Stock assessment of Australian east coast snapper, C*hrysophrys auratus*

Predictions of stock status and reference points for 2016

Queensland Government

This publication has been compiled by J. Wortmann, M. F. O'Neill, W. Sumpton, M. J. Campbell of Agri-Science Queensland, Department of Agriculture and Fisheries, and J. Stewart of New South Wales, Department of Primary Industries.

Summary

Snapper, *Chrysophrys auratus,* is a valuable commercial, recreational and charter fish species throughout its temperate/subtropical range along Australia's east coast. East coast snapper form a single genetic stock in ocean waters between Mackay (21.5^{0}S) in northern Queensland and about Eden (38^{0}S) in southern New South Wales. Fish in this eastern coast stock have been recorded to live for up to 41 years, with maturity occurring at four years of age.

This is the first assessment for the whole east coast stock. This comprehensive snapper stock assessment includes commercial, recreational and charter data sets from both New South Wales and Queensland (up to 2016). The assessment grouped the dynamics of the fishery into four fishing sectors: namely, 1) New South Wales commercial trap fishing, 2) New South Wales commercial and charter line, 3) Queensland commercial and charter line and 4) New South Wales and Queensland recreational. Changes in management arrangements through time were incorporated.

In 2017 management arrangements for snapper in New South Wales differ from those in Queensland. New South Wales has a minimum legal size of 30 cm (total length) and a recreational in possession limit of 10 snapper per person, whereas Queensland has a minimum legal size of 35 cm (total length) and a recreational in possession limit of four snapper per person (only one fish allowed to be greater than 75 cm). Line fishing is permitted in both New South Wales and Queensland. Fish trapping is the main commercial fishing method for snapper in New South Wales, however, this apparatus is not prescribed for use in Queensland.

Line fishing started in both states in the 1880s and the commercial trap fishery in New South Wales started in the 1940s. 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. Charter fishing total harvest peaked at 88 tonnes in 2001 before decreasing to 30 tonnes in 2016 across both states. Queensland recreational surveys estimated total recreational harvest in Queensland decreased from 552 tonnes in the 2005 survey to 82 tonnes in the 2013 survey. New South Wales recreational surveys in 2010 and 2013 estimated total recreational harvest to be 188 and 148 tonnes respectively. The estimated east coast snapper harvest since the late 1980s reduced and now was 700–800 tonnes per year since 2014.

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. 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. The Queensland recreational fishing sector showed declining catch rates from over the period 1994 to 2013 when estimates were derived from boat ramp and phone/diary surveys.

Past stock assessments, based solely on Queensland data, quantified snapper exploitable biomass levels of between 15 per cent and 50 per cent of unfished or virgin biomass levels, with the majority of analyses putting biomass levels below 35 per cent. A number of recommendations from these assessments included the continuation of fishery dependent monitoring of snapper size and age frequencies, the improvement of recreational harvest estimates, the continuation of fishery independent recruitment surveys and further research into the impact of discard mortality. These recommendations have largely been implemented and have improved the confidence in the overall assessment herein.

For National status reporting frameworks the differing management arrangements and catch trends between jurisdictions creates uncertainty around the status of the stock. Thus there is the need for a single, assessment approach across the east coast of New South Wales and Queensland. To quantitatively evaluate these concerns, the New South Wales and Queensland governments have commissioned this update to the stock assessment for east coast snapper, with the aim of incorporating all available information from New South Wales and Queensland into a single stock population model. A Fisheries Research and Development Corporation (FRDC) project conducted in parallel to the present assessment (FRDC project number 2015-216) will provide additional modelling on cross-jurisdictional management and projections of snapper stock biomass.

The present assessment used an annual age structured population model that analysed trends in east coast snapper data. Changes in management arrangements through time were incorporated in the model by including vulnerability to fishing according to minimum legal size. The model focussed on interpreting sector-based time series of catch rates (trap or line), to produce a series of results that examines the signals of different combinations of data, and provides a sensitivity analysis for various model settings.

There was an accelerating nature of decline in estimated spawning biomass relative to estimated virgin spawning biomass from 1950 to 1990. This decline was consistent with the harvest increases during that time period. After 1990, estimated spawning biomass ratios levelled off. For model analyses that used trap catch rates (New South Wales data) as the index of abundance, estimated spawning biomass ratios in 2016 were between 20 per cent and 45 per cent. Model analyses that used line catch rates (New South Wales and Queensland data) as the index of abundance estimated spawning biomass ratios in 2016 between 10 per cent and 23 per cent. The different signals in the New South Wales commercial trap catch rates and the line catch rates complicated the status of the stock as a whole, but suggests that localised depletion in Queensland is likely to have occurred.

Despite the differences/range of biomass estimates, the assessment recommends a reduction in overall fishing mortality to rebuild the stocks of this long-lived and iconic species to more sustainable levels. Effort will need to be reduced for any rebuilding of population sizes to occur. The rate of recovery will depend on the extent of the restrictions on harvest.

The Queensland Sustainable Fisheries Strategy 2017 to 2027 defines the following biomass targets:1) set catch limits based on achieving maximum sustainable yield (around 40 to 50 per cent original unfished biomass) by 2020, and 2) set catch limits based on achieving 60 per cent of original unfished biomass by 2027. For snapper, the maximum sustainable yield for target 1 was estimated to be between 780 and 1200 tonnes per year across New South Wales and Queensland and across all fishing sectors. During the 1970s and 1980s estimated total harvests appear to have been above the maximum sustainable yield, which is why harvests have declined thereafter.

The predicted long term average yield for target 2 (above) ranges from 600 to 940 tonnes per year across all waters and fishing methods. This means once the stock has rebuilt to a higher biomass level, harvests of this amount per year will be possible and will maintain the stock biomass target levels over the long term. Estimated harvest between 2014 and 2016 were of similar magnitude, however, given current stock levels are low, (between 10 per cent and 45 per cent biomass), rebuilding will not occur at this current level of harvest. Harvest and effort will need to be reduced for any rebuilding of stock biomass to occur. The results will take some time to see a change in the stock given the long lived nature of the species.

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Acknowledgements

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Definitions

AFMA	Australian Fisheries Management Authority.
AMLI	Australian Marine Life Institute.
B	Exploitable biomass: the combined weight of legal sized fish.
B_0	Mean equilibrium virgin exploitable biomass: average unfished 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).Catch Number or weight of all snapper caught (harvested and released).
Catch rate	Index of fish abundance, referred to as average (mean) catch rate standardised to a constant vessel and fishing power through time.EAC East Australian current.
Fishing year	months January to December.
FL	Fork length of snapper (cm); FL=0.857xTL-0.222.
FP	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. The elements of fishing power and catchability have the potential to bias abundance indices derived from catch rates. Therefore, methods of standardisation are required based on the data at hand.
FRDC	Fisheries Research and Development Corporation, Australian Government, www.frdc.com.au.
GBR	Great Barrier Reef.
Harvest	Number or weight of snapper caught and retained.
LMM	Linear mixed model.
LTMP	Long-Term Monitoring Program.MLS Minimum legal size, measured in cm (total length).
MSY	Maximum Sustainable Yield.
NSW	New South Wales.
NSWDPI	New South Wales Department of Primary Industries.
QFB `	Queensland Fish Board.
Qld	Queensland.
REML	Restricted Maximum Likelihood (type of linear mixed model); method used to standardise catch rates.
RFISH	Recreational Fisheries Information System.
Spatial areas	Figure i. The stock assessment covered the waters from Mackay (21.5^{0}S) to Eden (38^{0}S).SWRFS State-Wide and Regional Recreational Fishing Survey.TL Total length of snapper (cm); TL=1.167FL+0.259.

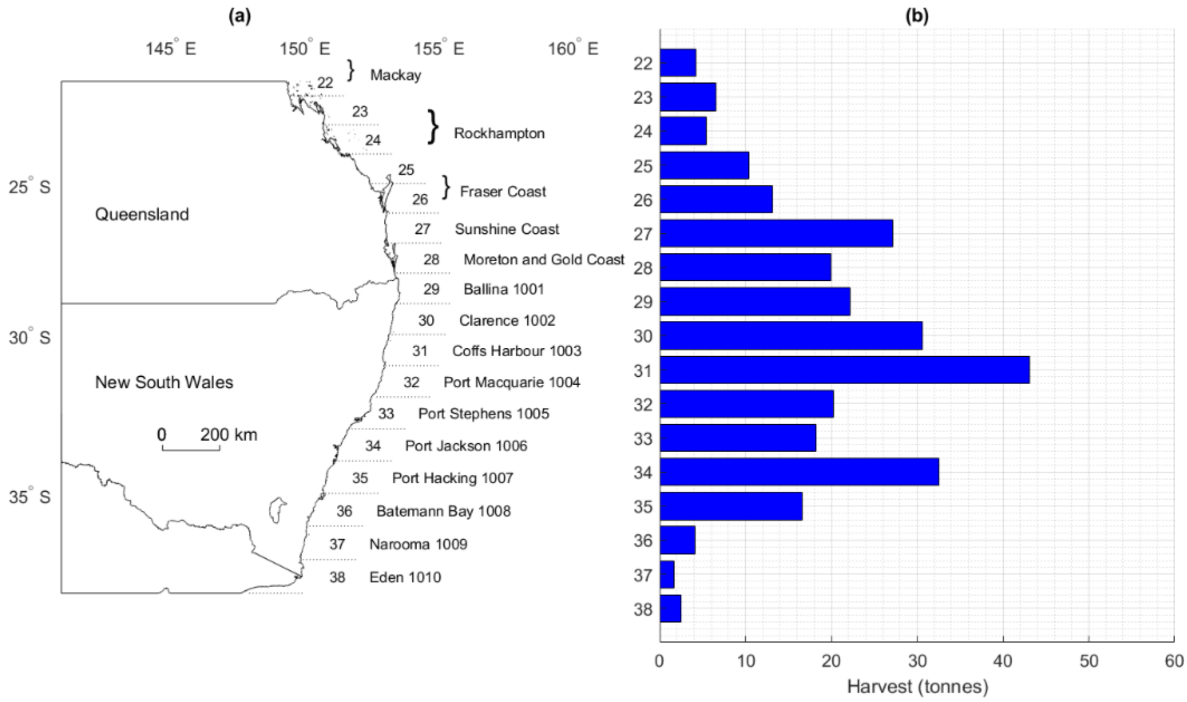

Figure i. (a) Map of Australian east coast waters and spatial stratifications for snapper. One degree latitude bands were used to stratify data for analyses. The analysis covered the regions from Mackay (21.5°S) to Eden (38°S). (b) The latitude distribution of average annual commercial landings of snapper (1988–2016). The port of Coffs Harbour, covering latitudes 30 and 31, traditionally had the highest commercial landings of snapper.

1 Background

1.1 Population genetics and stock structure

The genetic structure of east coast snapper was first investigated in 1980 using allozyme data as part of a study examining the Australian distribution of the species (MacDonald 1980). That study failed to detect population differences among the three east coast populations sampled. Sumpton et al. (2008) subsequently also used allozymes but sampled the east coast more intensively at seven sites spanning a finer spatial scale between Sydney and Rockhampton. They identified a genetic break on the central coast of New South Wales, north of Sydney but south of Forster.

The population genetics of east coast snapper was reassessed as part of FRDC project number 2015 to 2016. The study used 15 microsatellite markers to test the strength, and better resolve the location of the genetic break suggested by (Sumpton et al. 2008). Nine locations were sampled spanning four states and over 2000 km, including four sites located north, and five sites located south of central New South Wales on the east coast. Microsatellite markers confirmed the presence of two distinct biological stocks along the east coast (Figure 1.1). The genetic break was identified around Eden in southern New South Wales, roughly 400 km south of the genetic break reported by Sumpton et al. (2008).

The stock boundary of Sumpton et al. (2008), based on samples collected in the mid1990s, was likely the same genetic break identified in the latest genetic study, with the shift reflecting a southward movement of the ranges of the two stocks.

This shift in genetic “break” of east coast snapper stocks may be a result of changing ocean currents, temperatures and possibly salinities, and recognises an extensive mixing area where Victorian stocks may mix with the eastern stock. 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 warm water (Ridgway 2007). Water temperature has also been shown to be linked to spawning periods and spawning successes in snapper (Francis 1993; Lenanton et al. 2009). Furthermore, this southward shifting EAC has been associated with long-term shifts in the abundance and distribution of other temperate fish species (Last et al. 2011), which adds information to this assertion for snapper.

Therefore, in terms of the east coast, New South Wales and Queensland snapper were included in the same assessment while Victorian snapper were excluded.

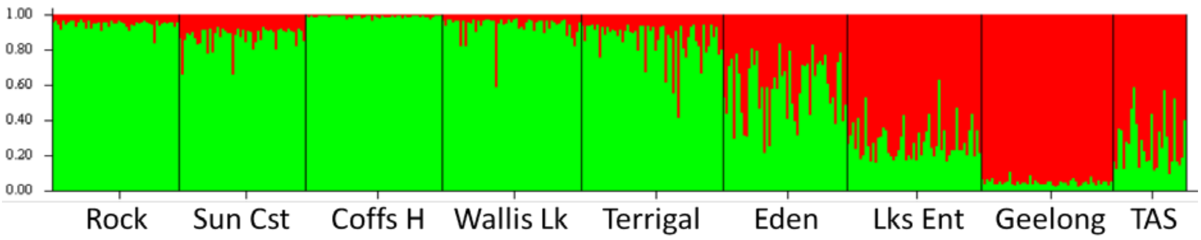

Figure 1.1. Genetic stock structure of snapper based on statistical grouping of microsatellite data. Fish were plotted from north (left) to south (right) by sample location (Rock = Qld - Rockhampton, Sun Cst = Qld - Sunshine Coast, Coffs H = NSW - Coffs Harbour, Wallis Lk = NSW - Wallis Lake, Terrig = NSW - Terrigal, Eden = NSW - Eden, Lks Ent = VIC - Lakes Entrance, Geel = VIC Geelong, TAS = Tasmania). Green denotes the probability of snapper belonging to New South Wales-Queensland stock, and red denotes the probability of snapper belonging to Victoria-Tasmania stock.

1.2 Snapper Biology

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 (>30 years), most of the population on the east coast of Australia were of ages less than 10 years old.

Inshore sheltered habitats (such as Moreton Bay and Hervey Bay) are important nursery areas for juvenile snapper. Tagging studies have shown that while most snapper do not migrate extensive distances, there are some individuals which will migrate over 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.

The age frequencies of the line catch of snapper were dominated by fish aged 3 to 5 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.

Snapper spawn in aggregations over several months (generally May to October) and synchronise spawning on the lunar cycle. Timing and duration of spawning 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. Snapper are sexually mature at 4 years of age. However, the faster growth rate of some subtropical snapper enables them to reach sexual maturity at about 2 to 4 years of age, earlier 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 can be subjected to high fishing pressure.

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 large recruitment years are known to migrate thousands of kilometres from spawning areas prior to becoming residents (Fowler et al. 2005).

1.3 Previous east coast snapper stock assessments

Ferrell and Sumpton (1997) conducted a basic yield per recruit analysis which indicated considerable scope for an increase in minimum legal size (MLS) to improve fishery yields. The study did not perform a population stock assessment. Subsequently, MLS were increased in both New South Wales and Queensland from 28 cm to 30 cm and from 30 cm to 35 cm respectively.

The first quantitative stock assessment for snapper for Queensland waters only was published in 2006 (Allen et al. 2006) which provided two alternate hypotheses on stock status.

1. Sustainably fished based on stable (but likely hyperstable) commercial line catch rates.
2. Overfished based on declining snapper catch rates taken from the charter and recreational fishing sectors.

A further Queensland based stock assessment was undertaken in 2008 (Campbell et al. 2009) which included additional fish size and age data. That assessment estimated the exploitable biomass of snapper in Queensland to be between 15 and 50 per cent of virgin biomass levels. The majority of modelled scenarios placed the biomass below 35 per cent. Recommendations from Campbell et al. (2009) included:

- the continuation of a then recently established fishery-dependent monitoring of snapper size and age frequencies
- the improvement of recreational harvest estimates
- the continuation, and improvement of fishery independent recruitment surveys
- further research into the impact of discard mortality
- the improvement of vulnerability at snapper age and length estimates.

The stock assessments of Allen et al. (2006) and Campbell et al. (2009) did not include data from New South Wales as these were not available at the time. Recent assessment of Stock Status reports have highlighted different interpretations of stock status across New South Wales and Queensland. The current stock model and assessment used a more extensive dataset than the stock assessments from Allen et al. (2006) and Campbell et al. (2009), which had been harmonised to enable incorporation of multiple jurisdictions and fishing sectors. The key differences between the current stock assessment and 2008 assessment are shown in (Table 1.1).

Table 1.1. Data differences between the 2008 stock assessment (Campbell et al. 2009) and the stock assessment herein.

Description	2009 Stock Assessment	2017 Stock Assessment
Time period	1946–2007	1880–2016
Region	Queensland	New South Wales and Queensland
Length and age data	1994, 1995, 2007	New South Wales: 1993–2015
		Queensland: 2007–2015
Recreational surveys	1994, 1995, 1997, 1999, 2000, 2002, 2005	1994, 1995, 1997, 1999, 2000, 2002, 2005, 2010, 2013
Historical catch rates	Not available	Catch rates for the decades 1880–1950
Moreton Bay pre-recruitment survey	Not available	Yearly catch rates for 2007–2015

1.4 Objectives and scope

The objectives of the stock assessment were:

- to collate and harmonise relevant fisheries data from Queensland, New South Wales and Victoria
- to incorporate all appropriate data into a population model of the east coast snapper stock
- to describe snapper stock status with respect to reference points described in the Queensland Sustainable Fisheries strategy 2017–2027 and provide recommendations for management and monitoring.

Results encompass Australian east coast snapper. The assessment was conducted on the whole (genetic east coast) snapper stock across jurisdictional waters of New South Wales and Queensland. Estimates of fish population size and limits on annual fishing cover the entire fishery of New South Wales and Queensland.

The assessment encompassed all east coast snapper harvests by the commercial, charter, recreational and traditional fishing sectors across New South Wales and Queensland. Harvests of snapper taken by indigenous traditional fishing were estimated in with the recreational sector. The key population status indicators were snapper catch rates and age frequencies.

The assessment covered the fishing (calendar) years 1880–2016.

The Queensland Sustainable Fisheries Strategy (SFS): 2017–2027 sets out clear target objectives to be achieved by 2020 and 2027 (https://www.daf.qld.gov.au/fisheries/sustainable-fisheries-strategy). The outputs from this assessment of snapper provide information on setting sustainable fishing and harvest limits to achieve the 2020 objectives under the SFS: i.e. reach a fish population size of 40–50 per cent of the original unfished level. For snapper, the original population size level was defined as year 1880. Results also provide insights on what is required by the fishery to meet the 2027 SFS objective of 60 per cent fish population size.

Estimated reference points of annual harvest tonnages were calculated for the whole east coast snapper stock. The reference point tonnages include all fishing sectors: commercial, charter, recreational and traditional across New South Wales and Queensland. Use of the reference point tonnages in management procedures need to consider the uncertainties in estimates and how many fish should be allocated to different fishing sectors and jurisdictions.

FRDC project number 2015-216, conducted in parallel to this assessment, will provide a separate report on additional modelling of cross-jurisdictional management and projections of snapper stock biomass.

1.5 New South Wales management

Management arrangements for snapper in New South Wales differ 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 (NSWDPI. 2006)

The main snapper management changes in New South Wales are summarised in (Table 1.2). The current minimum legal size of 30 cm total length was introduced in July 2001, an increase from 28 cm. The MLS of 28 cm 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 1.2. Management measures applied to the New South Wales snapper fishery. Source: New South Wales state government legislation.

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 per cent 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. Improved logbooks were introduced in July 1997 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 (Figure 1.2).

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).

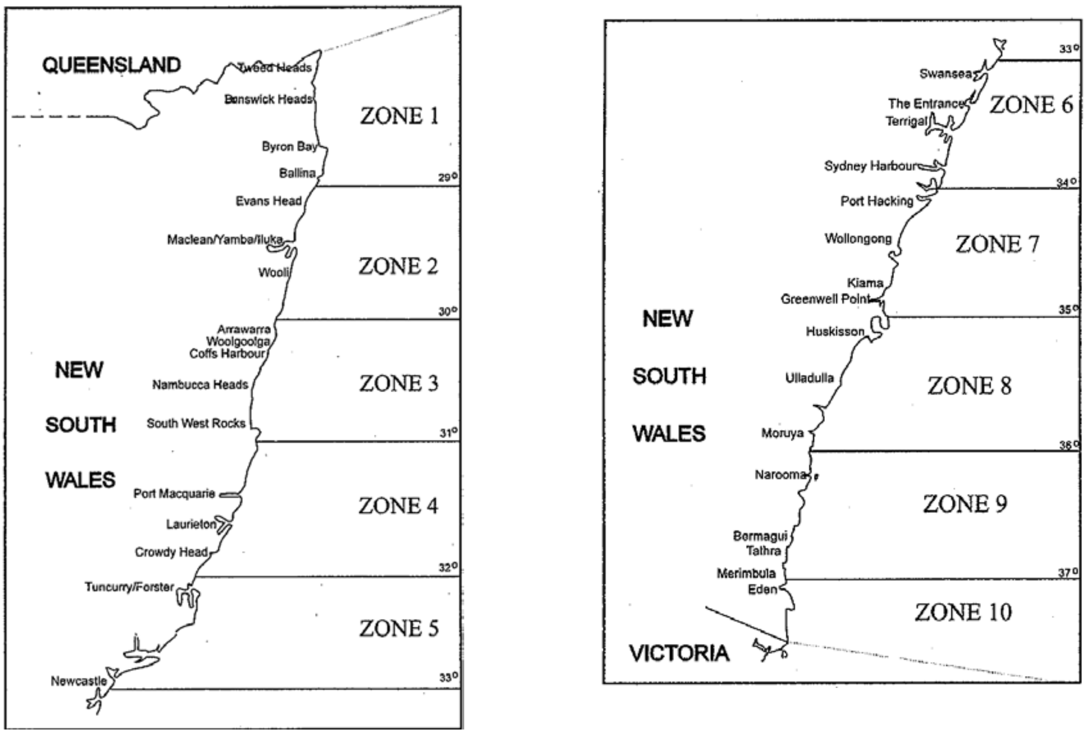

Figure 1.**2. **Spatial reporting areas in commercial New South Wales fishing logbooks 1984–2009.

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 restructure (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 share trading. 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.

1.6 Queensland management

Prior to 1979, line fishing for snapper was restricted by general fisheries management interventions. A snapper minimum legal size had been in place since 1900 at a size of 25 cm. 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 Australian 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 encompassed the entire snapper fishery off the coast of Queensland. Specific details including boundaries of the Queensland jurisdiction were contained in the *Queensland Government Gazette* of 10 February 1995. These allowed the inclusion of additional commercial fishers who had operated in adjacent waters outside of the State, where they had previously held Commonwealth licences. In the case of snapper this enabled some New South Wales trap fishers to operate in Queensland waters, a condition which has now lapsed with the retirement of those fishers.

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.

Recreational catch (harvested and released) and some effort information were collected from the mid-1990s from phone and diary surveys. Initially these surveys were part of an RFISH system which estimated catches in 1997, 1999, 2002 and 2005. In 2000 an improved National Survey of recreational catch was assessed in all Australian states. Subsequently, the same methods were used in 2010 and 2013 to estimate the Queensland catch. The latter three surveys used more frequent contact with fishers to reduce recall bias and "dropout" rate and were 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 to the *Fishing Industry Organisation and Marketing Act 1984* restricted the sale of recreationally caught fish to a limit of 50kg 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 the capacity of recreational fishers to sell any part of their catch.

Catch and effort information were collected from the charter boat fishery by way of a voluntary logbook established in 1993-94 which later became "compulsory" in 1996. Despite the introduction of the charter logbook, there were still some operators that did not submit logbooks or any other form of catch return. After 1 July 2006 only those operators in offshore waters were required to hold a licence and submit logbook data.

In 1993, a suite of new management arrangements was 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.

Commercial line fishers endorsed with an L1 symbol could effectively fish in all state-managed coastal and offshore waters south of the GBR and were 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 were no multi-hook commercial fisheries (longline) or trapping in Queensland.

In December 2002, the minimum size limit of snapper was further increased from 30 cm to 35 cm and the recreational in possession limits were reduced from 30 to 5 snapper per person (Table 1.3). An investment warning was issued for the Rocky Reef Finfish Fishery (RRFF) in September 2003 to warn those with a current interest or considering investing in the fishery that increases in commercial harvest levels or fishing effort may not be recognized as 'historical involvement' when developing future management arrangements.

Table 1.3. 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	35cm	4 snapper per person	Only 1 snapper greater than 70cm
Dec 2002	35cm	5 snapper per person	
1993	30cm	30 snapper per person	
1900	25cm		
Pre 1900	0		

Following the stock assessments of Allen et al. (2006) and Campbell et al. (2009) 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 five to four snapper per person and a maximum size limit of 70 cm introduced for recreational anglers (only one fish greater than 70 cm could be retained).

There are several small areas in southern Queensland closed to fishing: the Moreton Bay Marine Park and the Great Sandy Strait Marine Park (https://www.qld.gov.au/environment/coasts-waterways/marine-parks). The Great Barrier Reef Marine Park also contains closed areas to fishing.

2 Methods

2.1 Fishing data

The snapper harvest and fishing effort data were obtained from a number of data sources, namely: Queensland commercial fish board data, commercial logbook systems in New South Wales and Queensland, charter logbook systems in New South Wales and Queensland, and a range of research data that estimated recreational catches and commercial harvest data from the Australian Fisheries Management Authority (AFMA). For all data sources, the harvest data input to the model was snapper harvest from all fishing methods. The data were imported into a MS Access harmonised database and stored in a secure directory for 'stock assessment' on the Queensland Department of Primary Industries server at Dutton Park. The secure directory allowed access only to approved staff and ensured confidentiality, integrity and back-up of the data.

The stock model differed from the previous Queensland based assessment of Campbell et al. (2009), in that the assumed virgin state of this fishery was changed from 1945 to 1880. This was based on the levels of harvests from the historical data (Section 2.1.3 and Thurstan et al. (2016)) and fishing data from New South Wales (NSWDPI 1985). The setting of the start of the fishery in 1880 was based on the data and enabled a more accurate account of the history of fishing.

Thus from the various data sources, snapper harvests were compiled by year from the start of the fishery in 1880, defined by Thurstan et al. (2016) to the end of December 2016 (Table 2.1). For snapper, fishing year was the same as calendar year, i.e. January–December.

2.1.1 Commercial and charter fishing

New South Wales commercial harvest data were available from 1940–2016. Interpolations were conducted for pre–1940 fishing years using the fact that that a harvest of around 100 tonnes was observed in the 1900s (NSWDPI 1985). The harvest data for the years 1940–1984 were by financial year and thus converted to calendar year as described in (Table 2.1). The split between trap and line harvest was estimated for the years 1940–1997 as described in (Table 2.1).

New South Wales snapper harvests by charter operators were recorded from the year 2000. Predictions for the years pre-2000 were based on the fact that there were charter harvests present in the early years, as reported by Thurstan et al. (2016) (Table 2.1). It was reasonable to assume that there was a steady increase in snapper charter harvest from 1980–2000, when charter fishing began to formally operate. There was an increase in the number of charter fishing operators and associated fishing effort around 1995–1999, when the New South Wales Government announced investment warnings and that the sector would be moving to a limited access management.

Queensland commercial snapper harvests were recorded from 1946 onwards. Harvest totals for the years 1880–1945 were estimated using information from Thurstan et al. (2016) (Table 2.1). Harvests for the years 1981–1988 were missing and were interpolated using a linear regression to best fit the data before and after these years.

There were no Queensland charter harvest data pre-1996. Total annual harvests prior to 1996 were hind casted (Table 2.1), supported by the fact that charter harvests were present in the 1880s (Thurstan et al. 2016).

Table 2.1. Snapper harvest data sources and remarks for commercial and charter sectors. The harvest data input to the model was the total snapper harvest, that is, snapper caught and retained by all methods of fishing.

State	Sector	Period	Data source	Comment
NSW	Commercial	1880–1939	Interpolated	No record of trap fishing before 1940. Thus all fishing pre–1940 was allocated to the line fishing sector. Harvest = $year^{1.4946}$+10 where year=0 for 1880, giving harvest in 1900s of around 100 tonnes (NSWDPI 1985).
		1940–1984	Historical	Data was by financial year. Average of adjacent years was calculated for conversion to calendar year. 77.24 per cent of total harvest was assumed to be trap, rest was assumed to be line. The percentages were estimated from the percentage split between trap and line harvest for the years 1997–2016.
		1985–2016	Commcatch logbook	Compulsory monthly catch and effort data. Pre-1997 assumed split in trap and line harvest was as per historical split above.
		2009–2016	Fishonline logbook	Compulsory daily catch and effort data. This was the same as the commcatch logbook data but with daily records and over a shorter period of time.
		1999–2016	AFMA	Added to the New South Wales line harvest. Not projected back as it was likely covered by the NSW catch data pre-1999.
	Charter	1880–1999	Interpolated	The preceding year's harvest was hindcasted back from 1999 and down to 1983, was calculated by reducing the tonnage by a factor of 0.943. From 1982, the preceding years harvest was calculated by reducing the tonnage by a factor of 0.999.
		2000–2016	Logbook	Compulsory logbook data
Qld	Commercial	1880–1945	Interpolated	Fitted a parabolic equation to give harvest of around 100 tonnes in 1900.
		1946–1980	Fish Board	Harvest data only
		1981–1988	Interpolated	Applied a linear equation.
		1989–2016	Logbook	Compulsory daily catch and effort data
	Charter	1880-1995	Interpolated	The preceding year's harvest, starting from 1995, was hindcasted by reducing the tonnage by a factor of 0.989.
		1996–2016	Logbook	Compulsory from 1996–July 2006, although there were some operators who did not submit logbooks. After 1 July 2006 only those operators in offshore waters were required to hold a licence and submit logbook data.

2.1.2 Recreational fishing

Recreational harvest

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 2.2). 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.

Table 2.2. Survey estimates of recreational snapper harvests from New South Wales and Queensland waters. Estimated fish numbers was used in the stock assessment, with tonnages 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 1997)	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

The 1994-95 Queensland recreational estimates were based on aerial surveillance and access point creel surveys while all other surveys used phone and diary methods. The household surveys in 2000, 2010 and 2013 had improved follow-up contact procedures with diarists resulting in less drop out of participants over time compared to the other phone survey years. For the RFISH surveys 1997, 1999, 2002 and 2005, the higher drop out was regarded to inflate mean catch rates resulting in an overestimate of recreational fish catches. To account for this bias, a simple ratio formula from Leigh and O'Neill (2017) was applied to reduce RFISH estimates to better align with the 2001, 2010 and 2013 surveys:

$$c_{2001} \Big/ \left(\frac{2}{3} c_{1999} + \frac{1}{3} c_{2002} \right)$$

The assumption in this scaling was that the RFISH estimates were overstated by the same fraction in all survey years in which the RFISH methodology was employed. Leigh and O'Neill (2017) believed this assumption was reasonable.

Only two surveys in 2000 and 2013 were completed in New South Wales waters. For the missing surveys not matching Queensland, New South Wales snapper catches were calculated using a mean State (NSW:Qld) ratio estimator of one (calculated from the 2000 year) for harvested fish before 2010, and a mean state ratio of 2.17 for the 2010 year calculated from the 2000 and 2013 years. For input into the population model, final estimates of recreational snapper harvests (numbers of kept fish) for the nine years were combined across States.

Recreational effort

For population modelling, prediction of recreational harvest or fishing effort for non-survey years was required. Based on the suggestion by Dr Francis in the independent review of snapper stock assessment in Campbell et al. (2009), a history of recreational harvests was predicted based on a constructed history of fishing. This involved joining historical information on boat registrations (Figure 2.1 a), and survey estimates of fishing participation and effort (Webley et al. 2015) (Figure 2.1 b and c). (Figure 2.1 a) shows a proxy for fishing effort based on numbers of boat registrations. This is based on the assumption that changes in boat registrations correlate with fishing effort. There were also two survey estimates of fishing participation and effort, one estimate gave all offshore ocean boat fishing effort (Figure 2.1 b), and one estimate represented only the 'successful' ocean boat fishing effort where snapper were harvested or released, i.e. zero catches excluded (Figure 2.1 c). Both estimates of effort indicated a similar declining trend.

In total three proxies of recreational effort were constructed. The proxies were based on three levels of fishing power, described in Section 2.1.3, the pattern of exponential increase in boat licences, and a decrease in the fishing effort post 1996 based on declining participation in fishing estimated from 1996 (Webley et al. 2015).

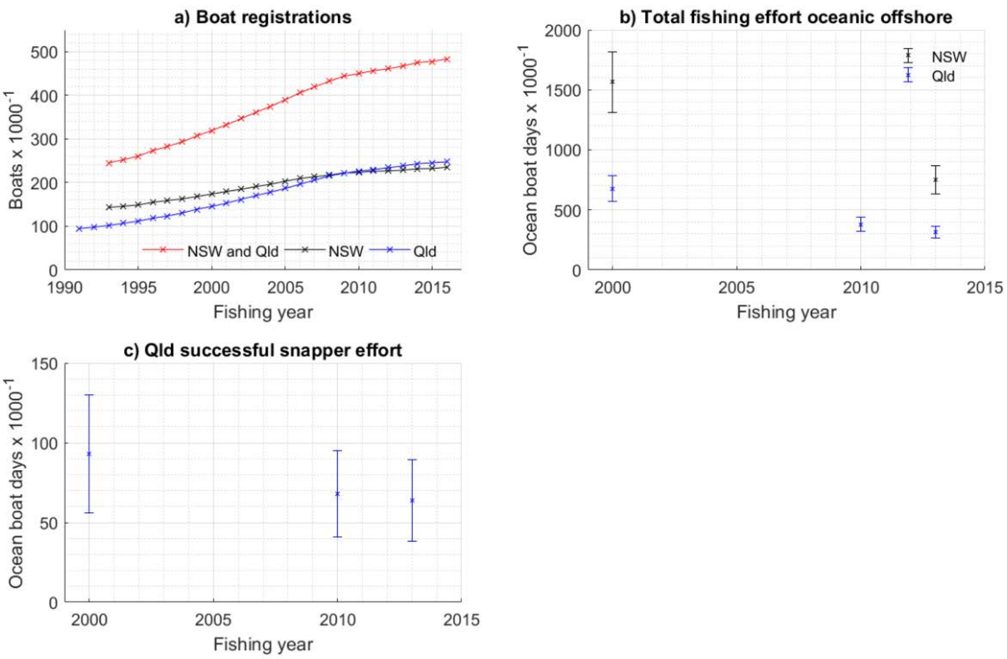

Figure 2.1. Annual estimates of snapper fishing effort by recreational anglers. a) Boat registrations over time, b) All offshore ocean boat fishing effort, c) Only 'successful' ocean boat fishing effort where snapper were harvested or released in Queensland, i.e. zero catches excluded. Error bars represent ± two standard errors.

2.1.3 Historical

A full discussion of the historic data used in this assessment is presented in FRDC report number 2015-216. This section summarises the key methods used to incorporate these data into the stock assessment.

Historic documents indicated that snapper were fished since the early development of the colony around Sydney Harbour in the late eighteenth century, but it was after 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 2.2). Exploitation of snapper thus commenced many decades prior to any formal government monitoring of the fishery. While some historical datasets had already been used in the previous snapper stock assessment (e.g., the Queensland Fish Board data spanning the years 1945–1981), these datasets were known to not encompass the full history of either the commercial or recreational fishery.

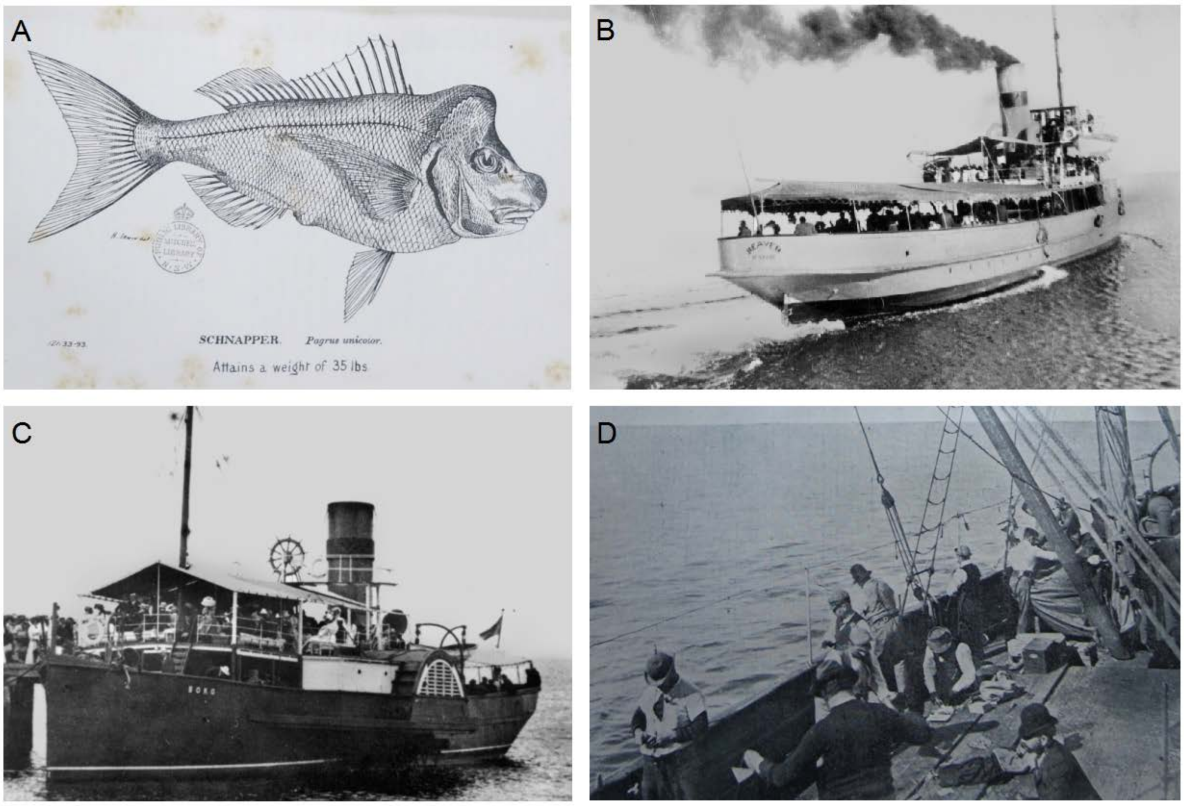

Figure 2.*2*. A) Sketch of a snapper (Thompson 1893), B) The SS Beaver was frequently chartered for snapper fishing trips from Brisbane during the 1880s and 1890s (State Library of Queensland, 1894), C) The SS. Boko was frequently chartered for snapper fishing trips from Brisbane during the 1870s and 1880s (State Library of Queensland ca. 1890), D) Snapper fishing on-board the SS. 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, catch and sightings of rare species. In some cases, the use of these ‘alternative’ sources have 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 the ability to rapidly examine large numbers of historical sources and enabling the extraction of data that would not previously have been accessible.

