch-MSY	This report
	Other species	483	276	Catch-MSY	This report
	Total	4,863	3,581		

5.3.1 Commonwealth

The total MSY for Commonwealth species/stocks assessed was just over 158,000 t, representing a potential increase of 120,000 t (Tables 3, 4; Appendix 8). Together with the catch of species that were not assessed, this leads to a total potential production of almost 170,000 t. This represents a potential tripling of the current catch.

The most striking potential increases include small pelagics, western tuna and billfish, southern bluefin tuna, various prawns and blue grenadier. The implications of small pelagic MSY estimates are dealt with separately below. Tropical tunas and billfish in the west are underutilised. SBT is a recovering stock and blue grenadier catches have been constrained in recent years by fleet dynamics.

Current catches of all species were below their estimated MSY (Table 4). This is, perhaps, not surprising, given the Commonwealth Fisheries Harvest Strategy Policy has target reference point of B_{MEY}. It also reflects catch limits applied to several species/stocks with biomass levels well below the target. However, for several species, particularly in the SESSF, catches are well below TACs or previously depleted stocks have not recovered despite reduced targeted fishing. The latter include eastern gemfish, blue warehou, and redfish. The reasons for under-caught TACs and non-recovery remain unclear (Knuckey et al., 2018).

5.3.2 South Australia

The total MSY for South Australian species/stocks assessed was just over 89,000 t, representing a potential increase of around 41,000 t (Tables 3, 5; Appendix 9). Together with the catch of species that were not assessed leads to a total potential production of almost 91,500 t. This represents an almost doubling of current catches (83%). However, the total MSY estimate for South Australia is dominated by Australian sardine (see below).

Current average catches are greater than MSY for 4 species/stocks:

- **Garfish** – Most catches are from northern part of the gulfs in the haulnet fishery. The Northern Gulf of St Vincent is classified as ‘depleted’ while Northern Spencer Gulf is classified ‘recovering’. Substantial management action implemented has included seasonal closures, increases to mesh size of nets, and raised minimum legal lengths. The next assessment is due in 2021.
- **Snapper** – Most of the catch occurs in the Gulfs. The Gulf of St Vincent stock is now classified as ‘depleting’, following deterioration in stock abundance from 2017. The Spencer Gulf/West Coast stock classified ‘depleted’, and has declined further since last assessment. Significant management action has been implemented (i.e. statewide 3-year closure except for south east part of SA), and has been coupled with a substantial research investment.
- **Southern Rock Lobster** – The South Australian Southern Zone is classified as "sustainable" while the Northern Zone is classified as "depleting" due to overfishing over two decades and lower lobster productivity (across all Australian Southern rock lobster jurisdictions) since around 2000. The current catch is about 11% above estimate MSY (173 t). For the Northern Zone, the TACC was reduced from 360 t in 2015 and 2016 to 310 t in 2017. It was further reduced to 296 t for 2018 and 2019. New harvest strategies have been endorsed (for the Southern Zone of SA) or are in development (for the Northern Zone) with rebuilding to the target over 15 years (to 2035).
- **Parrotfish** (Appendix 9) – low catches have driven high uncertainty in the Catch-MSY analysis. The SAFS classification for this species in South Australia is “sustainable”.

5.3.3 Western Australia

The total MSY for assessed Western Australian species/stocks was 37,485 t, representing a potential increase of almost 20,000 t (Tables 3, 6; Appendix 10). Together with the catch of species that were not assessed leads to a total potential production of 40,842 t. This represents a doubling of current catches.

Potential increases are apparent for most species. The largest include Australian sardine (see below), Ballots saucer scallops, Australian salmon and western rock lobster. For the latter, MEY is used as a target reference point.

Several species have current average catches greater than MSY:

- Average catches over the last 3-years of goldband snapper and saddletail snapper are slightly higher than their estimates of MSY.
- There has been high variability in recent catches and the implications of the assessments are under review. Bight redfish and black bream (these species are aggregated in "other") also had catches greater than their estimates of MSY, but differences were minor.

For all species other than western rock lobster, MSY was calculated in this report using the *simpleSA* package where default settings for initial and final depletion ranges were initially applied. These results demonstrate the uncertainty around the method. For example, where ancillary information indicated a lightly fished stock at the start of the times series, the initial depletion range was set to 0.5-0.975. Alternative final depletion ranges were applied according to whether the catch in the final year was more than half of the maximum catch in any year (0.15-0.7) otherwise 0.05-0.5. Additional information on stock status (http://fish.gov.au) was used for species listed as "sustainable" with final depletion range set to 0.15-0.7 and for a limited number of species final depletion was estimated from previous assessments.

5.3.4 Queensland

The total MSY for assessed Queensland species/stocks was just over 20,568 t, representing a potential increase of around 6,700 t (Tables 3, 7; Appendix 11). Together with the catch of species that were not assessed leads to a total potential production of just over 26,000 t. This represents a 34% difference in potential landings.

Potential differences were spread across most species, with coral trout, grey mackerel, and sharks the largest potential increases. However, four of the 29 species/stocks had average commercial catches greater than the estimated commercial MSY component. These fisheries exceeded the given MSY by 12% (dusky flathead), 7% (eastern king prawn), 19% (Spanish mackerel), and 49% (spotted mackerel). The tabulated MSYs were only for the Queensland commercial component, after apportioning assumed harvest shares to the other fishing sectors and/or jurisdictions. In general, MSY estimates alone are not a population indicator and stock assessments for these four species provided greater insight into the status of the stocks:

- **Dusky flathead** - the estimated 2017 spawning biomass of 36% of an unfished level was near the MSY reference point of 35%, and above the overfished reference point of 20% (Leigh et al., 2019).
- **Eastern king prawns** - the most recent assessment estimated that biomass in 2010 was 60–80% of the unfished 1958 level. More recently, for the Queensland component of the stock, standardised catch rates in 2016 and 2017 were mostly above MSY catch-rate reference-points, indicating the level of biomass was sufficient to sustain harvests near MSY (Prosser and Taylor, 2018).
- **Spanish mackerel** - the Queensland commercial MSY component was near the median estimate and below the upper commercial estimate around 400 t (O'Neill et al., 2018). These results suggest that fish population size estimates in the year 2016 were between

30–50% of original biomass estimates at the start of the fishery in 1911. The results indicate that the fishery in 2016 was at the biomass level for maximum sustainable yield (best estimate around 40% biomass).

- **Spotted mackerel** - since the implementation of management changes, fishing mortality has dropped below F_{MSY} and the current analyses predicted that spotted mackerel biomass has slowly increased (Bessell-Browne et al., 2019). Estimates of stock size ranged from 21 to 60% of unfished levels depending on assumptions of natural mortality and hyper-stability.

Currently for all four of these species and many others in Queensland, catch targets are being adjusted under the Sustainable Fisheries Strategy 2017–2027 to meet sustainable levels. The Sustainable Fisheries Strategy (QDAF 2017) defines target biomass reference point between 40–60%, which relates to managing fishing harvest and effort less than MSY.

5.3.5 New South Wales

The total MSY for assessed New South Wales species/stocks was just over 13,000 t, representing a potential increase of about 4,300 t (Tables 3, 8; Appendix 12). Together with the catch of species that were not assessed leads to a total potential production of around 15,700 t. This represents a 37% increase in potential landings, noting that substantially greater potential exists for the small pelagic species that are shared with the Commonwealth.

Potential increases are apparent for most species/stocks, in particular, Australian salmon, sea mullet and school prawns. The estimated MSY for several depleted (overfished) species (grey morwong, mulloway, blacklip abalone) are substantially greater than the current average catches, and these stocks have no capacity for increased harvest until they recover. Several species have current average catches greater than MSY. Blue swimmer crab and yellowtail scad had average current catches slightly higher than MSY (8 t and 3 t, respectively). The recent average catch for mud crab was the highest in the history of the fishery and this is reflected in catch being greater than MSY. It is believed to be partially due to high abundances in recent years, but also to a change in gear type and a response to fishing reforms.

The total average catch (NSW and QLD) for eastern king prawns is slightly (~7%) larger than the stock wide MSY estimate (Appendix 11). The MSYs for Queensland and NSW were estimated based on relative catches in recent years. This approach, however, does have limitations for estimates at the jurisdictional level if dynamics change in either or both jurisdictions. For example, the NSW fishery has had a major reduction in effort in recent years. Consequently, jurisdictional MSY estimates for multi-jurisdictional stocks should be treated cautiously.

5.3.6 Tasmania

The total MSY for assessed Tasmanian species/stocks was just over 9,000 t, representing a potential increase of around 5,600 t (Tables 3, 9; Appendix 13). Together with the catch of species that were not assessed leads to a total potential production of almost 10,000 t. This represents a 135% increase in potential landings. This result was influenced by the MSY estimate for Australian sardine. If this is removed, the potential increase is 64%.

Potential increases were spread across most species/stocks, with Australian sardine, Australian salmon and southern rock lobster the largest. It should be noted that while catches for blacklip abalone and southern rock lobster are lower than the estimate of MSY, catches are currently constrained by management to enable stock rebuilding and to target MEY (rock lobster). Southern rock lobster also has catch significantly reduced below MSY due to industry resistance to regulations better tailored to spatial patterns in the stock (Gardner et al., 2015).

Recent catches of some species were marginally higher than the MSY estimates (banded morwong: 1 t, and southern calamari: 7 t). In the case of calamari, the exceedance of MSY was caused by a large spike in catch in two recent years with the stock assessed as depleting in March

2019 (Moore et al. 2019). Closures were announced in September 2019 and came into effect in October 2019 (DPIPWE 2019).

5.3.7 Northern Territory

The total MSY for assessed Northern Territory species/stocks was almost 12,000 t, representing a potential increase of around 6,200 t (Tables 3, 10; Appendix 14). This figure combined with the catch of species that were not assessed increases the total potential production to 12,275 t and represents a doubling in potential landings.

Potential increases are apparent for many species, in particular, barramundi, mud crab, grey and Spanish mackerel, and various shark species. However, 6 of the 17 species/stocks assessed had recent commercial catches greater than the estimate of commercial MSY component:

- **Saddletail snapper** – this species which is targeted by the NT offshore snapper fisheries and represents an example of where current catch is substantially greater than the modelled MSY estimate. The biomass was estimated to be 18,000 t during an NT wide survey conducted in the early 1990's (Ramm, 1992, 1997). The most recent stock assessment for this species indicated that the current biomass is approximately 65% of unfished levels (Martin, 2018). The 1990s biomass estimate represented an historical low figure based on the model outputs (52% of unfished levels) as a consequence of significant Taiwanese catches (>3,000 t/year) of this species prior to the survey (Martin, 2018). Contemporary catches likely represent a sustainable fraction of a relatively large biomass and the (low) MSY estimated by the model is probably indicative of insufficient contrast in the abundance estimates based on recent low levels of fishing. In this scenario MSY will be biased towards lower estimates and the fishery could be considered in a development phase.
- **Golden Snapper -** the catch of this species is larger than the estimate of MSY. Golden Snapper has been recognised as an overfished species since 2011 (Grubert et al., 2013). Additional management actions were implemented for this species in 2015, including commercial catch limits and a series of area closures. The most recent model outputs indicate that there has been some improvement in the biomass however it remains in an overfished state (Penny et al., 2018).
- **Mangrove Jack** - the catch of this species is larger than the estimate of MSY. Historically, catches of mangrove jack have been on average approximately 15 t before they substantially increased from 2015 onwards (Langstreth et al., 2018). The catch-MSY model used for the assessment of this species has conservatively estimated at the MSY around the historical average and has given little "weight" to the recent higher catches.
- **Crimson snapper, black jewfish and trevally species** – catches slightly higher than the estimated MSYs (44 t, 18 t, and 16 t, respectively).

5.3.8 Victoria

The total MSY for assessed Victorian species/stocks was just over 4,800 t, representing a potential increase of around 1,300 t (Tables 3, 11; Appendix 15). Together with the catch of species that were not assessed leads to a total potential production of just over 5,600 t. This represents a 29% increase in potential commercial landings the lowest of any jurisdiction based on this analysis.

Some potential increases are apparent for almost all species/stocks in Table 11, in particular, southern rock lobster and blacklip abalone. However, catches of these species are currently constrained by management to enable stock rebuilding. The catch of Australian sardine is slightly higher than the estimated MSY, by 140 t (around 9%). However, there have been significant changes in the fishery that may have seen a negative bias in the MSY estimate. Three species aggregated within the “Other species” group (sand crab, pale octopus and tailor) also had catches greater than MSY. However, average catches and resultant MSY estimates were small 10 t or less.

5.3.9 Current commercial catches versus MSY estimates

Overall, the current catches for 41 of the 290 assessed species/stocks were larger than the corresponding estimate of MSY (Figure 10). However, the species/stocks where current catches were greater than MSY made up ~3.6% of all MSY estimates by weight. The sum of MSY estimates where catches were greater than MSY was 12,538 t compared to the sum of MSY estimates for species with catches less than MSY of 338,664 t. This indicates that the negative differences only make up a minor part of the total MSY estimates.

The current average catch exceeded MSY by at least 50 t for 7 out of the 41 species/stocks for which current average catches exceed MSY (Figure 10 lower panel). In contrast, the estimate of MSY exceeded the average current catch by at least 50 t for 146 of the 235 species/stocks for which current average catches were less than MSY. A Fisher’s Exact Chi-squared contingency test indicated a highly significant difference ($p<0.001$), with positive differences larger than 50 t being significantly more common when catches were less than MSY.

