Informing inter-jurisdictional snapper management in eastern Australia.

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In submitting this report, the researcher has agreed to FRDC publishing this material in its edited form.

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Abbreviations

Actual fishing power	Actual fishing power as calculated from the fisher knowledge data.
AFMA	Australian Fisheries Management Authority.
AMLI	Australian Marine Life Institute.
B	Exploitable biomass: the combined weight of legal sized fish.
B_0	Equilibrium virgin unfished biomass: exploitable biomass level if fishing had not occurred.
$B_{0.6}$	Exploitable biomass equal to 0.6 of B_0.
B_{MSY}	The exploitable biomass that can support harvest at the Maximum Sustainable Yield (generally 0.4 of virgin biomass).
BRUV	Baited Remote Underwater Video
Catch	Number or weight of all snapper caught (harvested and released).
Catch rate	Catch rate standardised to constant fishing or sampling conditions (e.g. constant vessel and fishing power through time). The index varies between data sets and the elements of catch recorded.
DAF	Department of Agriculture and Fisheries, Queensland Government, www.daf.qld.gov.au.
D_{EST}	Jost's estimate of differentiation
EAC	East Australian Current.
Fishing year	Months January–December.
FL	Fork length of snapper (cm); FL=0.857xTL-0.222.
Fishing power	Fishing power, measures 'a' or 'a group' of fishing operations effectiveness in catching fish. More generally, fishing power refers to a measure of deviation in actual fishing effort from the standard unit of effort. For example, the standard unit of effort used to calculate line catch rates is the number of lines deployed.
FRAB	Fisheries Research Advisory Board.
FRDC	Fisheries Research and Development Corporation, Australian Government, www.frdc.com.au .
GBR	Great Barrier Reef.
Growth Overfished	Occurs when fish are harvested at an average size that is smaller than the size that would produce the maximum yield per recruit. When a fish stock is growth overfished, increases in fishing effort and fishing mortality produce decreasing yields, even though more individuals are harvested, because of the reduced average size of harvested individuals.
Harvest	Number or weight of snapper caught and retained.
HWE	Hardy-Weinberg Equilibrium
LD	Linkage disequilibrium
LDNe	Estimating effective population size (Ne) from genotypic data on linkage disequilibrium.
LTMP	Long-Term Monitoring Program.
MLS	Minimum legal size, measured in cm (total length).

MSE	Management Strategy Evaluation.
MSY	Maximum Sustainable Yield.
NSW	New South Wales.
NSW DPI	New South Wales Department of Primary Industries, www.dpi.nsw.gov.au.
OCS	Offshore Constitutional Settlement.
QFB	Queensland Fish Board.
Qld	Queensland.
Recruits	The new age group of the population entering the exploited component of the stock for the first time or young fish growing into or otherwise entering that exploitable component.
Recruitment overfished	The point at which a stock is considered to be recruitment overfished is the point at which the spawning stock biomass has been reduced through catch so that average recruitment levels are significantly reduced.
Reduced fishing power	Calculated from the square root of the actual fishing power to account for possible overestimation in the actual fishing power effects.
REML	Restricted Maximum Likelihood (type of linear mixed model); method used to standardise catch rates.
RFISH	Recreational Fisheries Information System.
S_0	Original or unfished spawning egg production.
S_t	Spawning egg production at time t.
SAFS	Status of Australian Fish Stocks.
SARDI	South Australia Research and Development Institute.
SETFIA	South-east Trawl Fishery Industry Association.
Spawning biomass	Total egg production of mature female fish, denoted by S_t.
SWRFS	State-Wide Recreational Fishing Survey.
TAC	Total allowable catch (harvest).
TL	Total length of snapper (cm); TL=1.167FL+0.259.

Executive Summary

This report presents the results of the first joint fishery modelling of the east coast snapper stock: informing inter-jurisdictional snapper management in eastern Australia. The project was funded by the Fisheries Research and Development Corporation (FRDC) project 2015-216 for the period 1 July 2015 to 30 June 2018. Research involved the collaboration of fisheries scientists, biologists, managers and stakeholders from New South Wales, Queensland and Victoria. The latest microsatellite genetic techniques explored the stock structure of snapper along Australia's east coast, showing a two-stock genetic structure, a northern and a southern stock. The project also collated new data on historical snapper catches in both Queensland and New South Wales. Existing data from all jurisdictions were harmonised and used in a snapper simulation model to inform cross-jurisdictional east coast snapper management on the northern stock. Challenges in the work included harmonising data from different jurisdictions and fitting the model to multiple data sets with different trends. Hypothetical management strategies on changes to minimum legal size and total allowable harvest for all fishing sectors and waters were explored as advised by the project steering committee.

Background

The 2016 Status of key Australian Fish stocks (SAFS) report listed the east coast snapper stock status as undefined because the stock was given a different status in each jurisdiction based on different kinds of data, analyses and criteria for defining status. In 2014 Queensland snapper stocks were listed as overfished while New South Wales was 'growth overfished' but not 'recruitment overfished', as commercial landings remained stable. Information on Victoria's eastern snapper fishery were analysed in 2011 but available data were insufficient to adequately assess the stock status at that time. Similarly, only limited information was available for the snapper fishery in Tasmania.

Prior to the 1990s it was thought that the snapper fisheries of the east coast targeted the same biological stock. It was only in the mid-1990s that an allozyme-based study of snapper identified a genetic disjunction north of Sydney, questioning the single stock hypothesis. The present study, focussing on east coast snapper, used the latest microsatellite techniques to assess the validity of the allozyme break and investigated the genetic structure of snapper over a wider area, expanding the sampling regime further south into Victoria and Tasmania. Knowledge of the east coast snapper stock structure was important in determining snapper stock boundaries and the degree of spatial mixing of east coast populations. This was important in determining the use of spatial data in the fisheries assessment.

In Australia there is considerable variation in snapper management regimes imposed across jurisdictions. Most relevant to snapper management on the east coast of Australia is that management differs between New South Wales and Queensland. The current minimum legal size of 35 cm total length in Queensland is 5 cm greater than in New South Wales, while the New South Wales recreational in possession bag limit of 10 snapper per person is more than double that existing in Queensland. In Queensland, the vast majority of the catch is line-caught while there is a significant commercial trap fishery in New South Wales. Thus there is a lack of a consistent management framework across different jurisdictions, even though biological evidence to date, based on genetic data and information relating to growth, movement and otolith readability, suggested that both the New South Wales and Queensland snapper fisheries targeted the same biological population of fish.

Thus the need for a single consensus approach for research and management across the whole east coast was identified as a priority in a FRDC funded national workshop on snapper held at the South Australia Research and Development Institute (SARDI) in March 2013 and this project was subsequently conceived.

Objectives

The research aimed to define the spatial limits of the east coast snapper stock structure using the latest microsatellite genetic techniques and then to collate all relevant data, including archival records, to model the east coast snapper stock to inform on the utility of the data sets and to inform on cross-jurisdictional hypothetical snapper management strategies. Stakeholder involvement from all jurisdictions in the decision making processes was also an important objective.

Methodology

The genetic study, focussing on east coast snapper, used microsatellite markers to assess the validity of stock boundaries reported in the mid-1990s just north of Sydney. Nine regions were sampled spanning four states, and over 2,000 km, including sites north and south of the proposed genetic allozyme disjunction near Sydney.

Snapper data were assembled from the different jurisdictions and harmonised in a central, secure MS Access database. This included archival snapper data from newspapers, popular publications, Royal Commission reports and annual government reports spanning the years 1803–1953. In addition to the archival data, fisher surveys informed on the technologies and methods used for snapper fishing. Fishing records included catch (number of snapper and total number of other fish species) and historical catch rates.

The genetic stock structure was used to inform the development of an annual age structured population model of the east coast snapper stock. The population model was then further used to inform on inter-jurisdictional management strategies by modelling a range of management scenarios to project snapper stock biomass forty years from present. The management arrangements endorsed by the steering committee were changing the minimum legal size while keeping the current fishing effort, and setting yearly harvest taken by all fishing sectors while keeping the minimum legal size as it currently is in each jurisdiction.

A key part of the project was to engage with stakeholders from New South Wales, Queensland and Victoria and use their knowledge to improve the assessment. There were three steering committee meetings with the stakeholders and an additional workshop which had an expanded stakeholder membership. In addition, a cross jurisdictional stock assessment project team also developed the stock assessment and the project team met regularly to discuss data and model assumptions. This group consisted of fisheries managers, biologists and scientists from both New South Wales and Queensland. There were six meetings of this team. Project information posts were also provided on the FRDC website and media articles.

Results

Microsatellite data supported a two-stock genetic model for snapper along Australia’s east coast. The northern stock extended from Rockhampton to Eden; the northern and southern stocks overlapped around Eden, then the southern stock extended south from Eden to at least eastern Victoria (Lakes Entrance), including Tasmania. This genetic disjunction was roughly 400 km south of the genetic disjunction reported near Sydney in the mid-1990s.

Snapper archival and fisher knowledge data highlight information back to the early days of snapper fishing in the 1880s. Data from fishing trips between 1880 and 1960 were analysed, showing average catch rates (number of snapper caught per fisher per trip) halved over this time.

Catch and effort data across the jurisdictions were collected from commercial and charter logbooks, recreational surveys, fishery independent surveys, historical Fish Board records, archival data, fishing technology uptake rates, length and age frequency data and other scientific data (e.g. release survival, fecundity). These data were harmonised with the aid of stakeholders, and the utility of trends in total harvests and catch rates were influential in determining results. Expanded use of snapper age-length data and spatial-temporal extension of the fishery independent survey of juvenile snapper were also important datasets for developing inter-jurisdictional harvest control rules for fishery management.

Due to the limited data for Victoria and Tasmania and the finding that these regions were part of a separate stock, a single east coast population model was developed for the northern stock (encompassing New South Wales and Queensland). Improved data collections are required to assess status of the southern snapper stock. The model showed that the 2016 snapper spawning biomass was most likely between 10 and 45% of original unfished biomass. The result was below the 2027 target reference point of 60% in Queensland waters proposed under the Queensland Sustainable Fisheries Strategy. There were no targets for the fishery in New South Wales waters.

Forward projection modelling of cross-jurisdictional management suggested that changes in size limits alone would not promote larger stock sizes at current levels of fishing. Many modelling scenarios indicated that if larger stock sizes were desired, then direct reductions in harvest and fishing effort would achieve this.

Implications

Assembling all available east coast snapper data resulted in newly available information, the improvement of the interpretation of existing data, greater understanding of commercial and recreational perspectives, and better engagement with stakeholders. These factors work towards enhancing the quality of future management.

The computer model was influenced by trends in abundance indices, and those currently available were from different fishery sectors in different areas, and showed conflicting trends. These trends better informed stakeholders and managers about their jurisdictional data. These jurisdictional data, which may not have been previously available to management, have the potential to be incorporated into state-based stock assessments and management, thus benefitting all fishery stakeholders. However, work in this project does not overcome cross-jurisdictional management difficulties, different legislation and different reference points. More collaboration and engagement are needed before these issues can be resolved, including: defining operational objectives for the fishery, selecting and monitoring key indicators of the fishery performance, defining target, trigger and limit reference points for judging indicators and fishery performance, monitoring programmes with an agreed funding base to collect data, agreement of methods of stock assessment, agreement on harvest control rules and setting target levels of fishing.

Recommendations

Investigate spatial modelling of the east coast snapper stock. While the creation of a coast-wide model met the objectives of this project, the model did not include the influence of finer spatial or meta-population structure and therefore was not capable of assessing potential localised depletion differences in sub-areas. As future research, a combined model with spatial sub-structuring could be investigated. This level of sub-structuring was not endorsed by the steering committee due to complexities of data and modelling required, the need for more information on finer-scale population structure, and the complexity of multi-jurisdictional management.

Data harmonised during this research should be available to all jurisdictions. As more data are collected and further stock assessments are done, the database developed in this study should be maintained and be available to all jurisdictions (particularly Queensland, New South Wales and Victoria).

Consideration should be given to reporting the status of the East Coast Snapper stock at a sub-stock level. The Status of Australian Fish Stocks (SAFS) defines recruitment overfished as below 20 percent unfished biomass. Given the wide range of biomass estimates for 2016 (10 to 45 percent) the status of the overall east coast snapper stock remains uncertain. Catch rates for commercial line fishing in Queensland and New South Wales in the northern latitude bands were decreasing from 2002 onwards suggesting localised depletions in these areas. The reporting of status on a jurisdictional basis also over simplifies the extent of any localised issues that may be impacting on parts of the stock. The SAFS reporting is confusing for some stakeholders without understanding biomass reference points for maximum sustainable yield (≈ 35–45%).

Stock assessment project teams should involve scientists, and managers from all relevant jurisdictions. Queensland and New South Wales currently collaborate closely when assessing joint fisheries. The involvement of scientists and managers from all effected jurisdictions in assessment project teams is an important recommendation from this current research.

Keywords

East Coast Snapper, *Chrysophrys auratus*, Microsatellite Genetic Techniques, Harmonised Data, Archival and Fisher Knowledge Data, Computer Models, Inter-Jurisdictional Management Strategies, Stakeholder Engagement.

Introduction

This project was originally conceived during the Queensland snapper stock assessment in 2007–2008 (Campbell *et al.*, 2009). During that assessment it became apparent how important a unified east coast approach was, not just from a scientific standpoint, but also from a management and policy perspective and from stakeholder engagement perspectives. However, project momentum began to build after the inaugural national snapper workshop at the South Australia Research and Development Institute (SARDI) in March 2013. Since that time numerous consultations have been held with fishery managers and policy makers from all four jurisdictions (New South Wales, Queensland, Victoria and Commonwealth) over the duration of this project.

The project addresses a number of the FRDC's strategic priority areas. By making a unified stock status determination possible it will enable the development of efficient multi-sector fisheries management arrangements when more than one jurisdiction is spanned. The study will 1) lay the foundations and information for improving cross-jurisdictional resource access and management; 2) improve knowledge of key biological attributes for snapper; and 3) increase knowledge among diverse groups of stakeholders about each other's expectations about resource access and allocation.

This project also relates to FRDC project 2013/201 - Development of a harvest management, governance and resource sharing framework for a complex multi-sector, multi-jurisdiction fishery: the western Victorian biological stock, led by Paul Hamer of Victorian Fisheries Authority (co-investigator of this project). FRDC project 2013/201 is directly addressing the creation of a multi-jurisdictional harvest management framework for the western Victorian biological stock. Whereas this project is focused on data collection and modelling, and then "laying the groundwork" of information for stakeholders to use in a management framework (a significant task). In Queensland, this framework is functionally being established through the Rocky Reef Fishery Working Group.

The 2016 Status of key Australian Fish stocks report lists the east coast stock status as undefined (Fowler *et al.*, 2016) mainly because the stock was given a different status in each jurisdiction based on different assessment approaches and criteria for defining status. In 2014, snapper in Queensland were listed as overfished (low snapper abundance), while New South Wales was growth-overfished but not recruitment-overfished, as commercial landings remained stable (Finn *et al.*, 2015). The eastern Victorian biological stock was assessed in 2011 but available data were insufficient to adequately assess the stock status at that time (Kemp *et al.*, 2012). Similarly, only limited information was available for the snapper fishery in Tasmania. The need for a single consensus approach was identified as a priority in a FRDC funded national workshop on snapper held at SARDI in March 2013. In particular, it was noted that, underpinning a unified approach to assessment and management, there was a need for: a better understanding of stock structure, a better understanding of the utility of fishery data sources and better supply of information to stakeholders.

It was thought before the 1990s that the snapper fisheries along the east coast of Australia targeted the same biological stock. It was only in the mid-1990s that an allozyme-based study of snapper identified a weak genetic disjunction north of Sydney, questioning the single stock hypothesis (Sumpton *et al.*, 2008). The present study, focussing on east coast snapper, used the latest microsatellite techniques to assess the validity of the allozyme break and investigated if genetic structure of snapper existed further south. This new genetic study of the east coast snapper stock structure will confirm where the snapper stock boundary exists and the degree of spatial mixing of east coast populations, and thus whether or not the jurisdictions exploit the same biological stock and thus should be combined for fisheries assessment.

In Australia snapper are managed by both input and output controls and there is considerable variation in the management regimes imposed across jurisdictions. Most relevant to snapper management on the east coast of Australia is that Queensland and New South Wales management differ significantly between the two states. The current minimum legal size of 35 cm total length in Queensland is 5 cm greater than in New South Wales, while the New South Wales recreational bag limit of 10 per person is more than double that existing in Queensland. In Queensland, the vast majority of the catch is line-caught while there is a significant commercial trap fishery in New South Wales (see Scandol *et al.* (2008) for the New South Wales 2013/14 report). Thus there is a lack of a consistent management decision making framework across different jurisdictions, even though biological evidence to date, based on allozyme data and information relating to growth, movement and otolith readability, suggested that both the New South Wales and Queensland fisheries targeted the same biological population of fish (Sumpton *et al.*, 2008).

The need for a single consensus approach across the whole east coast was identified as a priority in the FRDC funded national workshop on snapper held at SARDI in March 2013 and this project was subsequently conceived.

Objectives

1 Apply the latest cost-effective microsatellite genetic techniques to clarify and refine understanding of snapper stock structure along Australia's east coast.

2 Assemble and harmonise all available data sets and information sources, including archival and fisher knowledge data, and develop a mechanism for stakeholder feedback on this resource.

3 Develop computer models for the east-coast snapper population that inform on inter-jurisdictional management strategies.

4 Develop protocols for inter-jurisdictional decision-making processes and stakeholder engagement.

Method

SNAPPER GENETIC STOCK STRUCTURE

Sample collection

Fresh fin clip tissue samples of *C. auratus* were collected from recreational and commercial fishers who donated samples from fish that were harvested between 2012 and 2016. Samples were stored in individual tubes of 100% molecular grade ethanol. Sampling was conducted along the east Australian coastline from nine areas, spanning four States and ranging over 2,000 km (Figure 5). The sampling strategy was designed to span a wide geographic range of commercial and recreational fisheries including sites from both sides of the genetic disjunction in central New South Wales identified in the allozyme study of Sumpton *et al.* (2008) (see Figure 5). The majority of Tasmanian samples (21) were sourced from waters near Devonport in the central north, however, due to a paucity of samples four additional fish from waters off Stanley in the northwest and four from waters closer to Hobart in the southeast, were included. All tissue samples were transferred to the Department of Agriculture and Fisheries at the Eco-Sciences Precinct in Brisbane for molecular analysis.

DNA extraction and microsatellite screening

Approximately 3 mm of fin clip tissue was washed in 1 mL of milliQ water to remove the ethanol preservative prior to DNA extraction. DNA was extracted using a DNeasy Tissue Kit (Qiagen, Chadstone, VIC, Australia) following the manufacturer’s guidelines, into a final elution volume of 50µL. DNA concentration was quantified using a Thermo Scientific NanoDrop 8000 spectrophotometer (Thermo Fisher Scientific, Scoresby, Victoria, Australia).

This project targeted nine microsatellite loci from the larger panel that Le Port *et al.*, (2014) used for their New Zealand *C. auratus* study. The Le Port *et al.* (2014) 17 loci panel was reduced to exclude loci that were difficult to amplify and those the authors had identified as out of Hardy-Weinberg equilibrium. Primer sequences, annealing temperatures multiplex combinations plus the original source of each locus are detailed in Supplementary Table 1.

Rather than individually labelling each primer with a fluorescent probe, the forward primer at every locus was modified with one of four M13 sequences (Supplementary Table 1). For each assay the reaction tube contained the primer pair plus a fluorescently labelled M13 primer (with FAM, NED, VIC or PET fluorophores) (Kirchoff *et al.*, 2008; Missiaggia and Grattapaglia, 2006; Oetting *et al.*, 1995; Schuelke, 2000). Thus the nine loci were PCR amplified in three multiplexed PCR reaction tubes (M1 to M3) and three single loci reaction tubes (S1 to S3, Supplementary Table 1). A Qiagen Multiplex PCR Kit (Qiagen, Chadstone, VIC, Australia) was used to amplify the DNA in a final volume of 6 µL. PCR reactions contained 3 µL of 2 x Master Mix, 0.6 µL of 5 x Q solution, varying primer concentrations (detailed in Supplementary Table 1 with labelled M13 primer concentration the same as the reverse primer), and approximately 20 ng of genomic DNA template. Microsatellite PCR amplifications were performed in a Biorad thermal cycler (DNA Engine Peltier). The DNA template and enzyme were denatured at 95°C for 15 min, followed by 37 cycles consisting of 94°C for 30 sec, 52-62°C (refer to Ta column in Supplementary Table 1) for 45 sec and 72°C for 90 sec. To ensure consistent allele calling during genotyping, a final extension at 72°C for 45 min was used to ensure complete extension of the PCR products. Allele sizing was determined using GeneScan 500 LIZ dye size standard (Thermo Fisher Scientific, Scoresby, Victoria, Australia). Products were separated via capillary electrophoresis on an ABI3130xl sequencer (Applied Biosystems, Thermo Fisher Scientific, Scoresby, Victoria, Australia). Following the manufacturer’s recommendation LIZ peaks at 35 and 250 were excluded prior to fragment analysis, due to their temperature sensitivity, then microsatellite peaks were scored using Geneious version 8.1.9 (http://www.geneious.com Kearse *et al.* (2012). A repeat positive control sample was run on every 96-sample plate to ensure scoring consistency was maintained between electrophoresis runs. Samples returning low (less than 200 fluorescence units) or no signal strength for a subset of loci were initially re-PCRed with increased starting DNA. If the signal continued to be weak the multiplex was broken into single-loci reactions.

Microsatellite analysis

Several programs were used to obtain genetic diversity metrics for the loci. A relatedness screen in GenAlEx version 6.5 (Peakall and Smouse 2006) was used to identify duplicate samples which were removed from subsequent screening. This program was also used to determine the average inbreeding coefficient (F_{IS}) and fixation index (F_{ST}) for each locus. Due to the downward bias in F_{ST} estimates caused by the high allelic diversity of microsatellite loci, the small number of populations and low sample numbers in this study, an additional standardised measure of genetic differentiation, Jost's estimate of differentiation (D_{EST}) (Jost 2008), was also calculated in GenAlEx version 6.5 (Peakall and Smouse, 2006). The program Cervus version 3.0.7 (Kalinowski *et al.*, 2007) was used to determine the number of alleles, to estimate the polymorphism information content (PIC) of the loci as well as to calculate observed and expected heterozygosity values. Exact Tests were used in Genepop-on-the-Web version 4.2 (http://genepop.curtin.edu.au/ Raymond and Rousset (1995); Rousset (2008)) to test each locus, in each population, for deviations from Hardy Weinberg Equilibrium (HWE). A Bonferroni-type correction for multiple tests was applied (Rice, 1989). For loci out of HWE, the program Microchecker version 2.2.3 (Van Oosterhout *et al.*, 2004) was used to determine the direction of bias, and to assess if the result could be attributed to scoring errors, allele dropout or null alleles. Linkage disequilibrium (LD) was tested using log likelihood ratio statistics (G-tests) to assess each pair of loci within each population in Genepop-on-the-Web version 4.2 (http://genepop.curtin.edu.au/ Raymond and Rousset (1995); Rousset (2008)) with Bonferroni correction.

A power analysis to assess the resolving power of the microsatellites to detect genetic differentiation was conducted in POWSIM version 4.1 (Gardner *et al.* (2015); Ryman and Palm (2006)). Following Gardner *et al.* (2017) effective population size (Ne) was set to 10,000. Time since divergence (t) was varied to obtain seven divergence levels (F_{ST}) between 0.0002 and 0.005. After drift the base population was subdivided into nine populations for simulations, with the size of each population following the sample data in Figure 5. The mean of 500 replicates was used to estimate the proportion of samples for which the F_{ST} values were significantly different from zero using Fisher's exact tests.

The population genetic structure of the species across the nine sampled locations in eastern Australia was investigated using four approaches. Firstly, Bayesian inference was used to assign individuals to expected stocks using Structure version 2.3.4 (Pritchard *et al.*, 2000). The most likely number of genetic clusters was determined following (Evanno *et al.*, 2005). Secondly, population pairwise D_{EST} (GenAlEx version 6.5, Peakall and Smouse (2006)) were estimated for all sampling locations. Neighbouring locations with non-significant fixation values were then pooled and pairwise fixation values re-calculated in an iterative approach to identify possible spatial boundaries to genetic stocks (Broderick *et al.*, 2011). Thirdly, a discriminant analysis of principal components (DAPC, Jombart *et al.*, 2010) available in the Adegenet package (Jombart, 2008), run through RStudio version 0.99.903 (Team, 2014), was used to distinguish genetic clusters. Finally an Analysis of Molecular Variance (AMOVA, Arlequin version 3.5.1.2, Excoffier and Lischer (2010)) was used to determine the percent of genetic variance explained by the groupings deduced from the Structure and D_{EST} –grouping analyses (K = 2 and 3 respectively). The model yielding the largest F_{ST} was inferred to be the best grouping.

Two assumptions of a Structure analysis are that populations are in HWE and loci are not linked. Loci failing to comply with these assumptions were removed prior to analysing the data. For the Structure analysis, a series of Markov chain Monte Carlo (MCMC) simulations were run using models of both admixture and no-admixture and using locations as priors correlated with allele frequencies (Falush *et al.*, 2003). Simulations were run for a range of stock sizes, K = 1 to 10. Ten repetitions were run for each stock size, burn-in was set to 10^4, and 10^6 repetitions were run after burn-in. Using the delta K (ΔK) estimator approach of Evanno *et al.*, (2005) the rate of change in the log probability of the data between successive K values was calculated (ΔK) and plotted against K to determine the most likely number of genetic stocks.

Multivariate DAPC were conducted using the complete data set as discriminate analyses are robust to loci out of HWE or in LD. Evidence of genetic clusters was examined in DAPC by running successive K-means clustering in the "find.clusters" function with scaling activated during the PCA to give higher influence in the clustering to loci with more alleles. The optimal number of clusters was determined as the K with the lowest Bayesian Information Criterion (BIC) (Jombart *et al.*, 2010). Analyses were then run for a priori stock numbers, K = 3 and 2 based on outcomes from the Structure analysis and population pairwise D_{EST} analysis. A scatter or density plot was constructed from the principal discriminant components for each model.

Spatial patterns of genetic divergence were investigated using a genetic model of isolation by distance (IBD) correlating genetic distance (D_{EST} / (1 − D_{EST})) to geographic coast distance (km) in Genepop-on-the-Web version 4.2 (http://genepop.curtin.edu.au/ Raymond and Rousset (1995); Rousset (2008)). Shoreline distances in km between sampled populations were manually estimated using Google Maps, factoring in land barriers (Map data ©2016 Google). The resulting correlation for all populations was plotted in Excel and was assessed using Mantel tests (Mantel, 1967) and distance based redundancy analysis (dbRDA, Legendre and Anderson (1999)) following the recommendation of Kierepka and Latch (2015) to combine statistical tests to assess IBD. Mantel tests were assessed using 5,000 permutations in Arlequin version 3.5.1.2 (Excoffier and Lischer, 2010). Distance based RDA used the Fstat matrix against the sampling locations run through the R package vegan version 2.4-2 (Oksanen *et al.*, 2013). IBD analyses were conducted on the complete data set and on the populations north of Eden (based on the K = 2 outcome from the Structure analysis).

A population genetic self-assignment test using a Rannala and Mountain Bayesian method with threshold 0.05 (Rannala and Mountain 1997) was conducted in GENECLASS2 (Piry *et al.*, 2004) to determine the probability of correctly assigning an individual to a stock in the K = 2 stock model. The test was run both including and excluding the mixed Eden population from the analysis.

Estimating Ne

The linkage disequilibrium method for estimating N_e (LDN_e) (Waples and Do, 2008) was applied using NeEstimator 2.01 (Do *et al.*, 2014) to the samples from each collection area. For each set of samples all loci and individuals were used and low frequency alleles were discarded if their observed frequency was below P_{crit}, the minimum allowed allele frequency. P_{crit} was chosen based on the sample size for the particular area according to standard methodology (Waples and Do, 2010). Due to the similar sample sizes from each area, $P_{crit} = 0.02$ for all of the LDN_e estimates produced. For each estimate a 95% confidence interval was also calculated according to the revised jack-knife method of Jones *et al.* (2016).

HARMONISED DATA AND HISTORICAL INFORMATION

Harmonised data

Snapper data from east coast jurisdictions were collated under the broad headings of 'Catch and Effort', 'Age and Length Frequency', 'Biological' and 'Research'. 'Research' data included alternative datasets that were considered relevant to the cross-jurisdictional assessment of east coast snapper. These data included fishery-independent surveys (used mainly as indices of abundance) and various "research" datasets. Within the data, three sectors were categorised: commercial, charter and recreational. The data were not further subdivided into Indigenous data as in many cases it could not be discriminated within the datasets but was considered a part of recreational fishing.

The data were imported into a MS Access harmonised database and stored in a secure directory on the Department of Agriculture and Fisheries (DAF) server at Dutton Park. The secure directory allowed access only to approved staff and ensured confidentiality, integrity and back-up of the data.

This part of the project did not make use of snapper data collected in previous studies if the data were not directly used in the simulation model and where data were not available in the original form. While many of these studies contain data that may be useful in the overall assessment the data products were only available in summary form. The harmonised database was presented to the steering committee and feedback and comments were noted in the minutes (Appendix 6).

Historical information

Snapper has likely been fished by Europeans since the early development of the colony around Sydney harbour in the late 18th century, but it was the arrival of steam power in the 1860s that enabled fishers to start regularly targeting the abundant schools of snapper occurring in the deep-water fishing grounds outside of the sheltered bays and estuaries (Figure 1). Exploitation of snapper thus commenced many decades prior to any formal government monitoring of the fishery. While some historical datasets are already used in snapper stock assessment (e.g., the Queensland Fish Board data spanning the years 1945-1981), these existing datasets are known to be incomplete and are subject to high levels of uncertainty. Furthermore, they do not encompass the full history of either the commercial or recreational fishery.

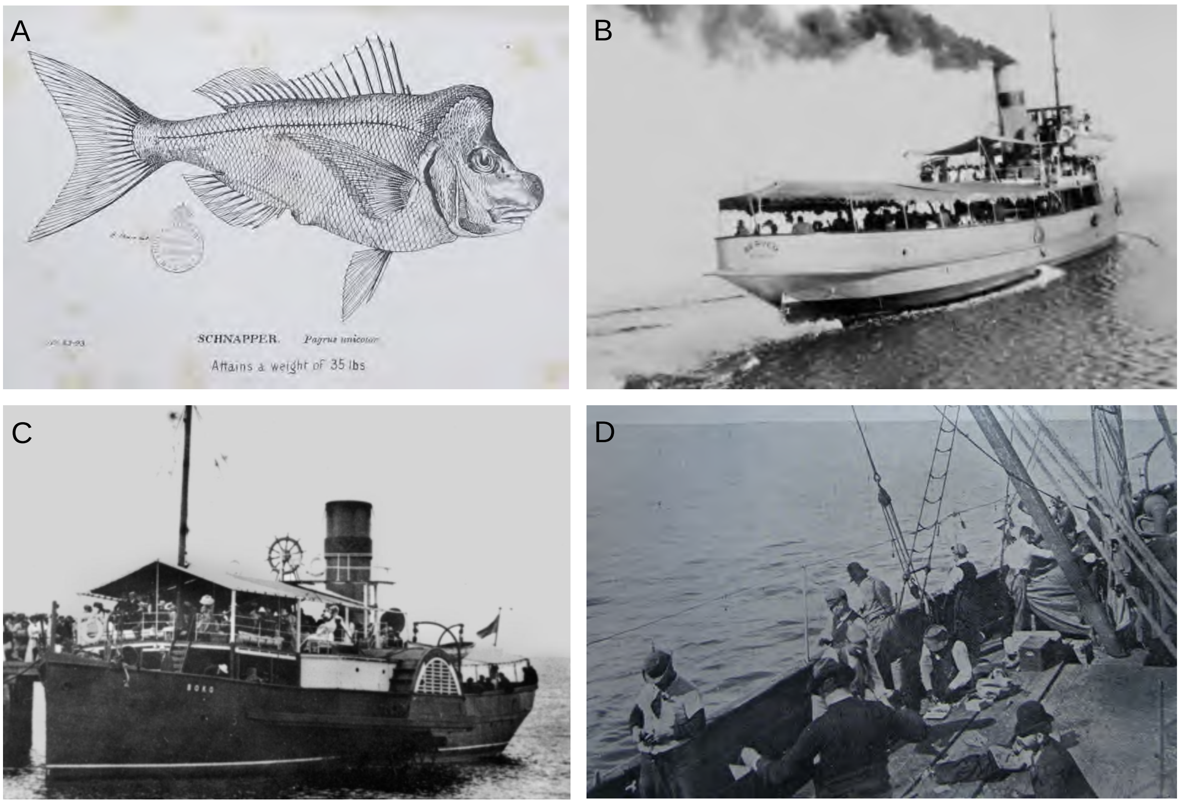

Figure 1 A) Sketch of a snapper (Thompson 1893), B) The S. S. Beaver was frequently chartered for snapper fishing trips from Brisbane during the 1880s and 1890s (State Library of Queensland, 1894), C) The S. S. Boko was frequently chartered for snapper fishing trips from Brisbane during the 1870s and 1880s (State Library of Queensland ca. 1890), D) Snapper fishing on-board the S.S Tarshaw (Welsby, 1905).

Sources such as newspapers, magazines and books (collectively referred to as popular media) have been increasingly accessed by scientists interested in examining historical trends, including trends in fish size or weight (Young *et al.*, 2015), catch rates (Thurstan *et al.*, 2016b) and sightings of rare species (Luiz and Edwards, 2011). In some cases, the use of these popular media sources has enabled trends to be reconstructed across much longer time periods than existing ecological or fishery monitoring data. In recent years, many archival records held by Australia's national and state libraries have been digitised, greatly enhancing our ability to rapidly examine large numbers of historical sources and enabling the extraction of data that would not previously have been accessible.

The last two decades have also seen an increase in scientific interest regarding the collection of fisher's ecological knowledge to inform fishery trends and contemporary management decisions. Fisher knowledge has been used to examine fisher's recall of changes in catch trends (Johannes *et al.*, 2000; Neis *et al.*, 1999), distribution and behaviour of population components of fish stocks (Ames, 2004), and trends in technological adoption (Marriott *et al.*, 2011).

We explored historical snapper catch data sourced from state and national archives and fisher knowledge data in Queensland, New South Wales and Victoria. It builds upon a previous FRDC report (Thurstan *et al.*, 2016a) which assembled archival and fisher knowledge data to examine historical trends in catch rate, fishing technology adoption and additional changes experienced by commercial and recreational fishers over the course of the Queensland snapper fishery's history.

Archival records

Searches and statistical analysis of archival data follow the methods used in (Thurstan *et al.*, 2016a). Queensland, New South Wales and Victorian newspapers are digitally archived by the State Library of Queensland spanning the years 1803-1954 (National Library of Australia, 2017). Online searches were conducted using key words and phrases to describe snapper fishing activities (e.g., snapper/schnapper trip; snapper/schnapper excursion; snapper/schnapper fishing). More recent popular media articles (1996-2017) are also archived online by the National Library, and were searched using the same search terms. Hard copy popular publications, Royal Commission reports and annual government reports housed in state library collections were also searched, however, the majority of data were sourced from newspaper articles. The trips collated from newspapers predominately refer to chartered fishing trips with recreational fishers on-board. Commercial trips were rarely mentioned and are not included in the archival database.

Both qualitative and quantitative data were extracted from the archival records. Qualitative data included information on the fishing technology used during snapper trips, locations fished, names of vessels chartered and fishing clubs involved. Quantitative data included catch (number of snapper and total number of other fish species), number of hours fished and number of fishers, where available.

Analysis of quantitative data

Due to only a small sample size being extracted from east Victorian archives (n = 8), only Queensland and New South Wales results are included in analyses. Since genetic analysis showed that snapper samples from eastern Victoria were mostly differentiated from the east coast snapper stock, this was a valid omission.

Quantitative data were extracted from records to produce a time series of catch rate (snapper fisher^{-1} hr^{-1} and snapper fisher^{-1} trip^{-1}). Where missing values occurred but additional information could be extracted from the qualitative information, assumed values were inserted into the database according to the following rules:

(1) Records that provided the hours spent fishing were collated by state and trends compared over time using linear regression. As no significant difference in the number of hours spent fishing was observed over time, the mean number of hours fished was calculated for each state time series as a whole, with this value applied to missing values for records where either a) the charter vessel or

fishing club were named and were known to keep regular hours, or b) if the narrative provided some indication of leaving/return time/numbers of days fished.

(2) Records that identified both the charter vessel and the numbers of fishers on-board during the trip were collated. Where at least two records reported the numbers of fishers on-board a specific charter vessel, these values were averaged and applied to all records identifying that same charter vessel, but for which the numbers of fishers were missing.

(3) Records that provided both numbers of snapper and total fish caught were collated by state and used to calculate the average proportion of snapper in the catch. For records where the total number of fish caught was provided and where snapper numbers were not identified but were recorded as representing the majority of the catch, the proportion of snapper was calculated using this value.

With any data source, potential reporting biases should be examined. This is particularly important for sources such as popular media, where it might be expected that only the best catches would be reported. To examine possible bias in reporting, Queensland newspaper sources that reported catch rates from >5 fishing trips (once qualitative estimates had been included), plus catch rates sourced from a published book by Thomas Welsby (1905), were compared to the Endeavour (1910) line survey catch rates. As no comparable survey occurred in New South Wales waters during the time series, this analysis could not be conducted for this region. Differences among catch rates from the different sources of catch and effort data were analysed using a one-way ANOVA.

<u>Fisher interviews</u>

Results from interviews undertaken for the FRDC report 2013-018 (Thurstan *et al.*, 2016a) were used for the Queensland component of this study. New South Wales and Victorian snapper fishers were contacted using the same techniques as in (Thurstan *et al.*, 2016a). Commercial, recreational and charter fishers who had targeted snapper for 10 years or longer were sought for interview. Commercial and charter fishers were initially contacted by phoning local businesses, with further interviewees then engaged using snowball sampling, where additional contacts are generated via interviewee referral (Faugier and Sargeant, 1997). Recreational fishers were contacted by phoning fishing clubs and phoning or visiting fishing tackle shops. Further contacts were then engaged using snowball sampling. All interview procedures complied with Deakin University ethical standards. Interviews were sought along the east coast of New South Wales and Victoria. Due to the large distances involved, the majority of interviewees were contacted and interviewed by phone, with 30% interviewed in person.

Once fishers had been informed of the objectives of the research and agreed to interview, they were asked a number of semi-structured questions, which were designed to allow interviewees to include additional information if they wish. Interview questions for New South Wales and Victorian fishers followed the same format as the interviews in (Thurstan *et al.*, 2016a), to allow for comparison. In brief, initial questions focused upon each fisher's personal fishing history (age they began fishing, how regularly they fished and locations fished over time). Questions then focused upon vessels and fishing gear and technology (technologies used, year adopted/upgraded, length and engine power of vessels over time). All New South Wales and Victorian fishers were asked if they could quantitatively define the impact that specific technologies had upon their fishing activities. As Queensland fishers interviewed were not previously asked to provide quantitative information, 18 fishers that had already been interviewed were randomly selected, called and retrospectively questioned about quantitative impacts of technologies on their fishing activities.

Analysis

Proportional uptake of technologies was calculated as a cumulative frequency distribution, where the year that each fisher started using each technology was recorded, as was the year that each fisher entered and exited the fishery. Proportional uptake thus does not take into account fishers prior to or after they have left the fishery. Technology uptake was analysed by state, but due to a low sample size (n = 3), results of interviews with Victorian fishers are not included.

BIOMASS FORECAST MODELS

Historical data and calibration of the model

Forward projection methodology (Richards *et al.*, 1998) was used as the simulation tool for the evaluation of a range of alternative management strategies to the current management regime. This involved an integrated modelling framework both for the estimation of historical stock status and for simulation of future status under management regimes. This section outlines the simulation model for estimation of historical stock status.

Results from objective 1 for this project indicated there was a two-stock genetic structure for snapper along Australia's east coast, the east coast biological stock (New South Wales and Queensland) and the eastern Victorian biological stock. Due to the lack of data from Victoria and Tasmania, the steering committee for this project advised to exclude the eastern Victorian biological from the current assessment and that quantitative age-structured modelling techniques be applied to assembled data from the east coast biological stock. Although the east coast biological stock was used as a single management unit in this research, there was enough evidence to suggest that this was an oversimplification for east coast snapper where recruitment processes, fishing mortality and general stock dynamics may be operating differently at scales significantly smaller than a broad genetic stock level. Localised depletion of snapper in Queensland has been recognised as an issue in earlier reports (Sumpton *et al.*, 2006) and by stakeholders as part of earlier discussions on rocky reef fisheries (QFMA, 1998). However, the steering committee did not wish to introduce further complexity in the model or management strategy options by including a spatial dimension at this time.

An age-structured model was developed and fitted to historical fishery and research data to estimate values for its parameters, and hence the numbers of fish-at-age or weight of fish–at-age at the start of the projection period, 2017. Uncertainty associated with the estimates of these quantities was simulated. A description of the modelling framework is given in Wortmann *et al.* (2018).

The dynamics and equations of the model followed the theory from O'Neill and Buckley (2018), Leigh and O'Neill (2017) and Campbell *et al.* (2009). The model accounted for the processes of fish births, growth, reproduction and mortality in every fishing year. The population dynamics model calculated the number (N) and weight of snapper by the following categories (Table 1):

- Yearly (t) time categories for the fishing years 1880–2016. (For snapper fishing, year was the same as calendar year).
- Age-group (a) from 0+ to the maximum age.
- Fishing sector (f) where sector 1 = New South Wales commercial trap, sector 2 = New South Wales commercial and charter line, sector 3 = Queensland commercial and charter line and sector 4 = New South Wales and Queensland recreational.

Model parameters were estimated by calibrating the model to standardised catch rates and age group frequency data (Table 2). The model estimation process was conducted in Matlab (MathWorks, 2017) and consisted of a maximum likelihood step followed by Markov Chain Monte Carlo sampling (MCMC).

Table 1 Equations for calculating snapper population dynamics. Variables are defined in Table 2 where C=harvest, B=estimated exploitable biomass and E=proxy of recreational effort.

Population dynamics	**Equation**
Number and weight of fish	(1)
$N_{t,a} = \begin{cases} R_t & \text{for } a = 0 \\ N_{t-1,a-1} \exp(-Z_{t-1,a-1}) & \text{for } a = 1,\dots,\max(a) \end{cases}$	
Recruitment	
Recruitment R_t was calculated based on Beverton-Holt formulation for stock recruitment with recruitment deviations $\eta(t)$, estimated only for the years 1980–2016.	
Fish survival	
$\exp(-Z_{t,a}) = \exp(-M)\prod_f (1 - v_{t,f,a} U_{t,f})$	(2)
Fish vulnerability to fishing	
$v_{t,f,a} = v_{f,a} \sum_l P_a(l)[r_l + (1-r_l)d]$	(3)
Harvest Rate	
$U_{t,f} = \begin{cases} C_{t,f} / B_{t,f} & f = 1,2,3 \\ 1 - \exp(-q_f E_{t,f}) & f = 4 \end{cases}$	(4)

Table 2. Parameter definitions for computer model.

Parameter	Equations and values	Notes
Assumed or estimated outside the model:		
max(a)	41 years	Based on the maximum age from the age and length data from New South Wales and Queensland.
w_l	Length–weight relationship, $w_l = 0.0000471 l^{2.79}$ w is the weight (kg), l is the fork length (cm).	From Campbell *et al.* (2009).
m_a	Maturity at age (proportion of female fish mature).	Estimated outside the model, snapper were generally mature by four years of age Campbell *et al.* (2009).
f_l	Fecundity, $f_l = 0.0005 l^{2.9777}$	From Campbell *et al.* (2009), l is the fork length (cm).
Growth	$l_a = 87.99\left(1 - \exp\left(-0.078(a - 2.548)\right)\right)$, standard deviation 6.47 cm $w_a = 15.39(1 - \exp\left(-0.029(a - 1.58)\right))$, standard deviation 0.848 kg.	Von Bertalanffy growth. Estimated outside model using age and length data from New South Wales and Queensland. The estimated model standard deviations for length and age and weight at age are shown. Growth of female and male fish was the same (Campbell *et al.*, 2009).
r	From equation (3), the probability of retention where $r = 0$ if $\mathrm{Tl} < \mathrm{MLS}$, else $r = 1$.	MLS is the minimum legal size measured in cm (total length), TL is the total length (cm), $\mathrm{TL} = 1.167\,\mathrm{l} + 0.259$ where l is the fork length (cm).
p	From equation (3), for a given fish age the normal distribution calculated the proportions of fish at length l.	
M	Natural mortality = 0.163 or 0.211 in equation (2).	The value of 0.163 was from Then *et al.* (2015) for max(a)=41 years. A second value of 0.211 was used for max(a)=31 years.
d	Discard mortality = 0.3 or 0.12 in equation (3).	0.12 was the published rate, (McLennan *et al.*, 2014). The high fraction of 0.3 was tested as per the steering committee recommendations to account for factors such as predation, e.g. by sharks, that may decrease the survival of discarded snapper. See Note 1 below on discard mortality.
Estimated:		
R_0	Virgin recruitment	Virgin recruitment was estimated on the log scale for the first model year.
r_{comp}	Recruitment compensation ratio	This parameter was the recruitment compensation ratio (Goodyear, 1977), based on the log scale coefficient ξ, $r_{comp} = 1 + \exp(\xi)$.
$\eta(t)$	Log-recruitment deviations for 1980–2016.	For the years 1880–1979 recruitment was deterministic.
v	Sector dependent vulnerability in equation (3), for the line equation see (Haddon, 2001), for the trap equation see (Leigh and O'Neill, 2017).	Trap selectivity was dome shaped with a right asymptote, with four parameters, line selectivity was logistic with two parameters.
q	Fish catchability in equation (4) for f=4.	Fish catchability parameter measuring proportion of exploitable stock taken by one unit of standardised fishing effort.

Note 1: Discard mortality

Management reforms affecting the trawl industry over the last 15 years have reduced the incidental trawl mortality of juvenile snapper. These include the introduction of trawl-bycatch reduction devices, the reduction in overall Moreton Bay trawl effort by around 75 per cent and the closure of some juvenile snapper habitat to trawlers as part of the Moreton Bay Marine Park enacted in 2009. Mortality of snapper caught and discarded by the gill net fishery was negligible since gill net mesh sizes typically select for legal sized fish. The gill net fishery contributed about 5 per cent to the total annual commercial harvest.

The model simulated historical management arrangements over time by accounting for changes to minimum legal size (Table 21 and Table 22 in Appendix 3.).

Because of the many combinations of assumptions, e.g. natural mortality, discard mortality, catch rates and age frequency data, numerous simulations were run. These simulations reflected the different hypotheses about the possible states of the east coast biological stock.

Biomass forecasting scenarios

This section outlines the methodologies used in forecasting the spawning biomass depletion (i.e. estimated spawning biomass relative to unfished spawning biomass, S_0) under various management regimes. The spawning biomass is the amount of mature (or spawning) snapper in the population at any given time. Because the estimates of current (S_{2016}) spawning biomass depletion depend on which fisheries data is used to inform the stock assessment model estimations, it was important to conduct forecasting from a number of different current spawning biomass depletion levels. This allowed comparisons of management outcomes (i.e. forecast spawning biomass depletion) among alternative plausible 2016 depletion levels.

In the independent review of the 2008 Queensland snapper stock assessment (Campbell *et al.*, 2009), Dr C. Francis argued that management reference points presented in terms of spawning biomass provided suitable measures of the sustainability of the stock in terms of measuring the stock reproductive potential. Indicators based on vulnerable biomass inform on the short-term health of the fishery but not the fish stock. For example, a low vulnerable biomass relative to its virgin level indicates low catch rates are likely: however, provided the spawning biomass is relatively high, the stock is not necessarily at risk of overfishing. Similarly, indicators based on total biomass provide no indication of whether or not the spawning biomass has fallen so low that future recruitment may be impaired.

Three S_{2016} scenarios were selected for the forward projections. These were based on three groupings of 2016 spawning biomass depletion estimates from 72 alternative models presented in the most recent snapper stock assessment (Figure 3.15 in Wortmann *et al.* (2018)).

- ***'Sustainable'*** scenario: where $S_{2016} = (0.4–0.5)S_0$,. where the 2016 spawning biomass is 40–50% of the unfished level. In general, a fish stock is classified as sustainable when spawning biomass is around 40–50% of the original unfished spawning biomass remains (Sainsbury, 2008).
- ***'Limit reference point'*** scenario where $S_{2016} = 0.2S_0$, where the 2016 spawning biomass is 20% of the unfished level. When spawning biomass is at 20% of the unfished level this often considered as a limit reference point and minimum level to avoid recruitment overfishing (http://fish.gov.au/Overview/Introduction, (Sainsbury, 2008)).
- ***'Overfished***' scenario where $S_{2016} = 0.1S_0$, where the 2016 spawning biomass is 10% of the unfished level. When the spawning stock biomass of a population falls under 20% of its unfished biomass, it can be difficult to successfully rebuild the fish stock (Sainsbury, 2008).

Table 3 describes the key model parameters and biomass index data (i.e. catch rate time series) that distinguished the three 2016 stock status scenarios above.

Table 3. Scenarios selected for forecasting of spawning biomass under alternative management arrangements. The scenarios reflected aspects of the snapper fishery (biology of the stock, input data) included in the stock model. S represents spawning stock biomass. Combined line catch rate was the combination of the similar trends in New South Wales commercial and charter line catch rate, the Queensland commercial line catch rate and Queensland AMLI charter line catch rate with reduced fishing power effects.

Scenario	Natural mortality (year^{-1})	Discard mortality	Recreational effort	Age frequency data	Catch rates	Estimated median S_{2016}/S_0
Sustainable	0.211	0.3	Reduced	NSW commercial trap and Qld commercial line	NSW trap (reduced fishing power effects) and historic	0.43
Limit reference point	0.163	0.3	Reduced	NSW commercial trap and Qld recreational line	NSW trap (reduced fishing power effects) and historic	0.22
Overfished	0.163	0.3	Reduced	NSW commercial trap and Qld recreational line	Combined line (reduced fishing power effects) and historic	0.12

Stakeholders were involved from the beginning of the project in determining objectives and choosing management strategies to achieve those objectives. Management arrangements considered included annual or biennial levers for minimum legal size, bag limit, effort controls such as fishing effort or fishing gear, closed seasons, closed waters or implementing a harvest tonnage limit. Given the complexities of cross-jurisdictional data and management, two basic management strategies were selected for assessment in this project by the steering committee, as described below and described in Table 4:

1. **Fixed harvest rate at status quo and variable minimum legal size**
   Harvest rate was set to the average estimated harvest rate for 2012–2016 with normal variation according to standard deviation, as given in Figure 2. Minimum legal size (MLS) was changed according to five arrangements, analyses 1-5 in Table 4:

   - Minimum legal size kept at 30 and 35 cm total length (TL) in New South Wales and Queensland, respectively,
   - Minimum legal size in both states of 30 cm TL, (the current New South Wales MLS),
   - Minimum legal size in both states of 35 cm TL, (the current Queensland MLS),
   - Minimum legal size for the New South Wales trap sector of 30 cm TL, (the current New South Wales MLS), and for all line sectors (both New South Wales and Queensland) of 40 cm TL,
   - Minimum legal size for the New South Wales trap sector of 30 cm TL, (the current New South Wales MLS), and for all line sectors (both New South Wales and Queensland) of 45 cm TL.