Historical snapper catch data were sourced from state and national archives and fisher knowledge data in New South Wales, Queensland and Victoria. These data have been used as an expanded time series of catch or catch rate trends to provide information that can be considered in the stock assessment model of the east coast snapper stock. This builds upon a previous FRDC report (Thurstan et al. 2016) 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.

2.2 Fishing power

Commercial, charter and recreational fishers of snapper along New South Wales and Queensland east coasts were interviewed to obtain data on fishing power technologies and their affects upon snapper catches, (Sumpton et al. 2013; Thurstan et al. 2016). Increasing fishing power technologies are a feature of virtually all fisheries around the world and are the result of advances in a range of different technologies from basic fishing gear to modern electronics. These technological changes effectively mean that it is easier to catch fish using modern gear compared to original gears used in earlier times. It is common scientific practice for stock assessments to standardise catch rates to take into account the effect that these changes have had over time.

Uptake rates of gear and technology

The uptake rates of gear and technology (Table 5.9 in Appendix 5.3) were determined from interviews with commercial, recreational and charter fishers in Sumpton et al. (2013) and Thurstan et al. (2016). The interviews asked questions on when fishers first started using, and discontinued use of, various gears and technologies. The gears and technologies covered in the interviews were GPS; colour, paper and monochrome sounders; 4-stroke engines; braid line; soft plastic lures and float lining. Fishers also highlighted other advances in fishing technology that were not specifically addressed by the specific interview questions posed in the studies, where the most important of these technologies were graphite rods, "glow" beads and "spot-lock". Graphite rods are lighter than fibreglass rods and being much stiffer, give a better strike than fibreglass rods. "Glow" beads are located by the trace near the fish hook and mirror biological triggers. "Spot-lock" are electronic GPS anchors that keep the fisher in one position. Virtually all fishers agreed that "spot-lock" and other ongoing improvements in fishing technology enhanced fishers' abilities to catch fish.

The interviews provided uptake rates up to the year 2012. Uptake rates for the years 2013–2016 were set to the uptake rates of 2012. Where both Sumpton et al. (2013) and Thurstan et al. (2016) provided uptake rates in the same year, the weighted average of the two uptake rates was taken according to their sample size.

Effects

Interviews from Sumpton et al. (2013) were conducted to determine fishers' perceptions of the impact of technologies on catch rates (Table 5.10 in Appendix 5.3). Fishers estimated as a percentage how much GPS, colour sounders, braided fishing line, soft plastic lures and float lining improved their ability to catch fish compared to not using that particular gear or technology. For each gear and technology, the average of the percentages from each fisher was used to give the overall percentage.

Fishing power model

The uptake rates of gears and technology, and fishers perceptions on how advances in fishing technology had improved their catches over time, were combined to calculate four time series of annual increases in fishing power for:

1. no change in fishing power
2. reduced fishing power from the square root of the actual fishing power
3. actual fishing power as estimated from the fisher knowledge data
4. high fishing power from the 75th percentile of the actual fishing power.

The reduced schedule of fishing power was calculated to account for possible overestimation; for example, in the interviews fishers may have overestimated the effect of a technology, while the high effects scenario was generated to cover the case where other fishing power variables that were not surveyed were important for increasing fishing power (e.g. improved fishing experience through time or other variables listed in (Table 5.10).

What was clear from interviews was the general view that technology had dramatically increased the ability of line fishers to 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 fact that many fishers attributed such a high level of impact of these technologies on their fishing power has important implications for the standardised catch data that are used in stock assessments. Catch rate trends that do not account for the impact of these technologies will present more optimistic views of stock status. Section 3.1.3 shows how including technological changes influences catch rates in the New South Wales and Queensland snapper fisheries.

2.3 Catch rates

Stock assessments for many fisheries rely on fishery-dependent catch and effort data to measure annual trends in the relative abundance of the stock (Hilborn and Walters 1992). Ideally, indices of abundance are based on fishery-independent data collected through scientific surveys which use standardised conditions to eliminate or minimize the influence on catch rates of factors other than resource abundance. However, such surveys are often not economically feasible due to the large spatial extent of many fisheries. Instead catch rates calculated from fishery-dependent catch and effort data are often relied upon in stock assessment, and assumed to be proportional to underlying resource abundance (Cosgrove et al. 2014).

For the snapper stock assessment there were seven fishery-dependent collection programs (Section 2.1) that were used to compile a time series of catch rates. These data were for the New South Wales commercial sector (Table 5.1 and Table 5.2), the Queensland commercial and charter sectors (Table 5.4 and Table 5.5), the AMLI (Australian Marine Life Institute) Queensland charter fishing sector (Table 5.6), and the Queensland recreational sector (Table 5.7 and Table 5.8). Data selection filters were applied and noted in each information table.

In addition to the fishery-dependent collection programs, catch rates were compiled from historical records for the early years of snapper fishing in New South Wales and Queensland. Section 2.1.3 describes the data and methods used to compile these catch rates.

Only one fishery-independent data set was available for stock assessment, namely the Moreton Bay pre-recruitment survey. This data involved sampling young snapper (less than 15 cm in length) from Moreton Bay and produced pre-recruitment catch rates from 2007–2015. The annual catch rates indicate trends in juvenile snapper abundance.

Before the fishery-dependent catch rate data were included in the stock assessment as an index of abundance, it was important to standardise the data to remove or minimize the effect that any varying factors other than resource abundance had on the catchability of snapper (Maunder and Punt 2004). Modelling of catch rates thus facilitated consideration of a range of factors that potentially affected catch rates (Campbell 2004) namely:

- The influence of lunar phase on catch rates was tested (Appendix 5.4.1) and was found to be non-significant in all standardisations and was thus not included in the catch rate standardisation.
- The influence of wind speeds and wind direction on each day for Queensland catch rates were tested by sourcing wind direction and strength data from the Bureau of Meteorology (BOM, Australian Government; www.bom.gov.au) (Appendix 5.4.2). The wind component variables were non-significant for the commercial and recreational snapper standardisations but were significant and included in the Queensland charter catch rate standardisation.
- The influence of seasonality on snapper catch rates was modelled using sinusoidal data to identify the time of year (Appendix 5.4.3). This was in place of using monthly or weekly factorisations of the data which would lead to more parameters being estimated. Seasonality was significant and was included in all catch rate standardisations.
- Increased fishing power and effort from better vessels, gear, techniques, improved knowledge and increased fishing time were included in the catch rate standardisations. The fishing fleet's structure was standardised explicitly with model parameters scaling each vessel-operation's or fisher's mean catching efficiency. Increases in the fleet mean or fisher mean (distribution) from year to year indicated more fishing by the higher catching fishers (example in (Figure 5.22) in (Appendix 5.7.1). Decreases in the fleet mean or fisher mean from year to year indicated the better fishers were leaving the snapper fishery (example in (Figure 5.28) in (Appendix 5.7.3).

The approach adopted for the standardisations was as follows:

- If the data set had a high frequency of zero snapper catches, a two-component approach was used where the expectation for mean catch rates $E(c)$ was defined as

$$E(c) = p(c)E_1(c|c > 0)$$

  - where $p(c)$ was the probability of catching a snapper, and $E_1(c|c > 0)$ accounted for where a number or weight of snapper were caught and retained.
- If the proportion of zero snapper catch in the data set was below 16 per cent, a single analysis was performed where the expectation for mean catch rates $E(c)$ was defined as

$$E(c) = E_2(c|c \geq 0)$$

  - where $E_2(c|c \geq 0)$ accounted for zero snapper catches together with snapper catches.

For E_1 and E_2 the standard catch-biomass equation from Hilborn and Walters (1992) was used:

$$c_{vta} = q_{vta} E_{vta} B_{ta}$$

where c_{vta} was the harvest of snapper taken at time t, from fishing operator v, from area a, q_{vta} was the measure of fish catchability including fishing power, E_{vta} was the fishing effort on the day fished (no information was available on the number of hours fished, travelled or searched, therefore analysis unit was harvest per boat-day=1) and B_{ta} was the biomass of snapper available on the day.

The logarithm of the catch-biomass relationship formed additive terms in a linear model and was used to standardise mean catch rates (Hilborn and Walters, 1992; Robins et al., 1998; O'Neill and Leigh, 2006). The linear models were the basis for determining indices of snapper abundance (Table 5.11-Table 5.14) in (Appendix 5.5). Catch rate indices were produced by using different log-scale offset schedules for annual changes in fishing power (i.e. effectively adjusting the catchability component in the catch-biomass relationship), for schedules of no increase, reduced effects, actual effects and high effects of fishing power.

The annual catch rate indices were calculated by year and latitude band (Figure i). Each latitude's prediction was weighted by their total harvest summed over all years. The latitude weightings w were scaled proportionally which satisfied $\sum_a w_a = 1$ and was kept constant over years. The spatial prediction methodology, of not changing weights through time, adhered to the concepts of Walters (2003), Carruthers et al. (2010), Carruthers et al. (2011) and Leigh et al. (2014). To ensure comparability of means between different latitudes, predictions were normalised annually as proportions measured against a selected fishing year for each data set. Standard errors or 95 per cent confidence intervals were calculated for all predictions.

The statistical software package Genstat (VSN International 2017) was used to carry out the analyses and provide asymptotic errors. The standardisation approach used generalised linear (GLM) and linear mixed (LMM) models (Table 5.11-Table 5.14) in (Appendix 5.5). The LMM's used the REML algorithm allowing for model terms that can contain both fixed and random effects. (Appendix 5.5) gives the Genstat code used to standardise catch rates.

2.4 Fish age data

Annual age and length compositions of snapper were monitored in New South Wales since 1982 and in Queensland since 2006 (Table 2.3) and (Appendix 5.8). Fish samples were collected from commercial, charter and recreational harvests of snapper along the east coast of Queensland, and commercial and recreational harvests of snapper from New South Wales. The New South Wales snapper ageing data were supplied by NSWDPI to be compatible with the Queensland ageing data, and these methods are outlined in (Appendix 5.8).

Table 2.3. Annual snapper age and length sampling programs in New South Wales (NSW) and Queensland (Qld).

Fleet	Years length frequency data	Years length and age frequency data
NSW commercial trap	1982, 1985, 1986, 1988, 1993–2015	1993–2005, 2007–2015
NSW commercial line	2002, 2004–2015	None
NSW recreational	1994	None
Qld commercial line and recreational	2006–2015	2006–2015

2.5 Population dynamics model

The dynamics and equations of the model followed the theory from O'Neill and Buckley (2017), 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 2.4):

- Yearly (t) time categories from the fishing year 1880–2016
- Age-group (a) from 0+ to the maximum age
- Fishing sector (f) where sector 1 = NSW commercial trap, sector 2 = NSW commercial and charter line, sector 3 = Queensland commercial and charter line and sector 4 = NSW and Qld recreational.

The model was run in two phases (Figure 2.3):

1. Historical estimation of snapper stock from 1880–2016
2. Estimation of management reference points.

Model parameters were estimated by calibrating the model to standardised catch rates and age group frequency data (Table 2.5). 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). The flow of the estimation process was summarised in (Figure 2.3).

Equilibrium harvest reference points were calculated for maximum sustainable yield (MSY), and for 0.6 of virgin exploitable biomass. The exploitable biomass that can support harvest at the maximum sustainable yield was denoted by B_{MSY}, $B_{MSY} \approx 0.4B_0$, and the biomass at 0.6 of virgin biomass was denoted by $B_{0.6}$, $B_{0.6} \approx B_0$, where B_0 was the mean equilibrium virgin exploitable biomass, (the average unfished biomass level if fishing had not occurred). These are the biomass target reference points and desirable levels of performance as outlined in the Queensland Sustainable Fisheries Strategy 2017–2027.

Table 2.4. Equations for calculating the snapper population dynamics. Variables were defined in Table 2.5 where C=harvest, B=estimated exploitable biomass and E=proxy of recreational effort defined in section 2.1.2.

Population dynamics	Equation
Number and weight of fish	(1)
$N_{t,a} = \begin{Bmatrix} R_t & \text{for } a = 0 \\ N_{t-1,a-1}\exp(-Z_{t-1,a-1}) & \text{for } a = 1,...,\max(a) \end{Bmatrix}$	
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	
$U_{t,f} = \begin{Bmatrix} C_{t,f} / B_{t,f} & f = 1,2,3 \\ 1-\exp(-q_f E_{t,f}) & f = 4 \end{Bmatrix}$	(4)

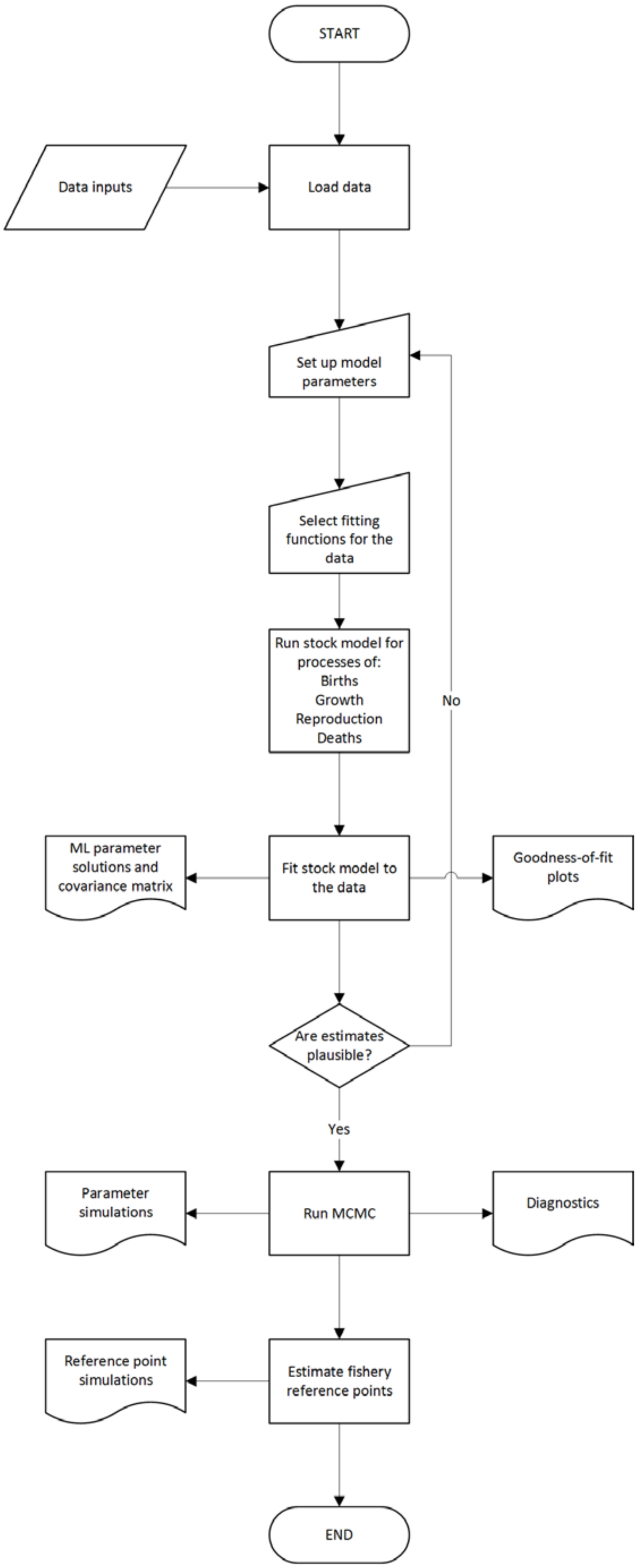

Figure 2.3. Flow of operations for the stock model from loading the data to evaluating model predictions.

Table 2.5. Parameter definitions for the snapper population dynamics 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 NSW and Qld.
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, Section 1.2 and 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	$l_a = 87.99(1 - \exp(-0.078(a - 2.548)))$, standard deviation 6.47 cm $w_a = 15.39(1 - \exp(-0.029(a - 1.58)))$, 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 rate of 0.3 was tested. 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 $\xi, r_{comp} = 1 + \exp(\xi)$.
$\eta(t)$	Log-recruitment deviations for 1980–2016.	For the years 1880–1979 recruitment was deterministic.

Parameter	Equations and values	Notes
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

Significant reforms and management affecting the trawl industry over the last 15 years have all dramatically reduced the incidental trawl mortality of juvenile snapper which we have assumed to be negligible in the model. These include:

- introduction of trawl bycatch reduction devices
- reduction in overall Moreton Bay trawl effort by around 75 per cent
- closure of some juvenile snapper habitat to trawlers as part of the Moreton Bay Marine Park in 2009.

Mortality of snapper caught and discarded by the inshore net fishery was assumed negligible since the gill net fishery contributed less than 5 per cent to the commercial harvest and gill net mesh sizes typically selected legal sized fished.

3 Results and discussion

3.1 Model inputs

3.1.1 Fishing harvest and effort

The distribution of snapper harvest across all fishing sectors is shown in (Figure 3.1) for the years 2000 and 2013. Recreational surveys in New South Wales and Queensland in 2000 and 2013 provided estimated harvests for the recreational sectors (Table 2.2).

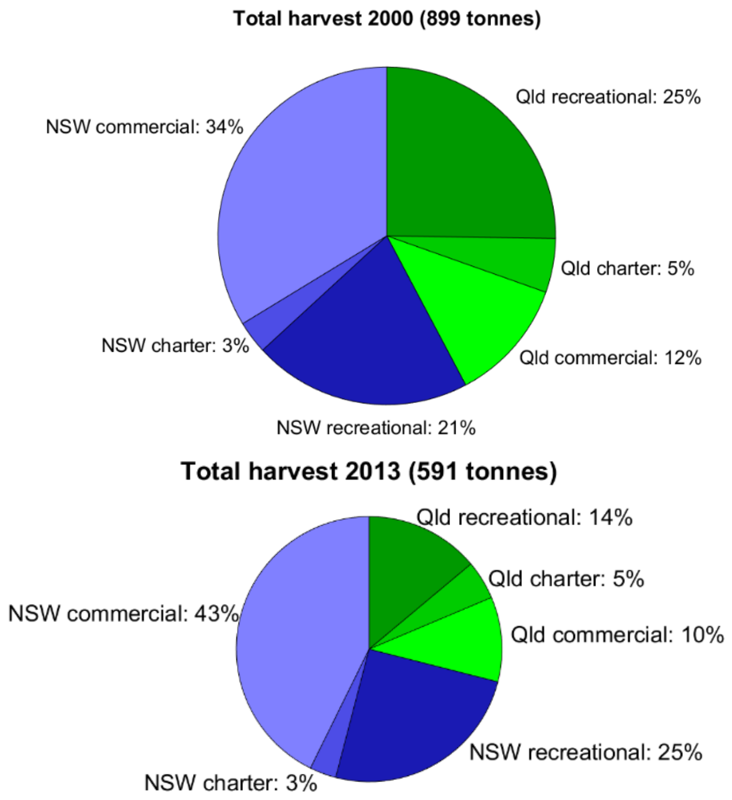

Figure 3.*1*. Total snapper harvest in tonnes (for all fishing methods) by fishing sector for the fishing years 2000 and 2013. The recreational harvests are the estimated harvests from the 2000 and 2013 recreational surveys (Table 2.2).

Snapper harvest landings for the commercial and charter sectors were derived from logbook recordings and estimations for missing years, as described in Section 2.1.1. The harvest totals represent the snapper harvest across all methods of fishing (Figure 3.2). For the New South Wales commercial data for 1997–2016 the total harvest consisted of 77 per cent from the trap method of fishing, 18 per cent from line methods of fishing, 5 per cent from netting and other fishing methods. For the Queensland commercial data for 1988–2016 the total harvest data consisted of about 96 per cent from line methods of fishing, 4 per cent from netting and other methods of fishing.

Figure 3.2 shows the strong building of the trap commercial harvest during the 1940s to 1980s and decline to 2000's. From 1880–1940 there was a steady build up in commercial harvests. In New South Wales the commercial harvests from 1880–1940 were mostly line, thus in the stock model commercial harvests from 1880–1940 followed the line vulnerability schedule (based on the project team committee recommendation). Records on trap fishing were first available from 1940, thus the trap sector was explicitly accounted from 1940 onwards.

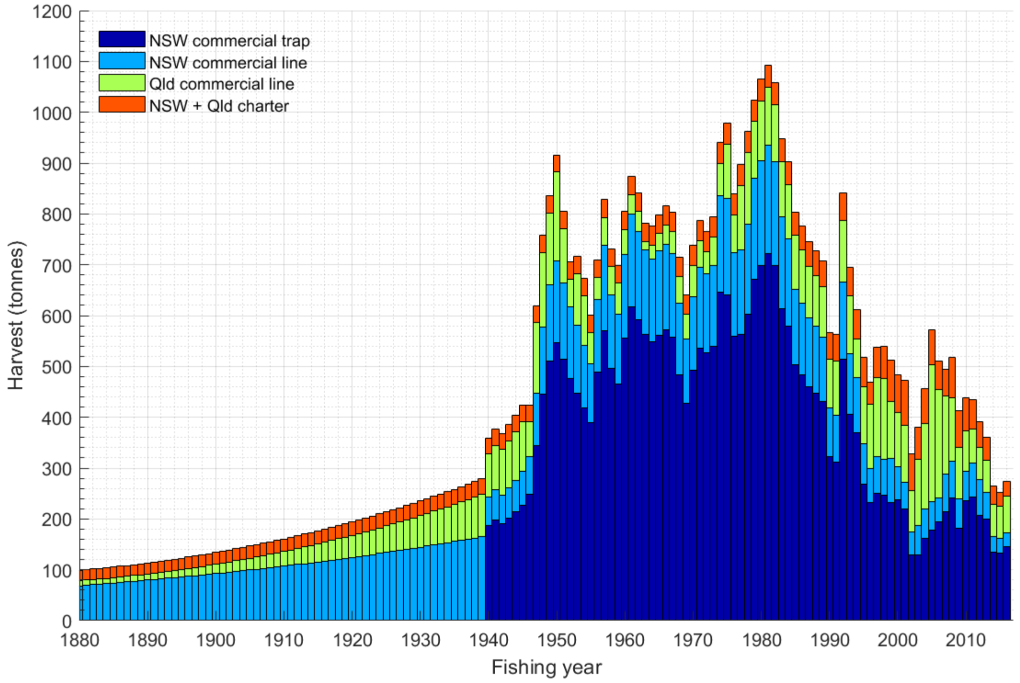

Figure 3.**2**. Estimated snapper harvest by commercial and charter sectors from New South Wales and Queensland. This figure does not illustrate the recreational harvest. Estimated recreational harvest for the survey years are shown in (Figure 3.3**) ***a. In 2013, the most recent recreational survey, the estimated recreational harvest from New South Wales and Queensland was 230 tonnes (Table 2.2).

Estimated recreational snapper harvests (numbers of kept fish) and fishing effort for 1880–2016 were modelled. The nine estimated recreational harvests across states are shown in (Figure 3.3 a). Before 2010, the estimated recreational harvest for snapper was the same across both states, with the estimated number of snapper in 2000 being 252 000 in each state. After the year 2000, the estimated number of snapper in Queensland and New South Wales decreased to 178 000 in 2002, after which the estimated number of snapper in Queensland continued to decline to 83 000 in 2010 and 55 000 in 2013, whereas in New South Wales the estimated number of snapper increased to 182 000 in 2010 and 185 000 in 2013.

Three proxies of recreational effort were constructed, based on three levels of fishing power, the pattern of exponential increase in boat licences, and a decrease in the fishing effort post 1996 based on survey estimates (Figure 3.3 b). The measure of recreational effort increased, following the pattern of growth in boat registrations in New South Wales and Queensland until around 2000, after which the recreational effort declined following the pattern of decline in ocean boat days fished (Figure 2.1). Inclusion of effects for fishing power measured recreational effort in 2016 being:

- fifty per cent more than the effort in 1996 using actual data
- nearly 100 per cent more than 1996 using a higher rate
- only slightly above 1996 for reduced fishing power.

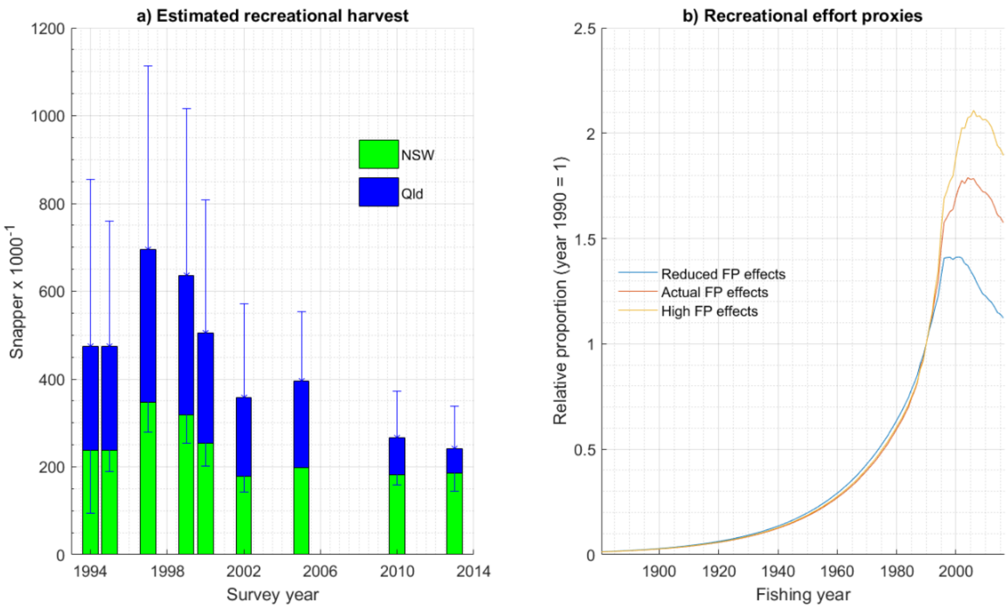

Figure 3.3. a) Estimated snapper recreational harvest, b) Estimated proxies of recreational effort for reduced, actual and high fishing power (FP) effects. The estimated fishing effort was used to calculate the harvest rate for fishing sector 4, the recreational sector.

3.1.2 Fishing power

Uptake rates

The time series of gear and technology use (Figure 3.4–Figure 3.6) provided an indication of the timing as well as the speed of uptake of a range of fishing technologies by commercial, recreational and charter snapper fishers across New South Wales and Queensland. Examples of these differing rates of uptake were:

- Commercial line fishers began using GPS technology during the late 1980's (Figure 3.4 b). Uptake was later by recreational fishers as the cost of this technology was initially prohibitive to most recreational fishers (Figure 3.5 b). The use of GPS became widespread with recreational fishers in the late 1990s when plotters began to replace the less sophisticated GPS units. By early 2000s plotters were almost universally used by offshore recreational anglers. Commercial trap operators believed GPS had a lesser effect on fishing power in New South Wales compared with line fisheries, (pers. comm. FRDC steering committee meeting 13–14 July 2017).
- Paper sounders were replaced by more electronic sounders during the 1980's and became widespread during that decade (Figure 3.4 a−Figure 3.6 a). The introduction of colour sounders in the last 29 years resulted in the virtual total replacement of the older monochrome equipment. High resolution, bottom discriminating colour sounders were further advances in sonar technology and these have been further developed into the modern three-dimensional high resolution sonars that are commonly used today by all fishing sectors. Sounders were believed to have a lesser effect on commercial trap fisheries in New South Wales compared with line fisheries, (pers. comm. FRDC steering committee meeting 13–14 July 2017).
- About 75 per cent of the offshore recreational fishers surveyed had used braided fishing line, some as early as 1995 (Figure 3.5 d). Other fishing techniques and technologies have had differential uptake based on the particular preferences of individual fishers. For example, the use of soft plastics (Figure 3.5 e) and float lining (Figure 3.5 f) were widespread, but not as widely used as plotters and modern sounders (which were almost universally used by offshore line fishers).

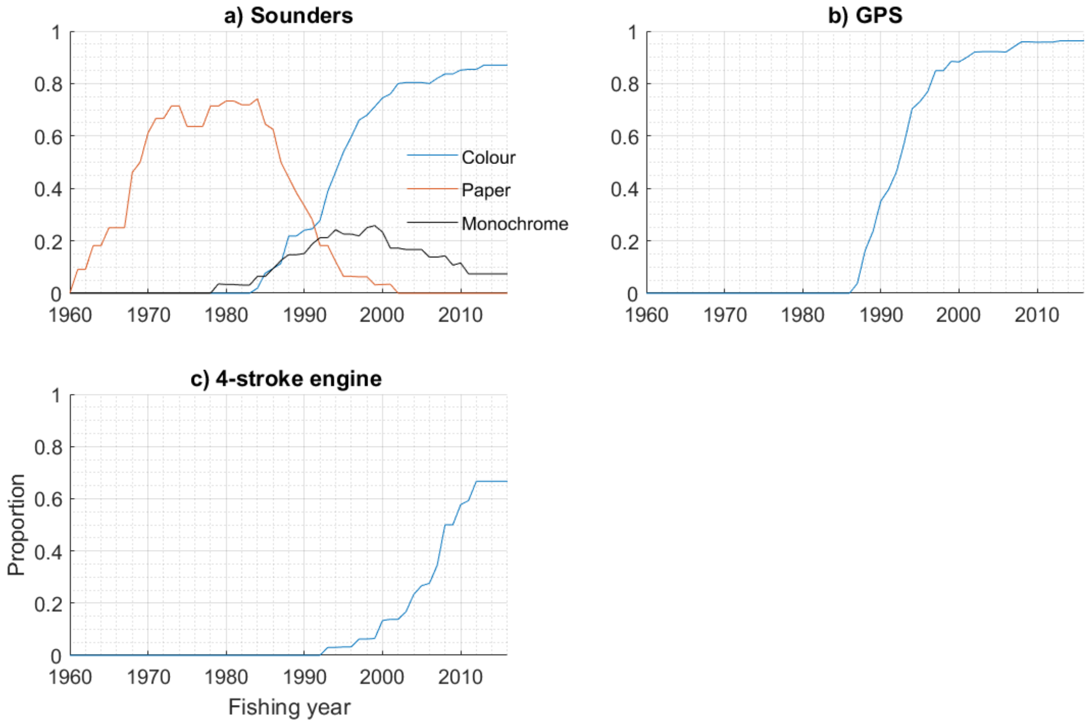

Figure 3.4. Mean attributes of fishing technology used by commercial fishers in New South Wales and Queensland waters. Figure subplots show the uptake rates by fishing year of a) Sounders, b) Global positioning systems, and c) 4-stroke boat engines.

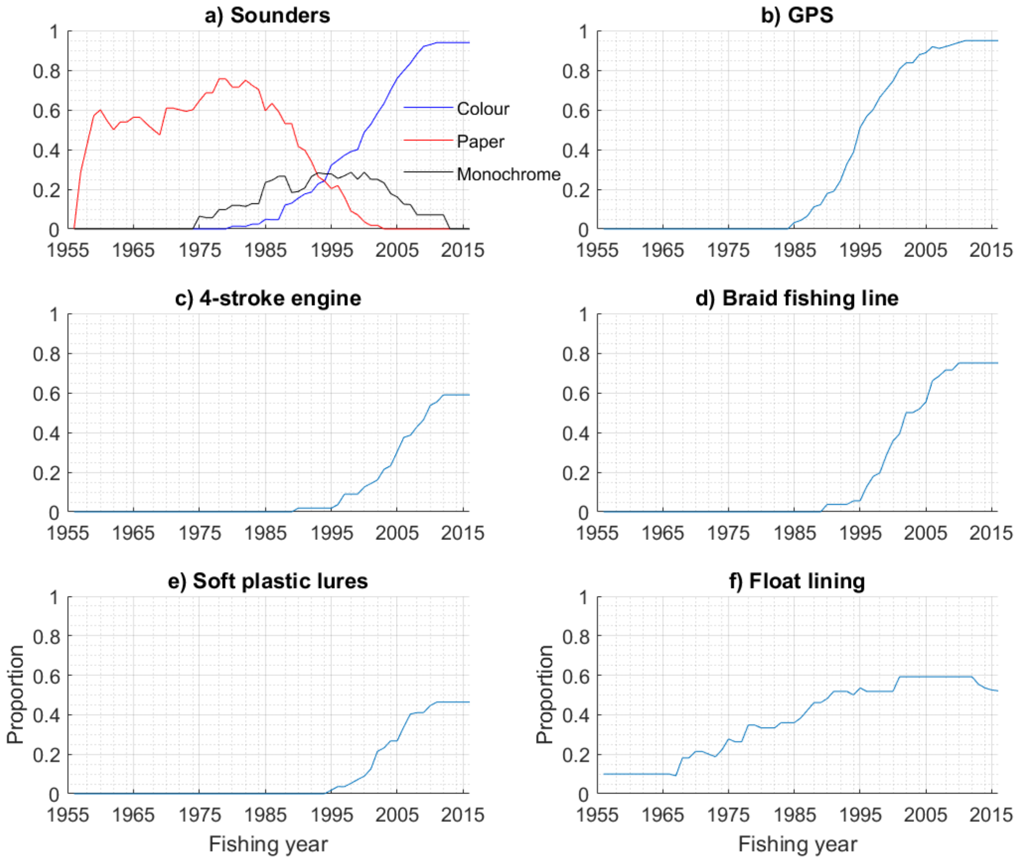

Figure 3.*5. *Mean attributes of fishing technology used by recreational anglers in New South Wales and Queensland waters. Figure subplots show the uptake rates by fishing year of a) Sounders, b) Global positioning systems, c) 4-stroke boat engines, d) Braided fishing line, e) Soft plastic lures, and f) Bait float lining.

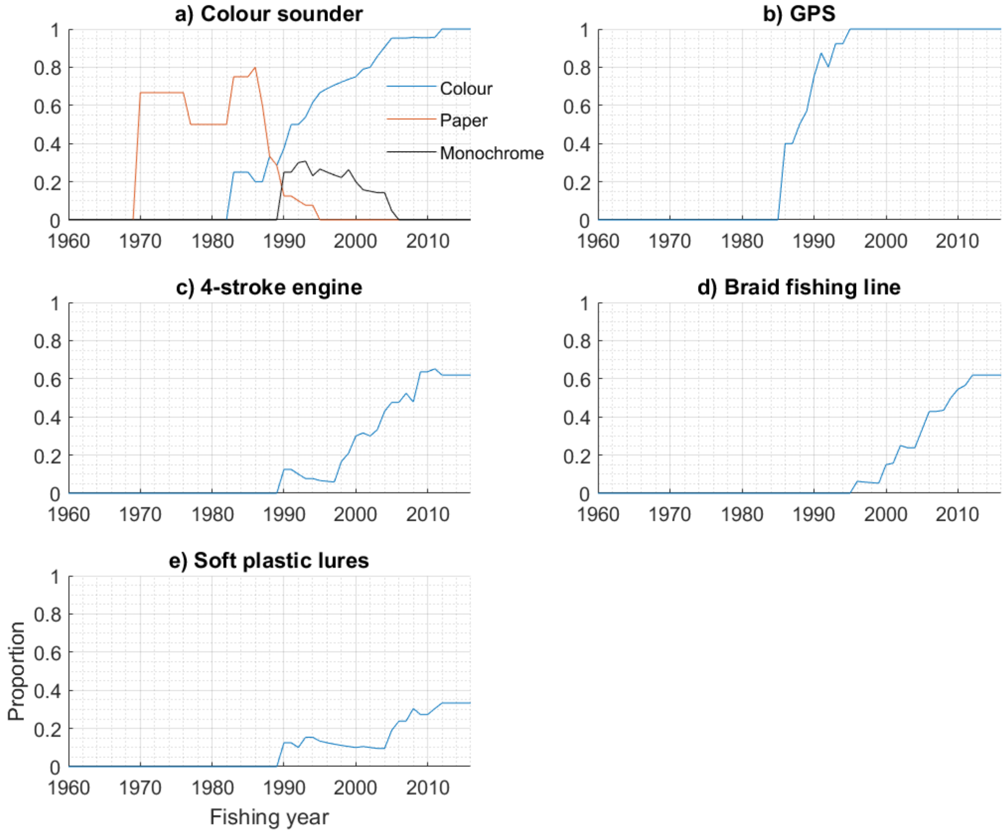

Figure 3.*6*. Mean attributes of fishing technology used by charter fishing operations in New South Wales and Queensland waters. Figure subplots show the uptake rates by fishing year of a) Sounders, b) Global positioning systems, c) 4-stroke engines, d) Braid fishing line, and e) Soft plastic lures.

Effects

The effects of GPS and colour depth sounders were calculated from Sumpton et al. (2013) as 43 per cent and 48 per cent, respectively. This means that on average over all fishers interviewed, fishers believed that the use of GPS improved their ability to catch fish by 43 per cent and the use of colour depth sounders improved their ability to catch fish by 48 per cent. To a lesser extent, the use of braided line or soft plastic lures or float lines were on average calculated to improve fishers ability to catch fish by only 25 per cent.

Fishing power

Using the annual uptake rates of gear and technology (Figure 3.4–Figure 3.6) and the information on the fishers' perceptions of the impact of these technologies on catch rates (Appendix 5.3 Table 5.10) four schedules of annual increases in fishing power were calculated for the commercial, recreational and charter sector:

1. no change in fishing power
2. reduced fishing power
3. actual fishing power as estimated from data
4. high fishing power.

The methods describing the fishing power calculations are outlined in Section 2.2.

The commercial increase in fishing power as estimated by the data was 68 per cent between 1989 and 2016 (Figure 3.7 a). The rate of increase was greatest between 1990 and 2000, but slowed in the last 10 years. The alternate reduced schedule of fishing power was estimated to increase 30 per cent between 1989 and 2016. The high effects scenario showed that fishing power doubled between 1989 and 2016.

For recreational fishing, higher increases in fishing power were estimated between 1989 and 2016 compared to the commercial sector (Figure 3.7 b). This was due to higher use of braided fishing line, soft plastic lures and float lining methods. Fishing power was estimated to have decreased between 2013 and 2016 due to less float lining of baits. The recreational increase in fishing power was doubled between 1989 and 2016. The reduced schedule of fishing power was estimated to increase 42 per cent between 1989 and 2016. The high effects scenario showed that fishing power had increased 2.5 times between 1989 and 2016.