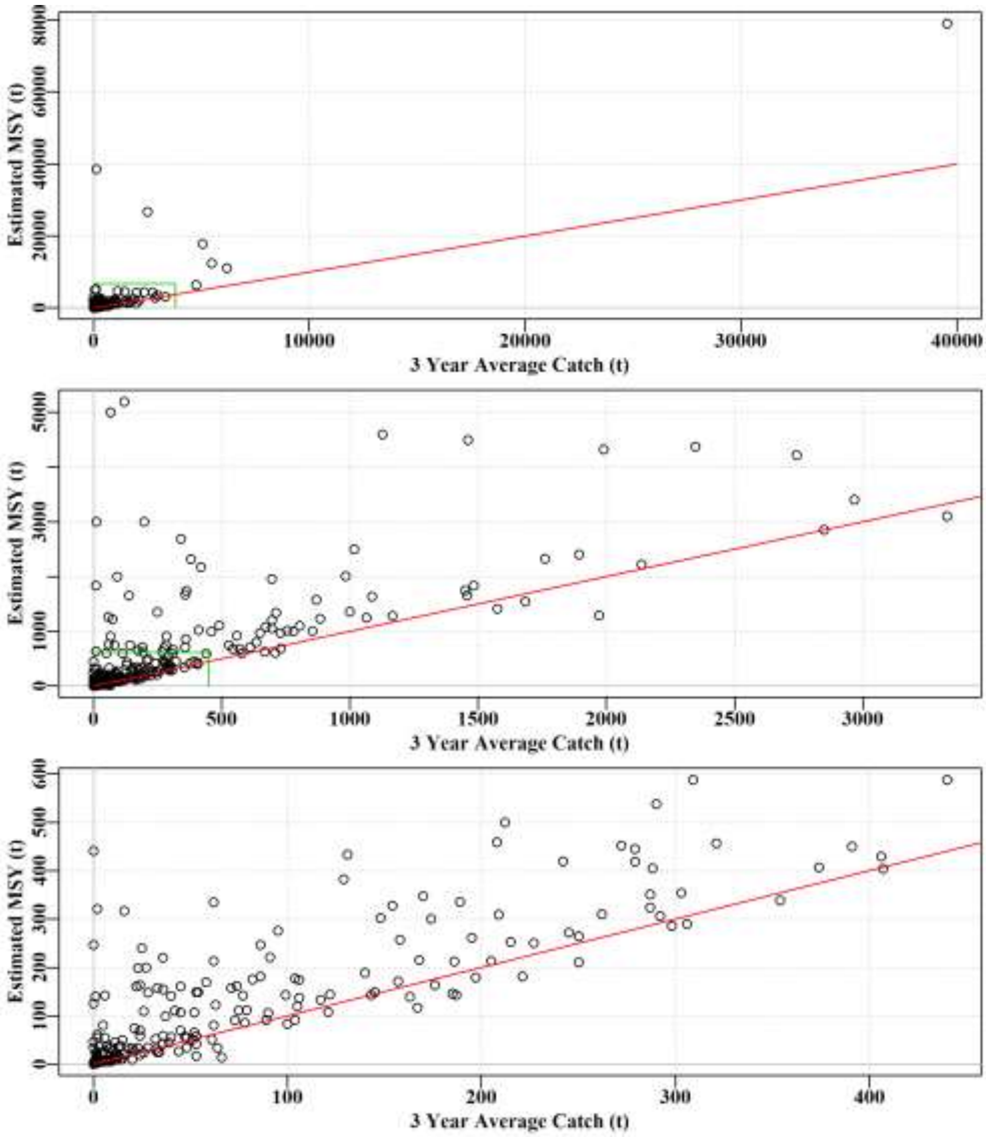

Figure 10. MSY versus average catch for 290 species/stocks assessed, with increasing detail in the lower plots, as defined by the green boxes in the upper plots, particularly for MSY estimates of less than 500t.

Catch-MSY was used extensively to estimate MSY in this study. Because it is a data-poor method delivering highly uncertain estimates, it was compared to other assessment methods to determine whether there was a relationship between the number of instances where the current average catch was greater than MSY and the method used to estimate MSY. A Fisher's Exact Chi-squared contingency test was applied to the ratios of catch-MSY to other methods for negative versus positive differences between the current catch and estimated MSY. No significant difference was found (p=0.1011). However, this was an overall analysis. When MSY estimates were grouped by tonnage there was a clear trend in the number of stocks where catch was greater than MSY and whether catch-MSY was the assessment method (Table 12).

Table 12 Relationship between average catch and MSY as moderated by the absolute level of the MSY estimate.

MSY range tonnes	Number stocks	Number av. catch>MSY	% av. catch>MSY	Number catch-MSY	% catch-MSY
>5,000	8	0	0	0	0
1,000-4,999	51	4	7.8	13	25.5
500-999	33	3	9.1	9	27.3
100-499	95	13	13.7	69	72.6
0-99	96	21	21.9	90	93.8

The proportion of species/stocks where the current average catch was greater than MSY increased as the MSY estimate decreased (Table 12). For example, when MSY was estimated to be larger than 5,000 t, catch was less than MSY and catch-MSY was typically not used as an assessment method. In contrast, for species with an MSY estimate less than 100 t, 21.9% had current average catches greater than MSY and catch-MSY was the assessment method for 93.8% of species. This result is perhaps not surprising. Those species/stocks with low MSY estimates and for which catch-MSY was used as an assessment method, were generally low catch and low value with limited data and differences were mostly small relative to current catches.

5.3.10 Implication of small pelagic fisheries on potential production

The potential for increased production, in absolute terms, was particularly high for Commonwealth, South Australian and Western Australian commercial fisheries. This, in part, reflects the influence of fisheries for highly productive small pelagic species. Reference points for small pelagic species are often set to reflect the ecosystem services these species provide. This is the case in Australia. Consequently, we examined the implications of fisheries for small pelagic species on overall potential production based on the three jurisdictions above. Three approaches are presented here:

1. total production based on all species;
2. excluding MSY estimates for small pelagic fishes, but including catches for “non-assessed” species; and
3. include small pelagic species but use current TACs instead of MSY estimates

The results are summarised presented in Table 13 for each jurisdiction and nationally in Table 14.

Table 13. Implications of MSY estimates for small pelagic species for Commonwealth, South Australian and Western Australian totals. Including MSY provides same totals as in the tables above. Excluding MSY estimates for small pelagic (SP) species involves adding the catches of these species to the non-assessed species totals. TACs refer to current total allowable catches.

Jurisdiction	MSY treatment	MSY species catch (t)	MSY estimate (t)	Difference (t)	Non-assessed species catch (t)	Total production (t)
Commonwealth	include MSY	38,106	158287	120,181	10,971	169,258
Commonwealth	Exclude SP MSY	30,296	70,101	39,805	18,781	88,882
Commonwealth	Include TACs	38,106	119,001	80,895	10,971	129,972
South Australia	include MSY	47,765	89,132	41,367	2,320	91,452
South Australia	Exclude SP MSY	8,217	10133	1,916	41,868	52,001
South Australia	Include TACs	47,765	52883	5,118	2,320	55,203
Western Australia	include MSY	17,522	37485	19963	3,357	40,842
Western Australia	Exclude SP MSY	15,532	29171	13639	5,347	34,518
Western Australia	Include TACs	17,522	34854	17332	3,357	38,211

Table 14. Implications of MSY estimates for small pelagic species for total production. Including MSY provides same totals as in Table 12. Excluding the estimates of MSY for small pelagic species involves adding the catches of these species to the non-assessed species totals. TACs refer to current total allowable catches.

Jurisdiction	MSY treatment	MSY species catch (t)	MSY estimate (t)	Difference (t)	Non-assessed species catch (t)	Total production (t)
Total	include MSY	138975	344634	205659	26741	371375
Total	Exclude SP MSY	89627	169135	79508	76089	245224
Total	Include TACs	138975	266468	127493	26741	293209

For Commonwealth fisheries, excluding MSY estimates for small pelagic species/stocks reduces the potential increase to about 80% of the original estimates. Including their TACs leads to a potential increase in production of around 160%. The results indicate that there is potential for significantly higher catches for other species.

MSY estimates for South Australia are particularly dominated by the influence of Australian sardine. Excluding the MSY estimate for Australian sardines sees the potential increase of other species at 4%. Including the sardine TAC gives an increase of 10%.

Excluding the estimate of MSY for Australian sardine in Western Australia reduces the potential increase in production to 65% and including the TAC to 83%. Similarly, to that for the Commonwealth, the results indicate that there is potential for significantly higher catches for other species.

Nationally, excluding small pelagic species/stocks implies a potential increase in catches of other species of about 80,000 t or 48% of current average catches. Including TACs for the small pelagic species implies a potential increase of 127,500 t or 77% of current catches. In either case there is the opportunity for a substantial increase in total catch.

5.3.11 Other Species

It is not possible to obtain quantitative estimates of MSY or potential production without adequate data. However, there are several unfished, lightly exploited or depleted stocks in most jurisdictions for which MSY estimates could not be obtained. In this study, unassessed species make up almost 27,000 t of average landings between 2014/15 and 2016/17. Given the potential doubling in the production of assessed species described, a similar increase is possible for unassessed species may well be possible, presuming they are currently not depleted and only lightly fished.

An additional potential catch of around 13,000 t has been suggested for Tasmania (C Gardener pers comm), comprising scallop species, following rebuilding, and various mollusc, echinoderm and crustacea species that are currently unfished or only lightly fished. A potential catch of 10,000 t of small pelagic species has been estimated for the Northern Territory (S Penny, Tim Ward unpublished). However, whether such catches are sustainable is unknown.

There is currently no active Commonwealth fishery for skipjack tuna although there are existing permits in both the Eastern and Western Skipjack Tuna fisheries. These species are taken in large quantities (greater than 1.5 million tonnes) in the western and central Pacific fisheries and the Indian Ocean (greater than 400,000 t; WCPFC 2018, IOTC-SC21 2018). Previous Australian catches ranged from 5,000 t to 9,000 t.

Many Australian fisheries have a significant bycatch that is usually discarded, particularly in the trawl fisheries. The catches of many of these species have been assessed as low risk using ERAEF (Hobday et al 2011). While there are on-going research projects on mitigation measures through technical solutions such as mesh size and mesh orientation, and bycatch reduction devices, for example, some bycatch is likely to remain. Currently tens of thousands of tonnes are discarded (Stevens 2019). Constraints to the retaining most of these species is due to market issues rather than concerns around sustainability (Stevens 2019)

While the above examples should be treated carefully, they do indicate that there is the potential for substantially increased production in addition to that from the MSY estimates.

5.4 Caveats and Assumptions

Caveats and assumptions to the approaches adopted here have both positive and negative aspects and biases. The aim of this project was to provide a first cut, approximate estimate of potential yield from Australia's commercial fisheries. While the results presented here should be treated cautiously, the project results still provide insights into biologically sustainable catches and the potential for increased production.

The Maximum Sustainable Yield (MSY) was chosen as a means of enabling a level of consistency across jurisdictions and species where different reference points might be used. The assumption is that MSY is a reasonable proxy for long-term sustainable production. However, it is important to note that we are not advocating MSY as a reference point or target, although it is widely used as such. Others consider the fishing mortality associated with MSY as more suited to be a limit reference point than a target. Setting reference points is a policy decision and not an objective of this project.

It is also important to note that many of the MSY estimates were derived specifically for this project. It is not suggested that such estimates, particularly those using catch-only data-poor methods, be used directly for management purposes without further work being undertaken. They are, however, indicative of potential production.

In general, MSY is a meaningful equilibrium concept for most species but it is of questionable validity for highly dynamic/variable species whose population size can exhibit considerable natural variation in the absence of fishing. Note, for these reasons scallops and squid were not included in the analyses undertaken, which implies total production will be under-estimated.

Fishing small pelagic species at their theoretical MSY implies substantial increases in potential production. We report total potential production including and excluding small pelagic species for two reasons. First, such species are often highly variable and thus the MSY estimates will be uncertain. Second, and more importantly, given the ecosystem function of small pelagic species it is unlikely MSY would be used as a reference point. In most Australian jurisdictions, catches are set at considerably more conservative levels.

Other factors that need to be considered when interpreting these results include:

- Some assessments completed for this project, particularly those using data-poor methods have not been independently reviewed and may be subject to change.
- The implications of climate change on productivity were beyond the scope of the current project and were not considered.
- The increase or decrease in catch relative to MSY for multi-sector and/or multi-jurisdictional species was estimated assuming the same proportion or “allocation” across these sectors and jurisdictions. Whether this would happen in reality is unclear and may vary among species.
- All stock assessments assume that fishing is the dominant influence on stock dynamics rather than management decisions, environmental influences or other factors. This can create increased uncertainty, particularly in assessments using the data-moderate and data-limited assessments (see below).
- Data are assumed to be representative of the fishery and estimates of catches from different sectors are assumed reasonable and consistent. In some cases, confidentiality issues around catch data can bias assessments because the time series is incomplete. Various jurisdictions, when reporting total annual catches, omit years where the number of fishers falls below some minimum number. An example of this can be seen at https://vfa.vic.gov.au/commercial-fishing/commercial-fish-production. In addition, discards were not accounted for in data-poor methods unless data on discards were already included in catch data.

- The project attempts to estimate potential production without considering species or fishing gear interactions. Such interactions may be technological and/or ecological. They are known to limit catches, particularly of minor species, in multi-species fisheries where species are caught together (Smith et al 2018).

Despite these uncertainties, the overall results indicating a potential increase in production are likely to be conservative. This conservatism is due to approximately 20% of total landings not being assessed and no increase in the potential catch of these species was assumed, species with zero or negligible catches that had some potential for increase were excluded and assessments of data-poor by-product species with a history of low catches, assume catches are representative of the productivity often leading to a conservative bias.

5.4.1 Catch-MSY

Additional comments regarding the assumptions and limitations of catch-MSY are warranted because it has been used extensively during this project. In common with all data-poor approaches it does have limitations and should be seen as a method of last resort (Haddon, 2018; Haddon et al., 2019; Dowling et al., 2019). The method assumes that changes in catch reflect changes in abundance and as with all stock assessment methods, contrast in the data (e.g. low and high catches reflecting changes in effort) is needed to obtain the most robust estimates.