2. **Variable TAC and fixed minimum legal size at status qou**
   Status quo MLS was 30 and 35 cm total length in New South Wales and Queensland respectively. A managed total allowed catch (TAC) in tonnes per year across all waters and fishing sectors was set, analyses 6-9 in Table 4. The TACs were allocated to the fishing sectors according to the average harvest split across the sectors for 2012–2016: New South

Wales trap 27.6% of TAC, New South Wales commercial and charter line 8.9% of TAC, Queensland commercial line and charter 13.6% of TAC and New South Wales and Queensland recreational 49.9% of TAC. The TAC management arrangements were:

- Total allowed catch limit of 1,000 tonnes per year. The 1,000 tonne setting was obtained from theoretical model simulations which showed that if the biomass was around 40–50% of original unfished biomass then catch limits of around 1,000 tonnes per year across all waters and sectors could be attained. The Queensland Sustainable Fisheries Strategy 2017–2027 defined a biomass target of 40% of unfished biomass by 2020 (Queensland Government, 2017).
- Total allowed catch limit of 800 tonnes per year. This 800 tonne setting was obtained from theoretical model simulations which showed that if the biomass was around 60% of original unfished biomass, then catch limits of around 800 tonnes per year across all waters and sectors could be attained. The Queensland Sustainable Fisheries Strategy 2017–2027 defined a biomass target of 60% of unfished biomass by 2027 (Queensland Government, 2017).
- A reduced total allowed catch limit to 600 tonnes per year.
- A further reduced total allowed catch limit to 400 tonnes per year. This was half of the 2016 estimated harvest from the model simulations.

Annual TAC error was applied to the 1,000 tonne and 800 tonne settings. Recent data and levels of fishing suggested these levels of tonnage were unlikely to be filled every year (Figure 3). The expected TAC fills were 78.5% (range 73.3–83.7%) for the 1000 tonne TAC, Figure 4, and 99% (range 95.9–100%) for the 800 tonne TAC, Figure 4. In behaviours, the 1000 tonne TAC and 800 t TAC error setting made the management strategies 6 and 7 in Table 4 similar. The data suggested the 600 tonne and 400 tonne TAC levels could be filled.

The simulated stock was projected forward for the nine scenarios when management was based on the simulated management strategies. One thousand simulations were run for each scenario regarding the specifications of the simulated management strategy. This number of simulations was selected because it was sufficient to determine differences among alternative strategies. Each simulation involved projecting the simulated stock forward for forty years (2017–2056) by annually applying the model and the fixed management rules and then updating the population dynamics. Forty years were selected for the length of the projection period based on the reported 40-year life cycle of snapper.

Table 4. Hypothetical management scenarios applied to each of the three 2016 stock status scenarios.

Management arrangement	Analysis	MLS (total length)	Harvest (tonnes) /harvest rate (proportion legal sized biomass harvested)
MLS changed, harvest rate fixed at status quo	1	30 cm (NSW) 35 cm (Qld)	Harvest rate fixed according to 2012–2016 estimated harvest rates with error. See Figure 2 for harvest rates for each scenario.
	2	30 cm (NSW) 30 cm (Qld)	As above
	3	35 cm (NSW) 35 cm (Qld)	As above
	4	30 cm (trap) 40 cm (line)	As above
	5	30 cm (trap) 45 cm (line)	As above
Catch limit TAC set, MLS fixed at status quo	6	30 cm (NSW) 35 cm (Qld)	Harvest=1000 tonnes per year with error. See Figure 4 for the harvest split between fishing sectors.
	7	As above	Harvest=800 tonnes per year with error. See Figure 4 for the harvest split between fishing sectors.
	8	As above	Harvest=600 tonnes per year. See Figure 4 for the harvest split between fishing sectors.
	9	As above	Harvest=400 tonnes per year. See Figure 4 for the harvest split between fishing sectors.

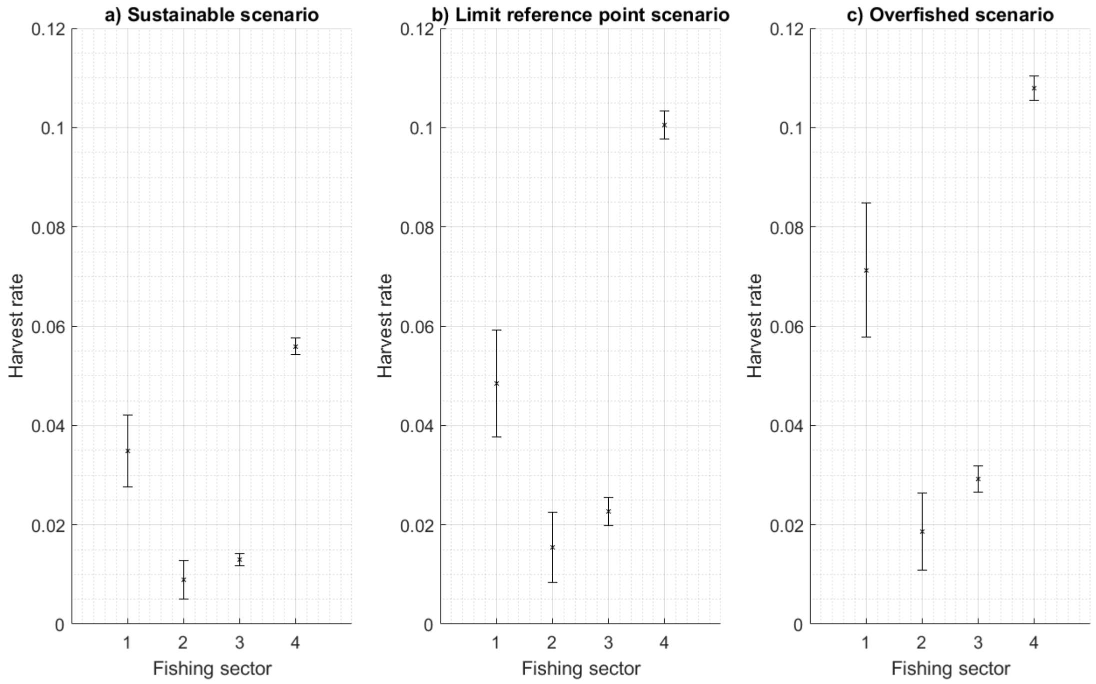

Figure 2. Sectoral harvest rates for management options 1-5 in Table 4, according to the average estimated harvest rate for each scenario for 2012–2016. Fishing sector 1=NSW trap, fishing sector 2=NSW commercial and charter line, fishing sector 3=Qld commercial and charter line and fishing sector 4=NSW and Qld recreational line. Harvest rates measure the retained fraction of legal-sized snapper biomass caught.

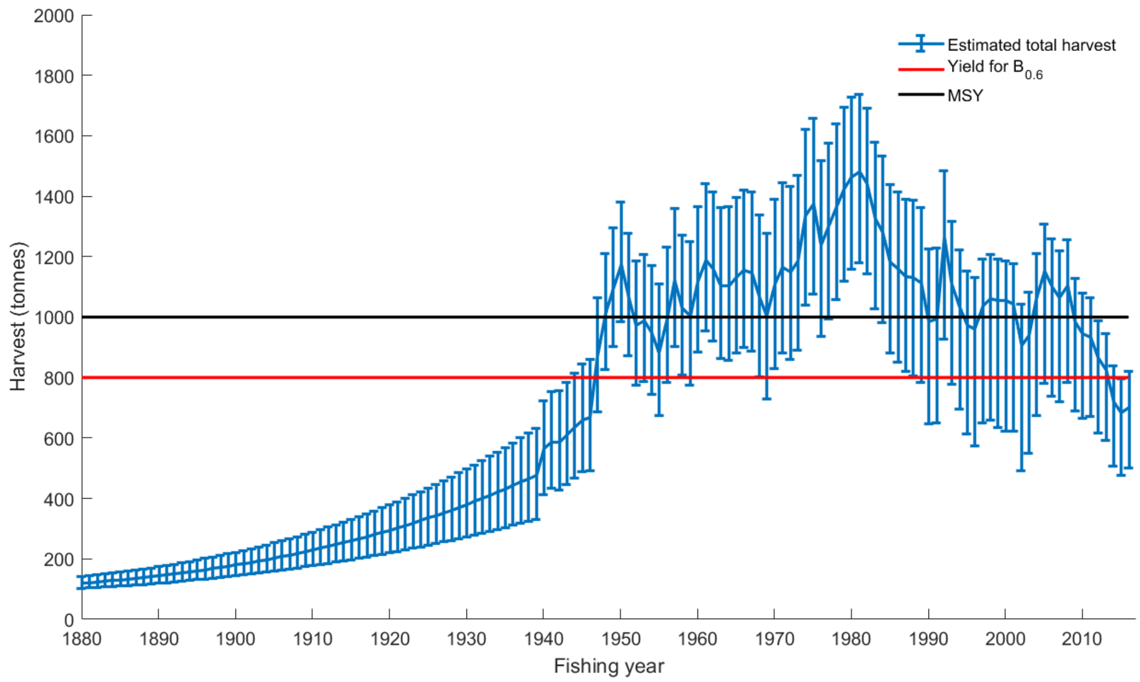

Figure 3. Estimated total snapper harvest with 95% confidence intervals. The red line represents the mean harvest per year across all waters and sectors for a virgin sized exploitable biomass of 60%. The black line represents the mean harvest per year for a 40% sized exploitable biomass across all waters and sectors.

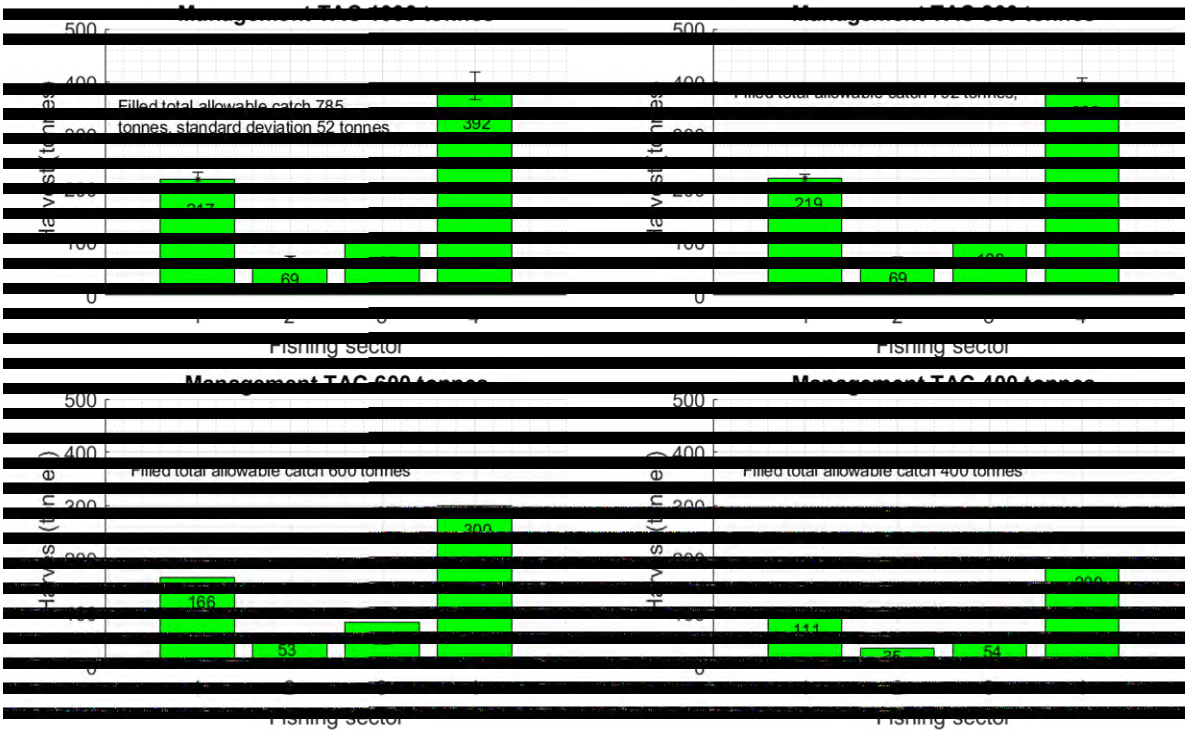

Figure 4. Harvest (tonnes) for the harvest management arrangements 6-9 in Table 4. Fishing sector 1=NSW trap, fishing sector 2=NSW commercial and charter line, fishing sector 3=Qld commercial and charter line and fishing sector 4=NSW and Qld recreational line.

The management performance measures were:

1. Graphs showing the behaviour of spawning biomass relative to unfished spawning biomass, S_t/S_0 , from 1880–2056.
2. Tables with information from the above graphs.
3. Probability forecast graphs for $S_t \geq 0.4S_0$ after 10 years (2026), 20 years (2036), 30 years (2046) and 40 years (2056). The 40% was a target reference point of the Queensland Sustainable Fisheries Strategy by 2020 (Queensland Government, 2017). In general, a fish stock is classified as sustainable when around 40–50% of the original unfished biomass remains (i.e. before fishing began), (Sainsbury, 2008).
4. Probability forecast graphs for $S_t \geq 0.6S_0$ after 10 years (2026), 20 years (2036), 30 years (2046) and 40 years (2056). The 60% was a target reference point of the Queensland Sustainable Fisheries Strategy by 2027 (Queensland Government, 2017).

Results

SNAPPER GENETIC STOCK STRUCTURE

A total of 449 *C. auratus* were collected and genotyped as part of this study. Commercial and recreational fishers provided samples from nine collection areas over a 2,278 km range from Rockhampton in the north to Tasmania in the south (Figure 5). Sampled fish ranged in size from 150 - 810 mm fork length with roughly an equal sex ratio (sex recorded in ~50% of samples). Genotypes were obtained for all animals, across nine loci with missing values per locus ranging from 0.2-9.4% (Table 5). Amplification difficulties due to poor quality DNA samples were improved by re-extracting and eluting samples into a smaller volume (50 µL instead of 100 µL) then amplifying the difficult loci as singletons on undiluted DNA instead of multiplexed reactions. A relatedness screen of the samples identified a duplicate animal in the data set. One of the duplicates was removed from subsequent analyses (taking the total number of *C. auratus* screened to 448, Table 5).

High allelic diversity was observed in the data with 18 or more alleles found in two thirds of the loci (allele number per locus ranged from 8 to 27, Table 5). Observed heterozygosity ranged between 0.342 and 0.879 and was lower than expected for all loci. All locus by population comparisons were in Hard-Weinberg Equilibrium (HWE) (Table 6). Screening for LD using exact G-tests (log likelihood ratio tests) to assess each pair of loci within each collection area identified three significant pairs (Sunshine Coast: Pma1 - CM3195, Eden: PaurGA2A - Pma68_23 and Eden: Pma22_99 - Pma68_23). The apparent genetic association of these pairs was not supported in other populations and is likely an artefact of reduced sample numbers at these sites due to missing genotypes (Akey *et al.* (2001); Gordon *et al.* (1999)). For this reason, at the conclusion of the exploratory analyses, all 9 loci were determined to be suitable (largely meeting the assumptions of HWE and no LD) for downstream analyses. Based on the power analysis the microsatellite data contain sufficient power to detect F_{ST} at or above 0.002 with 98% confidence (Figure 20 in Appendix 3).

Standardizing the fixation index to account for the high allelic diversity of microsatellites, and low population size and number, increased the overall estimate of $F_{ST} = 0.0151$ to $D_{EST} = 0.0232$. Analysing the data for genetic structure using Bayesian modelling (Structure, Pritchard *et al.* (2000)) identified a two cluster model as the most likely fit for all models, with a genetic transition occurring around Eden on the New South Wales south coast (Figure 6). The optimal 2 cluster model was determined by the highest average likelihood score (Figure 21, Appendix 3) and the highest change in mean likelihood score (delta K, Figure 22, Appendix 3).

Using pairwise D_{EST} statistics to pool undifferentiated adjacent collection locations, the spatial boundaries of potential genetic stocks were further investigated (Table 7a). The first round of pooling grouped Rockhampton & Sunshine Coast, Coffs Harbour & Wallis Lake, and Lakes Entrance & Tasmania (note Lakes Entrance is a linear neighbour to both Tasmania and Geelong). The second round of pooling combined Coffs Harbour & Wallis-Lake with Terrigal and merged Eden with Lakes Entrance &Tasmania. The end result of pooling was a three-stock model consisting of spatially distinct genetic stocks located north of Eden (Rockhampton to Terrigal), the South East (Eden, Lakes Entrance and Tasmania) and Geelong (Table 7b).

The optimum number of clusters (K with the lowest BIC score) determined using the DAPC find.clusters function was K = 1, although the BIC score for K = 2 was only a little higher (Figure 23a, Appendix 3). Results of the analyses run for a priori stock numbers, K = 2 and K = 3 cluster models, based on the outcomes from the Structure analysis and population pairwise D_{EST} analysis, show some overlap between neighbouring collection locations (Figure 23b and c, Appendix 3). The K = 2 model (Figure 23b, Appendix 3) clearly shows a distinct northern and southern stock with a region of overlap at Eden. The K = 3 model (Figure 23c in Appendix 3) differentiates the three regions but considerable overlap of the 95% inertia ellipses highlights the intermediate genetic signature of many of the samples.

Genetic distance was found to be correlated to linear geographic distance using an IBD genetic model on the complete data set (Figure 24 in Appendix 3). The geographic distance between collection areas explained 34% of their genetic distance ($R^2 = 0.3439$). The IBD signal for the complete data set was significant using both a Mantel test (5000 permutations, $p = 0.0014$) and the dbRDA analysis ($p = 0.001$). Focusing on the five populations north of Eden, the northern stock in the K = 2 cluster model, IBD was no longer detected using either test (Mantel $p = 0.27$, dbRDA $p = 0.217$).

Loci Pma1, PaurGA2A and CM278 were excluded from the AMOVA analysis because they were above the missing data threshold of 5%. Analysis of the remaining 6 loci using AMOVA found the 2 stock model accounted for 0.976% of the genetic variability ($F_{ST} = 0.00976$), explaining the data slightly better than the 3 stock model which accounted for 0.916% of the genetic variability ($F_{ST} = 0.00916$). Irrespective of model, the majority of genetic variation in *C. auratus*, (99%), was explained by within population differences.

Population genetic assignment tests correctly assigned 76.3% (including Eden) and 81.7% (excluding Eden) of samples to the correct stock in a K=2 model. There was no obvious bias in the direction of incorrect assignments with 18% of the northern stock incorrectly assigned to the southern and 19% of animals from the southern stock incorrectly assigned to the north (K=2 model excluding Eden).

Using the linkage disequilibrium method, estimates of LDN_e were calculated from six of the nine collection areas (Table 8). It was not possible to resolve LDN_e for Rockhampton, Wallis Lake or Geelong, possibly due to the relatively low power of the estimator and small sample sizes analysed. The upper 95% confidence interval was infinite (i.e. could not be estimated) for any of the sites. Terrigal returned an LDN_e estimate considerably higher than any other site (7 to 40 fold larger). Wide range sampling in Tasmania may also be lowering the LDN_e estimate from this region.

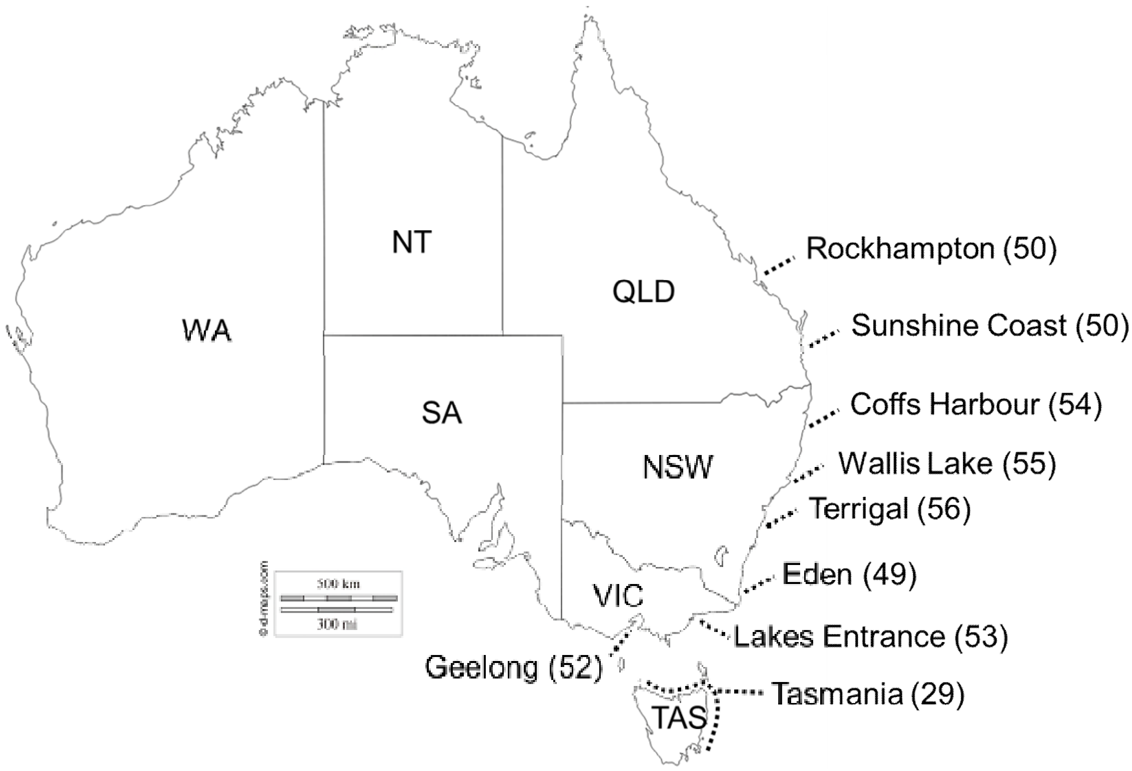

Figure 5 Sample collection areas for C. auratus. The number of unique fish genotyped is shown in brackets.

Table 5 Exploratory data analysis and statistics of microsatellite loci of Australian *C. auratus*. Headings are A = number of alleles, N = number of individuals genotyped, missing genotype = % of samples missing genotypes, H_{obs} = Observed Heterozygosity, H_{Exp} = Expected Heterozygosity, PIC = Polymorphic Information Content, F_{IS}= Inbreeding Coefficient, F_{ST} = Fixation Index, D_{EST} = Jost's estimate of differentiation.

Locus	A	N scored	Missing genotype	H_{Obs}	H_{Exp}	PIC	F_{IS}	F_{ST}	D_{EST}
Pma1	9	425	5.1%	0.67	0.743	0.713	-0.0010	0.0163	0.0185
PaurGA2A	22	424	5.4%	0.877	0.924	0.918	-0.0198	0.0128	0.0341
Pma22_99	19	447	0.2%	0.875	0.917	0.909	0.0259	0.0167	0.0805
CM3195	18	441	1.6%	0.857	0.883	0.872	-0.0081	0.0128	0.0273
CM278	8	406	9.4%	0.342	0.491	0.462	0.0103	0.0242	0.0096
Pma68-23	25	431	3.8%	0.864	0.93	0.925	0.0145	0.0115	0.0219
Sal10	8	441	1.6%	0.679	0.71	0.663	0.0010	0.0192	0.0253
Sal19	18	437	2.5%	0.768	0.809	0.794	0.0012	0.0167	0.0312
Pma4-32	27	440	1.8%	0.879	0.94	0.936	0.0341	0.0122	0.0380
Total		448					0.0068	0.0151	0.0232

Table 6 Population by locus summary p-values for Exact Tests assessing Hardy–Weinberg equilibrium (HWE) (number of fish genotyped in brackets) with Bonferroni corrected α=0.0006 for 81 tests.

	n (448)	Pma1	PaurGA2A	Pma22_99	CM3195	CM278	Pma68-23	Sal10	Sal19	Pma4-32
Rockhampton	50	0.87 (50)	0.31 (50)	0.19 (50)	0.92 (50)	1.00 (44)	0.78 (49)	0.77 (50)	0.18 (49)	0.10 (50)
Sunshine Coast	50	0.67 (46)	0.93 (47)	0.03 (50)	0.25 (48)	0.14 (46)	0.30 (47)	0.001 (50)	0.03 (49)	0.59 (48)
Coffs Harbour	54	0.33(54)	0.33 (52)	0.47 (54)	0.60 (54)	0.05 (52)	0.04 (52)	0.51 (54)	0.76 (54)	0.88 (53)
Wallis Lake	55	0.68 (47)	0.74 (51)	0.80 (55)	0.64 (55)	0.09 (40)	0.15 (53)	0.42 (55)	0.13 (55)	0.14 (55)
Terrigal	56	0.12 (56)	0.30 (54)	0.69 (56)	0.52 (56)	0.68 (56)	0.33 (55)	0.66 (56)	0.51 (53)	0.02 (54)
Eden	49	0.98 (46)	0.06 (49)	0.92 (48)	0.58 (48)	0.84 (49)	0.25 (49)	0.96 (46)	0.29 (48)	0.58 (47)
Lakes Entrance	53	0.74 (46)	0.87 (50)	0.86 (53)	0.02 (52)	0.18 (49)	0.033 (49)	0.48 (53)	0.40 (53)	0.94 (53)
Geelong	52	0.42 (51)	0.68 (49)	0.06 (52)	0.24 (50)	0.69 (41)	0.61 (49)	0.07 (51)	0.07 (51)	0.44 (52)
Tasmania	29	0.44 (29)	0.18 (22)	0.46 (29)	0.55 (28)	0.33 (29)	0.93 (28)	0.26 (26)	0.89 (25)	0.13 (28)

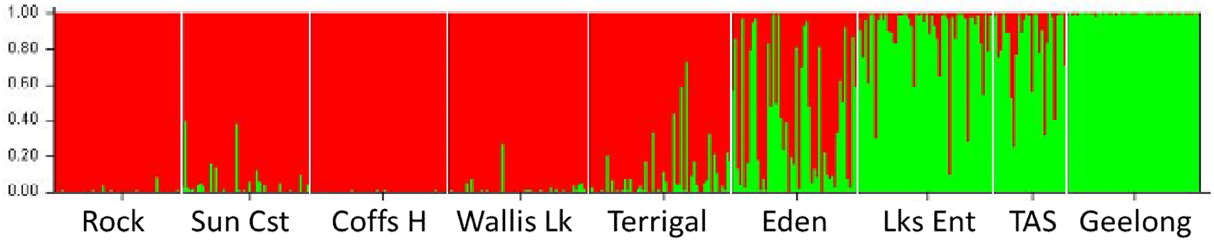

Figure 6 Predicted genetic stock structure of *C. auratus* based on population clustering of microsatellite data using a Bayesian model-based analysis. Vertical lines correspond to individual fish which are coloured by the posterior probability proportions of their genotype based on a k = 2 cluster model. Fish are plotted from north (left) to south (right) by population (Rock = Rockhampton Qld; Sun Cst = Sunshine Coast Qld; Coffs H = Coffs Harbour NSW; Wallis Lk = Wallis Lake NSW; Terrigal = Terrigal NSW; Eden = Eden NSW; Lks Ent = Lakes Entrance Vic; Tas = Tasmania; Geelong = Geelong Vic).

Table 7 Pairwise Jost's D_{EST} estimates based on nine microsatellite loci from 448 individuals of *C. auratus* among (a) nine sampling locations and (b) 3 groups of pooled locations. The final set of pooled locations was obtained after pooling strictly adjacent populations that showed no significant pairwise DEST until all pairwise DEST were significantly different. Pooled populations are Nth Eden = Rockhampton, Sunshine Coast, Coffs Harbour, Wallis Lake & Terrigal; South east = Eden, Lakes Entrance & Tasmania; Geelong = Geelong. Lower diagonal, D_{EST} estimates and upper diagonal, p-values with Bonferroni corrected significant comparisons shaded in grey (in a, significant if p<0.0014 and in b, significant if p<0.017). Note the Lakes Entrance population is a linear neighbour to both the Tasmanian and Geelong populations.

(a)

	Qld Rock	Qld Sun Cst	NSW Coffs Hbr	NSW Wallis Lke	NSW Terrig	NSW Eden	Vic Lakes Entr	Vic Geel	TAS
Rockhampton	-	0.906	0.435	0.664	0.601	0.254	0.004	0.001	0.009
Sunshine Cst	-0.008	-	0.572	0.696	0.250	0.123	0.001	0.001	0.017
Coffs Hbr	0.000	-0.002	-	0.906	0.216	0.010	0.001	0.001	0.001
Wallis Lke	-0.003	-0.004	-0.008	-	0.563	0.059	0.001	0.001	0.008
Terrigal	-0.002	0.004	0.005	-0.002	-	0.398	0.002	0.001	0.016
Eden	0.005	0.008	0.020	0.013	0.001	-	0.080	0.012	0.172
Lakes Entr	0.028	0.038	0.047	0.043	0.031	0.012	-	0.034	0.196
Geelong	0.079	0.067	0.095	0.087	0.061	0.027	0.018	-	0.172
Tasmania	0.032	0.025	0.038	0.030	0.024	0.010	0.009	0.011	-

(b)

	Nth Eden	South east	Geelong
Qld & NSW north of Terrigal	-	0.001	0.001
Eden, Vic Lakes Ent & Tas	0.023	-	0.016
Geelong	0.079	0.016	-

Table 8 Estimates of effective population size calculated using the linkage disequilibrium method (LDNe), with upper and lower confidence intervals estimated using jack-knifing, for east coast snapper populations using Pcrit = 0.02. Non-measurable values are indicated by a dash.

Population	Sample n	LDN_e	Lower 95% CI	Upper 95% CI
Rockhampton	50	-	832.1	∞
Sunshine Coast	50	1992.0	275.7	∞
Coffs Harbour	54	732.6	215.6	∞
Wallis Lake	55	-	385.2	∞
Terrigal	56	15968.2	320.4	∞
Eden	49	572.2	203.5	∞
Lakes Entrance	53	586.9	199.5	∞
Geelong	52	-	462.7	∞
Tasmania	29	371.9	91.1	∞

HARMONISED DATA AND HISTORIC INFORMATION

Harmonised data

Catch and Effort data

AFMA commercial harvest data by year, latitude and total snapper weight was provided from 1999 (Table 9). Although no fishing method was recorded in this dataset, the steering committee believed that the AFMA harvest applied to line methods of fishing.

In New South Wales, commercial harvest information was available for most species since the financial year 1940/41, primarily from mandatory monthly catch returns submitted by all licenced fishers (Table 9). A detailed description of the various commercial catch returns and an analysis of available data between 1940/41 and 1991/92 were presented in Pease and Grinberg (1995). Accurate catch per unit of effort cannot be calculated for most species prior to 1990 because the monthly catch return system did not provide adequate effort information. Improved logbooks were introduced in July 1997 to directly link catch and effort within a fisher's monthly return (Table 9). The spatial reporting of the commercial data has been by 60 nm grids with no data on distance offshore or depth since 1984 and with information generally summarised into 10 fishing zones, Figure 18. New South Wales catch records changed substantially in July 2009, moving to a finer level of spatial and temporal reporting (Table 9). This system was referred to as the "Fishonline" System. This system required daily catch and effort reporting, to six minute grids (30 sq nm or 103 sq km).

The Queensland Fish Board (QFB), which was responsible for marketing fisheries products, collected harvest (caught and retained) information from 1936 until 1981. After the closure of the QFB no harvest or effort data were collected on snapper until the introduction of the CFISH compulsory commercial logbook system in 1988. This was a compulsory system that required recording of daily harvest and effort information by all commercial fishers (Table 9). A voluntary logbook for the Queensland charter fishery was established in 1993/1994 and became compulsory in 1996. Data recorded included catch (retained, discarded) and effort information. There have been five versions of the logbook for the Queensland charter fisher, called the CFISH Queensland Commercial Fishing Tour Logbook (CV05) (Table 9). Prior to 1 July 2006, all charter fishing operators were required to hold a licence and submit logbook data. After 1 July 2006 only those operators in offshore waters were required to hold a licence and submit logbook data. In addition, there were no compliance checks for licence holder submission of compulsory logbook data, and there was no boat information recorded after June 2006.

The Australian Marine Life Institute (AMLI) collected fish catch, effort and environmental data from a sample of the Gold Coast charter boat fleet from 1993 to 2010 (Table 9). This normally involved an observer checking the harvest of vessels at the wharf after the completion of each fishing trip. Information on fishing activities including number of anglers on board, fishing time, bait and fishing location were recorded as well as a range of environmental data including water temperature, current speed and direction, wind speed and sea conditions on the fishing grounds. When an AMLI representative was not at the wharf to measure harvests, skippers and deckhands were asked to measure their harvest and record details of their fishing trips in voluntary logs which were later collected and entered into a database. The sample fraction for catch information was estimated at over 40% of the total charter landing from boats operating from the region during the period 1993 to 2010, although this percentage varied from year to year and not all vessels have maintained their association with the program. Declining participation rates eventually saw data collection terminated in 2010.

Table 9. Snapper catch and effort data sources for commercial and charter sectors.

Jurisdiction	Sector	Data source	Period	What does it provide
New South Wales	Commercial	Historical	1940–1984	Snapper harvest data (weight) by financial year. Data was converted to calendar year by averaging adjacent years. Fishing method was not recorded in this dataset.
		Commcatch logbook	1985–2016	Compulsory snapper monthly catch and effort data. From 1985–June 1997 data included year, month, area, boat, weight (fishing method was not recorded). From July 1997 fishing method and days fished were included.
		Fishonline logbook	2009–2016	Compulsory snapper daily catch and effort data. Data included latitude, longitude, grid, date, fishing method, effort defined by number of hooks or number of traps lifted or length of net, boat, area, weight.
		AFMA	1999–2016	Yearly snapper harvest (weight) data by latitude. Fishing method was not specified, but the steering committee found it likely to be harvest for line methods of fishing.
	Charter	Logbook		Compulsory snapper charter catch logbook data by year, number of snapper.
Queensland	Commercial	Fishboard	1946–1980	Yearly snapper harvest (weight) data.
		Logbook	1988–2016	Compulsory daily catch and effort data for snapper and the rocky reef species cobia, grass emperor, jobfish and kingfish. Data included date start, date end, days fished, fishing method, latitude, longitude, grid, boat, average depth, number of crew, weight, and species.
	Charter	Logbook	1996–2016	Compulsory daily catch and effort data for snapper and the rocky reef species cobia, grass emperor, jobfish and kingfish. Data included boat, date, day/night, full day, number of anglers, fish time, fishing method, days fished, location, depth, sea condition, date, weight and species.
		AMLI Gold Coast charter surveys	1993–2010	Charter data collected by AMLI representatives with records for fishing method, days fished, fish time, number of anglers, day or night, location, depth, sea condition, current, full or half day charter, number of snapper, date, and species (snapper and the rocky reef species cobia, grass emperor, jobfish and kingfish).
Victoria	Commercial	Logbook	1990–2016	Harvest data (weight) for Victorian ocean by financial year.

There were many historical reports of snapper catch in Victoria but limited information on the eastern Victorian biological stock (Figure 19 in Appendix 3, data available was total tonnage harvested by financial year, estimated recreational harvest (two points) and the number of commercial licences). Data collected from the western Victorian biological stock which currently represents over 90% of the state's fishery was not considered in this project. It is not possible to attribute snapper catches recorded in the Victorian catch and effort database to the western and eastern Victorian biological stocks.

Commercial catch and effort data were collected in the Victorian commercial fishery since 1978, but like the situation in Queensland and New South Wales, there have been many developments that have affected the consistency or quality of those data through time.

Recreational harvests (numbers of kept fish) of snapper were estimated from two State-wide surveys in New South Wales and eight State-wide surveys in Queensland, Table 10. For all survey years except 1994/95 the method used was telephone surveys of households to estimate participation rates in fishing, with diary records of fish catches and fishing effort maintained by a sample of fishing households. The Queensland 1994/95 data provided information on survey number, survey area, date, target fish, number of fishers, hours fished, launch time, return time, number of fish caught, number of fish retained for snapper, amberjack (*Seriola dumerili*), cobia (*Rachycentron canadum*), grass emperor (*Lethrinus laticaudis*), mahi mahi (*Coryphaena hippurus*), pearl perch (*Glaucostegus scapulare*), sweep (*Scorpis lineolate*), teraglin (*Atractoscion aequidens*) and kingfish (*Seriola lalandi*). The other Queensland surveys provided information on person identification, household identification, survey number, date, area, primary target, secondary target, number of fishers, hours fished, number of fish caught, number of fish retained for amberjack, cobia, grass emperor, mahi mahi, pearl perch, sweep, snapper, teraglin and kingfish. The New South Wales recreational survey data provided for this project was total estimated number of snapper kept and retained by area (estuary or ocean).

There were two recreational estimates of snapper harvest for Victoria, in 1990 and 2006 (Figure 19 in Appendix 3).

Table 10. Survey estimates of recreational snapper harvests from New South Wales and Queensland waters. Tonnages were calculated for display only. The estimated tonnages for New South Wales assumed an average fish weight 0.74 kg for 2000 and 0.80 kg for 2013, and for Queensland assumed an average fish weight of 0.90 kg for all surveys up to and including 2002, 1.68 kg for 2005, 1.61 kg for 2010 and 1.47 kg for 2013.

State	Fishing year	Survey	Harvest (number)	Tonnes (estimated)
NSW	2000/2001	(Henry and Lyle, 2003)	253298	188
	2013/2014	(West *et al.*, 2015)	185590	148
Qld	1994/1995	(Ferrell and Sumpton, 1997b)	237510	214
	1997	RFISH (Higgs, 1998)	577000	519
	1999	RFISH (Higgs, 2001)	527116	474
	2000	RFISH (Henry and Lyle, 2003)	252229	227
	2002	RFISH (Higgs *et al.*, 2007)	296440	267
	2005	RFISH (McInnes, 2008)	327783	552
	2010	SWRFS (Taylor *et al.*, 2012)	83898	135
	2013	SWRFS (Webley *et al.*, 2015)	55625	82

In recent years around 25 tonnes of snapper were taken annually as a by-product by the South East Trawl fishery, a Commonwealth-managed fishery that takes snapper predominantly using Danish Seine in eastern Victoria. This catch should be included in stock assessments of the southern stock.

The Victorian recreational data for the eastern Victorian biological stock (Eden to at least Lakes Entrance) which was previously considered to be part of the eastern Australian stock was limited. Estimates can be derived from the 2000/01 NIRFS survey but there were no other surveys that provided recreational catch and effort information for the Victorian regions of the southern stock.

Age and length frequency data

Both New South Wales and Queensland have extensive snapper age and length structured datasets. Length frequency datasets for the New South Wales commercial trap fishing sector were available for 1982, 1985–1986, 1988, 1993–2016, New South Wales commercial line fishing sector 2002, 2004–2016, and Queensland commercial, recreational and charter line fishing sectors 2006–2016. The steering committee agreed to exclude the New South Wales length frequency data from the 1980's in the model because these data include longlining from Coffs Harbour. Age frequency data were available for the New South Wales commercial trap fishing sector for 1993–2005, 2007–2016 and Queensland commercial, recreational and charter line fishing sectors 2006–2016. The age frequency data for 2006 for Queensland was deemed incomplete and thus the age frequency data for the 2006 sampling year was not included in the model.

The New South Wales snapper ageing data were adjusted to be compatible with the Queensland ageing data. Unlike Queensland data, opaque otolith edges were not recorded in New South Wales before 2005 and so raw fish age could not be adjusted in the same manner as the Queensland data. So for these years, New South Wales fish ages were adjusted (by adding 1) randomly within each month, in the same proportions that opaque edges were observed post 2004 (Table 11).

Table 11 Adjustments to the New South Wales snapper age data pre-2005 to make it compatible with the Queensland aging data. Fish sampled prior to 2005 did not have edge state (opaqueness) of otoliths recorded in the New South Wales database, so for these years fish were randomly assigned with an additional year in the same proportion that fish with opaque edges were observed post 2004.

Month	Proportion with opaque edges post 2004	Number of fish sampled pre 2004	Number of fish changed by adding 1
1	0.278606965	237	66
2	0.299065421	349	104
3	0.267605634	560	149
4	0.263157895	755	198
5	0.175438596	896	157
6	0.182320442	451	82
7	0.086206897	665	57
8	0.20754717	1885	391
9	0.259631491	1774	460
10	0.224880383	2515	565
11	0.277227723	1503	416
12	0.333333333	948	316

Without these adjustments it would not have been possible to assign New South Wales snapper ageing data into age group (grouping same cohort) in the same way as it was calculated in Queensland because of several factors. Firstly, in New South Wales there was significant latitudinal variation in spawning time and when opaque zones in otoliths were formed. This meant that usually New South Wales snapper ages were estimated directly from the number of completed annuli counted. Opaque edges were mainly observed between September and April in New South Wales, but fish with opaque and wide otolith edges occurred in all months (Table 11). Also, opaque zones in snapper in New South Wales formed/completed later than in Queensland. Opaque zone formation/appearance was May to September in Queensland and September to April in New South Wales.

Age group was defined as the maximum age a fish would have been at the end of a calendar year sampling period. Note that sampling of snapper in New South Wales was based on financial years and so dates were re-collated into calendar year. New South Wales fish were assigned an age group by adding one to the recorded age class of fish sampled between January and June inclusive (1 July representing the designated birthday in Queensland – noting that this will not represent the average birthday of the stock as spawning occurs later in more southern waters).

While there were considerable length- and age-structured samples available for the western Victorian biological stock there was only limited data available for the eastern stock, with samples being limited to a couple of years during the late 1990s. Whether these data were representative of the catch for this area was also uncertain. There were no snapper age and length frequency data available for the Commonwealth harvest.

<u>Biological data</u>

Snapper has a continuous distribution around the southern coastline of mainland Australia, from Proserpine in Queensland to Barrow Island in Western Australia inhabiting the coastal marine waters from the shallows up to 200 m in depth. Biological parameters vary widely among subtropical and temperate populations from various states. Although snapper are long lived (40+ years: Norriss and Crisafulli, 2010), most of the population on the east coast of Australia were of ages less than 10 years old. The age frequencies of the line catch of snapper were dominated by fish aged three to five years old and there is a paucity of older fish (>10 years old) compared with fisheries in the cooler latitudes of southern Australia and New Zealand. Campbell *et al*. (2009) discussed the biology of snapper and Table 2.5 in Wortmann *et al*. (2018) listed and cited all biological parameters of snapper.

Inshore sheltered habitats (such as Moreton Bay and Hervey Bay) are important nursery areas for juvenile snapper. Tagging studies have shown that snapper have complex and highly variable migratory habitats depending on the different stocks (Morgan et al., 2018). For some stocks most snapper do not migrate extensive distances, whereas for other some individuals will migrate over hundreds to thousands of kilometres. Small snapper feed mainly on small crustaceans, worms and other invertebrates. Adults consume other smaller fishes and a range of hard-shelled invertebrates which they easily crush with their powerful molar-like teeth.

In Queensland, snapper spawn in aggregations over several months (generally May to October) and synchronise spawning on the lunar cycle. Timing and duration of spawning, however, varies dependent on water temperature and other environmental conditions. Seasonal water temperature is known to regulate gonad development (Scott and Pankhurst 1992). Cooler water temperature down the New South Wales coast results in spawning later in the year compared to fish in Queensland, and in Victoria most spawning occurs from late October to early January (Coutin et al. 2003). On the east coast, snapper are generally sexually mature at four years of age. However, the faster growth rate of more subtropical populations enables them to reach sexual maturity earlier (2 to 4 years of age), than in more temperate latitudes.

Snapper are particularly vulnerable to fishing when they form spawning aggregations which are somewhat predictable in time and space. Snapper in spawning aggregations are easy to catch and at these times can be subjected to high fishing pressure by both commercial and recreational fishers.

Elsewhere in temperate Australia snapper populations are comprised of fish that have originated from different regions of the coast (Hamer et al. 2005), and juvenile snapper from stronger recruitment years are known to migrate hundreds of kilometres from spawning areas prior to becoming residents in other areas (Fowler et al. 2005).

Environmental conditions have an important impact on the recruitment of snapper. Reviews of spawning timing in relation to water temperature for wild populations and information from aquaculture trials have found that the ideal water temperature for spawning of snapper, is between 15ºC and 22ºC (Mihelakakis and Yoshimatsu, 1998; Wakefield, 2010). Further, Fielder *et al.* (2005) reported that larval survival was not significantly different for animals subjected to temperatures between 15º and 24ºC, while temperatures >24ºC resulted in 100% mortality within 9 days. In southern New South Wales, this temperature range typically occurs from November to December as water temperature rises and again when the temperature begins to drop through March-April. In Port Phillip Bay there is some evidence that snapper are spawning in this temperature range both as the temperature increases and decreases (P. Hamer, pers. comm). Along the east coast the timing of this optimal temperature window varies with latitude, with the implication that snapper spawning occurs more toward the winter months further to the north, and more towards the spring - summer further to the south.

While there were comprehensive biological data available for the western Victorian stock there are limited data for the eastern Victorian stock and no ability to spatially characterise the biological data of that stock. Growth, maturity, spawning and other parameters are not explicitly described for the eastern Victorian stock apart from earlier growth variations based on analysis of tagging data conducted over 30 years ago (Francis and Winstanley, 1989). It is known that this stock is primarily a coastal spawning stock, and that estuaries provide the main nursery areas. Hence the reproductive behaviour of snapper along eastern Victoria is consistent with those further to the north, and is different to the snapper further to the west that spawn in large bays such as Port Phillip Bay (Hamer and Jenkins, 2004).

Research data: Fishery-independent trawl surveys

Fisheries Queensland has been undertaking fishery-independent trawl surveys of eastern king prawns, blue swimmer crabs and snapper since 2006. Generally, this sampling has been relatively consistent, occurring in November and December each year, using beam trawl apparatus with about 100 sites sampled on each of the two sampling months (November and December). The Moreton Bay surveys predominantly caught fish in their first year of life (≤13 cm TL). This was in contrast to the offshore waters outside Moreton Bay where few juvenile snapper were caught, despite intensive sampling (a further 200 sites from the Gold Coast to Wide Bay).

Research data: baited remote underwater video surveying (BRUVS) data

There were some fishery-independent data sources that have collected data on fish such as snapper and pearl perch. Some of these have been described in Sumpton *et al.* (2013) but they will not be further discussed here. Our assessment at this time is that the BRUV data were of little value to the current simulation model due to the lack of time series for snapper. However, a well-designed and regulated BRUV program could provide a fishery-independent index of relative abundance suitable to include in stock assessment modelling.

There were other research programs that have used BRUVS to collected data on snapper relative abundance in New South Wales. These studies were designed to compare the relative abundance of snapper in marine protected areas with areas open to fishing (Harasti *et al.*, 2018). These data were not considered for the model as they were not available at the time of model development.

Historical information

The historical popularity of snapper fishing is reflected in the numerous articles published in east coast newspapers throughout the late 19th and early 20th centuries (Figure 7; Table 12). The earliest record of an individual fishing trip was retrieved from a newspaper published in 1871;

"Schnapper fishing is becoming quite a fashionable amusement among Brisbaneites, and considering the little difficulty there seems to be in making a good haul of these fish, it is surprising that professional fishermen don't turn their attention to catching them. The supply seems inexhaustible." The Brisbane Courier, 7 Sept 1871.

The content of the article suggests that chartered fishing trips, if not frequent during this period, were certainly well established. The earliest popular media article to quantitatively describe a charter fishing trip in New South Wales was in 1873, which described the activities of the already-established Nimrod Fishing Club. Over the years the activities of this club continued to be reported in the popular media;

"About fifty members of this club […] had a most enjoyable and successful fishing excursion outside yesterday. They […] left the Circular Quay in the steamer Mystery, shortly after 8 o'clock. Upon gaining the Heads the steamer was steered for Dee Yee, where she was allowed to drift about for three or four hours, and she had not long been there before the fun commenced, and reports were spread that there were fish about. The steamer arrived off Dee Yee at 9.30, and she drifted till 1 o'clock, when the anchor was thrown overboard. The sport, however, soon slackened, and the hauls were not so successful as when drifting. The anchor was taken in board at 4 o'clock, and after drifting again for a short time the Mystery was headed for home. The total number of fish landed was 826, principally consisting of schnapper, weighing on an average from 3 lbs. to 10 lbs." The Sydney Morning Herald, 16 Nov 1877.

Other archival sources record or allude to the occurrence of snapper fishing activities (recreational, commercial and indigenous) in New South Wales many decades prior to the 1870s. For example, by the time chartered fishing trips for snapper started to be recorded in the popular media, there were already concerns being expressed about the localised depletion observed in the waters around Sydney (New South Wales Royal Commission 1880; Pepperell 2004);

"20 and 30 dozen 'count' fish were often taken by two fishermen on [the Broken Bay] grounds. Now, however, the […] grounds about Broken Bay have fallen off in their productiveness to an alarming degree." New South Wales Royal Commission, 1880.

"For half a century and more, often as many as twenty boats, carrying at least two persons (amateurs) would proceed to Shark Island (the favourite spot) and each boat bring away from 20 to 40 dozen of red bream (young schnapper) from 3 to 6 inches long. The same may be said of the professionals, who have scraped our shores and left bushels of these little fellows to perish on the beaches." The Sydney Morning Herald, 9 Apr 1881.

"It must be within the knowledge of all fishermen, professional or amateur, of middle age, that less than 20 years ago they could easily take from six to twenty dozen large red bream in such fisheries as Port Hacking, Botany, our own harbour [Sydney], Pittwater, or Brisbane Water in a morning's fishing. The catch would now be at most one or two fish for the dozen of that time. Of course the reason of this decadence is that the destruction of the younger generations is so large and so persistent that the offing fisheries have long ceased to receive their regular succession of two and three year old bream! The number of spawning fish on the outside grounds is therefore continually being diminished." The Sydney Morning Herald, 13 May 1890.

Despite these concerns, large catches of snapper continued to be taken on the outside grounds, and the reporting of snapper fishing increased throughout the 1880s and 1890s (Figure 7), by which point steam vessels were frequently chartered for leisure trips, and snapper fishing clubs were growing in popularity;

"The steamer Otter, with the mayor's schnapper fishing party, returned to the Queen's Wharf at about 8pm on Saturday. The weather during the trip was fine, and in every way favourable for fishing, but although all the usual patches were visited only 100 fish were caught." The Brisbane Courier, 2 Jul 1888.

The second trip of the Commercial Schnapper Club took place last Saturday in the steamer Greyhound […]. The Mount Tempest grounds […] were reached at 2.30 am on Sunday. Before daylight over 300 fine large schnapper were on deck, and the total number of fish caught up to noon was 1111. The fish as a whole were a fine even lot, averaging from 5lb to 7lb in weight. The Brisbane Courier, 22 May 1906.

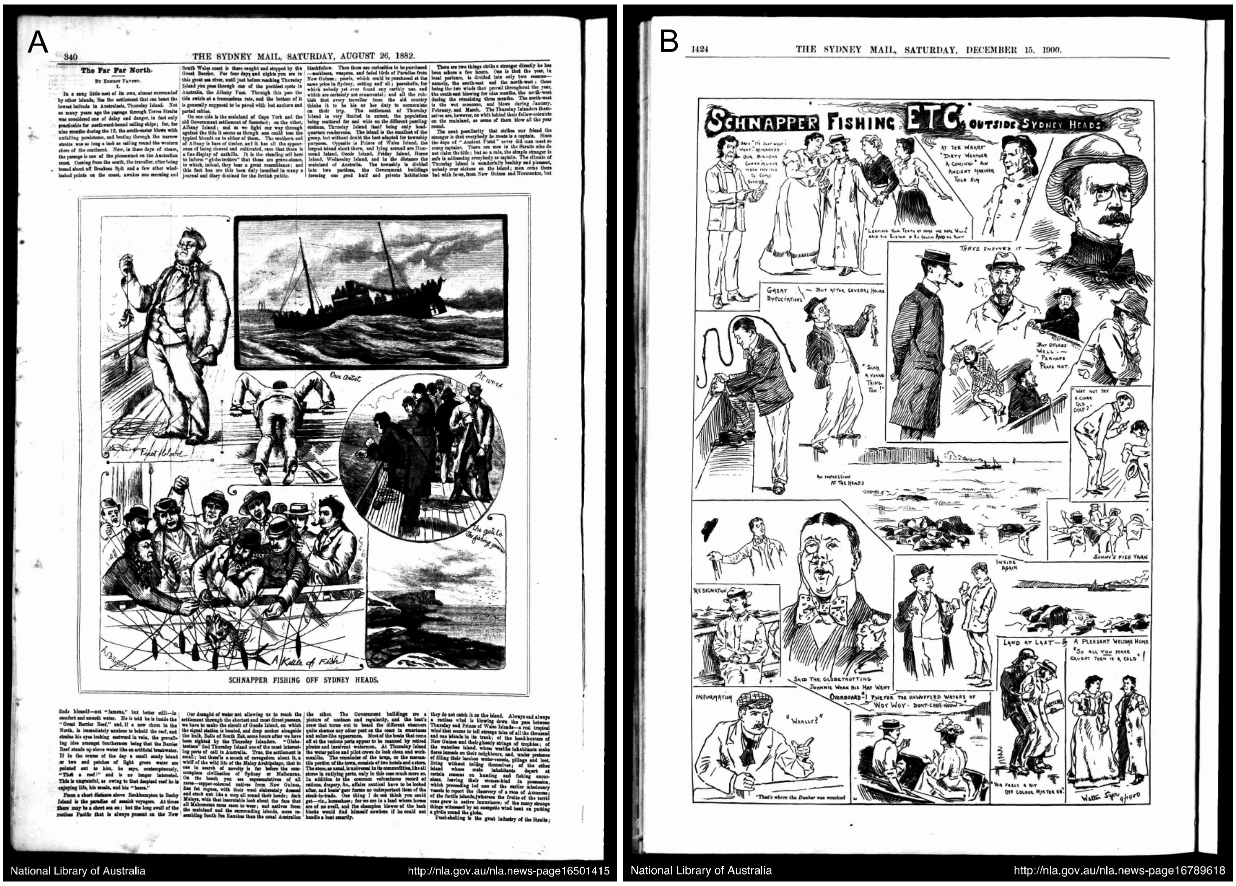

Figure 7 Light-hearted illustrations describing early snapper fishing trips, A) The Sydney Mail, 26 Aug 1882, B) The Sydney Mail, 15 Dec 1900. Source: The National Library of Australia.