The charter increase in fishing power, for actual effects, was 70 per cent from 1989 to 2016 (Figure 3.7 c). The rate of increase was greatest between 1990 and 2000. The alternate reduced schedule of fishing power was estimated to increase 30 per cent between 1989 and 2016. The high effects scenario showed that fishing power doubled between 1989 and 2016. These results were similar to the commercial fishing power results.

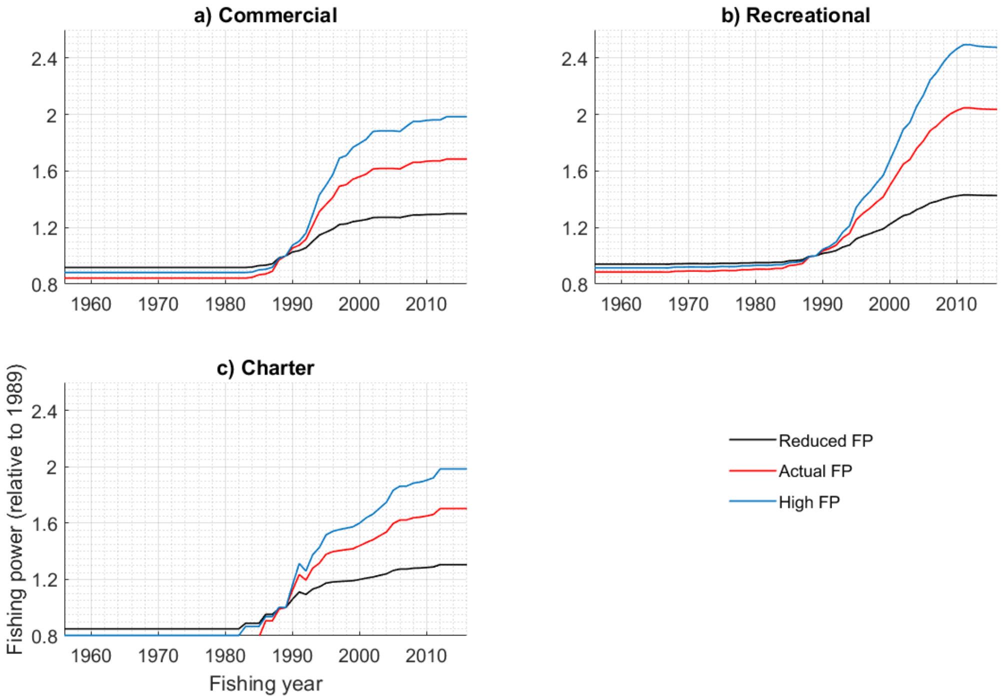

Figure 3.7. Annual time series of fishing power increases across New South Wales and Queensland for commercial, recreational, and charter fishing sectors. Standard errors for reduced, actual and high fishing power analyses were for subplots a) and c) 0.2, 0.4 and 0.5 respectively, and for subplot b) 0.23, 0.6, 0.6 respectively.

3.1.3 Catch rates

Catch rates from fishery-dependent data

Appendix 5.6–5.7 provide a detailed report of the catch rates calculated from the available snapper data. These are shown as yearly trends, and yearly trends for each latitude band. In analysing the catch rates, it was evident that the trap and line catch rates, (New South Wales commercial line, Queensland commercial line, AMLI Queensland charter), all showed declining trends until 2002, after which the trap sector showed a recovery in catch rates while the line sectors generally did not (Figure 3.8). A single trend from the line catch rates, namely New South Wales commercial line, Queensland commercial line and AMLI Queensland charter, was predicted, given their similarity (Figure 3.9).

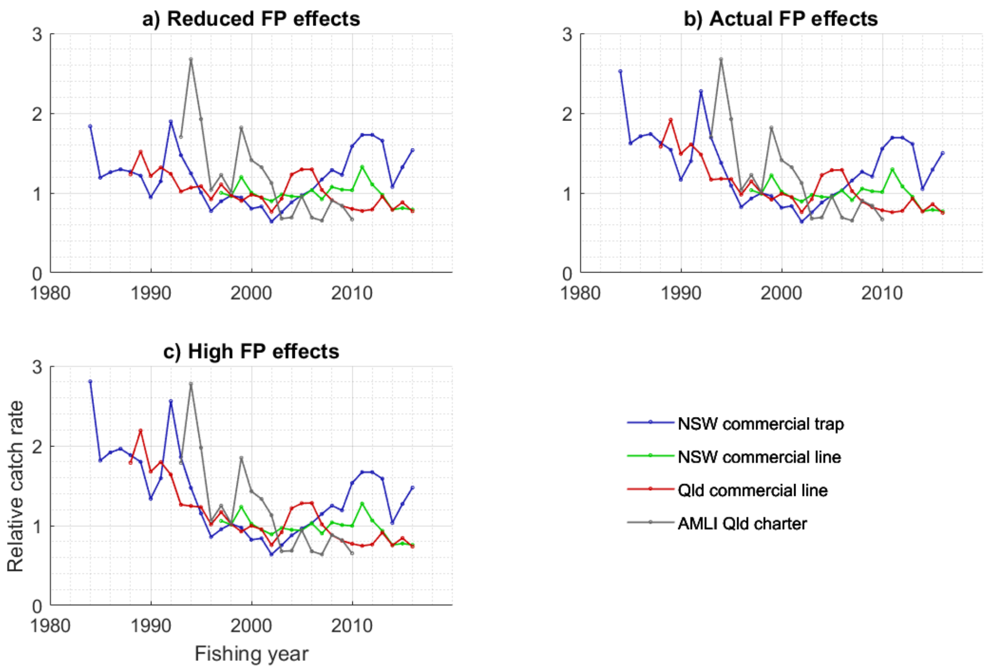

Figure 3.8. Standardised catch rates relative to the average of the years 1997–2010 for reduced, actual and high fishing power (FP) effects. The relative catch rate was defined to be the catch rate relative to the average catch rate of 1997–2010 for each of their own time series. More details of error bars are reported in (Appendix 5.6).

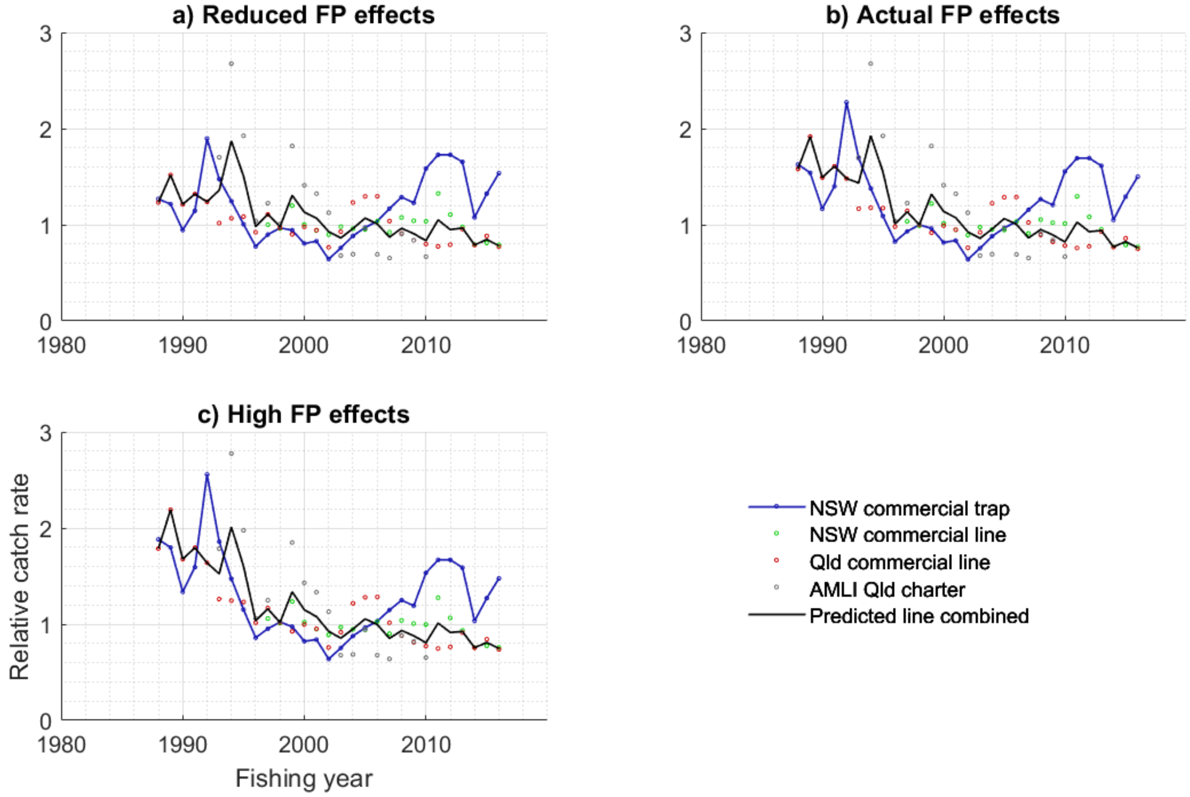

***Figure 3.*9*. Standardised catch rates relative to the average of the years 1997–2010 for reduced, actual and high fishing power (FP) effects. The black line is the catch rate predicted for line fishing and the blue line is the catch rate predicted for trap fishing. More details of error bars are reported in (Appendix 5.6*).**

Historical catch rates

Historic mean catch rates from New South Wales and Queensland catch rates are shown in (Figure 3.10). These catch rates were mainly derived from historical sources on charter fishing trips in New South Wales and Queensland (Section 2.1.3). The historical catch rates were important for the population dynamic model because they established that catch rates had fallen by roughly 50 per cent by the 1950s.

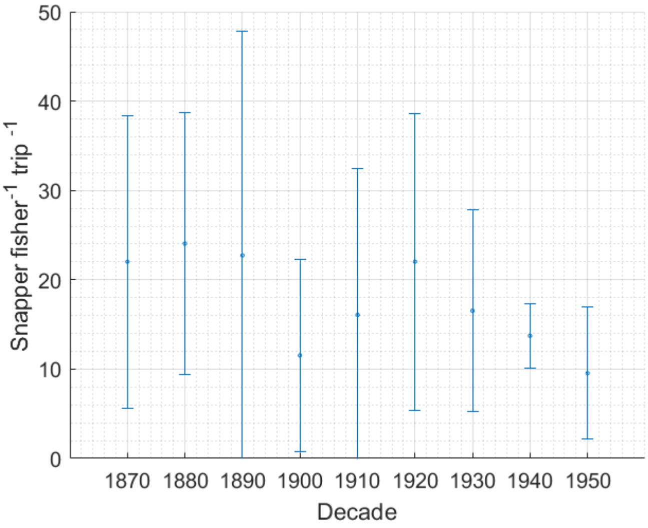

Figure 3.**10**. Historic mean catch rates from New South Wales and Queensland catch rates. Error bars correspond to 95 per cent confidence interval.

Moreton Bay pre-recruitment catch rates

Catch rates from the data collection 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). Abundance trends derived from this data set may not have been a true representation of the overall stock recruitment dynamics 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. Some model simulations were run with the addition of the Moreton Bay pre-recruitment catch rates as an index of abundance.

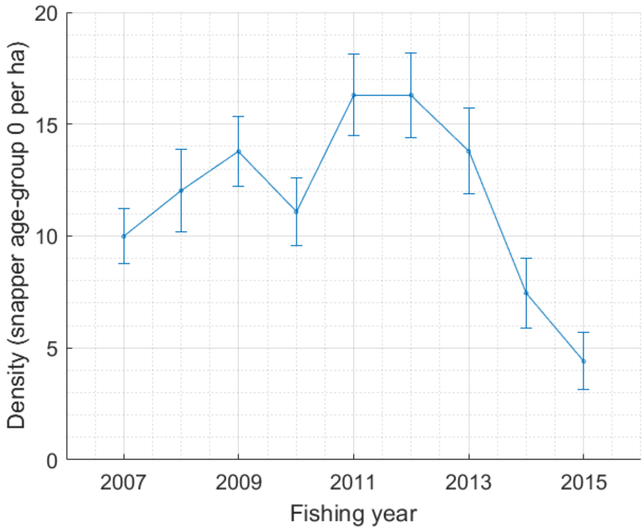

Figure 3.11. Standardised catch rates from the Moreton Bay sampling program of young snapper.

3.1.4 Fish age data

Age frequencies of snapper harvested from New South Wales and Queensland waters are shown in (Figure 3.12–Figure 3.14). For the trap sector 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. 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 (Stewart and Ferrell 2003). The Queensland age structures did not show a similar recovery in the later years that the trap fishery showed. 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 3–5 years of age for years from 2007–2015, with no evidence of strong year classes. The lack of strong year classes was also a feature of the New South Wales age data. Within the Queensland age structures, the commercial fish had a higher proportion of older fish than the recreational fish (Appendix 5.8).

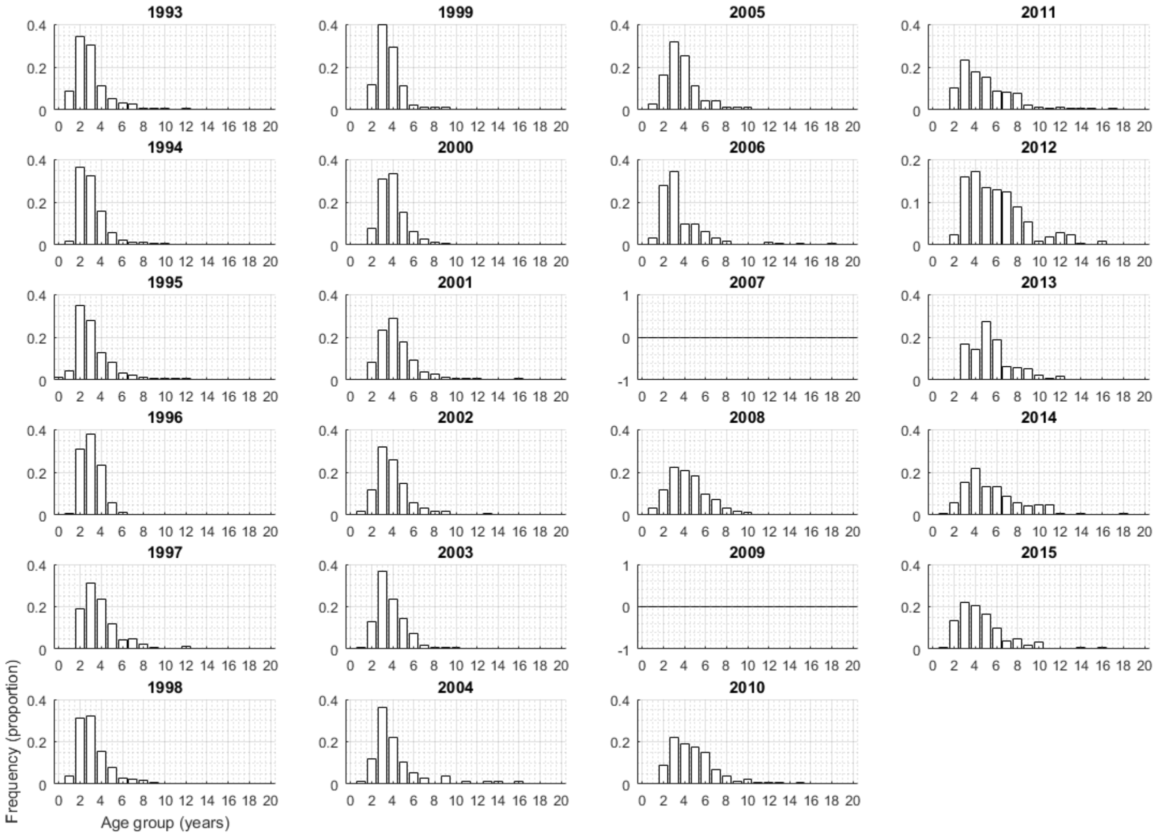

Figure 3.12. Age frequencies of snapper harvested by the New South Wales commercial trap sector. No sampling was done in 2007 and 2009.

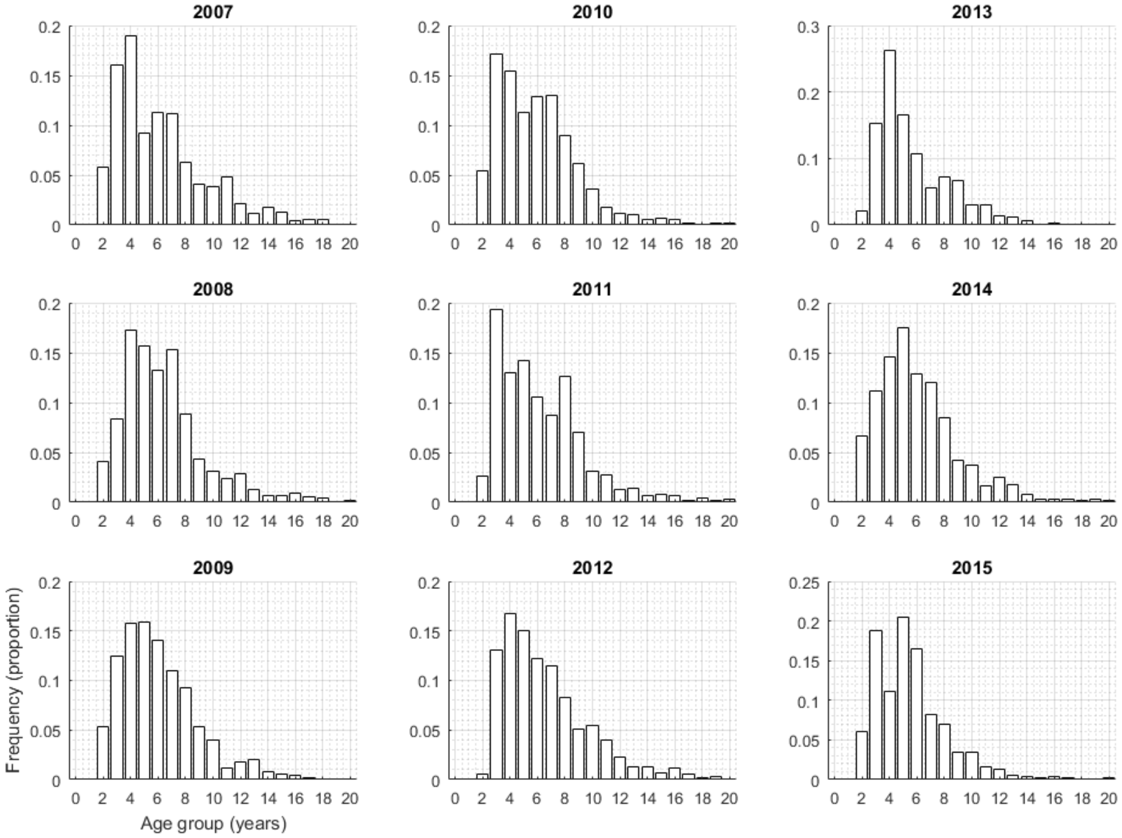

Figure 3.13. Age frequencies of snapper harvested by the Queensland commercial line sector.

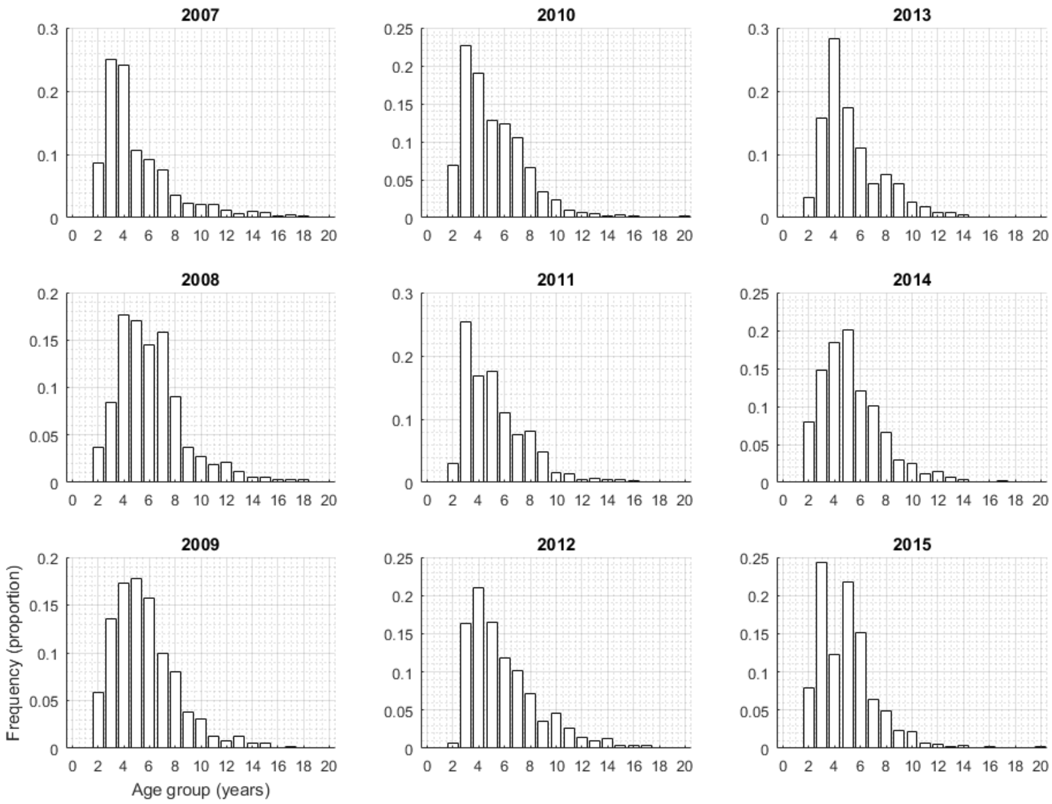

Figure 3.14. Age frequencies of snapper harvested by the Queensland recreational line sector.

3.2 Model outputs

Seventy-two analyses (Appendix 5.9) were conducted for various combinations of data including: catch rates as indices of abundance, natural mortality, discard mortality, age frequency data and recreational fishing effort. All of the analyses were sector driven, i.e. the analyses used catch rates from either the trap sector or from the line sector, except for one analysis that used catch rates from both the trap and line sectors. The trap age data was always included in the seventy-two analyses, whereas the Queensland age data included was either the recreational age data or the commercial age data because the Queensland commercial age frequencies were older than the Queensland recreational fish. (Appendix 5.10) provides a discussion on the stock model fitted trends in catch rates and age frequency data. (Appendix 5.11) provides a discussion on the estimated recreational harvest from the model analyses. Of the seventy two analyses conducted, five analyses were conducted in detail using MCMC simulations, namely analyses 1 (trap and historic catch rates with natural mortality of 0.163), 29 (trap and historic catch rates together with natural mortality of 0.211) and 67, 68 and 69 (combined line catch rates, namely New South Wales commercial line, Queensland commercial line and AMLI Queensland charter, for reduced, actual and high fishing power effects and historic catch rates). The MCMC simulations were used to show the general confidence interval widths in model predictions.

Spawning Ratios

The ratio of estimated spawning biomass in any given year to estimated virgin or unfished spawning biomass S_0 is an important indicator of stock status (Campbell et al. 2009). (Figure 3.15) gives the estimated snapper spawning ratios over the history of the fishery for each of the 72 model analyses. Note that the predicted pattern of decline in spawning ratios in (Figure 3.15) occurred later than in the previous stock assessment of Campbell et al. (2009), because that stock assessment only included Queensland data and the pattern of harvest decline in Queensland occurred later than in New South Wales.

The estimated spawning ratios from 1880–2016 in (Figure 3.15) show that:

- The time period 1880–1950 showed a slow decrease in spawning ratio for all analyses, whether or not they included historic catch rates. When the historic catch rates were excluded from the analyses, the model still predicted a decrease in spawning biomass, which was driven only by the increase in harvests from 1880–1950 (Figure 3.2). When the historic catch rates were included in the analyses, the same decline in spawning biomass was predicted, being driven for these analyses by both the building of harvest from 1880–1950 and the decline in historic catch rates (Figure 3.10) indicating that the historic catch rates were in line with the harvest data.
- For all analyses there was an accelerating nature of the decline in spawning biomass from 1950–1990. This result was driven by the large build up in harvests during 1950–1980 (Figure 3.2).
- The time period 1990–2016 showed a levelling of spawning biomass, with the range of estimates from all analyses between 10 and 45 per cent of virgin biomass levels.
    - The top four spawning ratios for 2016 were 42–45 per cent. Model input for these analyses were trap and historic catch rates, a higher natural mortality of 0.211 and the Queensland commercial age data (the Queensland commercial snapper age frequencies were older than the Queensland recreational fish, thus estimating higher spawning ratios).
    - There were six ratios between 27–33 per cent. Model input for these analyses were trap and historic catch rates, a higher natural mortality of 0.211 and the Queensland recreational age data, or trap and historic catch rates, a lower natural mortality of 0.163 and the Queensland commercial age data.

- There were 62 ratios between 10–23 per cent. Model input for 56 of these analyses used line catch rates as the index of abundance. There were six analyses using trap catch rates in this group. Model input for these trap analyses used the lower natural mortality and the Queensland recreational age data.
- In summary spawning ratios using trap catch rates as the index of abundance were between 20–45 per cent in 2016. Spawning ratios using line catch rates as the index of abundance were between 10–23 per cent in 2016.

The spawning ratios for 2016 from (Figure 3.15) were plotted in (Figure 3.16) in order to identify trends in the trap and line sectors. The following were deduced from the graph:

- Analyses using trap catch rates estimated higher spawning ratios than analysis with line catch rates (trap catch rates were labelled CPUE = 1 and 5, see Table 3.1).
- Analyses using the Queensland commercial age data (Qld age = 2) estimated higher spawning ratios than analyses with the Queensland recreational age data (Qld age = 1). Queensland commercial fish were bigger and older than the Queensland recreational fish, thus the predictions were higher, especially for the trap analyses.
- Analyses using the higher natural mortality of 0.211 estimated higher spawning ratios, especially for the analyses with trap catch rates as data input.
- Increasing the level of recreational fishing effort (rec effort =1 for reduced fishing power effects, 2 for actual fishing power effects or 3 for high fishing power effects) increased the 2016 spawning ratios slightly for analyses with the low natural mortality of 0.163 and for most analyses with the high natural mortality of 0.211.
- The analysis using catch rates from both the trap and line sectors (analysis 14) estimated spawning ratios that were lower than that estimated from the equivalent trap-only analysis and higher than that estimated from the equivalent line-only analysis.
- Lowering the discard mortality from 0.3 to 0.12 did not change the estimated spawning ratios.

Fishing mortality

The 2016 fishing and the maximum fishing mortality over the years 2012–2016 (Figure 3.17) were greater than the natural mortality M for most analyses for the low natural mortality rate of 0.163. For analyses with the higher natural mortality rate of 0.211, the fishing mortality was less than the natural mortality M.

Reference points

Figure 3.18 shows the harvest MSY estimates and harvest estimates for 0.6 of virgin biomass. The model estimated a MSY of between 780 and 1200 tonnes per year across New South Wales and Queensland and across all sectors, with the average value over the different analyses being close to 1000 tonnes per year over all waters and sectors. This indicates the rapid decline in biomass estimated by the model from 1950–1990 (Figure 3.14) where estimated total harvest across all waters and sectors was mostly above 1000 tonnes (1950–1990), and sometimes well above 1000 tonnes (e.g. the estimated harvest in the 1970s and 1980s) (Figure 3.19).

The estimated harvest to achieve 0.6 of virgin biomass was between 600 and 940 tonnes per year over all waters and sectors, across all years since fishing began, with the average value over the different analyses being around 800 tonnes per year across all sectors in New South Wales and Queensland. The estimated total harvest across all waters and sectors from 2014–2016 was below 800 tonnes (Figure 3.19). However because the 2016 stock ratio was 0.1−0.45 due to the high harvests between 1950 and 1990, maintaining current harvest to 800 tonnes would keep the stock levels low and risk even further reductions in harvest. In order to increase biomass levels to 0.6, harvest and effort would need to be reduced to allow the stock to rebuild. After the stock has rebuilt, implementing a yield of 800 tonnes per year across all waters and fishing sectors would be more likely to sustain the stock at biomass levels of 0.6.

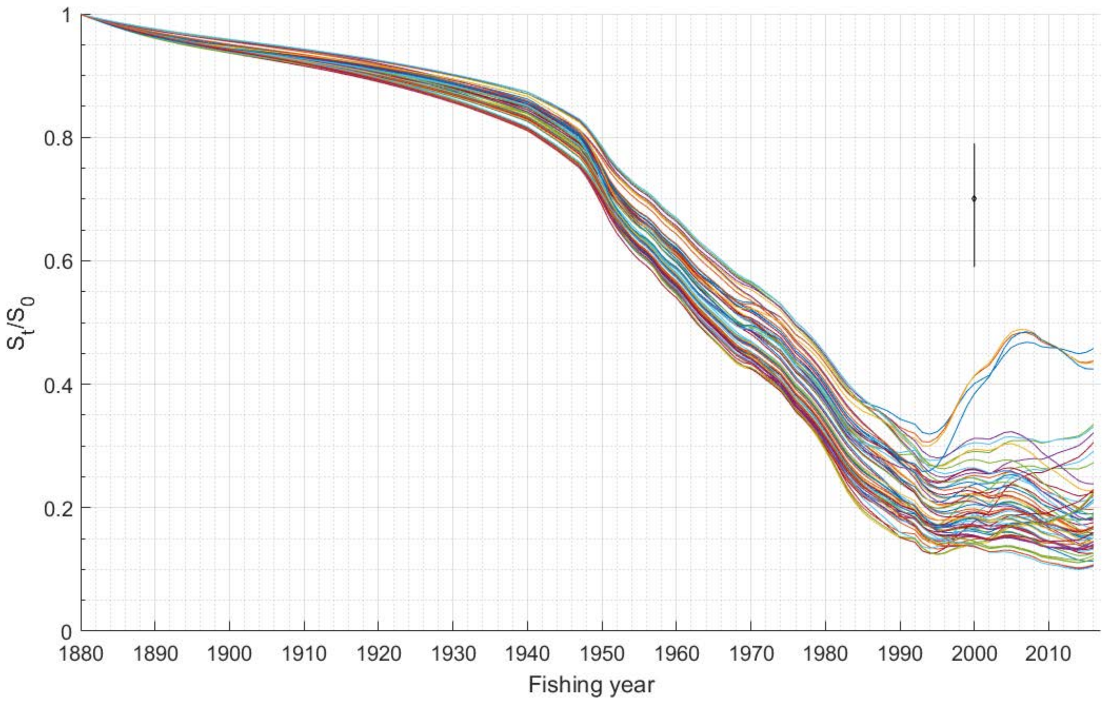

Figure 3.15. The predicted spawning biomass ratios for snapper from 1880–2016 for 72 analyses. The 95 per cent confidence interval error bar in the figure correlates to analysis 29, the analysis that gave the largest statistical error of the MCMC analyses.

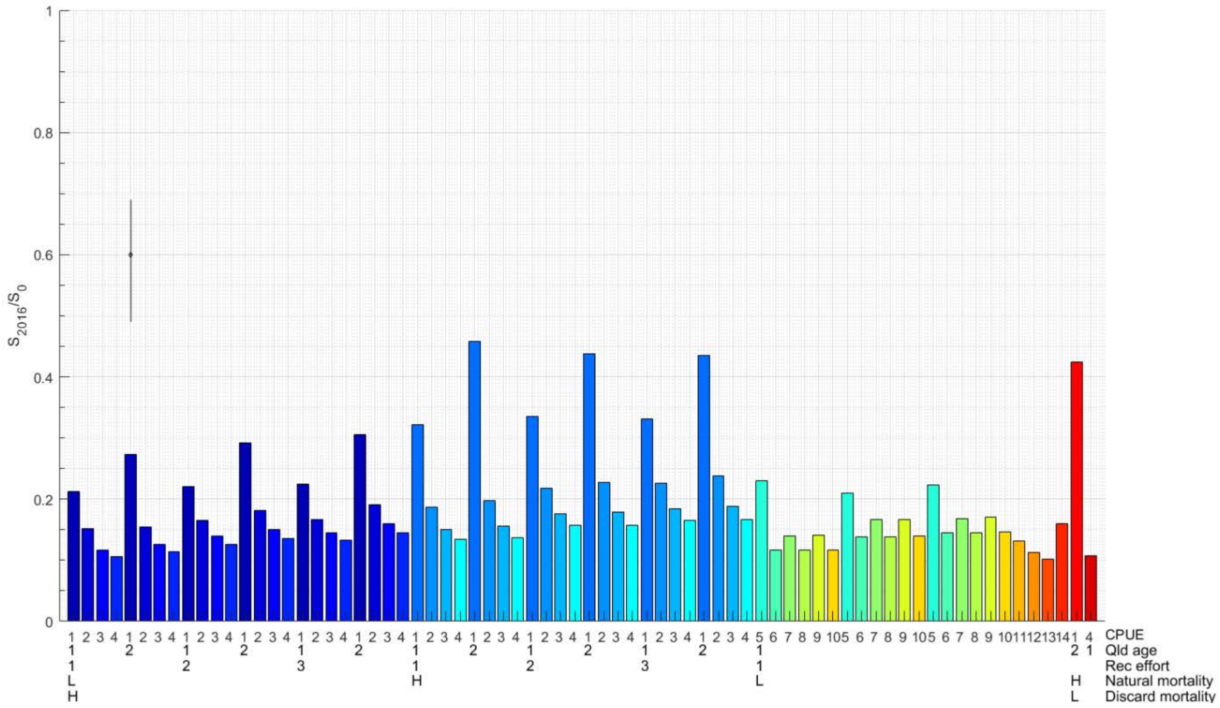

Figure 3.*16*. Predicted 2016 spawning biomass ratios for snapper for the 72 analyses. The largest 95 per cent confidence interval width was shown from the MCMC simulations. Details of the data used for each analysis are given on the x-axis: the CPUES are defined in Table 3.1 below, Qld age of 1 or 2 means Qld recreational or commercial age data (from the left the Qld age=1 until Qld age=2 (fifth bar), then remains at 2 until Qld age=1 at bar 9), recreational effort of 1 or 2 or 3 means recreational effort for reduced or actual or high fishing power effects, natural mortality was either L (0.163) or H (0.211) and discard mortality was either H (0.3) or L (0.12).

Table 3.1. Catch rate definitions used in (Figure 3.16). Trap catch rates were always trap catch rates with reduced fishing power (FP).

Catch rate	Definition
1	Trap + historic
2	Qld commercial line reduced FP + historic
3	Qld commercial line actual FP + historic
4	Qld commercial line high FP + historic
5	Trap only
6	Qld commercial line actual FP only
7	Qld commercial line reduced FP + historic + fishery independent Moreton Bay pre-recruitment survey catch rates
8	Qld commercial line actual FP + historic + fishery independent Moreton Bay pre-recruitment survey catch rates
9	Qld commercial line reduced FP + historic + AMLI Qld charter reduced FP
10	Qld commercial line actual FP + historic + AMLI Qld charter actual FP
11	Combined line (NSW commercial line + Qld commercial line + AMLI Qld charter) reduced FP + historic
12	Combined line (NSW commercial line + Qld commercial line + AMLI Qld charter) actual FP + historic
13	Combined line (NSW commercial line + Qld commercial line + AMLI Qld charter) high FP + historic
14	Trap + Qld commercial line actual FP + historic

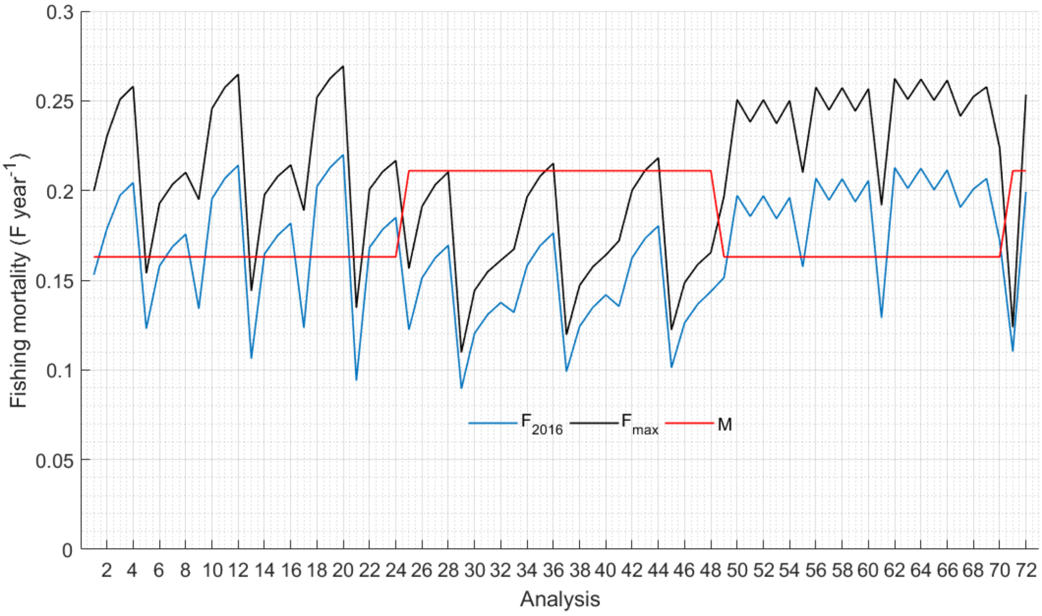

Figure 3.**17**. Predicted 2016 fishing mortality and maximum fishing mortality over the years 2012–2016 for 72 analyses. The red line is the natural mortality, either 0.163 or 0.211.