There are major limitations to the catch-MSY method. If catches remain very low through, for example, a lack of a market, then the estimated MSY will also be low. Unlike more data-rich approaches the method does not reconstruct abundance from other information such as size- and age-structure, or biomass indices. If abundance declines through time due to a shift to lower productivity, for because of example climate change, the method will overestimate MSY. If catches are restricted in more recent years due to management constraints the method will assume this is a reflection of productivity and bias the MSY estimates low. At the same time, after a period of low catches, however they are caused, it may predict that the stock will increase, but such increases are purely a result of the deterministic model dynamics underlying the method. Any depletion estimates from the catch-MSY method, especially where recent catches have been lowered through management, should be confirmed through independent evidence rather than just accepting outputs from the catch-MSY method. Depletion estimates from catch-MSY are not reported here.

There are, however, positive aspects of the approach. It is useful in that it can provide estimates of MSY for commercial catches, even when recreational catches are significant (Haddon, 2018) because it effectively provides the commercial component of any potential for increased catches or conversely decreased catches.

The method is based on the Schaefer surplus production model (Martell and Froese, 2013), but alternative production models could be used (and this is under development in the *datalowSA* R package). The use of the Schaefer model implies that MSY is calculated at a (B_{MSY}) biomass equivalent to 50% of unfished levels. In many cases this would be a conservative assumption (Haddon, 2011). If catches decline due to management intervention or changed markets, for example, the method will produce a biased estimate of MSY that is also conservative.

During this project we have found that the method performs almost surprisingly well for species with a long time-series of catches that exhibit some contrast. For example, in western rock lobster the MSY is estimated from a formal data-rich stock assessment. However, the estimate obtained from using catch-MSY had a median estimate that was very similar, even if it had greater uncertainty.

6 Discussion and Conclusions

The aim of this project was to provide a first cut, approximate estimate of potential yield from Australia's commercial fisheries. It provides the first national assessment of sustainable catches. With the cooperation of stock assessment staff in each jurisdiction it was possible to complete this project covering the enormous diversity of fisheries and extensive details concerning each fishery of species included.

The focus of the project was on biological productivity and estimating Maximum Sustainable Yield (MSY). This also had the advantage of enabling a level of consistency across species and jurisdictions in which different reference points (*e.g.* Maximum Economic Yield) might be used. Importantly, the results presented are only for species and/or stocks where there was sufficient data on which an assessment to determine MSY could be based. Expert judgement was not considered sufficient. While the results presented here should be treated cautiously, the project results still provide insights into biologically sustainable catches and the potential for increased production.

In choosing MSY as a target level of yield for stocks for this project, it is important to note that we are not advocating MSY as a reference point or target catch, although it is widely used as such. Many of the MSY estimates were derived specifically for this project. It is not suggested that such estimates, particularly those using catch-only data-poor methods, be used directly for management purposes without further analytical and review work being undertaken. They are, however, indicative of potential production.

Total Australian wild fisheries production between 2000/01 and 2016/17 peaked at 236,151 t in 2004/05. Total catch declined to around 152,000 t in 2013/14 and 2014/15 but increased in 2015/16 and 2016/17 to around 170,000 t pa. The decline was evident in all the main groups; fish and sharks, crustacea and molluscs. Trends in current catches were considered to place potential increased production in context. Consequently, trends in the catches of each jurisdiction are described qualitatively with a narrative addressing changes in overall catch and catch composition. The reasons for the decline in catches are complex and vary across fisheries and jurisdictions. Numerous factors have been identified including management measures to deal with previous overfishing, fishery restructuring, changed reference points, stock fluctuations due to environmental conditions, changing markets, re-allocation of resources and habitat loss and disease. In addition, there have been major changes to fisheries management in Australia over the last decade. Formal harvest strategies have been adopted by the Commonwealth and several other jurisdictions, and the advent of the Status of Australian Fish Stocks reports has also seen a greater focus on ensuring and reporting sustainability.

Estimating sustainable yields for target species where there is a formal stock assessment was relatively easy, because models can be run to estimate sustainable yields. Also, where existing MSY estimates were available these were used. A hierarchical system was developed that included methods from data-rich to data-poor assessments. Consequently, the assessment framework and resulting software addressed data-rich to data-poor assessment methods. An open source R package, *simpleSA* (as in "simple stock assessment"; Haddon et al., 2019), was developed to facilitate the estimation of MSY for relatively data-poor fisheries across Australia and was used extensively during the project, particularly Catch-MSY. However, the latter is a data-poor method delivering highly uncertain estimates compared to other assessment methods. Consequently, the limitations of this method were described in depth.

For species with significant recreational catches, if the MSY estimates included data from both commercial and recreational sectors, then any potential increase in catch was apportioned to each sector based on the ratio of current catches. Similarly, potential increases in catches were allocated across jurisdictions in the same manner for species that were assessed across jurisdictions. Any potential increase in catch was allocated to each sector or jurisdiction based on their proportional share of current catches. The aim was to ensure that no additional complexity or potential controversy was introduced through a change in hypothetical "allocation".

MSY was estimated for 290 species/stocks comprising 138,975 t, 84% of average total landings for the period 2014/15-2016/17. Overall, over 75% of estimates of MSY were produced as a direct result of this project. The remainder were based on existing assessments or from their outputs. Assessment methods used varied considerably among jurisdictions.

The total MSY for the species assessed across all jurisdictions was 344,634 t. This represents a potential increased production of almost 206,000 t relative to the current average catch of 138,975 t of the assessed species. Adding the non-assessed species average catch of just over 26,741 t gives a total potential production of just over 371,000 t. This is more than double the current national catch. However, potential increases in production varied considerably among jurisdictions.

The potential for increased production, in absolute terms, was particularly high for Commonwealth, South Australian and Western Australian commercial fisheries. This, in part, reflects the influence of highly productive small pelagic fisheries. Reference points for small pelagic species are often set to reflect the ecosystem services these species provide. This is the case in Australia. Consequently, we looked at the implications of small pelagic fisheries on overall potential production based on the three jurisdictions above. We calculated potential production excluding MSY estimates for small pelagic species and when current TACs for these species were included. Nationally, excluding small pelagic species/stocks gives a potential increase in other species of about 80,000 t or 48% of current average catches. Including TACs for the small pelagic species sees a potential increase of 127,500 t or 77% of current catches. In either case there is the opportunity for a substantial increase in total catch.

In most cases MSY was greater than the current catch. However, it is not suggested that this catch could be taken directly. It depends on the current biomass level of a particular species/stock, the implications of multispecies interactions, and the target reference point adopted for management of that species, for example B_{MEY} for Commonwealth fisheries.

41 of species/stocks out of 290 had catches greater than MSY, some significantly so. However, 33 of those came from species/stocks where MSY was estimated to be less than 500t, and the differences were quite small. These tended to be low-value, data limited species.

There are several unfished, lightly exploited or depleted stocks in most jurisdictions for which MSY estimates could not be obtained. However, there are indications that there is the potential for significantly increased production in addition to that from the MSY estimates.

There are caveats and assumptions that need to be taken into in the interpretation of these results. Technical interactions between and within fisheries were not considered. For example, such interactions may imply that fishing some economically important species in a sustainable manner would lead to under-utilizing some other species. Data-poor assessment methods, in particular catch-MSY, were used to estimate MSY for many species and these methods have increased uncertainty. However, this uncertainty can be largely accounted for with the significant level of conservatism built into the assessments as well as the substantial number of stocks that were not assessed and assumed to have no opportunity for increases in production. Consequently, these results do indicate the potential for increased production.

7 Implications and Further development

The results of this study indicate the potential for increased production from Australia's commercial fisheries. However, as indicated above, many of the assessments included in this document have not been independently reviewed and may be subject to change. Other factors such as whether there is a market for the potential production and whether the economic value will be optimal if production is maximized are clearly important, along with other market and economic issues, but were beyond the scope of the current project and were not considered here. The results presented here should be seen as a snapshot of maximum production and very much a first stage. Importantly, the MSY estimates do not provide a quantitative basis for assessing the declines in overall catches. The latter needs to be analysed separately and a national project is being proposed. Such an analysis, together with the results of the current study would make it possible to identify obstructions to increasing productivity and determine whether such increases are practical or even desirable.

8 Extension and Adoption

The project was overseen by the National Research Providers Network (RPN). This committee was established in response to the National Fishing and Aquaculture RD&E Strategy in 2010 (FRDC, 2010). Membership includes fisheries and aquaculture research heads from each jurisdiction, CSIRO, ABARES, AFMA, FRDC, Universities, OceanWatch, IRG and IMOS.

Given recent debate about the status of Australia's fisheries, the MSY estimates that are the results of this study will need to be communicated carefully. An article referring to this work has been published in FRDC's Fish magazine 27(4):16 Doubling up Wild Fisheries. In addition, the authors have agreed to prepare a paper for the peer reviewed literature.

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10 Appendices

Appendix 1. Members of the project team.

Jurisdiction (Agency)	Team member(s)
New South Wales (NSW Dept Primary Industries; NSW DPI)	John Stewart
Northern Territory (Fisheries NT	Thor Saunders
Queensland (QLD Dept of Primary Industries and Fisheries; QLD DPIF)	Michael O'Neill
South Australia (South Australia Research and Development Institute; SARDI)	Stephen Mayfield Jonathan Smart Richard McGarvey
Tasmania (Institute for Marine and Antarctic Studies; IMAS)	Caleb Gardener Brad Moore
Victoria (Victorian Fisheries Authority; VFA)	Simon Conron Justin Bell
Western Australia (WA Dept of Primary Industries and Regional Development; WA DPIRD)	Brent Wise Ainslie Denham Norm Hall Alex Hesp
Commonwealth (Australian Fisheries Management Authority; AFMA)	Beth Gibson Ryan Murphy
CSIRO	David Smith Rich Little Andre Punt Malcolm Haddon

	Jemery Day Rich Hillary

Appendix 2. Agenda - National Fisheries Production Workshop

Wednesday 23 and Thursday 24 August 2017

Location: Parkroyal Melbourne Airport

Day 1

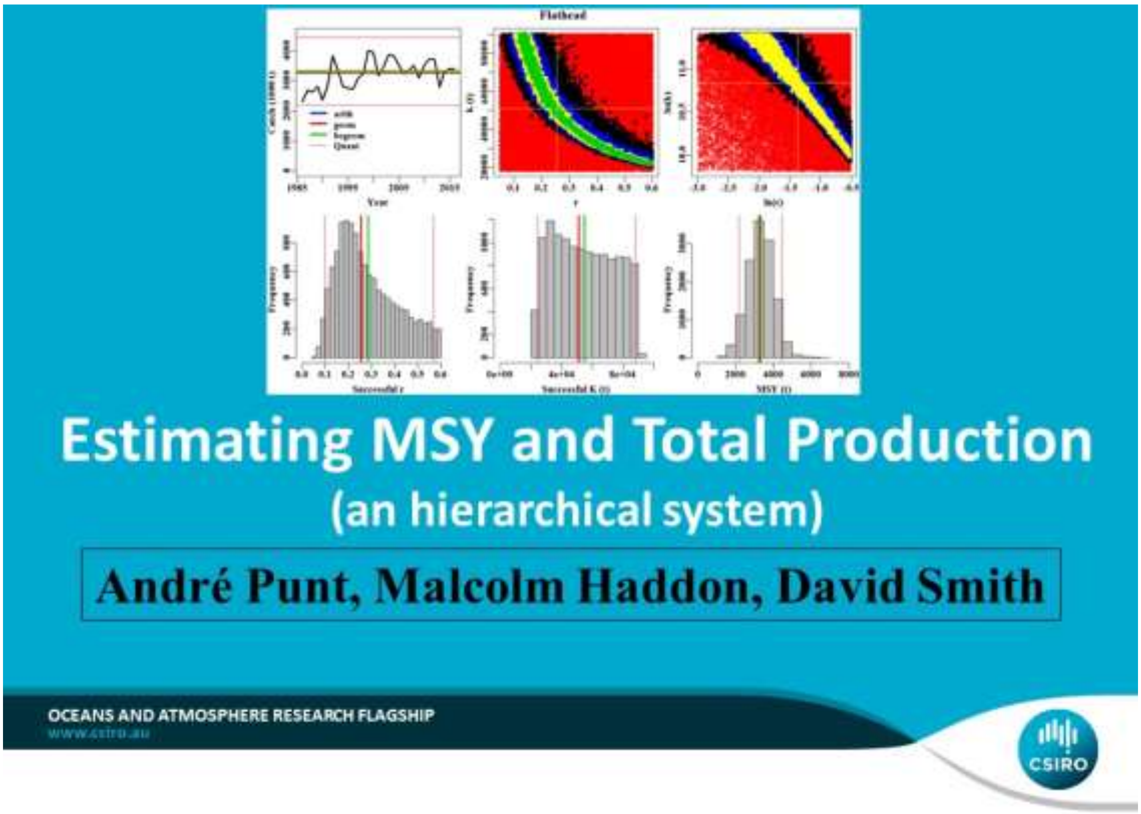
<table>
<tr><th>No</th><th>Item</th><th>Presenter/Lead</th></tr>
<tr><td>1</td><td>Introduction and aims of workshop
Agree on selection criteria for species/fisheries to be considered and 1st cut species list (SAFS plus)
Develop agreed assessment framework – likely to be tiered from data rich to data poor
Develop work plan</td><td>D Smith</td></tr>
<tr><td>2</td><td>Presentations from each jurisdiction (say max 30 mins)
Likely species/fisheries – reasons for selection
Available data
Assessment approaches</td><td>All</td></tr>
<tr><td>3</td><td>Example – theoretical SESSF-type fishery (Punt/Haddon</td><td>A Punt/M Haddon</td></tr>
<tr><td>4</td><td>Informal dinner</td><td></td></tr>
</table>