Calculating catch rate trends

In total, 611 and 698 fishing trips targeting snapper were recorded from Queensland and New South Wales sources, respectively (Table 12). These were largely collated from newspaper reports spanning the years 1871-1959. Many articles provided both qualitative and quantitative detail, including the numbers of fish and/or snapper caught, numbers of fishers, locations fished, and, in some cases, the number of hours fished;

"A party of thirty went on a fishing excursion six miles outside Port Jackson Heads the other day. They commenced fishing about half-past eleven, and knocked off about a quarter past three in the afternoon. The number of fish taken was no less than 1,260 schnappers, exclusive of a few commoners that were cut up for bait." The Morning Bulletin, 6 Aug 1878.

About twenty-two were on board [...], we reached Flat Rock at half-past 9am, and finding sport poor shifting to Boat Rock, and for two hours were all hard at it. Schnapper, groper, rock cod, and parrot fish came tumbling in till even the most inveterate sportsman was satisfied. At a quarter to 12 we started for home, and, counting over the fish, found 496, which, with those cut up for bait (about fifty) was a very good two hours' work indeed. The Brisbane Courier, 22 May 1879.

Using the original quantitative data sourced from the newspaper articles, catch rates of snapper fisher^{-1} hr^{-1} were limited due to fewer articles providing the number of hours fished, with only 62 and 34 data points existing for Queensland and New South Wales, respectively. Once the qualitative estimates were included, the number of data points increased to 145 and 342 (Table 12). The main reason for the higher sample size from New South Wales was that a larger number of records specified the number of snapper caught, while Queensland records more commonly specified the total number of fish caught, of which snapper was the predominant fish targeted but often comprised an unknown proportion of the total catch. In a number of cases the context of the popular media article suggested that the 'fish' being described were possibly snapper, but as this was unclear we assumed these were formed of different species of fish unless the number of snapper was explicitly stated.

Table 12 Number (N) of quantitative data points sourced from original data (no fill) and number of data points once estimates derived from qualitative data are included (grey fill).

State	N fishing trips recorded	N trips where n snapper reported		N trips where n fishers reported		N trips where n hours fished reported		N records of catch rate (1) (snapper fisher^{-1} hr^{-1})		N records catch rate (2) (snapper fisher^{-1} trip^{-1})	
Qld	611	176	204	376	502	137	566	62	145	129	155
NSW	698	428	458	308	501	81	676	34	342	201	349

Hours fished during the time series averaged 4.5 hr trip^{-1} for Queensland records, and 4.8 hr trip^{-1} for New South Wales records. Hours fished showed no significant change over time (Qld: n = 137, linear regression y = -1.605e-005x + 4.517, p = 0.9994; NSW: n = 81, linear regression y = 0.004239x - 3.288, p = 0.8406) and no significant difference between the two states (Welsh's two-tailed t-test = 0.6275, p = 0.5311).

Differences existed between the two states in the proportion of snapper recorded in the catch. In Queensland, the proportion of snapper to total fish caught averaged 85% (n = 60, range 0-100%) of the catch.

Twenty-seven of these data points were sourced from catches recorded during a government survey conducted in 1910. In New South Wales the proportion of snapper in the catch averaged 62% (n = 177, range 19-100%).

Two catch rate measures were examined; 1) snapper fisher^{-1} hr^{-1} and 2) snapper fisher^{-1} trip^{-1}. Catch rates were significantly higher for Queensland fishing trips compared to New South Wales (Welch's two-tailed t-test snapper fisher^{-1} hr^{-1} = 5.292, p= <0.0001; Welch's two-tailed t-test snapper fisher^{-1}

$trip^{-1}$ = 3.661, p= 0.0003). Catch rates in both states demonstrated high variability throughout the time series (Table 13; Figure 8).

Table 13 Count, median, mean and standard deviation of catch rates sourced from original data (no fill) and once estimates derived from qualitative data are included (grey fill).

State	Time-period	Number of records for snapper caught. $fisher^{-1}hr^{-1}$		Median number of snapper caught. $fisher^{-1}hr^{-1}$		Mean (and SD) number of snapper caught. $fisher^{-1}hr^{-1}$		Number of records for napper caught $fisher^{-1}trip^{-1}$		Median number of snapper caught $fisher^{-1}trip^{-1}$		Mean (and SD) number of snapper caught $fisher^{-1}trip^{-1}$	
Qld	1871-1949	62	145	5.8	4.3	7.9 (9.2)	6.3 (7.1)	129	155	13.4	13.6	20.3 (19.9)	20.2 (19.0)
NSW	1873-1959	34	342	4.2	2.2	5.3 (5.0)	3.1 (3.2)	201	349	11.9	10.3	16.3 (15.7)	14.0 (13.3)
All	1871-1959	96	487	4.7	2.5	7.0 (8.1)	4.0 (4.9)	330	504	12.5	11.5	17.9 (17.6)	15.9 (15.5)

In Queensland, catch rates throughout the historic time series ranged from 0-42 snapper $fisher^{-1}$ hr^{-1} and from 0-132 snapper $fisher^{-1}$ $trip^{-1}$. In New South Wales, catch rates ranged from 0-24 snapper $fisher^{-1}$ hr^{-1} and from 0-110 snapper $fisher^{-1}$ $trip^{-1}$. Queensland catch rates showed no significant change over time (linear regression snapper $fisher^{-1}$ hr^{-1}: y = -0.03434x + 71.97, p= 0.405; snapper $fisher^{-1}$ $trip^{-1}$: y = -0.1067x + 224.3, p= 0.300), while New South Wales data showed significant declines in catch rate for both snapper $fisher^{-1}$ hr^{-1} and snapper $fisher^{-1}$ $trip^{-1}$ (linear regression snapper $fisher^{-1}$ hr^{-1}: y = -0.02988x + 60.11, p= 0.001; snapper $fisher^{-1}$ $trip^{-1}$: y = -0.1385x + 278.5, p= 0.001). When both time series were combined, no decline was observed in catch rate of snapper $fisher^{-1}$ hr^{-1} (linear regression: y = -0.02404x + 49.94, p= 0.057), but a significant decline was observed for snapper $fisher^{-1}$ $trip^{-1}$ (linear regression: y = -0.1122x + 230.2, p= 0.004; Figure 8).

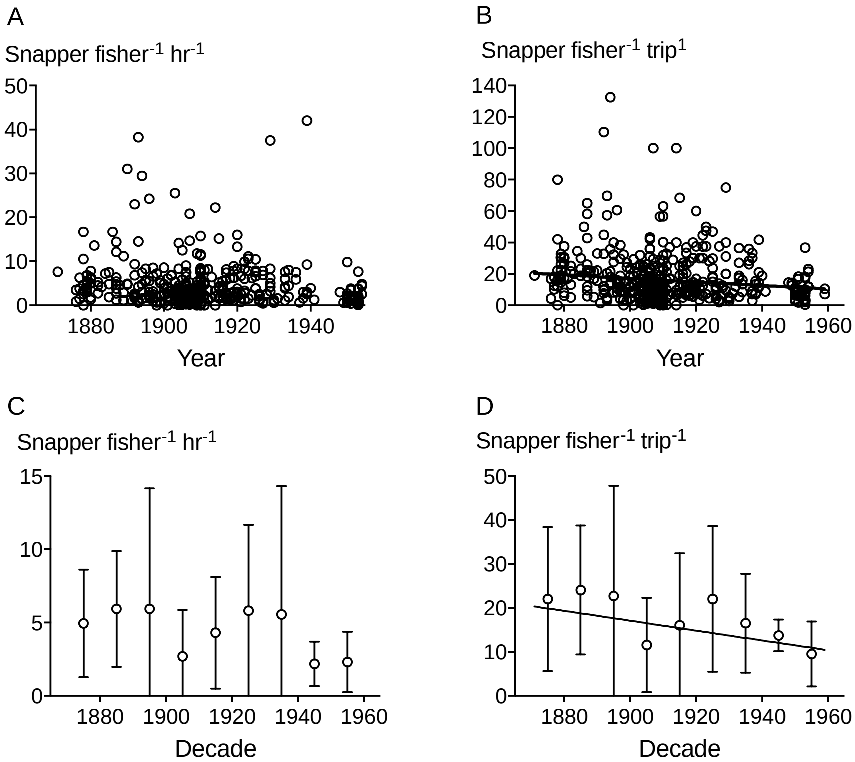

Figure 8 Aggregated New South Wales and Queensland data for A) snapper fisher^{-1} hr^{-1} with qualitative data included, B) snapper fisher^{-1} trip^{-1} with qualitative data included, C) mean snapper fisher^{-1} hr^{-1} by decade, D) mean snapper fisher^{-1} trip^{-1} by decade. Linear trend lines show significant trends over time, while vertical lines show standard deviation from the mean.

Examining bias in reporting of catch rates

Catch rates from Queensland newspapers and Welsby (1905) were compared to the Endeavour survey catch rates to examine if catch rates reported in popular media were significantly different to those reported from a government survey. Post-hoc tests revealed the only data source to demonstrate significantly higher catch rates to the survey data was Welsby (Figure 9; snapper fisher^{-1} hr^{-1} one-way ANOVA $F= 4.902$, $p = 0.0002$; fish fisher^{-1} hr^{-1} one-way ANOVA $F = 8.689$, $p = <0.0001$).

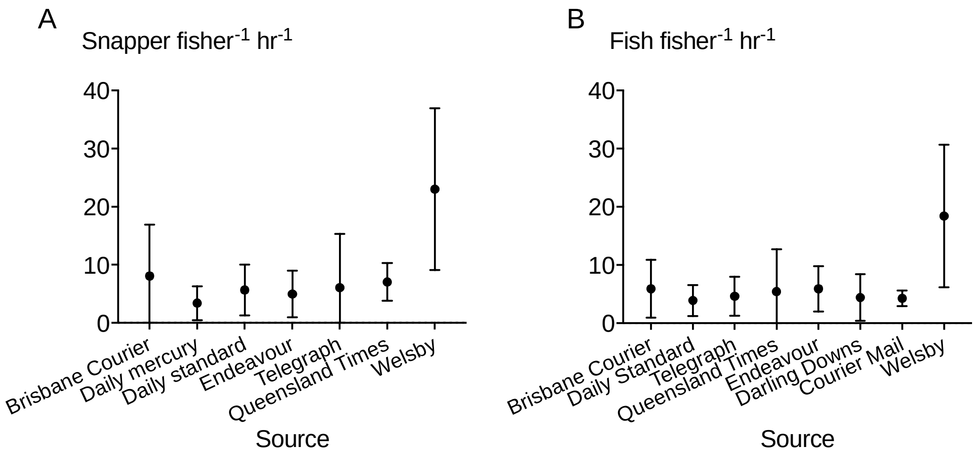

Figure 9 A) Mean snapper fisher^{-1} hr^{-1} and, B) mean fish fisher^{-1} hr^{-1} by source (where >5 catch rates provided) once qualitative data are included. Vertical bars show standard deviation from the mean.

Estimating total catch

Very few estimates of total, or charter vessel catch exist from the pre-World War Two period. The limited descriptions of snapper fishing in government reports suggest that the quantities landed each year varied considerably;

"The schnapper fishing along the coast has been very poor as compared with former years; very unfavourable weather contributing in a large measure to meagre results." Marine Department Report, 1906.

Two quantitative references on charter vessel catches were extracted from Queensland archives from 1904 and 1905;

"The fact of outside deep-fishing as a sport should not be lost sight of. It has become a very popular pastime, as many as ten or twelve steamers, with large parties on board, engaging in it each weekend. The average take is rarely less than a couple of hundred fish per steamer, but occasionally a steamer returns with a catch running into four figures. The fish caught in this way being some of the best and favourite edible kinds, it stands to reason that the licensed fishermen must sorely feel this growing influx of free fish in competition with their own net-caught fish during fully four months of the year. I am able to account for, say, 25,000 fish so landed from pleasure steamer trips during the last winter [1904]; and while such a supply is coming to Brisbane, the public cease to take the ordinary staple yield of mullet, whiting, taylor (sic), dew (sic), and garfish offered by the licensed men." Marine Department Report, 1905.

"Approximately, 21,000 fish have been caught during the present season by parties of anglers from Brisbane, and, averaging each fish at 3lb, the total weight represented is something over twenty-eight tons." The Brisbane Courier, 17 Jul 1905.

The total 1905 take of fish was likely to have been greater than estimated by the Brisbane Courier article, given that this quantity was provided at least one month prior to the end of the snapper fishing season. The 1904 popular media trips that we were able to extract landed a total of 8,428 fish, with trips recorded in 1905 landing a total of 20,089 fish (15,805 fish were landed up to the 17 Jul 1905, the date of the Brisbane Courier article). The greater number of fish recorded as landed in Queensland in 1905 was likely due to the publication of Welsby's book on snapper fishing, as the number of fishing trips retrieved from the archives for 1905 (n = 40) were higher than all other years in the time series (Figure 10). The number of trips retrieved from New South Wales popular media in 1905 were relatively low, at 15 trips, but numbers of recorded trips increased during 1906 (n = 85) and 1907 (n = 59). The greatest total number of fish recorded as caught in the New South Wales media were recorded in 1906 and 1907, at 17,616 and 19,250 fish, respectively (Figure 10).

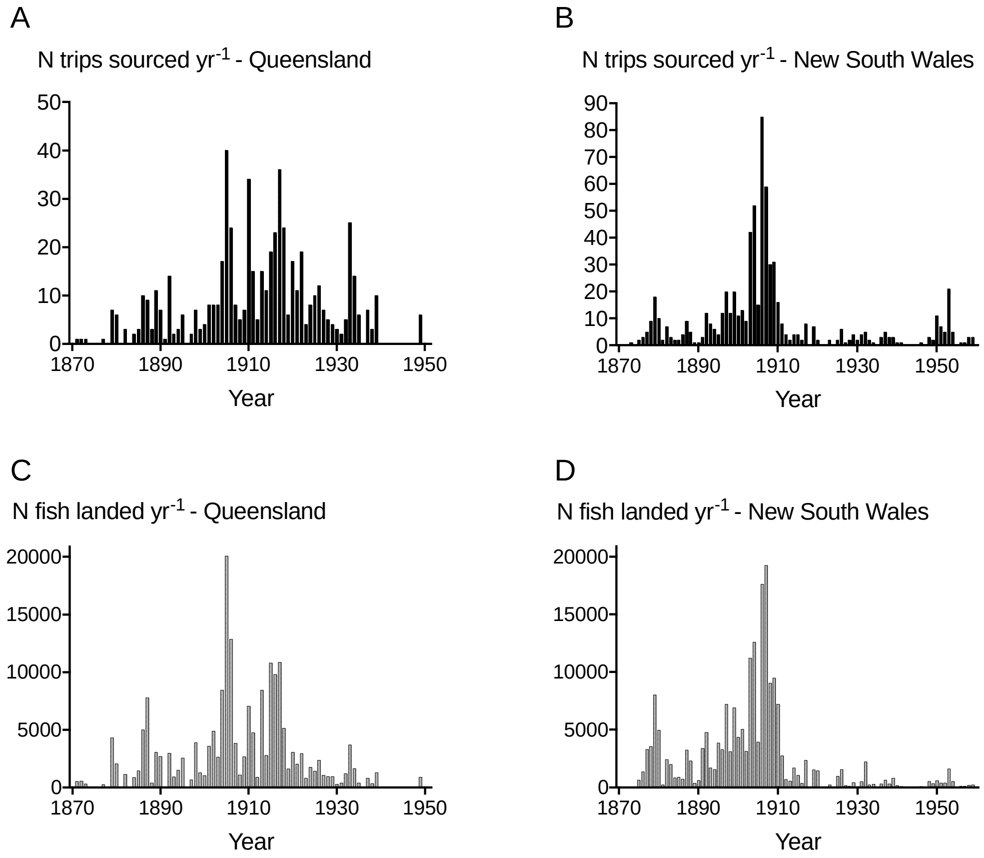

Figure 10 The number (N) of archival records that provided quantitative information on snapper fishing trips from A) Queensland and B) New South Wales. The sum of fish reported as landed from C) Queensland and D) New South Wales records. Due to the smaller number of trips that identified the number of snapper, total fish reported is used.

Using the average weight per fish calculated by records from the time, 3 lb (1.36 kg), 34 tonnes of fish were landed from deep-sea charter boats into southeast Queensland in the year 1904 (based on the 25,000 fish reported in the 1905 Marine Department Report). If snapper did indeed comprise 80% of the catch by number, 27.2 tonnes of snapper were landed. Using the number of fish recorded as landed in popular media records and the average proportion of snapper recorded, as a basis for the 1905 landings, 27 tonnes of fish (comprising 21.8 tonnes of snapper) were landed by charter vessels in the 1905 season. Assuming a similar average weight per fish in New South Wales during the 1906 and 1907 period, a minimum of 24 tonnes (14.4 tonnes of snapper at 60% percent of catch) and 26 tonnes (15.8 tonnes of snapper) were landed each year by charter boats, respectively.

While it is impossible to assess total catch using popular media coverage for other years, the similarities in patterns observed between states up to 1906-7 provide some confidence that the increasing trends observed in Figure 10 up to 1906-7 resemble historical fishing effort and catch trends. However, after this period, newspaper trends are unlikely to reflect trends in catch and effort, as recreational offshore fishing trips post-1910 continued to increase in popularity, while Figure 10 reporting trends show a decline. This disparity between archival record availability and fishing effort is likely due to individual fishing trips becoming less ‘newsworthy’ as motor boats increased in number and offshore fishing became accessible to greater numbers of people. A difference in reporting trends is also observed between Queensland and New South Wales. The total number of trips reported in New South Wales peaks in 1907 then drops off rapidly, whereas Queensland peaked in 1905, with reporting of trips in subsequent years varying substantially, but dropping off more gradually compared to New South Wales (Figure 10). The reasons behind this are unclear, but may be due to the “Welsby effect", where reporting of snapper fishing continued to be included in the newspapers due to the continuing local popularity of Welsby's publications.

Additional information from archival data

Descriptive information can also be sourced from archival data (Table 14; Figure 11). Such information can potentially be used to cross-check the reliability of the catch rate time series as provided (e.g., descriptions of catches across multiple trips by a fishing club or fishing vessel can provide indications on the variability of catch from trip to trip, or levels of bias in media reporting), or may provide additional indications of change (e.g. descriptions of localised depletion/declining size of snapper in shallow coastal waters). Some information on the fishing techniques used during these early charter fishing trips is also provided. This information may enable more accurate assessments of time spent fishing versus searching in the years prior to echo-sounders and GPS (Table 14).

A B

Figure 11 Large snapper landed in A) Coffs Harbour (29lb) in 1937, and B) Peel Island (24 lb) 1934. Source: Coffs Harbour Library No. 07-4229; Telegraph, National Library of Australia).

Table 14 Examples of additional information derived from archival sources.

Quote	Source
Catches of snapper	
"SOME ANCIENT HISTORY. In the year 1879 the Nimrod Schnapper Club started its season on March 1st. The club had nine outings, and the total catch of schnapper was 2,100, exclusive of other species. The number of members on the books was 56, though the full number never went to the one outing." *"Last year there were 16 excursions under Mr Campbell's management, 14 being abandoned on account of unfavourable weather. The total catch was 2,870 schnapper and 3,400 other varieties. The Manning River excursion resulted in a haul of 390*	Referee, 3 Jul 1907

schnapper and 220 other varieties." "The largest number of his excursionists went to Broughton Island. This run takes about 4 hours steaming from Newcastle, Seal Rocks 6 hours, Bungaree Norah 3.5 hours, Bird Island 3 hours, and the Caves 2 hours from Newcastle were also popular grounds. One party went to the Manning Heads, which takes 10 hours' steaming to reach […]. The public who attended the excursions were placed on the grounds before daybreak, and returned to Newcastle about 7 pm on the various Sundays on which they were held."	Newcastle Morning Herald and Miners' Advocate, 20 Mar 1908 and Sunday Times, 22 Mar 1908
Size of snapper	
"Quite a number of good old warriors have been tempted out on to the briny for schnapper fishing lately. They don't seem to care much whether they catch fish, and invariably carry the thick lines to which they were accustomed years ago when the schnapper averaged six times the size of those now being caught. The fish in the ocean waters close to Sydney are remarkably small. It is the exception to catch fish going over 8 lb now." *"The young schnapper are familiar to colonial fisher men as red bream or 'cockneys.' As they grow larger, say up to 2 lb., they are called bull bream. From 2 lb. to 6 lb. or 7 lb.— there can be no exact figures in this haphazard classification — the fish are styled squire, and above those figures they reach the dignity of schnapper [...]. The most popular method of schnapper fishing is in parties of 15 or more from a tug boat."* *"The general run of schnapper now caught is about 8 lb. Where all the large ones have gone to is a matter about which much speculation exists in old schnapper-fishing circles."* *"The regal schnapper once caught in our waters is not so common of yore. He seems to have given place to a smaller run of fish […]. Once schnapper were frequently caught between 15 and 30 lb weight."*	The Sydney Mail and New South Wales Advertiser, 2 Jul 1898 The Sydney Mail and New South Wales Advertiser, 1 Jul 1899 The Sydney Mail and New South Wales Advertiser, 5 Aug 1903 The Sydney Morning Herald, 29 Jul 1905
Fishing techniques	
"In Sydney the number of men likely to be engaged [in snapper fishing] either in an amateur or professional capacity will very likely run into thousands […]. The boats used are usually the harbour tug-boats, and the largest of these will accommodate 25 men comfortably when there is an easy drift. The fishing is carried on from only one side of the vessel as she drifts broadside to wind or current [...]." *"Three schnapper fishing parties were out from Sydney on Saturday fishing in the ocean. Two went north and one south, but all experienced poor sport. A fresh north-easter blew, and the steamers under its influence and that of the southerly current drifted too fast. Schnapper fishing from drifting steamers is pretty well done for this year. The only way to make sure of a haul now is from an open boat or yacht moored on a good ground."*	The Sydney Mail and New South Wales Advertiser, 7 May 1898 The Sydney Mail and New South Wales Advertiser, 3 Sept 1898

"A lot of time is lost while steamer-fishing through drifting over a prolific patch, and it is rarely exactly picked up again. The tug boats never anchor, if they did they could fish a place out satisfactorily. Some have suggested the dropping over of a sealed empty kerosene tin to indicate the spot, but the surface drift would put this off the spot before the party could turn around […]. If an anchor could be dropped on such a place as this hauls of a thousand fish would become the rule rather than the exception."	Referee, 28 Jun 1899
Fishing technology	
"Plaited or ordinary hemp lines of 150 to 200 yards length, 9, 15, 18, 27 or 36 cord, and a dozen or so hooks on double gut or double line, sizes ranging from 3-0 to 8-0 according to the size of fish expected [...]. The sinker is fixed at the end of the line, and one, two or three snoods with hooks attached are fixed above it at distances of 12in to 15in apart." *"From [retired] Capt McFarlane [year unknown]. 'In those days heavy tackle was used; it has to be different nowadays'."*	The Sydney Mail and New South Wales Advertiser, 7 May 1898 The Wingham Chronicle and Manning River Observer, 7 Jul 1950
Wider trends	
"Thousands upon thousands of undersized squire are murdered in the bay yearly, and as all fishing authorities and experts state that this fish is young schnapper, it is not hard to understand why the schnapper fishing is gradually deteriorating." *"For 40 years schnapper fishing was regarded in Sydney as purely a Winter pastime, but about the time motor boats came into general use men fond of deep-sea fishing discovered that schnapper could be caught in the fall of the year more plentifully than in the winter. Consequently, for the last 10 years many good hauls have been taken during March and April."* *"A great sport of the out-of-doors is snapper fishing; but it is not so good as it was a generation ago. Deep-sea fishermen often engage in arguments regarding the causes for the falling off in the quality of sport. Among the reasons assigned are overfishing, the spoiling of the feeding grounds by the deposition of silt and clay, the attraction of sharks by the frequent release of offal from punts, and the capture of small fish in the coastal havens. No doubt all these are factors in the business but the greatest is that of the capture of immature fish.... Like the nannygai, the snapper appears to be doomed near Sydney."*	Truth, 2 Mar 1913 Referee, 22 Mar 1916 The Week, 6 Jan 1922

Fisher interviews

Timing and rate of adoption of fishing technology

No major differences were observed in the timing of adoption of technology between fishers from New South Wales and Queensland, and both sectors reported starting to use colour echo-sounders from 1980-1987. However, the rate of adoption of GPS occurred earlier and slightly faster in the commercial sector compared to the recreational sector. In Queensland, 50% of fishers in both sectors were using GPS by 1993. By 1999, 90% of commercial fishers were using GPS, while it took until 2005 before 90% of recreational fishers adopted GPS. In New South Wales, 50% of commercial fishers reported using GPS by 1989, while it took until 1998 for 50% of recreational fishers to report using GPS. By 2007, 90% of commercial fishers were using GPS, while it took until 2013 before 90% of recreational fishers adopted GPS (Figure 12). Similar trends among sectors were observed in the rate of adoption of colour echo-sounders (Figure 12).

Recreational fishers reported adopting paper echo-sounders several years prior to the commercial fishers interviewed. In the Queensland sample, paper sounders were first recorded as being used in 1957 by recreational fishers, and 1961 by the commercial sample. In New South Wales, first recorded uses were 1957 and 1971, respectively. Paper echo-sounders were adopted by a greater proportion of Queensland recreational fishers (peaking at 87% of active fishers in 1978) compared to New South Wales recreational fishers (peaking at 68% of active fishers in 1983) (Figure 12).

Over the last 15-20 years, the recreational sector has reported an increased use of soft plastics and braid line technology. By 2012, >70% of interviewed Queensland recreational fishers reported using soft plastics in place of or in addition to bait, while only 25% of New South Wales recreational fishers reported using soft plastics. By 2012 braid was used by 85% and 65% of Queensland and New South Wales recreational fishers, respectively. Similar to bait technology, braid line might be used in place of, or in addition to monofilament, depending upon fisher preference and the depth and conditions experienced while fishing.

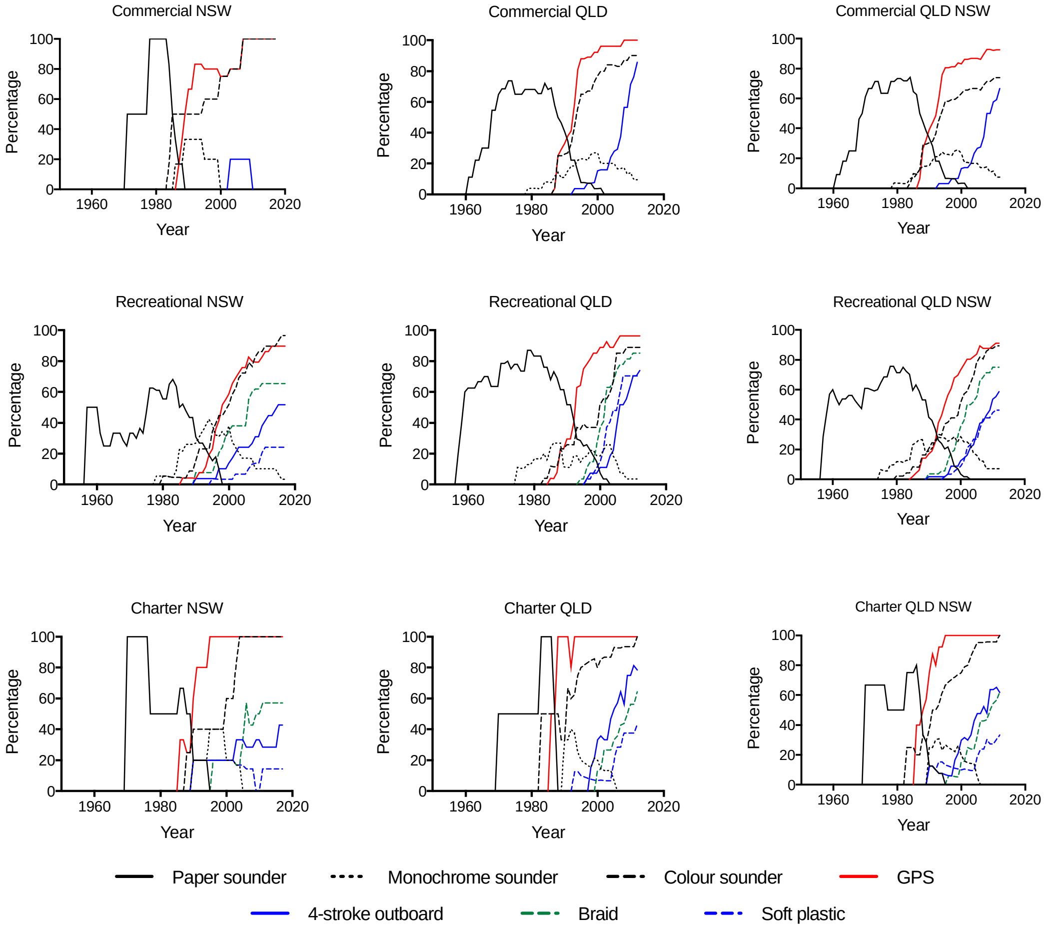

Figure 12 Percentage of interviewed fishers active in the fishery each year that used the named technology.

The impact of technology on fishing activities

Of the 68 fishers (50 in New South Wales, 18 in Qld) who were asked to provide quantitative estimates of change to their fishing activities as a result of technology, 38 fishers (56%) provided 1 or more quantitative estimates of change. Fishers most consistently felt able to quantify the impact of GPS and electronic echo sounders. Thirty-one fishers spoke of increases in the number of fishing spots they had marked as a result of GPS, with a 1788% increase in the number of known fishing spots compared to the period prior to GPS (Table 15). Only five fishers provided a quantitative estimate for an increase in catch rates as a result of GPS (average 223% increase, SD = 300%). Many more fishers qualitatively stated that their catch rates had significantly increased as a result of GPS and other available technologies (Table 16), but they felt unable to quantify this change due to the high variability of catches and confounding influence of multiple technologies. Ten fishers stated that GPS had influenced their travel time, with an average reported 14% (SD = 16%) decrease in travel time to the fishing grounds (Table 15).

Fewer fishers quantified the impact of echo sounders, probably because the majority of fishers interviewed had always used either a paper or electronic echo sounder. Of the 11 fishers who mentioned quantitative changes resulting from electronic echo sounders, 10 fishers provided an increase in known fishing spots, averaging 760% increase (SD = 777%). The impact of braid line was estimated by 7 fishers, with an average reported increase in catch rate of 136% (SD = 48%) over monofilament line (Table 15).

Table 15 Quantitative changes attributed to the use of specific technologies. GPS = geographic positioning system; ES = electronic echo sounder; Braid = braid line; SP = soft plastic lures.

Gear	State	Number of known fishing spots			Changes to catch rate			Changes to travel time		
		N of fishers	% change	% SD	N of fishers	% change	% SD	N of fishers	% change	% SD
GPS	NSW	21	2247.8	5353.4	5	223	300.7			
	Qld	10	823.3	1454.6				10	-14.4	16.2
	Total	31	1788.3	4494.3	5	223	300.7	10	-14.4	16.2
ES	NSW	6	625	849.6	1	900	-			
	Qld	4	962.5	718.1						
	Total	10	760	776.7	1	900	-			
Braid	NSW				3	133.3	57.7			
	Qld				4	137.5	47.9			
	Total				7	135.7	47.6			
SP	NSW				2	450	636.4			
	Qld									
	Total				2	450	636.4			

Table 16 Qualitative statements on the changes witnessed as a result of new technologies.

Technology and quotes	Source
GPS	
"GPS gave a significant and immediate improvement; the duds got good."	Recreational fisher, Qld.
"Prior to GPS you stayed within sight of land, now you travel further."	Commercial fisher, Qld.
"GPS was really the killer, you didn't have to worry about marks. Then the tackle stores giving out GPS marks really knocked the fishery."	Recreational fisher, Qld.
"GPS made a huge difference. They are accurate to 1 metre so you can find very small pieces of structure offshore. Marks are accurate to maybe 2-300 metres. Now you have a huge library of potential areas."	Recreational fisher, NSW.
Echo sounders	
"Sounders expanded the fishing grounds extensively."	Recreational fisher, Qld.
"Colour sounders opened whole new areas of reef, they gave a clearer definition of the bottom so you can gauge the type of fish you're looking at. If there's a bigger area to operate in you can concentrate on fishing in new areas, so it lifted the catch rate."	Commercial fisher, NSW.
Braid	
"Braid is one of the biggest changes in my fishing time."	Recreational fisher, Qld.
"Braid gives the passengers a better chance in the deep water to feel the bites, you get a slightly better hook up rate."	Charter fisher, Qld.
"Braid is so fine nowadays we're not nearly as affected by depth or current. They're a huge benefit offshore, you can feel every tiny bite which gives you a much better hook up rate."	Recreational fisher, NSW.
Soft plastics	
"Soft plastics were the big game changer, we were putting 10 snapper in the boat in 35 minutes between 2 people when they first came out."	Recreational fisher, Qld.
"Soft plastics can give you 10 for every one snapper caught with bait, if you get the right conditions. Plastics give you more options."	Recreational fisher, NSW.
Lures	
"Everyone is using lures now, which are better for catch and release."	Recreational fisher, Qld.
"Plastics target the big fish, so does live bait, so they help with the size limits."	Commercial fisher, Qld.
"Lures allow you to get the big snapper mid-water. It's the bigger fish zone and allows you to target snapper more. Bait catches three times the variety of species compared to lures."	Recreational fisher, NSW.

BIOMASS FORECAST MODELS

Diagnostics and parameter estimates for the historical model are presented in Appendix 16. Historical simulation details may also be found in Appendix 5.9 of Wortmann *et al*. (2018).

Sustainable scenario

The ‘sustainable’ scenario was based on the assumption that snapper abundance followed the New South Wales commercial trap catch rates index (which showed an increasing trend from 2002 onwards) and natural mortality was 0.211 year^{-1}, with S_{2016} around $0.43S_0$. Under this scenario the maximum sustainable yield to achieve 40% of original biomass was 1118 tonnes per year with 95% confidence level of (965, 1,271). The sustainable yield for 60% of original biomass was 860 tonnes per year with 95% confidence level of (760, 960). These levels were generally above the total allowable catch levels that were simulated for the harvest management arrangements, thus it would be expected for the fixed harvest arrangements that stock levels would be able to build to 60%.

Management arrangements that increased minimum legal size, (see previous Table 4), resulted in higher spawning biomass, Table 17 and Figure 13: Five analyses were performed to investigate this.

- Analysis 1, MLS and harvest rate as per status quo, estimated $S_{2056}=0.53S_0$
- Analysis 2, harvest rate as per status quo, reduced MLS to 30 cm total length in both jurisdictions, estimated $S_{2056}=0.52S_0$
- Analyses 3–5, harvest rate as per status quo, increased MLS 35–45 cm estimated an initial increase in spawning biomass over about 10–15 years, followed by a levelling off to $S_{2056}=(0.55–0.6)S_0$.

When total allowable catch (TAC) was reduced, (see previous Table 4), spawning biomass increased, Table 17 and Figure 13: Four analyses were performed to investigate this.

- TACs of up to 800 tonnes per year resulted in an estimated initial increase to $0.6S_0$ after about 24 years before levelling off to $S_{2056}=0.64S_0$.

- A TAC equal to 600 tonnes per year resulted in an estimated initial increase to $0.7S_0$ after about 24 years before levelling off to $S_{2056}=0.74S_0$.

- A TAC equal to 400 tonnes per year resulted in an estimated initial increase to $0.8S_0$ after about 24 years before levelling off to $S_{2056}=0.84S_0$.

Table 17. Results for the hypothetical management arrangements for the 'sustainable' scenario where S_{2016}=0.43S_0 (median of 1000 simulations).

Management arrangement	Analysis	Initial increase in median S_t/S_0 to	Number years for initial increase before levelling off	Median S_{2056}/S_0
MLS varied, harvest rate status quo	1	0.52	15 years (2032)	0.53
	2	0.5	14 years (2031)	0.52
	3	0.54	16 years (2033)	0.55
	4	0.56	18 years (2035)	0.57
	5	0.59	18 years (2035)	0.6
Catch limit TAC set, MLS status quo	6, 7	0.6	24 years (2041)	0.64
	8	0.7	24 years (2041)	0.74
	9	0.8	24 years (2041)	0.84

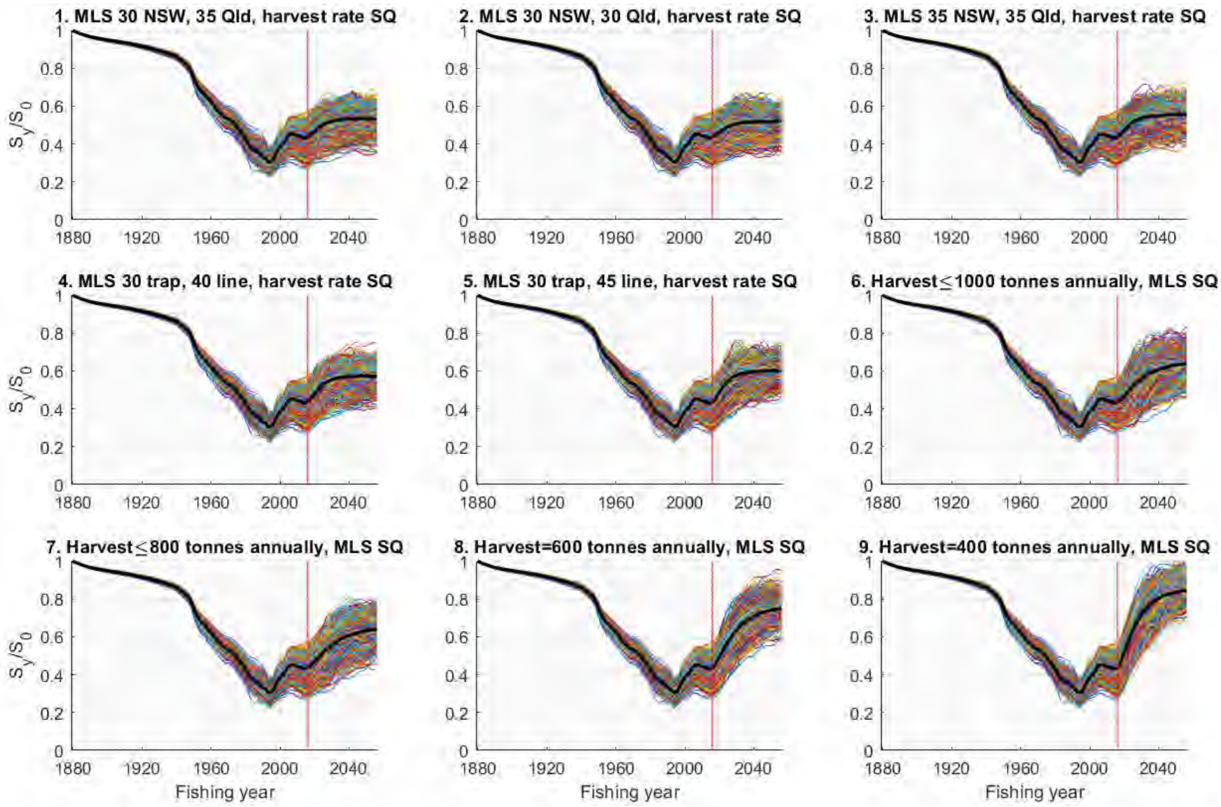

Figure 13. Spawning biomass depletion (spawning biomass relative to unfished spawning biomass) from 1880–2056 for 1000 simulations for the sustainable scenario for nine hypothetical management arrangements given in Table 4. The red line denotes the year 2016. The solid black line is the median of the 1,000 simulations.

Limit reference point scenario

The 'limit reference point' scenario was based on the assumption that snapper abundance followed the New South Wales commercial trap catch rates index (which showed an increasing trend from 2002 onwards) and natural mortality was 0.163 year^{-1}, with S_{2016} around $0.22S_0$. The maximum sustainable yield was 1089 tonnes per year with 95% confidence level of (981, 1,196). The sustainable yield for 60% of original biomass was 823 tonnes per year with 95% confidence level of (738, 908). These levels were both above the total allowable catch levels that were simulated for the harvest management arrangements. It would be expected for these arrangements that stock levels would rebuild but at a lesser rate that the sustainable scenarios due to lower S_{2016} around $0.22S_0$.

For management options that increased minimum legal size,(from Table 4) spawning biomass improved, Table 18 and Figure 14 as follows:

- Analysis 1, MLS and harvest rate as per the status quo, resulted in an estimated $S_{2056}=0.29S_0$
- Analysis 2, reduced MLS to 30 cm total length in both jurisdictions, resulted in an estimated $S_{2056}=0.28S_0$
- Analyses 3–5, increased line MLS 35–45 cm resulted in an estimated increase in spawning biomass over about 10–15 years, followed by a levelling off to $S_{2056}=(0.31–0.36)S_0$.

When total allowable catch was reduced, spawning biomass increased, Table 18 and Figure 14 as follows:

- TACs of up to 800 tonnes per year resulted in an estimated initial increase to $0.45S_0$ after about 20 years followed by a levelling off to $S_{2056}=0.58S_0$.
- A TAC equal to 600 tonnes per year resulted in an estimated initial increase to $0.57S_0$ after about 20 years followed by a levelling off to $S_{2056}=0.7S_0$.
- A TAC equal to 400 tonnes per year resulted in an estimated initial increase to $0.68S_0$ after about 20 years followed by a levelling off to $S_{2056}=0.8S_0$.

Table 18. Results for hypothetical management arrangements for the limit reference point scenario where $S_{2016}=0.22S_0$.

Management arrangement	Analysis	Initial increase in median S_t/S_0 to	Number of years for initial increase before levelling off	Median S_{2056}/S_0
MLS varied, status quo harvest rate	1	0.28	13 years (2030)	0.29
	2	0.27	12 years (2029)	0.28
	3	0.3	13 years (2030)	0.31
	4	0.32	13 years (2030)	0.33
	5	0.35	15 years (2032)	0.36
Catch limit TAC set, status quo MLS	6, 7	0.45	20 years (2037)	0.58
	8	0.57	20 years (2037)	0.7
	9	0.68	20 years (2037)	0.8

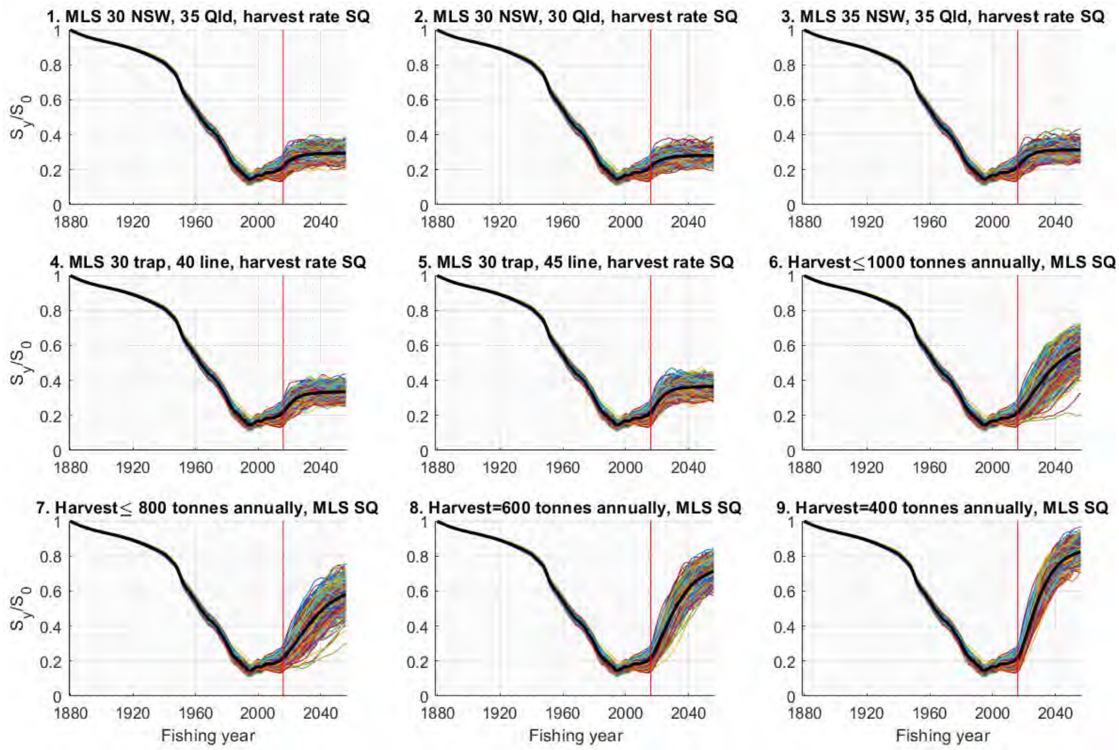

Figure 14. Spawning biomass ratios (spawning biomass relative to unfished spawning biomass) from 1880–2056 for 1,000 simulations for the limit reference point scenario for nine hypothetical management arrangements shown in Table 4. The red line denotes the year 2016. The solid black line is the median of the 1000 simulations.

Overfished scenario

The ‘overfished’ scenario was based on the assumption that the index of snapper abundance followed the line catch rate trends (which showed declining trends) and natural mortality was 0.163 $year^{-1}$. When the spawning stock biomass of a population falls under 20% of its unfished amount, it can be difficult to successfully rebuild the fish stock, and is considered recruitment overfished (Sainsbury, 2008). Thus it was important to explore if any management strategies had potential to rebuild stock levels, if S_{2016} was indeed around $0.12S_0$. The maximum sustainable yield to achieve 40% of original biomass was calculated from the 1000 simulations to be 1160 tonnes per year with 95% confidence level of (1071, 1249). The sustainable yield for 60% of original biomass was calculated from the 1000 simulations to be 925 tonnes per year with 95% confidence level of (849, 1001). Thus both the maximum sustainable yield and yield for 60% biomass were above the simulated harvests, and it should be expected that stock should rebuild under the harvest management strategies.

Management options that increased minimum legal size, (see previous Table 4), improved spawning biomass, Table 19 and Figure 15 as follows:

- Analysis 1, MLS and harvest rate as per the status quo, resulted in an estimated $S_{2056}=0.17S_0$
- Analysis 2, reduced MLS to 30 cm total length in both states, resulted in an estimated $S_{2056}=0.15S_0$
- Analyses 3–5, increased line MLS 35–45 cm resulted in an estimated $S_{2056}=(0.2–0.24)S_0$.

When total allowable catch was reduced, spawning biomass increased, Table 19 and Figure 15 as follows.

- TACs of up to 800 tonnes per year resulted in uncertain predictions with half of the simulations declining and half increasing. For this scenario, the median of the 2016 estimated harvest was around 660 tonnes, thus imposing a total harvest of 800 tonnes, resulted in many simulations declining to zero.
- A TAC equal to 600 tonnes per year yielded some uncertainty in rebuilding, but generally most simulations showed a recovery in biomass to S_{2056}=0.62S_0.
- A TAC equal to 400 tonnes per year resulted in an estimated S_{2056}=0.77S_0.

Table 19. Results for hypothetical arrangements for the overfished scenario where the median spawning ratio, S_{2016}/S_0, was 0.12.

Management arrangement	Analysis	Initial increase in median S_t/S_0 to	Number of years for initial increase before levelling off	Median S_{2056}/S_0
MLS varied, status quo harvest rate	1	0.15	14 years (2031)	0.17
	2	0.13	9 years (2026)	0.15
	3	0.17	16 years (2033)	0.2
	4	0.19	20 years (2037)	0.21
	5	0.22	23 years (2040)	0.24
Catch limit TAC set, status quo MLS	6, 7	0.104	20 years (2037)	0.004
	8	0.32	20 years (2037)	0.62
	9	0.47	20 years (2037)	0.77

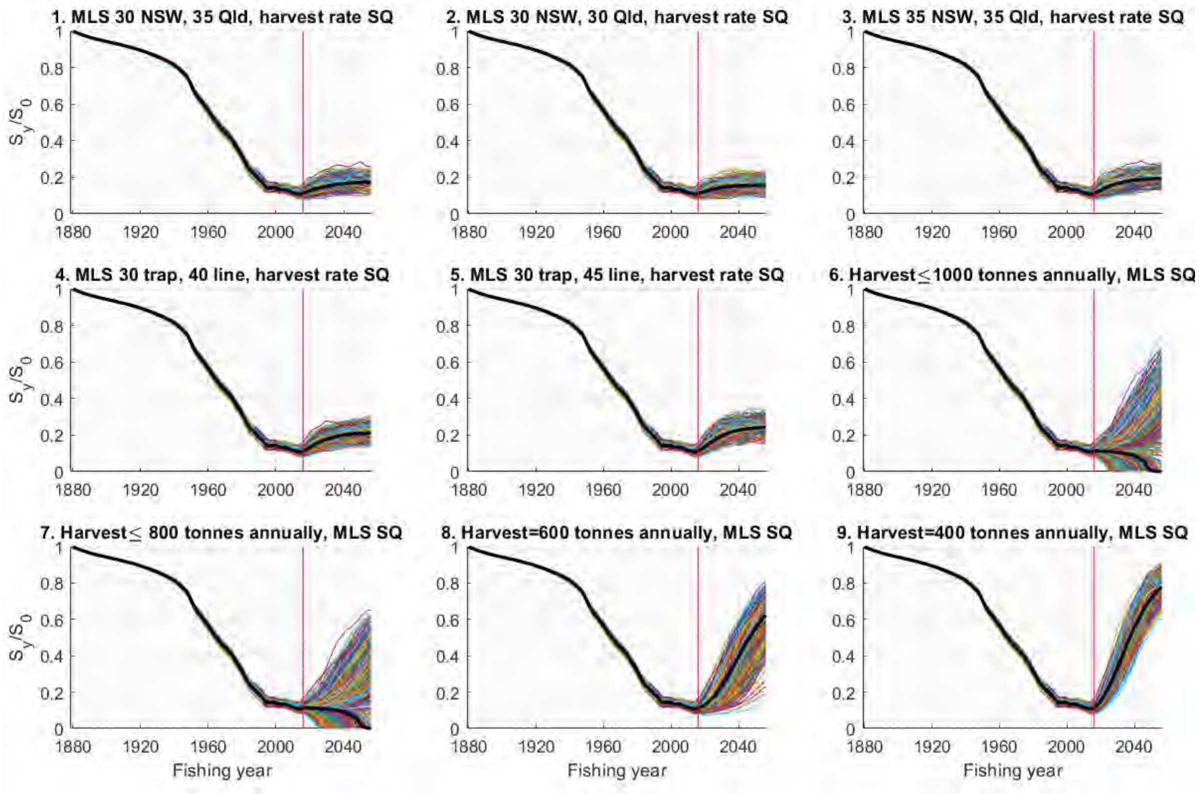

Figure 15. Spawning biomass ratios (spawning biomass relative to unfished spawning biomass) from 1880–2056 for 1000 simulations for the overfished scenario for nine hypothetical management arrangements shown in Table 4. The red line denotes the year 2016. The solid black line is the median of the 1000 simulations.