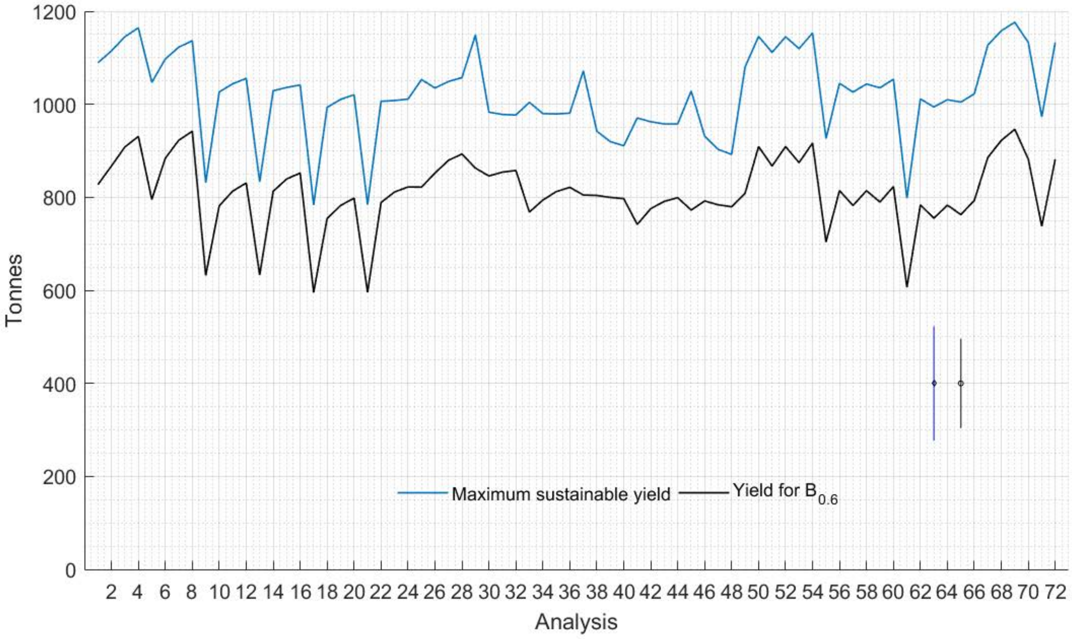

Figure 3.18. Equilibrium MSY and harvest for $B_{0.6}$ for 72 analyses, with the largest 95 per cent confidence interval from the MCMC analyses.

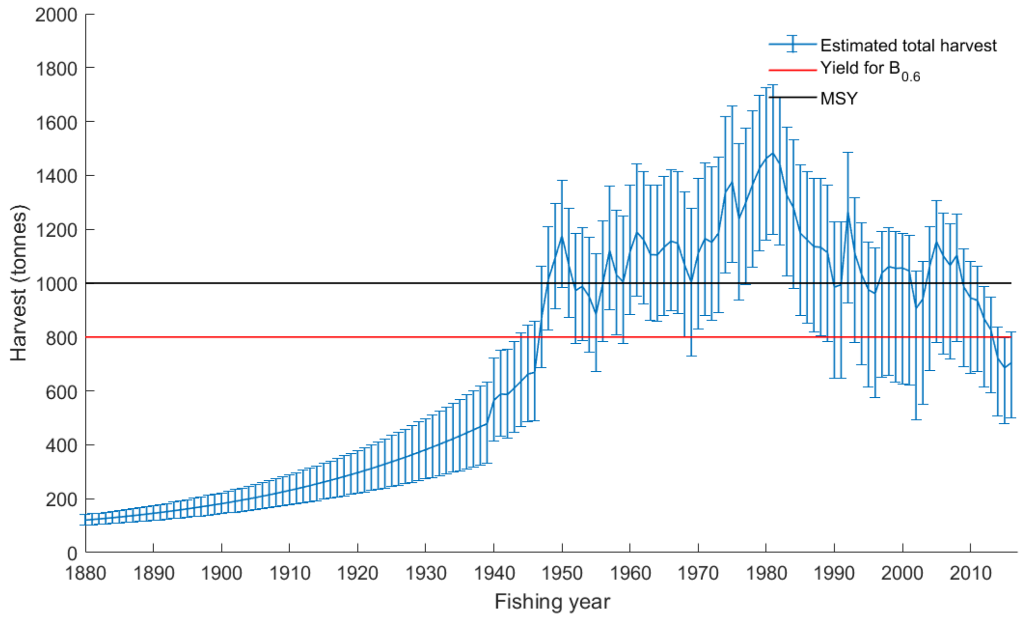

Figure 3.*19*. Estimated total harvest from the 72 analyses with 95 per cent confidence intervals. The red line represents the harvest per year across all waters and sectors to attain 0.6 of virgin exploitable biomass and the black line represents the MSY across all waters and sectors. It is important to note that maintaining current total harvest levels at around 800 tonnes will not rebuild stocks to $B_{0.6}$ given high harvest levels between 1950 and1990, and low estimated spawning ratios in 2016.

3.3 Discussion

3.3.1 Stock status

Since the 1980s estimated snapper harvest has fallen for the amount of fishing effort exerted. East coast harvests have been 700–800 tonnes per year across all waters and fishing sectors since 2014 (Figure 3.19).

Standardised catch rates showed differing trends across the trap and line sectors. Both trap and line sectors declined to historic lows in 2002, after which the trap sector showed a recovery in catch rates while the line sectors generally did not. There was a recovery in reported trap harvest from 2000, while reported harvest from the line sectors showed no recovery post 2000 (Figure 3.2). The different signals in the New South Wales commercial trap catch rates and the line catch rates suggests that localised depletion in Queensland is likely to have occurred. Similarly the recreational catch rates from the Queensland boat ramp surveys decreased from 1994 to 2008 (Appendix 5.6.6). Recreational catch rates from the Queensland RFISH and SWRFS surveys also showed declining trends from 1997 to 2013.

There was an accelerating nature of decline in the estimated spawning biomass relative to estimated virgin spawning biomass from 1950–1990. This was the result of the commercial harvest build up in that time period. In 2016 estimated spawning biomass ratios were between 20 per cent and 45 per cent of virgin biomass when trap catch rates were used as the index of abundance, and between 10 per cent and 23 per cent when line catch rates were used as the index of abundance. Thus the estimates generally varied below the maximum sustainable harvest reference point of 40 per cent for population size.

Past stock assessments, based solely on Queensland data, quantified snapper exploitable biomass levels of between 15 per cent and 50 per cent of unfished or virgin biomass levels, with the majority of analyses putting biomass levels below 35 per cent (Allen et al. 2006; Campbell et al. 2009). The current stock assessment using data from New South Wales and Queensland, was run from 1880–

2016 whereas the previous stock assessment was run from 1946–2007. In addition the present assessment used historic catch rates which were not available in the previous stock assessment and included more age structured information and more recent estimates of recreational catch and effort. However, despite the addition of these data and increase in the time period for the present assessment, stock levels for this assessment were still estimated to be low (between 10–45 per cent of virgin or unfished spawning biomass).

The Queensland Sustainable Fisheries Strategy 2017–2027 defines biomass targets for 2020 and 2027 that will ensure healthy fish stocks. The first target is to achieve a sustainable level of fishing by 2020 (generally 0.4–0.5 virgin biomass). For snapper, the model estimates maximum sustainable yield to be between 780 and 1200 tonnes per year across all waters and all fishing sectors, for all years since fishing began, with an average of 1000 tonnes per year across all waters and fishing sectors. Because the estimated total harvests in the 1970s and 1980s were above the maximum sustainable yield, harvests declined thereafter as the stock was unable to sustain such high levels of harvest.

The second target for the Queensland Sustainable Fisheries Strategy is to achieve an economically efficient and more ecologically resilient fishery by 2027 (0.6 virgin exploitable biomass). For snapper, the stock model predicted that the yield for this target ranged between 600 and 940 tonnes per year across all waters and sectors, with an average of 800 tonnes per year, across all waters and all fishing sectors. Although estimated harvests between 2014 and 2016 were of similar magnitude, estimated stock levels were low (10–45 per cent of virgin) due to high historic harvests. Rebuilding stocks to target levels of maximum sustainable yield or yield for 60 per cent biomass would not occur at this current level of harvest. Thus harvest and effort would need to be reduced for any building of population sizes to occur.

Although the east coast stock was modelled as a single genetic stock, there may effectively be “local” stocks with dissimilar fishery dynamics. Localised depletion of snapper has been recognised as an issue in earlier reports (Sumpton et al. 2006) and by stakeholders as part of earlier discussion papers on rocky reef fisheries (QFMA 1998). While genetic stock is often used as a management unit there is enough evidence that this is an over simplification for east coast snapper where recruitment processes, fishing mortality and general stock dynamics may be operating differently at scales significantly smaller than a genetic stock level.

A Fisheries Research and Development Corporation (FRDC) project conducted in parallel to the present assessment (FRDC project number 2015-216) modelled a range of scenarios to project snapper stock biomass to 2056 under a range of different management strategies. Preliminary modelling indicated that changes to MLS alone for any fishing sector did not build higher stocks when 2016 levels were below 40 per cent. Reductions in harvest were required to rebuild stocks to the reference levels stated in the Queensland Sustainable Fisheries Strategy. These results will be described in detail in FRDC report – project number 2015-216.

3.3.2 Recommendations

Management

Stock biomass levels are currently below the maximum sustainable harvest reference point of 40 per cent for population size. From the analyses it can be concluded that snapper is likely to be overfished past maximum sustainable yield. Management is required to reduce total harvest to allow the stock biomass to rebuild to target levels outlined in the Sustainable Fisheries Strategy.

Scenario modelling

A Fisheries Research and Development Corporation (FRDC) project conducted in parallel to the present assessment (FRDC project number 2015-216) modelled a range of scenarios to project snapper stock biomass to 2056 by either managing the fishery by fixing the fishing effort to status quo and varying the MLS, or by managing the fishery using a quota tonnage harvest limit and maintaining status quo MLS. These scenarios could be extended to model other options to determine what management is required to build snapper stocks to meet the maximum sustainable yield target outlined in the Strategy to 40–50 per cent by 2020 or what should be implemented now so that a 60 per cent population size is reached by 2027.

Monitoring: Commercial and charter logbook data

Data in the CFISH Queensland Commercial Fishing Tour Logbook (CV05), i.e. the charter logbook data, as it currently stood, was of limited use to the quantitative stock assessment because the 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.

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.

Monitoring and research: Recreational data

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 per cent of the harvest was believed to be taken by recreational fishers. The regular monitoring and estimates of snapper harvests taken by the recreational sector through SWRFS should be an ongoing priority and methodological improvements should always be pursued, thereby improving the accuracy and precision in estimation of recreational catch.

There needs to be a better understanding of recreational fishing effort for stock assessment. The current data on fishing effort showed conflicting trends in the declining trend in fishing effort according to ocean boat days fished and the increasing trend in fishing effort implied by boat registrations. It is important to better quantify the overall changes in recreational fishing effort to improve assessments in the future. This needs to consider patterns of the use of recreational vessels for pursuits other than recreational fishing and improved survey methodology. Regular on-site survey measures of boat and angler numbers should be recorded.

Monitoring: Long term monitoring of fish age-length samples

As recommended by the previous stock assessment (Campbell et al. 2009), the annual long term monitoring of snapper age-length structures should continue. The snapper from LTMP Queensland commercial program had a higher proportion of larger and older fish than the LTMP Queensland recreational snapper. This may be due to the fact that commercial boats fish further offshore thus catch larger snapper in deeper water. Investigation of the Queensland size and age data showed that the commercial fish were not sampled from as broad a range of areas as the recreational fish. Thus it is important that every effort is made to ensure that future length and age samples are spatially representative of all areas along the Queensland east coast.

Monitoring and research: Fishing power

The impact of improved technology in fisheries is an important consideration for catch rate standardisation and fishing effort. Some technologies have been included in this assessment, but there were others that have not been included due to lack of information. In many fisheries there were advances in technology in addition to the ones assessed in this report. For the recreational sector, field survey approaches may be required to collect fishing power information. The collection of fishing power data from the commercial and charter sectors should be continuous through compulsory logbook gear sheets. Further research is required to quantify the catchability effects of different fishing gears and technologies; and thus repeated field based experiments may be needed.

Research: Recruitment Surveys

The fishery independent surveys in Moreton Bay should continue to collect data designed to assess snapper recruitment. Juvenile snapper abundance in Moreton Bay reached the lowest density recorded since the start of the survey in Moreton Bay. Thus it is important to continue monitoring to alert if the juvenile stock continues to decline to even lower levels.

The monitoring should also be extended to more bays, inlets and estuaries, important nursery areas for snapper in New South Wales and Queensland (pers. comm. FRDC steering committee meeting 13–14 July 2017) to obtain a spatially representative index of juvenile snapper abundance that can be used in future stock assessments.

4 References

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5 Appendices – supplementary information

5.1 Fishing data

Table 5.1. New South Wales commercial commcatch logbook data. Filters were applied to the logbook data records for snapper catch rate standardisation.

Data	Details	Notes
File name and location	'NSW catch data commercial snapper.xlsx'	COMMCATCH data for 1.7 1984–31.12.2016
Calendar time period for analysis	1.7.1984–31.12.2016	
Records	Monthly records were provided.	
Harvest Conversions	Kilograms of snapper catch were provided by the data.	Weightkg was used for kg of snapper.
Fishing year	Defined from 1st January through to 31st December.	Fishing year=calendar year.
Stock or fishing area	Single area: this covered the main fishing waters of east-coast latitudes south of 28ºS inclusive and north of 38ºS inclusive	
Snapper species codes	comspeciesid=353001	Identified snapper for calculating abundance.
Logbook area regions analysed for catch rate standardisation	1001–1010	These area bands represented 99.9 per cent of the total harvest. (The area band that was removed for catch rate standardisation was area band 1000 which corresponded to Moreton and Gold Coast.
Fishing method codes	MethodName = "Dropline" or "Driftline" or "Handline" or "Jigging" or "Longline (midwater/pelagic) or "setline, midwater" or "Setlining" or "Trolling" or "Trotline, bottom set" or "Fish trap (bottom/demersal)".	Identified line fishing or trap fishing.
Snapper boats	LFB_Encr (boats) that had caught snapper for more than one year in the logbook data.	
Access table for catchrate analysis	Nswcommcatch genstat 9 fp trap Nswcommcatch genstat 10 line	For catch rate standardisation for trap and line fishing methods.

Table 5.2. New South Wales commercial fishonline logbook data. Filters were applied to the logbook data records for snapper catch rate standardisation.

Data	Details	Notes
File name and location	'NSW catch data commercial snapper.xlsx'	Fishonline data for 1.7 2009–26.7.2016
Calendar time period for analysis	1.7.2009–26.7.2016	
Records	Daily records were provided.	.
Harvest Conversions	Kilograms of snapper catch were provided by the data.	SumWholeWeight was used for kg of snapper.
Fishing year	Defined from 1st January through to 31st December.	Fishing year=calendar year.
Stock or fishing area	Single area: this covered the main fishing waters of east-coast latitudes south of 28°S inclusive and north of 37.8°S inclusive.	
Snapper species codes	Speciescode=SNA-01	Identified snapper for calculating abundance.
Logbook area regions analysed for catch rate standardisation	1001–1010	These area bands represented the total harvest.
Fishing method codes	MethodName = "Dropline" or "Driftline" or "Handline" or "setline, midwater" or "Setlining" or "Setline (demersal)" or "Fish trap (bottom/demersal)".	Identified line fishing or trap fishing.
Snapper boats	Boats (boat) that had caught snapper for more than one year in the logbook data.	
Access table for catchrate analysis	Nswfishonline6a + fp Nswfishonline7 + fp	For catch rate standardisation for trap and line fishing methods.

Table 5.3. Snapper commercial data supplied by AFMA. The AFMA data was not used for standardisation of snapper catch rates. AFMA harvest data were added to the New South Wales commercial line harvest.

Data	Details	Notes
File name and location	'AFMA catch data.xlsx'	AFMA data for 1.1.2009–31.12.2016
Calendar time period for analysis	1.1.2009–31.12.2016	
Records	Daily records were provided.	.
Harvest Conversions	Kilograms of snapper catch were provided by the data.	Catchwt was used for kg of snapper.
Fishing year	Defined from 1st January through to 31st December.	Fishing year=calendar year.
Stock or fishing area	Single area: this covered the main fishing waters of east-coast latitudes south of 26ºS inclusive and north of 40ºS inclusive.	
Snapper species codes	caabcode=37353001	Identified snapper for calculating abundance.

Table 5.4. Queensland commercial logbook data. Filters were applied to the logbook data records for snapper catch rate standardisation.

Data	Details	Notes
File name and location	'DR2427 Updated Sep '16 Matt.accdb'	CFISH data for 1.1.1998–31.12.2016
Calendar time period for analysis	1.1.1988–31.12.2016	
Records	Daily records and bulk records were provided. A daily record had the same fishing start date and fishing end date, and maxfishingdaycount=1. A bulk record covered multiple fishing days and maxfishingdaycount>1.	Bulk records were excluded for catch rate standardisation, i.e. maxfishingdaycount=1.
Harvest Conversions	Kilograms of snapper catch were provided by the data.	Retainedwholeweightderived was used for kg of snapper.
Fishing year	Defined from 1st January through to 31st December.	Fishing year=calendar year.
Stock or fishing area	Single area: this covered the main fishing waters of east-coast latitudes south of 21°S inclusive and north of 28.5°S inclusive	
Snapper species codes	caabspeciesid=37353001	Identified snapper for calculating abundance.
Logbook grids analysed for catch rate standardisation	T26, T28, T29, U28, U29, U30, U31, V25, V26, V27, V28, V30, V31, V32, V33, W27, W31, W32, W34, W35, W36, W37, W38, X31, X32, X33, X34, X35, X36, X37, X38, X39, Y35, Y38, Y39	These 30x30 minute logbook grids represented 95 per cent of the total harvest
Fishing method codes	FishingMethoddescription = "Line fishing" or "Handline" or "Dropline (demersal longline)" or "Trotline (demersal longline)"	Identified line fishing.
Main species groups	Mainsppgroup in cobia, grassemp, jew, jobfish, kingys, mahi, pearl pearch, snapper, teraglin, wrasse	Species groups identified as main species caught with snapper catches and used to define Rocky Reef fishing effort.
Snapper boats	Authority chain numbers that had caught snapper for more than one year in the logbook data.	
Access table for catchrate analysis	Qldcommcatchrate	For catch rate standardisation

Table 5.5. Queensland charter logbook data. Filters were applied to the logbook data records for catch rate standardisation.

Data	Details	Notes
File name and location	'DR2427 CFISH Charter data Updated Sep 2016.accdb'	CFISH data for 1.1.1996–31.12.2015
Calendar time period for analysis	3.3.1996–29.12.2015	
Records	Daily records and bulk records were provided. A daily record had the same fishing start date and fishing end date, and maxfishingdaycount=1. A bulk record covered multiple fishing days and maxfishingdaycount>1.	Bulk records were excluded for catch rate standardisation, i.e. maxfishingdaycount=1.
Harvest Conversions	Number of snapper catch were provided by the data.	TotalRetainednumber was used for number of snapper.
Fishing year	Defined from 1st January through to 31st December.	Fishing year=calendar year.
Stock or fishing area	Single area: this covered the main fishing waters of east-coast latitudes south of 21ºS inclusive and north of 28.5ºS inclusive	
Snapper species codes	caabspeciesid=37353001	Identified snapper for calculating abundance.
Fishing method codes	FishingMethodTypeId=1	Identifies line fishing.
Main species groups	Mainsppgroup in cobia, grassemp, jobfish, kingys, pearl pearch, snapper, teraglin	Species groups identified as main species caught with snapper catches and used to define Rocky Reef fishing effort.
Snapper boats	Authority chain numbers that were key charter operators	Key charter operators identified by tbl JR Charter ACN_Id in DR2427 CFISH Charter Update Sept 2016..accdb.
Access table for catchrate analysis	Qldcharcatchratedata2+seasonality	For catch rate standardisation

Table 5.6. AMLI Queensland charter data. Filters were applied to the data records for snapper catch rate standardisation.

Data	Details	Notes
File name and location	'Charter data cleaned.xlsx'	Charter data for 9.6.1993–30.12.2010
Calendar time period for analysis	9.6.1993–30.12.2010	
Records	Daily records were provided.	.
Harvest Conversions	Number of snapper kept were provided by the data.	Snapper was used for the number of snapper caught.
Fishing year	Defined from 1st January through to 31st December.	Fishing year=calendar year.
Stock or fishing area	Single area: this covered the fishing waters of Moreton and the Gold Coast, latitude of 27^{o}S–28^{o}S.	
Main species groups	Mainsppgroup in cobia, grassemp, jew, jobfish, kingys, mahi, ppearch, snapper, teraglin, wrasse	Species groups identified as main species caught with snapper catches and used to define Rocky Reef fishing effort.

Data from Gold Coast charter boats were collected by a community based volunteer group the Australian Marine Life Institute from 1993 to 2010. Charter skippers and crews were interviewed by Ray Joyce (Founder of the Institute) at the wharf upon completion of their fishing trip. At this time all fish were identified and on some occasions their total lengths were measured to the nearest centimetre.

Information on fishing activities including number of anglers, fishing time and bait were recorded as were a range of environmental data including water temperature, current speed and direction, wind speed and sea conditions on the fishing grounds. On occasions, when Ray Joyce was not at the wharf to measure catches, skippers were asked to measure their catch and record details of their fishing trips in voluntary logs. The sample fraction for catch information was estimated at over 50 per cent of the total charter landing from boats operating from the region for much of this time period.

Table 5.7. Queensland recreational boat ramp survey data. Filters were applied to the data records for catch rate standardisation.

Data	Details	Notes
File name and location	'Boatramp RFSIH Creel Kept and Released.xlsx'	Boat ramp survey data for 1994, 1995, 2007 and 2008.
Calendar time period for analysis	1994, 1995, 2007, 2008	
Records	Daily records were provided. A daily record represented a fishing trip.	
Harvest Conversions	Number of snapper kept and released were provided by the data.	Number_kept+number_released were used for number of snapper.
Fishing year	Defined from 1st January through to 31st December.	Fishing year=calendar year.
Stock or fishing area	Single area: this covered the main fishing waters of east-coast latitudes south of 21ºS inclusive and north of 28.5ºS inclusive	
Snapper species codes	speciesid=353001	Identified snapper for calculating abundance.
Main species groups	Mainsppgroup in cobia, grassemp, kingys, mahi, pearl pearch, snapper, teraglin	Species groups identified as main species caught with snapper catches.
Fishers	Nfishers = number of fishers on the trip	Records where nfishers = 0 (number of fishers) were excluded for catch rate standardisation.
Access table for catchrate analysis	Boatramp glm5 + fp	For catch rate standardisation

Table 5.8. Queensland recreational RFISH and SWRFS survey data. Filters were applied to the data records for snapper catch rate standardisation.

Data	Details	Notes
File name and location	'Rocky Reef Old Rfish data and analysis.xlsx' 'Copy of DR2682-2000-2010-2013 rec data 2017.03.20 USE THIS ONE.xlsx'	RFISH surveys for 1997, 1999, 2002, 2005 RFISH survey for 2000 and SWRFS surveys for 2010 and 2013
Calendar time period for analysis	1997, 1999, 2000, 2002, 2005, 2010, 2013	
Records	Daily records were provided. A daily record represented a fishing trip.	.
Harvest Conversions	Number of snapper kept and released were provided by the data.	Number_kept+number_released were used for number of snapper.
Fishing year	Defined from 1st January through to 31st December.	Fishing year=calendar year.
Stock or fishing area	Single area: this covered the main fishing waters of east-coast latitudes south of 21ºS inclusive and north of 28.5ºS inclusive	
Snapper species codes	speciesid=353001	Identified snapper for calculating abundance.
Main species groups	Mainsppgroup in amberjack, cobia, grassemp, kingys, mahi, pearl pearch, snapper, teraglin, smason, sweep	Species groups identified as main species caught with snapper catches.
Excel file for catchrate analysis	Rfishgenstat.xlsx	For catch rate standardisation

5.2 Investigation of Queensland charter logbook data

An investigation the CFISH Queensland Commercial Fishing Tour Logbook (CV05) data – commonly referred to as the CFISH charter data was undertaken to determine:

- What did the CFISH charter data represent?
- Could an index of abundance be derived from the data for the 2016 stock assessment of snapper in eastern Australia, and what were the assumptions and limitations of such an index?

The study found that:

- Data in the CFISH Queensland Commercial Fishing Tour Logbook (CV05), as it currently stood, was of limited use to quantitative stock assessment as the 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 as there was no compliance check on logbook submission, and it was fairly certain that data from certain operators had not been submitted in recent years.
- For the CFISH Queensland Commercial Fishing Tour Logbook to provide useful information, the following would be required
  - reinstatement of the collection of information on the charter boat table
  - number of fishers (already on the CV05 logbook)

- number of hours fished.

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. 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.

Updated data for the CFISH charter data were provided by Fisheries Queensland in September 2016, based on DR2427. Two tables within the Access database related to the charter data: *tblCharBoatInfo* and *tblCharRawData*. The table *tblCharBoatInfo* contained 290 individual records. Data in this table were only maintained until the mid 2006, after which no boat/licence holder information was collected. The table *tblCharRawData* contained 730205 individual records.

In the course of creating data summaries from the tables *tblCharBoatInfo* and *tblCharRawData* the following issues with the CFISH charter data were identified:

1. There were unlikely grid locations (for numerous reasons), namely F36, X24, Q34, X34.
2. There were bulk data, indicated by MaximumFishingDayCount >1, although 2 is likely to indicate overnight charter trips.
3. Some operators reported half day trips individually, which was apparent from multiple records for a single AuthorityChainNumber on a single day, with consistent LicenceNo and AuthorityID.
4. Some operators reported daily, but it was likely that they were pooling the number of fishers, catch retained and catch discarded from two half day trips, which was suggested by the NumberOfFishers being significantly greater than the likely maximum capacity of the vessel.
5. Some operators had multiple records for an AuthorityChainNumber with multiple LicenceNo and AuthorityID values (and fisher numbers), suggesting the use of multiple boats.

The nominal annual catch (retained and discarded) of snapper is illustrated in (Figure 5.1). Reported total snapper retained peaked in 1999 and 2001 and declined from 21 995 fish in 2008 to 10 455 fish in 2015. Reported total snapper discarded increased in 2003, was relatively consistent between 2003 and 2013 (range 14 500 to 19 500) and declined in 2014 and 2015.

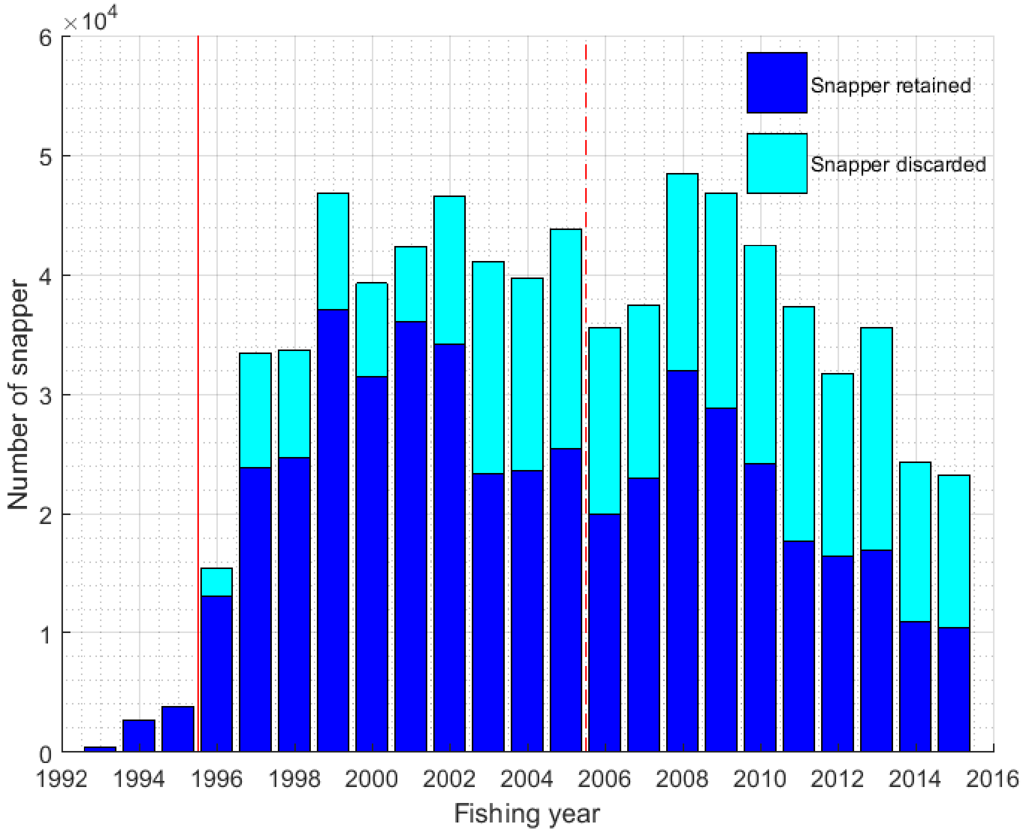

Figure 5.1. Nominal total annual snapper catch (retained and discarded) reported to the Queensland Commercial Fishing Tour Logbook for MaxFishingDayCount=1 and FishingMethodTypeId = 1 (Line). The red solid line indicates the introduction of compulsory reporting for all charter vessels in 1996. The red dashed line indicates the change in reporting requirement for only charter vessels operating in 'offshore waters'.

Effort (e.g. boat day fished) was a non-exact quantity in the CFISH charter data because of the variation in the data recorded by different AuthorityChainNumbers (ACN) and changes in reporting requirements over time. While 547 AuthorityChainNumbers had only one associated LicenceNo and AuthorityID, the remaining ACNs had between two and 25 associated LicenceNo and/orAuthorityIDs. This caused issues in calculating the number of 'boat days fished'. Some operators reported multiple trips (on multiple vessels) for a single day under the one ACN, and some of these ACN's had large datasets within the CFISH charter data.

Aggregation of the data by ACN x StartFishingDate underestimated the number of 'boat-days' in the charter fishery because of multiple daily reporting on some ACN's for different LicenceNos. To adjust for this, a new field was created (ACN_Id) that identified the linkages between ACN and LicenceNo and AuthorityID.

Figure 5.2 provides an estimate of the number of days fished in the Queensland charter fishery reported in the logbooks (filtered for MaxFishingDayCount = 1 and FishingMethodTypeDescription = Line) and represented over 99 per cent of the data for all species and for snapper. Excluding bulk data and for fishing method = Line, reported effort in the fishery peaked in 2003 at approximately 10 000 days then slowly declined to approximately 4500 days (all species, 2006 days for snapper) in 2015. In the last 10 years of the data, snapper was caught (retained or discarded) on approximately 45 per cent of reported days fished (filtered for MaxFishingDayCount = 1 and FishingMethodTypeDescription = Line).

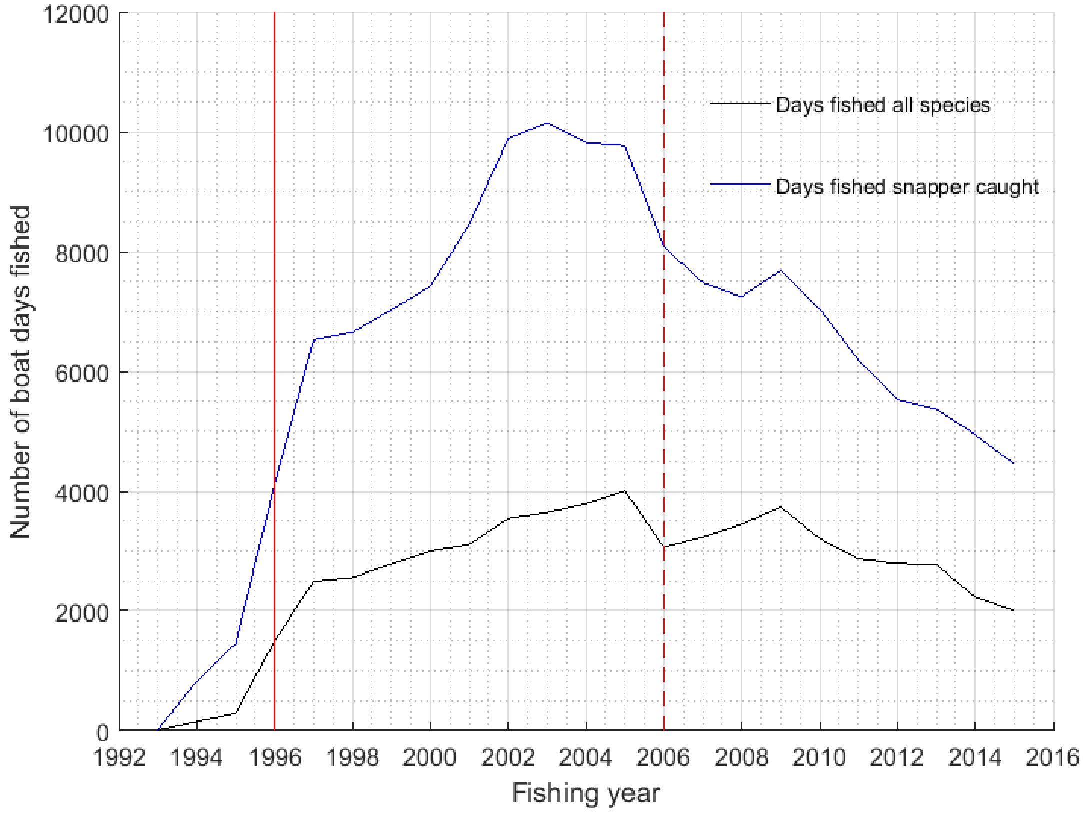

Figure 5.2. Nominal effort (days fished) reported to the Queensland Commercial Fishing Tour Logbook for MaxFishingDayCount=1 and FishingMethodTypeId = 1 (Line). The red solid line indicates the introduction of compulsory reporting for all charter vessels in 1996. The red dashed line indicates the change in reporting requirement for only charter vessels operating in 'offshore waters'.

The pattern in the gross annual number of snapper retained per day fished, varied depending on whether all days fished in the calculation were used, (blue line in Figure 5.3), or whether only days on which snapper were retained or discarded were used in the calculation (black line in Figure 5.3). Note that all days fished included effort during which it was unlikely that a snapper would have been caught, such as river and game-fishing days.

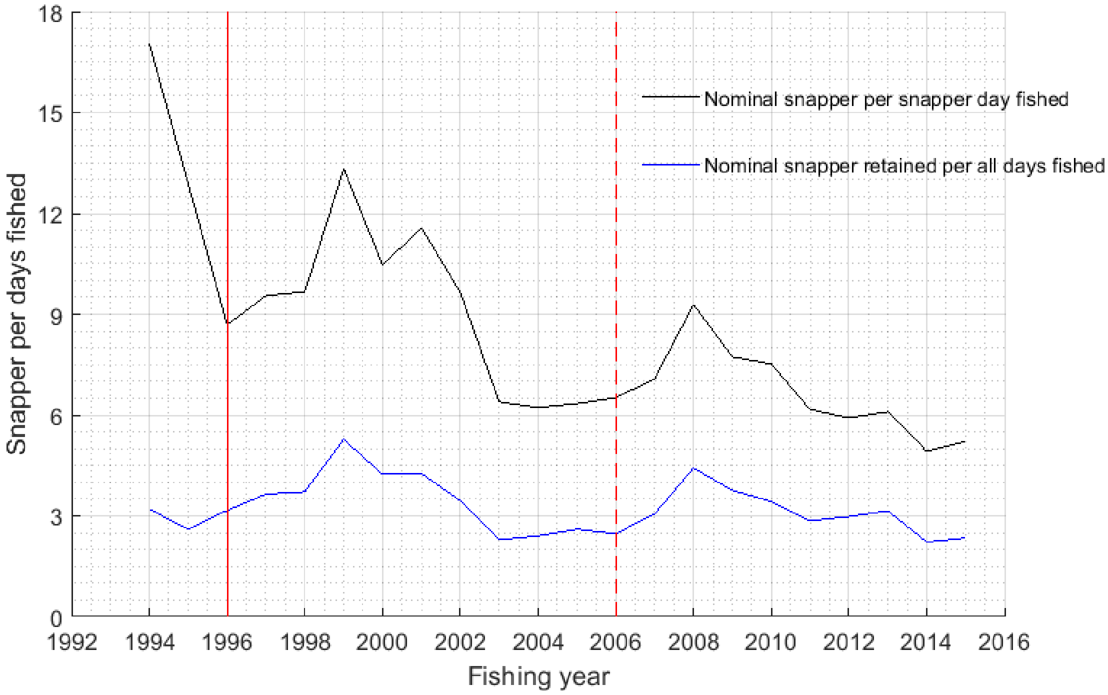

Figure 5.3. The number of snapper retained per day fished (tallied by year) reported to the Queensland Commercial Fishing Tour Logbook for MaxFishingDayCount=1 and FishingMethodTypeId = 1 (Line). Charter reporting became compulsory in 1996 and then changed in mid-2006 to be compulsory only for fishing in offshore waters. The black line is based on only days when snapper were caught. The blue line is based on all days reported to the logbook.

5.3 Fishing power

Table 5.9. Interview data used to determine the rate of uptake of fishers' gear and technology.

Description	Sector	Thurstan et al. (2016)	Sumpton et al. (2013)
Number fishers interviewed	Commercial	27	21
	Recreational	56	42
	Charter	28	0
Gear and Technology uptake rates available for	Commercial	GPS, colour sounder	GPS, colour sounder, paper sounder, monochrome sounder,4-stroke engine
	Recreational	GPS, colour sounder, paper sounder, monochrome sounder, 4-stroke engine, braid, soft plastic lures, float lining	GPS, colour sounder
	Charter	GPS, colour sounder, paper sounder, 4-stroke engine, braid, soft plastic lures	None

Table 5.10. Description of the add-on fishing power data for the standardisation of catch rates of snapper. The mean proportional catch improvements suggested by fishers were listed under the 'treatment effect' column (Sumpton et al. 2013). Fishing power aspects above the dotted line related to finding fish verse catching fish below the dotted line.

Aspect	Data	Treatment effect	Comments and elements of fishing power (FP)
Global Positioning System (GPS)	Percentage use	Offset; 43%	Adoption (% of vessels) by year. Used to minimise search time spent locating fishing areas and marking locations of fish. GPS data are often displayed using colour depth contour mapping software. Used for commercial, recreational and charter fishing power models.
Colour depth sounders	Percentage use	Offset; 48%	Adoption (% of vessels) by year. Used to locate schools of fish (snapper and bait) at depth. Interpretation of what is being seen is easier than monochrome sounders because of the colour. Used for commercial, recreational and charter fishing power models.
Paper sounders	Insufficient data.	Not used.	Adoption (% of vessels) by year. Paper sounders were used in the 1970's and 1980's to locate schools of fish at depth. They have been replaced with colour and monochrome sounders.
Monochrome sounders	Insufficient data.	Not used.	Adoption (% of vessels) by year. Used to locate schools of fish at depth. Gives shades of grey, whereas the colour sounders provide colours with shading within them. The use of monochrome sounders has decreased over time.
4-stroke engine	Insufficient data.	Not used.	Adoption (% of vessels) by year. There was a surge in the adoption of 4-stroke engines between 2000 and 2012. 4-stroke engines offer better range than 2-stroke engines and provide exceptional fuel economy.
Braid, soft plastic lures and float lining	Percentage use.	25%	Braid has zero stretch making it easier to set hooks (for lures) and cast more distance. Thinner braid lines have higher breaking strain compared to equivalent diameter monofilament line. Braided lines have smaller diameters than monofilament ones, making it easier to fit more line on your reel and giving a greater casting range. One of the biggest changes in snapper fishing in recent years has been the explosion in targeting them with soft plastics. The biggest advantage to artificial lures is the increased action. In general, they produce more noise, more flash, and more vibrations. Float lining is becoming the preferred way to fish for larger snapper. This technique is the most effective method of presenting bait naturally, the bait wafts slowly and naturally, and is therefore more tempting to the fish. The offset of 25% was applied to the average uptake of braid, float lining and plastic lures for recreational model and excluded float lining for charter model (no uptake data available).
Jigs/ hardbodies	Insufficient data	Not used.	Hard bodied lures.
Paternosta rigs	Insufficient data	Not used.	The most popular technique used for snapper from the rocks is to fish the bottom using a sliding paternoster rig. As well as giving you more than one hook to fish with, the paternoster is highly effective because of its tangle-resistant design.
Circle hooks	Insufficient data	Not used.	Circle hooks are designed to turn and hook in the corner of the fish mouth very effectively. They decrease mortality rates of released fish, improve hook up, and the strike time is not as crucial using circle hooks.