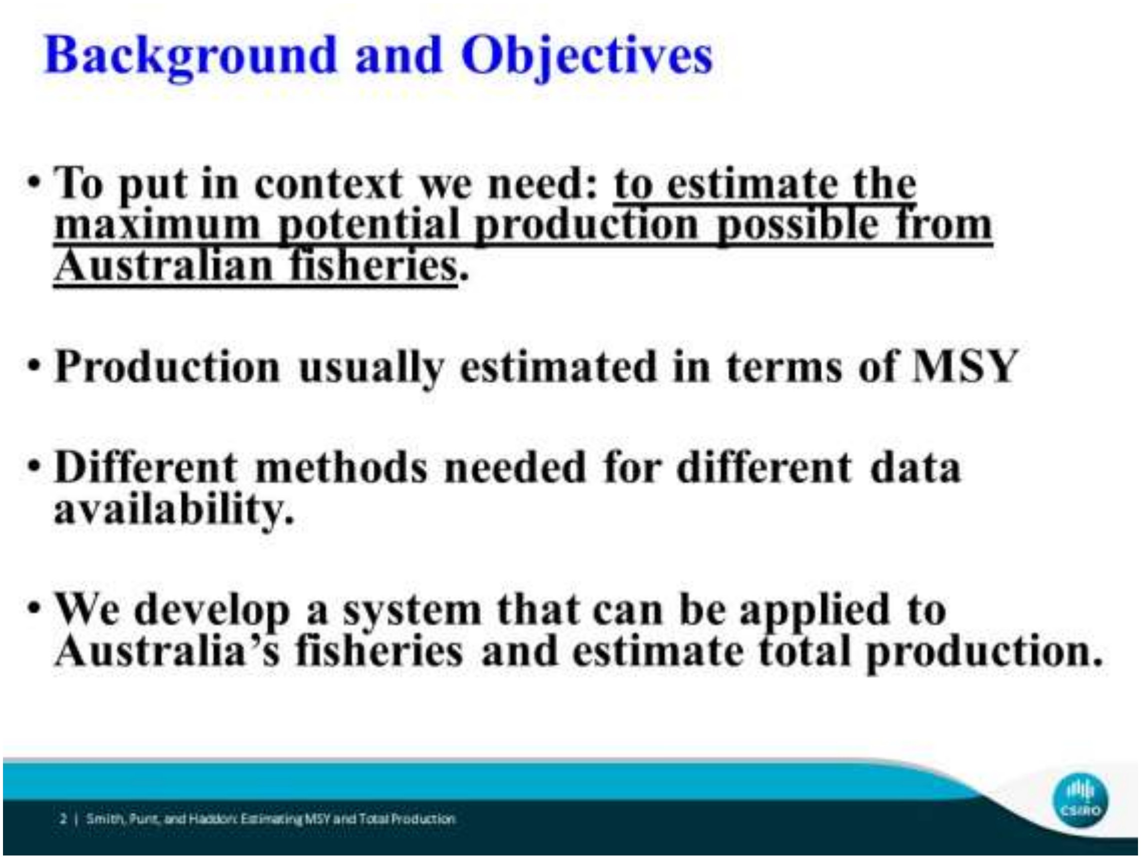
Day 2

<table>
<tr><th>No</th><th>Item</th><th>Presenter</th></tr>
<tr><td>1</td><td>Agreeing on selection criteria for:
Target species
Other commercial
By product
Bycatch</td><td>All</td></tr>
<tr><td>2</td><td>Developing an agreed assessment framework
Tiers and methods
Software
What can be done in Stage 1?</td><td>All</td></tr>
</table>

3	Work Plan and next steps	D Smith

Appendix 3. Hierarchical assessment system for estimating MSY





Principles of the Hierarchical system

- **Use the 'best data' available.**
- **Provide 'off the shelf', easily applied approaches.**
- **Provide estimates of both MSY and uncertainty**
  - **Levels reflect decreasing data availability and potentially increasing uncertainty**

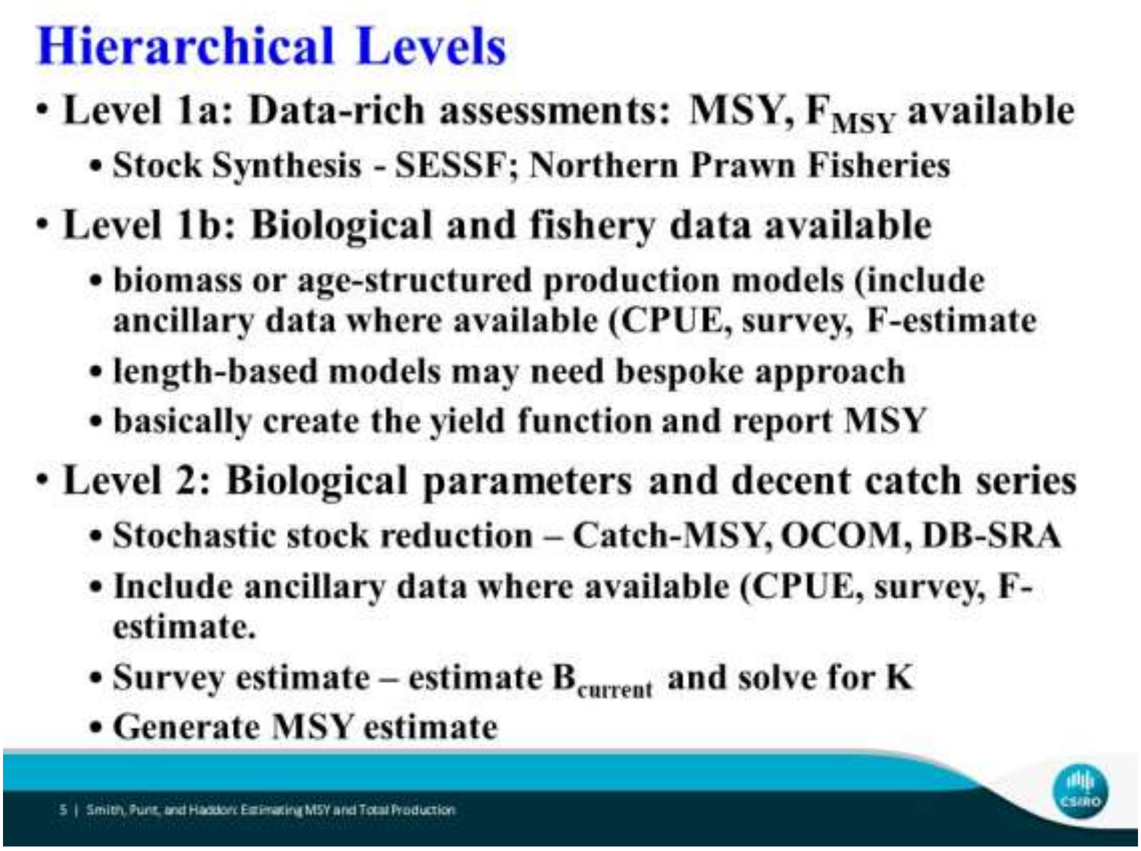
- **Note: The system ignores technical interactions and whether it is financially worthwhile harvesting the species.**

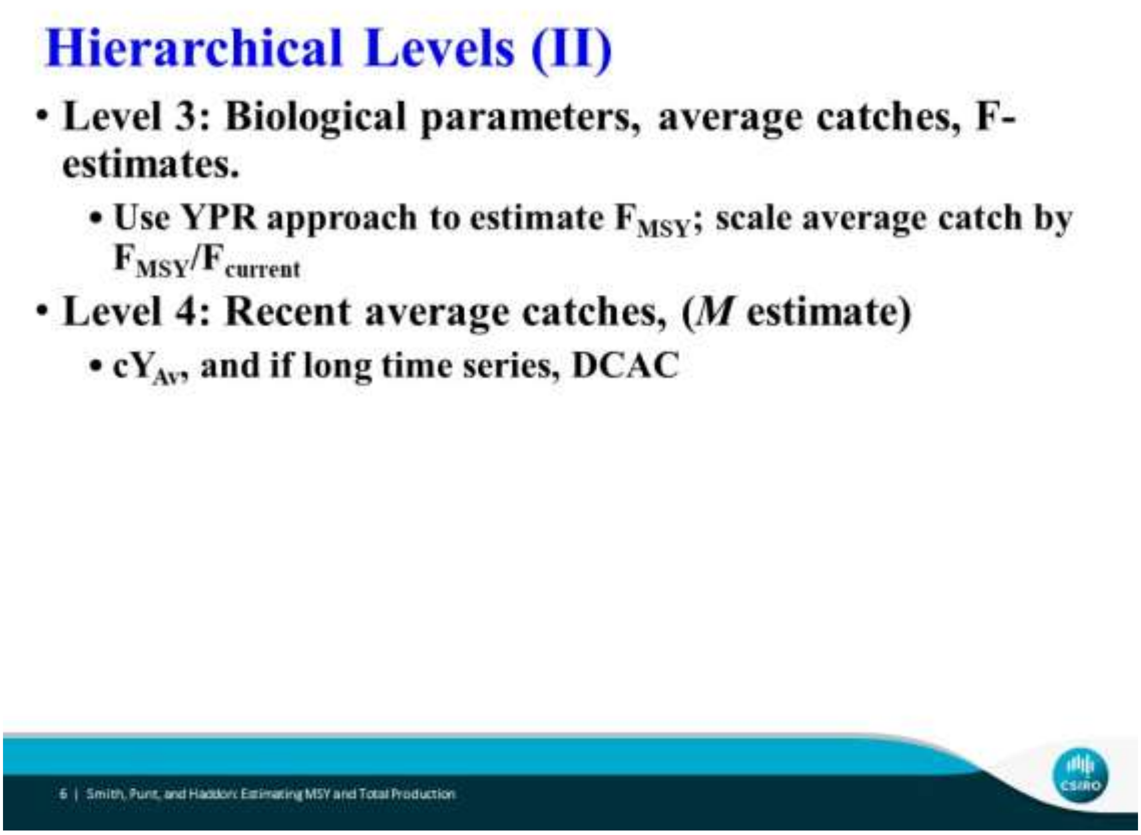
3 | Smith, Punt, and Haddon: Estimating MSY and Total Production

What Data can be used.

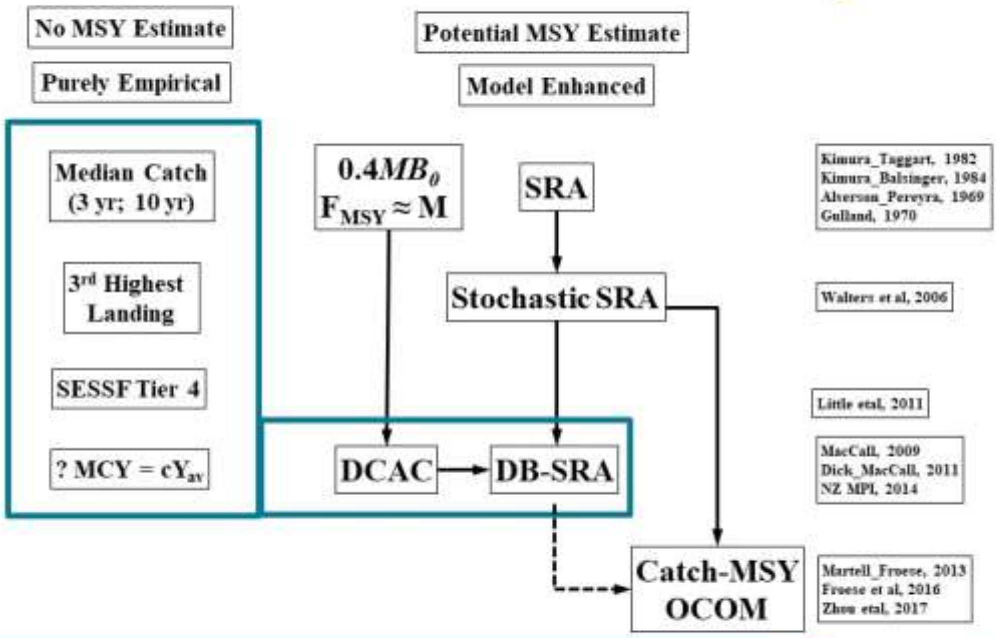
- **Data rich:**
  - **Well sampled biological and fishery data leading to a full assessment –provides an estimate of MSY.**
- **Data moderate:**
  - **catches, CPUE, biological data (growth, maturity, *M*), limited age- or length-composition data, equilibrium *F* estimate**
- **Data Limited:**
  - **catch time-series, CPUE (FishBase, meta-analyses)**
- **Data Poor:**
  - **catch time-series (FishBase, meta-analyses)**

4 | Smith, Punt, and Haddon: Estimating MSY and Total Production


Hierarchical Levels
• Level 1a: Data-rich assessments: MSY, F_{MSY} available
• Stock Synthesis - SESSF; Northern Prawn Fisheries
• Level 1b: Biological and fishery data available
• biomass or age-structured production models (include ancillary data where available (CPUE, survey, F-estimate
• length-based models may need bespoke approach
• basically create the yield function and report MSY
• Level 2: Biological parameters and decent catch series
• Stochastic stock reduction – Catch-MSY, OCOM, DB-SRA
• Include ancillary data where available (CPUE, survey, F-estimate.
• Survey estimate – estimate $B_{current}$ and solve for K
• Generate MSY estimate
5 | Smith, Punt, and Haddon: Estimating MSY and Total Production
CSIRO


Hierarchical Levels (II)
• Level 3: Biological parameters, average catches, F-estimates.
• Use YPR approach to estimate F_{MSY}; scale average catch by $F_{MSY}/F_{current}$
• Level 4: Recent average catches, (*M* estimate)
• cY_{Av}, and if long time series, DCAC
6 | Smith, Punt, and Haddon: Estimating MSY and Total Production
CSIRO

Some Data-Poor Method Relationships



7 | Smith, Punt, and Haddon: Estimating MSY and Total Production

Next Steps

- Confirm species of interest in each jurisdiction
- Arrange for Workshops in each jurisdiction
  - Send data formats and requirements for each available method within the simple stock assessment R-package
- Run the workshops, demonstrating the methods and tools
- Expected Outcomes
  - identify suitable methods for use in jurisdictions
  - Provide local staff experience with simple stock assessment R-package
  - Estimates of potential production of main species

8 | Smith, Punt, and Haddon: Estimating MSY and Total Production

Conclusions

- Methods exist to estimate potential productivity for a wide range of species with different data availability.
- 'Fisheries common sense' also required to apply such methods appropriately (how representative are the data?).