Comparison of scenarios

Figure 16 shows probability forecasts for the nine hypothetical management scenarios for achieving $0.4S_0$ (on the left of the figure) and $0.6S_0$ (on the right of the figure).

The graphs on the left of Figure 16 showed that the overfished scenario had zero probability for achieving $0.4S_0$ except for a TAC of 600 or 400 tonne per year which after twenty years had probabilities of 16% and 89% of reaching the target. In contrast, the limit reference point scenario reached $0.4S_0$ after 10 years under the 600 or 400 tonne quota with probabilities of 51% and 95%.

The graphs on the right of Figure 16 showed that the sustainable scenario had probabilities of 43 and 80% of reaching $0.6S_0$ for 600 and 400t TACs after 10 years. The limit reference point scenario had probabilities of 26 and 96% reaching $0.6S_0$ for the same strategies after 20 years, while the overfished scenario had probabilities of 7 and 86% of reaching the target in 30 years under the same strategies.

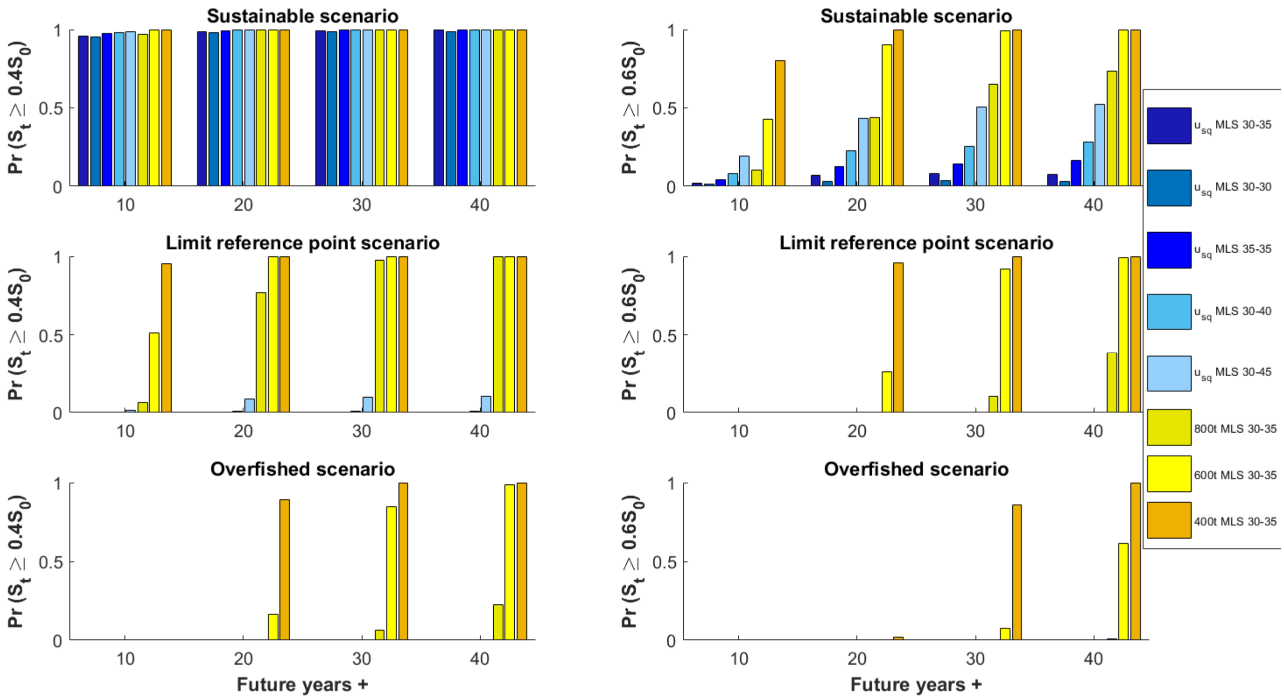

Figure 16. Probability forecasts for the nine hypothetical management arrangements. The management strategies were shaded from blue to yellow. In the legend U=harvest rate, sq=status quo, and MLS=minimum legal size fish (total length in cm).

Utility of datasets

The utility of the commercial and charter catch and effort datasets is discussed in Table 20.

The recreational surveys were important in the model because they were used to estimate recreational effort, and recreational harvest accounted for 50% of the total harvest.

The age frequency data were important for modelling the structure and recruitment of the population. Without the age frequency data, a simpler model would have had to be developed.

The sampling of young snapper (less than 15 cm in length) from Moreton Bay produced pre-recruitment catch rates from 2007–2015. The annual catch rates indicated trends in juvenile snapper abundance.

Table 20. Utility of datasets from the commercial and charter sectors.

Jurisdiction	**Sector**	**Data source**	**Period**	**Utility of data set**
New South Wales	Commercial	Historical	1940–1984	This dataset was a valuable source of historical harvest information.
		Commcatch logbook	1985–2016	This dataset contributed to total harvest and was used for catch rate standardisations for trap and line fishing. It was possible to do standardisations for the line sector from 1997, whereas by extracting records from 1985–1997 that had one fishing method in one month and assuming these were trap fishing records, it was possible to standardise trap catch rates from 1985.
		Fishonline logbook	2009–2016	This dataset contributed to total harvest and was used for catch rate standardisations for trap and line fishing. The logbook provided daily detailed catch information from which it was possible to standardise catch rates for the trap and line fishing sectors. For future catch rate standardisations records for other rocky reef species such as cobia, grass emperor, jobfish and king fish harvested could be included in the dataset. This would enable the standardisation to be done in the same way as the Queensland commercial line catch rate standardisation where the expectation for mean catch rates was determined from the probability of catching snapper and the expectation where a weight of snapper were caught and retained.
		AFMA	1999–2016	This was a valuable dataset to include in the line harvest of the New South Wales commercial line fishing sector.
	Charter	Logbook		While the charter dataset provided harvest data for the New South Wales line fishing sector, it was not possible to standardise catch rates from this dataset because it lacked information on fishing effort.
Queensland	Commercial	Fishboard	1946–1980	The early fishboard data was a valuable historical source of harvest information.
		Logbook	1988–2016	This dataset was used for harvest data and catch rate standardisations for commercial line fishing. The logbook provided daily detailed catch information from which it was possible to standardise catch rates for the commercial line fishing sector.
	Charter	Logbook	1996–2016	The charter logbook data contributed to the total harvest for the line fishing sector. It was not used as an index of abundance because the logbook was incomplete and had limited associated effort information.
		AMLI Gold Coast charter surveys	1993–2010	The AMLI charter data contributed to the total harvest for the line fishing sector and produced standardised catch rates for the line fishing sector.

Discussion

SNAPPER GENETIC STOCK STRUCTURE

Testing the hypothesis of genetic subdivision of *C. auratus* stocks on the east coast, based on a weak allozyme signal (Sumpton *et al.*, 2008), was important to ensure that development of stock assessment and management strategies was informed by understanding of stock structure. Temporal replication spanning a decade has also offered a unique opportunity to investigate the geographic stability of the genetic break.

Microsatellite analysis of Australian east coast *C. auratus* has revealed a consistent genetic signal, across all methods of analysis (Bayesian modelling, DAPC and F_{ST}/D_{EST} statistics), for two distinct genetic stocks. The two genetic stocks overlap at Eden in southern New South Wales. The east coast biological stock spans most of New South Wales and Queensland while the eastern Victorian biological stock encroaches into the southern part of New South Wales, but is predominantly found in Victorian and Tasmanian waters. Sumpton *et al.* (2008) also identified an east coast genetic disjunct among *C. auratus* populations using allozyme data, however, the break in that study was over 400 km further north, between Sydney and Forster on the central coast of New South Wales. The genetic break of Sumpton *et al.* (2008), based on samples collected in the mid-1990s is very likely the same genetic break identified here, with the shift reflecting a southward movement of the ranges of the two stocks.

The spatial distributions of the east coast and eastern Victorian biological stocks is fluid and likely varies with changing oceanographic and environmental conditions. Long term ocean temperature monitoring shows that the southward penetration of the East Australian Current (EAC) has increased over the past 60 years resulting in a poleward advance of warmer and saltier water (Ridgway, 2007). Water temperature has been shown to be linked to spawning periods and spawning success in *C. auratus* (Francis, 1993; Lenanton *et al.*, 2009; Scott and Pankhurst, 1992). The southward shifting EAC has also been associated with long-term shifts in the abundance and distribution of other temperate fish species (Last *et al.*, 2011).

The mechanism responsible for creating distinct biological stocks may also be linked to water temperature. Fish living in warmer waters at the northern end of the range spawn during winter, while fish living in more temperate waters spawn approximately three months later (Ferrell and Sumpton, 1997a). As a result, northern fish have an extended growing season; they mature earlier and are less fecund than their southern counterparts (Ferrell and Sumpton, 1997a; Stewart *et al.*, 2010). Biological parameters for the eastern Victorian biological stock are not well characterised. Interestingly, anecdotal evidence from Eden fishers suggests they can differentiate fish landed from either biological stock (John Stewart, New South Wales-DPI 2016 pers comm.). Future studies should focus on populations at a finer scale between Lakes Entrance and Terrigal to determine if the east coast and eastern Victorian biological stocks remain reproductively distinct in this region of overlap.

Standardized fixation measures may be less comparable between studies if mutation rates differ and heterozygosity is high (Leng and ZHANG, 2011), thus following the recommendation of Meirmans and Hedrick (2011) standardized measures should be used in combination with F_{ST}. The total standardized fixation index D_{EST} (0.0232) and F_{ST} (0.0151) estimates for the east coast samples were low but significant, p=0.001 for both measures. The estimates were almost an order of magnitude higher than the values recorded among Western Australian *C. auratus* populations from Shark Bay D_{EST} (0.002) and F_{ST} (0.002) with the caveat being that only locus Pma1 overlapped between the two studies (Gardner *et al.*, 2017). These results support the findings of (Gardner *et al.*, 2017) that *C. auratus* from Shark Bay represent a single genetic stock.

By pooling genetically undifferentiated adjacent collection areas, the spatial boundaries within the two east coast genetic stocks were further investigated. Following three rounds of pooling, three separate biological stocks were identified: east coast, eastern Victorian and western Victorian. Being a mixture of the east coast and eastern Victorian biological stocks, the Eden population is not significantly different to either of its neighbouring populations, Terrigal to the north and Lakes Entrance to the south (Table 7a). The decision to pool Eden with the eastern Victorian samples was made to highlight the finding that animals from that stock also occur in southern New South Wales waters. The fixation values for *C. auratus* are low compared to other marine fish. A meta-analysis by Cooke *et al.* (2016) found microsatellite based F_{ST} estimates of marine fish were generally below 0.2. For microsatellites, an $F_{ST} \geq 0.15$ is usually significant, however, for loci where allele diversity is high, F_{ST} values will typically be low (Jakobsson *et al.*, 2013). Low but significant F_{ST} values have been reported in other fish species. For example, coastal Atlantic cod had low but significant average $F_{ST} = 0.0037$. Using temporal sampling and mark-recapture studies the authors determined that the significant F_{ST} was biologically meaningful and corresponded to separate, temporally persistent, local populations (Knutsen *et al.*, 2011). In northern Australian waters, significant pairwise F_{ST} estimates comparing stocks of *Protonibea diacanthus*, the black spotted croaker, range from 0.012 - 0.046 (Taillebois *et al.*, 2017). Although their F_{ST} estimates were low, the authors found strong spatial variation in otolith chemistry and parasite analyses to support the genetic boundaries (Taillebois *et al.*, 2017). For *C. auratus* populations in New Zealand waters the few but significant pairwise F_{ST} values measured (between the most distant sites) were similar to those seen here, ranging from 0.0061 – 0.0477 (Ashton, 2013).

The separation of western Victorian biological stock from the eastern Victorian biological stock using pairwise D_{EST} suggests that southern Australian *C. auratus* populations will likely have their own distinct genetic signature. Tasmanian samples were somewhat intermediate genetically between the eastern and western Victorian biological stocks. Low catch numbers unfortunately resulted in the Tasmanian population being represented by pooled fish collected from both northern and eastern waters. It is possible that two genetic stocks have been captured within the Tasmanian sample. This issue will only be resolved with further sampling.

High levels of connectivity were found among collection locations with a weak IBD signature detected using only the complete data set. With increasing geographic distance, a linear increase in genetic differences was observed. The slope of the IBD correlation falls within the interquartile range reported for fish stocks based on a meta-analysis of marine fish (Cooke *et al.*, 2016). The slightly positive slope value indicates that fish are probably not actively recruiting back to natal sites (Cooke *et al.*, 2016) but neither are they moving large distances, they are sharing their DNA with neighbouring populations, either via mixed spawning aggregations or larval dispersal. The IBD signature could not be detected when the microsatellite data set was reduced to the east coast biological stock alone (five sites north of Eden) although a weak signal was found by Sumpton *et al.* (2008) using allozyme analysis. Biological knowledge of the fish would suggest that an IBD pattern likely does exist in the east coast biological stock but has not been detected with the current genetic markers. For this biological stock, the EAC is likely transporting larvae to the south, while adult snapper follow a general northward migration pattern (Sumpton *et al.*, 2008). A similar result was obtained using a microsatellite analyses of New Zealand snapper over a 900 km range which found stocks were largely panmictic with no IBD signal, and low level genetic differentiation between sites (Ashton, 2013).

This study has demonstrated that suitable genetic markers exist to characterise the population genetic structure of *C. auratus* stocks in Australian waters. Further research is needed to characterise stocks in southern and western Australian waters. A broad scale nation-wide study is recommended, with a consistent set of variable genetic markers, before fine scale spatial variation is assessed to assist in the management of local stocks. It would also be valuable to compare Australian *C. auratus* stocks to populations from New Zealand. Although the microsatellite loci screened in this study were the same as those reported by Le Port *et al.* (2014), unfortunately different size-scaling ladders were used by the two laboratories for scoring alleles and consequently the results require cross validation before they can be combined.

It would be premature to infer population numbers from the LDN_e estimates calculated without a better understanding of how the two numbers correlate in *C. auratus*, however, some interesting observations can be made from the results. It is promising that LDN_e values were estimated using a data set limited by low sample numbers, relatively few loci and with a high occurrence of rare alleles (which are currently excluded by the P_{crit}). Having infinite upper bounds the estimates are currently fairly meaningless, however, with more intensive sampling and the addition of more loci, the LDN_e estimates could offer comparative means to assess the health of local stocks.

For stock assessment modelling purposes, *C. auratus* from the east coast of Australia should be separated into two biological stocks. Queensland and most of New South Wales down to around Eden should be combined and assessed as the east coast biological stock. Currently 85% of the New South Wales catch is taken from waters north of Sydney (New South Wales Department of Primary Industries, unpublished data). On average, 50% of the fish caught off Eden were from the east coast biological stock. Snapper caught south of Eden should be included in an assessment of the eastern Victorian biological stock.

HARMONISED DATA AND HISTORICAL INFORMATION

Harmonised data

<u>What did the harvest data show?</u>

There was an increase in commercial trap harvests from 1950 to 1990. In the 1970s the commercial harvest of the eastern stock reached over 900 tonnes per year, before declining to around 350 tonnes per year in the years 2014 to 2016, Figure 3.2 in Wortmann *et al.* (2018). Charter fishing total harvest peaked at 88 tonnes in 2001 before decreasing to 30 tonnes in 2016 across both states, Figure 3.2 in Wortmann *et al.* (2018). Queensland recreational surveys estimated total recreational harvest in Queensland decreased from 552 tonnes in the 2005 survey to 82 tonnes in the 2013 survey, Figure 3.3 in Wortmann *et al.* (2018). New South Wales recreational surveys in 2010 and 2013 estimated total recreational harvest to be 188 and 148 tonnes respectively, Figure 3.3 in Wortmann *et al.* (2018). The estimated total east coast snapper harvest since the late 1980s reduced from 1400 tonnes to 700–800 tonnes per year from 2014 to 2016, Figure 3.

There was considerable uncertainty in the catch and effort estimates for the recreational sector. This was a concern for the snapper model because over 50 per cent of the harvest was believed to be taken by recreational fishers.

<u>What did the catch rate standardisations show?</u>

Standardised mean catch rates of snapper from trap and line fishing declined to historic low levels in 2002, after which the trap sector showed a recovery while the line sectors generally did not, Figure 3.9 in Wortmann *et al.* (2018). The different signals in the New South Wales trap catch rates and the line catch rates suggested that localised depletion is likely to have occurred in some regions. The Queensland recreational fishing sector showed declining catch rates over the period 1994 to 2013 when estimates were derived from boat ramp and phone/diary surveys, Figure 5.19 and Figure 5.20 in Wortmann *et al.* (2018).

The sampling program of young snapper from the Moreton Bay area showed an increase in abundance from 2006 to 2012, followed by a decline from 2012 to 2015 to reach the lowest density recorded since the start of the survey, Figure 3.11 in Wortmann *et al.* (2018) (there was no survey done in 2016). Abundance trends derived from this data set may not have been a true representation of the overall stock recruitment dynamics for the overall stock as there are other sheltered estuarine recruitment grounds along New South Wales and Queensland different in structure to the Moreton Bay nursery grounds, and the extent to which these recruitment areas contribute to the stock remains poorly understood.

Historic mean catch rates mainly derived from historical sources on charter fishing trips in New South Wales and Queensland were important because they established that catch rates had fallen by roughly 50 per cent by the 1950's, Figure 3.10 in (Wortmann *et al.*, 2018).

What did the age and length data show?

For the trap sector for the years 1993–2006 most fish were two or three years of age. From 2008 onwards the proportion of fish in age groups 4–10 increased, suggesting an increase in the proportion of larger and older fish in recent years, Figure 3.12 in Wortmann *et al.* (2018). The trap fishery traditionally featured a high proportion of smaller size classes, suggesting selectivity against larger/older fish. This size selectivity is a feature of the trap fishery.

The Queensland age structures did not show any increase in the proportion of older fish in the later years that the trap fishery showed. However, the Queensland snapper age structures showed a higher proportion of older fish than the New South Wales age structures. For both the commercial and recreational sectors in Queensland, most fish were three to five years of age for years from 2007–2015, with no evidence of strong year classes, Figure 3.13 and Figure 3.14 in Wortmann *et al.* (2018). The lack of strong year classes was also a feature of the New South Wales age data. The lack of strong year classes differs from the snapper fisheries in other more temperate latitudes (New Zealand, South Australia and Victoria) where years of successful recruitment are seen as strong year classes progressing through the fishery.

Historical Information

Shifting baselines

Significant changes have occurred over the last two centuries in coastal marine ecosystems across the world as a result of land-use change, coastal development, and the intensification of fishing, among other activities (Lotze *et al.*, 2006). Yet formal monitoring records rarely extend beyond the last few decades, and in many cases only commenced after significant ecological changes had already occurred, leaving us with limited understanding of the magnitude of changes that have taken place.

This lack of information on past conditions results in a phenomenon called the 'shifting baseline syndrome' (Pauly, 1995), where we fail to appreciate the environmental changes that occurred prior to our lifetimes. With each subsequent generation a shift occurs in what we perceive to be a 'natural' environment, meaning we become more likely to overlook the true magnitude of change that humans have exerted on ecosystems. One way we can improve our understanding of past changes is to examine historical sources for clues as to what our marine ecosystems looked like prior to the commencement of formal data collection (Saenz-Arroyo *et al.*, 2005).

Reconstruction of historical trends

Archival sources provided quantitative data that were used to reconstruct catch rate trends in the snapper fishery during the late 19th and early 20th centuries, as well as source additional information on fishing behaviours and fishing gears used during this period. Popular media reporting encompasses the period of early exploration of the outside fishing grounds, which only became readily accessible with the introduction of steam power. However, some inshore regions (e.g., Sydney harbour) had already undergone localised declines by the commencement of regular popular media reporting in the 1880s.

The early charter fishery was seasonal, and comprised of a few large charter vessels operating from major population centres, that hosted small (<10 individuals) to large groups (>40 individuals) of fishers for weekend and mid-week trips. Catches of hundreds of fish, the majority of which were often snapper, were reported to occur frequently during the fishing season, and large catches appeared – in many cases – to be expected by the fishers on board. While large catches were common, due to variation in numbers of fishers on board and individual skill, catch rates per fisher were highly variable, although vessels were rarely reported as returning with no fish during this early period.

While large catches and high catch rates occurred throughout the time series, the archival data provide some evidence of declining catch rates over the period of data collection, and particularly in the post-World War period (although concerns about near-shore declines surfaced in reports from the late 19th century). These declines occurred despite vessels finding new grounds and reported improvements in boat and line technology, which we were unable to account for quantitatively during this early period. As a result, declines in catch rate may be underestimated in this historical time series.

Fisher knowledge was used to examine the timing and rate of adoption of fishing technologies, and to understand how these technological innovations impacted fishing ability and catch. Records of improvements to fishing lines and a shift from steam to motor boats were recorded in the early archival literature, but during the mid- and late 20th century, new fishing technologies were introduced and these continue to be adopted and refined. What was clear from most interviews was the view that technologies had dramatically increased the ability of fishers (and line fishers in particular) to locate and catch fish. There were still some people who had changed their activities little over the years but this was only a small proportion of the people interviewed. The majority of fishers adopted technologies once they became affordable.

The adoption of technologies such as depth sounders and GPS had a much higher and quicker uptake amongst commercial fishers than recreational fishers. While there was considerable expense associated with these technologies in the early phases of their market release there was clearly economic benefit to commercial fishers, in particular, in adopting such technology early. As technologies became more affordable they were adopted by recreational fishers. Ultimately all sectors accessed improved technologies within a few years of each other. These advances in technology have continued in recent years, with increases in the uptake of new line, fish finding and bait/lure technologies as well of ongoing improvement in existing technologies.

Considerations for data interpretation and stock assessment

Both the archival and fisher knowledge datasets will contain various sources of bias which are important to acknowledge. Sourcing of archival data prior to 1955 was facilitated by digitised databases that are freely available online. After this period, copyright legislation means the majority of newspaper issues are only available to be searched in hard copy. The large volume of newspaper resources and the low frequency of newspaper articles reporting on fishing, coupled with the sporadic reporting of dedicated snapper fishing trips, makes locating catch reporting data increasingly difficult after 1955. Additional to this was a real reduction in the reporting of snapper trips after the Second World War, as motor boats became increasingly affordable and "successful" recreational fishing trips became less 'newsworthy'. Hence the proportion of snapper trips reported on in newspapers, relative to the total number of trips taking place, declined over the time series. While we see little reason for this to have markedly impacted the observed trend in individual catch rates, it does have implications for which parts of the time series can be used to estimate broad fishing trends (e.g. trends in total catch, fishing effort). As highlighted in the results, it is unlikely that wider fishery trends can be extracted from the popular media data after the 1910 period.

Reporting bias is also a possibility. The most likely way in which reporting biases will be manifested are through newspapers failing to report on trips that returned with small catches, thus increasing our estimate of mean catch rate during this period. Comparison with a government survey demonstrated that catch rates reported by newspapers (with the exception of the Welsby source) did not differ from government-reported catch rates. However, beyond this one source we are unable to quantify the magnitude of reporting bias. Together with a lack of overlap between the archival data and other fishery data sources, this makes comparing historical catch rates with contemporary time series very difficult. Searches of more recent popular media articles failed to provide catch data. Trips undertaken in more recent years would also be subject to increasingly restrictive in-possession limits that did not exist during the historical time series. As a result, the historical catch rates are not directly compared to other data sources in the stock assessment model, and are instead integrated as a separate catch trend.

The variation in the response of recreational fishers to questions posed in the survey was high, reflecting the wide variation in motivations, fishing practises, fishing abilities and general economic and social demographics. Our sample of recreational fishers was biased towards more experienced anglers (>10 years' experience). To some extent this is a desirable characteristic as these people would be in the best position to comment on the impact of various technological changes having experienced a wider range of those changes. Offshore fishers also tend to be older and more experienced than estuarine fishers because the vessels normally required to fish these areas are much larger and more expensive than inshore vessels. From an economic perspective, younger people are less often in a financial position to afford such vessels and are thus underrepresented in any long-term sampling program. Nonetheless it is important to stress that the sampled fishers were not necessarily representative of the entire sampling frame of offshore anglers.

The fact that many fishers attributed such a high level of impact of fishing technologies on their fishing power compared with fishing gear has important implications for catch standardisations used in stock assessments. Catch rate trends that do not account for the impact of these technologies will present overly optimistic views of stock status. Alternatively, if the abundance of fish has decreased, fishers may underestimate the effect that fishing technology has had on improving their catches over time, as improvements in technology may have masked the increasing difficulty of catching fish, rather than visibly improving catches. The introduction of new fishing technologies may also alter catch rates but only in certain conditions. For example, a number of fishers commented that braid was more effective at catching snapper in deep water compared to monofilament, but provided no clear advantage over monofilament in shallow water (although not all fishers agreed on this point, reflecting differing fishing conditions and individual preferences). This makes accurate comparisons over time more difficult as new technologies influence fishing and targeting behaviour as well as catch. Another potential issue is how to reflect the combined impact of multiple technologies. A number of fishers in our sample found it difficult to quantify the impacts of individual technologies as either several technologies (e.g. electronic echo sounders and GPS) became available in quick succession, they've always fished using certain technologies, or subsequent models of the same basic technology have gradually improved over time, making changes difficult to estimate. In our stock assessment model the overall effect of the technologies is additive and so the model may overestimate the overall effect. To balance this not all technologies and gears have been included. These include 4 stroke engines, electric reels and spot-lock.

BIOMASS FORECAST MODELLING

Forecasting models for the east-coast snapper population that inform on inter-jurisdictional management strategies were developed. An integrated modelling framework both for the estimation of historical stock status and for the simulation of future status under management regimes was used (Richards *et al.*, 1998). For the purposes of this work the projection period extended 40 years after 2016. To deal with uncertainty in estimates, simulations were conducted 1,000 times using an ensemble of parameterisations of the fishery data. Thus by considering a range of uncertainties, the results provided information to compare alternative management arrangements and predictions of their likely success.

The results showed that changes in size limits alone would not promote larger stock sizes at current levels of fishing, leaving direct regulation of harvest or fishing effort as the most viable management option. The sustainable scenario predicted that rebuilding to levels of $0.6B_0$ (The Queensland target Reference Point under the current Sustainable Fisheries strategy) in 10 years was only possible with a 400–600 tonne fishery-wide quota. A risk analysis for this scenario suggested that the probability of being below target in 10 years' time was around 20% for 400 tonne quota and 40% for 600 tonne quota. In contrast, if the limit reference point scenario is true, then the same 400 tonne quota would not meet the target by 10 years, and would have a 4% risk of not meeting the target by 20 years. The overfished scenario, (the most pessimistic scenario), only had a 2% probability of getting to levels of $0.6B_0$ after 20 years under the 400 tonne quota and an 86% probability of reaching the target after 30 years.

The forward projections in the snapper stock assessment of Campbell *et al.* (2009) which were based on Queensland data only, also indicated that changes in size limits alone did not promote rebuilding and that fishing effort or harvest needed to be reduced significantly to reach exploitable biomass targets of 0.4. Similarly, the snapper model of Allen *et al.* (2006), based only on Queensland data, predicted that increases in minimum legal size alone would increase biomass only slightly.

The forward projections of the current project showed that under the current management regime with current fishing effort, after 10 years, the sustainable scenario would continue to be sustainable and the limit reference point scenario would increase to just below $0.3S_0$. For these scenarios snapper abundance followed the New South Wales commercial trap catch rate trends.

Under the current management regime with current fishing effort, the overfished scenario would remain overfished with levels below $0.2S_0$. This scenario corresponded to the simulation when line catch rates (New South Wales commercial line, Queensland commercial line and Queensland AMLI charter line), were used as the index of abundance. Thus if it is assumed that snapper abundance followed the trends predicted by Queensland commercial line catch rates, then the stock will remain below 0.2 S_0 under current management measures. A 400 tonne harvest quota across all waters and sectors would be needed to rebuild stock to $0.4S_0$ and this would take 20 years. This was half of the current estimated harvests across all waters and fishing sectors.

All three scenarios modelled (sustainable, limit reference point and overfished scenarios), were selected for the forward projections in order to provide contrasting perspectives and to indicate to what extent future projections would vary based on a given alternative starting point of snapper stock health. The scenarios represented three groupings of spawning biomass of 72 analyses of snapper data in the model, Section 5.9 in Wortmann *et al.* (2018). Thus forward projections for the additional scenarios would fall within the range of the current projections.

The current project focussed on snapper management across New South Wales and Queensland. Victoria was not included in the model because the majority of the Victorian catch was from different snapper stocks and there was a lack of data for eastern Victoria, (total harvest by financial year, two recreational harvest estimates, and number of licences was the only available data from Victoria). As Victorian catch and effort data becomes available, the eastern Victorian biological stock could be added as a separate genetic stock to the snapper simulation model. This would enable a consistent assessment of the east coast snapper population and assist in determining the status of the east coast stock(s) (New South Wales, Queensland and eastern Victoria/Tasmania) which in 2016 was undefined in the SAFS report (Fowler *et al.*, 2016).

The forward projection methodology developed in this project could be used to develop a management strategy evaluation model (MSE). MSE is a modelling-based approach that allows comparisons of the robustness of alternative management arrangements in meeting objectives under various biological and assessment uncertainties. MSE can be used to examine which sets of decision rules used to recommend TACs or effort, perform the best in achieving the management objectives for the stock. The introduction of a spatial component to the MSE would enable management to be simulated by management areas rather than across the whole east coast. For example, areas may be defined according to the health of the snapper stock and the amount of fishing effort, as is the case for the snapper fishery in New Zealand. The New Zealand fishery is divided into six fishery management areas and catch allowances are set differently for each area and fishing sector depending on the health of the fish population and regional fishing pressure (https://www.mpi.govt.nz/travel-and-recreation/fishing/fish-species/snapper/).

There is enough evidence to suggest recruitment processes, fishing mortality and general stock dynamics of snapper may be operating differently at scales significantly smaller than a broad genetic stock level. Localised depletion of snapper has been recognised as an issue in earlier reports (Sumpton *et al.*, 2006) and by stakeholders as part of earlier discussions on rocky reef fisheries (QFMA, 1998). The spatial reporting of New South Wales commercial data has been by 60 nautical mile grids and with information generally summarised into 10 fishing zones. The Queensland CFISH program records commercial logbook data by 30 nautical mile grids. Thus the commercial catch and effort data is available spatially. The recreational harvest was about 50% of the total harvest. It is clearly important to get more detailed recreational spatial catch and effort data to understand the spatial extent of the snapper fishery and for use in spatial assessments.

A major difficulty in forecasting fisheries is the knowledge of future conditions. It was implicitly assumed that the future growth, natural mortality and recruitment was consistent with the past. Furthermore, only constant catch policies were examined. Potential rebuilding policies, with varying harvest levels depending on the health of the snapper stock could be implemented in an MSE model in the future. More realistic projections would have adaptive control policies based on the health of the snapper population. Robustness of management strategies to biological uncertainty such as recruitment could also be tested in an MSE framework. The forecast simulation framework developed in this project has provided a foundation tool upon which an integrated modelling environment can be developed with a full MSE across New South Wales and Queensland with a spatial age-structured population model that enables the projection of numerous management arrangements. We also suggest the future development of visualization tools for clearly portraying these results and risks to fisheries managers and stakeholders.

STAKEHOLDER ENGAGEMENT AND DECISION MAKING

During the consultative process after the release of the previous Queensland snapper stock assessment (Campbell *et al.*, 2009), many fishers, particularly from the recreational sector, were critical of some of the data and models used in determining the status of the snapper stock which was considered to be overfished and requiring rebuilding (Campbell et al., 2009). None of the proposed management options were deemed acceptable to many recreational anglers in Queensland.

Subsequently, the only permanent changes made to the management arrangements for snapper in Queensland were a reduction in the recreational in-possession limit from five to four, with one-only snapper larger than 70 cm TL allowed. These changes were similar to those proposed by the peak recreational fishing representative body, Sunfish Queensland, who called for no reductions to in-possession limits and allowing only two fish above 70 cm TL. The structural adjustment process of New South Wales commercial fisheries in 2017 was a significant reform for the commercial sector but there have been no other significant management changes affecting snapper in New South Wales since the increase in size limit in July 2001.

This project involved stakeholders from all jurisdictions providing input into the stock assessment of the east coast snapper stock. The input of stakeholders in discussions about datasets was particularly important where disparate data sources had to be harmonised and decisions made about how these data were to be used and interpreted.

The project Steering Committee was convened to not only provide direction for, and advice to, stock assessment scientists and to assist in making decisions about use of data, but also to help with disseminating information and results from the stock assessment process. The Steering Committee was comprised of commercial fishers, recreational fishers, scientists and fishery managers from the three jurisdictions involved. The individual commercial and recreational fishers were appointed to the committee as they had access to a broad network of industry contacts. These appointees were asked to act as intermediaries between the stock assessment scientists and the stakeholders they represented in a two-way process: 1) disseminating results to stakeholders while 2) collating comments from those they represented for discussion at Steering Committee meetings.

The Steering Committee members were:

Queensland	Wayne Sumpton (Fisheries Biologist, DAF) Michael O'Neill (Stock Assessment Scientist, DAF)

	George Leigh (Stock Assessment Scientist, DAF)
	Joanne Wortmann (Stock Assessment Scientist, DAF)
	Jess Morgan (Geneticist, DAF)
	John Kung (Principal Policy Officer, DAF)
	Steve Campbell (Commercial line fisher)
	Dave Bateman (Sunfish, recreational fisher)
	Matthew Campbell (Fisheries Biologist, DAF)
New South Wales	John Stewart (Fisheries Scientist, DPI)
	Doug Ferrell (Fishery Manager, DPI)
	Paul Sullivan (Commercial trap fisherman)
	David Rae (Recreational fisher)
Victoria	Paul Hamer (Fisheries Scientist, VFA)
	Dallas D'Silva (Manager Policy and Licensing, VFA)
	Ross Winstanley (Recreational fisher)

A Communication and Engagement Strategy was developed by project staff, in collaboration with the DAF communications group, and this was endorsed by the project steering committee members in early 2017. As the lead agency for the research project, DAF led the communication and engagement planning, working with other jurisdictions as required. Each jurisdiction was responsible for engaging with stakeholders located in their own jurisdictions and ensuring their respective communication and engagement policies were followed. The objectives of the Communication and Engagement Strategy (Appendix 5) were to:

- Raise awareness of the project and the importance of harmonising data sets, information collection tools, and how it benefits fishers.
- Provide scientists and managers with a harmonised database of all relevant information, to facilitate feedback by all fishery stakeholders. Data from all relevant jurisdictions were included in the database.
- Raise awareness amongst scientists and managers of modelling tools that can be used to inform on the utility of various data sets and cross-jurisdictional management strategies.
- Encourage stakeholders to provide feedback on these data modelling tools.
- Provide scientists, managers and fishery stakeholders with updated information on the stock structure of east coast snapper.

The target audience for the Communications and Extension Strategy were members of the following groups from Queensland, New South Wales and Victoria: recreational, commercial and charter fishers, fishery managers, fisheries scientists, conservation groups, fishing industry stakeholder groups, Australian Government agencies involved in managing inter-jurisdictional, multi-sector fisheries, and other interested stakeholders.

The inclusion of representatives from the three state jurisdictions helped the stock assessment process to inform on data and stock assessment outcomes, extension of results and the dissemination of information required a targeted and collaborative strategy. Input was, therefore, required from the three jurisdictions and decisions made about how data from each of the jurisdictions was harmonised and used in the assessment models.

Several tools were employed to address the objectives of the Communications and Engagement Strategy and to provide guidance in decision making about data used in the assessment model.

1. Steering committee

The Steering Committee was seen as the primary method of information exchange between stakeholders and project staff. These meetings allowed for two-way information exchange and detailed discussion of points of interest. Stakeholder representatives were appointed to the Committee after an

Expression of Interest process with applications assessed by Alex Campbell (DAF: original PI), Doug Ferrell (NSW DPI Manager) and Crispian Ashby (FRDC). The successful applicants were Ross Winstanley (Victorian recreational fisher), Dallas D'Silva (General Manager, VRFish), Steve Campbell (Qld line fisher) and Paul Sullivan (NSW trap fisher). Subsequent to this process, David Bateman (Sunfish Qld) and David Rae (Recreational fishing journalist, NSW) were further added.

Three separate Steering Committee meetings were held during the project (see Appendix 6 – Appendix 11 for Meeting Notes). The role and responsibilities of the Steering Committee were to:

- Contribute knowledge of, and experience in, the snapper fishery to committee deliberations;
- Contribute to the development and implementation of strategies to gather information from, and deliver information to, the wider fishing community and public; and
- Consult closely with stakeholder peers through port-level associations, regional associations, peak industry bodies and other avenues as necessary.

The first Steering Committee meeting was held on 25 November 2016 in Brisbane (Appendix 6 - Appendix 8). An important first task of the Steering committee was to assess the genetic stock of east coast snapper and to agree on the extent of the stock boundaries and how this should be handled in the assessment model. The results from the genetics analysis of the east coast stock revealed that the east coast stock extends from north Queensland to southern New South Wales. A mixing area, where both east coast and southern snapper stocks mix, was detected around Eden near the Victoria/New South Wales border. The genetic analyses showed that the stock on the east coast of Victoria was more likely related to the southern stock which extends down to Tasmania and west to Wilsons Promontory. This was an important early finding of the project as it affected the scope of the modelling and the datasets that were to be used, effectively excluding the Victorian snapper fishery from the current stock assessment. Despite this, Mr. Winstanley and Dr. Hamer continued to contribute positively to the project.

Specific items discussed at the first Steering Committee meeting included: the role of the steering committee, fishery description and management in each jurisdiction, genetic stock structure of east coast snapper, data available to be used in modelling, use of historical fisheries data, developing a "harmonised" database (principles and progress), stock model framework for simulating inter-jurisdictional management, current policies and strategies for stakeholder engagement in each jurisdiction, and stakeholder feedback mechanisms and decision making processes (see Appendix 6 for meeting notes).

The second Steering Committee meeting was held on 14 July 2017 in Sydney (see Appendix 9 - Appendix 10 for meeting notes). This meeting was convened primarily for discussion about the data used in the stock assessment and the Communications and Engagement Strategy. The main topics of discussion were snapper data, communication and engagement channels used by stakeholder groups, workshopping key messages and content of project updates (e.g. snapper genetics, fishing technology, historical fishing), data knowledge gaps, developing an online survey tool to gather stakeholder feedback and clarifying unresolved issues from a workshop held on the previous day. The workshop had a wider membership and also considered the harmonised data, discussed the stock assessment and made decisions on hypothetical cross jurisdictional management scenarios to explore in forward projections of stock biomass (see Appendix 12 for workshop notes).

The third, and final, Steering Committee meeting was held in Brisbane on 1 March 2018 (see Appendix 11). The objective of this meeting was primarily to report the final results of the stock assessment, discuss model uncertainty and report on the effect of hypothetical cross jurisdictional management strategies on projected stock biomass into the future (see Appendix 11 for meeting notes). Specifically, topics covered were: recap of data used in the assessment model, description and features of stock model, model outputs, model uncertainty, forecasting stock biomass, defining snapper stock

status for Status of Australian Fish Stocks (SAFS) reporting, and decision-making processes in cross-jurisdictional fisheries.
Throughout the project the Steering Committee provided positive input into the stock assessment process and was influential in making decision about how data was to be used in models. For example, a second level of post-release survival (70%) due to predation by sharks and a higher level of natural mortality (M) resulting from an increase in predation by sharks was used in some modelling scenarios.

2. Assessment Project Team

This team comprised a wider group of scientists as well as managers from Queensland and New South Wales. This group met formally six times during the project to discuss harmonization of the data sources and deal with various detailed scientific issues as they arose.

3. Website

A project website was developed on the Fisheries Research and Development Corporation Website with aims of providing a central point from which stakeholders and the wider community could access information[1]. The project website provided a repository of available information such as datasets, fishing power, historical catch and stock structure. All of the content on the website was discussed at Steering Committee meetings and approved by members. However, traffic on the website was limited (Figure 17), with only 216 views from 143 individuals.

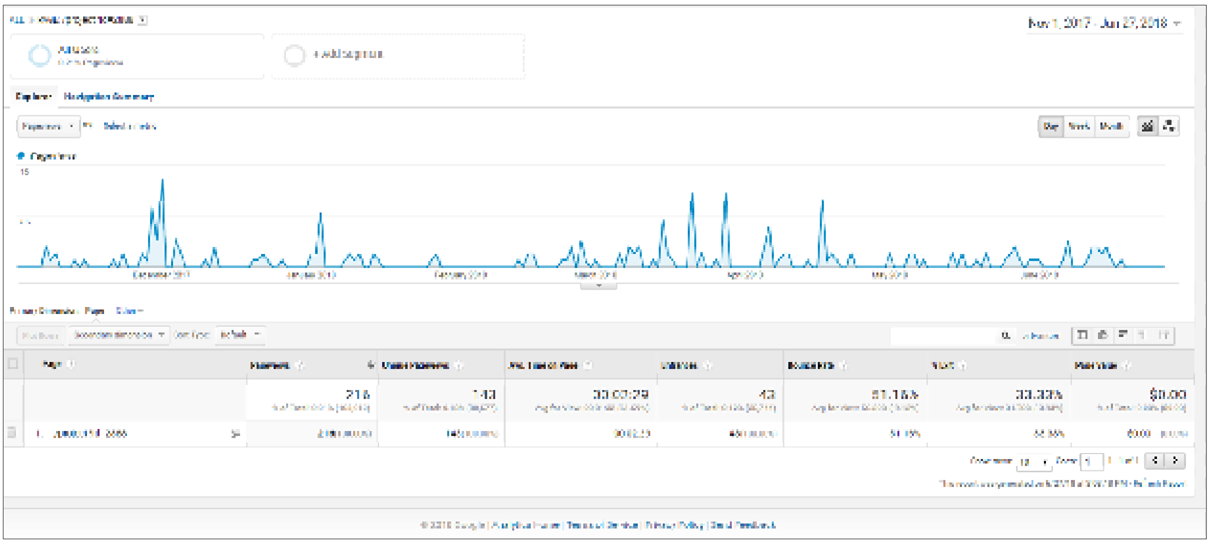

Figure 17. Page statistics for the project web page (http://www.frdc.com.au/project?id=2888) on the FRDC website for the period 1 January 2018 to 27 June 2018. One hundred and forty-three individual users accessed the site during this time.

Throughout the later part of 2017, the on-going upgrade of the FRDC website restricted the ability to provide web updates and include material on the website. This, combined with the fact that the Queensland Government called an election in late 2017 resulting in an extended period of caretaker mode, caused significant delays in meeting the deadlines outlined in the Communications and Engagement Strategy (Table 24 in Appendix 5).

4. Data and Assessment Workshop

Prior to the second Steering Committee meeting, a workshop was convened with a wider membership than the steering committee where the stock assessment was discussed and hypothetical cross-

[1] http://www.frdc.com.au/project?id=2888

jurisdictional management scenarios were collaboratively determined for further modelling (Appendix 12).

Specifically, topics covered included: implications of genetics work and stock structure, historic data of snapper fishery in Queensland and New South Wales, harmonised data used in stock model, description and features of stock model, and modelling hypothetical changes in management.

Along with the input of the steering committee this workshop was an important "tool" used to make decisions about data used in the assessment model as well as deriving hypothetical cross jurisdictional management scenarios for further modelling.

An important outcome from the workshop was agreed hypothetical cross jurisdictional management scenarios where the response of the east coast snapper stock could be modelled into the future: These scenarios included varying the size limits as well as levels of harvest as shown below:-

- Various minimum legal size scenarios (30 cm and 35 cm for New South Wales and Queensland); and
- Two levels of harvest, 400 tonnes and 600 toones, along with current level (~800 tonnes).

Notes taken from the meeting can be found in Appendix 11.

5. Social media

Social media has become a common method of communicating information to stakeholders. Project staff collaborated with Fisheries Queensland communication staff to produce a Facebook post which contained links to the project site on the FRDC website (https://www.facebook.com/FisheriesQueensland/photos/a.219577731387938.65083.141031799242532/1811932925485736/?type=3&theater). In the past, social media sites such as Ausfish (http://www.ausfish.com.au/) were an avenue for information dissemination: however, many recreational fishers now use Facebook and subscribe to groups such as Queensland Snapper Fishing[2], SEQ Fishing Reports[3], Australian Snapper Fishing[4] and Fishing Southeast Queensland[5].

The Fisheries Queensland Facebook page has 36,975 followers and, as such, this was seen as the most effective method with which to reach a wide audience. The post received 25 likes and four shares.

6. Fishing World article

After the first Steering Committee meeting in Brisbane, which showed that the Victorian fishery was a separate stock to the remainder of the east coast, Mr Dallas D'Silva opted to only participate in the Steering Committee process through email-only and didn't attend any further meetings. Project staff then recruited Dave Rae, a fishing journalist based on the north coast of New South Wales, who writes for the national recreational fishing magazine, Fishing World, to participate in subsequent Steering Committee meetings. At the second Steering Committee meeting, it was agreed that the historical catch rate information (which was an important data input in the assessment model) should be the basis of a Fishing World article. The article appeared in the July 2018 edition Fishing World and is reproduced in Appendix 13 with permission (Scott Thomas, editor of Fishing World, pers. comm, 18 June 2018).

7. Online survey

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[2] https://www.facebook.com/groups/683575158375968/
[3] https://www.facebook.com/SEQ-Fishing-Reports-452464478130351/
[4] https://www.facebook.com/AustralianSnapperFishing/
[5] https://www.facebook.com/fishingseqld/

The steering committee also developed an online survey tool (Appendix 14) for gathering public feedback but this was not progressed due to the intervention of the Queensland state election (at a critical time at the end of 2017) and progress in management reforms as part of the Queensland Sustainable Fisheries Strategy. This tool may prove important in any future engagement strategy planned as part of reforms in the rocky reef fishery when the Queensland snapper working group considers harvest strategies for this fishery. However it will be up to the Working Group to suggest appropriate strategies which will be considered by Fisheries Queensland.

8. Recreational fishers workshop

Early on, the current project attempted to engage recreational fishers, about datasets available for use in the current snapper stock assessment, how the datasets were used and their limitations (Appendix 15). To this end, project staff organized a workshop with aims of presenting data and gaining feedback on how each dataset was perceived by workshop participants. The workshop was also designed to seek alternate datasets that recreational fishing groups maintain for their own record-keeping which may have benefitted the stock assessment. A total of 29 key recreational fishers, journalists and recreational fishing representatives were invited to the workshop scheduled for 15 October 2016 (Appendix 15). Unfortunately, only six invitees confirmed attendance and, as such, the workshop was cancelled.

Subsequent to the cancellation of the workshop, Stefan Sawynok from InfoFish Services asked that the data used in the stock assessment be presented to a group of keen snapper fishers that also tag fish as part of the Suntag program. Twelve fishers attended a presentation held at the EcoSciences Precinct on 17 November 2016.

Decision making processes around data to use in assessments and how these data are to be used in the assessments is often left to scientists.

The Communication and Engagement Strategy was designed to disseminate information to stakeholders, particularly recreational fishers, regarding the data used in the stock assessment. Media releases, updates on the FRDC website, Steering Committee meetings and the stakeholder workshop on cross-jurisdictional stock assessment and management, social media, Fishing World article, scientific publications and the recreational fishing data workshop were the main communication channels used. Two metrics are available to assess public interest in the project. The FRDC website and the Facebook post have a quantifiable measures of the number of individuals that were engaged by the project. Quantifying the effectiveness of the other methods is far less straightforward.

The FRDC web page had very little traffic (Figure 17). Steering Committee members were alerted to the presence of the revamped FRDC site on 17 April 2018, which resulted in an increase in interest. After this date, however, traffic decreased. During the project, the FRDC were renovating their website which caused delays in posting relevant information. One hundred and forty-three individual visits to the page was a disappointing result. It is also not possible to determine the number of times that an information document was downloaded from the site. The website was designed to be a repository of information used in the stock assessment and project staff originally intended posting all datasets on the website. However, this proved difficult, logistically, and concerns were raised regarding the privacy of the commercial catch data supplied.

The process of publishing information on the FRDC website was complicated. Initial drafts were considered by Steering Committee members before being sent through the Agri-Science Queensland (DAF) approval process. The finalized document was then sent to DAF Communications and Fisheries Queensland resource managers for editing, after which the Steering Committee members were given final approval. This process, combined with the FRDC website upgrades, slowed the posting of relevant information which required postponement of Communication and Engagement Strategy milestones.

The Facebook post generated little interest in the project. Despite the Fisheries Queensland Facebook page having in excess of 37,000 followers, the post only received 25 "likes". Additionally, the link to the project site on the FRDC website only received 5 "clicks".

The recreational fishing social media website Ausfish (www.ausfish.com.au) was an avenue of engagement with recreational fishers prior to the 2009 snapper stock assessment. One of the members of that earlier Snapper Working Group was a high-profile member of the Ausfish site and made regular reports regarding the progress of the assessment. After the RIS was released, however, discussions around snapper management were argumentative and subsequent attempts to engage with Ausfish members failed.

The article in Fishing World magazine was published in the July 2018 edition. Fishing World magazine has a readership of 148,000 as of March 2018[6]: However, it is difficult to quantify the effect of the article in relation to the communication and engagement. The article was available in late June 2018 and there has been some recent activity on the website (Figure 17), which suggests the article may have motivated recreational fishers to access the website.

Although the recreational fishing workshop was seen as an efficient method of interacting with stakeholders, the lack of interest was disappointing. It was not, however, unexpected: generally, interactions between stock assessment scientists and stakeholders are restricted to Steering Committees or project teams until the stock assessment is completed. There is often little interest in scientific data until it is incorporated into products such as stock assessments that use a range of different data types. Engagement with stakeholders usually increases after the reports are released, particularly if the stock assessment indicates a stock in decline requiring some type of management intervention. During the previous stock assessment (Campbell *et al.*, 2009) the Snapper Working Group was productive and members contributed significantly to stock assessment outcomes. The engagement process broke down after the proposed management arrangements were communicated as part of a Regulatory Impact Statement (RIS). Recreational fishers and charter operators were particularly adamant that the measures outlined in the RIS were unnecessary which generated animosity between these stakeholders and DAF. The lack of trust that resulted from the 2009 snapper stock assessment process has persisted through to the present time.

Stakeholder engagement in Queensland has become generally difficult in recent years. The last snapper stock assessment was widely criticised and, consequently, recreational fishers and charter operators have expressed concern in relation to snapper management in Queensland. For example, prior to the RIS, charter operators were supplying Fisheries Queensland with biological samples as part of the Assessment and Monitoring Unit's Long-term Monitoring Program of the rocky reef fishery: however, after the RIS, the charter operators ceased their involvement in the program. Further, the introduction of three net-free areas in November 2015, the closure of the scallop fishery in central Queensland in 2017 and an imminent requirement for a compulsory commercial vessel monitoring system (VMS) has seen many commercial fishers disengage with the management and monitoring process. Similarly, the Commercial Fisheries Business Adjustment Program undertaken in New South Wales, which was opposed by the Professional Fisherman's Association and the Wild Caught Fishers Coalition, has led to angst among commercial fishers and a reluctance to assist in fisheries management (Paul Sullivan, pers. comm). These issues have resulted in difficulties in engaging with industry representatives in both Queensland and New South Wales.

Stock assessments include complicated mathematical models that have increased in complexity in the last two decades. For some stakeholders, stock assessments are seen as a "black box" where data are "manipulated" to satisfy a desired, predetermined outcome or that stock assessment scientists are influenced by a political ideology: a populist but unfounded and ill-informed assertion perpetuated by some stakeholders. This was certainly the case for the Campbell *et al.* (2009) snapper stock

[6] http://www.roymorgan.com/industries/media/readership/magazine-readership

assessment, which received considerable criticism despite two independent reviewers broadly agreeing with the methods and outcomes of the assessment (Chambers and Larcombe, 2010; Francis, 2009).