5.4 Factors tested for catch rate standardisation

5.4.1 Lunar

The influence of lunar phase on catch rates was tested by the addition of a sinusoidal luminance (lunar) pattern as described by O'Neill and Leigh (2014) using a continuous daily luminous scale of 0 (new moon) to 1 (full moon) throughout the lunar cycle. A lagged response of catch rates to lunar phase was assessed using a covariate (lunar_adv) which advanced the luminance measure seven days (~¼ lunar period). The two variables were modelled together to estimate the variation of snapper harvest according to the moon phase (i.e. contrasting waxing and waning patterns of the moon phase).

5.4.2 Wind

Wind direction and strength data were sourced by Fisheries Queensland from the Bureau of Meteorology (BOM, Australian Government; www.bom.gov.au). The wind data were from 76 representative coastal weather stations along Queensland east coast and spatially referenced to latitude bands. The recorded measures of wind speed (km hour^{-1}) and direction (degrees for where the wind blew from) in each latitude band were converted to an average daily reading based on recordings between 6 am and 6 pm. From this data the north-south (NS) and east-west (EW) wind components were calculated:

$$NS = \text{km hour}^{-1} \times \cos(\text{radians}(\text{degrees})), \text{ and}$$

$$EW = \text{km hour}^{-1} \times \sin(\text{radians}(\text{degrees})).$$

The wind components were used to test their effect on snapper catch rates for different wind directions and strengths. The component functions considered the BOM defined wind directions as degrees measured clockwise from true north. (http://www.wmo.int/pages/prog/www/IMOP/publications/CIMO-Guide/Ed2008Up2010/Part-I/WMO8_Ed2008_PartI_Ch5_Up2010_en.pdf; http://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html); 0 degrees = North, 90 degrees or π/2 radians = East, 180 degrees or π radians = South, and 270 degrees or 3π/2 radians = West.

5.4.3 Seasonality

Four trigonometric covariates were used, which together modelled an average monthly pattern of catch (Marriott et al. 2013): $s_1 = \cos(2\pi d_y / T_y)$, $s_2 = \sin(2\pi d_y / T_y)$, $s_3 = \cos(4\pi d_y / T_y)$, $s_4 = \sin(4\pi d_y / T_y)$, $s_5 = \cos(6\pi d_y / T_y)$, $s_6 = \sin(6\pi d_y / T_y)$,where d_y was the cumulative day of the year and T_y was the total number of days in the year (365 or 366) (Figure 5.4). The reason for using both sine and cosine functions together was similar to modelling lunar phases, where the functions together identify the seasonal patterns of catch rates corresponding to autumn, winter, spring and summer periods.

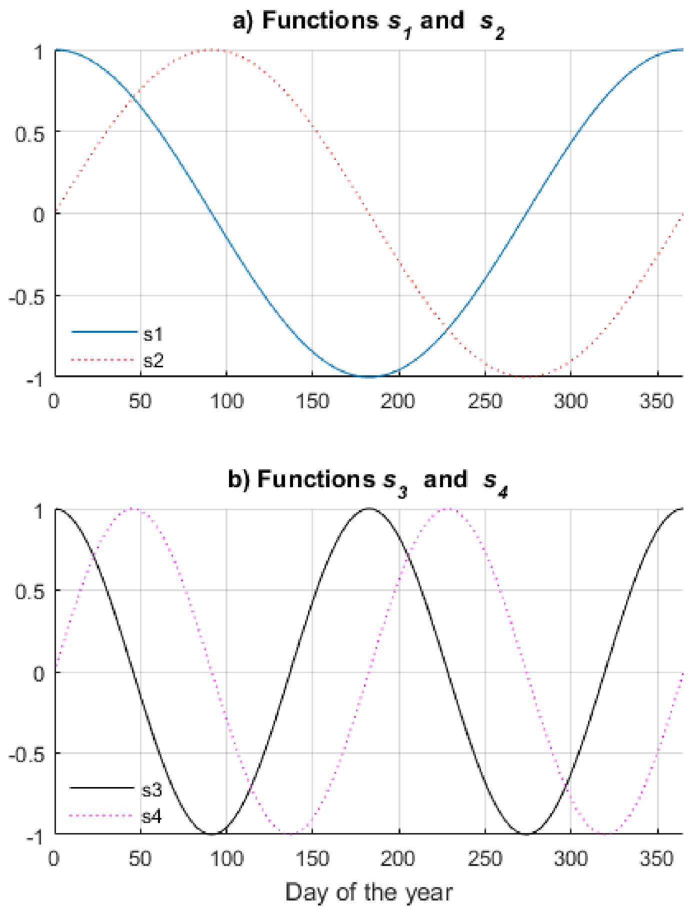

Figure 5.4. Illustration of the sinusoidal DayYear data for a) the annual cycle and b) the 6-monthly cycle. For the x-axis day of the year, 1 = 1 January and 365 = 31 December and the y-axis is the function value. For more information on the relationship between unit circles and the sine and cosine function, see https://en.wikipedia.org/wiki/Trigonometric_functions.

5.5 Genstat code for catch rate standardisation

Table 5.11. GenStat code for commercial catch rate standardisations of snapper from New South Wales logbook data records. The data sets did not include zero snapper catches.

Standardisation from commcatch data for trap linear mixed model for $E\left(c \middle| c > 0\right)$ **1984–2016**

```
calculate logsnapper=log(snapper_kg)

calculate logdays=log(daysfished)

VCOMPONENTS [FIXED= year*latband+month+logdays; FACTORIAL=2] RANDOM=boat;  INITIAL=1;
CONSTRAINTS=positive

REML [PRINT=model,components,effects,deviance,waldTests; PSE=allestimates; MVINCLUDE=*; method=ai;] logsnapper
```

Standardisation from commcatch data for line linear mixed model for $E\left(c \middle| c > 0\right)$ **1997–2016**

```
calculate logsnapper=log(snapper_kg)

calculate logdays=log(daysfished)

VCOMPONENTS [FIXED= year*latband+month+logdays; FACTORIAL=2] RANDOM=boat;  INITIAL=1;
CONSTRAINTS=positive

REML [PRINT=model,components,effects,deviance,waldTests; PSE=allestimates; MVINCLUDE=*; method=ai;] logsnapper
```

Standardisation from fishonline data for trap linear mixed model for $E\left(c \middle| c > 0\right)$ **2009–2015**

```
calculate logsnapper=log(snapper_kg)

VCOMPONENTS [FIXED= year*latband+latband.s1+latband.s2+latband.s3+latband.s4+latband.s5+latband.s6

; FACTORIAL=2]\

RANDOM=boat;  INITIAL=1; CONSTRAINTS=positive

REML [PRINT=model,components,effects,deviance,waldTests;\

 PSE=allestimates; MVINCLUDE=*; method=ai;] logsnapper
```

Standardisation from fishonline data for line linear mixed model for $E\left(c \middle| c > 0\right)$ **2009–2015**

```
calculate logsnapper=log(snapper_kg)

VCOMPONENTS [FIXED= year*latband+latband.s1+latband.s2+latband.s3+latband.s4+latband.s5+latband.s6\

; FACTORIAL=2]\

RANDOM=boat;  INITIAL=1; CONSTRAINTS=positive

REML [PRINT=model,components,effects,deviance,waldTests;\

 PSE=allestimates; MVINCLUDE=*; method=ai;] logsnapper
```

Note: The importance of individual model terms was assessed formally using F statistics by dropping individual terms from the full model. boat = factor variable identifying fishing operations

Table 5.12. GenStat code for commercial and charter catch rate standardisations of snapper from Queensland logbook data. 21 per cent of the commercial data used for catch rate standardisation had zero snapper catch and 10 per cent of the charter data used for catch rate standardisation had zero snapper catch.

Standardisation for commercial line binary (presence of snapper) : generalised linear model for $p(c)$ 1988–2016

```
calculate bin_caught=snapper_kg.gt.0

MODEL [DISTRIBUTION=binomial; LINK=logit; DISPERSION=1] bin_caught; NBINOMIAL=1

FITINDIV [PRINT=model,summ,accum,estimates;CONSTANT=est;FPROB=yes; TPROB=yes; FACT=2; \

selection=%variance,%ss,adjustedr2,r2,%meandeviance,%deviance,aic,sic;] year*latband+latband.s1+latband.s2

RWALD
```

Standardisation for commercial line linear mixed model for $E\left(c \mid c>0\right)$ 1988–2016

```
calculate logsnapper=log(snapper_kg)

VCOMPONENTS [FIXED= year*latband+latband.s1+latband.s2+latband.s3+latband.s4;FACTORIAL=2]\

RANDOM=acn;  INITIAL=1; CONSTRAINTS=positive

REML [PRINT=model,components,effects,deviance,waldTests;\

 PSE=allestimates; MVINCLUDE=*; method=ai;] logsnapper
```

Standardisation for charter generalised linear model for $E\left(c \mid c>0\right)$ 1996–2016

```
MODEL [DISTRIBUTION=poisson; LINK=logarithm; DISPERSION=*] snapper_number

FITINDIVIDUALLY [PRINT=model,summary,estimates,accumulated; CONSTANT=estimate; FPROB=yes;\

selection=%variance,%ss,adjustedr2,r2,%meandeviance,%deviance,aic,sic;\

 TPROB=yes; FACT=9] acnid+year*latband+latband.s1+latband.s2+latband.s3+latband.s4\

+lunar+lunar_adv+windew+windew^2
```

Note: The importance of individual model terms was assessed formally using F statistics by dropping individual terms from the full model. acn = factor variable identifying fishing operations

Table 5.13. GenStat code for AMLI Queensland charter catch rate standardisations. 26 per cent of the data records had zero snapper catch.

AMLI binary (presence of snapper) : generalised linear model for $p(c)$ 1993–2010

```
calculate bin_caught=snapper_number.gt.0

MODEL [DISTRIBUTION=binomial; LINK=logit; DISPERSION=1] bin_caught; NBINOMIAL=1

FITINDIV [PRINT=model,summ,accum,estimates;CONSTANT=est;FPROB=yes; TPROB=yes; FACT=2; \

selection=%variance,%ss,adjustedr2,r2,%meandeviance,%deviance,aic,sic;] \

year*location+c12+cs12+daytime+\

boat+nanglers+fishtime+depth

RWALD
```

AMLI linear mixed model for $E\left(c \mid c > 0\right)$ 1993–2010

```
calculate logsnapper=log(snapper_number)

VCOMPONENTS [FIXED= year*location+location.depth+c12+cs12+c6+cs6\

+lunar+lunar_adv+daytime+fullday+fullday.loganglerhours; FACTORIAL=2]\

RANDOM=boat;  INITIAL=1; CONSTRAINTS=positive

REML [PRINT=model,components,effects,deviance,waldTests;\

 PSE=allestimates; MVINCLUDE=*; method=ai;] logsnapper
```

Note: The importance of individual model terms was assessed formally using F statistics by dropping individual terms from the full model. Boat = factor variable identifying fishing operations

Table 5.14. GenStat code for Queensland boat ramp standardisations (16 per cent of the data included zero snapper catch) and RFISH and SWRFS catch rate standardisations (30 per cent of the data included zero snapper catch)

Standardisation for boat ramp generalised linear model for $E\left(c \mid c \geq 0\right)$ **1994, 1995, 2007 and 2008**

```
calculate loghrs=log(hoursout)

MODEL [DISTRIBUTION=poisson; LINK=logarithm; DISPERSION=*] snapper_number

FITINDIVIDUALLY [PRINT=model,summary,estimates,accumulated; CONSTANT=estimate; FPROB=yes;\

selection=%variance,%ss,adjustedr2,r2,%meandeviance,%deviance,aic,sic;\

 TPROB=yes; FACT=9] year+stratacode+month+loghrs
```

Standardisation for RFISH and SWRFS generalised linear model for $E\left(c \mid c \geq 0\right)$ **1997, 1999, 2000,2002, 2005, 2010, 2013**

```
calculate loghrs=log(hours)

MODEL [DISTRIBUTION=poisson; LINK=logarithm; DISPERSION=*] snapper_number

FITINDIVIDUALLY [PRINT=model,summary,estimates,accumulated; CONSTANT=estimate; FPROB=yes;\

selection=%variance,%ss,adjustedr2,r2,%meandeviance,%deviance,aic,sic;\

 TPROB=yes; FACT=9] year+month+loghrs
```

5.6 Catch rate time series

Relative trends in snapper abundance were inferred from standardised catch rates from logbook datasets discussed in Section 2.1. The catch rate index informed proportionally on the annual magnitude of change in abundance of legal sized fish. This was a primary assumption for the stock assessment. Focus was on the standardised year, and year by latitude band trends. The annual standardised catch rate predictions were generated to cover four levels of fishing power. For standardisations that started before the 1990s the effect of increasing fishing power pushed catch rates down, highlighting the difference in predictions between not using fishing power adjustments and including some level of fishing power adjustment. For standardisations that started after the 1990s, the major fishing power increases had already occurred, and thus the inclusion of fishing power increases pushed catch rates down minimally.

5.6.1 NSW commercial catch rates from commcatch data

The New South Wales commcatch logbook data provided monthly catch and effort information from 1985–2016 (Table 2.1). The standardisations for trap fishing (Figure 5.5) and line fishing (Figure 5.7) from the commcatch data records were done separately. For all fishing power adjustments, trap catch rates decreased in the 1990s and showed an overall increasing trend from 2002–2016, with reduced adjustments showing catch rates increased three times from 2002–2016 (Figure 5.5).

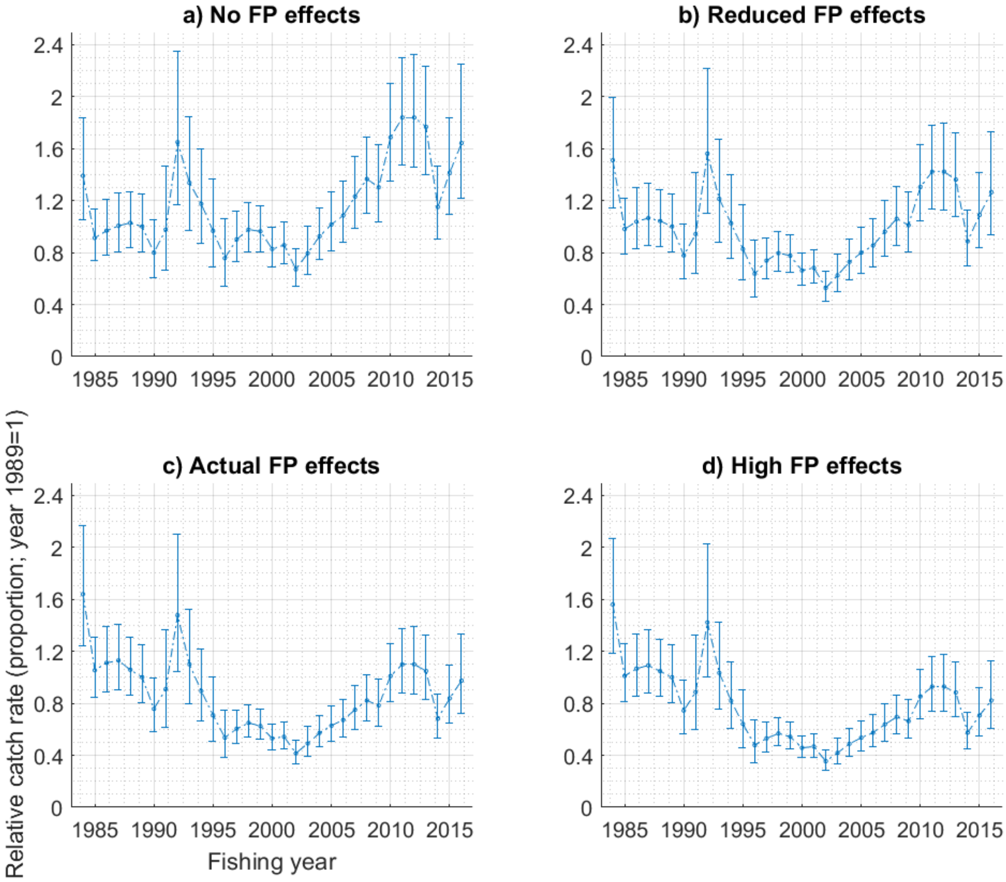

Figure 5.5. Standardised mean catch rates of snapper by fishing year from New South Wales commcatch data records for trap fishing. Catch rates were scaled proportionally, with year 1989=1. Results were presented with fishing power (FP) adjustments; 95 per cent confidence interval error bars shown.

The decrease in catch rates in the 1990s in the yearly standardisations (Figure 5.5) were predicted over many regions in the latitudinal predictions (Figure 5.6). Similarly, the overall increase in catch rates between 2002 and 2016 from the yearly predictions (Figure 5.5) was observed in many of the regions in the latitudinal predictions. The two latitude bands just below Coffs Harbour, namely latitude bands 32 and 33, which constituted 23 per cent of the total snapper harvest of the standardised trap fishing data records from 1984–2016, showed fairly constant catch rates over time. The catch rates for the main region of snapper catch, the Coffs harbour region, latitude band 31, followed the yearly catch rate trend.

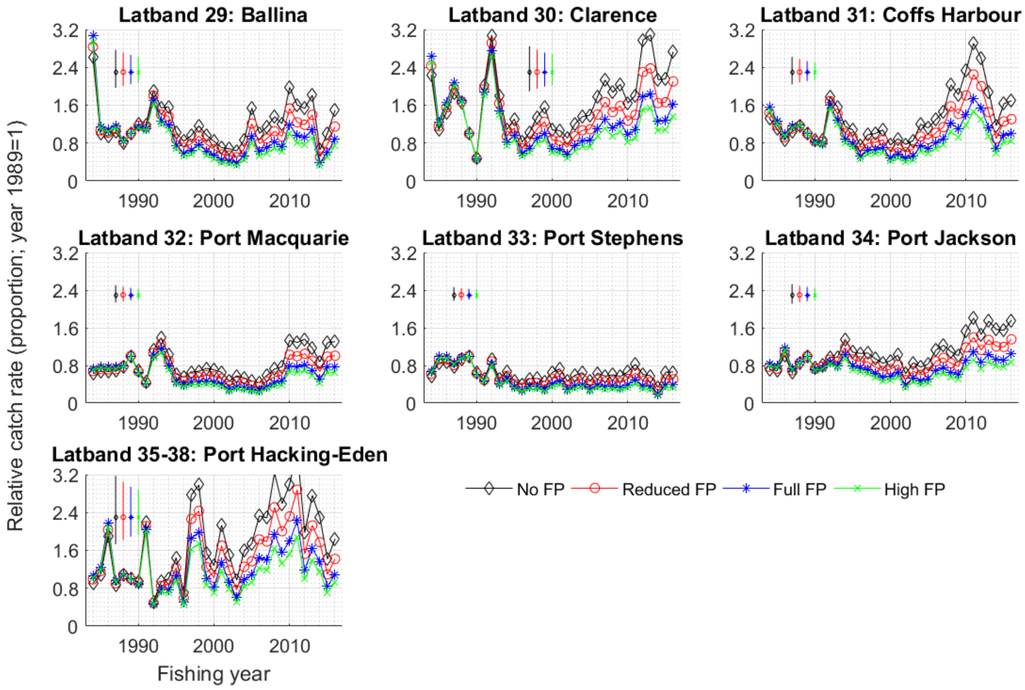

Figure 5.6. Standardised mean catch rates of snapper by latitude band and fishing year for New South Wales trap fishing from commcatch data records. Catch rates were scaled proportionally, with year 1989=1. Results were presented to compare four fishing powers (FP). Average 95 per cent confidence interval widths are shown.

The New South Wales catch rate standardisation for line fishing methods started from 1997 instead of 1984 as in the trap standardisation, because it was not possible to extract line fishing records pre-1997. For all fishing power adjustments, catch rates remained relatively constant from 1997-2010, increased by 28 per cent for actual adjustments from 2010-2011, and then decreased from 2011-2016, with actual adjustments showing catch rates were down about 40 per cent between 2011 and 2016 (Figure 5.7).

Latitudinal predictions (Figure 5.8) showed that the increase in line snapper catch rate from 2010-2011 for the yearly predictions occurred in all latitude bands except the southern regions from Port Hacking to Eden (latitude bands 35-38, Figure i) with the latitude band including Port Macquarie, latitude band 32, showing a more than double increase in catch rate from 2010-2011 for all fishing power adjustments. The northern regions from Ballina to Port Stephens (latitude band 29-33), showed a recovery in catch rates from 2014–2016. The southern regions below Port Stephens (latitude band 34-38) showed declining catch rates from 2014–2016.

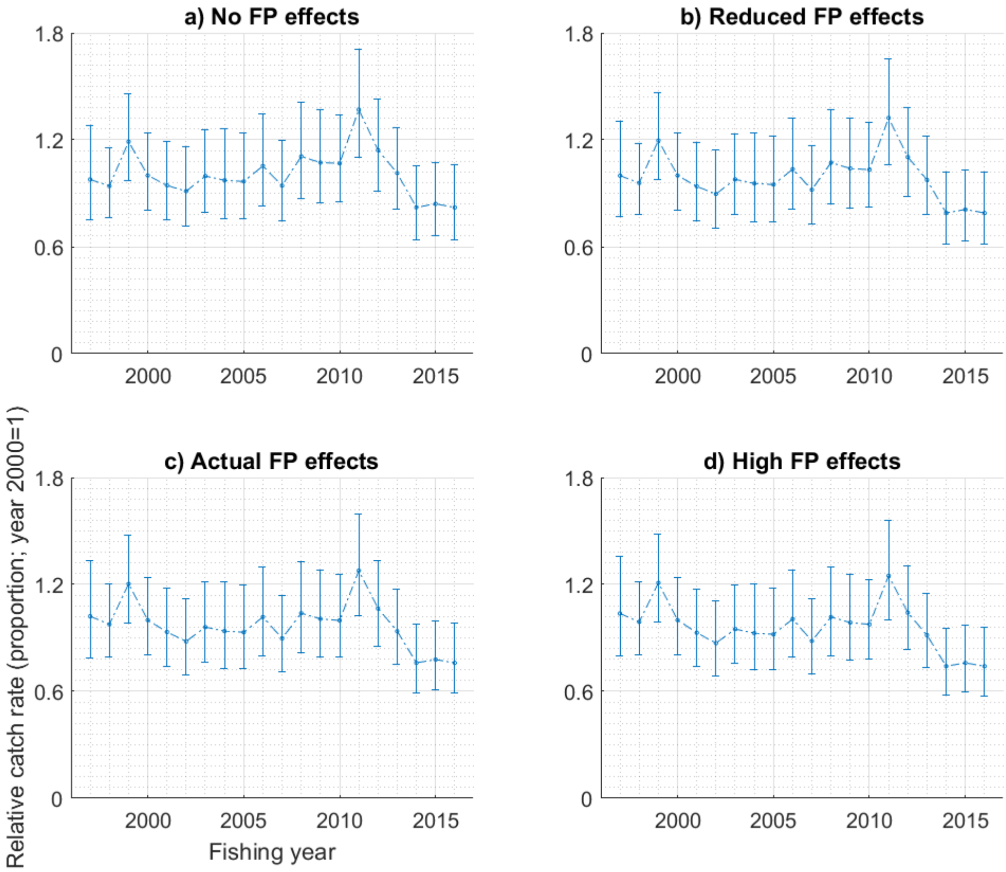

Figure 5.7. Standardised mean catch rates of snapper by fishing year from New South Wales commcatch data records for line fishing. Catch rates were scaled proportionally, with year 2000=1. Results were presented to compare fishing power (FP) adjustments; 95 per cent confidence interval error bars shown.

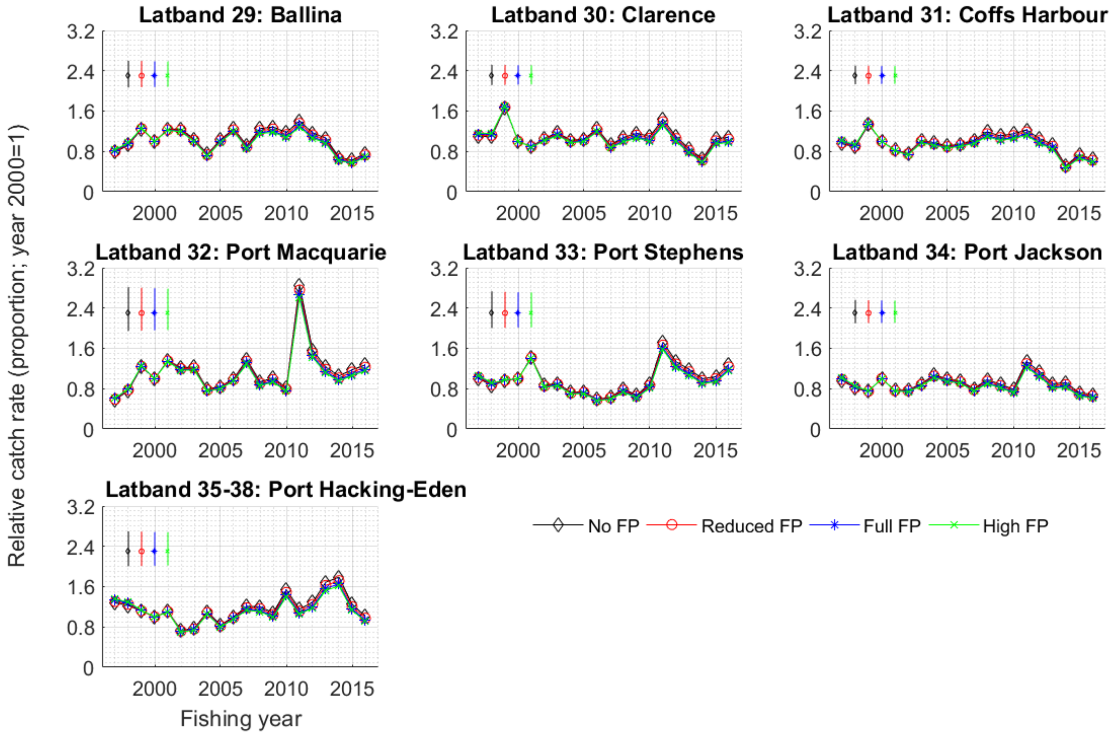

Figure 5.8. Standardised mean catch rates of snapper by fishing year and latitude band for New South Wales commcatch data records for line fishing. Catch rates were scaled proportionally, with year 2000=1. Results were presented to compare four fishing powers (FP), average 95 per cent confidence interval widths are shown.

5.6.2 NSW commercial catch rates from fishonline data

The New South Wales fishonline logbook records provided daily catch and effort data from 2009–2016 (Table 2.1). The standardisations for trap fishing (Figure 5.9) and line fishing (Figure 5.11) from the New South Wales fishonline data were done separately.

For all fishing power adjustments, trap catch rates increased from 2009–2011, decreased from 2011–2014, and recovered from 2014–2015 (Figure 5.9). The trap predictions from the daily fishonline data agreed closely with the predictions from the monthly commcatch data (Figure 5.10).

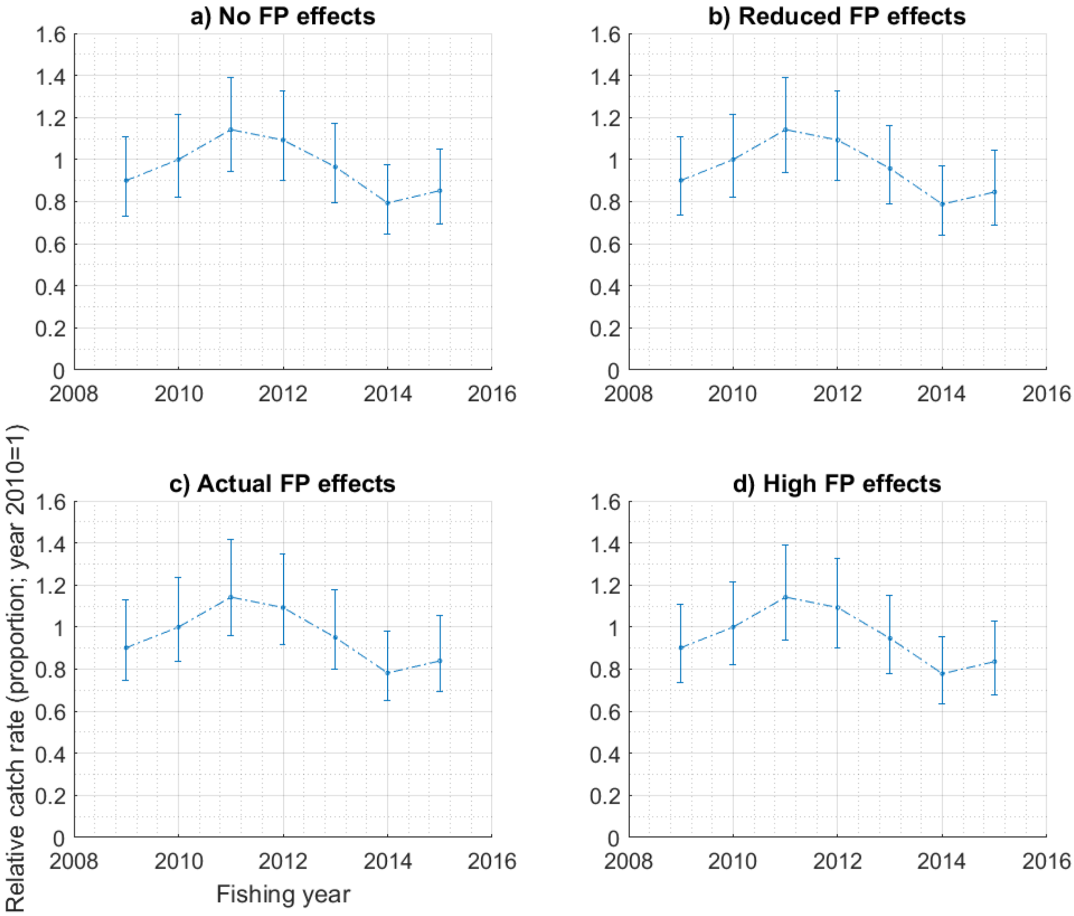

Figure 5.9. Standardised mean catch rates of snapper by fishing year from New South Wales fishonline data for trap fishing. Catch rates were scaled proportionally, with year 2010=1. Results were presented to compare fishing power (FP) adjustments; 95 per cent confidence interval error bars shown.

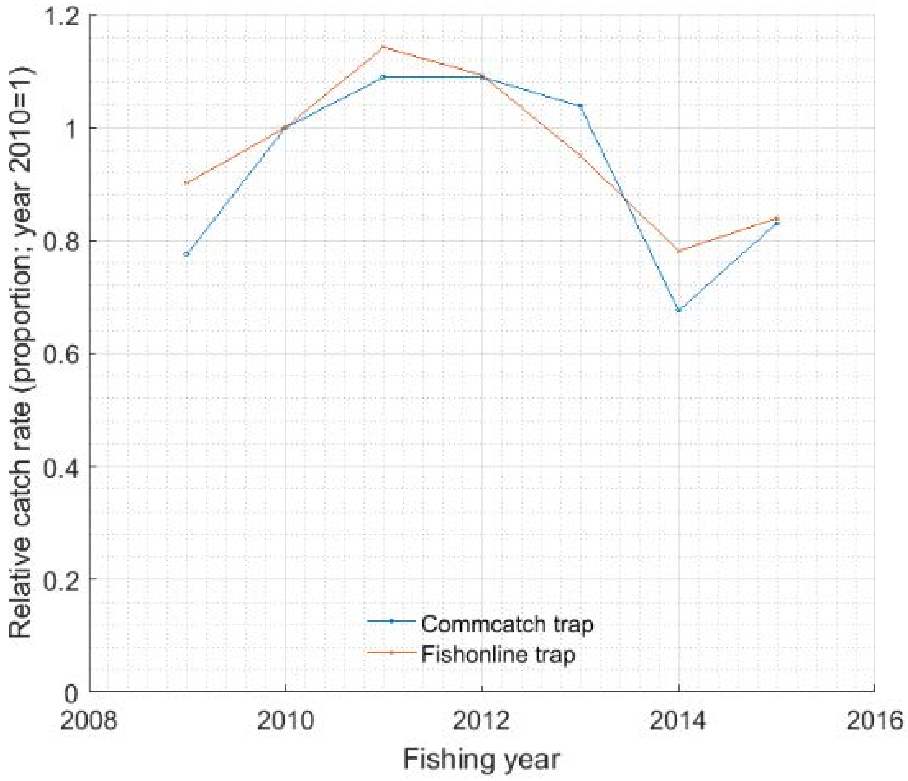

Figure 5.10. Standardised mean catch rates of snapper by fishing year from New South Wales commcatch and fishonline data records for trap fishing. Catch rates were scaled proportionally, with year 2010=1. Results were presented to compare fishing power (FP) adjustment of actual effects. The graphs for no FP effects, reduced FP effects and high FP effects were similar.

For all fishing power adjustments, the line catch rate predictions from the fishonline data showed an overall decrease from 2011–2015, with actual fishing power adjustments showing a decrease in catch rates of 18 per cent from 2011–2015. The predictions from the commcatch data for line fishing methods also showed a decrease in catch rates from 2011–2016, with actual adjustments showing a 40 per cent decrease from 2011–2016. The catch rate time series from the fishonline data matched the corresponding predictions from the commcatch data (Figure 5.12).

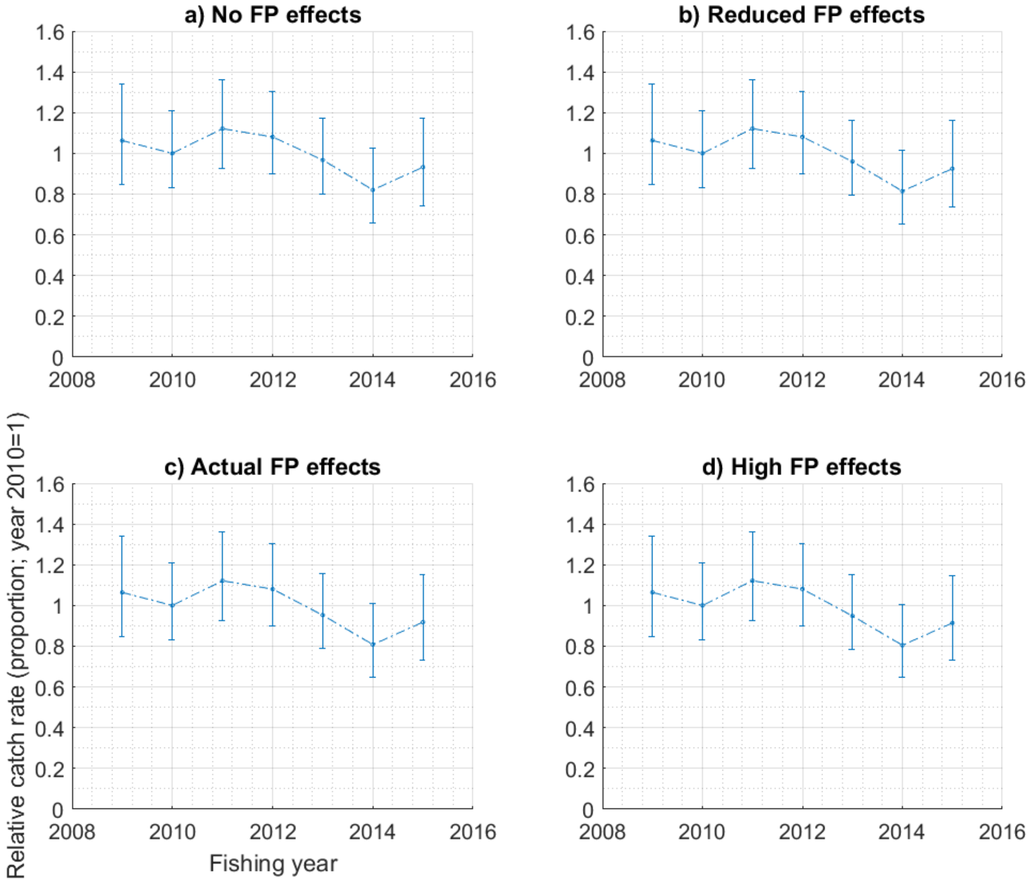

Figure 5.11. Standardised mean catch rates of snapper by fishing year from New South Wales fishonline line fishing records. Catch rates were scaled proportionally, with year 2010=1. Results were presented to compare standardisations with fishing power (FP) adjustment; 95 per cent confidence interval error bars shown.