9 | Smith, Punt, and Haddon: Estimating MSY and Total Production

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Thank you

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Appendix 4: Computing MSY using the results of an age-structured model

A.4.1 Mathematical specifications

Maximum Sustainable Yield (MSY) is defined as the catch at which the (deterministic) relationship between catch (yield) and (fully-selected) fishing mortality is maximized, i.e.:

$$\left.\frac{dC(\tilde{F})}{d\tilde{F}}\right|_{\tilde{F}=F_{MSY}} = 0 \qquad \text{(App.4.1)}$$

where $C(\tilde{F})$ is catch as a function of fully-selected fishing mortality. The exploitation rate corresponding to MSY is $MSY / SSB(F_{MSY})$, where $SSB(F_{MSY})$ is the spawning biomass corresponding to a fully-selected fishing mortality of F_{MSY}.

Now, $C(\tilde{F})$ and $SSB(F_{MSY})$ can computed as:

$$C(\tilde{F}) = YPR(\tilde{F})R(\tilde{F}); \qquad SSB(\tilde{F}) = SPR(\tilde{F})R(\tilde{F}) \qquad \text{(App.4.2)}$$

where $YPR(\tilde{F})$ is yield-per-recruit as a function of fully-selected fishing mortality, $R(\tilde{F})$ is age-0-abundance (recruitment) as a function of fully-selected fishing mortality, and $SPR(\tilde{F})$ is spawning biomass-per-recruit as a function of fully-selected fishing mortality.

The quantities needed to compute $C(\tilde{F})$ are based on a multi-fleet, sex- and age-structured population dynamics model, i.e.:

$$N_a^s = \begin{cases} 0.5 & \text{if } a = 0 \\ N_{a-1}^s e^{-Z_{a-1}^s} & \text{if } 1 \le a < x \\ N_{x-1}^s e^{-Z_{x-1}^s} / (1 - e^{-Z_x^s}) & \text{if } a = x \end{cases} \qquad \text{(App.4.3)}$$

where N_a^s is the number of animals of age *a* and sex *s*, Z_a^s is the total mortality for animals of age *a* and sex *s*, and *x* is plus-group age. Total mortality is divided into natural and fishing mortality, i.e.:

$$Z_a^s = M_a^s + \sum_f S_a^{s,f} \phi^f \tilde{F} \qquad \text{(App.4.4)}$$

where M_a^s is the rate of natural mortality for animals of age *a* and sex *s*, $S_a^{s,f}$ is the selectivity by fleet *f* for animals of age *a* and sex *s*, ϕ^f is the proportion of total fully-selected fishing mortality due to fleet *f*, and $\tilde{F}$ is an overall fishing mortality multiplier (fully-selected fishing mortality).

The yield- and spawning biomass-per-recruit are computed from Equations App.4.3 and App.4.4 using:

$$YPR(\tilde{F}) = \sum_f \sum_s \sum_a w_a^{s,f} \frac{S_a^{s,f} \phi^f \tilde{F}}{Z_a^s} N_a^s (1 - e^{-Z_a^s})$$
$$SPR(\tilde{F}) = \sum_a f_a N_a^{\text{fem}} \qquad \text{(App.4.5)}$$

where $w_a^{s,f}$ is the weight of an animal of age *a* and sex *s* in the catches by fleet *f*, and f_a is the fecundity of a female of age *a*.

Equilibrium recruitment (which is assumed to be governed by the Beverton-Holt stock-recruitment relationship) is a function of fully-selected fishing mortality and is computed using the equation:

$$R(\tilde{F}) = \frac{B_0}{SPR(\tilde{F})} \frac{4hSPR(\tilde{F}) / SPR_0 + h - 1}{5h - 1} \qquad \text{(App.4.6)}$$

where *h* is the "steepness" of the stock-recruitment relationship (proportion of unfished recruitment at $0.2B_0$), and SPR_0 is spawning biomass-per-recruit when fully-selected fishing mortality is zero (Equation App.4.5).

A.4.2 Computation details

The values of the parameters needed to apply this method for computing MSY are the plus-group age, the rate of natural mortality by age and sex, fecundity-at-age, selectivity- and weight-at-age by sex and fleet, the relative fishing intensities by fleet, the steepness of the stock-recruitment, and the unfished equilibrium spawning biomass. These quantities are available from most stock assessment packages (see review by Dichmont et al. [2016]).

The derivative of the yield function with respect to fully-selected fishing mortality is computed using a central difference method, and Equation App.4.1 is solved using Brent's method (as implemented in R using the *unitroot* function).

The method is based on one set of parameters, but the impact of parameter uncertainty can be evaluated using Monte Carlo methods (i.e. by sampling the values for the parameters from distributions that capture their uncertainty).

A.4.3 Reference

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Appendix 5: Computing MSY using data-moderate Bayesian methods

A.5.1 Mathematical specifications

This method is based on three population dynamics models (age- and sex-structured model; delay-difference model; Schaefer production model), the first two of which include process error (recruitment variation). The method produces estimates of MSY based on priors for productivity (the exploitation rate at MSY) and initial depletion, as well as a prior on one of recent biomass, recent depletion, or recent fishing mortality. The priors for the estimable parameters of the model can be updated using indices of relative abundance (catch-rate indices).

A.5.1.1 Age- and sex-structured model

The population dynamics are governed by the equation:

$$N^s_{y,a} = \begin{cases} 0.5R_y & \text{if } a = 0 \\ N^s_{y,a-1}\, e^{-Z^s_{y,a-1}} & \text{if } 1 \le a < x \\ N^s_{y,x-1}\, e^{-Z^s_{y,x-1}} + N^s_{y,x}\, e^{-Z^s_{y,x}} & \text{if } a = x \end{cases} \qquad \text{(App.5.1)}$$

where $N^s_{y,a}$ is the number of animals of age *a* and sex *s* at the start of year *y*, $Z^s_{y,a}$ is the total mortality for animals of age *a* and sex *s* during year *y*:

$$Z^s_{y,a} = M^s_a + S^s_a F_y \qquad \text{(App.5.2)}$$

M^s_a is the rate of natural mortality for animals of age *a* and sex *s*, S^s_a is the selectivity for animals of age *a* and sex *s*, F_y is the fully-selected fishing mortality for year *y*, R_y is the recruitment during year *y*:

$$R_y = \frac{4h\,R_0\,SSB_y\,/\,SSB_0}{(1-h)+(5h-1)\,SSB_y\,/\,SSB_0}\, e^{\varepsilon_y - \sigma_R^2/2} \qquad \text{(App.5.3)}$$

SSB_y is the spawning biomass at the start of year *y*, SSB_0 is the unfished spawning biomass, *h* is the steepness of the Beverton-Holt stock-recruitment relationship, R_0 is the unfished recruitment, σ_R is the standard deviation of the recruitment deviations, and *x* is plus-group age. The spawning biomass in year *y* is given by:

$$SSB_y = \sum_a f_a N^{\text{fem}}_{y,a} \qquad \text{(App.5.4)}$$

where f_a is the fecundity of a female of age *a*.

The value for F_y is obtained by solving the catch equation:

$$C_y = \sum_s \sum_a w^s_a \frac{S^s_a F_y}{Z^s_{y,a}} N^s_{y,a}(1-e^{-Z^s_{y,a}}) \qquad \text{(App.5.5)}$$

where C_y is the catch in weight during year *y*, and w^s_a is the weight of an animal of age *a* and sex *s* in the catch.

A.5.1.2 Delay-difference model

The population dynamics are governed by the equation:

$$B_{y+1} = (1+\rho)B_y e^{-M}(1-E_y) - \rho B_{y-1} e^{-2M}(1-E_y)(1-E_{y-1}) + w_r R_{y+1} - w_{r1}\rho e^{-M} R_y \quad \text{(App.5.6)}$$

where B_y is the biomass (spawning=exploitable) at the start of year *y*, ρ is the Brody growth coefficient, w_r is weight of a recruit, w_{r1} is the weight of a recruit one year prior to recruitment, $E_y = C_y / B_y$, and R_y is recruitment for year *y*:

$$R_y = \frac{4h R_0 B_y / B_0}{(1-h)+(5h-1)B_y / B_0} e^{\varepsilon_y - \sigma_R^2/2} \quad \text{(App.5.7)}$$

where *h* is the steepness of the Beverton-Holt stock-recruitment relationship, R_0 is the unfished recruitment, B_0 is the unfished biomass, and σ_R is the standard deviation of the recruitment deviations.

A.5.1.3 Schaefer biomass model

The population dynamics are governed by:

$$B_{y+1} = B_y + rB_y(1 - B_y / B_0) - C_y \quad \text{(App.5.8)}$$

where B_y is the biomass (spawning=exploitable) at the start of year *y*, *r* is in the intrinsic rate of growth, and B_0 is the carrying capacity (unfished biomass).

A.5.1.4 Calculation of MSY

The values for SSB_{MSY}/SSB_0 and MSY/SSB_0 for the age-structured model are computed using the approach of Appendix 4 (except that there is only one fleet). The same basic approach is used for the delay-different model, except that equilibrium yield as a function of exploitation rate is given by:

$$C(E) = \frac{E}{5h-1}\left(\frac{1-(1+\rho)e^{-M}(1-E)+\rho e^{-2M}(1-E)^2}{(w_r - w_{r1}\rho e^{-M})4hR_0} - (1-h)\right) \quad \text{(App.5.9)}$$

MSY is $rK/4$ and $B_{MSY} = 0.5B_0$ for the Schaefer model.

A.5.2 Computation details

The pre-specified parameters of this method for computing MSY depend on the type of model:

- Age- and sex-structured model: the plus-group age, the rate of natural mortality by age and sex, fecundity-at-age, selectivity- and weight-at-age by sex, and the extent of variation in the deviations in recruitment about the stock-recruitment relationship
- Delay-difference model: the plus-group age, the rate of natural mortality (assumed to be independent of age and sex), the age-at-recruitment/-at-maturity, the Brody growth coefficient, the weight at recruitment and a year before recruitment, and the extent of variation in the deviations in recruitment about the stock-recruitment relationship.
- Schaefer model: no additional parameters.

The data provided to apply the model are annual catches (which need not start when the fishery started), and several catch-rate (relative abundance) indices. The information for each catch-rate index is the year, the catch-rate and the relative CV of the catch-rate.

A.5.2.1 Bayesian approach

The Bayesian estimation is based on the Sample-Importance-Resample algorithm. This involves generating many samples from the priors, projecting the model forward to produce the predicted catch rates for each parameter vector, recording the likelihood for each parameter vector, and finally resampling from among the parameter vectors (with replacement), with probability given the likelihood. The likelihood function is given by:

$$L = \prod_i \prod_y \frac{1}{\sqrt{2\pi}\sigma_i} e^{-\frac{(\ell n I_{y,i} - \ell n[q_i B_y])^2}{2\sigma_i^2}} \qquad \text{(App.5.10)}$$

where $I_{i,y}$ is the catch-rate for year *y* and catch-rate index *i*, B_y is the biomass at the start of year *y*, q_i is the catchability coefficient for index *i*, and σ_i is the residual standard deviation for index *i*. In order to simplify the calculations, the likelihood is marginalized analytically with respect to the catchability coefficients and the residual standard deviations.

The results are shown as posteriors for the model parameters, as well as for MSY and the time-trajectory of biomass. Posterior predictive distributions for the catch-rate time-series are produced to assist with diagnostic evaluation.

A.5.2.2 Generation process

The values for the parameters (initial depletion; exploitation rate at MSY [E_{MSY}]; recent biomass; recent depletion; recent exploitation rate) are generated from log-normal distributions that are truncated at 1 for initial depletion, and recent exploitation rate. The recruitment deviations (used only by the age- and sex-structured model and the delay-difference model), ε_y, are generated from $N(0;\sigma_R^2)$.

The exploitation rate at MSY needs to be converted into the productivity parameter of the model. For the Schaefer model, the latter parameter is *r* (and *r*=2*E_{MSY}), while for the age- and sex-structured model and the delay-difference model, this parameter is the steepness of the (Beverton-Holt) stock-recruitment relationship. The value for steepness for these models is calculated from generated value for E_{MSY} such that the derivative of the yield function evaluated at E_{MSY} equals zero (Equations App.4.5 and App.5.9).

For the age- and sex-structured model, the initial age- and sex-structure is computed from the initial depletion by finding the value of *F* such that SSB_F / SSB_0 equals the generated initial depletion if the population was in equilibrium, and setting the initial age- and sex-structure to the corresponding age- and sex-structure. This calculation is based on the equations:

$$SSB_F = SPR(F)R(F) \qquad \text{(App.5.11)}$$

$$SPR(F) = \sum_a f_a N_a^{\text{fem}}(F) \qquad \text{(App.5.12)}$$

$$N_a^s(F) = \begin{cases} 0.5 & \text{if } a = 0 \\ N_{a-1}^s(F) e^{-(M_{a-1}^s + S_{a-1}^s F)} & \text{if } 1 \le a < x \\ N_{x-1}^s(F) e^{-(M_{x-1}^s + S_{x-1}^s F)} / (1 - e^{-(M_x^s + S_x^s F)}) & \text{if } a = x \end{cases} \qquad \text{(App.5.13)}$$

$$R(F) = \frac{SSB_0}{SPR(F)} \frac{4hSPR(F) / SPR(0) + h - 1}{5h - 1} \quad \text{(App.5.14)}$$

Appendix 6: Corrected average catch

A.6.1 Mathematical specifications

This approach computes *MSY* by "correcting" the average catch by the difference between the current exploitation rate and that at F_{MSY}, i.e.:

$$MSY \sim \bar{C}_{CUR} \frac{1-e^{-F_{MSY}}}{1-e^{-F_{CUR}}} \qquad \text{(App.6.1)}$$

where $\bar{C}_{CUR}$ is a recent average catch, and F_{CUR} is the current fishing mortality. In common with many simple methods for estimating MSY, this method assumes that the population is in equilibrium (and that fishery selectivity is uniform).