Like many mathematical models, stock assessment models incorporate intrinsic uncertainty. For the layperson, "uncertainty" can have a range of meanings and some stakeholders may reject stock assessment outcomes due to the perception of unacceptable levels of imprecision around model outputs (Budescu *et al.*, 2009; Diethelm and McKee, 2009). Further, a layperson may interpret terms commonly used in stock assessments such as "error", "bias" and "adjusted" as evidence that scientists are manipulating data to suit a pre-determined agenda or other biases. This attitude is a significant impediment to meaningful engagement between stock assessment scientists and stakeholders.

Along with the inherent suspicion of stock assessments, some stakeholders are distrustful of science produced by government departments. Martin *et al.* (2016) reported that recreational groups (including fishers and divers) were more likely to engage and share observations with research organizations independent of government such as universities. Again, this makes engaging with recreational fishers difficult for government researchers and assessment scientists.

The establishment of an Expert Panel[7] and several working groups in Queensland in mid-2017 as part of the Queensland Sustainable Fisheries Strategy was designed to counter these concerns among stakeholders. These bodies were convened principally for: (1) the provision of independent expert advice to the Minister responsible for fisheries and Fisheries Queensland on best practice fisheries management, (2) to improve stakeholder engagement, and (3) support evidence–based fisheries management. It is hoped that these bodies will facilitate the two-way information flow between stakeholders and Fisheries Queensland that is necessary to ensure management changes that occur as a result of future stock assessments are not only acceptable to stakeholders but are endorsed by them.

Ironically, the recent changes in the engagement process in Queensland has also led to difficulties in interacting with stakeholders during the current project. The introduction of fishery working groups has necessitated increased interactions with stakeholders in Queensland which has led to "management fatigue". This management fatigue has taken the form of an unwillingness to interact with DAF among some stakeholder groups (David Bateman, Sunfish Queensland, pers. comm). The working groups are comprised of a range of stakeholders: commercial and recreational fishers, charter operators, seafood marketers, processors and conservationists. Presently, Fisheries Queensland have formed the Rocky Reef Working Group which will, initially, be advising on a harvest strategy for snapper. The results from the current project will inform that harvest strategy. The snapper fishery represents an interesting case study for the Expert Panel and the recently-established engagement process. This project has shown that management intervention is required in order to restore the stock back to the $B_{0.6}$ levels specified in the Sustainable Fisheries Strategy and that substantial reductions in catch are required.

Previous fisheries engagement has shown that some stakeholders won't accept results if they don't correspond with their own personal experience and the complex nature of stock assessment models is a convenient reason to exploit pre-conceptions. If the outcomes of a stock assessment do not correspond with an individual's personal experience, the results are readily dismissed.

From a more scientific perspective, the results from the genetic analysis completed as part of the project have been accepted for publication in the Journal *Marine and Freshwater Research*. This was a very important outcome of the project as it increases our understanding of the interaction of the snapper populations on the east coast and is vital to management in Queensland, New South Wales, Victoria and Tasmania. A recent publication in *Global Environmental Change* also details the changes in catch and technological innovations in the snapper fishery over the last 140 years (Thurstan *et al.*, 2018).

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[7] https://www.daf.qld.gov.au/business-priorities/fisheries/consultations-and-legislation/sustainable-fisheries-expert-panel

Further planned publications on the impact of technology on fishing power are also important communication outputs, because fishing power increases were shown to be highly influential in catch standardizations and have implications for all line fisheries catch standardizations.

Conclusion

This report presented the results of the first joint fishery modelling of the east coast snapper stock: informing inter-jurisdictional snapper management in eastern Australia. Research involved the collaboration of fisheries scientists, biologists, managers and stakeholders from New South Wales, Queensland, Victoria and the Commonwealth.

Objective 1: Apply the latest cost-effective microsatellite genetic techniques to clarify and refine understanding of snapper stock structure along Australia's east coast.

The latest microsatellite genetic techniques explored the stock structure of snapper along Australia's east coast, showing two separate biological stocks, the east coast biological stock and the eastern Victorian biological stock, which had previously been recognised as a single east coast stock. The east coast biological stock extends from Rockhampton to Eden and the eastern Victorian biological stock extends south from Eden to at least eastern Victoria (Lakes Entrance), including Tasmania. Other studies have suggested that mixing of snapper between populations to the east and west of Wilsons Promontory in Victoria is limited (Coutin *et al.*, 2003; Hamer *et al.*, 2011), but is likely enough to explain the inability of the current study to separate the western Victorian biological stock (i.e. Geelong and Port Phillip Bay) from the eastern Victorian biological stock. The consequence of this finding, in terms of computer modelling and fisheries management along the east coast, is that New South Wales and Queensland fisheries should be assessed together as the east coast biological stock.

Objective 2: Assemble and harmonise all available data sets and information sources, including archival and fisher knowledge data, and develop a mechanism for stakeholder feedback on this resource.

Assembling and harmonising data collected across jurisdictions is complex but if two or more states share a common stock it is preferable to have a unified assessment that recognises stock boundaries rather than jurisdictional boundaries. Harmonisation scripts and data decision rules should be available to all jurisdictions so that data are handled consistently in future assessments. Historical information was important in showing that significant reductions in snapper biomass had likely occurred well before formal data collection processes were established during the mid-20th century. Fishing power effects were shown to dramatically change catch standardisations, significantly reducing standardised catch rate indices over time. The input of steering committee members and stakeholders was invaluable in assessing the utility of particular datasets and which combinations of data to use in model simulations.

Objective 3: Develop computer models for the east-coast snapper population that inform on inter-jurisdictional management strategies.

An age-structured computer model showed that current biomass estimates generally varied below the maximum sustainable harvest reference point of 40% of virgin population size. Although the east coast stock was used as a single management unit in the computer model, there was enough evidence to suggest that this was an oversimplification for east coast snapper where recruitment processes, fishing mortality and general stock dynamics may be operating differently at scales significantly smaller than a broad genetic stock level.

The computer model was influenced by trends in standardised abundance indices, and those currently available were from different fishery sectors in different areas, and showed conflicting trends. These trends better informed stakeholders and managers about their jurisdictional data. These data, that may not have been previously available to management, have the potential to be incorporated into state-based stock assessments and management, thus benefitting all fishery stakeholders.

Forward projections of stock biomass showed that current management and current fishing effort would not rebuild east coast snapper stock to levels of 60% of original unfished biomass as required by the Queensland Sustainable Fisheries Strategy. Results showed that increases in minimum legal size alone did not promote larger stock sizes at current levels of fishing. Direct regulation of harvest or fishing effort was the only viable management option identified that can be expected to rebuild stock biomass.

Objective 4: Develop protocols for inter-jurisdictional decision-making processes and stakeholder engagement

Members of the steering committee contributed positively throughout the project and their involvement improved the assessment, particularly as suggestions about release survival and natural mortality were able to be incorporated as scenarios in stock modelling.

Assembling and harmonising all available east coast snapper data resulted in the improvement of available datasets, the improvement of the interpretation of existing data, and highlighting missing data. Stakeholder perspectives on the data and assessment enhanced the quality of the assessment and should improve future management.

The computer model was used to set catch limits and consequently assess east coast snapper status against the sustainable target and limit reference points of 40, 60 and 20% of unfished biomass. Fisheries Queensland has established a Rocky Reef Fishery Working Group to develop harvest strategies and encourage a greater stakeholder role in providing advice on management options. The computer model from this study will be used to assist the Queensland working group in developing a harvest strategy that ensures the fishery operates according to specific targets and limits.

Status of Australian Fish Stocks

The 2016 Status of key Australian Fish stocks (SAFS) report listed the east coast snapper stock status as undefined because the stock was given a different status in Queensland and New South Wales based on different data, analyses and criteria for defining status. This study was the first joint fishery modelling of the east coast biological stock. Results have placed east coast snapper biomass estimates between 10 and 45% of original or unfished biomass. When trap catch rates were used as the index of abundance, 2016 biomass estimates were between 20 and 45% of original biomass, whereas if line catch rates were used as the index of abundance then 2016 biomass estimates were generally below the reference limit point of 20% of original unfished biomass (between 10 and 23% of unfished biomass).

Relationship with FRDC project 2013-201

The FRDC project 2013-201 - Development of a harvest management, governance and resource sharing framework for a complex multi-sector, multi-jurisdiction fishery: the south-east Australian ‘western’ snapper stock, was led by Paul Hamer of VIC DEPI, who was also a co-investigator of this project. 2013/201 was directly addressing the creation of a full multi-jurisdictional harvest management framework, however, work in that project was delayed due to unforeseen circumstances, thus it was not possible to relate the present study, which focussed on data collection, modelling and stakeholder engagement, to the framework of the Victorian FRDC project.

Implications

Management Arrangements

What we have defined as the eastern Victorian biological stock is still poorly defined and the mixing area of the two eastern stocks is quite extensive as well as dynamic. As more data are gathered for the eastern Victorian biological stock and more is understood about stock boundaries the spatial extent of the data to be included in any east coast assessment may need further revision. This will add further spatial complexity and uncertainty to any assessment.

Current management arrangements are a minimum legal size of 30 and 35 cm total length in New South Wales and Queensland respectively. The New South Wales' recreational bag limit of 10 snapper per person is more than double that existing in Queensland. In Queensland, the vast majority of the catch is line-caught while there is a significant commercial trap fishery in New South Wales.

If these management arrangements remain, and harvest rates of between 9.5 and 20% persist, (i.e. between 9.5 and 20% of exploitable biomass is harvested), then stocks will not rebuild and Queensland biomass targets of 60% will not be achieved. Fishing effort would need to be reduced further in order to build snapper stock levels.

Models showed that increasing minimum legal size while keeping the current level of fishing effort of between 9.5 and 20% did not promote larger stock sizes at current levels of fishing. (Note current levels of fishing were an annual harvest of around 800 tonnes across all waters and sectors).

Significant stock rebuilding was only possible by reducing harvest across all sectors and jurisdictions. If stock levels were currently around 40% of unfished biomass then rebuilding to levels of 60% in 10 years was possible with a 400 tonne fishery-wide quota. If stock levels were currently at the limit reference point of 20% of original biomass, then the same 400 tonne quota would meet the 60% target in 20 years. If current snapper levels were overfished (the most pessimistic scenario), then the same 400 tonne quota would meet the 60% target after 30 years.

Status of Australian Fish Stocks

Despite the model encompassing both New South Wales and Queensland snapper stocks, and producing 2016 biomass estimates of between 10–45% for the east coast snapper stock, the 2018 SAFS framework is currently being completed at the state level, with the Queensland stock being defined as depleted and the New South Wales stock being defined as sustainable. One of the aims of this study was to provide SAFS with an overall status of the east coast stock, which puts stock levels at 20–45% if trap catch rates were used as the index of abundance, and 10–23% if line catch rates were used as the index of abundance.

Inter-jurisdictional Management

The work in this project does not overcome the hurdle of cross-jurisdictional management issues, different legislation and different reference points. Queensland has a Sustainable Fisheries Strategy, (Queensland Government, 2017), with target biomass levels of 40 and 60% by 2020 and 2027, respectively. New South Wales does not have target biomass levels for snapper. A cross-jurisdictional co-management approach would reduce management costs and enhance inter-jurisdictional collaboration.

Recommendations

Further development

Data

The combined New South Wales and Queensland database should be maintained and updated as more data and stock assessments become available.

It is important for harvest totals and standardised catch rate assessments that the commercial and charter logbook data records are verified. Accurate tallies of fish numbers and weight will better inform age-size structures of fish and measures of fishing mortality. Other important indices for catch rate standardisation that are not yet included in the commercial and charter logbook records are the fishing operation's target species, travel time, search time and efficiency, locations fished, active fishing time, zero catches (indication of fishing effort) and data codes to link fishing trips over multiple days. These extra data will improve the ability to model changing dynamics of the fishery and produce better indices of snapper abundance.

The Queensland charter logbook data were incomplete and had limited associated effort information. At a gross scale, the charter logbook offered a minimum estimate of the total number of snapper caught (both retained and discarded) in the charter fishery because there was no compliance check on logbook submission and it was likely that some operators had not submitted logbooks in recent years. For the logbook to provide useful information the following would be required: reinstatement of the collection of information in the charter logbook, number of fishers and number of hours fished.

The New South Wales charter data could be improved by the collection of fishing effort information.

There was uncertainty in the catch and effort estimates obtained for the recreational sector. This was a concern for the snapper stock assessment because over 50% of the harvest was believed to be taken by recreational fishers. The regular monitoring and estimates of snapper harvests taken by the recreational sector in all jurisdictions should be an ongoing priority and methodological improvements should always be pursued, thereby improving the accuracy and precision in estimation of recreational catch.

New South Wales should engage in boat ramp surveys with regular on-site survey measures of boat and angler numbers recorded. This would enable catch rates to be determined for the New South Wales recreational fishing sector.

Sampling methods for fish aging should be moved to a consistent process in New South Wales and Queensland. The methods for calculating the age frequency using an age length key should be the same across both states. Locations from where fish were sampled need to be recorded. Spatial patterns of fishing and sampling need to be accounted

New South Wales should engage age and length sampling from the charter and recreational fishing sectors.

The fishery independent surveys in Moreton Bay should continue to collect snapper recruitment data. Independent indices derived from this survey are invaluable in monitoring successful recruitment patterns and highlighting possible recruitment failures. The steering committee recommended that monitoring should also be extended to more bays, inlets and estuaries, important nursery areas for snapper in New South Wales and Queensland to obtain a spatially representative index of juvenile snapper abundance that can be used in future stock assessments.

The impact of improved technology in the recreational fishing sector is an important consideration for catch rate standardisation. Some technologies have been included in this assessment, but there were others that have not been included due to lack of information. For the recreational sector, field survey approaches may be required to collect fishing power information. A recently submitted FRDC project proposal proposes to investigate recreational fishing power data. If funded the proposed research will add greater clarity to our understanding the effects of increased fishing power.

Modelling tool

The computer model developed in this study could form the basis of the operating model for a management strategy evaluation (MSE) framework. MSE is not the same as conducting forward projections from a stock assessment model, although the computer model normally forms the basis for the operating model of the MSE. MSE takes feedback control into account, that is, it takes account of the collection and use of future data on the status of the managed system. Testing harvest strategies through MSE provides a way of viewing the performance of the proposed harvest control rules against a variety of fishery objectives and uncertainties in assessment and biology.

Harvest Strategy

Currently New South Wales and Queensland snapper stocks are managed separately with minimum legal size limits (different in each state) and bag limits for the recreational and charter sectors (different in each state). In collaboration with key stakeholders, Queensland will be developing a harvest strategy for snapper through the Rocky Reef Fishery Working Group. This involves providing clarity about the overall fishery objectives, fishery performance targets, triggers for management action and appropriate management responses.

To have cross-jurisdictional management of snapper, there must be collaboration and agreement on key elements for management procedures. This includes agreement on harvest control rules and setting target levels of fishing across both New South Wales and Queensland. Further discussions would be required to promote the adoption of a single harvest strategy.

Spatial Indicators

Genetic information was used to show a common “northern” genetic stock currently for the east coast from Queensland to New South Wales, separating from a “southern” stock in southern New South Wales. However, even this boundary has potentially changed through time due to warming ocean temperatures and southward movement of fish stocks. The biology of snapper suggests that the east coast stock may comprise a number of sub-stocks linked to estuaries and other protected inshore waters where juveniles are recruited and grow, before moving as adults to offshore reef areas. Adults have been known to travel large distances, but generally seem to become resident in local reef areas. These biological characteristics are likely to result in regional sub-populations with sufficient cross-mixing to make them genetically indistinguishable, but important within modelling timeframes where localised depletion is possible.

Cooler water temperature down the New South Wales coast results in spawning later in the year compared to fish in Queensland. Snapper are sexually mature at four years of age. However, the faster growth rate of some subtropical snapper enables them to reach sexual maturity at about two to four years of age, earlier than in more temperate latitudes. This indicates perhaps differences in maturity and growth by sub-regions that may also influence modelling results.

As endorsed by the steering committee, the model did not include the influence of spatial stock structure and particularly potential localised depletion differences in sub-areas. As future research, a model with spatial sub-structuring could be developed. There has been general research into appropriate scales for models where different regions have been subjected to different catch histories (Cope and Punt, 2011).

Other Performance Measures

The performance measures in this study were direct observations such as catch rate trends, a fishery independent index of abundance, age and length frequency data, or they were output from the computer model, e.g. spawning biomass. The spawning biomass size of 60% was considered by Queensland as a desirable and safe target at which stakeholders and management should aim for the public good.

Exploitable biomass ratios were available from model results and may be used as a performance measure. In the independent review of the Queensland snapper stock assessment (Campbell *et al.*, 2009), Dr C. Francis argued that indicators based on exploitable biomass inform on the short-term health of the fishery but not the fish stock. For example, a low vulnerable biomass relative to its virgin level is usually bad news for the fishery because it means that the fish are harder to catch, but this may not be bad news for the fish stock if the spawning biomass is still relatively high.

Exploitation measures of the harvest rate on fish stocks (the fish removed through fishing). This indicator was available from the computer model in Figure 3.17 in (Wortmann *et al.*, 2018). The fishing mortality rate is generally compared to the natural mortality rate, with the desirable outcome being that fishing mortality rate is below the natural mortality rate.

The study identified the need for additional pre-recruitment surveys of snapper in areas outside of Moreton Bay (i.e. other areas of Queensland and to be extended to New South Wales). Charter logbook information needed to be improved in both New South Wales and Queensland (the logbook data from New South Wales did not have effort information, and the logbook data from Queensland had minimal effort information and data was not provided by all operators accessing the fishery). An improved understanding of historical changes in recreational fishing effort would further improve model accuracy. The length and age monitoring in New South Wales did not include the charter or recreational fishing sectors, and future monitoring plans in New South Wales should also include these fishing sectors.

Extension and Adoption

The main beneficiaries of the research were the fishers, fishery managers and scientists:

- New South Wales commercial snapper trap and line fisheries
- New South Wales charter and recreational line fisheries
- Queensland commercial snapper line fisheries
- Queensland charter and recreational line fisheries
- The Australian Fisheries Management Authority (AFMA)
- Victorian Fisheries Authority
- The New South Wales Department of Primary Industries (NSW DPI), Australian Government
- The Queensland Department of Agriculture and Fisheries (DAF), Australian Government.

The research provided a number of benefits and updated our understanding of east coast snapper stocks. The collations of data and analyses have:

- Updated information on the stock structure of east coast snapper
- Collated and improved information on key biological attributes of east coast snapper
- Produced a harmonised database of all relevant information from New South Wales, Queensland and Victoria, including archival and fisher knowledge data, for future research and assessment
- Informed on the utility of the various data sets
- Developed modelling tools which will provide a framework for future modelling of stocks
- Used computer models to inform cross-jurisdictional management strategies
- Enhanced cross-jurisdictional collaborations
- Provided opportunity for increased industry confidence through an open and transparent process.

During the timeframe of this project a clearly communicated cross-jurisdictional stock assessment was conducted. Close collaboration with the management agencies in these jurisdictions ensured that all relevant stakeholders were informed and working together to develop a single stock assessment model across the east coast snapper stock. An independent review of this stock assessment was conducted and the stock assessment together with the review may be found in (Wortmann *et al.*, 2018).

In terms of direct contact and adoption of the research, each jurisdictions fishery managers have been involved directly through discussions in the steering committee meetings. A presentation of project outcomes has been delivered to key snapper industry members. Adoption of cross-jurisdictional management will be post-project. The structure of future snapper management across jurisdictions is dependent on industry acceptance and each jurisdictions endorsement.

The data, methods and historical model for this project were developed by a cross-jurisdictional stock assessment project team. The team met regularly to discuss data and model assumptions. This group consisted of managers, researchers, biologists and stock assessment scientists from both New South Wales and Queensland. There were six meetings of this team.

Australian stakeholders and managers will benefit from this first modelling tool for the whole east coast stock. At present, the long term effects of current management arrangements are highly uncertain, but with the modelling tool developed in this project it is possible to predict snapper stock based on current and future hypothetical management arrangements. The results will help fishery managers to set future harvest levels and also provide managers with a measure of the uncertainty of the management strategies implemented.

The Fisheries Queensland Rocky Reef Fishery Working Group will provide advice on the operational aspects of the management of the rocky reef fishery. The rocky reef fishery is an important commercial, recreational and charter fishery which predominantly targets snapper. Results from this research and the modelling tool will be used to help develop and refine harvest strategies.

Project coverage

An article on "Insights into snapper genetics" was published on the internal DAF website (http://dafintranet.lands.resnet.qg/our-department/news-events/news/forestry-and-fisheries/2017/february/insights-into-snapper-genetics). A snapper genetics manuscript has been produced in Morgan *et al.* (2018).

An article on the historical trends and transitions observed in the snapper recreational fishery has been published in a scientific journal, (Thurstan *et al.*, 2018).

A popular fishing magazine printed an article on the archival information to show readers what fishing was like in the 18th century (Rae, 2018).

The following articles were published on the FRDC website: Historic snapper catch information from Qld and NSW, East coast snapper genetic stock structure, Summary of data available for the inter-jurisdictional snapper project and Impact of advances in fishing technology on the snapper fishery.

An industry meeting with Sunfish Queensland, Queensland Seafood Industry Association and Fisheries Queensland was held on 16 August 2018. The aim of the meeting was to give an overview of the snapper stock assessment results in Wortmann *et al.* (2018).

A keynote speech on inter-jurisdictional management of east coast snapper will be presented at the ASFB 2018 conference (Australian Society for Fisheries Biology) in the session "challenges in fisheries management and assessment.

Project materials developed

A snapper genetics manuscript has been submitted for publication on the Marine and Freshwater Research special issue for Women in Marine Science (Morgan *et al.*, 2018).

Research on the archival and fisher knowledge information was published in the journal of Global Environmental Change (Thurstan *et al.*, 2018).

A popular fishing magazine printed an article on the archival information to show readers what fishing was like in the 18th century (Rae, 2018).

Appendix 1.

Project staff

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Appendix 2.

Intellectual Property

The research was for the public domain. The report and any resulting manuscripts and extension material are intended for wide dissemination and promotion

Appendix 3.

Detailed History of Snapper Management in East Coast Snapper Jurisdictions

Queensland Management Arrangements

Prior to 1979, line fishing for snapper, was only restricted by general fisheries management interventions. A snapper minimum legal size had been in place for decades being introduced at a size of 10 inches and subsequently changed to 25 cm with the introduction of metric measurement in Australia in 1966. Prior to 1984, there were no limitations on commercial harvesting of snapper other than the requirement for a person to hold a licence, the issue of which was not restricted. In 1984, limited licensing of commercial fishing boats was introduced with the advent of primary and tender fishing boat licences. At this time, licences issued under the *Fishing Industry Organisation and Marketing Act (FIOMA) 1984* were restricted with no further primary boat licences to be issued. In 1987, further restrictions were applied to commercial fishers through licensing, with a general ‘freeze’ on the grant of new tender boat licences, a process that was later adopted into law in 1993.

The Offshore Constitutional Settlement (OCS) came into force in 1987, at which time responsibility for management of snapper (and other offshore fisheries), was delegated by the Commonwealth Government to the Queensland Government. The state jurisdiction, which was previously limited to a distance of three nautical miles from the coast was replaced by a jurisdiction line set further to sea which largely encompasses the entire snapper fishery off the coast of Queensland. Specific details including boundaries of the Queensland jurisdiction are contained in the *Queensland Government Gazette* of 10 February 1995. These amendments caused further changes in the licensing arrangements for commercial fishing, to allow the inclusion of additional active fishers who had operated in adjacent waters now the responsibility of the State, who had previously held Commonwealth licences. In the case of snapper this enabled a few NSW trap fishers to operate in Queensland waters. A condition which is now lapsed with the retirement of those fishers.

The Queensland Fish Board (QFB), which was responsible for marketing fisheries product, collected catch information from 1936 until 1981. This included some recreational catch and it is widely acknowledged that not all commercial fishers marketed their catch through the QFB. After the closure of the QFB no catch or effort data were collected on snapper until the introduction of the CFISH compulsory commercial logbook system in 1988. This is a compulsory system that requires recording of daily catch and effort information by all commercial fishers. Recreational catch (and some effort information) has only been collected since the mid-1990’s catch (and some effort data) based on phone and diary surveys. Initially these surveys were part of an RFISH system which estimated catch in 1997, 1999, 2002 and 2005 but updated and more rigorous methods were also used to estimate recreational catch. The first of these was conducted in 2000 and formed part of a National Survey where recreational catch was assessed in all Australian states. Subsequently the same methods have been used in 2010 and 2013 to estimate the Queensland catch. The latter three surveys use more frequent contact with fishers to reduce recall bias and “dropout” rate and are widely used throughout Australia and internationally.

Prior to 1988, there were no significant restrictions on the quantity of fish recreational fishers could take. In addition, recreational fishers were able to sell fish surplus to their personal requirements. An amendment of the *Fishing Industry Organisation and Marketing Act 1984* restricted the sale of recreationally caught fish to a limit of 50 kg of whole fish to be sold per permit with a limit of 12 permits to be available to each fisher annually. Further amendments to the legislation in 1990 removed altogether the capacity of recreational fishers to sell any part of their catch.

Catch and effort information was collected from the charter boat fishery by way of a voluntary logbook established in 1993/4 which later became “compulsory” in 1996. Despite the introduction of the charter logbook there are still some operators that do not submit logbooks or any other form of catch return.

In 1993, a suite of new management arrangements were introduced for the snapper fishery which included an increase in the minimum legal size from 25 to 30 cm and the establishment of a 30 per person recreational, in-possession bag limit.

Line fishers endorsed with an L1 symbol can effectively fish in all state-managed coastal and offshore waters south of the GBR and are restricted to using rod-and-reel or hand line fishing gear and methods under the same restrictions as recreational fishers. Other than the restriction to use there are no multi-hook commercial fisheries (longline) or trapping in Queensland.

In December 2002, the minimum size limit of snapper was further increased from 30 to 35 cm and the recreational in possession limits were reduced from 15 to 5 snapper per person (Table 21). An investment warning was issued for the RRFFF in September 2003 to warn those with a current interest or considering investing in the fishery that increases in commercial catch levels or fishing effort may not be recognized as 'historical involvement' when developing future management arrangements.

Table 21 Management measures applied to the Queensland snapper fishery. Source: Queensland state government legislation.

Month/ Year	Minimum legal size	Recreational bag limit (in possession)	Maximum size limit
Sep 2011	35 cm	4 snapper per person	Only 1 snapper greater than 70 cm
Dec 2002	35 cm	5 snapper per person	
1993	30 cm	30 snapper per person	
1900	25 cm		
Pre 1900	0		

Following a number of stock assessments from 2006 to 2008 and significant stakeholder consultation which highlighted concerns of the sustainability of snapper an interim six week closure was implemented in March/April 2011 with a total ban on the harvest of snapper, pearl perch and teraglin by all sectors. Further rocky reef management was introduced in September 2011 which saw a lowering of the recreational snapper bag limit from 5 to 4 and a maximum size limit of 70cm introduced for recreational anglers (only one fish greater than 70 cm could be retained).

There are several areas in southern Queensland that offer some level of protection for snapper. These are the Moreton Bay Marine Park and the Great Sandy Strait Marine Park. In addition the Great Barrier Reef Marine Park protects a proportion of the stock at the northern extreme of the species range.

New South Wales Management Arrangements

Management arrangements for snapper in New South Wales differed from those in Queensland. The main difference was commercial fish trapping as the primary commercial fishing method. Fish trapping is not a prescribed or permitted method in Queensland.

Recreational fishing methods in New South Wales are similar to those in Queensland, but with a maximum of four lines per person with each line having a maximum of three hooks (ganged hooks are regarded as a single hook). Multi-hook commercial fishing is more widespread in New South Wales with the use of both droplines and longlines (NSW Department of Primary Industries, 2006).

The main snapper management changes in New South Wales are summarised in Table 22.The current minimum legal size (MLS) of 30 cm total length was introduced in July 2001, an increase from 28 cm. The MLS of 28 cm (or equivalent in inches) had been in place since 1939. In 1999, New South Wales Fisheries scientists recommended a 4 cm increase in the MLS of snapper from 28 to 32 cm to reduce the problem of growth overfishing. Given concerns about the financial impacts of a 4 cm size increase for some commercial fishers, the Minister for Fisheries at the time committed to implementing two separate increases of 2 cm. The first increase from 28 to 30 cm took effect 1 July 2001; the second increase was to occur after a study of the biological and economic effects of the first increment. That biological and economical assessment was completed in 2008 and recommended that the MLS be increased to 32 cm.

Since 1993 the current recreational in possession limit for snapper is 10 snapper per person.

Table 22 Management measures applied to the New South Wales snapper fishery. Source: New South Wales state government legislation. Information in brackets show the conversion of the actual length or weight measure into the equivalent Total length.

Month/Year	Minimum legal size	Recreational bag limit (in possession)
July 2001	30 cm	10 snapper per person
1993	28 cm	10 snapper per person
1939	11 inches (~28 cm)	No limit
1914	9 inches (~23 cm)	No limit
1903 Legal weight	16 oz (~32 cm)	No limit
1884 Legal weight	12 oz (~29 cm)	No limit
1881 Legal weight	16 oz (~32 cm)	No limit
Pre 1881	8 oz (~25 cm)	No limit

Demersal fish traps in New South Wales were traditionally covered in 50 mm hexagonal wire mesh. Two separate surveys during the 1990s estimated between 2.5 and 2.8 undersized snapper were discarded per trap lift, equating to roughly 500,000 snapper discarded each year with unknown mortality (Stewart and Ferrell, 2001). In 2008 ‘escape’ panels of 50 x 75 mm mesh in the ‘back’ of demersal fish traps were introduced to reduce this level of discarding (Stewart and Ferrell, 2002). Research predicted zero loss of marketable fish but a reduction of 33% in the numbers of under-sized snapper captured and subsequently released (Stewart and Ferrell, 2002).

In New South Wales, commercial harvest information was available for most species since the financial year 1940/41, primarily from mandatory monthly catch returns submitted by all licenced fishers. A detailed description of the various commercial catch returns and an analysis of available data between 1940/41 and 1991/92 was presented in Pease and Grinberg (1995).

Accurate catch per unit of effort cannot be calculated for most species prior to 1990 because the monthly catch return system did not provide adequate effort information. Restricted fisheries were implemented between July 1984 and June 1997 in New South Wales and during this period catch could only be linked to effort where a single method was reported on the monthly forms. However, with the introduction of more detailed logbooks in July 1997 it became possible to directly link catch and effort within a fisher’s monthly return.

The spatial reporting of the commercial data has been by 60 nm grids with no data on distance offshore or depth since 1984 and with information generally summarised into 10 fishing zones (See Figure 18).

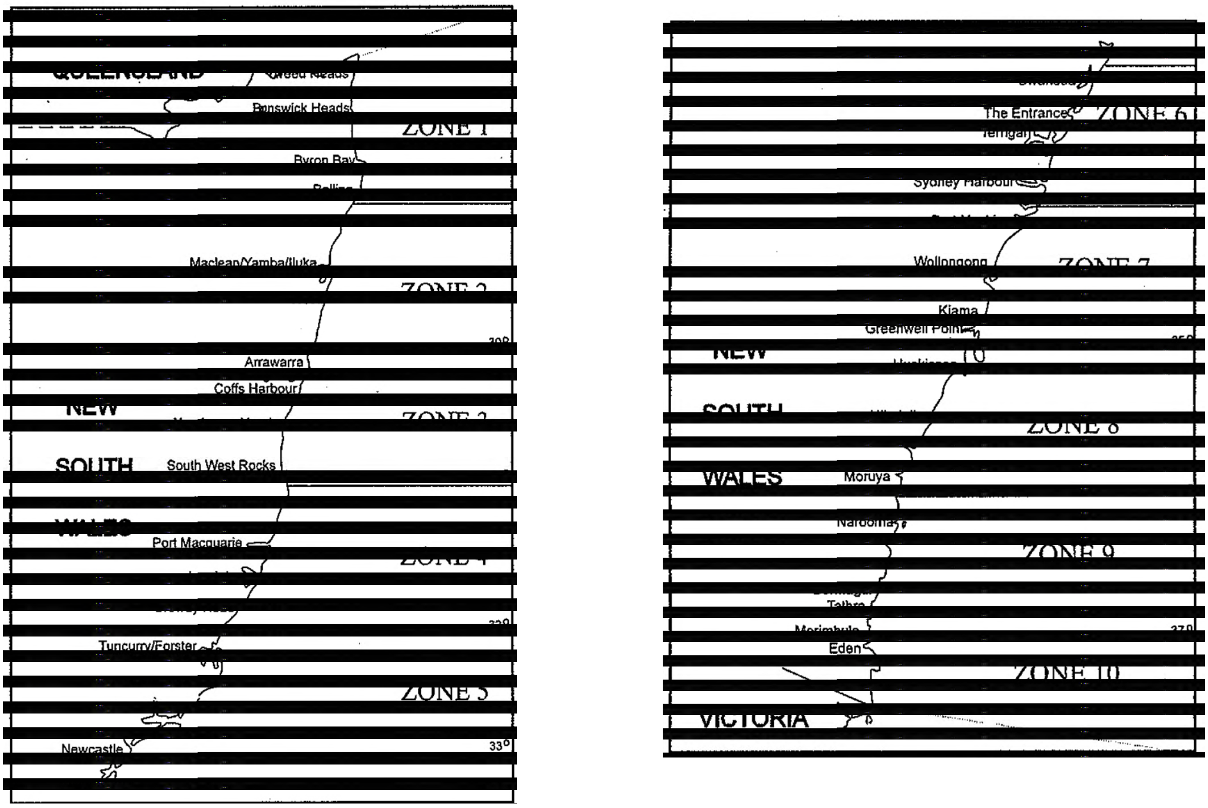

Figure 18 Spatial reporting areas in commercial fishing logbooks 1984 to 2009.

New South Wales catch records changed substantially in July 2009, moving to a finer level of spatial and temporal reporting. This system was referred to as the “Fishonline” System. This system required daily catch and effort reporting, to six minute grids (30 sq nm or 103 sq km).

Zoning restrictions within the six New South Wales marine parks have reduced the available fishing grounds. The extent of the protection afforded to snapper has not been quantified. These Marine Parks are: Cape Byron Marine Park, Solitary Islands Marine Park, Lord Howe Island Marine Park, Port Stephens-Great Lakes Marine Park, Jervis Bay Marine Park and Batemans Marine Park.

The New South Wales commercial fisheries are currently undergoing restructuring (Commercial Fisheries Business Adjustment Program). Details of the scheme are available at http://www.dpi.nsw.gov.au/fishing/commercial/reform. These reforms involve fisheries access linked to hare trading and for the Demersal Fish Trap share class all fishers must hold the minimum shareholding of 50 shares to be endorsed to fish from July 2017.

Victorian Management Arrangements

The Victorian fishery, like those in New South Wales and Queensland, has had a long history of exploitation dating back to the 19th century with most fishing effort concentrated in Port Phillip Bay. There is minor catch of snapper from bays and estuaries. This is because the estuaries along eastern Victoria that have historically, and are currently, open to commercial fishing typically only support juvenile life stages that are mostly below the historical and current Victorian Statewide snapper MLS of 27 cm (established 1926) and 28 cm (established 2008) respectively. Occasional catches of larger snapper are taken commercially in Corner Inlet, but these are small in comparison to the catches from coastal waters.

From 1979 until 1998 snapper catches by trawl methods including Danish seine and otter trawls were managed and reported under Victorian jurisdiction. Under the 1997 Offshore Constitutional Settlement

(OCS) agreement, management and reporting of all trawling/Danish seine fishing, excepting otter trawling under the Victorian Inshore Trawl licence, was handed over to the Commonwealth to be managed under Commonwealth legislation. Further, the OCS also recognised that certain species were to be State managed species, snapper was one of these. The impact of these changes on catch reporting can be seen in Figure 19 where the majority of commercial catch is reported under Commercial – Victorian (Offshore Fishery Access Licence (OFAL) and Victorian Inshore Trawl (VIT)) prior to 1999, but post 1999 the Commercial catch became increasingly reported by Commonwealth operators using otter trawl and Danish seine methods in the Southern and Eastern Scalefish and Shark Fishery (SESSF).

Since 2009/10 the catch by Victorian licenced commercial fishers has become small and there is currently an annual 10 tonne catch cap for snapper caught by the Victorian Inshore Trawl in the eastern stock. This State trawl license type was never intended to be used to target scalefish, however, loopholes in the legislation do not prevent this and the catch cap was introduced to limit growth in scalefish targeting using this method.

The issue of increasing Commonwealth licenced catch of snapper from the eastern stock in Victoria was a topic of high interest to Victorian management in the late 2000s leading to much discussion with AFMA (Australian Fisheries Management Authority) and SETFIA (South-east Trawl Fishery Industry Association). Ultimately these discussions led SETFIA and AFMA to develop and implement a management arrangement in 2015 with respect to snapper catches aimed at reducing Commonwealth reported catches from the eastern stock in Victorian waters. The key requirements of the code are a 200 kg trip limit, or if more than 200 kg are landed at sea the operators require permission to land the catch from SETFIA. To be approved to land the catch the operator must demonstrate the catch was incidental. Operators are urged to move away from areas where significant incidental catches of snapper occur. Recent catches by the Commonwealth sector have been less than 10 tonnes per year compared with a recent peak in 2011 of approximately 25 tonnes (Figure 19). Catches of snapper by Commonwealth operators have been reported from all areas along the east Victorian coast and out to over 200 m.

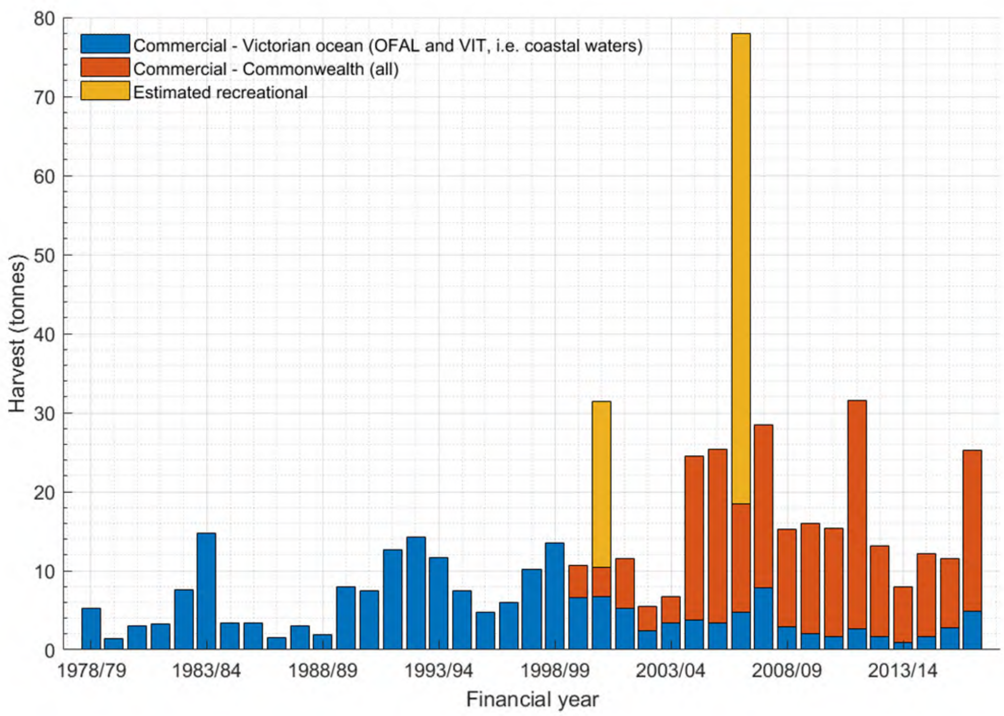

Figure 19 Harvest history for snapper in eastern Victoria (east of Wilsons Promontory).

Recreational

The recreational snapper fishery in eastern Victoria has received no ongoing monitoring, and despite the recognition of eastern and western snapper stocks in Victoria, the recreational fishing regulations for snapper have always been applied State-wide.

The recreational catch of snapper from eastern Victoria is mostly from coastal waters between Lakes Entrance and Corner Inlet, with a smaller catch from Corner Inlet. Anglers target spawning aggregations along inshore reefs in this region during November/December, and smaller sub-adults in the same general areas in late summer/autumn/winter. There is no evidence for significant recreational snapper catches from waters off far eastern Victoria.

There have been two recreational snapper catch estimates for the eastern stock in Victorian waters; 2000/01 (National Recreational and Indigenous Fishing Survey, Henry and Lyle (2003) and 2006/07 (FRDC project 2003/047). The recreational catch estimates have a high degree of uncertainty, as data on size/weight of harvested fish was not obtained, instead a weight of 0.7 kg per fish is applied based on estimates from coastal caught fish in western Victoria. The estimates suggest that recreational catches were between 20-60 tonnes from 2000/01-2006/07 (Figure 19), and were therefore the largest harvest component. It is likely that recreational catches have remained the largest harvest component in recent years as the Commonwealth SESSF catch has reduced and anecdotal reports of increased recreational fishing effort on spawning aggregations over recent years.

Recreational fishery regulations in eastern Victoria have been driven by issues in western Victoria, due to the State-wide application of the regulations, and the focus of management and assessment on the more important western stock.

From 1926–2008 the MLS was 27 cm. From 2008 onwards the MLS was 28 cm. Bag and slot limits have been applied since the early 1990s. The current regulations have been place since 2008 and allow 10 fish per person per day, with all fish being greater than 28 cm total length, and only 3 fish allowed longer than 40 cm total length. The first bag limits were applied in the early 1990s; 15 snapper per person per day, with only 5 allowed longer than 50 cm total length. This was reduced to 10 snapper per person per day, with only 3 allowed longer than 50 cm total length in 1997.

Table 23 Management measures applied to the Victoria snapper fishery. Source: Victoria state government legislation.

Month/Year	MLS	Recreational bag limit (in possession)	Maximum Limit
2008	28 cm	10 snapper per person	Only 3 longer than 40 cm total length
Early 1990s	27 cm	15 snapper per person	Only 5 longer than 50 cm total length
1926	27 cm	No limit	

WA, SA and Tasmania Management Arrangements

Snapper management regimes in Western Australia for both the commercial and recreational (including charter) fisheries vary by and within area or “bioregion” with total allowable catches applied on this basis. Recreational management controls include minimum legal size (41 cm), daily bag limits, in possession limits, closed areas and seasons and gear restrictions. In addition, a fishing licence in the form of a “recreational fishing from boat licence” is required if fishing for snapper from a power boat. Depending on bioregion, the recreational daily bag limit for snapper is either 2 or 3 with possession limits varying between 5–20 kg of fillets. Closed seasons also vary between regions. Controls for the commercial fishery include closed seasons, gear controls and size limits with the addition of individual transferable quota system in some bioregions and in others a permit system systems based on effort in the form of “hours of fishing time” monitored via VMS.

Recreational management in South Australia did vary by area but recently changed on 1st December 2016. The daily bag limit and daily boats are now the same across the state with a daily limit of 5 fish 38–60 cm and 2 over 60 cm per person and a daily boat limit of 15 snapper 38–60 cm and 6 over 60 cm. Gear restrictions apply to both the recreational and commercial fisheries as do closures including designated spawning areas (closed 15th December – 31st January) and a seasonal closure (1st November – 15th December). Daily commercial catch limits apply based on area fished and duration of trip.

Appendix 4

Snapper Genetics Stock Structure – Supplementary Information

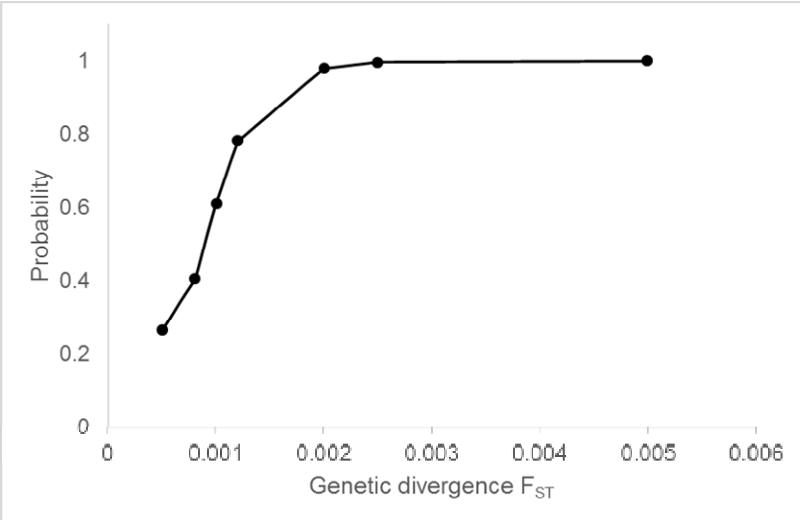

Figure 20 Power analysis results of simulations to assess the resolution of 9 microsatellite loci to detect genetic structure in 9 C. auratus populations given a range of divergence (FST) levels. Probabilities reflect the average of 500 replicates for which the FST values were significantly different to zero using Fishers exact tests (POWSIM).

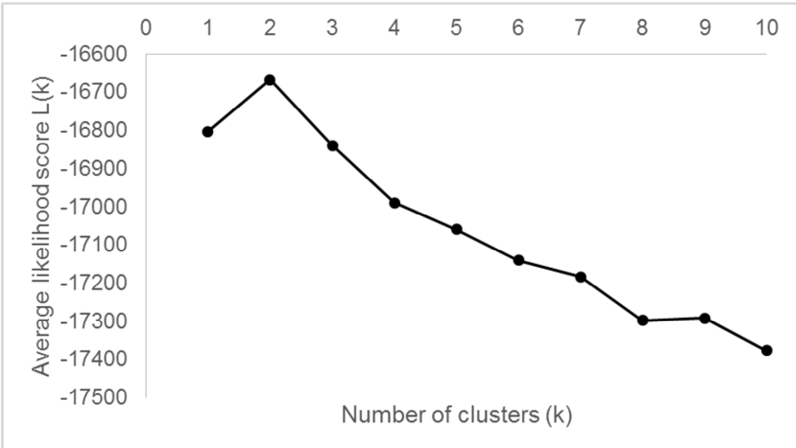

Figure 21 The best likelihood score at k = 2 for predicted genetic stock structure of C. auratus based on population clustering of microsatellite data using a Bayesian model-based analysis.

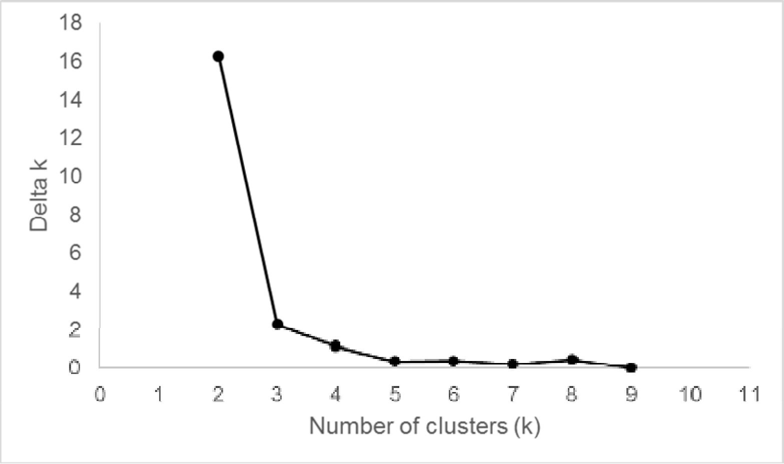

Figure 22 The optimal k = 2 cluster model determined by the peak point on a plot of changes in mean likelihood scores (Delta k) against cluster size (k) for predicted genetic stock structure of C. auratus based on population clustering of microsatellite data using a Bayesian model-based analysis.

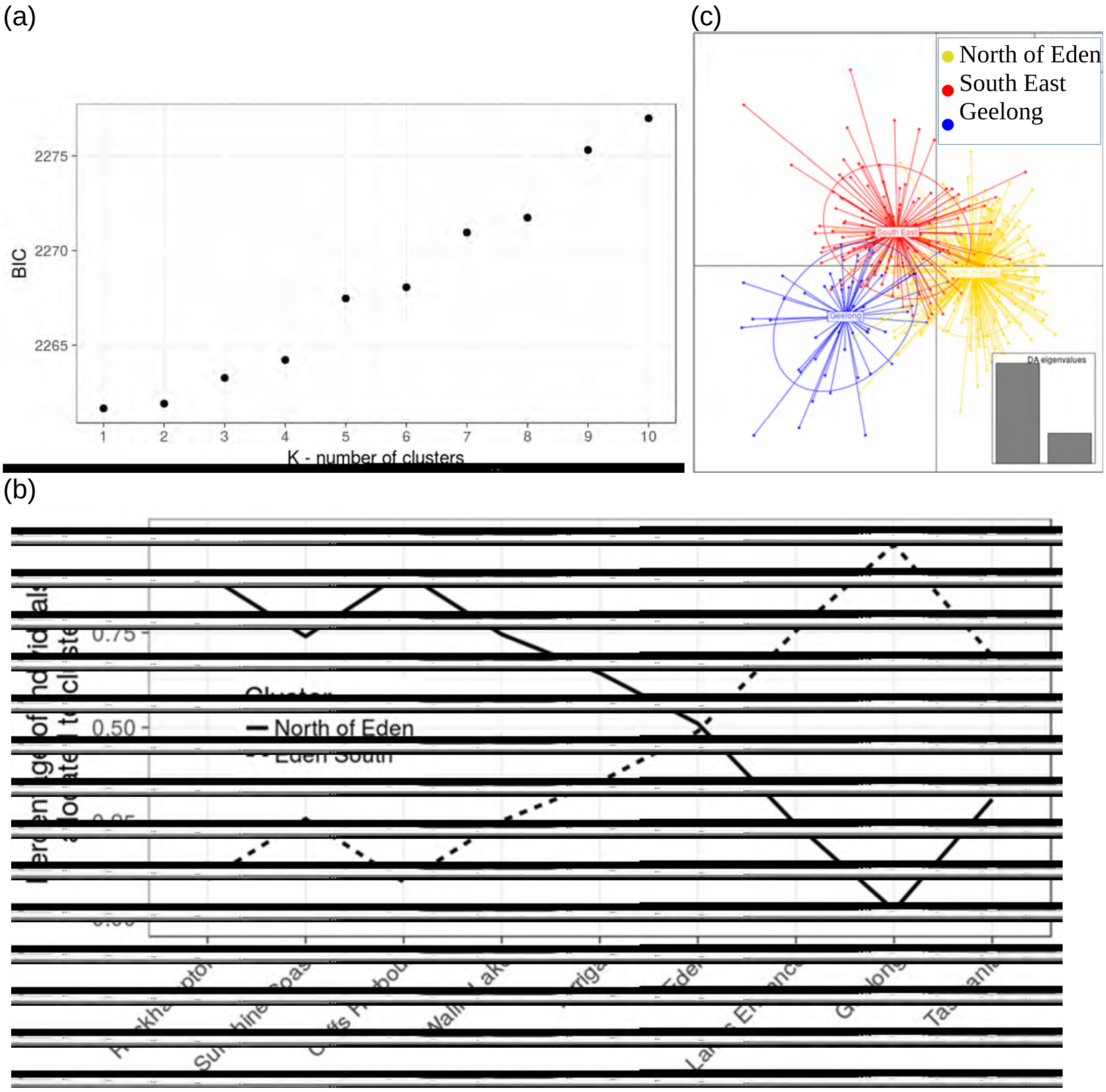

Figure 23 Discriminant analysis of principal components (DAPC) using 9 loci (a) plot of cluster size (K) versus Bayesian Information Criterion (BIC) to predict optimal K using scaling (b) percent frequency plot of two stock a-priori model separating north of Eden (solid) from Eden south (dashed) (c) scatter plot of three stock a-priori model separating yellow = North of Eden, red = South East, blue = Geelong. In (c) individual genotypes appear as dots, clusters are depicted by colours and 95% inertia ellipses are given. The bottom-right inset in (c) depicts the relative eigenvalues for the principal components with the x and y axis constituting the first two principle components, respectively.