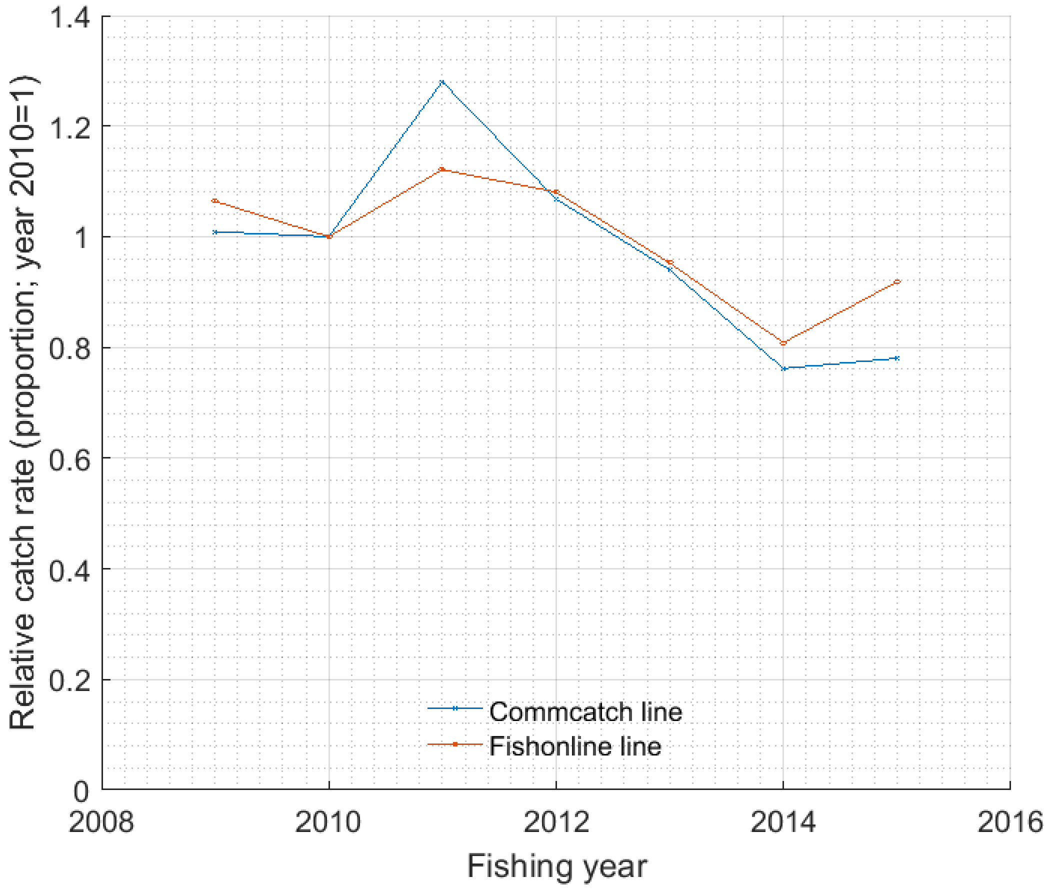

Figure 5.12. Standardised mean catch rates of snapper by fishing year from New South Wales commcatch and fishonline data records for line fishing. Catch rates were scaled proportionally, with year 2010=1. Results were presented to compare standardisations with fishing power (FP) adjustment of actual effects. The graphs for no FP effects, reduced FP effects and high FP effects were similar.

5.6.3 Qld commercial catch rates from logbook records

Overall, there was a decrease in Queensland commercial line catch rates from 1989–2016, with a 2005 peak in catch rates for all fishing power adjustments (Figure 5.13). This peak was not present in the New South Wales commercial standardisations. The catch rates with no fishing power effects gave catch rates in 2016 of two thirds the catch rates in 1989; the catch rates for reduced fishing power effects produced half the catch rate in 2016 compared to 1989; the catch rates with actual effects as estimated from the fisher knowledge data produced a decline in catch rates in 2016 to 40 per cent of what catch rates were in 1989; and catch rates for higher fishing power effects gave one third of the catch rates in 2016 compared to 1989 (Figure 5.13).

Latitudinal predictions showed that the northern latitude bands from Mackay to Rockhampton, latitude bands 22–24, had improved catch rates from 2010–2016 (Figure 5.14). Apart from the 2005 peak, the next two southern latitude bands, namely latitude bands 25 and 26, encompassing Fraser Coast, showed clear declining trends in catch rates. Most of the Queensland commercial line harvest for the standardised data came from the Sunshine Coast region, latitude band 27, (30 per cent of total Queensland commercial line harvest from 1988–2016 for the standardised data records) and Moreton and Gold Coast regions, latitude band 28, (30 per cent of total Queensland commercial line harvest from 1988–2016 for the standardised data records). These main latitude bands of Queensland snapper harvest showed an overall decline in snapper catch rates.

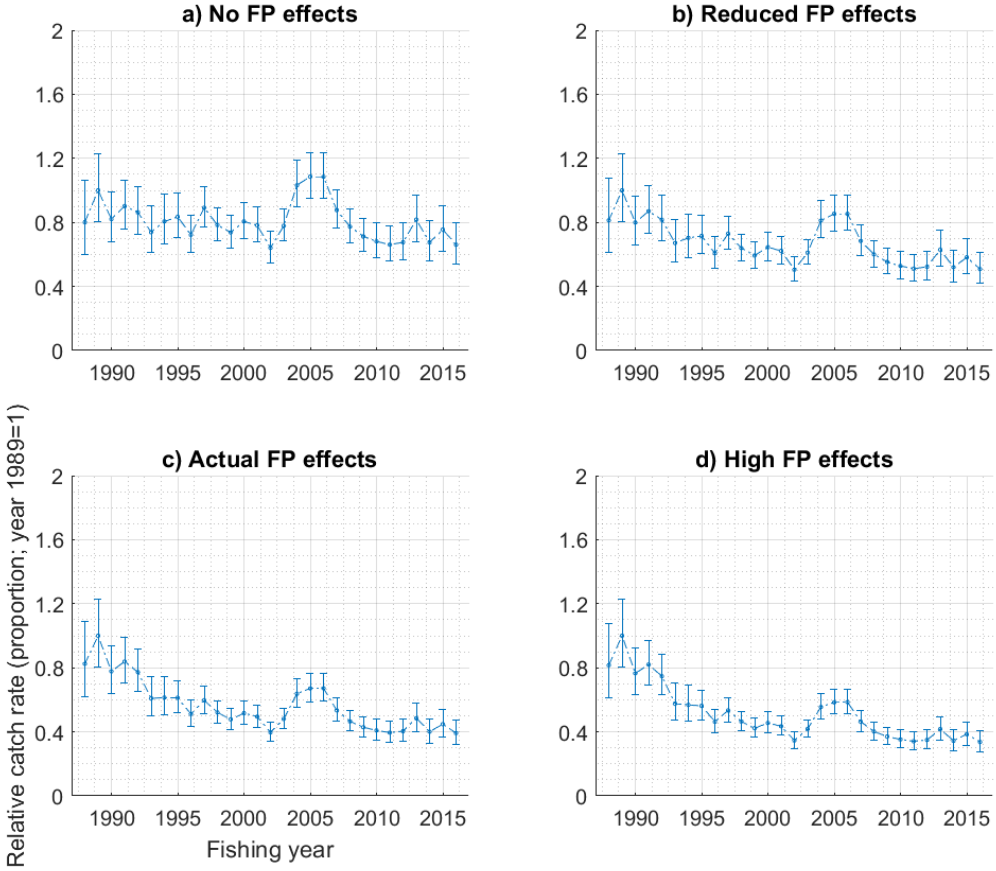

Figure 5.13. Standardised mean catch rates of snapper by fishing year for Queensland commercial logbook data for line fishing records. Catch rates were scaled proportionally, with year 1989=1. Results were presented for standardisations with fishing power (FP) adjustment; 95 per cent confidence interval error bars shown.

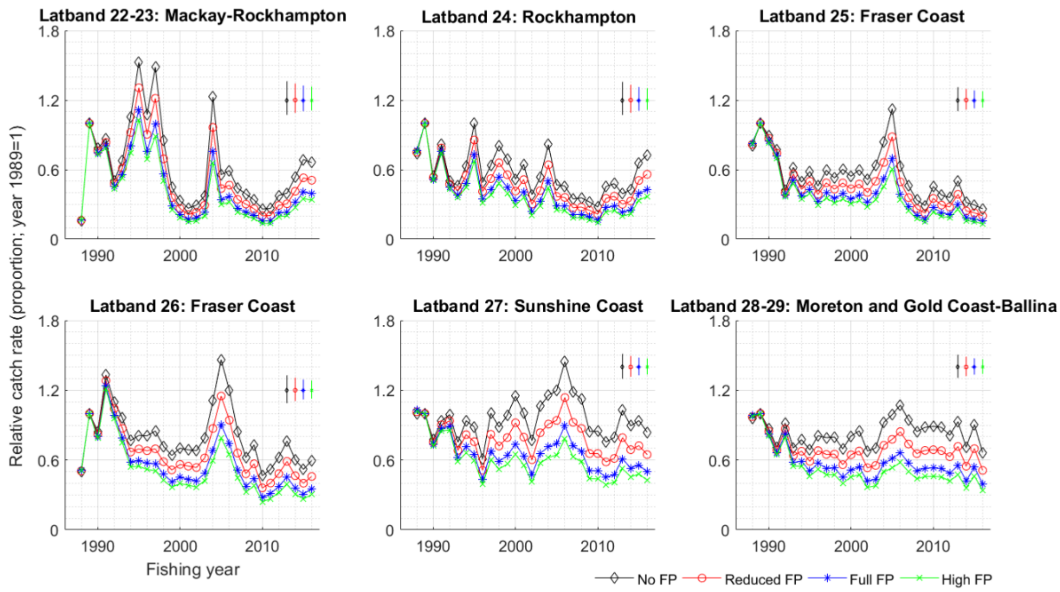

Figure 5.14. Standardised mean catch rates of snapper by fishing year for Queensland waters for commercial line fishing. Catch rates were scaled proportionally, with year 1989=1. Results were presented to compare four fishing powers (FP). Average 95 per cent confidence interval widths are shown.

5.6.4 Qld charter catch rates from logbook records

For all fishing power adjustments Queensland charter catch rates were constant from 2004–2015 (Figure 5.15). For no fishing power adjustment, catch rates were almost the same as those in 2000 (92 per cent of 2000 catch rate), whereas for the range of adjustments, (reduced fishing power to high fishing power), catch rates in 2015 were between 80-70 per cent of catch rates in 2000.

The main areas of snapper charter catch were the Sunshine Coast region, latitude band 27 in (Figure 5.16), with 34 per cent of the total harvest over the years 1996–2015 for the standardised data, and the Moreton and Gold Coast region, latitude band 28 in (Figure 5.16), with 53 per cent of the total snapper harvest over the years 1996–2015 for the standardised data. The latitudinal predictions showed declining catch rates in the Sunshine Coast region and increasing catch rates from 2005 onwards in the Moreton and Gold Coast region.

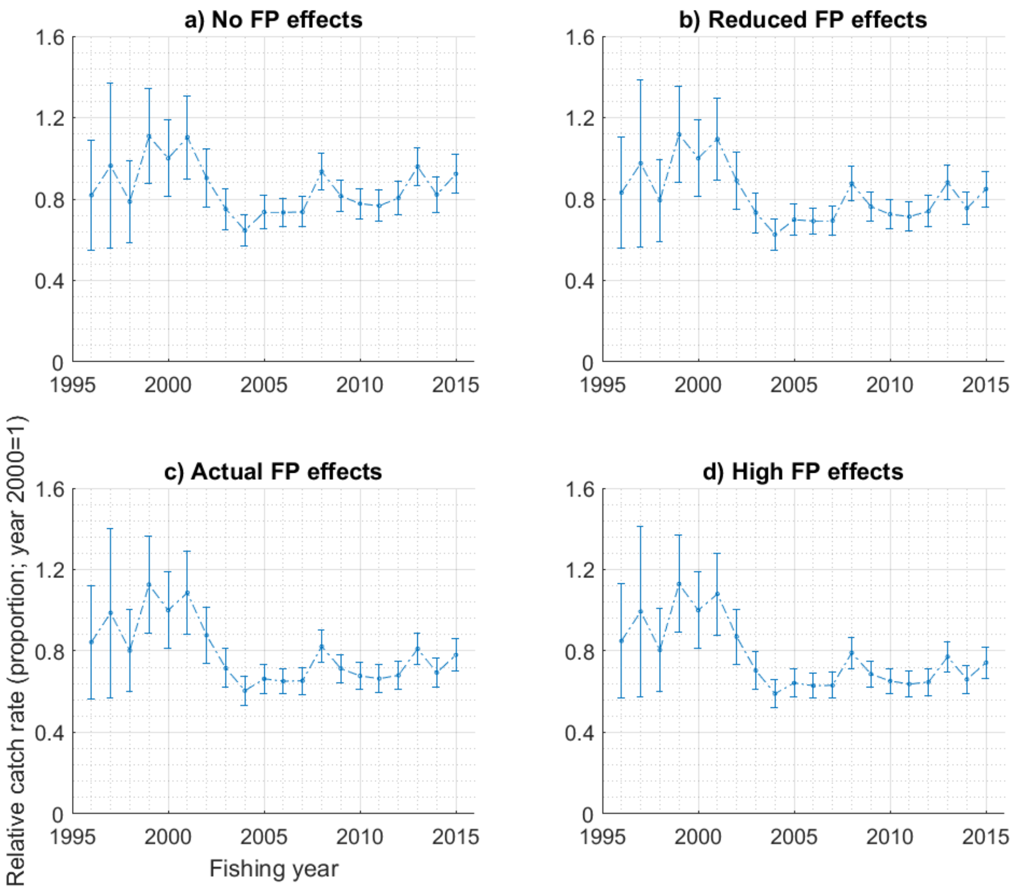

Figure 5.15. Standardised mean catch rates of snapper by fishing year from catch data provided by Queensland charter logbook records. Catch rates were scaled proportionally, with year 2000=1. Results were presented for standardisations with fishing power (FP) adjustment; 95 per cent confidence interval error bars shown.

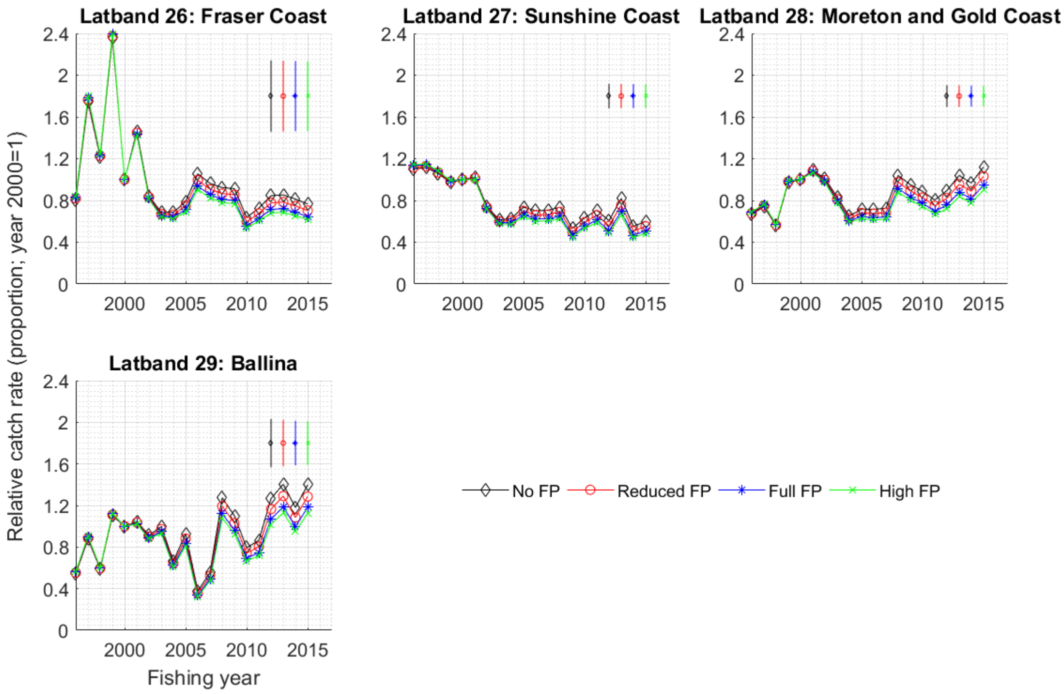

Figure 5.16. Standardised mean catch rates of snapper by fishing year for Queensland waters for charter line fishing. Catch rates were scaled proportionally, with year 2000=1. Results were presented to compare four fishing powers (FP). Average 95 per cent confidence interval widths are shown.

5.6.5 Catch rates from AMLI Queensland charter data

Apart from the two peaks in catch rates in 1994 and 1999, all fishing power adjustments showed declining catch rates from 1993–2010 for the AMLI Queensland charter data set (Figure 5.17).

The latitudinal predictions (Figure 5.18) showed that all locations showed an overall decline in catch rates over time, where: locations 1 and 2, the Sunshine Coast region, comprised 30 per cent of the snapper harvest, while locations 3-5, the Gold Coast and Moreton Bay regions, comprised 70 per cent of the snapper harvest.

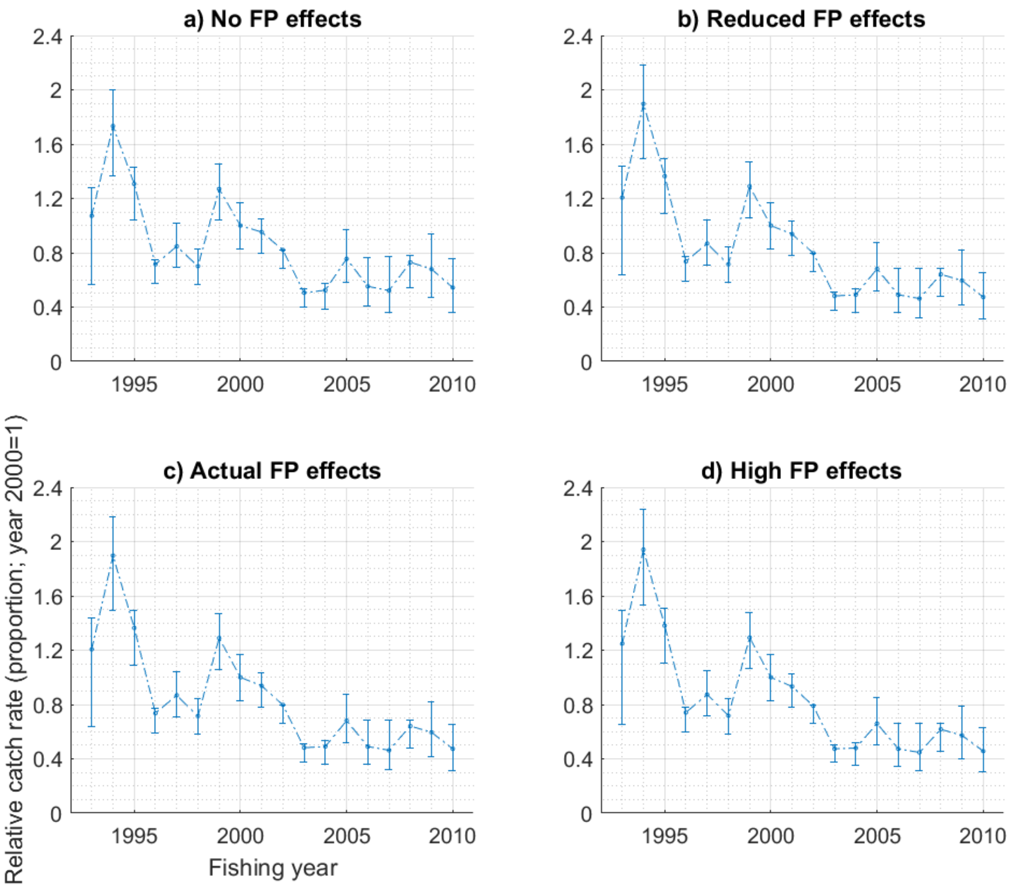

Figure 5.**17**. Standardised mean catch rates of snapper by fishing year for AMLI Queensland charter logbook data. Catch rates were scaled proportionally, with year 2000=1. Results were presented for standardisations with fishing power (FP) adjustment; 95 per cent confidence interval error bars shown.

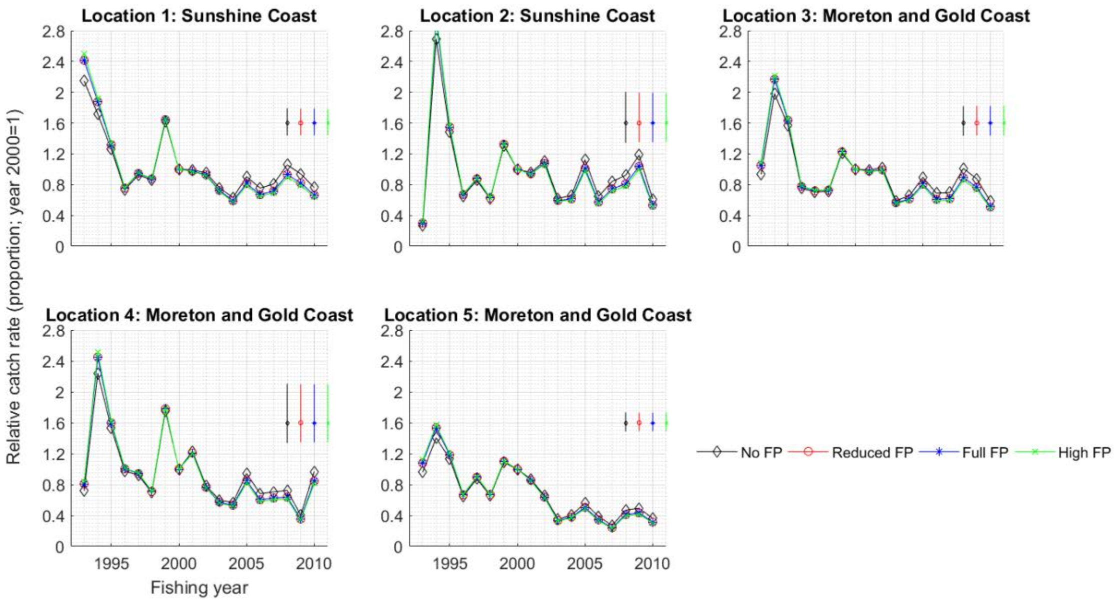

Figure 5.18. Standardised mean catch rates of snapper by fishing year from AMLI Queensland charter data. Catch rates were scaled proportionally, with year 2000=1. Results were presented to compare four fishing powers (FP). Average 95 per cent confidence interval widths are shown.

5.6.6 Recreational catch rates from Qld boat ramp surveys

Annual standardised catch rates were generated to cover four levels of fishing power (Figure 5.19) for the years 1994, 1995, 2007 and 2008 of boat ramp surveys. The catch rates declined over time with catch rates in 2008 equal to between 40–20 per cent of what catch rates were in 1994 for the various fishing power adjustments.

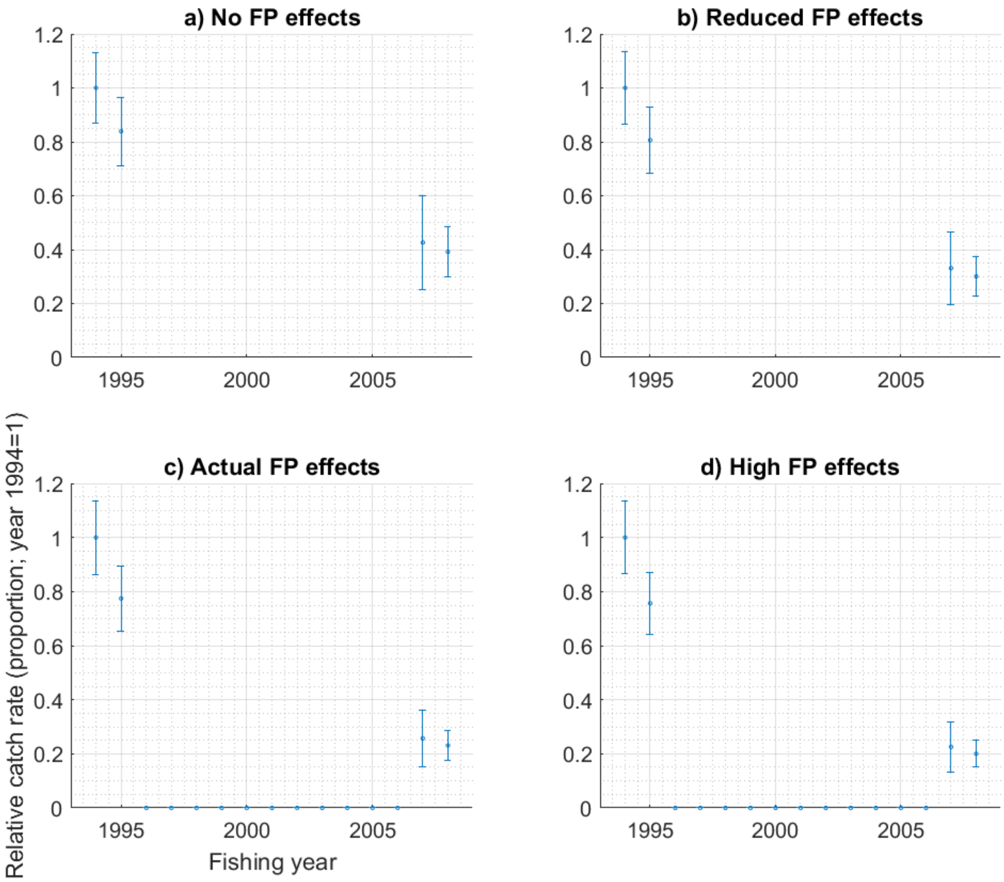

Figure 5.19. Standardised mean catch rates of snapper by fishing year for Queensland waters from boat ramp surveys. Catch rates were scaled proportionally, with year 1994=1. Results were presented to compare four fishing powers (FP). Average 95 per cent confidence interval widths are shown.

5.6.7 Recreational catch rates from RFISH diary and SWRFS surveys

Annual standardised catch rates were generated to cover four levels of fishing power (Figure 5.19) for the years 1997, 1999, 2000, 2002, 2005, 2010 and 2013. The catch rates declined over time with catch rates in 2013 down to between 35–20 per cent of what catch rates were in 1997 for the various fishing power adjustments.

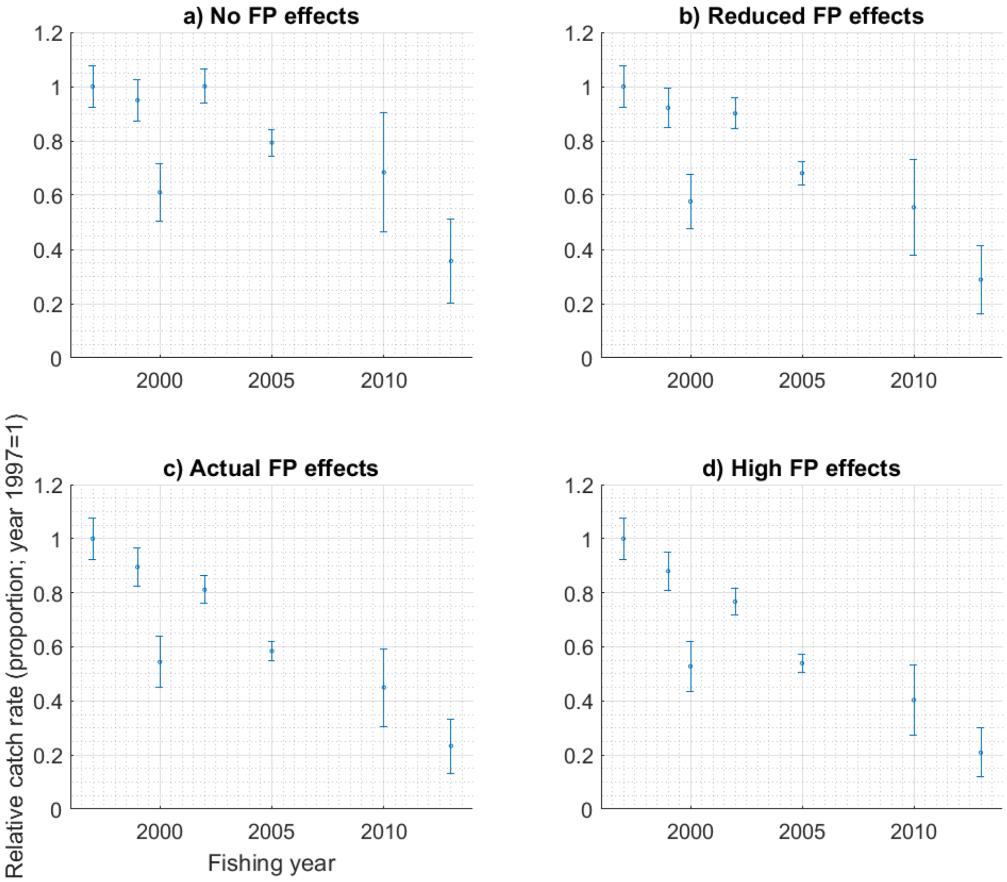

Figure 5.20. Standardised mean catch rates of snapper by fishing year for Queensland waters for RFISH and SWFRFS surveys. Catch rates were scaled proportionally, with year 1997=1. Results were presented to compare four fishing powers (FP). Average 95 per cent confidence interval widths are shown.

5.7 Catch rate diagnostics

5.7.1 NSW commercial catch rates from commcatch data

Table 5.15. Summary of analysis statistics for the linear mixed model for New South Wales commcatch trap. The statistics were the same for the four levels of fishing power adjustments.

Estimated variance components		
Random term:	Component	s.e.
Boat	0.9073	0.0519
Residual:	Sigma2	s.e.
	0.945	0.0088
Deviance:	-2*Log-Likelihood	
	Deviance	d.f.
	25911.92	24009
Fixed term	n.d.f.	F statistic
Year.latband	192	4.64
Month	11	20.35
Logdays	1	10108.29

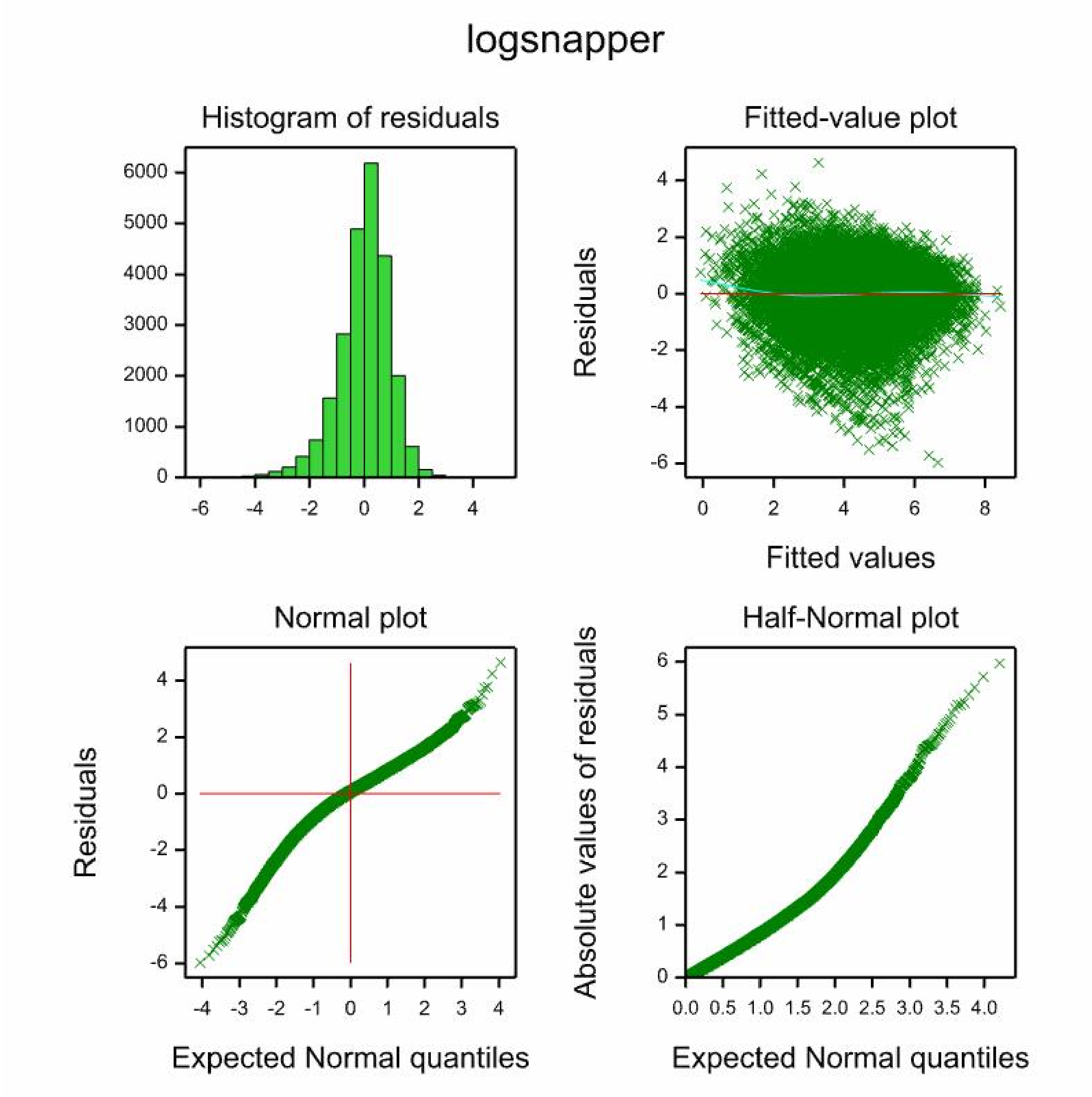

Figure 5.21. Residual diagnostic plots for the linear mixed model for New South Wales commcatch trap fishing assuming no fishing power increases. The plots were similar for analyses with fishing power.

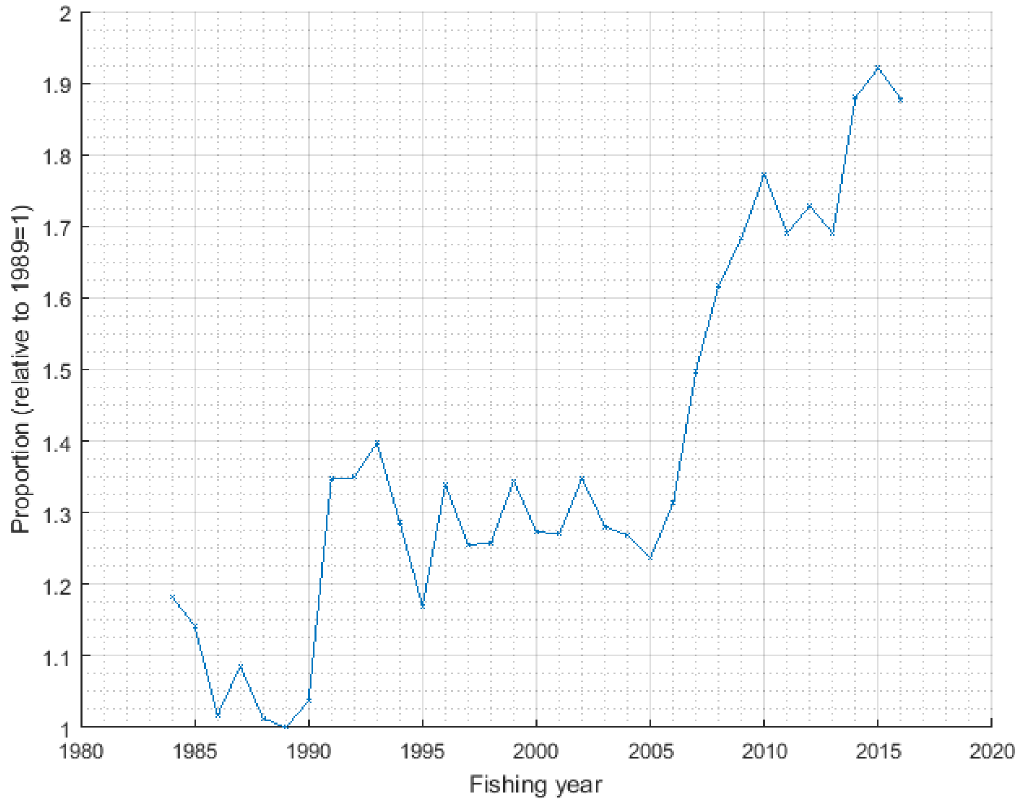

Figure 5.22. Estimated New South Wales trap-sector 'fleet' mean fishing power as calculated from the vessel-boat REML model parameters. The parameter estimates and variance components were stable across the different REML analyses (Table 5.15). The 'fleet' mean fishing power for snapper was estimated to be almost double in 2016 compared to 1989; and there was a large increase in the 'fleet' mean fishing power in the years 2005–2010.

Table 5.16. Summary of analysis statistics for the linear mixed model for New South Wales commcatch line. The statistics were the same for the four levels of fishing power adjustments.

Estimated variance components		
Random term:	Component	s.e.
Boat:	0.871	0.055
Residual:	Sigma2	s.e.
	1.214	0.014
Deviance:	-2*Log-Likelihood	
	Deviance	d.f.
	21525.07	16122
Fixed term	n.d.f.	F statistic
Year.latband	192	2.68
Month	11	51.93
Logdays	1	1985.05

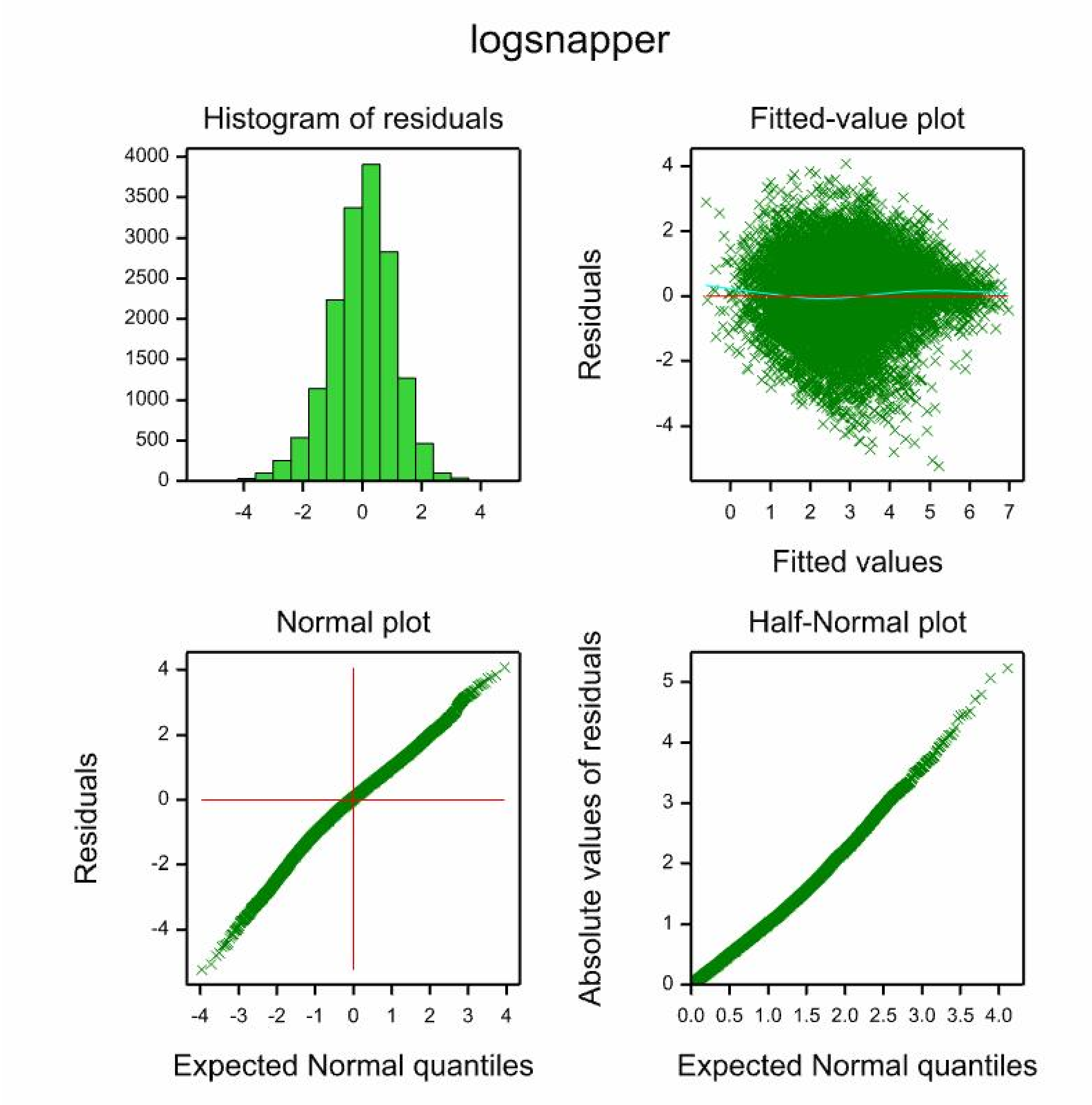

Figure 5.23. Residual diagnostic plots for the linear mixed model for New South Wales commcatch line fishing assuming no fishing power increases. The plots were similar for analyses with fishing power.