A.6.2 Computation details

The method is provided with a time-series of catches from which $\bar{C}_{CUR}$ is computed, as well as probability distributions for F_{CUR} and F_{MSY}. A (sampling) distribution for F_{CUR} can be obtained from a catch curve analysis, while the method in Appendix 4 can be used to create a distribution for F_{MSY}. Uncertainty in MSY from this method is obtained by applying Equation App.6.1 multiple times where $\bar{C}_{CUR}$ is obtained by sampling annual catches with replacement from the time-series of catches, and F_{CUR} and F_{MSY} are sampled from the supplied distributions.

Appendix 7: The *simpleSA* Package

A.7.1 R Packages

Two open source R (R Core Team, 2017) packages, *simpleSA* and ***cede***, were produced to facilitate the analysis of relatively data-poor fisheries across Australia.

- *cede* contains software to assist with data exploration (simple mapping and data summary functions) and with illustrating and comparing different catch-effort standardization techniques.
- *simpleSA* contains three common data-poor stock assessment techniques (catch-MSY, surplus-production modelling, and age-structured surplus production modelling) plus functions to assist with catch-curve analysis.

Both R packages are freely available. Currently, they are available in a shared DropBox folder although this will likely change to a publicly open BitBucket or GitHub directory hosted by CSIRO. Eventually at least s*impleSA* may be put onto the CRAN (Comprehensive R Archive Network), which, along with GitHub, is the standard repository for R packages.

A.7.2 The simpleSA R package

An open source R package *simpleSA* (as in "simple stock assessment"; Haddon et al., 2018) was developed to facilitate the analysis of relatively data-poor fisheries across Australia. *SimpleSA* was designed to contain three common stock assessment methods suitable for Australian conditions plus other additional routines or functions for conducting analyses of value when conducting stock assessments. The three main methods considered were:

1. The catch-MSY method (Martell and Froese, 2013);
2. surplus-production modelling (Prager, 1994; Haddon, 2011); and
3. age-structured production modelling (Punt et al., 1995)

SimpleSA also includes were some utility functions for conducting catch-curves. The three main methods are listed with the least robust method (catch-MSY) first and, assuming the availability of representative data, the more robust assessment last (age-structured production modelling).

A.7.3 The *cede* R package

The *cede* package (as in "catch effort and data exploration" ; Haddon et al., 2018), was developed to provide tools to assist the jurisdictions with data exploration to aid in understanding the factors influencing the fishery data they work with (e.g. by mapping their data, and plotting their data subdivided by years or areas or some other factor). It also attempted to simplify the process of CPUE standardization.

A.7.4 Catch-MSY

The catch-MSY method (Martell and Froese, 2013; Froese et al., 2017) is just one of several methods that only require a time-series of catches from a fishery (Zhou et al., 2017), and could be termed a 'model-assisted' stock assessment method. In the Australian Fisheries Production project, this was the method used most often by the jurisdictions when estimating MSY for data-poor species, requiring only a time-series of catches would appear to promise many opportunities for assessing currently undefined stocks. However, as concluded by Carruthers et al. (2014) "*for most life-histories, we found that methods that made use of only historical catches often performed worse than maintaining current fishing levels. Only those methods that dynamically accounted for changes in abundance and/or depletion performed well at low stock sizes. Stock assessments that make use of historical catch and effort data did not necessarily out-perform* *simpler data-limited methods that made use of fewer data. There is a high value of additional information regarding stock depletion, historical fishing effort and current abundance when only catch data are available*."

In Australia, part of the reason for the poor performance of catch-only methods is that catches are influenced by many factors other than abundance, including management changes, and other causes of changes in fisher behaviour. Catch-MSY should be regarded as the formal stock assessment of last resort because of its inherent uncertainty, even though it can generate estimates of MSY, current depletion and fishing mortality, and thus determine a stock status. There are many circumstances where the outputs can appear to make sense but in reality, are invalid. For example, species whose catch time-series primarily exhibit increasing catches up until the present day will generate misleading results. The catch-MSY needs the catch time-series to exhibit contrast through time (i.e. it should increase but also decrease).

The catch-MSY method also assumes that any on-going declines in catch are due to earlier catches depleting the stock, and thus it becomes unable to maintain catches as large as have been experienced in the past. Without significant and on-going decreases in catch it cannot validly estimate any useful statistics.

The underlying stock dynamics are described by the simple model used, which in the case of *simpleSA* is a Schaefer surplus production model with parameters *r*, the intrinsic growth rate, and *K*, the population carrying capacity or unfished biomass. The model uses ratios of the initial and final catches relative to the maximum catch to set up arrays of potential values for the initial and final depletion levels as well as for the potential range of *r* and *K* values (in *simpleSA* all of these assumptions can be modified by the user). The method sequentially steps through the years of the fishery by randomly selecting pairs of *r-K* values from the wide initial ranges, which defines the initial biomass, subtracting the catches, and moving the population dynamics forward each year using the predictions from the simple model. Essentially this is a stock reduction analysis that removes catches from a known set of dynamics. However, the very many *r-K* pairs used (at least 20,000) are combined with a fixed set of initial depletion levels (about 20 steps between the minimum and maximum initial depletion set) to generate often 100s of thousands of possible stock reduction trajectories. Criteria are included that lead to numerous potential trajectories being rejected (e.g. no trajectory is kept if it predicted zero biomass or biomass above *K*). Those that are left after all criteria for acceptance have been completed constitute the set of trajectories deemed to be consistent with the known catches. The implications of these successful trajectories are used to produce an assessment of the possible status of the stock.

A.7.5 Surplus Production Modelling

Surplus production modelling has a longer history than catch-MSY, with the first surplus production model described in detail by Schaefer (1954, 1957). A surplus production model treats the stock biomass as an aggregated mass and ignores details such as length- or age-composition. It is a method that is well covered in the literature (Polacheck et al., 1993; Prager, 1994; Haddon, 2011). It was selected as a data-poor method because it only requires time-series of total catches and of an index of relative abundance (most often CPUE in Australia). This is a model-assisted data poor method and two versions of the modelled dynamics are available, those of Schaefer (1954, 1957) and of Fox (1970).

Surplus production models are one of the simplest analytical methods available that provides for a full fish stock assessment of the population dynamics of the stock being examined. First described in the 1950s (Schaefer, 1954, 1957), modern versions with discrete dynamics are relatively simple to apply. This is partly because they pool the overall effects of recruitment, growth, and mortality (all the aspects of positive production) into a single production function. The stock is considered solely as undifferentiated biomass; that is, age -and size-structure, along with sexual and other differences, are ignored (this is one reason these models are also called "biomass-dynamic models"). Details of the equations can be found in Haddon et al. (2018). In addition, details of the parameters and other aspects can be found in the help files for each of the functions within *simpleSA*(try ?spm or ?simpspm, or even ?simpfox). In brief, the model parameters are:

- *r,* the maximum net population rate of increase (combined individual growth in weight, recruitment, and natural mortality);
- *K,* the population carrying capacity or median unfished biomass (B_0) (not to be confused with B_{init} (sometimes, in other contexts confusingly, also called B_0)); and
- B_{init}, which is only required if the index of relative abundance data (usually CPUE) only becomes available after the fishery has been conducted for a few years, and after the stock has been depleted to some extent. B_{init} is set equal to *K* if no initial depletion is assumed. If early catches are known to be small relative to the maximum catches taken (< 10 - 25% of maximum), then it may well be true that initial depletion is only minor and might not be distinguishable from unfished.

The minimum data requirements needed to estimate parameters for such models are:

- a time-series of an index of relative abundance; and
- a time series of associated catch data.

The catch data can extend beyond either end of the index data if it is available. In Australia the index of relative stock abundance is most often catch-per-unit-effort (CPUE) but could also be some fishery-independent abundance index (e.g., from trawl surveys, acoustic surveys), or multiple abundance indices could be used. The analysis will permit the production of on-going management advice as well as a determination of stock status.

A.7.6 Age-Structured Production Models

Age-structured production models require time-series of catches and CPUE (or another index of relative abundance). However, they also require some biological information such as estimates of natural mortality, age-at-maturity, length-at-age, weight-at-length and -at-age, and perhaps selectivity- at-age. Strategies for what to use if some of these biological data requirements are missing or vague are discussed in Haddon et al. (2018).

Age-structure models have a long history in population dynamics (Lotka, 1925) but were developed much further in the 1980s and 1990s to enable them to be fitted to catch and CPUE data, combined with biological information concerning growth, maturity, selectivity and recruitment (Fournier and Archibald, 1982; De La Mare, 1989; Francis, 1992; Punt, 1994, Punt et al., 1995). However, with the on-going development of such models to include age- and length-composition data (and other data sources) the simpler age-structured production models became far less used. With their limited data requirements, these constitute the most sophisticated 'data-limited' assessment models included into *simpleSA*. Once again, full details and the equations of the model options are provided in Haddon et al. (2018).

The age-structured production model (ASPM or aspm) is literally a surplus production model that is based upon an age-structured model of production rather than an aggregated biomass model.

There are some specific data requirements for fitting an age-structured production model to fishery data. The following data from the fishery need to include as a minimum:

- an accurate catch time-series plus; and
- an index of relative abundance for at least some of the years within the catch timeseries.

In addition, information (or defensible assumptions) is needed for the species concerned in relation to the description of:

- its natural mortality;
- its growth;
- its maturation; and
- the selectivity of the fishery (maturity and selectivity could be knife-edge).

If just the catches and CPUE data are available, then one might try fitting a simple, aggregated biomass, surplus production model. However, the above biological data and information are also available, then an age-structured production model opens the way to ongoing improvements with respect to the inclusion of occasional age-composition data or other observations that could be predicted by a suitable model, and hence included in the model fitting process. More details on age-structured production models can be found in Punt et al. (1995).

A.7.7. References

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Appendix 8 Commercial MSY estimate and average 3 year (2014/15 – 2016/17) catch for selected Commonwealth species/stocks. The first and last years of data used are shown. Other species include minor species/stocks and those aggregated for confidentiality reasons. AP4 and APP5 refers to Appendix 4 and 5, this report.

Species name	Common name	Fishery	Data	years	MSY estimate (t)	Av 3 yr catch (t)	Method	Reference
			First	Last				
Pseudocyttus maculatus	Oreodory: smooth, Cascade Plateau	SESSF Cascade Plateau	1990	2007	34	0	Catch-MSY	This report
Hoplostethus atlanticus	Orange roughy Cascade	SESSF Cascade Plateau	1989	2009	441	0	SS3 A4	Morison et al. (2013)
Centroberyx gerrardi	Bight redfish	SESSF GAB	1960	2014	625	267	SS3 A4	Haddon (2016)
Platycephalus conatus	Deepwater flathead	SESSF GAB	1980	2015	1200	695	SS3 A4	Haddon (2016)
Metapenaeus endeavouri	Prawn blue endeavour	NPF	1970	2017	752	282	delay difference	Hutton et al (2018)
Metapenaeus ensis	Prawn red endeavour	NPF	1970	2017	328	154	delay difference	Hutton et al (2018)
Penaeus esculentus	Prawn brown tiger	NPF	1970	2017	1083	672	size-age structured	Hutton et al (2018)
Penaeus semisulcatus	Prawn grooved tiger	NPF	1970	2017	1654	1457	size-age structured	Hutton et al (2018)
Penaeus indicus	Prawn red-leg banana	NPF	1970	2017	750	142	statistical popn dyns	Hutton et al (2018)
Beryx splendens	Alfonsino	SESSF	1992	2017	220	36	Catch-MSY	This report
Macruronus novaezelandiae	Blue Grenadier	SESSF	1960	2012	4492	1461	SS3 A4	Tuck (2014)
Seriolella brama	Blue warehou	SESSF	1986	2008	1833	10	SS3 A4	Punt (2008)
Hyperoglyphe antarctica	Blue-eye trevalla	SESSF	1980	2016	588	309	Catch-MSY	This report