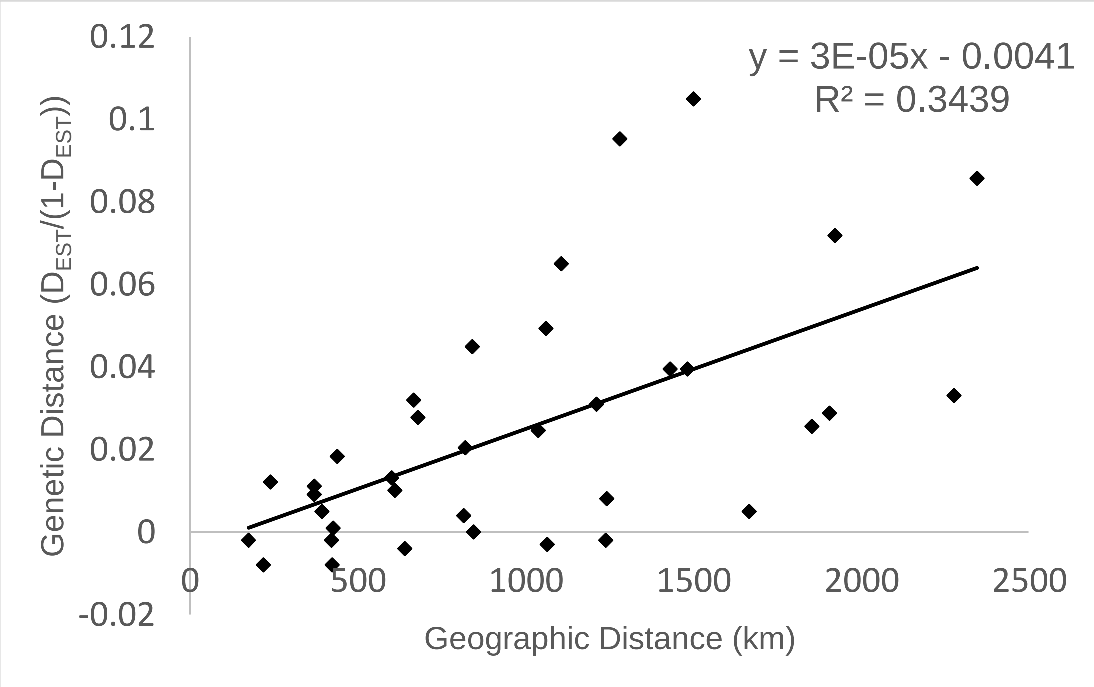

Figure 24 Correlation of genetic distance and geographic coastal distance (isolation by distance IBD model) based on 9 microsatellite loci and 448 C. auratus collected from 9 populations along the east coast of Australia.

Supplementary Table 1. Details of microsatellite loci targeted in study modified from Le Port *et al.* (2014) .

Multiplex Number	Locus	Primers (5'-3') with modified M13 tail underlined	FLU	Ta (˚C)	Primer concentration (uM)	Allele repeat motif	Source
M1	Pma1	**TAAAACGACGGCCAGTGC**CATGCCAGTATTCCAATGTGC	NED	60	0.016	(GT)21	*
		AGGACAAATTCCCAAGGTCATCC			0.16		
	Pma68-23	**TTTCCCAGTCACGACGTTG**ATCCTGACACGCTGGAAACT	FAM	60	0.033	(CA)3AA(CA)18	□
		TCTGGAAGTGGGAATAAAAGG			0.33		
M2	Pma22-99	**TTTCCCAGTCACGACGTTG**CAATGACTGGCACCGTATCA	FAM	62	0.02	(CA)22(TA)3	□
		AAAGGGTTCATTTTGGATGG			0.2		
	CM3195	**GCGGATAACAATTTCACACAGG**AGTGTTATCACAGCTTTGCAG	VIC	62	0.016	(TG)13	†
		CTTGTGCTGTACCTATTCTGAG			0.16		
M3	Pma4-32	**GCGGATAACAATTTCACACAGG**CCTGCCACCTACTGTTTCCT	VIC	60	0.02	(CA)24	□
		CGGTGATTACAGTCGGGTTT			0.2		
	Sal19	**TAAAACGACGGCCAGTGC**ATTCTTCACAGGCCCAACACAAA	NED	60	0.02	(GT)25	●
		GAAAACACCGGCCCAGTACGA			0.2		
S1	CM278	**TTTCCCAGTCACGACGTTG**GTGTGCGATCATCTTTGTGA	FAM	52	0.033	(TG)16	†
		TTAGCGGCTGTAAGACCAT			0.33		
S2	PaurGA2A	**GCGGATAACAATTTCACACAGG**ACGGACAGAGAGGGAGTGG	VIC	59	0.02	(AG)16	‡
		CATCATCATCAGTCAGAGCTG			0.2		
S3	Sal10	**CACAGGAAACAGCTATGACC**TCACGGGGGACCAAGACTG	PET	57	0.02	(GT)37	●
		CTCACACTGCCTAATTAGCACAGA			0.2		

Fluorescently labelled M13 primer at reverse primer concentration. * Takagi *et al.* (1997); □ Hatanaka *et al.* (2006); † Chen *et al.* (2005); ‡ Adcock *et al.* (2000); ● Brown *et al.* (2005)

Appendix 5

Methods and deliverables from the Communications and Engagement Strategy

Table 24. Communications and engagement strategy

Timing	Milestone	Message	Target audience	Communication tool	Status*
6 January 2016	Understanding the science of east coast snapper stocks – media release	See previous media release	Completed previously	Media release distributed	Complete. Media release available at DAF's website[8].
Early 2016 onwards	Input invited from stakeholders re: available data	See previous website text	Completed previously	Call for submissions open on FRDC website. Submissions invited via email.	Complete. Invited data submissions to be sent to eastcoastsnapper@frdc.com.au
29 April 2016	Data summary available online	See previous website text	Completed previously	Uploaded to FRDC website	Complete. Available via FRDC website[9].
29 April 2016	Review of snapper stock summary available online	See previous website text	Completed previously	Uploaded to FRDC website	Complete. Available via FRDC website. This was removed from the FRDC website when Objective 1 was achieved. A scientific manuscript has been submitted to *Marine and Freshwater Research*.
9 February 2017	Genetics – media release	Qld and NSW one genetic stock Separate stock off Victoria and Tasmania	Qld, NSW and Vic media Recreational fishers Commercial fishers Industry organisations	Queensland media Request NSW DPI to distribute to NSW media Social media (FQ, NSW and FRDC). DAF intranet story	Complete. Available via DAF website[10].
30 May 2017	Progress update 1 – information on website	Genetics and stock structure	Qld, NSW and Vic media Recreational fishers Commercial fishers Industry organisations	Web content update on FRDC site Social media post on Fisheries Queensland, FRDC and also ask NSW and Victoria to share post. Email to steering committee	Completed. Available via the FRDC website[11].
15 June 2017	Progress update 2 – information on website	Impacts of improved fishing technology	Qld, NSW and Vic media	Web content update on FRDC site	Completed. Available via the FRDC website[12].

[8] https://www.daf.qld.gov.au/our-organisation/news-and-updates/fisheries/news/understanding-the-science-of-east-coast-snapper-stocks
[9] http://www.frdc.com.au/project?id=2888
[10] https://www.daf.qld.gov.au/our-organisation/news-and-updates/fisheries/news/insights-into-snapper-genetics
[11] http://www.frdc.com.au/Archived-Reports/FRDC%20Projects/2015-216%20-%20East%20coast%20snapper%20genetic%20stock%20structure.pdf
[12] http://www.frdc.com.au/Archived-Reports/FRDC%20Projects/2015-216-FRDC%20Update%20-%20Fishing%20Technology.PDF

Timing	Milestone	Message	Target audience	Communication tool	Status*
			Recreational fishers Commercial fishers Industry organisations	Social media post on Fisheries Queensland, FRDC and also ask NSW and Victoria to share post. Email to steering committee	
30 June 2017	Progress update 3 – information on website	Fishery differences in each state	Qld, NSW and Vic media Recreational fishers Commercial fishers Industry organisations	Web content update on FRDC site Social media post on Fisheries Queensland, FRDC and also ask NSW DPI and Vic to share post. Email to steering committee	Incomplete
15 July 2017	Magazine article distributed	Snapper stocks (genetic differences), differences between the snapper fisheries in Qld and NSW, historical catch rates	Recreational fishers. Article to be sent to rec fishing magazines e.g.: Fishing World Magazine Modern Fishing Fish and Boat magazine (Qld) Bush n beach	Feature article (media release)	Completed. David Rae, a writer for the recreational fishing magazine Fishing World, drafted an article in consultation with Ruth Thurstan and Matthew Campbell. It was published in the July 2018 edition of Fishing World.
13&14 July 2017	Workshop and steering Committee Meeting in Sydney	Meeting to discuss east coast snapper data and assessment model	Qld, NSW and Vic media Recreational fishers, Commercial fishers, Industry organisations, scientists	Web content update on FRDC site Social media post on Fisheries Queensland, FRDC and also ask NSW DPI and Vic to share post Email to steering committee	Completed. See notes in Appendix 2
30 July 2017	Survey open for stakeholder feedback	Will display the data and seek feedback on the types of data, views of the data being used and further information on additional data sources that will help create a better picture of snapper fishing in Qld and NSW	Qld, NSW and Vic media Recreational fishers Commercial fishers Industry organisations Snapper scientists	Online survey (Survey Monkey) Website (FRDC and DAF) Email to recreational fishing industry groups Catch newsletter story Media release Social media post on Fisheries Queensland's pages and FRDC Email to Qld snapper scientists Email to steering committee	Questions discussed at Sydney workshop. See Appendix 5 for the completed list of questions. The survey was initially delayed when the Queensland Government went into caretaker mode at the calling of the state election.
30 September 2017	Progress update 4 – information on website	Final update of process and outcomes	Qld, NSW and Vic media Recreational fishers	Web content update on FRDC site Social media post on Fisheries Queensland, FRDC and also ask NSW DPI and Vic to share post Email to steering committee	The steering committee were updated with project progress throughout the final stages of the project.

Timing	Milestone	Message	Target audience	Communication tool	Status*
			Commercial fishers Industry organisations		
30 November 2017	Snapper stock assessment	Current Qld snapper stock assessment report available online	Recreational fishers in Queensland Commercial fisheries in Queensland Scientists Conservationists	Publication on DAF website (liaise with Fisheries Queensland)	Delayed. Stock assessment document presented to Expert Panel on 8 March 2018. The Expert Panel recommended that the assessment be externally reviewed. Fisheries Queensland initiated the process of review.
31 December 2017	Final report to FRDC complete	Project completed Final report now available online	Qld, NSW and Vic media Recreational fishers Commercial fishers Industry organisations Snapper scientists	Email to steering committee and industry stakeholders Publication uploaded to websites (FRDC and Fisheries Queensland)	Delayed until 30 June 2018. The Queensland government called an election for 25 November 2017 and went into caretaker mode on 29 October 2017. This delayed the stock assessment.
31 December 2017	Media release distributed	Final project outcomes, highlighting the benefits of the project	Qld, NSW and Vic media Recreational fishers Commercial fishers Industry organisations	Media release to Queensland media Request NSW DPI to distribute to NSW media Social media (Fisheries Qld, NSW and FRDC) DAF intranet story	To be progressed once the stock assessment is available on the stock assessment website
End of project	Evaluation report complete	See section 'Evaluation report' in this strategy	Fisheries Science and Fisheries Qld	Evaluation report	

*Status as at 30 June 2018: draft final report stage.

Appendix 6

Notes from first steering committee meeting

Below are the minutes/notes from the Steering Committee meeting 1 as endorsed by the respective attendees.

Inter Jurisdictional Snapper Project Steering Committee

Meeting 1

25 November 2016

Floor 5 Conference Room

Primary Industries Building, Brisbane

RECORD

RECORD OF MEETING

Attendees

Paul Sullivan, Steve Campbell, David Bateman, Wayne Sumpton, Matthew Campbell, Michael O'Neil, George Leigh, Joanne Wortmann, Jess Morgan, John Stewart, Paul Hamer, Ross Winstanley, Dallas D'Silva

Apologies

Doug Ferrell, John Kung

Meeting Opened at 9:30am

WELCOME AND PROJECT BACKGROUND

After the introduction of steering committee members the history of the FRDC project and roles of the steering committee were discussed.

Snapper are classified as overfished in Qld, growth overfished in NSW, "Not defined" in SAFS (Qld, NSW, East Vic). Some concern over the different assessments between states and the need for a cross-jurisdictional snapper stock assessment was highlighted by the recent productivity commissioner's report as a priority.

National snapper workshop (2014) also recommended cross jurisdictional integration of data and modelling and recommended the use of genetics to help define "east coast stock"

The objectives of the project as described in the FRDC Project Description are:

1. Apply the latest cost-effective microsatellite genetic techniques to clarify and refine understanding of snapper stock structure along Australia's east coast.

2. Assemble and harmonise all available data sets and information sources, including archival and fisher knowledge data, *and develop a mechanism for stakeholder feedback on this resource.*

3. Develop computer models for the east-coast snapper population that *inform on inter-jurisdictional management strategies.*

4. *Develop protocols for inter-jurisdictional decision-making processes and stakeholder engagement.*

Note that the objectives of the project do not include implementation of management outcomes, rather to supply the tools that will assist inter-jurisdictional management and to highlight decision making processes when dealing with data gathered across jurisdictions.

ROLE OF STEERING COMMITTEE

The role and responsibilities of the steering committee were explained and in particular the role of stakeholder representatives were reiterated as:-

1. Contribute knowledge of and experience in the snapper fishery to committee deliberations.

2. Contribute to the development and implementation of strategies to gather information from, and deliver information to, the wider fishing community and public.

3. Consult closely with stakeholder peers through port-level associations, regional associations, peak industry bodies and other avenues as necessary.

Steering committee will be required to do some work out of session work but there will be a Workshop in Sydney in late March/Apr 2017 which will include the steering committee and other stakeholders from each state. The workshop and Steering Committee meeting will take place over 2 days.

There will also be a final meeting in Brisbane, probably sometime in June 2017

There was some discussion on the best way to engage with fishers. Social media was discussed as an option. Victoria is able to use social media easily as there is a good process in place. For other jurisdictions approval processes are in place. The challenge is the different policies and processes between states in using social media and the various communication and approval processes that each jurisdiction may have in place. This is partly what the project is about, coming up with protocols for cross jurisdictional decision making.

FISHERY DESCRIPTION AND MANAGEMENT IN EACH JURISDICTION

The management and nature of the fishery in each jurisdiction was then discussed. The snapper fishery in Qld is exclusively a line fishery, there is no trapping, some limited netting and some trawl bycatch. It is mainly a recreational offshore fishery, managed by MLS of 35cm TL and bag limit of 4 with one fish over 70cm total length for recreational fishers. There have been reductions in recreational bag limits over time and increase in size limit from 25 cm to 30 cm in 1993 and to the current 35cm in 2003.

The most recent quantitative stock assessment determined the Qld component of the stock to be overfished (using data up until 2007); with the majority of analyses estimating biomass below 35% of the unfished level (1945).

There is no indication of any type of recovery or improvement in the stock in Queensland and most of the lines of evidence have the Qld component of the eastern biological stock look in a poorer condition than when the previous stock assessment was reported in 2009.

Mention was made that the Moreton Bay green zones extend outside Moreton Bay and that the introduction of the green zones in the GBR particularly in the Capricorn channel all reduced the available area to be fished and should have had a positive effect on the stock.

The modelling will need to capture these changes over time in management regimes for each state.

John Stewart presented information on the NSW fishery noting the current MLS of 30cm TL with a recreational bag limit of 10. There are gear restrictions for recreational and commercial line fishers and for the trap fishery, restriction on trap sizes and numbers. There were also spatial restrictions such as marine parks/green zones. There have been recent commercial management reforms to do with share management. The two fisheries that deal with snapper are the demersal trap fishery and the line fishery with changes in the shareholding arrangements. Proposed 50 shares to get 30 traps + 20 shares will get you 10 more traps – currently 40 shares for 30 traps (up from 25 shares for 30 traps some years ago).

The commercial catch is mostly taken by trap (81%) and is highly selective. A further 16% is taken by line with 3% taken by other methods. As a comparison in 2013/2014 the commercial landings were 208t, recreational 148t with the charter sector taking between 10 to 20t. Most commercial landings are taken from north of Sydney, in contrast the recreational catch is taken right along the coast. Historically the total catch was about 800t a year.

Based on yield per recruit analysis done in the 1990s snapper are growth overfished in NSW; assessed by SAFS as undefined but considered sustainable as the biomass is not believed to be recruitment overfished.

Paul Sullivan points out that commercial fisher numbers are declining in NSW as well as closures causing further restrictions on where commercial fishers can fish.

John Stewart questions if technology has made a major difference to the trap fishery in NSW – Paul is working with SIMRAD on mapping bottom including hardness and softness.

Ross Winstanley presented a summary of the situation in Victoria and noted that Port Philip Bay has had ups and downs related to the removal of the scallop dredges during the mid-1990s and the scaling down of the commercial net fishery. Two surveys show that the recreational take makes up the majority of the catch in Victoria. A proportion of the Victorian Eastern stock (east of Wilsons Promontory) is taken commercially by trawlers and Danish seiners (managed by AFMA, Australian federal government) with the majority of the catch again taken recreationally. Of note is that the recreational fishery is made up of different sub-fisheries targeting different sizes fish. Target weights of individual fish range from 0.5 kg to 10 kg. As a result, a boat-based angler may take home up to 30 kg of snapper while a pier-based angler would be lucky to take a catch totaling 5 kg. Recreational bag limits of 10/day with only 3 over 40 with a 28 cm MLS. Ross mentions the value of research anglers with his graph reflecting similar statistics between his catch and those obtained by fishery independent research trawl surveys.

Challenges include estimating recreational catch and effort and the effects of changes in rainfall conditions and other environmental impacts upon recruitment. The western stock is strongly affected by good year classes which contribute to the fishery for several years. Mortality resulting from barotrauma in snapper released by anglers in coastal waters off eastern Victoria is regarded as a significant issue.

GENETIC STOCK STRUCTURE OF EAST COAST SNAPPER

Dr. Jess Morgan presented the results of a genetic study of the presumed east coast snapper stock. Earlier genetic research conducted during the 1990's using allozyme techniques had shown a weak genetic split at Forster. Research conducted as a part of the current genetic study which used microsatellites showed a split further south, at around Eden. A number of analyses were described and all analyses (Structure analyses; Pairwise F_{ST}; Discriminant Analysis of Principal Components and Genetic Isolation by Distance – IBD Correlation plus Mantel Test) reinforced this finding of two east coast stocks. If there has been a shift south in the split in the stock, it may be due to shifting boundary temperatures or currents but investigating causal mechanisms is beyond the scope of this investigation. Dallas noted that Victoria's take home message is they are masters of their own fate. Ross points out that it is a dynamic situation and that we need to keep that in mind. Wayne agrees, and the area of mixing of the two stocks in southern NSW may shift in relation to currents or other factors. CSIRO research suggests no snapper spawning in Qld within 30 years due to climate change.

Given that prior to this current research the east coast stock was thought to be one stock the relevant question is: what impact will having 2 stocks have for the modelling?? Paul mentions the need to ensure that there is good biological information on the different stocks. The bottom line of the genetics work is that localised depletions are possible within a given stock and the previous interpretation of a single stock from Wilsons

Promontory to North Queensland should now be regarded as two stocks. There is a mixing zone which may not be temporally stable in southern NSW. The genetic links with Tasmanian snapper samples are complicated by the small sample size from Tasmania and the fact that samples were collected over a wider geographic range along the northern and eastern Coasts of Tasmania. From a modelling perspective, this project will just be assessing the northern east Australian Stock but will still discuss the southern data, and significance of the southern components of the east coast stock. John Stewart noted that there was only a small proportion of the catch (approx. 5% of NSW catch) taken from the "mixing zone" in southern NSW.

DATA AVAILABLE TO BE USED IN MODELLING

Wayne described the data that is available from Queensland, noting an extensive history of commercial data dating back to 1988. Fish Board records are also available since 1937 up to about 1973. The commercial catch data is recorded in 30nm square grids and data can be summarised in a range of different spatial ways depending on the modelling requirements.

The reported snapper catch north of Proserpine is believed to be misidentification of tropical snappers, <1% of the total commercial catch and is not included.

The majority of the net harvest (which is a minor component in Queensland taken in Moreton Bay (in 2015 this was 1t). Fishery occurs in the southern regions of the state; catch locations are as expected and our monitoring captures this.

There has been an expansion into the northern area of the fishery in recent years, particularly around the Swains and offshore from Rockhampton and this has seen this area of the fishery contribute a larger proportion towards commercial catch (~40% in 2015); the relative importance of the southern component of the commercial fishery has decreased (but still accounts for ~50%).

To qualify that statement the reason the northern area has increased in importance proportionally is because the tonnages have increased in these areas (which is clearly evident in the data over the last four years where Snapper has maintained similar total harvest levels; 16t RO and 7t M from 7-9t RO and 2-4t M).

This expansion in fished area/ moving further offshore may be an indication of serial depletion.

Commercial catch (approx. 80t) and charter catch (approx. 10t) have declined as has recreational catch based on log book data and recreational surveys.

The pre-recruit abundance surveys show decline in raw snapper 0+ abundance from fishery-independent trawl surveys. 2015 estimates show (<1/ hectare) a relative decrease of ~60% since 2014 and a decrease of ~94% since 2011. Poor recruitment in recent years and very poor recruitment in the last two years.

The effect of technology (e.g., sounders, GPS, gear technology, electric reels) has increased the ability of fishers to find and subsequently catch fish. Other effects are the increase in range for recreational fishers with modern outboards and the use of electric reels enabling fishers to target deeper waters.

Release survival of snapper was an important input in the previous model. Recent research has shown that release survival of snapper was high (approx. 90%) regardless of depth of capture. There was some discussion around release survival with some members noting that their experience suggested that survival was much lower. The steering committee will assist in determining appropriate levels of discard mortality to be used in the models.

Recreational boat registrations are increasing and are often used as a proxy for fishing effort, however recent surveys have shown a decline in participation rate of fishers. Steve Campbell pointed out that the boats are bigger and often carry more than 2 fishers and this may need to be captured in any modelling.

There is good age and length frequency data available from Qld that has been regularly collected as part of monitoring programs and earlier research. These data are available for 1993 to 1996 and from2006 onwards.

There is good biological information on growth, maturity, spawning season and fecundity available from Queensland.

John Stewart presented the available NSW data. Data recording practices have changed over time for the commercial sector. Changes over time include: 1984 – 1997 catch and effort by month but only able to assign one method used in a month; 1997 onwards catch and effort by month by fishery and method; and 2009 onwards we have daily catch and effort by fishery and method. Note that NSW has reliable CPUE data back to 1984 from trap-only fishers (no confusion as to what mode of fishing was used).

Catch rates for trap and line fishery are available as well as some rec survey data (effectively only two points in time). NSW also have length frequency data from the port monitoring program including if it is from the trap or line fishery. This data is available from 1985 onwards with the most complete data from 2004 onwards. We can also compare the catch sizes between fisheries, however the trap fishery is a very selective fishery (selecting for smaller fish) which may cause issues when using the data. Different selectivities of the line and trap fisheries will need to be accounted for in the model.

Ageing snapper protocol is very similar to Qld but some work is needed on assigning the ages based on these protocols. **ACTION** John Stewart to work with Steve Wesche to “harmonise” the ageing protocols and assignment of cohorts between the two states. Possibly apply Queensland data algorithms to the NSW increment count data?

Need to look at growth and maturity as there are longitudinal differences with snapper from northern NSW maturing smaller and younger than those in the south. Spawning times are also later in southern NSW.

Also mentioned is the high post release survival of snapper. Previous models have used a fairly low figure but recent research suggests a much higher rate of survival.

Other sources of data have been suggested such as the charter data, however as this is a voluntary log book it is not considered robust enough to be of use. BRUV’s have also been suggested but suffer from the same problem. The rec licence is not as useful as would be thought as there are many concessions within the data that are not recorded.

Paul Hamer presented the Victorian data noting that the Western Victoria stocks are very different to the eastern stocks with regard to spawning behavior. 25000 snapper have been tagged with 735 recaptures, snapper are no longer tagged. Large recruitment spikes where Port Phillip Bay supplies up to 80% of recruitment to the adult fishery. Recruitment survey supplies a key indicator for recruitment to the fishery. Eastern Victoria fishery is very small whilst there is a small commonwealth managed trawl fishery with a 10t per year cap the reality is that only a few hundred kilos are taken per year. The open ocean access fishery can use various methods but don’t target snapper in particular, so Victorian commercial catch is less than 5 tonnes. The commonwealth catch is the largest (Danish Seine) but new rule mean they now have 200kg trip limits so 10 – 20 tonnes a year.

The recreational fishery is growing and there are concerns (discard mortality) about the catch and release component of the snapper fishery.

Unlike the situation in Qld and NSW there isn’t really much data available on the eastern Victorian stocks other than catch as there hasn’t been any length frequency or age data recorded. Hope to get some of this in the future.

USE OF HISTORICAL FISHERIES DATA

Ruth Thurstan presented (via Skype) some historical data collected from information as far back as the late 1890’s from a range of sources including 200 interviews of long term snapper fishers; government surveys, newspapers and historic books and other documents.

Information collected included types of fishing gear and technology used and impacts of changes in these; impact of regulation; motivation of fishers over time, catches, fishing effort.

Catch rate historically of 3.5 fish per person per hour without much change over time (at least up to 1950's).

Ruth notes that how the data will be used in the model is challenging given disparate data sources; small sample sizes; incomplete data; reporting bias; contemporary comparisons limited. This will be an important discussion point for the steering committee. Note especially that recreational fishing boats, and the numbers of fishers they carry, have become much smaller since around 1900, which is the main reason why catch rates per boat have dropped greatly since that time.

Historic data collected so far mainly comes from Qld but data is also being collected in NSW as part of this ongoing research. Ruth is also investigating current uses of social media as a source of data

The uptake of technology data will be useful in catch standardisations used in the fisheries model as GPS, sounders and fishing gear have influenced fishing power.

DEVELOPING A HARMONISED DATABASE (PRINCIPLES AND PROGRESS)

A Microsoft Access database will be used to store all the relevant data across the three jurisdictions. The database development is well underway and should be completed by February 2017 as per the relevant FRDC milestone. Currently the data entered into the database includes: Commercial: NSW and Qld commercial raw data; Charter: NSW and Qld charter raw data, Ray Joyce Gold Coast charter data - raw data and scripts; Recreational NSW and Qld Boat registration raw data and scripts; Age and length data: Qld raw data and some scripts; Weather and lunar data.

The database will not be live on the web but data products will be made available on the web over time.

Still to be worked out is how to enable access to the database for inter-jurisdictional users and this will be reported to the committee members out of session.

STOCK MODEL FRAMEWORK

Joanne presented the model framework along with some of the limitations and assumptions it will operate under. The Model is designed to handle the range of data both spatially and temporally. Model limitations include: do we need Victoria in the model given the separate stocks; the fine spatial aspect and trying to capture only some management procedures.

Progress is underway with the draft theoretical outline for model by end of December. Stock model (historic and current) code by Feb, March. Forward simulations completed by Sep 2017 (draft report).

There was discussion about fisheries modelling and how that related to the previous assessment. Wayne's opinion was that stock assessment models were inherently difficult to explain and many of the technical and mathematical aspects could not be It is possible to explain parts of the processes.

Dave Bateman and Paul Sullivan were asking how the model accounted for the changes in MLS and bag limits over time. George demonstrated on the white board a visual graph explaining how the model accounts for changes in size limits over time.

Paul Hamer noted that it was important for stakeholders to understand what the models were trying to achieve and to explain the model.

POLICIES AND STRATEGIES FOR STAKEHOLDER ENGAGEMENT IN EACH JURISDICTION

The Queensland Department of Agriculture and Fisheries Stakeholder Engagement strategy was presented as a template for deciding how to engage with stakeholders.

Previous costly engagement process used in 2008 when management of the snapper fishery was last reviewed will not be possible in Queensland due to budgetary constraints. That earlier process had a large representative working group which met many times over a two year period, many well publicised port meetings and technical meetings but was still criticised.

Wayne noted that stakeholders will need to go back and get approval from each jurisdiction on mode of engagement and communications strategies.

John Stewart described stakeholder engagement in NSW noting the use of working groups but no real representative bodies for engagement. NSW still have some avenues for engagement in rec fishing NSW, commercial bodies (struggling), indigenous body. Some use of Facebook but no policy, so everything has to go through a departmental communication unit but they are good to deal with.

Steve makes the point that you want people to be informed regarding the stock assessment so that you don't get the problems experienced with the 6 week closure last time management was changed in Queensland.

Paul Hamer noted that there was no engagement policy in Victoria that he was aware of but approval protocols were in place. Facebook used and much more fluid – easy to use. Targeted forums on key species i.e. Annual trout conference and the "Codference" work well. So forums more about education rather than management and the resultant conflict. The share issue between recreational anglers and commercial has been resolved (recs won). No management plan currently in place. Looking at angler satisfaction in creel surveys.

Matt Campbell pointed out issue of biased data due to removal of commercial netters in Corio Bay. Questions are targeted to how satisfied fishers are on the days fishing.

Dallas remarks on the success of getting the message out through Facebook and social media channels.

Wayne asks what the main objectives are and what is the message that we want to put out? Issues with getting info back rather than getting info out. Good news stories easy but problems arise when you bring in tougher management issues or discuss unpopular issues. So you have to be careful with open communication like Facebook. Particularly in jurisdictions that have had a history of conflict.

Ross spoke about how Victoria has had quarterly meetings with rec, media and fisheries reps instead of advisory bodies.

Paul H Reason of engagement in Victoria is currently to find out what objectives the recreational anglers want with regards to fishery performance etc. .

Steve Campbell makes the point on informing people with regards to stock issues to alleviate poor responses.

Wayne - how to get feedback from stakeholders: Rec fishing; Commercial, green groups, and the general public. Media releases and other project information is already available on the FRDC website.

Dallas mentions using survey monkey from your Facebook page. There was discussion on the desirability of a single point in time for feedback for ease of analysis.

Dave B mentions that a large percentage of people over 60 don't use Facebook and it is important to engage with this demographic.

Point was raised that a recreational licence in Queensland would be good for creating a database of fishers even if the licence has no fee, but FQ would require cost recovery. Ross mentioned a level of administration and handling cost for Victorian licences of about $3 per licence.

Dallas message: "you care about Snapper, we care about Snapper this is why our scientists are working on snapper"

Dave B don't put out messages from Fisheries Queensland, rather put them out under FRDC or Agri-Science Qld due to previous history of management conflict.

Dave B noted the importance of stressing the feedback is on research and data NOT management.

Paul Sullivan queried what would happen if researchers don't agree with each other on the outcomes i.e. NSW says snapper are fine and Qld says it's stuffed. Wayne's answer is that this project is about ensuring that issues are dealt with and some form of consensus is reached.

Paul S also noted that the current snapper season where he works was the best in 30 years so how do you deal with the fact that Qld snapper may be in trouble? He thinks closures of estuaries to trawling have been especially good for juvenile snapper nursery areas. Jess replies localised depletion still possible as the model looks at the overall stock.

Wayne pointed out that members should go back to communication groups in each state and investigate acceptable ways to move forward with regard to stakeholder engagement, i.e. survey monkey and email/posted surveys. This will be dealt with out of session over coming weeks and more information will be provided to committee members for their consideration and input.

Meeting closed at 3:30pm.

Appendix 7

Presentation on New South Wales snapper fishery description and management from first steering committee meeting

NSW management

- 30 cm TL minimum legal length (all sectors)
- Recreational bag limit 10 fish
- Gear restrictions
  - Trap dimensions
  - Trap numbers
  - Recreational & Commercial line
- Spatial restrictions
  - Marine parks

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NSW commercial management reforms

- Two major snapper fisheries moving to increased minimum share holdings.
  - Demersal fish trapping
  - Line west
- 30 fish traps per minimum share amount and more can be used if more shares are owned.

Department of Primary Industries

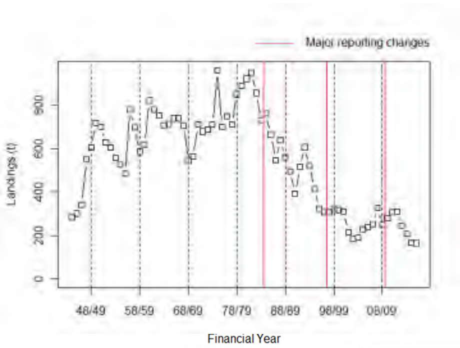
Fishing sectors and gear

- Commercial sector ~ 208 t in 2013/14
- Recreational sector ~ 148 t in 2013/14
- Charter sector ~ 10 to 20 t

- Commercial catch
  - Traps 81% (highly selective over size range)
  - Line 16%
  - Other 3%

NSW GOVERNMENT | Department of Primary Industries

Commercial landings



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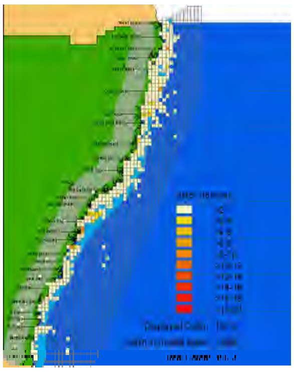
NSW GOVERNMENT | Department of Primary Industries

Commercial catch



- All NSW coastal waters
- Majority of commercial catch is in from Sydney north
- Important recreationally everywhere

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Stock status

- Snapper are GROWTH OVERFISHED in NSW
  - Based on yield per recruit analysis since 1990s
- SAFS – Snapper are assessed as Undefined
  - The NSW component of the biological stock is considered Sustainable (biomass not recruitment overfished and fishing pressure unlikely to cause the stock to become recruitment overfished).

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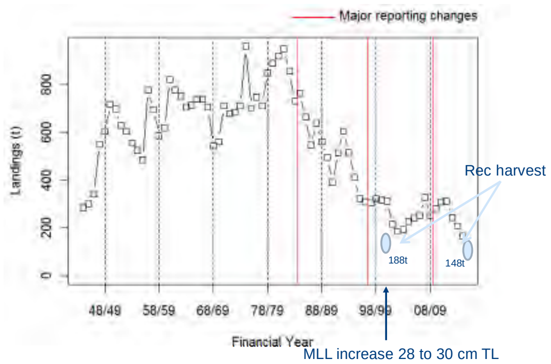
The new state of business

NSW Snapper fishery data available

[redacted]

Harvest



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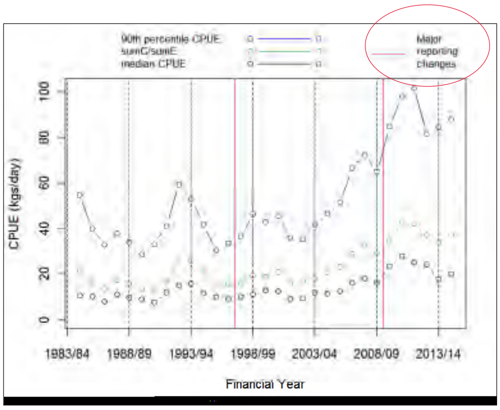
Catch rates



2009 an issue??

Trap

Line

Recreationa
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(2 points)

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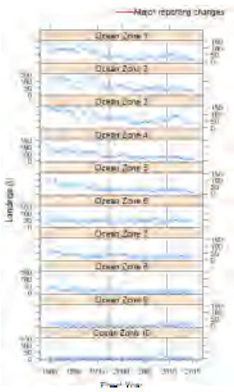
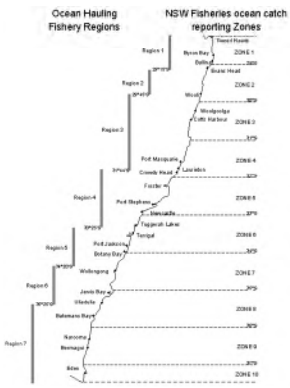
Spatial resolution 1984 onwards





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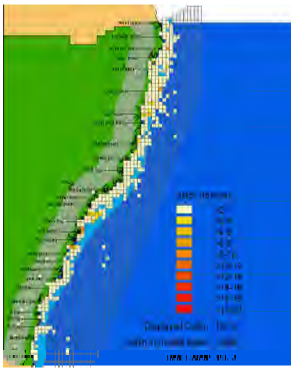
Spatial resolution 2009 onwards



6 minute grids

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Temporal resolution

1984 to 1997 - catch and effort by month

- Only assign to method when single method used in a month

1997 onwards - catch and effort by month by fishery and method

2009 onwards – daily catch and effort by fishery and method

NSW GOVERNMENT Department of Primary Industries

Commercial monitoring program

- Port sampling (co-ops and Sydney Fish Market)
- Stratified spatially (ocean zone) and temporally (month)

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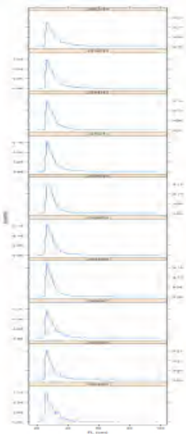
Sizes in commercial landings



- Length data 1985 onwards
- 'Best' series 2004 onwards
- Trap vs line methods (trap very stable)
- Can be in financial or calendar years
- Some trap and some line fishing observer work (discards)

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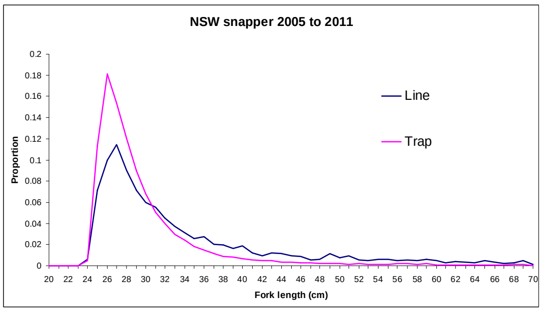
Trap selectivity



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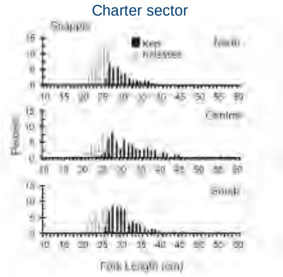
Sizes in recreational and charterboat landings

- Snapshots – 1993 to 1995 (Steffe et al. trailer boats)
- Charter – 2014 observer study

Charter sector



- High proportion discarded
- Substantially smaller fish than commercial line catch
- Few fish observed

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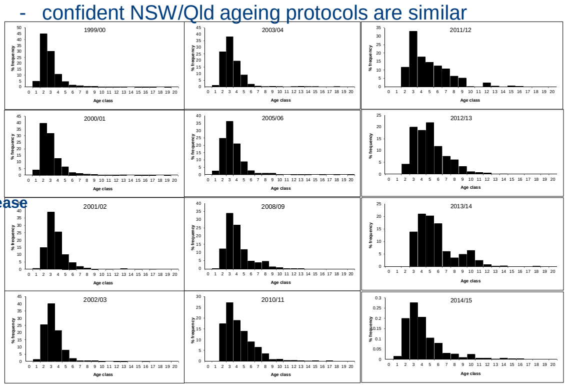
Ages in commercial landings

- currently exist in financial years
- confident NSW/Qld ageing protocols are similar

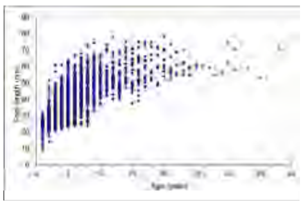
MLL increase



NSW GOVERNMENT | Department of Primary Industries

Growth and maturity

- Growth - size-at-age data. Some tagging data
- Maturity - varies with latitude.
  - Nth NSW 50% mature at ~22 cm FL and < 2 yrs (much smaller and younger than in 1980s)
  - Sth NSW 50% mature at ~27 cm FL and 3 yrs
- Spawning time varies with latitude – later in the Sth
  - Peak August Nth NSW
  - October? Sth NSW



NSW GOVERNMENT | Department of Primary Industries

Discard rates and survival estimates

- Observer data on the commercial trap and line sectors
- Observer data on inshore charter sector
- Very high rates of survival of released snapper

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Data sources not considered robust for assessment

- Charterboat – logbook catch, effort, lengths
- BRUVS – marine park monitoring
- NSW licence sales as proxy for recreational effort???

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Appendix 8

Victoria notes on stock assessment of snapper

20th century snapper fishery assessment

Ross Winstanley

Victoria's snapper fishery is at the front of the wave when it comes to the development and application of technology and modelling the way fisheries and fish stocks respond to changing conditions. And yet, with the greater part of the fishery for Victoria's western snapper stock shifting further into the hands of Port Phillip Bay anglers, stock monitoring and fishery management are becoming increasingly dependent on a band of volunteer anglers.

There are several significant implications of the phase-out of commercial netting and the scaling down of longlining in the Bay. From 2022, commercial snapper fishing will be restricted to 88 tonnes shared among up to eight longline anglers.

So, this year marks the start of an 8-year process that will end the 100+ year time series of commercial net fishing records, including the detailed catch and effort statistics collected across a range of commercial fishing methods since 1978. Until recently, this commercial fisheries information has provided the main basis for monitoring and assessing the state of the snapper stocks and the impacts of fishing. After 2022, all that will remain will be a maximum of eight longliners.

This provides one of several good reasons for anglers to get behind the snapper monitoring and assessment program as its importance rises. As the 'major shareholders' in the western Victorian snapper stock and the Port Phillip Bay fishery, anglers have a strong proprietary and emotional interest. Their demands essentially drove the incoming Labor Government's 2014 commitment to phase out commercial netting in Port Phillip Bay. Now that their demands are being met, anglers have more reason than ever to actively engage in stewardship of the Bay fish stocks. Bay anglers along with all other Victorian recreational fishers now bear the costs of the creel survey, Angler Diary and Research Angler programs, met from the Recreational Fishing Licence trust account.

2016 STOCK ASSESSMENT

Early in June, Fisheries Victoria held the first Victorian snapper stock assessment workshop since 2011. In the interim there has been a great deal of research work done, reviewed and reported on snapper. However, this workshop provided the first look at how the future might look as the Port Phillip Bay fishery begins to transition to an even more strongly angler-dominated state. While the workshop's main focus was on the fisheries in the two bays, it examined the current state of knowledge of the western Victorian snapper stock as far as its boundary near Kangaroo Island, SA, and the eastern stock as far as the NSW border (see figure 1).

The workshop covered and updated information on the year-to-year pattern of recruitment (spawning success), the continuing fish-down of the large year classes spawned in 2001 and 2004 reflected in the recent decline in catches of big snapper, and a Melbourne University study of the critical Yarra River flows, temperature and nutrient requirements that determine snapper larval survival in the first few days after hatching.

The updated monitoring of annual year-class strength at age 0+ years shows that, after average or above average recruitment in 2008, 2009, 2010, 2013 and 2014, we've had two very poor years. The pattern of declining catch rates of pinkies in the January-April period, since 2011, was reflected in Angler Diary and creel survey results for Port Phillip Bay. What matters most is the healthy recruitment in five of the past nine years. As reported in the April issue of VFM, the 2013 and 2014 'recruits' are now entering the legal-sized pinkie fishery and will progress into the adult (ie >40cm) snapper fishery from 2020.

Until now, the separate trends in commercial haul seine and longline catch rates have provided excellent indicators of trends in the abundance of juvenile and adult snapper. Haul seining mainly targets pinkies while longlines mainly target larger adult snapper. Catch rates by the eight longliners who are expected to continue operating beyond 2022 will provide a vital ongoing indicator of the stock of large snapper. With the licence buy-out already leaving just 10 commercial operators in 2016/17, we cannot rely much longer on haul seine catch rates as a fishery 'performance measure'. This means that far greater reliance will now rest on monitoring the recreational fishery through the ongoing creel survey, Angler Diary and Research Angler program.

Annual commercial catches from Port Phillip Bay varied between 30 and 100 tonnes from 1991/92 until 2011/12 when they rose to a 20-year high of 162 tonnes before falling away over the past four years. The recent pattern of reducing commercial catches was reflected in longline catch rates for large (>8 years) snapper. Length composition data from both creel surveys and Angler Diaries clearly showed the steady depletion of snapper larger than 40 cm between 2011 and 2015.

The only two available estimates of the recreational take from this stock, were approximately 300 tonnes in 2000/01 and 450 tonnes in 2006/07.

The overall assessment of the western snapper stock was that the abundance of legal-sized fish is stable, undersized snapper numbers are increasing and the stock status is healthy.

It was pointed out that a significant sector of the snapper fishery in both bays – the recreational fishing charter industry – remains unregulated and unmonitored in terms of the impact of their activities on the snapper stock. While recreational fishers continue to bear fishery monitoring costs, the charter industry is exempt from any requirement to contribute catch, effort and size composition information that could be so valuable to stock and fishery assessments.

SA LONGLINE FISHERY

New information presented showed the emergence and impact of a commercial snapper fishery targeting 'Victoria's' western snapper stock in southeastern South Australian waters, beginning in 2005. In both 2009 and 2010, SA longliners took more than the catch by Victoria's commercial Port Phillip Bay and ocean fisheries combined. Catches by the SA fishery dwindled to virtually zero by 2015, apparently as a result of the decline in large snapper numbers as those older year classes were fished down or moved out of the area, making longlining unviable there. Still, this is a legitimate and potentially substantial fishery to keep an eye on in future. Fisheries Victoria and their South Australian counterparts are looking into this cross-jurisdictional aspect of the western stock fishery.

In contrast, off the Victorian coast the reported annual trawl and Danish seine take of snapper, which got anglers irate around 10 years ago, has rarely exceeded 30 tonnes and has decreased to less than 10 tonnes in recent years.

EASTERN VICTORIAN SNAPPER STOCK

Since detailed records began in 1978, the annual Victorian-managed commercial snapper fishery east of Wilsons Promontory rarely exceeded 10 tonnes. The harvest by Commonwealth-managed trawlers rose sharply in 2004/05, peaking at around 25 tonnes in 2011/12 before falling to average less than 10 tonnes in the past three years. The only two estimates of the recreational take from this stock, in 2000/01 and 2006/07, were both around 30 tonnes.

Spawning aggregations are known to occur off the Ninety Mile Beach. At times, along the East Gippsland coast and up into NSW, small juvenile snapper move in large numbers to coastal inlets before moving out into open coastal waters at 1-3 years of age. Even as juveniles, eastern stock snapper move from eastern Victoria, where the stock is lightly exploited by both commercial and recreational fishers, up into NSW and southern Queensland waters where the stock

Snapper stock structure in south-east Australia

Figure 1: Distribution and movement patterns of snapper stocks in Victorian and SA waters.

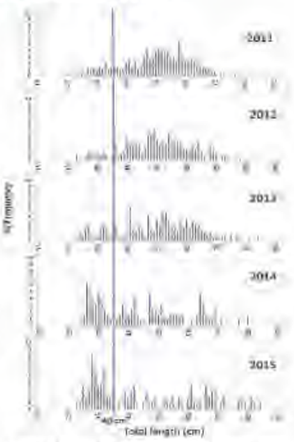


Figure 2: Port Phillip Bay Spring creel surveys show the decline in numbers of adult snapper (>40cm) and the entry of pulses of pinkies in 2014 and 2015 snapper stocks in Victorian and SA waters.

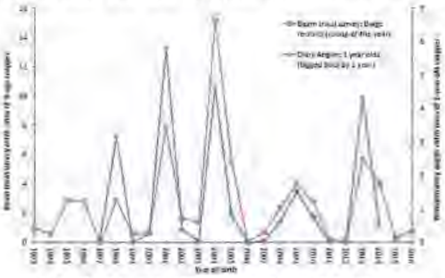


Figure 3: The remarkable agreement in research-trawl catch rates of 0+ year olds and a single volunteer's catch rates of 1+ year old snapper shows the value of the Angler Diary Program.

has been assessed as being over-fished.

The overall assessment of the eastern snapper stock in Victorian waters was limited by a lack of fisheries data but information from fishers in that region suggested that the fishery appears to be in a healthy condition. The workshop heard that a three-state study is being conducted with a view to a consensus approach to assessing this stock, which is exploited to such widely varying degrees from Victoria to Queensland.

A growing concern off the Ninety Mile Beach is the increased recreational catch and release fishing targeting spawning aggregations in 35-45m depths. Numbers of distressed 8-9kg fish are being sighted on the surface during the peak November fishery. This indicates the need for a targeted angler education campaign highlighting the fate of these snapper, urging anglers to stop fishing once they achieve their allowable bag limit and advising them on catch and release methods that can maximise the survival of snapper released in these depths.

CREEL SURVEY

Queenscliff's creel survey program has been operating continuously since 1998 in Western Port Bay and since 2002 in Port Phillip Bay. This program provides essential information on angler catch rates and the size composition of the legal sized snapper retained by anglers during the spring 'big snapper' and summer-autumn pinky fishing seasons. The latest results show spring catch rates of large snapper rising steadily from 2002 to 2012 then falling sharply (see figure 2) as overall fishing pressure and natural mortality finally began to exhaust the large pulses of fish spawned back in 2001, 2004 and 2005.

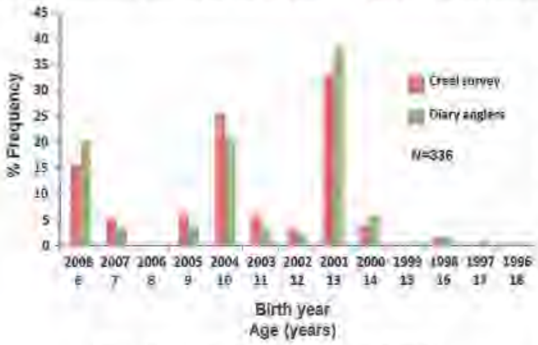


Figure 4: Age composition of snapper taken by Angler Diary and creel survey anglers in spring, 2014.

The results for the January to April period showed a generally declining trend in the mainly pinky fishery from 2004 with an up-turn in 2015 as legal-sized pinkies from the successful 2013 spawning began to appear.

Today, catch rate estimates derived from the creel survey program enjoy a high level of confidence. In the near future, the program's detailed continuous data set is about to assume an even greater role in the monitoring of the snapper stock and fishery, including the estimation of the recreational snapper catch. There have only been two recent estimates of the recreational snapper catch – in 2000/01 as part of the National Recreational Fishing Survey and, in 2006/07, as a separate snapper catch survey. Both surveys directly measured the recreational catch using methods that are expensive and time-consuming, hence the lack of more recent and frequent estimates.

To overcome this, Queenscliff researchers are trialling the use of cameras mounted at six boat ramps around Port Phillip Bay and one at Hastings. These 'ramp-cams' record and store boat launch-and-retrieve images every two minutes. An upgrade of this approach, using motion-activated cameras is planned. This approach is a real advance over the traffic counters, which have the inherent inaccuracies resulting from non-fishing vehicle counts and regular vandalism.

The large bulk of the recreational snapper catch in both bays is taken by boat-based fishing. Once the ramp-cams are developed to the point of providing comprehensive estimates of boating trips, it will be possible to estimate the snapper catch from each bay annually, simply by multiplying the catch rate (from creel surveys) by boat trips (from ramp-cams). These estimates are absolutely essential to ensuring that snapper fishing is maintained at sustainable levels and are a key piece remaining in the effort to make this the most well managed and sustainable snapper fishery in Australia.

ANGLER DIARY CONTRIBUTION

This was much more than some earlier workshops which had amounted to little more than plotting the most recent data points onto a few graphs. What particularly impressed the 12 Angler Diary volunteers who participated were the advances being made in the application of technology and modelling and the increasing importance of their contribution to snapper assessments.

Dating back to 1997, the Angler Diary Program has provided a continuous time series of information on catch rates and size composition of snapper and other species targeted by anglers. The key characteristic of these angler volunteers has been their commitment to fish in much the same ways in the same areas, year after year, recording complete details of their fishing activities, gear, bait and catches, including undersized and released fish.

Twice yearly, the volunteers also operate as Research Anglers, fishing to researchers' directions and using standard hooks provided to enable them to catch snapper of all ages from age 1+ year upward.

Dating back to 1997, the Angler Diary Program has provided a continuous time series of information on catch rates and size composition of snapper and other species targeted by anglers.