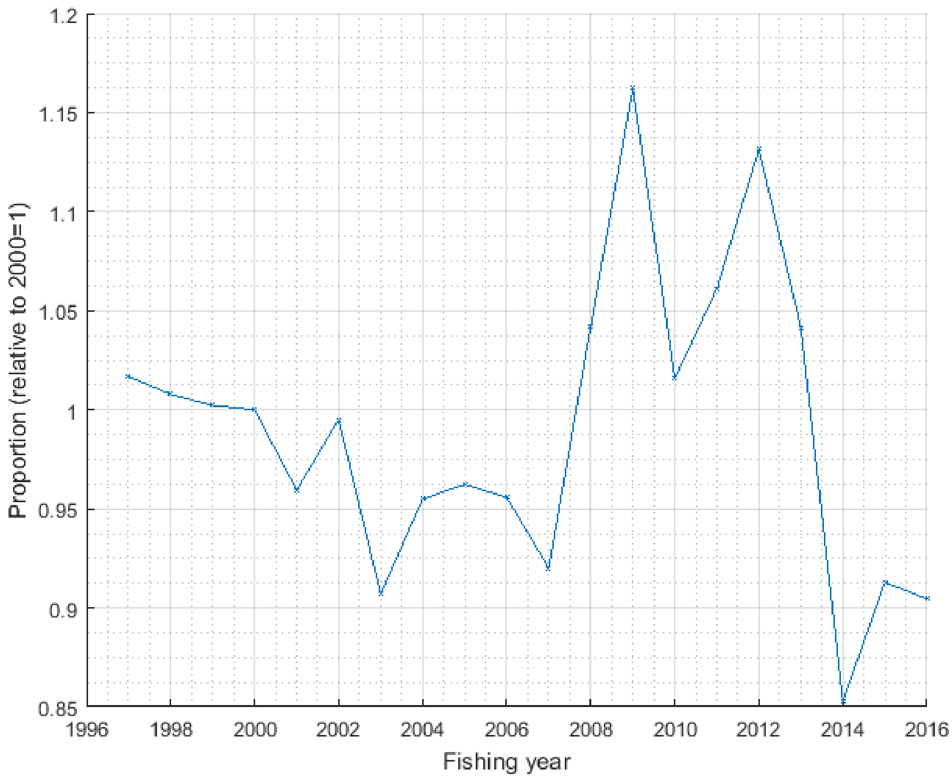

Figure 5.24. Estimated New South Wales line-sector 'fleet' mean fishing power as calculated from the vessel-boat REML model parameters. The parameter estimates and variance components were stable across the different REML analyses (Table 5.16). The mean 'fleet' fishing power for snapper was estimated to be the same in 2016 compared to 2000; there was a large increase in the years 2007–2009 and a large decrease in the 'fleet' mean fishing power in the years 2012–2014.

5.7.2 New South Wales commercial catch rates from fishonline data

Table 5.17. Summary of analysis statistics for the linear mixed model for New South Wales fishonline trap. The statistics were the same for the four levels of fishing power adjustments.

Estimated variance components		
Random term:	Component	s.e.
Boat:	0.5553	0.0861
Residual:	Sigma2	s.e.
	0.888	0.0080
Deviance:	-2*Log-Likelihood	
	Deviance	d.f.
	22684.64	24637
Fixed term	n.d.f.	F statistic
Year.latband	36	17.44
Latband.s1	7	83.44
Latband.s2	7	57.15
Latband.s3	7	18.04
Latband.s4	7	19.75
Latband.s5	7	25.81
Latband.s6	7	17.77

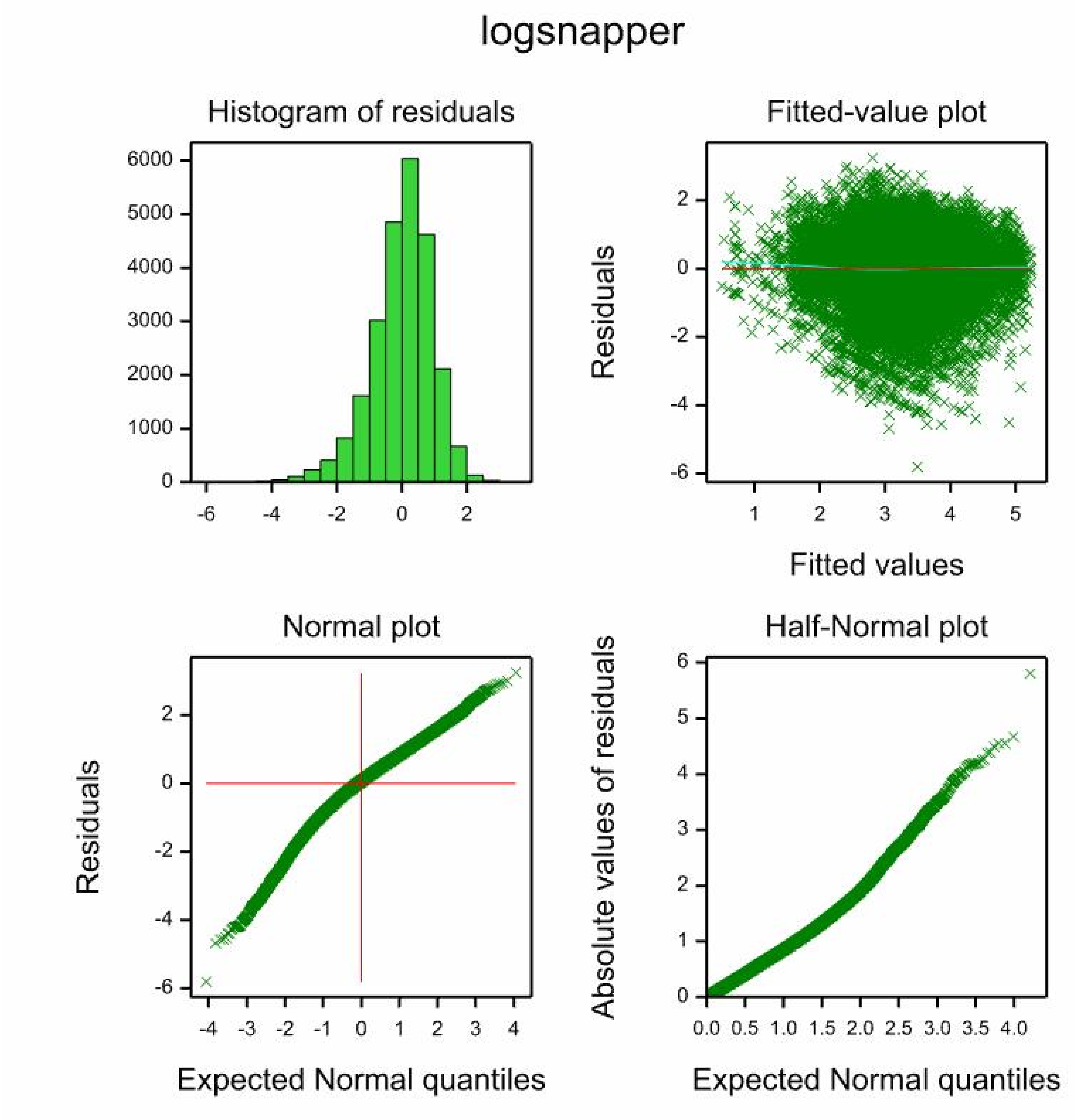

Figure 5.25. Residual diagnostic plots for the linear mixed model for New South Wales fishonline trap fishing assuming no fishing power increases. The plots were similar for analyses with fishing power.

Table 5.18. Summary of analysis statistics for the linear mixed model for New South Wales fishonline line. The statistics were the same for the four levels of fishing power adjustments.

Estimated variance components		
Random term:	Component	s.e.
Boat:	0.4928	0.0589
Residual:	Sigma2	s.e.
	0.951	0.0114
Deviance:	-2*Log-Likelihood	
	Deviance	d.f.
	14554.16	14177
Fixed term	n.d.f.	F statistic
Year.latband	54	5.56
Latband.s1	10	23.39
Latband.s2	10	12.97
Latband.s3	10	4.33
Latband.s4	10	2.40

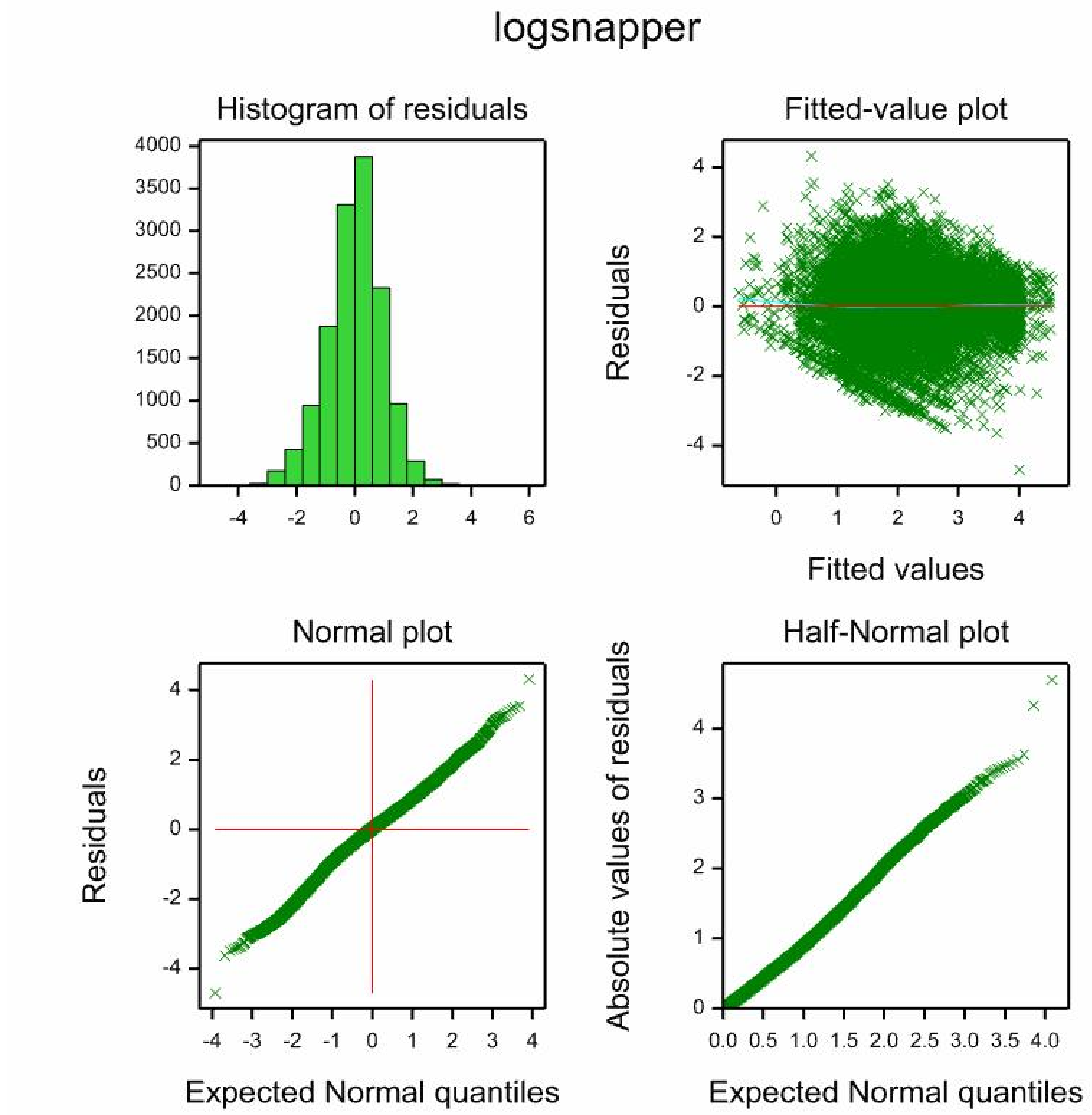

Figure 5.26. Residual diagnostic plots for the linear mixed model for New South Wales fishonline line fishing assuming no fishing power increases. The plots were similar for analyses with fishing power adjustments.

5.7.3 Queensland commercial catch rates from logbook data

Table 5.19. Summary of analysis statistics for the binomial generalised linear model for Queensland commercial line.

Regression analysis

Response variate: bin_caught (see definition Table 5.12)

Binomial totals: 1

Distribution: Binomial

Link function: Logit

Fitted terms: Constant + year + latband + year.latband + c12.latband + cs12.latband

(FACTORIAL limit for expansion of formula = 2)

Summary of analysis

Source	d.f.	deviance	mean deviance	deviance ratio	approx chi pr
Regression	185	11458.	61.9328	61.93	<.001
Residual	81505	71900.	0.8822		
Total	81690	83358.	1.0204		

Percentage mean deviance accounted for 13.5

Percentage deviance accounted for 13.7

Adjusted r-squared statistic (based on deviance) 0.135

R-squared statistic (based on deviance) 0.137

Akaike information criterion is estimated to be 72272.

Schwarz Bayes information criterion is estimated to be 74004.

Wald tests for dropping terms

Term	Wald statistic	d.f.	chi.pr
year.latband	1330.4	140	<0.001
latband.s1	747.5	6	<0.001
latband.s2	149.0	6	<0.001

Table 5.20. Summary of analysis statistics for the four linear mixed models for Queensland commercial line. All F-statistics were significant (p<0.001) and assessed by dropping terms from the full fixed model.

Estimated variance components		
Random term:	Component	s.e.
Boat:	0.409	0.026
Residual:	Sigma2	s.e.
	1.024	0.006
Deviance:	-2*Log-Likelihood	
	Deviance	d.f.
	69105.44	64566
Fixed term	n.d.f.	F statistic
Year.latband	140	11.77
Latband.s1	6	114.37
Latband.s2	6	133.40
Latband.s3	6	4.38
Latband.s4	6	14.79

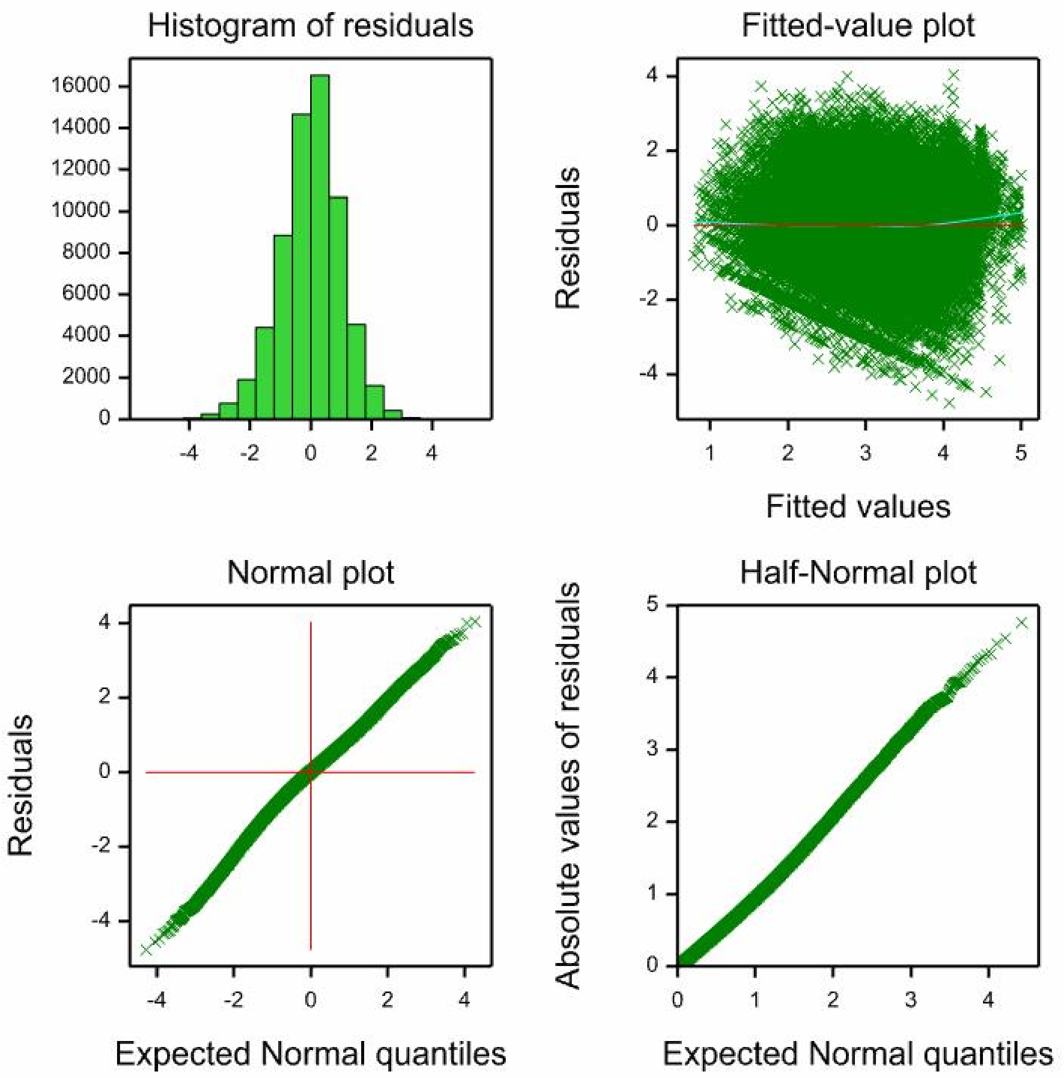

Figure 5.27. Residual diagnostic plots for the linear mixed model for Queensland commercial line fishing assuming no fishing power increases. The plots were similar for analyses with fishing power.

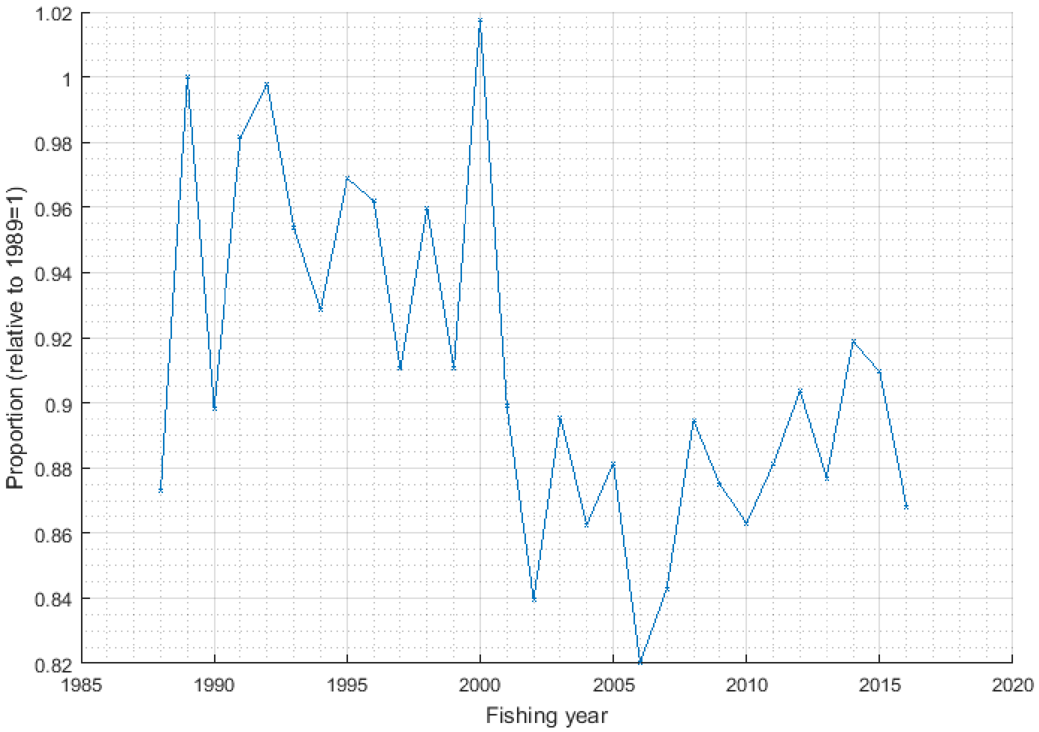

Figure 5.*28*. Estimated Queensland commercial line-sector 'fleet' mean fishing power as calculated from the vessel-acn REML model parameters. The parameter estimates and variance components were stable across the different REML analyses (Table 5.20). The 'fleet' mean fishing power for snapper was estimated to be about 2 per cent higher in 2000 compared to 1989; and near 14 per cent lower in 2016.

5.7.4 Queensland charter catch rates from logbook data

Table 5.21. Summary of analysis statistics for the four generalised linear models for Queensland charter. All F-statistics were significant (p<0.001) and assessed by dropping terms from the full fixed model.

Response variate: snapper_number

Distribution: Poisson

Link function: Log

Fitted terms: Constant + acnid + year + latband + year.latband + c12.latband + cs12.latband + c6.latband + cs6.latband + lunar + lunar_adv + windew + windew2

Source	d.f.	deviance	mean deviance	deviance ratio	approx F pr.
Regression	462	231159.	500.343	60.35	<.001
Residual	55828	462881.	8.291		
Total	56290	694040.	12.330		

Percentage mean deviance accounted for 32.8

Percentage deviance accounted for 33.3

Adjusted r-squared statistic (based on deviance) 0.328

R-squared statistic (based on deviance) 0.333

Akaike information criterion cannot be estimated.

Schwarz Bayes information criterion cannot be estimated.

Term	d.f	F statistic
acnid	363	46.36
year.latband	57	11.95
latband.s1	4	374.08
latband.s2	4	76.82
latband.s3	4	32.93
latband.s4 4	5.94	
lunar	1	6.14
lunar_adv	1	9.66
windew	1	11.20
windew2	1	57.60

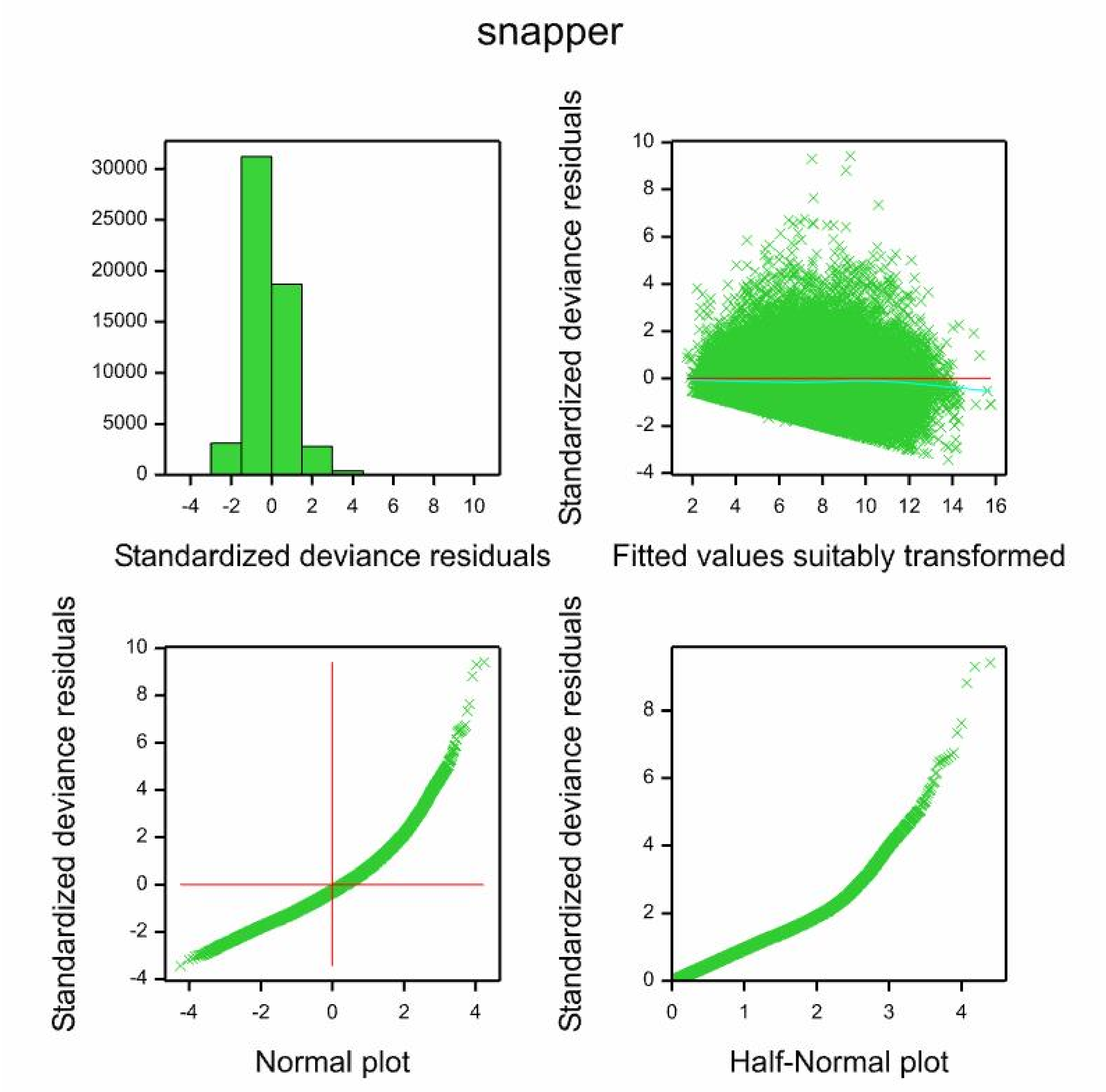

Figure 5.29. Residual diagnostic plots for the generalised linear model for Queensland charter assuming no fishing power increase. The plots were similar for analyses with fishing power.

5.7.5 Catch rates from AMLI Queensland charter data

Table 5.22. Summary of analysis statistics for the binomial generalised linear model for AMLI Queensland charter data.

Regression analysis

Response variate: bin_caught (for definition see Table 5.13)

Binomial totals: 1

Distribution: Binomial

Link function: Logit

Fitted terms: Constant + year + location + year.location + c12 + cs12 + daytime + boat + nanglers + fishtime + depth2 (FACTORIAL limit for expansion of formula = 2)

Summary of analysis

Source	**d.f.**	**deviance**	**mean deviance**	**deviance ratio**	**approx chi** pr
Regression	115	5018.	43.6337	43.63	<.001
Residual	17280	14970.	0.8663		
Total	17395	19988.	1.1491		
Change	-2	-667.	333.5072	333.51	<.001

Percentage mean deviance accounted for 24.6

Percentage deviance accounted for 25.1

Adjusted r-squared statistic (based on deviance) 0.246

R-squared statistic (based on deviance) 0.251

Akaike information criterion is estimated to be 15202.

Schwarz Bayes information criterion is estimated to be 16103.

.**Wald tests for dropping terms**

Term	**Wald statistic**	**d.f.**	**chi. pr.**
year.location	181.5	68	<0.001
c12	170.3	1	<0.001
cs12	156.6	1	<0.001
daytime	7.0	1	0.008
boat	275.2	19	<0.001
nanglers	5.5	1	0.019
fishtime	163.8	1	<0.001
depth2	606.3	2	<0.001

Table 5.23. Summary of analysis statistics for the linear mixed model for AMLI Queensland charter data. The statistics were the same for the four levels of fishing power adjustments.

Estimated variance components		
Random term:	Component	s.e.
Boat:	0.0361	0.0134
Residual:	Sigma2	s.e.
	0.783	0.0098
Deviance:	-2*Log-Likelihood	
	Deviance	d.f.
	10214.05	12737

Fixed term	n.d.f.	F statistic
Year.location	68	2.64
Location.depth2	10	87.88
c12	1	424.86
cs12	1	17.24
c6	1	56.76
cs6	1	0.15
lunar	1	4.96
lunar_adv	1	6.22
daytime	1	8.38
fullday2.loganglerhours	1	75.81

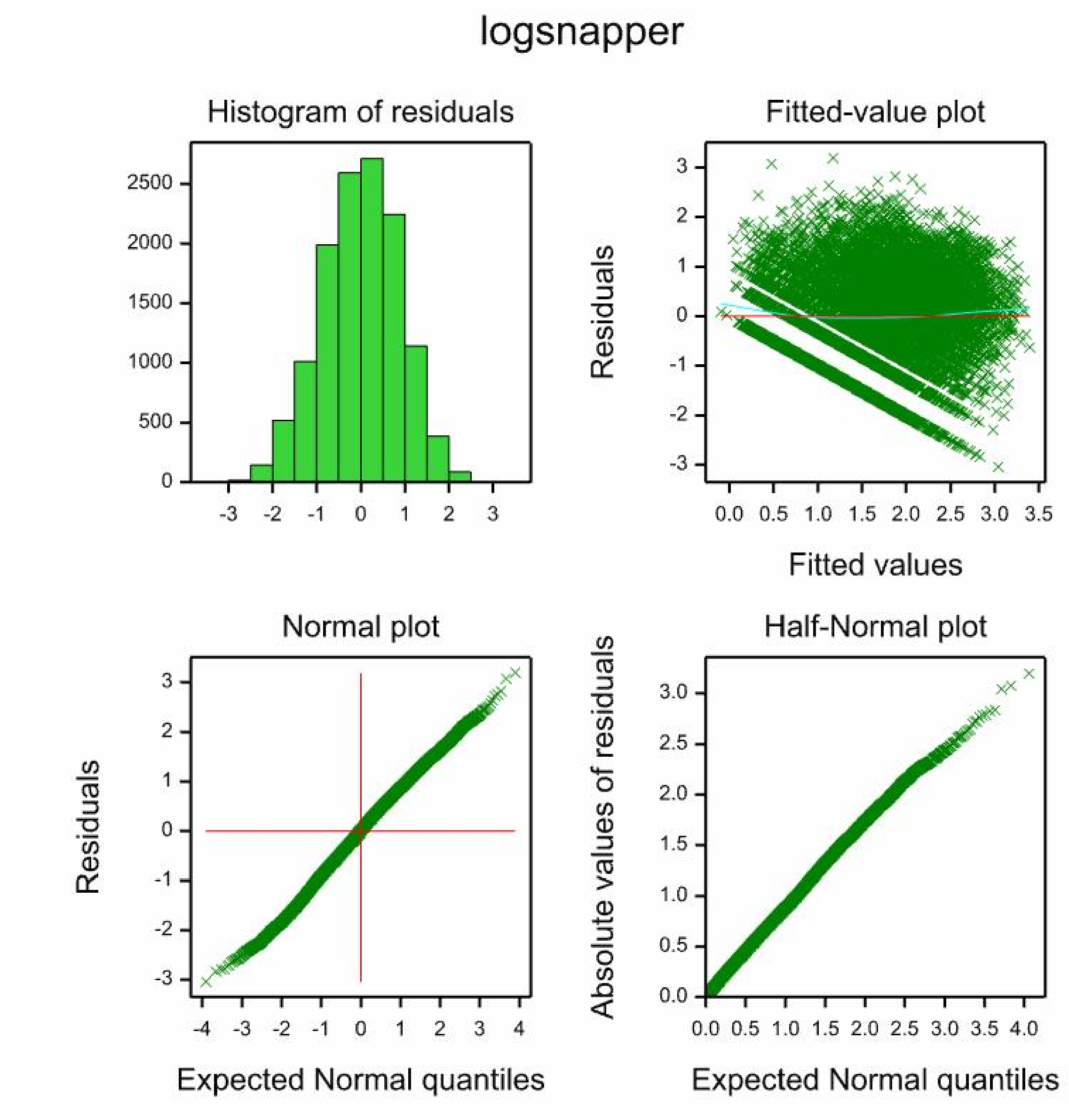

Figure 5.30. Residual diagnostic plots for the linear mixed model for AMLI Queensland charter data assuming no fishing power increase. The plots were similar for analyses with fishing power.

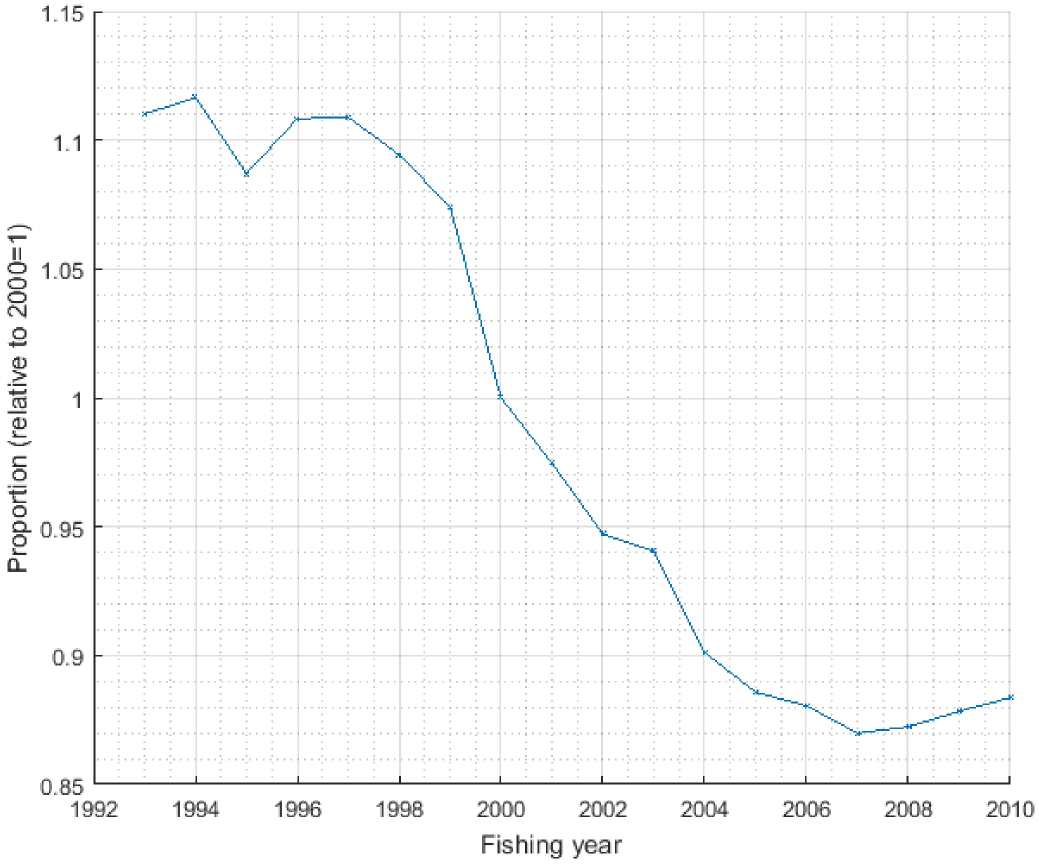

Figure 5.31. Estimated line-sector 'fleet' mean fishing power as calculated from the vessel-boat REML model parameters from the AMLI Queensland charter catch rate standardisation. The parameter estimates and variance components were stable across the different REML analyses (Table 5.23). The 'fleet' mean fishing power for snapper was estimated to be decreasing from 1993–2007, and then increased slightly from 2007–2009.

5.7.6 Recreational catch rates from Queensland boat ramp surveys

Table 5.24. Summary of analysis statistics for the four generalised linear models for Queensland boat ramp recreational data records. All F-statistics were significant (p<0.001) and assessed by dropping terms from the full fixed model.

Response variate: snapper

Distribution: Poisson

Link function: Log

Fitted terms: Constant, year, stratacode, month, loghrs

Summary of analysis

Source	**d.f.**	**deviance**	**mean deviance**	**deviance ratio**	**approx F pr.**
Regression	17	3660.	215.30	17.87	<.001
Residual	1685	20301.	12.05		
Total	1702	23961.	14.08		
Change	-1	-332.	331.53	27.52	<.001

Percentage mean deviance accounted for 14.4

Percentage deviance accounted for 15.3

Adjusted r-squared statistic (based on deviance) 0.144

R-squared statistic (based on deviance) 0.153

Akaike information criterion cannot be estimated.

Schwarz Bayes information criterion cannot be estimated.