Various	Deepwater sharks, eastern zone	SESSF	1995	2017	110	26	Catch-MSY	This report
Various	Deepwater sharks, western zone	SESSF	1995	2017	149	54	Catch-MSY	This report
Rexea solandri	Gemfish eastern	SESSF	1968	2008	1219	74	SS3 A4	Little and Rowling (2009)
Sillago flindersi	Eastern School Whiting	SESSF	1947	2016	973	729	SS3 A4	Day (2017)
Callorhinchus milii	Elephantfish	SESSF	1997	2017	169	58	Catch-MSY	This report
Mustelus antarcticus	Gummy shark	SESSF	1927	2015	4375	2347	statistical popn dyns	Punt and Thompson (in prep)
Nemadactylus macropterus	Jackass morwong	SESSF	1915	2014	654	174	SS3 A4	Tuck et al (2016a,b)
Zeus faber	Dory John	SESSF	1971	2016	213	62	Catch-MSY	This report
Zenopsis nebulosa	Dory mirror	SESSF	1986	2016	264	250	Catch-MSY	This report
Nelusetta ayraud	Ocean jacket, eastern zone	SESSF	1986	2017	213	205	Catch-MSY	This report
Hoplostethus atlanticus	Orange roughy, western zone	SESSF	1986	2015	240	25	aspm	This report
Neocyttus rhomboidalis, Allocyttus niger, A. verrucosus	Oreodory: other	SESSF	1986	2016	133	117	Catch-MSY	This report
Pseudocyttus maculatus	Oreodory: smooth, non-Cascade Plateau	SESSF	1987	2007	81	5	Catch-MSY	This report
Genypterus blacodes	Pink ling	SESSF	1970	2013	1578	869	SS3 A4	Whitten and Punt (2014)
Centroberyx affinis	Redfish, eastern	SESSF	1975	2016	913	66	SS3 A4	Day (2017)
Mora moro	Ribaldo	SESSF	1992	2017	120	105	Catch-MSY	This report
Hoplostethus atlanticus	Orange roughy eastern zone	SESSF	1980	2016	2314	380	SS3 A4	Haddon (2017)
Haliporoides sibogae	Royal red prawn	SESSF	1978	2016	347	170	Catch-MSY	This report
Pristiophorus cirratus, P. nudipinnis	Sawshark	SESSF	1997	2017	336	189	Catch-MSY	This report
Pseudocaranx georgianus	Silver trevally	SESSF	1986	2017	247	86	Catch-MSY	This report
Seriolella punctata	Silver warehou	SESSF	1980	2014	2064	342	SS3 A4	Burch et al (2019)
Platycephalus richardsoni	Tiger flathead	SESSF	1915	2015	2854	2850	SS3 A4	Day et al (2016)
Rexea solandri	Gemfish western	SESSF	1985	2010	761	59	SS3 A4	Helidoniotis and Moore (2016)

Dissostichus eleginoides	Patagonian toothfish MI	Sub Ant	1985	2016	588	440	SS3	Day and Hilary (2017)
Dissostichus eleginoides	Patagonian toothfish HIMI	Sub Ant	1997	2015	3405	2967	SS3	Ziegler and Welsford (2015)
Panulirus ornatus	Tropical Rock Lobster Fishery	TS	1973	2017	680	570	statistical popn dyns	Plaganyi et al (2017)
Scomberomorus commerson	Spanish mackerel	TS	1940	2018	111	75	age-structured	Hutton et al (2019)
Plectropomus leopardus	Coral trout	TS	1950	2018	141	40	age-structured	Hutton et al (2019)
Metapenaeus endeavouri, M. ensis	Prawn endeavour	TS	1988	2007	1000	460	delay difference	Turnbull et al (2009)
Penaeus esculentus, Penaeus semi-sulcatus	Prawn tiger	TS	1980	2006	600	113	size-age structured	O'Neill et al (2006)
Thunnus Maccoyii	Southern blue fin	SBT	1931	2017	11530	5489	statistical popn dyns	Hilary et al (2017)
Sardinops sagax	Australian sardine	SP	1999	2017	38536	127	App5	This report
Scomber australasicus	Blue Mackeral	SP	1984	2017	26723	2500	App5	This report
Trachurus declivis	Jack Mackeral	SP	1985	2017	17730	5062	App5	This report
Emmelichthys nitidus	Redbait east	SP	1999	2017	5197	121	App5	This report
	Tuna and billfish, east				7592	5058	TAC	
	Tuna and billfish, west				10125	357	TAC	
	Total				**158287**	**38106**		

Appendix 9 MSY estimate and average 3 year (2014/15 – 2016/17) catch for selected South Australian species/stocks. Note: total MSY and total catch is shown as well as commercial (comm) MSY and catch to account for recreational catches in assessments. The first and last years of data used are shown. Other species include minor species/stocks and those aggregated for confidentiality reasons. APP5 refers to Appendix 5, this report.

Scientific Name	Common name	Jurisdiction/stock	Data Start	Years Last	MSY total (t)	MSY comm (t)	Av 3 yr catch total (t)	Av 3 yr catch comm (t)	Method	Reference
Haliotis rubra	Abalone blacklip	SA - CZ	1979	2017	30	30	18	18	Catch-MSY	This report
Haliotis rubra	Abalone blacklip	SA - SZ	1979	2017	149	149	136	136	Catch-MSY	This report
Haliotis rubra	Abalone blacklip	SA - WZ	1979	2017	273	273	199	199	Catch-MSY	This report
Haliotis laevigata	Abalone greenlip	SA - CZ	1979	2017	165	165	138	138	Catch-MSY	This report
Haliotis laevigata	Abalone greenlip	SA - WZ	1979	2017	336	336	211	211	Catch-MSY	This report
Arripis truttaceus	Australian herring	SA	1984	2017	350	155	194	86	Catch-MSY	This report
Arripis georgiana	Australian salmon	SA	1984	2017	741	686	394	365	Catch-MSY	This report
Sardinops Sagax	Australian sardine	SA	1992	2017	79000	79000	39548	39548	SS3	Ward et al (2017)
Potunus armatus	Blue crab	SA-Gulfs	1984	2017	951	680	865	619	Catch-MSY	This report
Potunus armatus	Blue crab	SA - WC	1984	2017	55	42	47	36	Catch-MSY	This report
Hyporhamphus melanochir	Garfish	SA	1984	2017	146	117	208	167	length-age struct	McGarvey et al (2007).
Sillaginodes punctatus	King George whiting	SA	1984	2016	1240	835	407	274	length-age struct	McGarvey et al. in prep
Monacanthidae	Leather jackets	SA	1984	2017	54	36	37	25	Catch-MSY	This report
Nelusetta ayraudi	Ocean jackets	SA	1984	2017	433	433	163	163	Catch-MSY	This report

Octopus spp.	Octopus	SA	1984	2017	14	13	12	12	Catch-MSY	This report
Notolabrus tetricus	Parrotfish	SA	1984	2017	13	11	18	15	Catch-MSY	This report
Donax deltoides	Pipi	SA	2000	2017	921	921	536	536	surplus prod	This report
Ovalipes australiensis	Sand crab	SA	1984	2017	105	84	65	52	Catch-MSY	This report
Chrysophrys auratus	Snapper	SA - SG	1984	2018	278	143	117	60	DEPM/App5	McGarvey et al (2018).
Chrysophrys auratus	Snapper	SA - GSV	1984	2018	217	125	563	325	DEPM/App5	McGarvey et al (2018).
Sphyraena novae-hollandiae	Snook	SA	1984	2017	172	55	145	46	Catch-MSY	This report
Sepioteuthis australia	Southern calamari	SA	1984	2017	510	450	447	394	Catch-MSY	This report
Jasus edwardsii	Southern rock lobster	SA	1984	2017	1460	1408	1633	1575	Length structured	McGarvey et al (2016).
Katelysia spp.	Vongole	SA	1984	2017	158	158	65	65	Catch-MSY	This report
Panaeus (Melicertus) latisulcatus	Western king prawn	SA - GSV	1984	2017	251	251	227	227	Catch-MSY	This report
Panaeus (Melicertus) latisulcatus	Western king prawn	SA-SG/WC	1984	2017	2358	2358	2301	2301	Catch-MSY	This report
Aldrichetta forsteri	Yellow Eye Mullet	SA	1984	2017	104	55	32	17	Catch-MSY	This report
Sillago schomburgkii	Yellowfin Whiting	SA	1984	2017	154	123	121	119	Catch-MSY	This report
	Other species		1984	2017	**226**	**40**	**222**	**36**	Catch-MSY	This report
	Total				**90863**	**89132**	**49069**	**47765**		

Appendix 10 Commercial MSY estimate and average 3 year (2014/15 – 2016/17) catch for selected Western Australian species/stocks. The first and last years of data used are shown. Other species include minor species/stocks and those aggregated for confidentiality reasons.

Scientific Name	Common name	Jurisdiction	Data Start	years Last	MSY	Av 3-yr catch (t)	Method	Reference
Arripis georgianus	Australian Herring	WA	1976	2017	743	81	Catch-MSY	This report
Sardinops sagax	Australian Sardine	WA	1976	2017	8314	1990	Catch-MSY	This report
Ylistrum balloti	Ballot's Saucer Scallop	WA	1976	2017	4600	1127	Catch-MSY	This report
Penaeus merguiensis	Banana Prawn	WA	1976	2017	457	321	Catch-MSY	This report
Lates calcarifer	Barramundi	WA	1976	2017	51	51	Catch-MSY	This report
Carcharhinus, Loxodon & Rhizoprionodon spp.	Blacktip Shark	WA	1986	2017	46	0	Catch-MSY	This report
Metapenaeus endeavouri	Blue Endeavour Prawn	WA	1976	2017	368	298	Catch-MSY	This report
Portunus armatus	Blue Swimmer Crab	WA	1976	2017	677	544	Catch-MSY	This report
Lethrinus punctulatus	Bluespotted Emperor	WA	1973	2017	537	354	Catch-MSY	This report
Lutjanus erythropterus	Crimson Snapper	WA	1988	2017	252	215	Catch-MSY	This report
Carcharhinus obscurus	Dusky Whaler	WA	1976	2017	302	148	Catch-MSY	This report
Cnidoglanis macrocephalus	Estuary Cobbler	WA	1976	2017	123	63	Catch-MSY	This report
Pristipomoides multidens	Goldband Snapper	WA	1980	2017	677	709	Catch-MSY	This report
Haliotis laevigata	Greenlip Abalone	WA	1976	2017	174	106	Catch-MSY	This report
Mustelus antarcticus	Gummy Shark	WA	1976	2017	429	406	Catch-MSY	This report
Chrysophrys auratus	Pink Snapper	WA	1976	2017	692	275	Catch-MSY	This report
Epinephelus multinotatus	Rankin Cod	WA	1973	2017	170	187	Catch-MSY	This report

Lutjanus sebae	Red Emperor	WA	1976	2017	306	292	Catch-MSY	This report
Lethrinus miniatus	Redthroat Emperor	WA	1987	2017	66	52	Catch-MSY	This report
Haliotis roei	Roe's Abalone	WA	1976	2017	107	52	Catch-MSY	This report
Lutjanus malabaricus	Saddletail Snapper	WA	1973	2017	184	221	Catch-MSY	This report
Carcharhinus plumbeus	Sandbar Shark	WA	1985	2017	158	33	Catch-MSY	This report
Mugil cephalus	Sea Mullet	WA	1976	2017	459	208	Catch-MSY	This report
Pinctada maxima	Silverlip Pearl Oyster	WA	1999	2017	212	186	Catch-MSY	This report
Jasus edwardsii	Southern Rock Lobster	WA	1976	2017	56	40	Catch-MSY	This report
Lethrinus nebulosus	Spangled Emperor	WA	1973	2017	201	100	Catch-MSY	This report
Scomberomorus commerson	Spanish Mackerel	WA	1976	2017	324	287	Catch-MSY	This report
Penaeus esculentus & Penaeus monodon	Tiger Prawn	WA	1976	2017	1003	855	Catch-MSY	This report
Glaucosoma hebraicum	West Australian Dhufish	WA	1976	2017	161	45	Catch-MSY	This report
Arripis truttaceus	Western Australian Salmon	WA	1976	2017	1652	138	Catch-MSY	This report
Melicertus latisulcatus	Western King Prawn	WA	1976	2017	1749	1450	Catch-MSY	This report
Panulirus cygnus	Western Rock Lobster*	WA	1944	2018	11115	6193	Biomass dynamic	de Lestang et 2016
Aldrichetta forsteri	Yelloweye Mullet	WA	1976	2017	317	16	Catch-MSY	This report
Sillago schomburgkii	Yellowfin Whiting	WA	1976	2017	181	86	Catch-MSY	This report
	Other species	WA	1976	2017	622	392.9	Catch-MSY	This report
	Total				**37485**	**17522**		

* western rock lobster MSY estimate has been reduced by 5% to take into account recreational catches.

Appendix 11 MSY estimate and average 3 year (2014/15 – 2016/17) catch for selected Queensland species/stocks. Note: total MSY and total catch is shown as well as QLD commercial (comm) MSY and catch to account for when multiple jurisdictions and recreational catches are included in assessments. The first and last years of data used are shown.