The combination of their fish size and catch rate data has yielded what has proved to be a reliable indication of the relative abundance of juvenile snapper, mainly 1-5 year olds. Until 2011 when the annual Bay trawl surveys ended, Research Angler records provided a third-string indicator of year-to-year recruitment as one-year-old pinkies became vulnerable to hooking at lengths of above 15 cm. As Figure 3 illustrates, this information closely mirrors the annual recruitment trends determined by Queenscliff researchers' fishery-independent sampling.

Port Phillip Bay diary catch rates of mainly spawning snapper during October-December since 2006 varied between 1.0 and 1.5 snapper per angler hour. Size composition records clearly showed the decline in numbers of snapper above 40 cm since 2011. Aging of samples of these larger fish taken from October to December 2014 showed the dominance of year classes spawned in 2001, 2004 and 2008 with only small numbers of fish from spawning in other years as far back as 1997 (See figure 4). The current decline in adult numbers is not expected to stabilise until 2020 when improved numbers of pinkies spawned in 2013 and 2014 reach maturity.

Since 1999, during the pinky season from January to April, the diary catch rates varied between 3-6 snapper per angler hour, with a downward trend from 2011.

RECRUITMENT OF DIARY VOLUNTEERS

The termination of the annual trawl survey in 2011 has left the Angler Diary Program as the only ongoing medium for monitoring snapper year-class strength at ages above one year. Increasing researchers' reliance on these angler volunteers. Given the older ages of current participants, there was general agreement at the workshop on the need to recruit younger Angler Diary members.

The results of a review of the Angler Diary Program conducted earlier in the year were not available at this workshop. One of the issues discussed during the review was the desirability of moving from on-board pencil and paper recording of fishing and catch details – later transcribed and submitted in paper logbooks – to immediate electronic data entry and reporting. Anglers at the workshop considered that a shift to on-board electronic data entry will be vital to attracting younger members.

ACOUSTIC TAGGING

The tracking study of snapper movements into, around and out of Port Phillip Bay, using acoustic tags ran from 2011 until 2014. The study followed the movements of 160 tagged snapper, tracked by 47 'listening stations' around the Bay and across Port Phillip Heads. Adult fish were found to move into the Bay, mainly in October, while many left in December immediately after the main spawning period, with a smaller wave of fish exiting in April and May each season.

The Department website shows highlights of the program (see http://agriculture.vic.gov.au/fisheries/science-in-fisheries/fisheries-research-findings) and a final report on the project is being prepared.

WHERE IS THIS ALL HEADING?

Distinct from the long-standing monitoring and assessment of the state of snapper stocks and fisheries, Victoria's snapper research has been advancing in areas of modelling and the development of 'harvest management strategies'. The aim of this is to measure and improve the quality of fisheries management and to make quantitative forecasts based on the array of data now being collected across snapper lengths, ages, growth, recruitment, catches, catch rates and fishing effort.

Harvest strategies provide a structured approach to responding to changes in the snapper stock or fishery in order to keep within boundaries set to ensure that fishing remains sustainable. The modelling tools being developed can compare the risks and benefits of different management options.

All this may seem quite abstract and academic to many anglers, given the 'healthy' status attached to Victoria's snapper stocks and fisheries over the past decade or more. However, as we are already seeing with the Port Phillip Bay sand flathead stock decline, long term environmental changes are occurring and can have significant impacts requiring adjustments to management arrangements. With southeastern Australia seen as a climate change 'hotspot' we need to be preparing to make management adjustments to ensure the best ongoing benefits from snapper, whiting, flathead and other fisheries resources.

Until now we have managed with just two estimates of annual recreational snapper catches, most recently in 2006/07. However regular, reliable and less expensive catch estimates will be critical ingredients to the models and harvest strategies needed to manage our fisheries sustainably in the face of change. That's why the ongoing combination of creel survey, volunteer angler and ramp camera data are so important to the future of our snapper fisheries.

ANGLER DIARY VOLUNTEERS NEEDED

The contribution by angler diarists in tracking undersize year-classes of snapper fills an important knowledge gap and helps us forecast future snapper catch rates in the fishery. The Angler Diary program is funded by Recreational Fishing Licence fees and is a great example of volunteer anglers giving back to the management of their fishery.

If you're keen to know more, contact Pam Oliveiro on 5258 0233.

Appendix 9

Notes from second steering committee meeting.

Inter-Jurisdictional Snapper Project Steering Committee

Meeting 2

14 July 2017

Mercure Airport Hotel, Sydney

RECORD OF MEETING

RECORD OF MEETING

Attendees

John Stewart, Paul Hamer, Steve Campbell, Michael O'Neill, Dave Bateman, Dave Rae, Matt Campbell, John Kung, Joanne Wortmann, Jess Morgan, George Leigh, Ruth Thurstan, Wayne Sumpton.

Review of issues from Workshop conducted previous day

- Qld charter data. Wayne says that the charter data is compromised by the fact that charter operations are businesses rather than fishing operations. Issues around whether charter catches are a reliable index of abundance. George L. says that charter operators are fickle and their target species change from year to year. Charters are commercial operations and fish regularly knowing where fish are and can return to the same locations and follow schools of fish (hyperstability)

- Michael says Ray Joyce's data is a reasonable fishery-independent index of abundance. Critical issue is that we don't know how Ray Joyce's data relates to the entire stock. Ray Joyce is a long-term collaborator with Wayne. Wayne helped set up Ray's database. Ray collected lots of data from 13 vessels, measured fish and quantified discards. Citizen science. Michael highlighted the fact that the Ray Joyce data also contains zero catches which is a significant plus. Note fishers didn't want to cooperate with the Ray Joyce data collection from 2009 onwards so data from this period should not be used. Probably shouldn't use Ray Joyce data as it isn't representative of the stock – like the MB recruitment survey. More localised. It was decided to not include Ray Joyce charter data in the base case model but use it in a scenario run.

- The last snapper stock assessment only included Qld but now we have to include NSW data and the only source of long-term commercial time series.

- John S. brought up the point that we could be using some datasets twice i.e. charter data used in rec survey. They are not independent. Rec data recorded by recreational surveys for charter should be removed from the rec estimates (i.e. reduce rec estimate) and rely on charter logbook data instead but the charter data is underestimated due to under reporting in the logbooks. How important are these data to the model needs to be resolved.

- John S. cautioned against using catch rates from recreational surveys which are designed only to measure catch *size*. The analysis to get catch *rates* is very complex. Contact Jeremy Lyle and Kate Stark in Tasmania for details. Michael thought project timelines would not permit this. The meeting was therefore in favour of omitting recreational catch rates. George L. said rec catch rates would be much more useful if the same fishers could be surveyed from year to year, instead of a different set of fishers each time, as the skill levels of fishers varied greatly.

- Maximum fish age up to 38 years

- Why compare with 1880, explain why science needs to do this in the report

Historical data

- Issues around both hyperstability (maintaining catch rates by going to new ground) and hyper depletion (catch rates fall because fishing starts in areas of highest abundance and new ground is less productive) for the historical data. Difficult to link the historical data to modern day. Steve said that the 1880 data would be viewed as not correct by the community; people tend to distrust history that predates their own fishing experience. But not a reason to exclude from the analysis. Michael said we would use the various MLS to assess the historical data. Paul asked how the data would be used: George L. said that it is the trend that will be used, not the observed, i.e. all data (historical and present) standardised to the same scale. John Stewart said that we should include management changes that have occurred over the historical time scale and Ruth said that we should also add technological changes.

- Effects of shifting baseline syndrome - The phrase describes an incremental lowering of standards that results with each new generation lacking knowledge of the historical, and presumably more natural status.

- After discussion: Michael and George suggested that we should run a scenario with and without the historical data.

- Historic data and graphs need sample size by decade and region – need to describe data – who, where, when.

- Note that variance in the data is included in the stock assessment modelling.

Moreton Bay recruitment survey data

- George suggested we do a run with that data included. Not in base case. Michael says it would be best to have recruitment surveys across more locations to get a good idea about abundance. John S. agrees that this may be a good idea. Jess suggests adding it with zero weighting so that there is scope to add it if future surveys are conducted. John also suggested that it may become problematic to have data and then omit it. We would need to defend our actions in omitting these data.

- The MB survey is the most localised data set and thus may not represent the situation in the whole stock.

- Recommend to expand recruitment surveys into NSW and do more locations along the coast.

- The MB survey can be used in harvest strategies and setting TAC for Qld. Regardless of its use in the stock model it is important to use and consider in stock status reporting for Queensland.

Data sources

- NSW trap, NSW commercial line, Qld line, Ray Joyce data, Qld rec, historical all in base case. Michael said that the Qld rec data is good in that it includes a large number of fishers and areas. Wayne says that they rec CPUE should be included. Paul questioned George L. about avidity, asking if we could subset the rec data for only avid anglers (>5 trips per year). Final discussion: Recreational catch rates should be removed but discuss with Jeremy Lyle et al.

- Note 2005 point should not be included in the recreational catch rate graph of 2000, 2010 and 2013 as it was estimated by a different methodology

- In the report the 94/95 rec estimate needs to be explained better as it uses another methods (on site creel surveys and aerial surveillance)

- Important for commercial catch rate data to keep track of skipper id

- Recreational catch rates – distribution of random fishers need to be similar between years; subset and check avidity for fishing power effects

Biological data

- *Discard rates* are a problem. Survival is high when predation is excluded. Steve said sharks are a problem on the way up and Dave B said dolphins are a problem for discarded animals. John Stewart and Matt C said that we should use the published rate of post-release survival (about 0.86). Need to run another scenario where the mortality is 0.3 (survival 0.7). No real consensus achieved here. Need to handle with sensitivity analysis.

Communication and Engagement

- John Kung presented the Fisheries Queensland Sustainable Fisheries Strategy. No discussion apart Steve expressing frustration about Fisheries Queensland strategy of mandatory satellite location monitoring.

- Paul Hamer: Science extended through Facebook. Vic uses YouTube clips to extend research. Lots of research projects funded by Recreational Licence fees so they extend these results using video rather than science reports like an FRDC report. Also expecting to invite other scientists to discuss a species and broadcast that on Facebook.

- Steve noted that for the QSIA most communication was via email and word-of-mouth. Wayne said DAF's communication strategy is aimed at rec fishers. Sunfish have an extensive network through which communications can be extended. Steve said that contacting fishers via SMS is a good idea and linking to information on the FRDC website.

- Wayne said the strategy will revolve around using simple social media posts pointing people who are interested to more detailed information on the FRDC website. This will be the strategy used by DAF but stakeholders can use whatever method they think is appropriate to inform their members. Dave Rae said that lead times are two months for Fishing World but a brief of information could be posted to the Fishing World website, linking to the FRDC website.

Online Updates

It was agreed to re-order the timing of the updates presented in the Communication strategy to the following order and timing for release on FRDC site is also shown.

1) Genetics update (31 July)

- Map needs to be improved. Best to put place names rather than latitudes. Put place names on y-axis and catch on x-axis. Paul said that breaking the Victorian stock into two based on Wilsons Prom. Steve said graphs are important and Dave B said that the graph needs improvement. Change catch to proportional catch. Decision: remove graph and replace with a picture of a snapper or someone with a fin clip.

2) Historical snapper data (15 August)

- Important to show snapper fishery started before many other fisheries. See Ruth's notes.

3) Differences between NSW and Qld (30 August)

- John Kung said that it is important to point out that catch is 80:20 NSW and trap is dominant sector. Should also put in descriptions of the four sectors accessing the fishery. Important to capture the differences in methods and how they contribute to stock assessment. Also include some management arrangements like MLS and bag and size limits.

4) Technology update (15 September)

- Facebook page should say technology has increased efficiency and have a graph of GPS and sounder uptake only, then link to FRDC website where more info is located.

5) Biology (15 September)

- John Stewart said that a growth scatter plot is a good idea showing longevity and variability in growth. Check with George L. about a plot showing LF bar graphs stacked by ages with MLS superimposed. Dave suggested that we should have links to previous updates and also let people know when the next update will come out. Release survival video links to DAF, InfoFish and NSW Fisheries.

Magazine article

- Dave Rae thinks the history stuff should be included. Photos interspersed with information about historical catch rates. Should link to survey monkey. Paul said at the end of the article there should be a paragraph saying that the historical data will be used in the stock assessment.

Climate change and environmental impacts - Paul Hamer

- Larvae linked to recruitment and larvae numbers driven by environment. Composition of plankton driven by rainfall. High flows result in high numbers of diatoms which produce chemicals that result in high mortality of copepods which the snapper larvae prey on.

- South-east Australian waters are likely to experience significant increases in temperature in the future so it is important to examine the links of temperature and recruitment. Looks to be temperature window – 16.5-22°. Aquaculture has shown the optimal temp for egg survival 15-22 while larvae 18-27. So for both, 18-22°.

- Models predict that in 2063-2072 there will be no months when water will be at optimal temperature in Queensland. In contrast, more southern areas will have more time in optimal temperature range.

Stakeholder Feedback - Design of questions for the online survey

- Background info re avidity, etc. will be part of the preamble. How often you fish, how many years you have fished, do you fish for snapper. After some discussion it was agreed that the survey should go on the FRDC website (after checking with FRDC and FQ). It was also agreed that a categorical rating system be used which allows quantification of results rather than a system of extensive comments which need interpretation and are time consuming to analyse. Short questions are much better and we need to check if images can be used in the surveys as well. Get final guidance from communication experts but questions and preamble should include the following questions (very rough draft at this stage).

Preamble of survey to include the following

- Age of fisher (Check boxes)
- Postcode
- Location where usually fish for snapper (divide into 10 regions?)
- Sector (com, rec, charter)
- How often you fish? (Check boxes)
- How many years of snapper fishing experience do you have? (Check boxes)
- What technology do you use (Check boxes)

There was wide ranging discussion about possible questions. Broad question topics discussed and agreed to were those listed below. Once the questions are better crafted they will be forwarded to committee members for further comment and agreement. We need to work on a consistent categorical scheme for recording answers. This will be done in consultation with communications specialists.

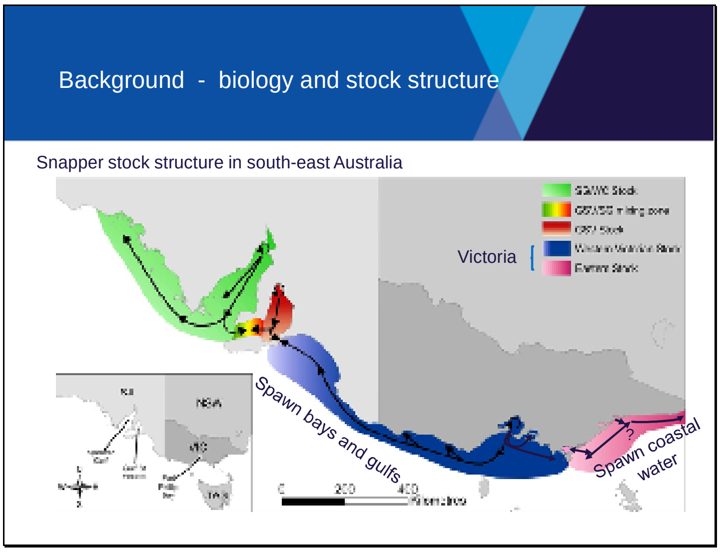
1. Fishing power: If you didn't have a GPS what would happen to your catch rates? More Less Same?
2. Fishing power If you didn't have a colour sounder what would happen to your catch rates? More Less Same?
3. Fishing power: If you think fishing technology in general has improved your catching ability, by what percentage do you think it has improved your ability to catch fish? Check boxes
4. Discard mortality: Published science has estimated release survival of snapper at about 85%. From your experience is it - more, less don't know.
5. Mortality: since you started fishing have you noticed a change in predation of you catch by sharks more, less don't know.
6. Catch rates: We have information on historical catch rates from 1880-1960. Do you see value in using these data in assessing current fishery status?
7. Catch rates: based on you experience how has the abundance of snapper changed in your fishing area -Same, less, more, don't know
8. Size: Since you started fishing, and allowing for the changes in size limit, do you think that the size of snapper you catch is increasing, decreasing, same, don't know.
9. Size: To what do you attribute that change? List items to tick off.
10. Effort: In your experience, the number of fishing vessels/people targeting snapper has - increased, decreased, same, don't know.
11. Management: Do you feel that sustainability will be maintained given status quo management arrangements?
12. General Comments – Should we allow people the opportunity to make general comments??

Final steering committee meeting for this project will be late October or November.

The meeting concluded at 1600hrs.

Appendix 10

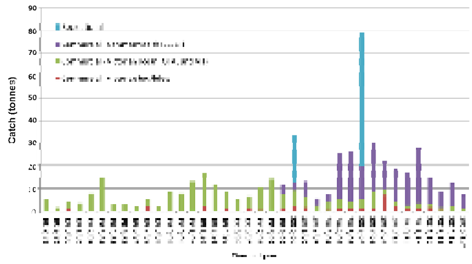
Presentation on eastern snapper stock in Victoria in second steering committee meeting



CATCH HISTORY SINCE 1978

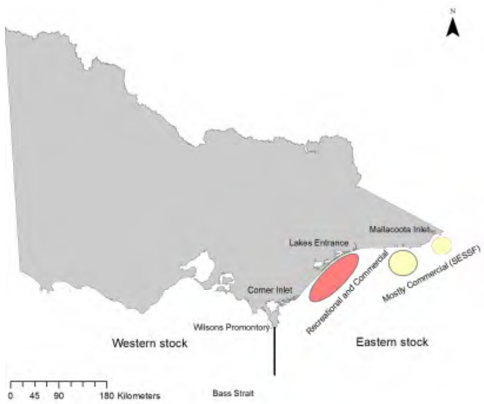
Eastern stock

-Commercial catch has declined since late 2000's
-Recreational ???

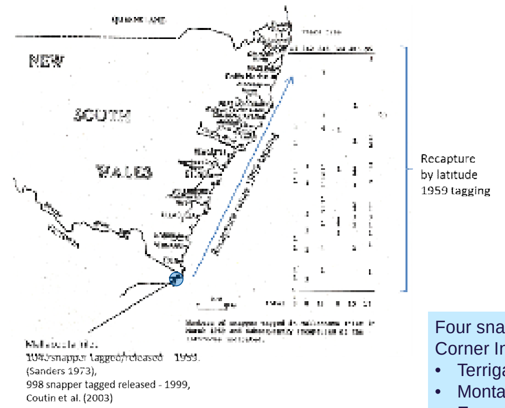


* Recreational catch estimates only available 2000/01 and 2006/07

MAIN FISHING AREAS – EAST STOCK



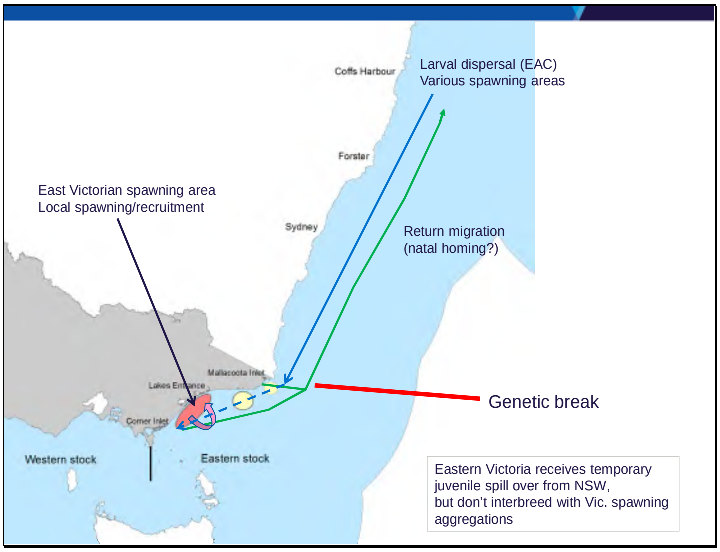
EASTERN STOCK VICTORIA: RATIONALISING TAGGING AND GENETICS

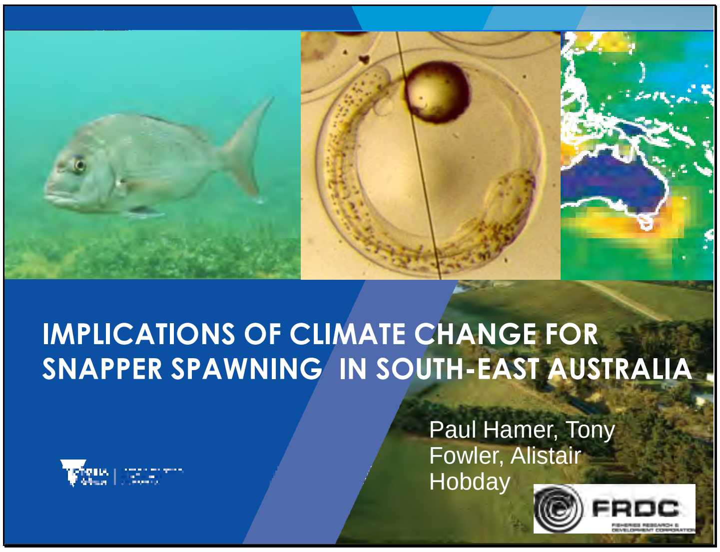


(Sanders 1973),

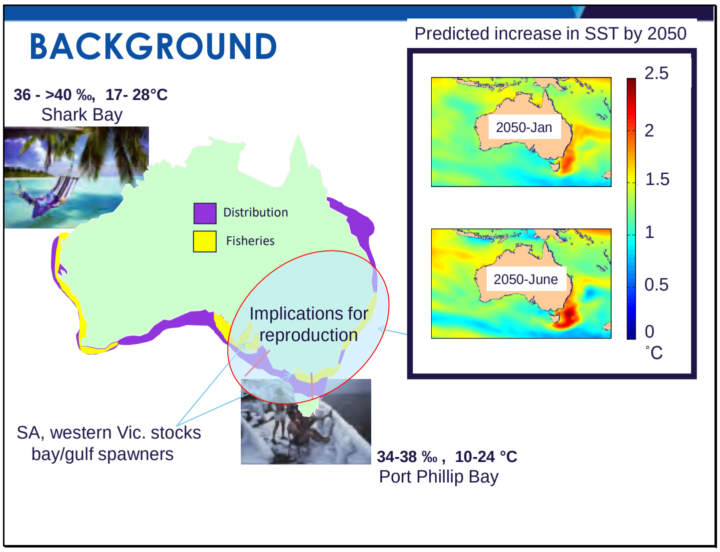
Four snapper tagged off Corner Inlet recaptured in NSW

- Terrigal,
- Montague Island,
- Evans Head
- Forster



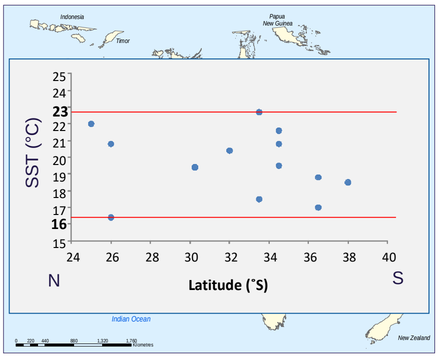


IMPLICATIONS OF CLIMATE CHANGE FOR
SNAPPER SPAWNING IN SOUTH-EAST AUSTRALIA
Paul Hamer, Tony
Fowler, Alistair
Hobday
FRDC



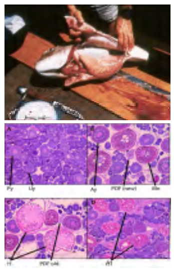
BACKGROUND
36 - >40 ‰, 17- 28°C
Shark Bay
Distribution
Fisheries
Implications for
reproduction
SA, western Vic. stocks
bay/gulf spawners
34-38 ‰ , 10-24 °C
Port Phillip Bay
Predicted increase in SST by 2050
2050-Jan
2050-June
2.5
2
1.5
1
0.5
0
˚C

REVIEW OF SPAWNING TIMING AND TEMPERATURE (SST)

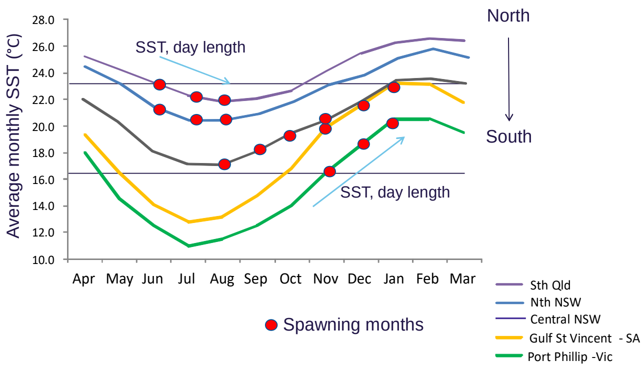


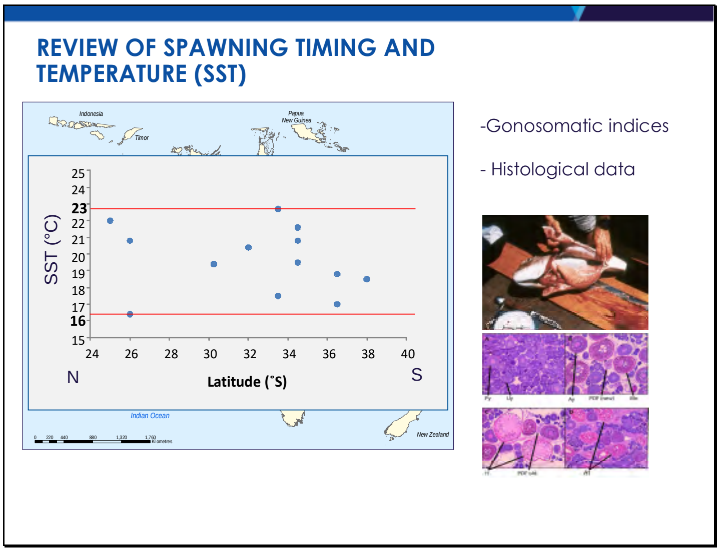
-Gonosomatic indices

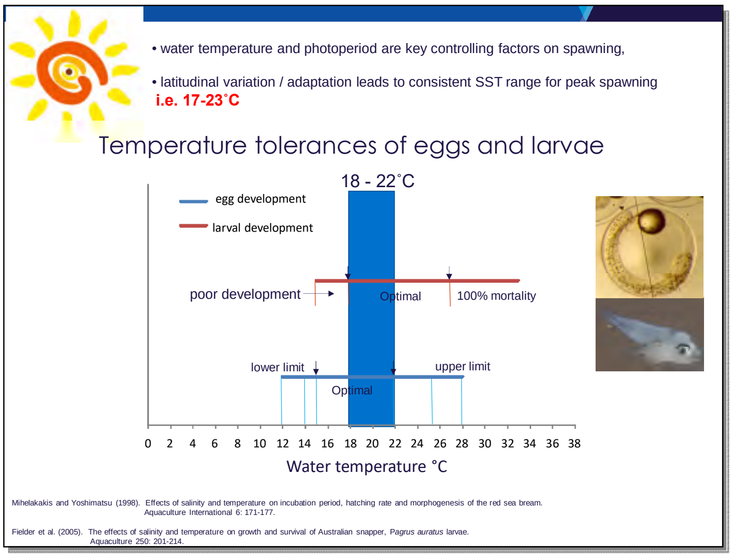
- Histological data



Spawning seasonality and SST in sth. east Aust.




REVIEW OF SPAWNING TIMING AND TEMPERATURE (SST)
Indonesia
Papua New Guinea
Timor
SST (°C)
25
24
23
22
21
20
19
18
17
16
15
24 26 28 30 32 34 36 38 40
N
Latitude (˚S)
S
Indian Ocean
New Zealand
-Gonosomatic indices
- Histological data

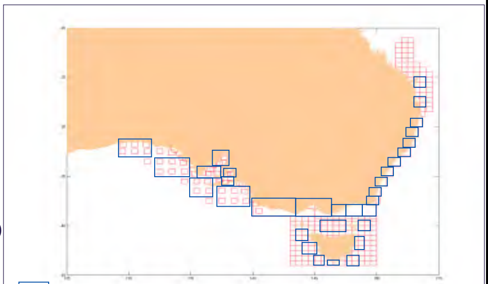

• water temperature and photoperiod are key controlling factors on spawning,
• latitudinal variation / adaptation leads to consistent SST range for peak spawning i.e. 17-23˚C
Temperature tolerances of eggs and larvae
18 - 22˚C
egg development
larval development
poor development
Optimal
100% mortality
lower limit
upper limit
Optimal
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
Water temperature °C
Mihelakakis and Yoshimatsu (1998). Effects of salinity and temperature on incubation period, hatching rate and morphogenesis of the red sea bream. Aquaculture International 6: 171-177.
Fielder et al. (2005). The effects of salinity and temperature on growth and survival of Australian snapper, Pagrus auratus larvae. Aquaculture 250: 201-214.

Predicting implications of warming SST

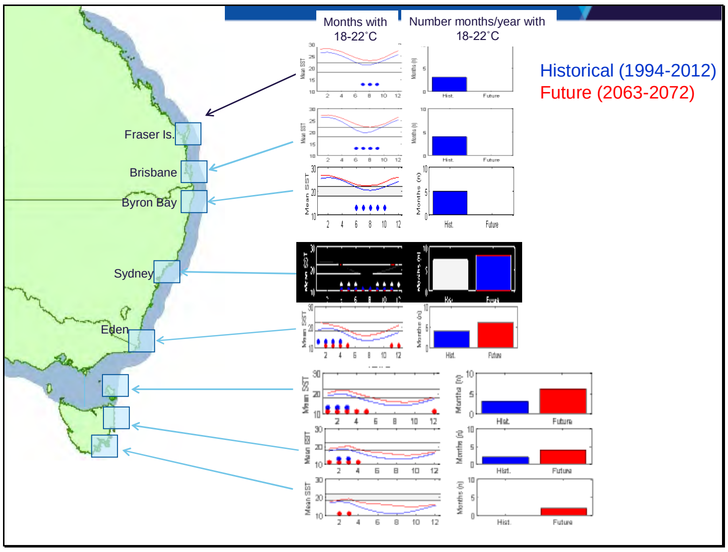
- Use SST forecast model to predict changes in the timing or the length of the spawning season (18-22˚C optimal window) in different regions.
- Consider locations for each state
  - NSW
  - Vic
  - TAS
  - QLD
  - SA

- Historical (1994-2012)
- Future (2063-2072)

(IPCC - A1B emission scenario for 2060s (mid range scenario))



Zones for snapper spawning SST study (n=33)



Implications

1. North NSW and Queensland coastal waters not suitable for snapper spawning in 50 years time (northern range contraction),

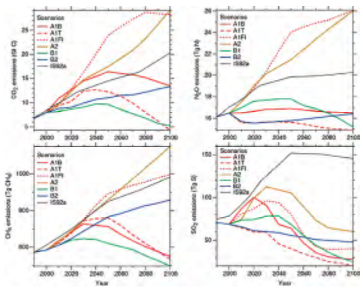
2. Increased opportunity for snapper spawning in eastern Bass Strait and Tasmania (southern range extension),

3. Changes in timing and continuity of optimal spawning temp. windows - consideration of continuous spawning or cue-reversal, 'match-mismatch' and dispersal (both coastal and bay spawners),

4. And for bay/gulf spawners, consideration of migratory dynamics.

FRDC

The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).



Appendix 11

Notes from third steering committee meeting.

Inter-Jurisdictional Snapper Project Steering Committee

Meeting 3

Mineral House, 41 George Street, Brisbane

1 March 2018

Record of Meeting

Record of Meeting

Attendees

Michael O'Neill, Joanne Wortmann, John Stewart, Paul Sullivan, Dave Bateman, Steve Campbell, Sian Breen, Matthew Campbell, John Kung, Jess Morgan, Paul Hamer, Ross Winstanley

Apologies

Wayne Sumpton, Dave Rae, Ruth Thurstan, Dallas D'Silva, Doug Ferrell, George Day

Introduction

- Go through agenda, apologies.
- Bulk of meeting will focus on data and forward projections.
- Only general talk on decision making process (Objective 4).
    - Talk about results and what they mean. Hoping to get views from the committee regarding what the story is and what can be concluded, particularly for the report.
    - Also, will talk about Status of Australian Fish Stocks (SAFS) reporting, particularly regarding the genetics component that showed there are separate stocks.
- Aim of today is to discuss results, committee are encouraged to ask questions and contribute to any discussions.
- It's important to note the uncertainty in the data and the assumptions made when undertaking any stock assessment.
- Any additions to agenda – answer no.
- Committee roles

  - Ensure we get robust outcomes for the public good – funded by Australian Government and Qld/NSW/Vic Governments – ensure we understand the data and get consistent and logical conclusions.
  - Steering committee is convened to contribute fishery knowledge and experience to interpret results from stock assessment.
  - Results are confidential at present, will be publicly released in the future according to FRDC timelines
    - SB – No copies of slides are available until the data have been endorsed by FQ.
  - Important to note that the stock assessment process is occurring outside of the FRDC project and it has separate, and more immediate, timelines compared to the FRDC project timelines.
    - Also the fisheries working groups will likely use outputs from the stock assessment and FRDC project to inform management discussions.
- Objectives
  - Stock structure (Objective 1) – JM analysed samples and concluded that east Vic stock is separate from Qld and central-northern NSW, and there is overlap of genetics between southern NSW and east Victoria
  - Compile data (Objective 2) – historical data from Ruth as well as data from NSW and Qld government databases
  - Model (Objective 3) – a tool convert to synthesise data into biological meaning regarding the status of the stock and forecasting scenarios.
  - Processes for decision making and also stakeholder engagement (Objective 4) – will touch on this today.
- Where are we up to?
  - Objectives 1 and 2 complete
  - Reporting on Objectives 3 and 4 today. Feedback important.
  - Aiming for the FRDC final report drafted by mid-end of March. Discussions today will shape the final write-up. Stock assessment report (NSW & Qld) will be available before the FRDC report. Different timelines – FRDC reports take longer due to review processes.
- Summary of meetings to date
  - Meeting 1
    - Brisbane, Nov 2016
    - Introduce project and path forward
    - Summarised harvest data and genetics results which led to removal of eastern Vic from the modelling component of the project.
  - Meeting 2
    - Sydney, July 2017.

  - Reported on genetics, data and trends, proposed modelling scenarios and management levers (MLS, quota, etc).
  - Action items? Action items from meeting 2 were afforded to be discussed. No. People happy to move on with current meeting. They were referred to as needed through todays presentations.

- Scope – data covered from NSW and Qld
  - Two states and three sectors – six combinations which have been condensed to four for the purposes of the assessment.
  - Lots more information now compared to 2009 when Qld stock was last assessed. More information on: recreational catches, historical data back to 1880 from Ruth, age/length data from NSW, NSW catch data including trap, recruitment data from Moreton Bay.
  - More data sources lead to challenges dealing with conflicting indices of abundance: all line time series are declining but NSW trap index shows recovery.
  - DB asked about recruitment survey, saying there are currently lots of undersize snapper in the bay, noting he has to fish away from them. They are becoming a nuisance. JK said this corroborated anecdotal evidence from LTMP staff conducting the recruitment survey that more were caught in 2017 compared to 2015.
- Scope – results covered by JW
  - Reference points – MO talked about reference points and what they mean: 40% B_0 represents MSY, 60% aspirational ≈ MEY. Consistent with Sustainable Fisheries Strategy. MSY is maximum yield that can be taken annually, balancing components for natural mortality and fishing mortality against spawning, recruitment and growth. Spawning biomass is an indicator of stock health: number of adult spawning females. Harvest rate is the % of stock legal sized taken each year.

Data and Model

- Genetic stock structure
  - Genetic break occurs around Eden possibly, more south than previous studies possibly due to changes in current. JM – likely that the mixing area is a range north and south of Eden. PH – there may be groupings within the large stock, i.e. fish in Brisbane likely not breeding with fish at Terrigal. Localised issues that the DNA cannot resolve – there is still some mixing at a local level but we see a disjunct between the northern stock and southern stock suggesting that those two stocks are not inter-breeding.
  - DB – are there southern stock fish in Sunshine Coast (from Jess's graph), JM – they are carrying traits of the southern stock. They are rare but individuals carry traits like those from southern stock. These dilute out through time but it's expected to see some fish with southern traits.
  - PS – Why does Coffs have ~100% northern stock and Geelong have 100% southern stock? JM – the animals tested from these areas only had traits from the respective stocks. Tasmanian samples had a lot of mixing but low sampling rates for Tasmania (~30) meant a lot of variation. Could expect that the Tasmanian fish are likely both east coast stock and western Victorian stocks on east and west coasts, respectively. More samples from western Victoria might reveal a third stock.

- Stock assessment for Mackay to Eden
    - Highest catches from area around Coffs Harbour
    - Include commercial, charter and rec up to 2016
        - Four sectors: NSW commercial trap, NSW commercial and charter line, Qld commercial and charter line, NSW and Qld recreational.
        - Harvest: NSW dominated by trap, Qld dominated by line (commercial and rec)
    - Assessment incorporates changes in management rules: most importantly the MLS arrangements. JS to clarify if NSW bag limit is in-possession (yes they are)?
    - Harvest estimates
        - Back to 1880 in this assessment compared to 1946 in last assessment
            - MO – need to extrapolate harvests based on known information. Harvest to commence at the time when fishing commenced.
        - Strong build-up of commercial harvest through to the 1990s, then decrease to current day. PS queried the decline, asking what drove that. MO – we are tracking catch only. Yearly total harvests by fishing sector is an important metric for stock assessment and is used to determine fish mortality. PS – suggested marine park closures and estuary harvest stopped and this has caused the catch declines since the 1990s. JW – harvest is used to determine harvest rates.
        - Charter harvests peaked in 2001 at 88 tonnes before a decrease to 30 tonnes. Decline doesn't necessarily mean a decline in stock size.
        - Rec sector only have 9 yearly estimates
            - Estimated recreational harvest tonnages based on length/age sampling (surveys use fish numbers). RW – would be interesting to impute rec harvest for all years where data is missing. MO – the model estimates annual rec catch based on trends in effort. Effort trends were calculated from boat registrations and survey estimates. Participation has been declining, i.e. annual effort declining, according to surveys.
            - SC – lots of error in rec estimates – need more rec data. MO – we incorporate error into rec effort estimates and try to capture that variability.
            - DB – changes in bag limits have caused declines in harvest by recs: people not targeting snapper any more. DB – back in the 1980s I could go out and catch 60 – 80 snapper but now I can only keep 4. SC – catch and release not accounted for and C&R is not a good thing for fisheries. DB – doesn't mean the stock isn't there it's just that they can't catch and retain them because of bag limits: people catch four snapper incidentally.
            - PS – keen rec anglers in the competition sector gave up fishing when bag limits were introduced – it was a waste of time so they bought golf clubs.
            - JS – use harvest rate so reduced rec harvest not an issue. MO – recognise there are a number of drivers causing harvest declines.
        - Fishing power

- Standardising catch rates to give an accurate index of abundance

- Use gear technology uptake data from Sumpton (21 commercial fishers and 42 recreational fishers) and Thurstan (27 commercial, 28 charter and 58 recreational fishers). Factors affecting catch rates differed:

    - Commercial − sounders, GPS and four-stroke engines.

    - Charter – same plus soft plastic lures and braided fishing lines.

    - Rec – same as charter plus float-lining.

        - PS – how does four-stroke engines affect fishing power? Range isn't a concern in NSW. MC – fishers could be travelling 50-60 miles to catch snapper. SC – agree that four-strokes do increase snapper catches. MO – not used in the standardisation.

- Uptake rates x effects to get a measure of fishing power. How much did GPS help your catch rates?

- We have used 3 levels of fishing power: fishing power estimated by using the uptake multiplied by the effects, and then a higher level of fishing power and a lower level than fishing power.

- Rec fishing increased more than commercial

- Rec fishing lags behind commercial in terms of uptake. PS – asked about slope of curves.

- Catch rates

    - Quantify the effects of factors affecting catch rates in order to isolate the effects of fish abundance. E.g. lunar effects, weather effects (BOM data), latitude band.

    - Three fishing power effects: actual, high and low

    - Trap and line catches decline to 2002 then stabilise. In contrast, trap catches increasing

    - Historic catch rates decreased by about 50% to between 1880 and 1950

    - Moreton Bay recruitment data not used in all models

    - MO – different data sources used. Historic data included by itself and not directly appended to other datasets. Also included error data around historical data. Tended to align with more recent data – data are in the 'ball park'. JW – results were similar when the historic data were added compared to when they were dropped, i.e. it didn't make a big change to the results.

    - MO – committee recognises recruitment survey is focussed on Moreton Bay and may not be representative of the entire fishery. Therefore, this index was used in the model for some scenarios and not for others.

        - Rec catch rates – from phone and diary surveys, and creel surveys. Include kept and released fish for a measure of catch rates which have declined.
        -

    - Fish age data

        - NSW trap age frequencies, Qld age frequencies
        - Trap - lack of recruitment pulses (no strong year classes), before 2006 most fish 2-3 years of age. From 2008 onwards there are a higher proportion of older fish suggesting a recovery? Looks like there are more slower growing fish being trapped – 10 year olds being caught in traps despite very narrow selectivity.
        - For Qld line, commercial catches higher proportion of older fish compared to rec.
        - SB – what does it mean that there are no pulses; PH and RW – consistent recruitment, and multiple of sources of stock recruitment (i.e. estuary nursery areas) along the NSW coast.

- Annual age structured population model, changes in management incorporated
- 72 analyses: 2 levels of *M*, two levels of discard mortality, 3 levels of fishing power
- Maximum fish age is 41 years from sampling data. Used a single growth curve to get weight at age. Weight-at-maturity is about 1kg (3-4 years old). Fecundity 200,000 – 1 million eggs per kg. Two levels of natural mortality 0.163 and 0.221 per year = 15% and 19% per year. Two levels of discard mortality - 10% and 30%. Recruitment rate estimated in the model – r_{max} between 3 and 20, i.e. each spawner produces between 3 and 20 replacement spawners over their lifespan. Vulnerability is estimated by the model.
- Results

    - Spawning ratio was variable of interest: ratio of spawners each year compared to 1880 (baseline). Have 72 individual lines.
    - Sharp decline in spawning ratio from 1956 – 1990 in line with harvest build up. Level off around 2012.
    - Trap catch rates push spawning ratio above 40%; trap 20-45%; all line combinations between 10-23%; 72 scenarios gave spawning ratio of 10-45%.
    - JS asked about error bars – error bar on the graph is for the most optimistic ratios, error would be less for more pessimistic scenarios

        - Action – Joanne to add error bar for scenarios that resulted in low spawning ratio.

    - DB – why are the traps more efficient? SC – traps are there all the time. Bite times vary and line fishers may miss optimum bite times.
    - JS – some of the scenarios using line catch rates are improving. MO – catch has dropped in recent years resulting in lower harvest rate. JK asked JS why catch rates have increased since 2002. JS – harvest rate likely decreased in NSW.

- Model was sensitive to *M*: not sensitive to discard mortality or recreational fishing power.

- SC – sharks are a problem, predation is an issue during fishing. Many more around than what conservation groups would have us believe. JK – if so, the higher *M* (0.221) used in the model is more likely. DB – dolphins are causing increased discard mortality.

- DB – stated that natural mortality would not allow spawning biomass to increase back to reference level of 60%. Discussion among group as to what *M* measures.

    - Action – MO to include some wording around virgin biomass and what is meant by that term for future stakeholder meetings, particularly the working group when convened.

- SC – 2009 stock assessment: catch rates talked down, i.e. weighted differently?? MO and JK explained that the last stock assessment was for Queensland only. In the previous assessment commercial catch rates meant better spawning ratios while rec catch rates led to lower spawning ratios. Fishing power changes have resulted in better alignment between these two abundance indices. All data in current assessment are treated equally.

- Reference point – F v M. Generally, want F to be below M. This is the case for scenarios where 0.221 is used.

- Average MSY estimated at 1000 tonnes by the model. Average yield for $B_{0.6}$ reference level is about 800 tonnes. Something needs to be done to rebuild the biomass before applying the full reference point catch limits. For example, if we use line data, fishery at ~20% → can't catch 800 tonnes. DB – catches need to decrease by some percentage for improved snapper stocks.

- SC asked if management changes have improved other stocks – orange roughy, SBT, WA snapper, Spencer Gulf prawns all improved. JS – not always the case, particularly for some Commonwealth fisheries.

- PS – asked about temperature and its effect on snapper stock. Directed to last meeting where PH gave a presentation. PH asked SC if he believes catch rates have dropped and SC said yes.

- DB asked about catch rates in northern NSW: JW showed a graph of catch rates by region. Some regions were declining, others not. Some discussion about catch rate trends in both line and trap by region. Generally, catch rates are improving in the southern regions (NSW). Catch rates decreasing off Sunshine Coast and Fraser Offshore. SC – increasing catch rates in 2004 – 2007 due to high levels of effort from a small number of large, efficient boats. MC – investment warning confounds commercial catch rate data for this period.

- MO – model goodness of fit: model fits the catch rate trends well. Given the age frequencies have little contrast, most variability in the catch rate data. For example, Ballina has peaks and troughs but the model can't explain this biologically. Results in higher variability of results.

- JW – in summary: estimated harvest has decreased since the 1980s to 700 – 800 t; different trends in standardised catch rates from commercial line and trap; recreational catch rates have declined; spawning biomass ratio at 20-45% if trap catch rates are used but 10-23% if line catch rates are used; previous stock assessment suggested that spawning biomass was at 35% of B_0. Average MSY was estimated around 1000 t – catches in 1970s and 1980s was higher which may explain the declining catch rates after this period; stock levels are low – stock needs to rebuild before catches of MSY or MEY (60%) can be reached.

- SC asked about the NSW line fishery: JS – bottom set longline, dropline, normal line, etc. Line data not much good. PS – not many people commercially line fish in NSW.

Forward projections

- Two management approaches: 1) Set harvest rates and change MLS and 2) Fix MLS and change harvest limits like a TAC setting on harvest.
  - Harvest rates were the average of the last 5 years: 2011 – 2016 for entire stock (Qld and NSW).
- Three groups with 1000 simulations
  - High group – trap catch rate, historic catch rate, high natural mortality
  - Middle group – trap catch rate, historic catch rate and low natural mortality
  - Low group – line catch rate combined, historic catch rate and low natural mortality
    - Line: Qld commercial line, NSW commercial line and Ray Joyce data
- 9 analyses with various levels of harvest and changes to MLS up to 2056 (41 years – theoretical maximum age of snapper)
  - Analysis 1: status quo MLS (30cm NSW, 35cm Qld) + constant status quo harvest rate
  - Analysis 2: MLS 30 cm in both states + constant status quo harvest rate
  - Analysis 3: MLS 35cm in both states + constant status quo harvest rate
  - Analysis 4: MLS NSW trap at 30 cm and increased line to 40cm + constant status quo harvest rate
  - Analysis 5: MLS NSW trap at 30 cm and increased line to 45cm + constant status quo harvest rate
  - Analysis 6: 1000 t harvest + status quo MLS regime
  - Analysis 7: 800 t harvest + status quo MLS regime
  - Analysis 8: 600 t harvest + status quo MLS regime
  - Analysis 9: 400 t harvest + status quo MLS regime
  - Didn’t show results for Analysis 6 as results similar to analysis 7
  - Performance measures: 1) spawning biomass and 2) probability that spawning biomass will be at greater than or equal to 0.4 or 0.6 of B_0 in 10, 20, 30 or 40 years.
- Results

- For high group – starting point at ~45% virgin spawning biomass:
    - Increase in MLS results in a slight recovery in Analyses 3 – 5, then stock levels off.
    - Analysis 7 – 9 all scenarios reach 60% virgin spawning biomass. Analysis 9 – reach 80% before 2056.
    - Unlikely to reach 60% virgin spawning biomass using the various MLS regimes under status quo fishing pressure
- For middle group – starting point at ~ 23% virgin spawning biomass:
    - Status quo – slight increase over next 10 – 12 years then levelling off at ~32% virgin spawning biomass
    - Same for other MLS changes except for 30cm trap and 45cm line → up to 35%
    - Status quo MLS and 800 t (Analysis 7) – Get close to 60% by 2056. Lower harvest results in reaching 60% by 2056
- For low group – starting point at ~10% virgin spawning biomass:
    - MLS changes have no effect
    - A catch quota of 800 t (Analysis 8) – uncertain results. Some of the runs had the stock going lower.
    - Again harvest of 600 and 400 t have the spawning biomass ratio increasing to 60% by 2056 but only after 30 or 40 years.

- Discussion
    - DB – can we operate at 0.35 and see stable spawning biomass levels? Although aim is to get back to 60%, it may not be practical.
        - PS – if going to 60% destroys an industry why do it? Policy makers need to be aware that the stock can be sustained at 30 – 40% and can improve with gradual changes rather than sweeping changes that can have a detrimental effect on people's livelihoods.
    - DB – what if we dropped the MLS to 25cm? MO – unknown but likely would have no beneficial effects. We looked at increasing the size limit and each increase result in slightly better spawning biomass ratios. A reduction in MLS would likely see a reduction in spawning biomass ratio.
    - DB – It seems NSW and Qld cannot have cross jurisdictional management. SB – as long as there is a genuine attempt to get back to 60% – future catch rates increasing will mean that management intervention has been successful to some extent.
    - Discussion about discard survival – PS questioned discard survival. He said lower MLS will decrease discard survival. DB agreed.
    - MO – important to note that the reference points may differ between states as it does here. PH – lots of uncertainty around B_0. Used as a guide for management and working group may determine most appropriate target levels for rebuilding. Need to make decisions re target and

rate of rebuild considering socio-economic impacts – slower rebuild will mean less immediate pain.

- JK – can we have more scenarios if the working group want them? JW – yes, no problem: if, for example, we said we want the biomass at 40% at time *x*, we could model some scenarios that achieved this. Also, if we wanted to increase biomass by 20% with certain management arrangements we could determine how long it would take.
- PS – hypothetical cross-jurisdictional arrangements: Are there any?? DB – regardless of stock status, neither jurisdiction will take advice about management from the other state.

SAFS

- Undefined recently because in Qld snapper are overfished, sustainable in NSW and undefined in Victoria
- Federal government wants stock-based assessment, NSW and Qld want jurisdiction-based.
    - Rationale: very different management across states
- Eastern Victoria – no information, will likely be undefined in SAFS

Communications and engagement

- Genetics data published online
- Historical snapper data published
- Outline of NSW and Qld fisheries
- Fishing technologies – government caretaker mode and a re-design of FRDC website interrupted the publication of the article detailing changes in fishing power
    - PH – the fishing technology article is interesting and should be published
    - Action item: JW to progress
- Magazine article by Dave Rae uncertain to happen
    - No action
- Online survey for the same reason as above – progress through working groups
    - DB – the report will give people good background knowledge to inform their answers to online survey
- Snapper genetics manuscript: feedback from co-authors and final editing
    - Action item: JM to progress

Final wrap-up

- Sian – Harvest in 591 in 2013, suggest making pie charts different in size according to total catch. Agreed by group.

    - Action item: Joanne to progress

- MO – committee will be informed about the progress of the draft report
    - Sian – caution required after last assessment. Results will be distributed in due course.

Meeting closed at 15:02.

Appendix 12

Notes from the Sydney Workshop.

Inter-Jurisdictional Snapper Workshop

13th July 2017

Mercure Airport Hotel, Sydney

Record of meeting

Record of meeting

Attendees

Wayne Sumpton, Ruth Thurstan, George Leigh, Jess Morgan, Paul Hamer, Joanne Wortmann, John Kung, Matt Campbell, Doug Ferrell, Dave Bateman, Tony Ham, Paul O'Sullivan, Michael O'Neill, George Day, Steve Campbell, John Stewart, Dave Rae.

Apologies

Ross Winstanley and Dallas D'Silva

Project update: (see PowerPoint presentation)

Stock structure completed by Jess and presented at first meeting.

- East coast stock only. Southern stock (eastern Victoria) ignored in current assessment.

Preliminary historic data

- all data now gathered for Qld, NSW and Victoria. There will be further discussion today about using Ruth's historic catch data in the model.

Development of harmonised database

- All data now input and harmonised, available to be used in the models

Stock model running but still needs work

Communications to be discussed during the steering committee meeting on Day 2.

Genetics and Stock Structure

- East coast stock – Qld and NSW, a broad mixing zone occurs between Sydney and Victoria. Victorian eastern stock considered separate to the east coast stock for this assessment.