Species name	Common name	Jurisdiction/stock	Data First	Years Last	MSY Total (t)	MSY comm (t)	Av 3 yr catch Total (t)	Av 3 yr catch comm (t)	Method	Reference
Ylistrum balloti	Ballot Saucer Scallop	QLD	1977	2016	500	500	212	212	Month age struct	Yang et al 2016
Penaeus merguiensis, Penaeus indicus	Banana Prawn	QLD	1968	2004	802	802	634	634	Age-structured	Tanimoto et al (2006)
Portunus armatus	Blue Swimmer Crab	QLD	1937	2013	713	499	610	427	Monthly length-struct	Sumpton et al (2017)
Platycephalus fuscus	Dusky Flathead	QLD (SEC)	1945	2017	108	39	121	44	Sex, age length struct	Leigh et al (2019)
Carcharhinus spp. & Sphyrnidae spp.	Whaler & Hammerhead shark	QLD	1974	2013	1025	1025	410	410	Regional-age-struct	Leigh (2016)
Carcharhinus limbatus	Common Black Tip Shark	QLD, NT, NSW (EC/GOC)	1974	2013	247	247	0	0	Regional-age-struct	Leigh (2016)
Plectropomus leopardus	Common Coral Trout	QLD (EC)	1962	2013	2010	1648	983	806	Regional-age-struct	Campbell et al (2019)
Lutjanus erythropterus	Crimson Snapper	QLD, NT (GOC)	1945	2009	155	155	36	36	Age-structured	O'Neill et al (2011)
Melicertus plebejus	Eastern King Prawn	QLD, NSW	1958	2010	3100	2478	3329	2661	Popn dyn model	O'Neill et al (2014)
Metapenaeus endeavouri, M. ensis	Endeavour Prawn	QLD (EC)	1988	2013	1112	1112	491	491	Weekly delay-diff	Wang et al (2015)
Lutjanus johnii	Golden Snapper	QLD (GOC)	1945	2009	55	55	2	2	Age-structured	O'Neill et al (2011)

Scomberomorue semifasciatus	Grey Mackerel	QLD (EC)	1988	2011	215	215	168	168	Sex and age-struct	Lemos et al (2014)
Scomberomorus semifasciatus	Grey Mackerel	NT/QLD (GOC)	1970	2011	1958	1799	695	639	Sex, age-struct, SRA	Bessell-Browne et al (2019)
Lutjanus argentimaculatus	Mangrove Jack	QLD (GOC)	1945	2009	24	24	5	5	Age-structured	O'Neil et al (2011)
Glaucosoma scapulare	Pearl Perch	QLD, NSW	1938	2014	175	61	82	29	Age length struct	Sumpton et al (2017)
Lutjanus sebae	Red Emperor	QLD (GOC)	1945	2009	23	23	1	1	Age-structured	O'Neill et al (2011)
Lethrinus miniatus	Redthroat Emperor	QLD	1946	2004	862	431	360	230	Regional-age-struct	Leigh et al (2006)
Melicertus longistylus	Redspot King Prawn	QLD (EC)	1988	2013	716	716	191	191	Weekly delay-diff	Wang et al (2015)
Lutjanus malabaricus	Saddletail Snapper	QLD, NT (GOC)	1945	2009	164	164	24	24	Age-structured	O'Neill et al (2011)
Sillago ciliata	Sand whiting	QLD (SEC)	1945	2017	452	348	272	209	Age length struct	Leigh et al (2019)
Mugil cephalus	Sea Mullet	QLD, NSW	1899	2016	6350	2134	4758	1599	Sex and age-struct	Lovett et al (2018)
Pagrus auratus	Snapper	QLD, NSW, VIC	1946	2016	1000	81	780	63	Age-structured	Wortmann et al (2018)
Scomberomorus commerson	Spanish Mackerel	QLD (EC) NSW	1911	2016	600	246	579	293	Age-structured	O'Neill et al (2018)
Ranina ranina	spanner crab	QLD	1988	2017	1250	1138	1064	1063	multiple	O'Neill (unpublished)
Scomberomorus munroi	Spotted Mackerel	QLD, NSW (EC)	1960	2017	210	92	250	138	Sex and age-struct	Bessell-Browne et al (2018)
Sillago robusta	Stout Whiting	QLD, NSW	1991	2015	1363	1097	1000	805	Age-structured	O'Neill and Leigh (2016)
Pomatomus saltatrix	Tailor	QLD, NSW	1945	2014	1350	351	250	65	Age length struct	Leigh et al (2017)
Penaeus esculentus, P semisulcatus	Tiger Prawns	QLD	1988	2013	1836	1836	1482	1482	Weekly delay-diff	Wang et al (2015)
Acanthopagrus australis	Yellowfin Bream	QLD (SEC)	1945	2017	420	227	242	131	Age and length struct	Leigh et al (2019)
Scylla serrata	Mud crab	QLD (EC)	1988	2017	1230	898	884	884	Catch-MSY	This report
Scylla serrata	Mud crab	QLD (GOC)	1988	2017	144	127	122	122	Catch-MSY	This report
	Total					**20568**		**13862**		

Appendix 12 MSY estimate and average 3 year (2014/15 – 2016/17) catch for selected New South Wales species/stocks. Note: total MSY and total catch is shown as well as QLD commercial (comm) MSY and catch to account for when multiple jurisdictions and recreational catches are used in in assessments. The first and last years of data used are shown. Other species include minor species/stocks and those aggregated for confidentiality reasons.

Species name	Common name	Jurisdiction	Data	years	MSY Total (t)*	MSY comm (t)	Total catch (t)	Av 3 yr catch comm(t)	Method	Reference
			First	Last						
Portunus armatus	Blue swimmer crab	NSW	1985	2017		164		176	Catch-MSY	This report
Platycephalus caeruleopunctatus	Bluespotted flathead	NSW	1947	2016		221		91	Catch-MSY	This report
Ibacus spp.	Bugs	NSW	1991	2017		59		24	Catch-MSY	This report
Platycephalus fuscus	Dusky flathead	NSW	1953	2017		189		140	Catch-MSY	This report
Arripis trutta	Eastern Australian salmon	NSW	1945	2017		1015		757	Catch-MSY	This report
Metapenaeus macleayi	Eastern school prawn	NSW	1979	2017		972		649	Catch-MSY	This report
Hyporhamphus autralis	Eastern sea garfish	NSW	1941	2017		99		37	Catch-MSY	This report
Nemadactylus douglasii	Grey morwong	NSW	1979	2017		199		23	Catch-MSY	This report
Girella tricuspidata	Luderick	NSW	1945	2017		538		290	Catch-MSY	This report
Scylla serrata	Giant mud crab	NSW	1979	2017		146		185	Catch-MSY	This report
Argyrosomus japonicus	Mulloway	NSW	1945	2017		142		77	Catch-MSY	This report
Nelusetta ayraudi	Ocean jacket	NSW	1945	2017		405		288	Catch-MSY	This report
Donax deltoides	Pipi	NSW	1985	2017		257		158	Catch-MSY	This report
Sillago ciliata	Sand whiting	NSW	1953	2017		143		99	Catch-MSY	This report

Mugil cephalus	Sea mullet	NSW (QLD)	1899	2016	6350	4216	4758	2742	Age structured	Lovett et al (2018)
Sepioteuthis australis	Southern calamari	NSW	1991	2017		70		45	Catch-MSY	This report
Acanthopagrus australis	Yellowfin bream	NSW	1945	2017		419		279	Catch-MSY	This report
Seriola lalandi	Yellowtail kingfish	NSW	1945	2017		276		95	Catch-MSY	This report
Trachurus novaezelandiae	Yellowtail scad	NSW	1970	2017		404		407	Catch-MSY	This report
Sagmariasus verreauxi	Eastern Rock Lobster	NSW	1884	2018		171		157	Po model	NSW DPI unpublished
Haliotis rubra	Blacklip abalone	NSW	1958	2018		382		129	Catch-MSY	This report
Pagrus auratus	Snapper	NSW (QLD)	1946	2017	1000	223	780	174	age-length struct	Wortmann et al (2018)
Melicertus plebejus	Eastern King Prawn	NSW (QLD)	1958	2010	3100	622	3329	668	Pop model	O'Neill et al (2014)
Sillago robusta	Stout Whiting	NSW (QLD)	1991	2015	1363	261	1000	195	age structured	O'Neill unpublished
Pomatomus saltatrix	Tailor	NSW (QLD)	1945	2014	1350	335	250	62	age length struct	Leigh et al (2017)
Sillago flindersi	Eastern School Whiting	NSW (C'wealth)	1947	2016	2070	1097	1551	805	SS3 App4	Day (2017)
	Other species	NSW	vari-ous	various		192		175	various	
	Total					**13218**		**8926**		

* MSY Total includes all jurisdictions and sectors

Appendix 13 Commercial MSY estimate and average 3 year (2014/15 – 2016/17) catch for selected Tasmanian species/stocks. The first and last years of data used are shown. Other species include minor species/stocks and those aggregated for confidentiality reasons.

Species name	Common name	Jurisdiction	Data First	years Last	MSY (t)	Av 3 yr catch (t)	Method	Reference
Haliotis rubra	Abalone blacklip	TAS	1964	2017	2163	1613	Catch-MSY	This report
Haliotis laevigata	Abalone greenlop	TAS	1964	2017	164	148	Catch-MSY	This report
Arripis trutta	Australian Salmon	TAS	1970	2005	599	50	Catch-MSY	This report
Sardinops sagax	Australian Sardine	TAS	1995	2016	3000	11	DEPM	Ward et al 2015
Thyrsites atun	Barracouta	TAS	1983	2005	140	1	Catch-MSY	This report
Cheilodactylus spectabilis	Banded morwong	TAS	1995	2017	31	32	age-structured	Moore et al 2018
Latridopsis forsteri	Bastard Trumpeter	TAS	1990	2005	37	7	Catch-MSY	This report
Platycephalidae	All flathead species	TAS	1990	2005	81	62	Catch-MSY	This report
Nototodarus gouldi	Gould's Squid	TAS	1990	2016	309	209	Catch-MSY	This report
Trachurus declivis	Jack Mackerel	TAS	1990	2010	321	2	Catch-MSY	This report
Octopus spp	Octopus species	TAS	2000	2017	96	80	Catch-MSY	This report
Sepioteuthis australis	Southern Calamari	TAS	1995	2016	93	100	Catch-MSY	This report
Hyporhamphus melanochir	Southern Garfish	TAS	1995	2016	70	24	Catch-MSY	This report
Jasus edwardsii	Southern rock lobster	TAS	1970	2011	1635	1087	Catch-MSY	This report
Latris lineata	Striped Trumpeter	TAS	1990	2016	45	11	Catch-MSY	This report
Notalabrus spp	Wrasse	TAS	1995	2016	85	78	Catch-MSY	This report
	Other species	TAS	various	various	329	32	Catch-MSY	This report
	Total				**9198**	**3547**		

Appendix 14 MSY estimate and average 3 year (2014/15 – 2016/17) catch for selected Northern Territory species/stocks. Note: total MSY and total catch is shown as well as commercial (comm) MSY and catch to account for when multiple jurisdictions and recreational catches are included in assessments. The first and last years of data used are shown.

Species name	Common name	Jurisdiction	Data First	years Last	MSY Total (t)	MSY Comm (t)	Av 3 yr catch (t) Total	Av 3 yr catch comm(t)	Method	Reference
Lates calcarifer	Barramundi	NT	1973	2017	2765	1741	573	361	Stochastic SRA	Unpublished
Scylla serrata	Mud Crab	NT	1983	2017	717	618	226	195	Deriso Delay Difference	Grubert et al (2019)
Lutjanus malabaricus	Saddletail Snapper	NT	1970	2016	1300	1286	1992	1971	Stochastic SRA	Martin (2018)
Lutjanus erythropterus	Crimson Snapper	NT	1970	2016	706	687	751	731	Stochastic SRA	Unpublished paper
Pristipomoides multidens	Goldband Snapper	NT	1970	2016	750	749	528	527	Stochastic SRA	Unpublished paper
Scomberomorus semifasciatus	Grey Mackerel	NT	1970	2011	1671	1669	359	359	Stochastic SRA	Grubert et al (2013)
Scomberomorus semifasciatus	Grey Mackerel	NT/Qld	1970	2011	1958	149	695	53	Stochastic SRA	Grubert et al (2013)
Carcharinus tilstoni/limbatus	Blacktip Shark	NT	1970	2011	1351	1264	62	58	Stochastic SRA	Grubert et al (2013)
Scomberomorus commerson	Spanish Mackerel	NT	1970	2011	2420	2173	467	419	Stochastic SRA	Grubert et al (2013)
Carcharinus sorrah	Spottail Shark	NT	1970	2011	700	630	10	9	Stochastic SRA	Grubert et al (2013)
Protonibea diacanthus	Black Jewfish	NT	1970	2017	268	179	295	197	Stochastic SRA	Grubert et al (2013)
Lutjanus sebae	Red Emperor	NT	1983	2015	97	91	95	89	Stochastic SRA	Unpublished
Lutjanus johnii	Golden Snapper	NT	1983	2017	41	17	127	53	Stochastic SRA	Penny et al (2018)
Eleutheronema tetradactylum	Blue Threadfin	NT	1983	2018		15		10	Catch-MSY	This report
Polydactylus macrochir	King Threadfin	NT	1983	2018		310		262	Catch-MSY	This report

Lutjanus argentimaculatus	Mangrove Jack	NT	1983	2018	14	66	Catch-MSY	This report
unspeciated	Trevally	NT	1983	2018	290	306	Catch-MSY	This report
	Total				**11883**	**5666**		

Appendix 15 Commercial MSY estimate and average 3 year (2014/15 – 2016/17) catch for selected Victorian species/stocks. The first and last years of data used are shown. Other species include minor species/stocks and those aggregated for confidentiality reasons.

Species name	Common name	Jurisdiction	Data years First	Last	MSY (t)	Av 3 yr catch (t)	Method	Reference
Arripis georgiana	Australian salmon	Vic	1978	2018	354	303	Catch-MSY	This report
Sardinops Sagax	Australian sardine	Vic	1978	2018	1543	1683	Catch-MSY	This report
Haliotis rubra	Blacklip abalone	Vic	1969	2018	1343	713	Catch-MSY	This report
Acanthopagrus butcheri	Bream, black	Vic	1978	2018	161	22	Catch-MSY	This report
Sepioteuthis australis	Calamari, Southern	Vic	1978	2018	52	32	Catch-MSY	This report
Platycephalus fuscus	Flathead, dusky	Vic	1978	2018	15	13	Catch-MSY	This report
Platycephalus laevigatus	Flathead, rock	Vic	1978	2018	44	39	Catch-MSY	This report
Platycephalidae	Other flathead species	Vic	1978	2018	47	24	Catch-MSY	This report
Hyporhamphus melanochir	Garfish, Southern (Sea)	Vic	1978	2018	107	45	Catch-MSY	This report
Aldrichetta forsteri	Mullet, yelloweye	Vic	1978	2018	148	28	Catch-MSY	This report
Octopus spp.	Octopus species	Vic	1978	2018	45	45	Catch-MSY	This report
Jasus edwardsii	Rock lobster, Southern	Vic	1978	2018	445	279	Catch-MSY	This report
Chrysophrys auratus	Snapper	Vic	1978	2018	162	74	Catch-MSY	This report
Pseudocaranx georgianus	Trevally, silver	Vic	1978	2018	111	42	Catch-MSY	This report
Sillaginodes punctatus	Whiting, King George	Vic	1978	2018	137	106	Catch-MSY	This report
	Other species	Vic	1978	2018	150	133	Catch-MSY	This report
	Total				**4863**	**3581**		

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