- Paul Hamer – fluid boundary between Vic and SA. Looks like Vic stock goes all the way to Kangaroo Islansd in SA. Vic treats eastern population (east of Port Phillip Bay) as a separate stock. Genetics from eastern Vic confirms mixing in southern NSW.

- Localised depletions possible – despite an east coast stock, things can occur at local scales but resolution of assessment is coarse. Healthy populations in one area and not the next. May not get recruits from other areas.

    - Paul O'Sullivan commented that depletions in 1900 doesn't sit right. He catches lots of snapper off Sydney. Wayne explained relative levels of biomass – once fishing mortality occurs, catch rates drop off from the unfished state.

    - Paul O also asked if environmental factors are used because they clearly affect catches. Michael said the model takes into account recruitment and not necessarily the reasons for good and bad recruitment.

Historic Data – Ruth's presentation

- Data after 1960 – copyright kicks in and can't search online. Manual searches are inefficient. Steve asked how many people on the charter vessels. Ruth answered 8 – 50 but variable according to whether it was dedicated fishing charter or a pleasure trip. Steve said that it was important to note that the catch rates from the past are not that much greater than today and care should be taken when interpreting the catch rates from newspapers.

- It was agreed to use Ruth's data as an additional time series so its data points would be compared only to each other, not to other abundance time series.

- Tony asked about fishing an area out– Ruth said it was likely to be a temporary depletion and the catches would come back in the future.

- Early skippers spent a lot of time searching for new grounds, so the fishery was expanding and trips were going further afield.

- Possible recall bias in Welsby data– Welsby recounted past catches with resultant higher catch rates compared to real-time reporting in newspapers at the time.

- Dave Bateman asked about number of hooks. Ruth says it varies but some data are available and there is some information about line type. Tony Ham pointed out that it is difficult to relate historic catches to modern catches as the gear and boats back then would've been rudimentary and eight fish per fisher day is high given the gear. Doug asked about whether the paper reports were inflated because they were advertising the vessel and Ruth said that there is some info about that.

- Effects of weather on numbers of fish

- Historic reports suggest that there was some fishing prior to 1870s but there is limited information of the scale of the catch. AS an example there is information that the1905 Qld charter catch was between 28–34t

- Fishing gear being used in the late 1800s and early 1900s was very rudimentary.

- Need to clarify and tally sample sizes spatially of the data through time.

Harmonised Data – Joanne's presentation

- Model is working but outputs are not sensible so need advice from group.

- Steve asked whether we have CPUE for each lat band (in relation to the graph showing catch by lat band) – Joanne said we do, i.e., lat band is a factor in the CPUE standardisation.

- Paul O. is concerned that we are not taking into account the effort reductions that have occurred since the 70's. Also the MPA's and grey nurse shark closures. It's important to take this into account. Also Paul O says that if you just report catch it looks like there is a big decrease in snapper stocks. Important to have some caveats when reporting catch only. Says that management arrangements are hampering his operation. Dave R. asks if the reduction in fisher numbers has resulted in increased catch rates – Paul O said the number of fishers varies but catch rates have increased over the last 3–4 years. Yellow jackets (leatherjackets) were very abundant for the last 15 years, reaching plague proportions, but are now declining.

- Paul O. also said rec fishing interferes with commercial trapping; rec fishing lines ("spider wire") accidentally cut through the ropes attached to the traps. NSW commercial trap fishers no longer go to the excellent fishing spot of Browns Mountain for this reason. Also rec fishers can mark the commercial fishers' fishing spots by GPS.

- Steve commented that there are now more rec fishers per boat since bag limits were tightened.

- Steve said there had been an explosion in offshore deep-water recreational fishing with electric reels and bigger boats.

- John Stewart wanted to ensure that the estimated NSW charter catch prior to 1940 was not going to affect model outcomes. Steve Campbell said that the lack of charter catch before 1960 is not consistent with what we heard from Ruth's talk. It was agreed that the historic data should be added to the charter catch used in the model.

- John Stewart questioned the fishing method used in the AFMA data – George Day said this was likely trawl. Paul H. said that the OCS was a fairly blunt tool and with no real enforcement it didn't effectively limit the snapper harvests. The situation has improved with the greater attention by AFMA and SETFIA and industry imposed reporting and move on rules. It was recognized that there could be an issue with the AFMA data in that it does not cover discarded fish, but overall it was a small contribution to the total catch.

- Steve C asked about how numbers of rec fish are changed into weights. George Leigh said that they use both in the model. Weight estimated from length frequency data from surveys, LTMP, etc.

- 94 and 95 rec data used different survey methods to estimate recreational catch. (Aerial surveillance of effort and on-site creel surveys). Doug asked about the adjusted catch rates and the Rfish surveys adjusted down. Michael said this was about recall bias and reflected stakeholder views that the estimates may be too high.

- Paul O. asked about fishing power – GPS had big effects. Rec fishers have benefitted most. Wayne asked Paul O what effect fishing power has had: GPS highest effect, about 10% overall fishing power increase for Paul O. It was acknowledged that fishing power varies between sectors and gear type. Likely lower effect in the trap fishery. Steve said that boat length likely increases fishing power of rec fishers. Dave B asked if traps had changed and Paul O said they are bigger because the vessels are larger. The funnels for fish to enter are still about the same size, although some traps have slits running the whole height of the trap and these have obviously increased in height.

- Doug asked about the boat registration data. Asked if the peak (blue line) will effect model outputs. Joanne then presented next slide where fishing power effects are added and the peak is less evident.

Some discussion about what is an offshore vessel – difficult to quantify accurately, but larger vessels operating beyond smooth water and can include Moreton Bay. Rec fishers' participation rates are declining, whereas in last stock assessment the rec effort proxy kept increasing with boat regos.

- Paul Hamer asked about data weighting. Catch rates weighted by catch spatially but weighting is the same in all years (important to avoid creating bias). Doug asked about the sharp increase in catch rates from the trap fishery and it's difficult to work out why. Joanne spoke to Doug during the tea break and she will send him the trap catch rates by latitude band in order to investigate the trap catch rates further.

- Some discussion about recruitment strength. No pulses of recruitment in east coast like there are in Vic, SA and NZ.

- Need to report standardised catch rate trends by latitude in the report.

- Need to describe how much estuary area is closed to commercial fishing and what that means. Closure of Sydney Harbour and Botany Bay; 33 estuaries closed in NSW.

- Some specific actions were proposed

  - Under reporting of historical charter harvests to be corrected in charter catch graphs.

  - Describe when bag limits came in against the rec harvest estimates.

  - Sample sizes of Ruth's catch rate data and fishing power data to be shown temporally and spatially.

  - Why a drop in later trap catch rates? Check nominal data and standardised outputs.

  - Check length frequency histograms from Queensland, commercial and recreational differences in particular

  - Fishing power effects – faster boats and extra deck hands allow to work more traps. Important fishing power effect not captured? Also the number of traps used has increased ~ 10–30%. Is this data in logbooks and are we using it? Need to if so! Also bigger sized traps today. What to do about this?

  - LF NSW trap sampling to be described – 4 locations Tweed to Sydney – port sampling.

  - Can we combine spatial CPUE's as done?

Stock Modelling - Joanne slides after lunch

- John Stewart questioned the LF of NSW trap on model output - NSW trap slide – Doug says this is likely because these data include longlining data from Coffs Harbour. Summary – improve source data for 80s data or exclude 80s data. Tony Ham asked about the truncation in the trap fishery – Doug said that catchability is the cause. He said that the vulnerability should shift to the right where apex is at 40cm not at 25. Sweet spot for trap fishing is 25–35 cm. Steve suggested that the shape of the trap vulnerability should be flatter on top, i.e. vulnerability = 1 for larger size range. Dave B. said that the vulnerability should reflect that smaller snapper are caught. Wayne made the point that the line vulnerability should decrease in larger sizes. Discussion had about correct vulnerability and where curves should fit. Some confusion about what vulnerability is. Steve C got up and showed what he thought his vulnerability was in his fishery. Doug asked about separate vulnerability for different sectors given commercial catch more. Paul said the fish traps successfully release very small fish (John Stewart said about 20cm TL and Paul said 10cm FL). George L. commented that the data only contain legal-sized fish so we can't model vulnerability of small fish. John S. said he thought there were some NSW trap data that provided information on sub-legal-sized fish.

- Pre-recruitment surveys were discussed. No outcomes, except that the Moreton Bay survey was very localised and should be excluded from the model's base case. Population model is for a single stock only, not regional. The Moreton Bay survey catches "young of the year", < 15 cm in length.

- Doug asked about mean weight of historical catches and how that relates to current day. Average weights have declined but there are biases in reporting of snapper and squire which were often considered as two categories of fish in early records.

- Discussion about the recruitment deviations used in the model and how they are small -, possibly reflecting low variation in recruitment? Difficult to fit the CPUE time series and the LF data at the same time. Doug says that error in ageing could be one of the drivers of the lack of signal in recruitment. Ageing of snapper is difficult in subtropical regions. It is much easier in Vic and NZ, and these jurisdictions show some strong recruitment years.

- Discussion about significance of data inputs. NSW combined line and trap – Doug says this is messy as fishers use both gears and it's not differentiated in logbooks prior to 1997. The meeting was in favour of omitting the combined line–trap series and using only the trap data where we could be confident that fishers didn't use any other method during the month.

- Michael spoke about the catch rate standardisations and discussed the various factors used. Factors include the year*month*region, lunar phase,, day or night fishing, full day or half day, hours fished and a wind factor, along with a fishing power variate.

Hypothetical cross jurisdictional management

- Steve Campbell suggested that size limits should be scrapped. To have the least impact on stocks, fishers should "get their take and get out." Doesn't believe the post release survival estimates and suggests mortality is higher than 30%.

- Michael asked for likely scenarios such as MLS of 30 (liberal) or 45 (conservative). John Kung is interested to know what rec fishers want. Dave B says he agrees with Steve Campbell that the MLS should be put back to 30 and keep bag limit of 4 and one over 70. George Day asked what is the objective of a snapper fishing experience? More numbers of big fish or are people getting a feed of three small fish? Tony and John Kung says it varies in Qld. Doug says that in NSW they prefer small number of big fish. Paul says increase in MLS would ruin the trap fishery.

- Dave B said that we should get rid of stout whiting trawling. Also said that environmental factors are resulting in poor survival of larvae.

- Paul O asked about the ramifications of managing as a single stock and the fact that trap fishing is allowed in NSW and not in Qld. Population effects operating at regional scales were acknowledged.

- Dave Rae: MLS is too small in NSW and should be higher. Says that it's unfair that mulloway MLS is 70 for recs but net fishers can keep 10 over 45cm. He would like to see a quota system implemented for rec fishers. Perhaps a scenario where pros have a MLS of 30cm and recs have a MLS of 45.

- First modelling scenario was agreed to as: Two MLS scenarios 30cm and 35cm across both NSW and Qld. Model risk factors of 30cm and 35 cm MLS

- There was some discussion on the modelling of rec effort: Difficult according to Tony Ham. Managers want to know the effect of capping effort. How to quantify effort is a problem for later on! Some discussion about how to include green zones. Michael says it's difficult and we should be looking at aspirational catch rates. John K. suggested looking at high catch rates and look for an associated catch amount and use that as catch target for the fishery.

- Michael raised the question of AFMA data and whether we need to project catch back in time. George Day and Doug said that the data are likely to be covered by the NSW catch records.

- Tony Ham wants a novel solution – targets to meet at certain time dates; set on stakeholder aspiration.

- What level of spawning is enough? Project by harvest rates?

- After further discussion the second hypothetical management measure agreed to was to model two levels of total harvest. Levels still to be decided after model has produced biomass trajectories and MSY estimates.

Appendix 13

Recreational fishing article which appeared in the July 2018 edition Fishing World.

[redacted]

Dave uses historical records

to discover why stocks of this

[redacted]

By Dave Rae

[redacted]

Saturday after the usual club breakfast at

[redacted]

Reef was the scene of operations, and it

[redacted]

rarely taken place so near Sydney Heads. The wind

[redacted]

drifting off the ground, so that the fishing-proper

[redacted]

over four hundred schnapper were caught. The fish

[redacted]

mounted with two hooks, caught eight good sized

[redacted]

This description from the *Sydney Mail* and *New*

[redacted]

references to the increasingly popular

[redacted]

(Chrysophrys auratus), known back then as

[redacted]

There's no doubt in my mind that I am now

[redacted]

years ago. Prior to using soft plastics (2002), I

[redacted]

a berley trail to target snapper. Long fibreglass

[redacted]

and my catch rate was pretty consistent,

[redacted]

catch when I started using soft plastics.

[redacted]

snapper fishery commenced using rope and then

[redacted]

nylon after WW1:

[redacted]

yards length, 9.15.18,27 or 36 cord, and a dozen or

[redacted]

from 3-0 to 8-0 according to the size of fish expected

[redacted]

one, two or three snoods with hooks attached are

[redacted]

The Sydney Mail and *New South Wales Advertiser,*

[redacted]

Adopting new technology (with uptake aided

[redacted]

depletions as catches increased in both

[redacted]

the catch is about equal for both sectors (I kid you

[redacted]

that came with soft plastics, have suffered. Chart

[redacted]

have made a significant impact!

[redacted]

my involvement in a research project with

[redacted]

for the east coast snapper stock. The project,

[redacted]

management in eastern Australia", was a

[redacted]

[redacted]

SPECIES GUIDE: SNAPPER

[redacted]

Department of Agriculture and Fisheries, NSW [redacted] Victorian Fisheries Authority funded by the [redacted] (FRDC). It was at a project Steering Committee [redacted] capacity as the 2015 Alfred Deakin Postdoctoral [redacted] and the State Library's 2015 David Scott Mitchell [redacted] What really got me thinking was the following [redacted] 'generational shift': each successive generation of [redacted] own experience, thus losing the ability to [redacted] snapper stocks been effected over time? Dr [redacted] information that puts current catches in context. [redacted] Indigenous people and from the early history of [redacted] during the 1860/70s that allowed charter fishing [redacted] waters outside of the sheltered bays and [redacted] caught large numbers of fish, and their catches and [redacted] local newspapers. So much detail was provided, that [redacted] number of snapper caught per fisher per trip." [redacted] to be collected in the 1940s in Queensland, [redacted] information on the snapper fishery up to [redacted] data collection.

EARLY QUOTES ON THE [redacted]

fishing trip in Queensland was retrieved [redacted] suggests that charter fishing trips were still [redacted]

"Schnapper fishing is becoming quite a fashionable [redacted] *little difficulty there seems to be in making a good* [redacted] *fishermen don't turn their attention to catching* [redacted] Courier, 7 Sept 1871. [redacted] quantitatively describe a charter fishing trip in [redacted] the activities of the already-established Nimrod [redacted]

[redacted]

involves modelling management

[redacted]

enjoyable and successful fishing excursion outside [redacted] *steamer Mystery, shortly after 8 o'clock. Upon gaining* [redacted] *she was allowed to drift about for three or four hours,* [redacted] *commenced, and reports were spread that there were* [redacted] *and she drifted till 1 o'clock, when the anchor was* [redacted] *and the hauls were not so successful as when drifting* [redacted] *drifting again for a short time the Mystery was headed* [redacted]

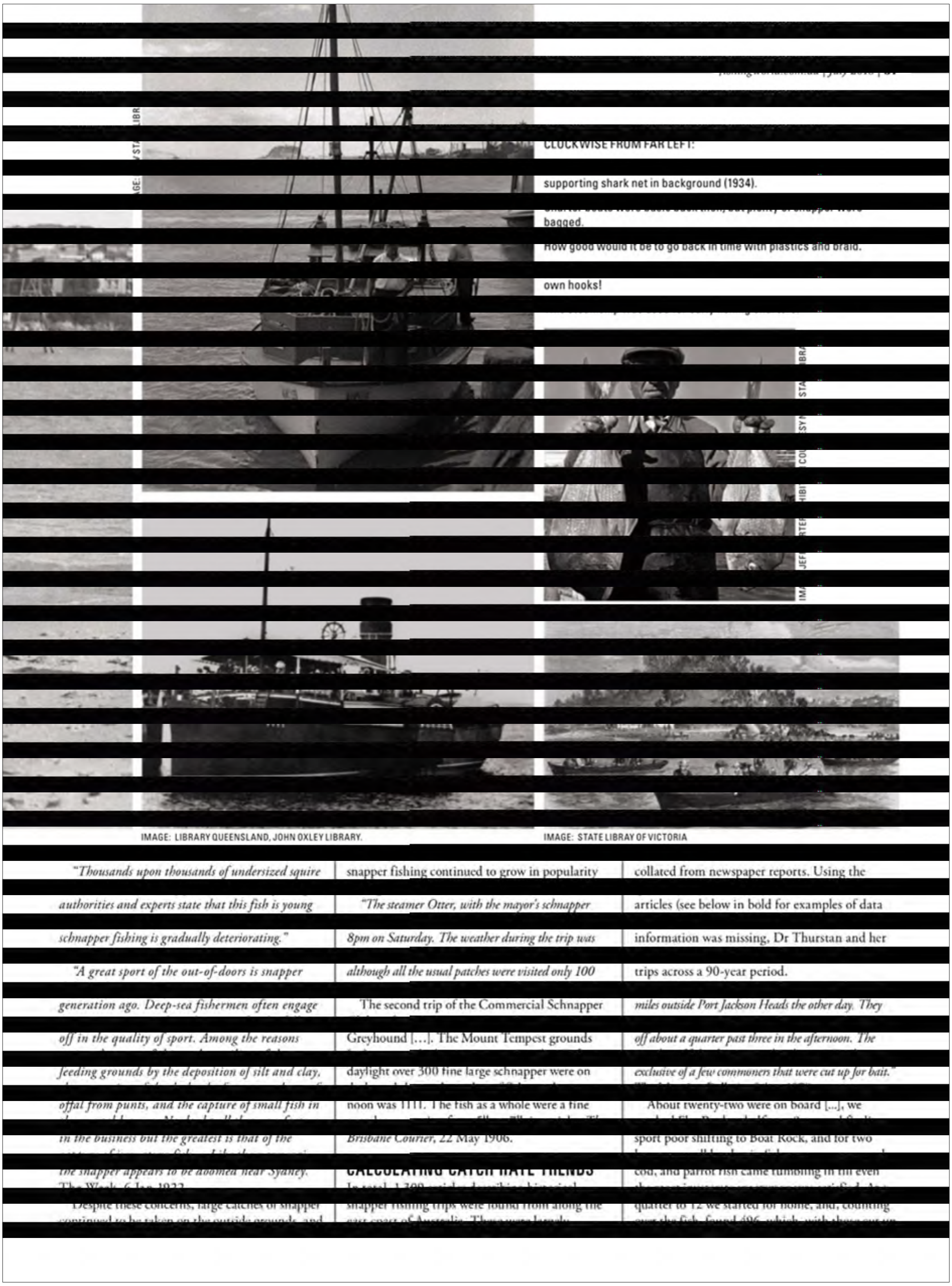
IMAGE: NSW STATE LIBRARY

[redacted] *principally consisting of schnapper, weighing* [redacted] *Sydney Morning Herald*, 16 Nov 1877.

CONCERNS ABOUT [redacted]

on-going for many decades by the time charter fishing [redacted] being expressed about the localised depletion [redacted]

"20 and 30 dozen 'count' fish were often taken by [redacted] *however, the [...] grounds about Broken Bay have* [redacted] New South Wales Royal Commission, 1880. [redacted] *not so common of yore. He seems to have given place* [redacted] *frequently caught between 15 and 30lb weight."* The [redacted]



[redacted]

supporting shark net in background (1934).

[redacted]

bagged.

How good would it be to go back in time with plastics and braid.

[redacted]

own hooks!

[redacted]

IMAGE: LIBRARY QUEENSLAND, JOHN OXLEY LIBRARY.

IMAGE: STATE LIBRARY OF VICTORIA

[redacted]

"Thousands upon thousands of undersized squire [redacted] *authorities and experts state that this fish is young* [redacted] *schnapper fishing is gradually deteriorating."* [redacted]

"A great sport of the out-of-doors is snapper [redacted] *generation ago. Deep-sea fishermen often engage* [redacted] *off in the quality of sport. Among the reasons* [redacted] *feeding grounds by the deposition of silt and clay,* [redacted] *offal from punts, and the capture of small fish in* [redacted] *in the business but the greatest is that of the* [redacted] *the snapper appears to be doomed near Sydney.* [redacted]

Despite these concerns, large catches of snapper [redacted]

snapper fishing continued to grow in popularity [redacted]

"The steamer Otter, with the mayor's schnapper [redacted] *8pm on Saturday. The weather during the trip was* [redacted] *although all the usual patches were visited only 100* [redacted]

The second trip of the Commercial Schnapper [redacted] Greyhound [...]. The Mount Tempest grounds [redacted] daylight over 300 fine large schnapper were on [redacted] noon was 1111. The fish as a whole were a fine [redacted] *Brisbane Courier, 22 May 1906.*

CALCULATING CATCH RATE TRENDS

[redacted] snapper fishing trips were found from along the [redacted]

collated from newspaper reports. Using the [redacted] articles (see below in bold for examples of data [redacted] information was missing, Dr Thurstan and her [redacted] trips across a 90-year period. [redacted]

miles outside Port Jackson Heads the other day. They [redacted] *off about a quarter past three in the afternoon. The* [redacted] *exclusive of a few commoners that were cut up for bait."* [redacted]

About twenty-two were on board [...], we [redacted] sport poor shifting to Boat Rock, and for two [redacted] cod, and parrot fish came tumbling in till even [redacted] quarter to 12 we started for home, and, counting [redacted]

[redacted]

work indeed. The Brisbane Courier, 22 May 1879.

[redacted]

rates remained stable throughout the time series,

[redacted]

fishery expanded into new grounds. In

[redacted]

south-east Queensland charter fishery produced

[redacted]

hour. One can only wonder what the average

[redacted]

So, what should we do? The research project is

[redacted]

modelling management scenarios designed to

[redacted]

example, what happens to the snapper stock if

[redacted]

happens if catch is reduced? How long would the

[redacted]

management changes were implemented?

[redacted]

that east coast snapper stocks are in dire straits,

[redacted]

advised the Minister of the need to reduce bag

[redacted]

Times have changed, but poor boating

[redacted]

snapper 70 cm or more, to one fish per trip.

[redacted]

follow suit on an increased minimum length but

[redacted]

required modification to fish traps may not be

[redacted]

these changes are necessary for the fish, so we as

[redacted]

and move past the "if they can catch 32 cm

[redacted]

P.S. just as an aside, these anglers were as keen,

[redacted]

consider the dangers of travelling the open ocean

[redacted]

"The largest number of his excursionists (a

[redacted]

This run takes about 4 hours steaming from

[redacted]

3.5 hours, Bird Island 3 hours, and the Caves 2

[redacted]

One party went to the Manning Heads, which

[redacted]

who attended the excursions were placed on the

[redacted]

Newcastle about 7pm on the various Sundays on

[redacted]

Herald and Miners' Advocate, 20 Mar 1908

[redacted]

[redacted]

Appendix 14

On-line Survey.

During the second Steering Committee meeting held in Sydney, one objective was to develop an online survey. The survey was designed to obtain information on a range of issues relating to the snapper fishery. The final survey questions are shown below.

Age

□ <20 □ 21-30 □ 31-40 □ 41-50 □ 51-60 □ >60

Postcode: ………………

Location where usually fish for snapper: ………………………………

Sector: □ Commercial □ Recreational □ Charter

How often you fish?

□ More than once a week □ Once a week □ Twice a month □ Once a year

How many years of snapper fishing experience do you have?

□ <5 years □ 5 – 10 years □ 10 -20 years □ >20 years

What technology do you use:

□ Colour sounder □ Side imaging □ Soft plastic lures □ Braided fishing line

□ Four stroke motor □ Electric reels □ Spot-lock electric motor □ Chart plotter

□ Other, please specify:……………………………………………………………………

Fishing power

If you didn’t have a GPS what would happen to your catch rates?

□ More □ Less □ Same

If you didn’t have a colour sounder what would happen to your catch rates?

□ More □ Less □ Same

If you think fishing technology in general has improved your catching ability, by what percentage do you think it has improved your ability to catch fish?

☐ <25%   ☐ 25 – 50%   ☐ 50 – 75%   ☐ > 75%   ☐ Other, please specify…………

Discard mortality

Published science has estimated release survival of snapper at about 85%. From your experience is it:

☐ More   ☐ Less   ☐ Same

Since you started fishing for snapper, predation of your catch by sharks has:

☐ Increased   ☐ Decreased   ☐ Same

Catch rates

We have information on historical catch rates from 1880-1960. Do you see value in using these data in assessing current fishery status?

☐ Yes   ☐ No   ☐ Not sure

Based on you experience how has the abundance of snapper changed in your fishing area?

☐ More   ☐ Less   ☐ Same   ☐ Not sure

Size

Since you started fishing, and allowing for the changes in size limit, the size of snapper has:

☐ Increased   ☐ Decreased   ☐ Same   ☐ Not sure

To what do you attribute that change?

☐ Too many fishers   ☐ Climate change   ☐ More fish   ☐ Better fish-finding technology

☐ Better fishing tackle   ☐ GPS   ☐ Commercial fishing pressure

☐ Marine parks   ☐ Information availability   ☐ Improved outboard motor technology

☐ Other, please specify……………………………………………………………………...

Fishing pressure

In your experience, the number of fishing vessels/people targeting snapper has:

☐ Increased ☐ Decreased ☐ Same ☐ Not sure

Management

Do you feel that current management arrangements in your state support the long-term sustainability of the snapper stock?

☐ Yes ☐ No ☐ Not sure

If No, what do you think needs to be done?..

…………………………………………………………………………………………………...

Appendix 15

Recreational fishing representatives

Table 25. List of recreational fishing representatives invited to the recreational fishers workshop.

Invitee	Organisation/Affiliation
Barry Pollock	Sunfish Queensland
Barry Lewis	Redland Bay Amateur Fishing Club
Ben Colllins	Bush n Beach Fishing magazine
Ben Diggles	Digsfish services
Bill Corten	Charter operator/fisher
Chris Ryan	EcoFishers
Daryl McPhee	Recreational fisher
David Bateman	Sunfish Queensland
Geoff Clarke	Tackle shop proprietor
Gordon Macdonald	Fishing journalist
Greg Lamprecht	Recreational fisher
Jeff Sorrell	Recreational fisher
John Bennett	Recreational fisher
John Haynes	Moreton Bay Trailer Boat Club
Judy Lynne	Sunfish Queensland
Kim Martin	Qld Recreational Fishing Network
Lance Murray	Mackay Recreational Fishers Alliance
Mark Rose	Redcliffe Peninsula GSC
Mike Streets	Redlands Boat Club
Nathan Johnston	ANSA President
Phil Kliese	Ausfish/EcoFishers
Ray Ozich	Fisher - Hervey Bay
Rob Schomberg	Powerboat Anglers Club
Scott Mitchell	Fraser Coast Fishing Alliance
Sean Conlon	Moreton Bay charter operator
Stefan Sawynok	Suntag/InfoFish
Steve Morgan	Queensland Fishing Monthly
Steve Simonis	Blue Fin Fishing Club
Troy Dixon	Wilson Tackle Company

Appendix 16

Historical model diagnostics

Historical model estimates and parameter values are shown in Table 26, Figure 25 and Figure 26. Myers *et al.* (1999) concluded that steepness, h, would vary with species, natural mortality and age-at-maturity, with the number of annual replacement spawners typically ranging 1–7 per spawner per year. Using Myers *et al.* (1999) generalisation, an expected steepness (h) for snapper could range 0.36 to 0.83. Note this range is large, and most of the estimates for snapper based on the data through the stock model were in the upper part of the range (Table 26). Estimated lower steepness values were from the stronger declines in catch rates. The range of steepness estimates appeared plausible for the data scenarios analysed.

Table 26 Model estimates for spawning ratio, maximum sustainable yield, yield for B0.6, negative log likelihood and steepness from the historical model for 72 analyses.

Analysis	S_{2016}/S_0	MSY (tonnes)	Yield for B0.6 (tonnes)	Nll	Steepness
1	0.213010	1,089.20	827.29	-1003.60	0.833
2	0.151240	1,114.60	867.07	-1023.50	0.761
3	0.117140	1,145.20	908.18	-1023.40	0.702
4	0.106080	1,164.50	930.93	-1021.70	0.678
5	0.272970	1,047.00	795.51	-1003.40	0.833
6	0.154880	1,097.40	884.05	-1017.90	0.655
7	0.126580	1,122.80	922.77	-1013.60	0.595
8	0.113500	1,136.70	942.12	-1010.50	0.570
9	0.220560	831.91	632.08	-1004.10	0.833
10	0.165740	1,026.50	781.74	-1020.80	0.825
11	0.139060	1,044.00	813.40	-1017.00	0.755
12	0.126460	1,055.70	830.80	-1014.20	0.725
13	0.291500	833.13	633.02	-998.68	0.833
14	0.181920	1,029.10	812.83	-1011.90	0.713
15	0.150680	1,036.20	839.43	-1005.70	0.637
16	0.136060	1,041.50	852.21	-1001.70	0.607
17	0.225360	783.63	595.46	-1002.80	0.833
18	0.167010	993.24	754.37	-1018.20	0.833
19	0.145180	1,010.60	782.52	-1013.40	0.774

Analysis	S_{2016}/S_0	MSY (tonnes)	Yield for B0.6 (tonnes)	Nll	Steepness
20	0.132830	1,020.40	798.15	-1010.10	0.743
21	0.305900	784.23	595.83	-997.87	0.833
22	0.190720	1,006.40	788.90	-1008.50	0.735
23	0.159760	1,008.10	811.44	-1001.50	0.656
24	0.145350	1,011.20	822.26	-997.25	0.625
25	0.321210	1,053.10	821.96	-1009.20	0.724
26	0.187100	1,035.00	852.24	-1022.70	0.572
27	0.151100	1,049.10	879.51	-1021.30	0.523
28	0.134550	1,057.20	893.18	-1019.70	0.501
29	0.457720	1,149.10	862.78	-997.16	0.833
30	0.197110	983.00	845.88	-1015.00	0.450
31	0.155200	978.15	854.17	-1011.40	0.406
32	0.136590	976.98	857.73	-1008.70	0.389
33	0.334700	1,004.10	768.26	-1002.60	0.782
34	0.217330	979.91	794.08	-1018.30	0.616
35	0.175990	979.33	812.32	-1015.10	0.551
36	0.157180	980.94	821.43	-1012.60	0.525
37	0.437970	1,071.60	804.96	-991.72	0.833
38	0.226960	942.17	804.03	-1009.40	0.473
39	0.179080	919.84	799.80	-1004.50	0.419
40	0.157570	910.80	797.11	-1001.20	0.399
41	0.331230	970.53	741.74	-997.18	0.784
42	0.225890	962.45	775.61	-1015.90	0.632
43	0.184220	957.72	791.25	-1011.90	0.562
44	0.165280	957.81	799.23	-1009.00	0.535
45	0.435610	1,028.50	772.59	-989.02	0.833
46	0.238300	931.40	792.22	-1006.60	0.482

Analysis	S_{2016}/S_0	MSY (tonnes)	Yield for B0.6 (tonnes)	Nll	Steepness
47	0.188670	903.16	783.94	-1001.00	0.424
48	0.166510	892.12	779.68	-997.56	0.403
49	0.229540	1,080.50	809.00	-1012.70	0.878
50	0.117080	1,145.90	908.98	-1023.50	0.701
51	0.139820	1,111.50	867.34	-1014.30	0.752
52	0.116710	1,145.10	909.15	-1012.80	0.699
53	0.140890	1,119.60	874.65	-1017.20	0.748
54	0.117090	1,153.20	916.54	-1017.50	0.695
55	0.209340	926.60	703.96	-1003.90	0.833
56	0.138900	1,044.90	814.43	-1017.20	0.754
57	0.166060	1,026.30	782.39	-1010.10	0.822
58	0.138660	1,043.50	814.22	-1006.40	0.751
59	0.167180	1,035.40	789.91	-1012.70	0.819
60	0.139470	1,053.90	823.02	-1010.70	0.748
61	0.223440	798.18	606.56	-1002.50	0.833
62	0.144960	1,011.50	783.58	-1013.60	0.772
63	0.168530	994.20	755.08	-1007.50	0.833
64	0.144670	1,009.80	783.19	-1002.80	0.769
65	0.170310	1,004.70	762.91	-1009.80	0.833
66	0.146030	1,022.50	793.34	-1006.80	0.767
67	0.131660	1,127.37	885.66	-997.72	0.729
68	0.112078	1,158.02	922.33	-999.76	0.684
69	0.101334	1,176.26	946.27	-999.41	0.657
70	0.424500	973.00	738.00	-985.00	0.787
71	0.107700	1,133.00	882.00	-1022.50	0.670
72	0.160300	1,133.00	882.00	-1015.00	0.757

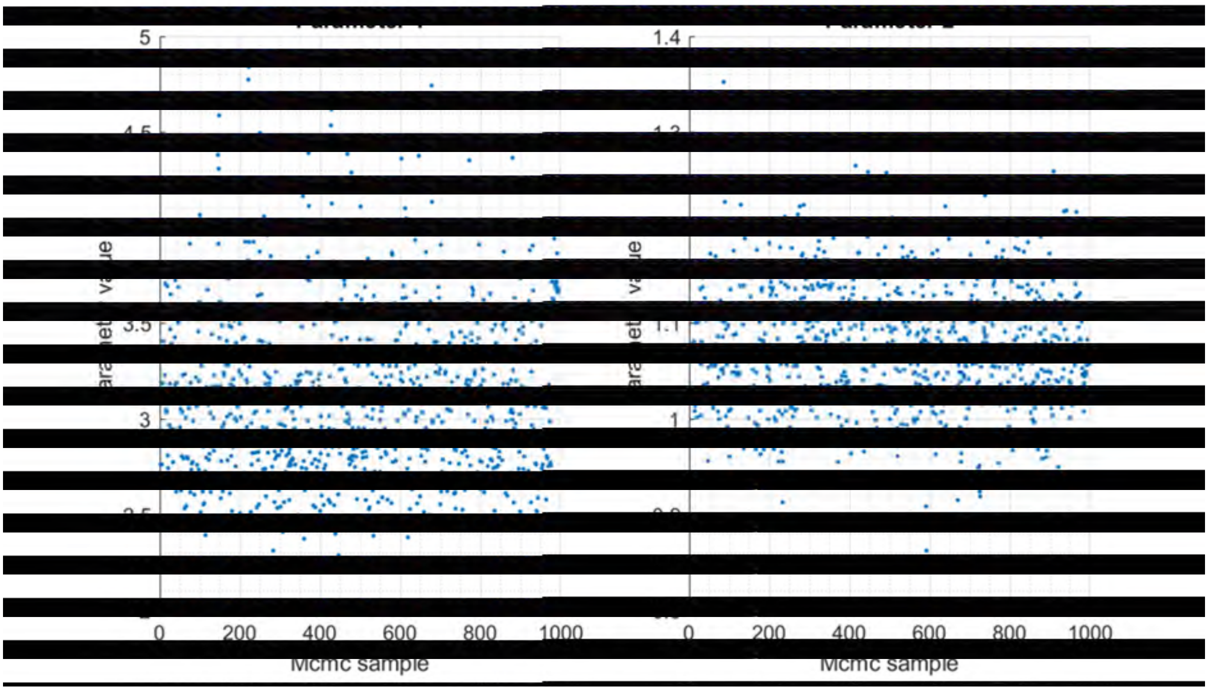


Figure 25. Parameter estimates from 1000 MCMC simulations from an historical model analysis. Parameter 1 gives the recruitment compensation ratio = 1+e^{parameter1}, from which the steepness is calculated, steepness=recruitment compensation/(4+ recruitment compensation). Parameter 2 gives the initial recruitment=e^{parameter2}*100.

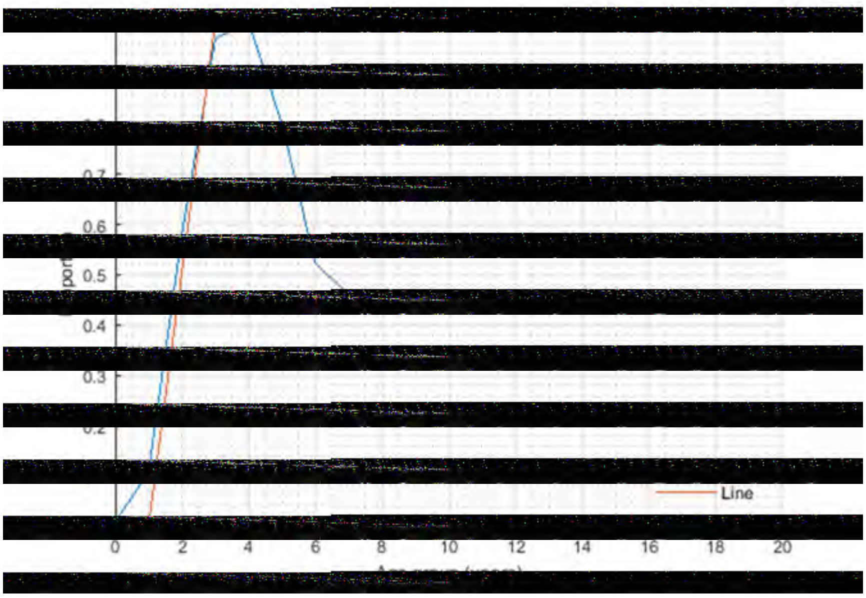


Figure 26 Estimated vulnerability schedules for the trap and line sectors. The vulnerability schedules for all analyses were similar, with parameter values: trap: Age at 50% vulnerability (rise) 1.903829, difference age at 95% vulnerability- age at 50% vulnerability (rise) 0.2, age at 50% vulnerability (falling dome) 5.152, asymptote 0.4373 and line: Age at 50% vulnerability 1.998 and difference age at 95% vulnerability- age at 50% vulnerability 0.227. The formulas for the trap and line vulnerability curves are given in Leigh and O'Neill (2017).

Model fits for selected analyses are shown in Figure 27, Figure 28 and Figure 29. For all historical analyses runs the model fits were similar. Graph (a) in Fisgures 27 - 29 compares the actual catch rate and the predicted catch rate. The model predicted the overall trend in catch rate but did not fit to the peaks and troughs of the observed catch rates. A histogram plot (graph b) of the residuals (difference between observed catch rate and estimated catch rate) suggested that the residuals (and hence the error terms) were normally distributed. The normal probability plot of the residuals (graph c) was approximately linear supporting the condition that the error terms were normally distributed. The graph of residuals verses the logarithm of fitted plots (graph d) showed that the residuals and the fitted values were uncorrelated, scattered randomly about 0, regardless of the size of the fitted value.

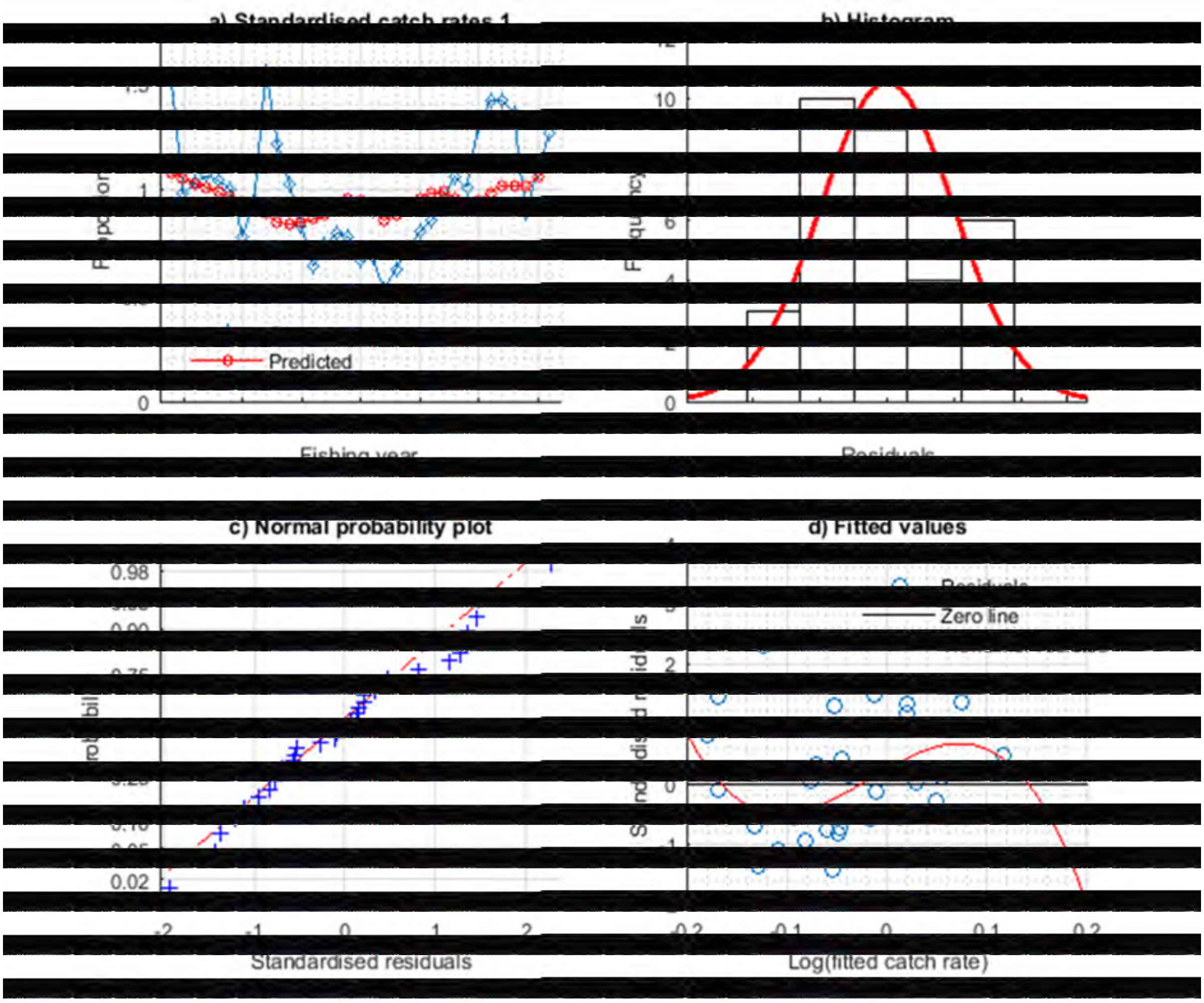


Figure 27 Model diagnostics for the trap catch rate time series.

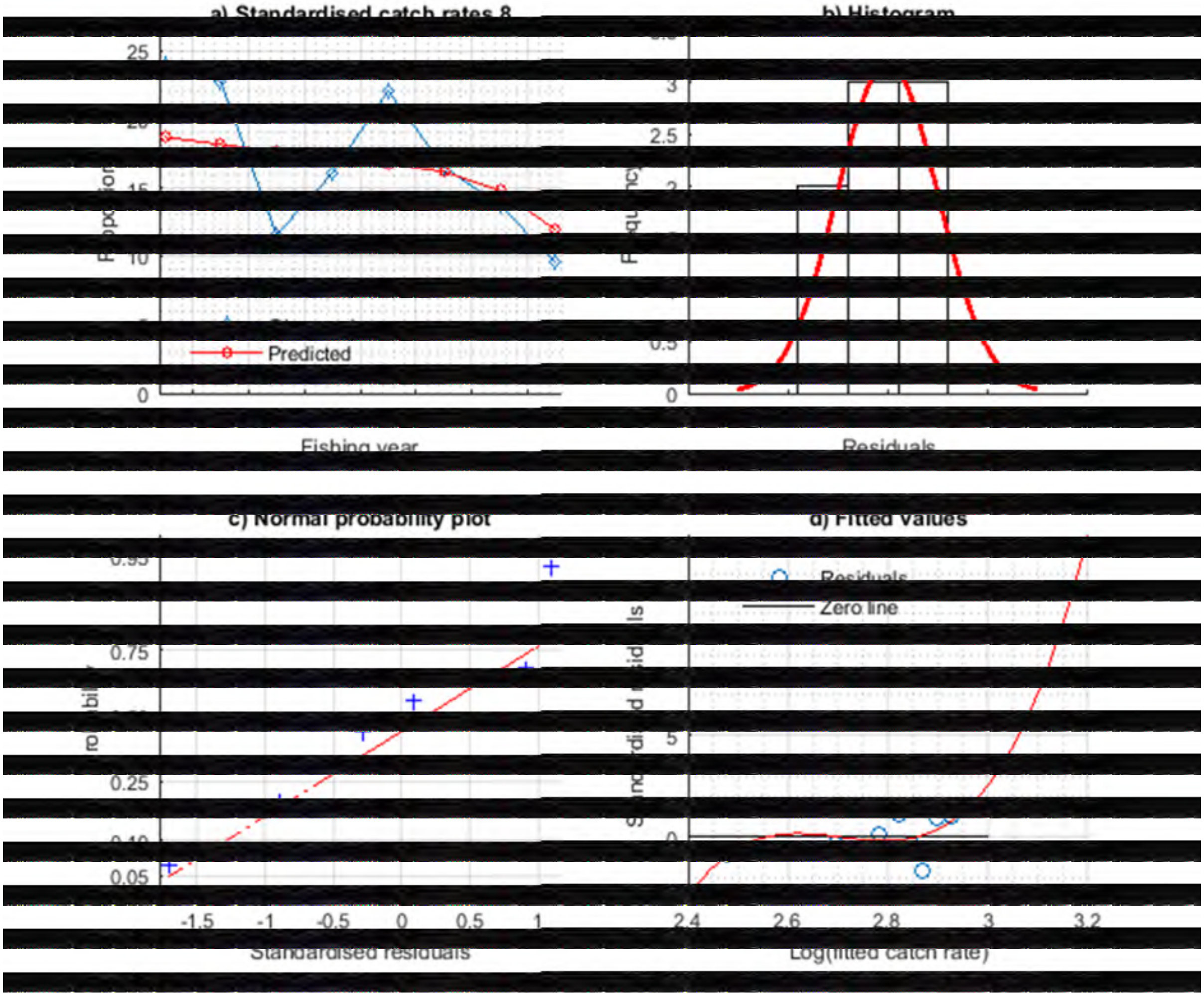


Figure 28 Model diagnostics for the historic catch rate time series.

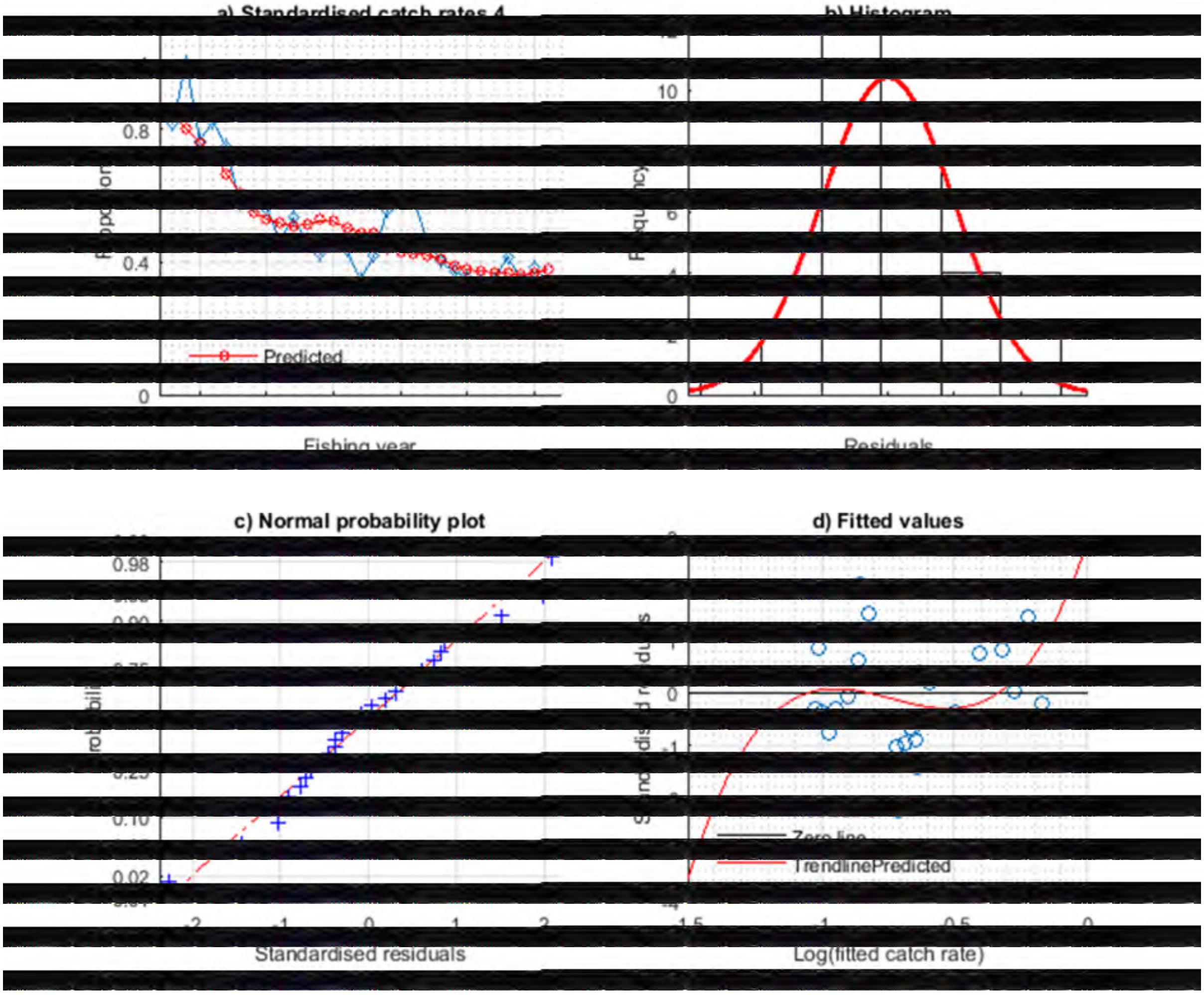


Figure 29 Model diagnostics for Queensland commercial line catch rate time series.

Appendix 17

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FRDC FINAL REPORT CHECKLIST

Project Title:	Informing inter-jurisdictional snapper management in eastern Australia		
Principal Investigators:	O Neill, M		
Project Number:	2015/216		
Description:	This report presents the results of the first joint fishery modelling of the east coast snapper stock: informing inter-jurisdictional snapper management in eastern Australia. Research involved the collaboration of fisheries scientists, biologists, managers and stakeholders from New South Wales, Queensland and Victoria. The latest microsatellite genetic techniques explored the stock structure of snapper along Australia's east coast, showing a two-stock genetic structure, a northern and a southern stock. These results were used to inform a snapper simulation model to inform cross-jurisdictional east coast snapper management on the northern stock. Challenges in the work included harmonising data from different jurisdictions and fitting the model to multiple data sets with different trends. Alternative management strategies on changes to minimum legal size and total allowable harvest for all fishing sectors were explored.		
Published Date:	XX/XX/XXXX (if applicable)	**Year:**	2018
ISBN:	978-0-7345-0460-9 (if applicable)	**ISSN:**	N/A
Key Words:	East coast snapper, Chrysophrys auratus, microsatellite genetic techniques, harmonised data, archival and fisher knowledge data, computer models, inter-jurisdictional management strategies, stakeholder engagement.		

Please use this checklist to self-assess your report before submitting to FRDC. Checklist should accompany the report.

	Is it included (Y/N)	Comments
Foreword (optional)	N	
Acknowledgments	Y	
Abbreviations	Y	
Executive Summary		
- **What the report is about**	Y	
- **Background – why project was undertaken**	Y	
- **Aims/objectives – what you wanted to achieve at the beginning**	Y	
- **Methodology – outline how you did the project**	Y	
- **Results/key findings – this should outline what you found or key results**	Y	
- **Implications for relevant stakeholders**	Y	
- **Recommendations**	Y	
Introduction	Y	
Objectives	Y	
Methodology	Y	
Results	Y	
Discussion	Y	

Conclusion	Y	
Implications	Y	
Recommendations	Y	
Further development	Y	
Extension and Adoption	Y	
Project coverage	Y	
Glossary	N	
Project materials developed	Y	
Appendices	Y	