Wald tests for dropping terms

Term	Wald statistic	d.f.	F statistic	F pr.
year	63.81	3	21.27	<0.001
stratacode	131.92	2	65.96	<0.001
month	38.20	11	3.47	<0.001
loghrs	26.31	1	26.31	<0.001

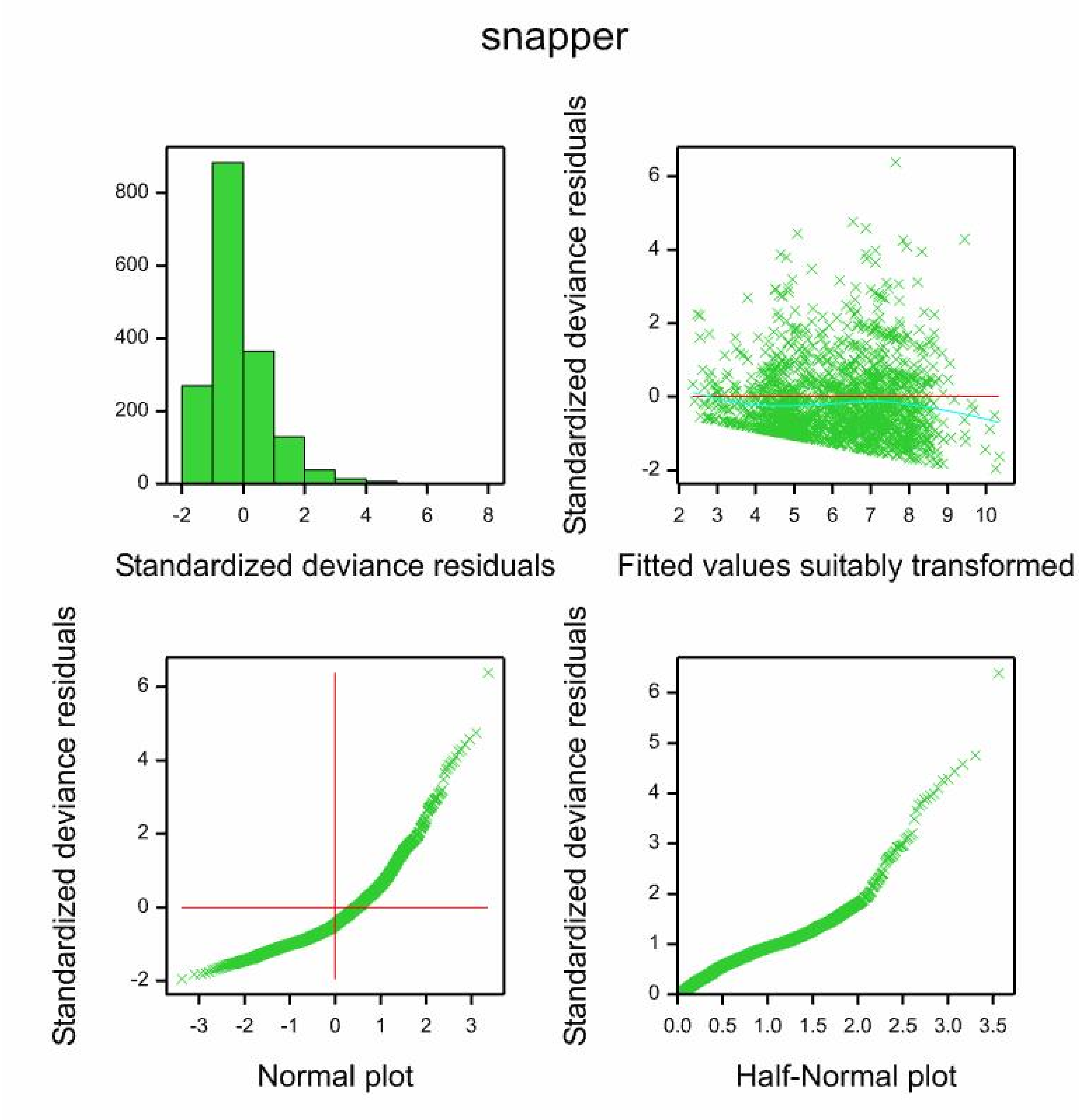

Figure 5.32. Residual diagnostic plots for the generalised linear model for Queensland recreational boat ramp records assuming no fishing power increase. The plots were similar for analyses with fishing power.

5.7.7 Recreational catch rates from RFISH diary and SWRFS surveys

Table 5.25. Summary of analysis statistics for the generalised linear model for Queensland recreational boat ramp surveys.

Response variate: snapper

Distribution: Poisson

Link function: Log

Fitted terms: Constant, year, month, loghrs

Summary of analysis

Source	**d.f.**	**deviance**	**mean deviance**	**deviance ratio**	**approx F pr.**
Regression	21	2537.	120.833	19.49	<.001
Residual	5939	36822.	6.200		
Total	5960	39359.	6.604		

Percentage mean deviance accounted for 6.1

Percentage deviance accounted for 6.4

Adjusted r-squared statistic (based on deviance) 0.061

R-squared statistic (based on deviance) 0.064

Akaike information criterion cannot be estimated.

Schwarz Bayes information criterion cannot be estimated.

Wald tests for dropping terms

Term	**Wald statistic**	**d.f.**	**F statistic**	**F pr.**
year	202.3	9	22.48	<0.001
month	93.8	11	8.53	<0.001
loghrs	62.9	1	62.92	<0.001

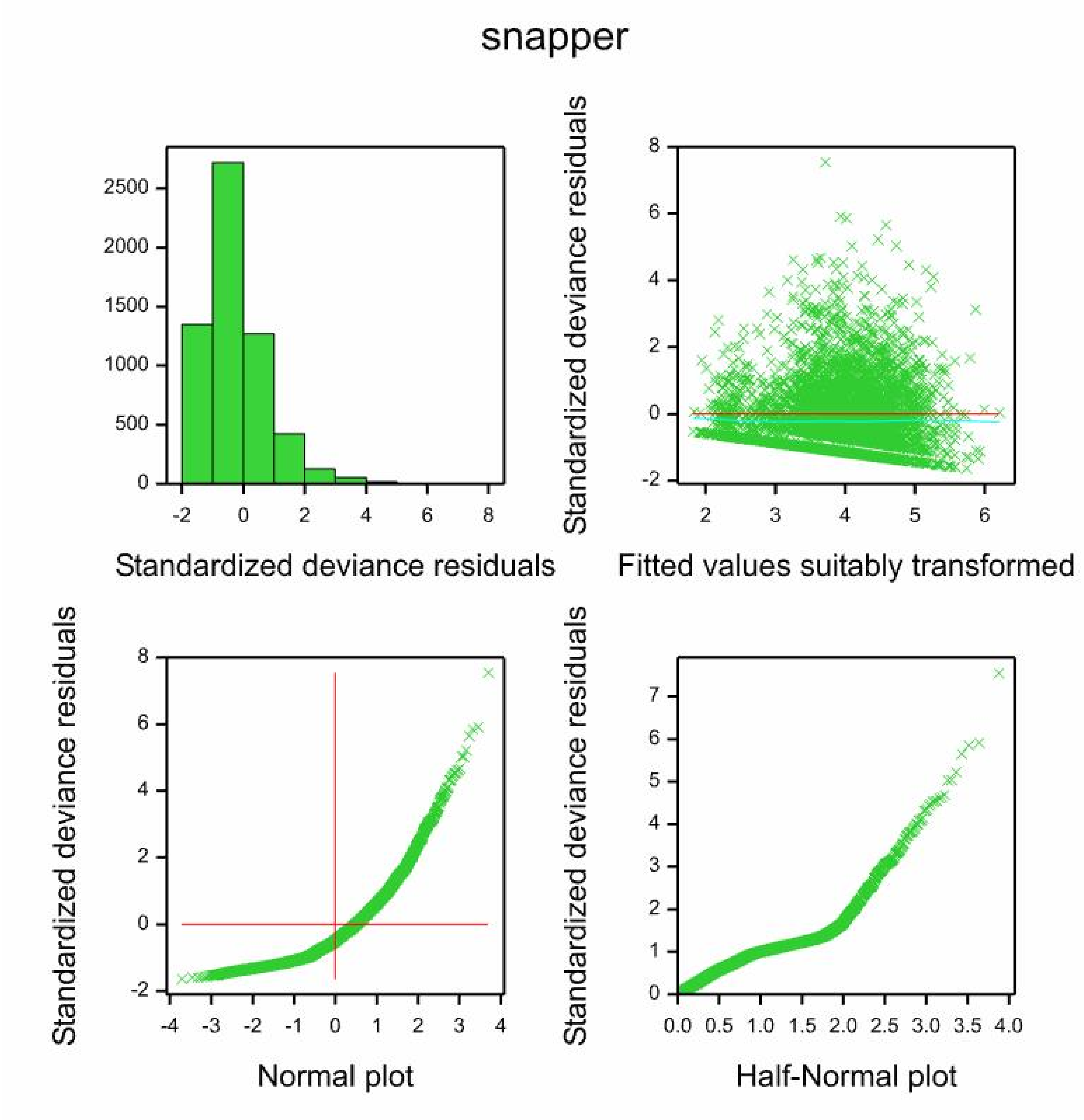

Figure 5.33. Residual and fitted diagnostic plots for the generalized linear model analysis for Queensland recreational RFISH and SWRFS surveys.

5.8 Fish age and length data

The New South Wales snapper ageing data was supplied to be compatible with the Queensland ageing data, with ages being adjusted by adding one for fish with opaque edges, (in New South Wales opaque edges were not counted whereas in Queensland they were counted). Fish sampled prior to 2005 did not have edge state recorded in the New South Wales database, so for these years, fish to have one added were randomly selected from all fish sampled in a month in the same proportions as fish with opaque edges were observed post 2004 (Table 5.26).

Table 5.26. Adjustments to the New South Wales ageing snapper data pre-2005 to make it compatible with the Queensland aging data. Fish sampled prior to 2005 did not have edge state recorded in the New South Wales database, so for these years fish to have one added were randomly selected from all fish sampled in a month in the same proportion as fish with opaque edges were observed post 2004.

Month	Proportion opaque post 2004	Number sampled pre 2004	Number 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

It was not possible to provide New South Wales snapper ageing data as Age Group in the same way it was calculated in Queensland because of several factors including that in New South Wales there was considerable latitudinal variation in spawning time and when opaque zones in otoliths were formed. This, in combination with the typically messy appearance of snapper otoliths on the east-coast, meant that usually New South Wales snapper ages were estimated directly from the number of annuli counted. Opaque edges were mainly observed between September and April in New South Wales, but fish with opaque and wide edges occurred in reasonable proportions in all months (Table 5.26). Note that 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, so as a stock annuli formation spanned an entire 12 months. There was huge variation in otolith appearance and edge state throughout the year which precluded any sensible algorithms to correct for months in which some fish had annuli scored as complete and others as not complete.

Thus for Age Group for 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), then one was added to the age class. 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 a financial years and so effects sample sizes when collated into calendar years).

Table 5.27. Number of snapper lengths measured by long term monitoring program in New South Wales for line fishing.

Year	North	Mid-North	Central	South
2003	0	0	18	34
2004	0	0	0	0
2005	28	6	234	80
2006	0	302	0	189
2007	0	1123	141	267
2008	0	1242	0	0
2009	0	848	68	0
2010	66	826	78	0
2011	120	1358	84	149
2012	0	1234	87	0
2013	49	1911	91	83
2014	770	943	149	0
2015	50	1544	170	0

Table 5.28. Number of snapper lengths measured by long term monitoring program in New South Wales for trap fishing.

Year	North	Mid-North	Central	South
1982	0	0	9	0
1985	752	1683	727	31
1986	318	0	431	249
1987	0	0	0	19
1988	21	0	0	0
1993	1654	3337	296	0
1994	11765	10575	2185	0
1995	3910	8436	3510	0
1996	1714	5444	2609	0
1997	1358	1843	0	243
1998	12642	6759	1835	1085
1999	6579	11651	2698	265
2000	10304	6420	486	2969
2001	8102	4139	3288	3762
2002	2032	3127	1567	2896
2003	0	36	702	168
2004	0	0	212	47
2005	744	1115	1855	899
2006	1815	6349	5322	187
2007	440	9882	4536	204
2008	2475	12100	4327	106
2009	2895	8485	2252	43
2010	3242	12151	1635	0
2011	1190	13177	3877	108
2012	1445	15239	1754	84
2013	161	10610	3543	176
2014	212	6119	3387	684
2015	727	9178	2896	553

Table 5.29. Number of snapper lengths measured by long term monitoring program in Queensland.

Year	Mackay	Rockhampton Offshore	Fraser Inshore	Fraser Offshore	Sunshine Coast Offshore	Brisbane Offshore	Moreton Bay	Gold Coast Offshore
Commercial								
2006	0	0	0	0	263	93	0	0
2007	0	0	38	213	2225	170	8	0
2008	0	0	3	108	862	301	17	6
2009	0	39	12	179	450	98	10	0
2010	0	84	9	204	1095	187	0	0
2011	0	64	27	324	315	160	0	0
2012	0	170	26	266	449	272	12	0
2013	124	36	0	321	1033	219	41	0
2014	0	931	21	638	462	185	6	0
2015	0	479	0	336	604	102	0	0
Recreational								
2006	0	0	9	105	323	111	18	51
2007	0	0	205	138	381	287	467	139
2008	0	0	222	131	818	625	280	227
2009	0	0	95	61	339	282	180	146
2010	0	0	179	60	611	378	224	100
2011	0	0	116	103	553	261	318	60
2012	0	0	197	82	603	372	357	26
2013	0	0	167	192	826	540	807	100
2014	2	0	126	64	481	265	485	148
2015	2	0	141	178	786	408	335	194

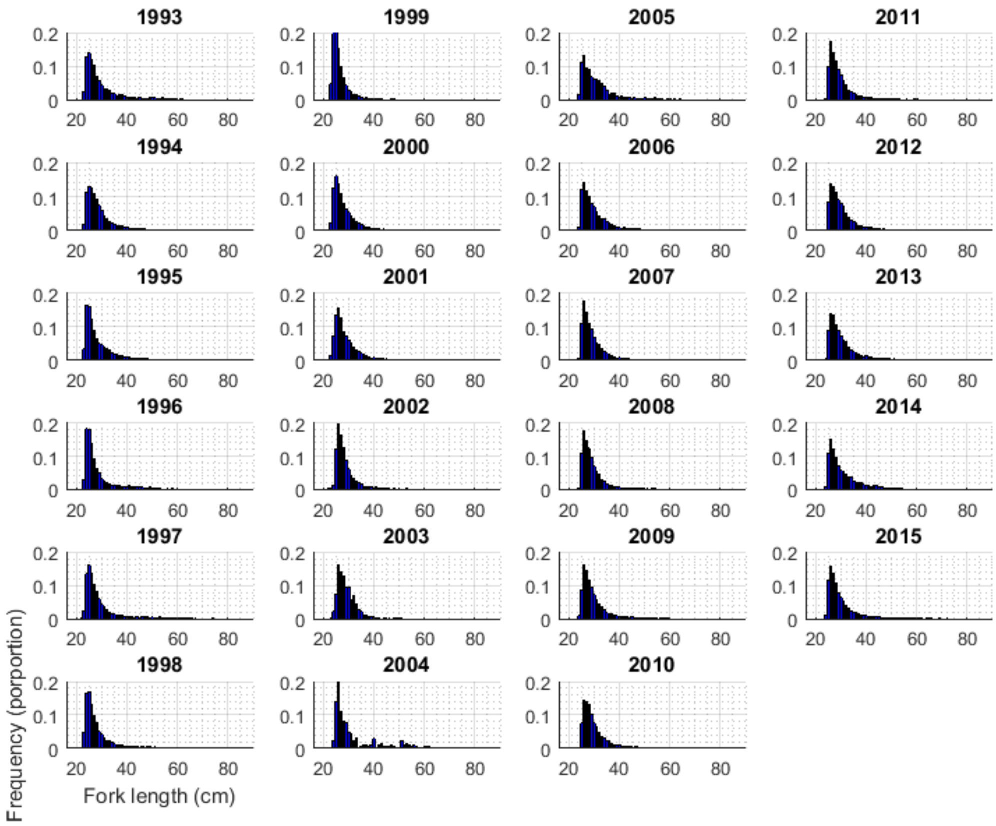

Figure 5.34. Length frequency distributions from New South Wales commercial trap sector.

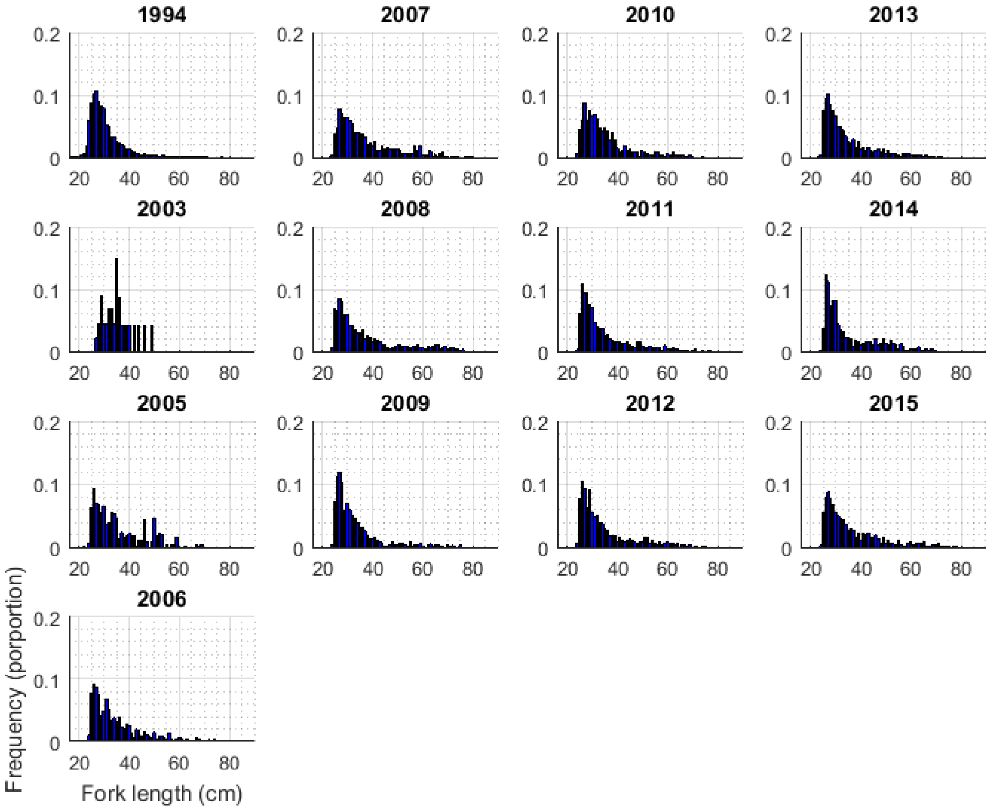

Figure 5.35. Length frequency distributions for snapper from New South Wales commercial line sector.

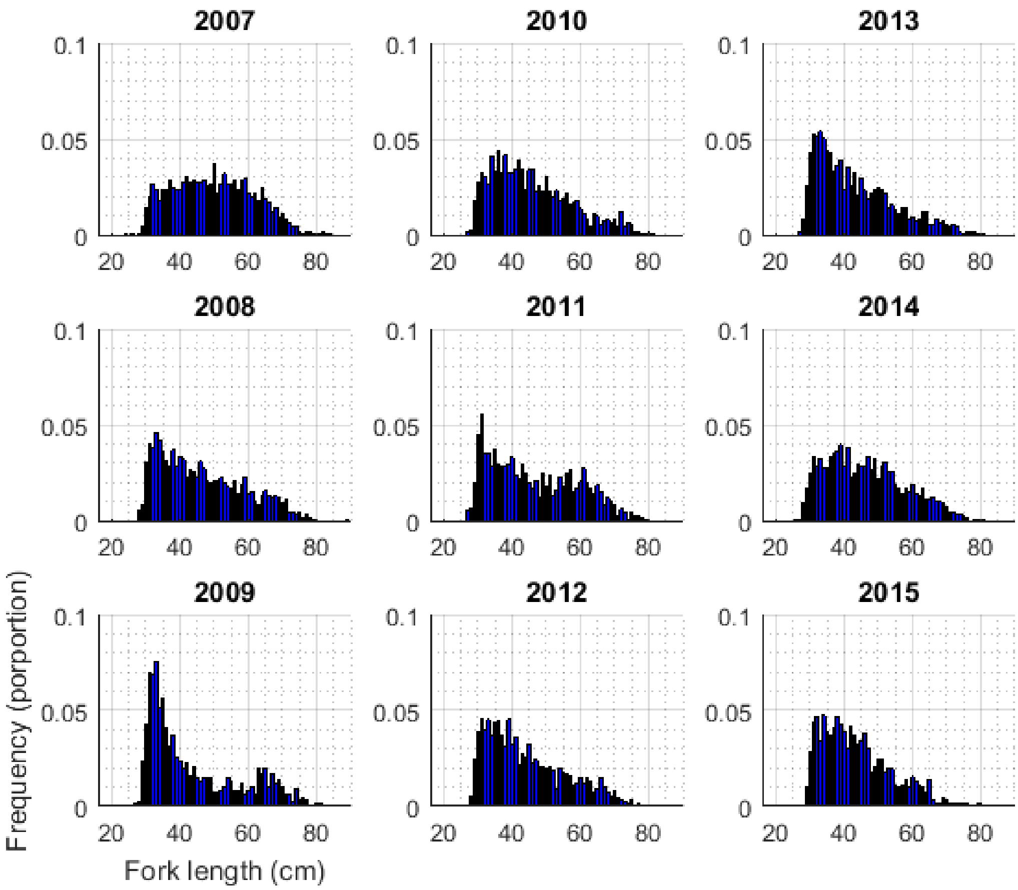

Figure 5.36. Length frequency distributions for snapper from Queensland commercial line sector.

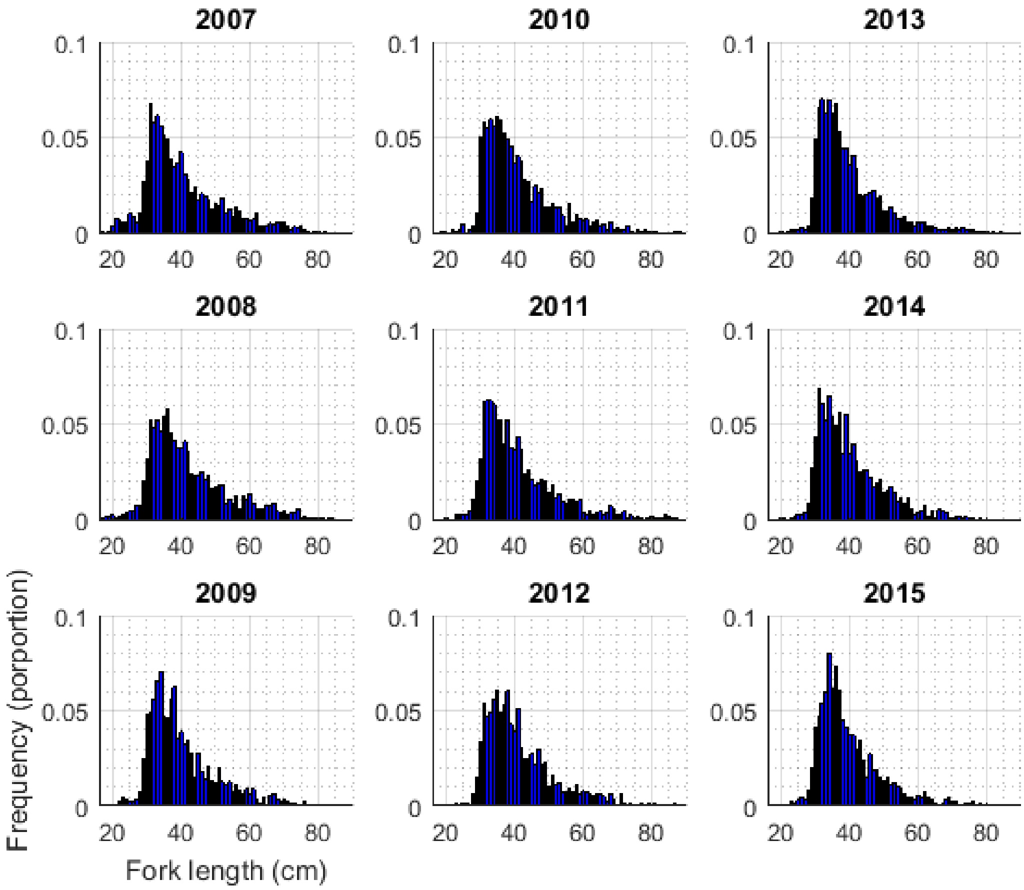

Figure 5.37. Length frequency distributions for snapper from Queensland recreational sector.

Investigation of the Queensland size and age data showed that the commercial fish were not sampled from as broad a range of areas as the recreational fish (Figure 5.38 and Figure 5.40). The sampling regions for the commercial sector (Figure 5.38) showed that the size and age samples were mainly from the Sunshine Coast region, especially in the years 2007–2010. The harvest from the Queensland commercial logbook records (Figure 5.39) came from a much broader range of regions than the regions from the size and age sampling program. On the other hand, the Queensland size and age sampling for the recreational sector came from a much broader range of areas than the regions for commercial sampling (Figure 5.40). Thus model analyses were run with either the trap and Queensland recreational age frequency data or the trap and the Queensland commercial age frequency data.

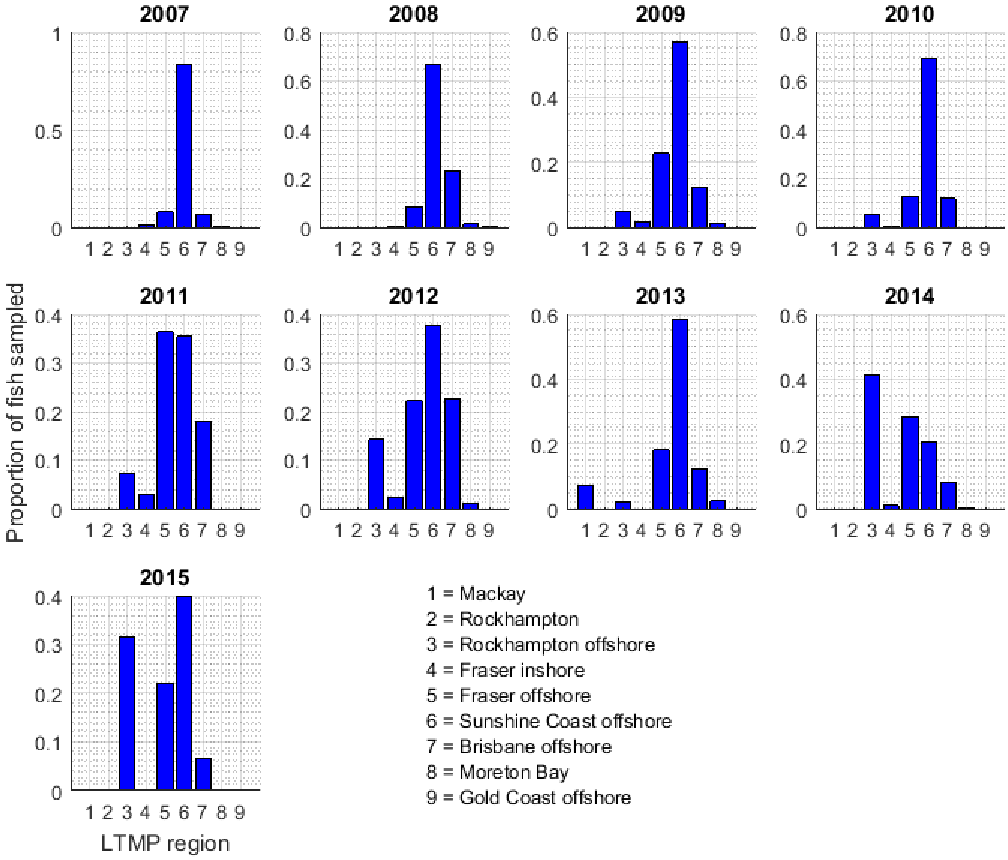

Figure 5.38. LTMP snapper sampling regions for Queensland commercial sector.

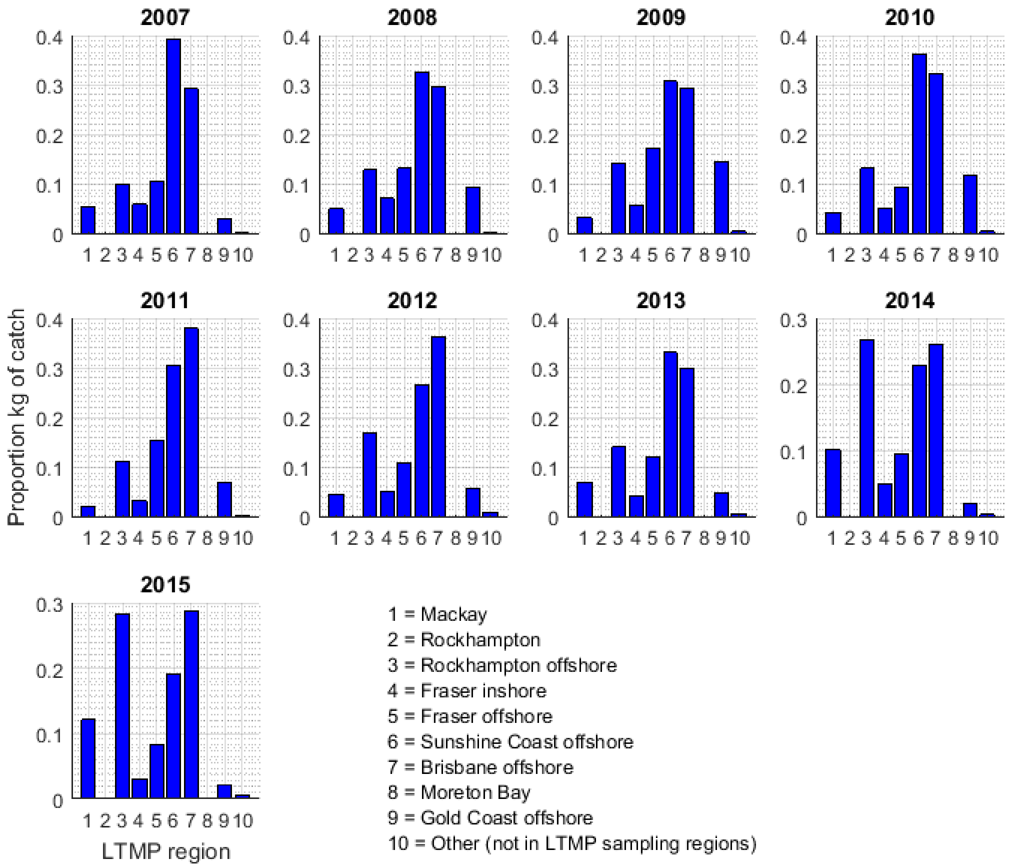

Figure 5.39. The distribution of the Queensland commercial logbook snapper harvest in relation to the LTMP sampling regions. Region 10 represents those regions of catch that were not from one of the LTMP sampling regions.

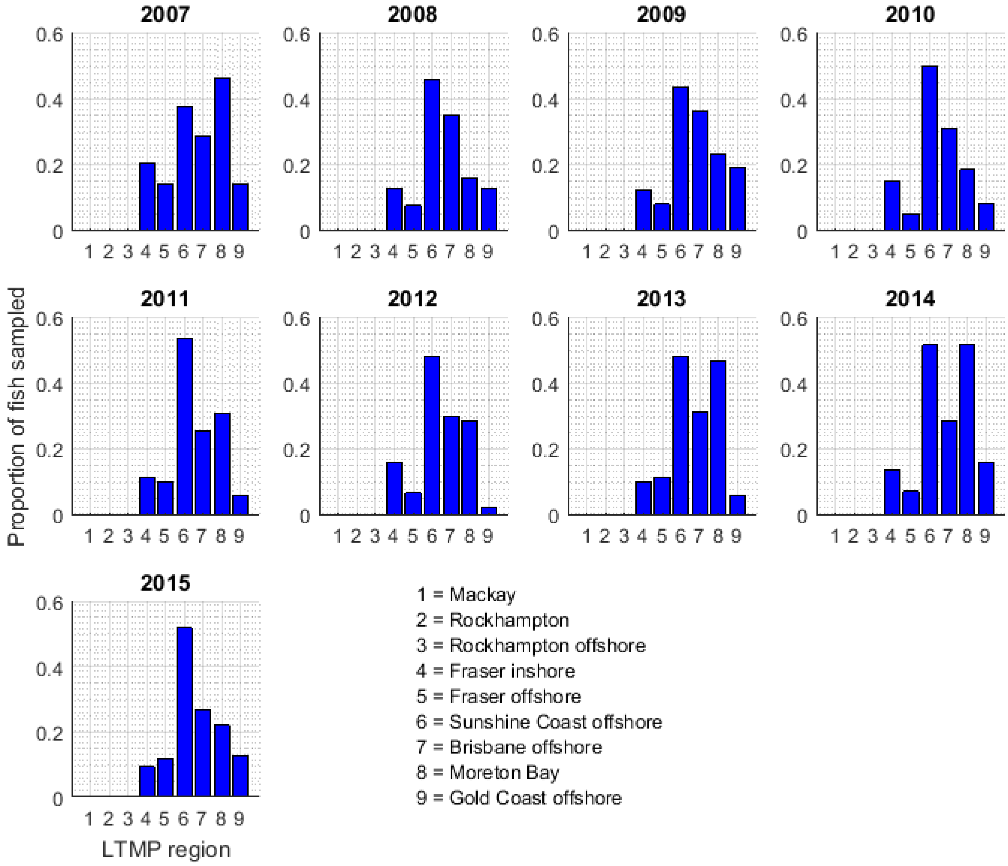

Figure 5.40. LTMP snapper sampling regions for Queensland recreational sector.

5.9 Model analyses

Table 5.30. Analyses selected for the population dynamic model. Rec effort of 1=reduced effort, 2=actual effort, and 3=high effort. The model was run using trap age data and either Queensland recreational age data (Qld age=1) or Queensland commercial age data (Qld age=2). The catch rate definitions appear in Table 5.31.

Analysis	Natural mortality	Discard mortality	Rec effort	Qld Age	Catch rate
1	0.163	0.3	1	1	1
2	0.163	0.3	1	1	2
3	0.163	0.3	1	1	3
4	0.163	0.3	1	1	4
5	0.163	0.3	1	2	1
6	0.163	0.3	1	2	2
7	0.163	0.3	1	2	3
8	0.163	0.3	1	2	4
9	0.163	0.3	2	1	1
10	0.163	0.3	2	1	2
11	0.163	0.3	2	1	3
12	0.163	0.3	2	1	4
13	0.163	0.3	2	2	1
14	0.163	0.3	2	2	2
15	0.163	0.3	2	2	3
16	0.163	0.3	2	2	4
17	0.163	0.3	3	1	1
18	0.163	0.3	3	1	2
19	0.163	0.3	3	1	3
20	0.163	0.3	3	1	4
21	0.163	0.3	3	2	1
22	0.163	0.3	3	2	2
23	0.163	0.3	3	2	3
24	0.163	0.3	3	2	4
25	0.211	0.3	1	1	1
26	0.211	0.3	1	1	2
27	0.211	0.3	1	1	3
28	0.211	0.3	1	1	4
29	0.211	0.3	1	2	1
30	0.211	0.3	1	2	2
31	0.211	0.3	1	2	3
32	0.211	0.3	1	2	4
33	0.211	0.3	2	1	1
34	0.211	0.3	2	1	2
35	0.211	0.3	2	1	3
36	0.211	0.3	2	1	4
37	0.211	0.3	2	2	1
38	0.211	0.3	2	2	2
39	0.211	0.3	2	2	3
40	0.211	0.3	2	2	4
41	0.211	0.3	3	1	1
42	0.211	0.3	3	1	2

Analysis	Natural mortality	Discard mortality	Rec effort	Qld Age	Catch rate
43	0.211	0.3	3	1	3
44	0.211	0.3	3	1	4
45	0.211	0.3	3	2	1
46	0.211	0.3	3	2	2
47	0.211	0.3	3	2	3
48	0.211	0.3	3	2	4
49	0.163	0.3	1	1	5
50	0.163	0.3	1	1	6
51	0.163	0.3	1	1	7
52	0.163	0.3	1	1	8
53	0.163	0.3	1	1	9
54	0.163	0.3	1	1	10
55	0.163	0.3	2	1	5
56	0.163	0.3	2	1	6
57	0.163	0.3	2	1	7
58	0.163	0.3	2	1	8
59	0.163	0.3	2	1	9
60	0.163	0.3	2	1	10
61	0.163	0.3	3	1	5
62	0.163	0.3	3	1	6
63	0.163	0.3	3	1	7
64	0.163	0.3	3	1	8
65	0.163	0.3	3	1	9
66	0.163	0.3	3	1	10
67	0.163	0.3	1	1	11
68	0.163	0.3	1	1	12
69	0.163	0.3	1	1	13
70	0.163	0.3	1	1	14
71	0.211	0.12	1	2	1
72	0.211	0.12	1	1	4

Table 5.31. Catch rate definitions used to define the analyses in Table 5.30. Trap catch rates always mean trap catch rates with reduced fishing power (FP) effects.

Catch rate	Definition
1	Trap + historic
2	Qld commercial line reduced FP + historic
3	Qld commercial line actual FP + historic
4	Qld commercial line high FP + historic
5	Trap only
6	Qld commercial line actual FP only
7	Qld commercial line reduced FP + historic + fishery independent Moreton Bay pre-recruitment survey catch rates
8	Qld commercial line actual FP + historic + fishery independent Moreton Bay pre-recruitment survey catch rates
9	Qld commercial line reduced FP + historic + AMLI Qld charter reduced FP
10	Qld commercial line actual FP + historic + AMLI Qld charter actual FP
11	Combined line (NSW commercial line + Qld commercial line + AMLI Qld charter) reduced FP + historic
12	Combined line (NSW commercial line + Qld commercial line + AMLI Qld charter) actual FP + historic
13	Combined line (NSW commercial line + Qld commercial line + AMLI Qld charter) high FP + historic
14	Trap + Qld commercial line actual FP + historic

5.10 Model output

The stock models generally fitted the annual standardised catch rates well. The standardised residuals of model fits were normally distributed and complied with the loglikelihood assumptions. The range of standard deviations of model fits were:

- New South Wales commercial trap: mean of 0.2867, minimum of 0.2340 and maximum of 0.3569
- Queensland commercial line: mean of 0.1513, minimum of 0.1380 and maximum of 0.1732
- AMLI Queensland charter: mean of 0.3804, minimum of 0.3735 and maximum of 0.3859
- Historic: mean of 0.2505, minimum of 0.2425 and maximum of 0.2646
- Moreton Bay survey: mean of 0.9076, minimum of 0.9023 and maximum of 0.9139.

Even though the stock model fitted the trend in catch rates well, the standard deviations indicate some variance in annual fits that were unable to be accounted. This was due to differences in some annual signals between data sets. For example the catch rates showed variation between years and sectors, but the annual fish age frequencies were relatively stable with little variation in fish cohort or recruitment strength.

The model did predict the pattern of fish age frequencies very well. Measures of effective sample sizes indicate this:

- New South Wales commercial trap: mean of 106, minimum of 13 and maximum of 879
- Queensland commercial age: mean of 352, minimum of 142 and maximum of 957
- Queensland recreational age: mean of 445, minimum of 89 and maximum of 1248.

Low values of effective sample size (numbers of fish assuming independent samples) indicate a poorer fit compared to higher values. From overall fits it looks like 3 out of 21 years of New South Wales commercial trap data had limited fits whereas remaining years were fairly sound. The Queensland age data had higher values of effective sample sizes as higher fish ages were observed and all fits were good.

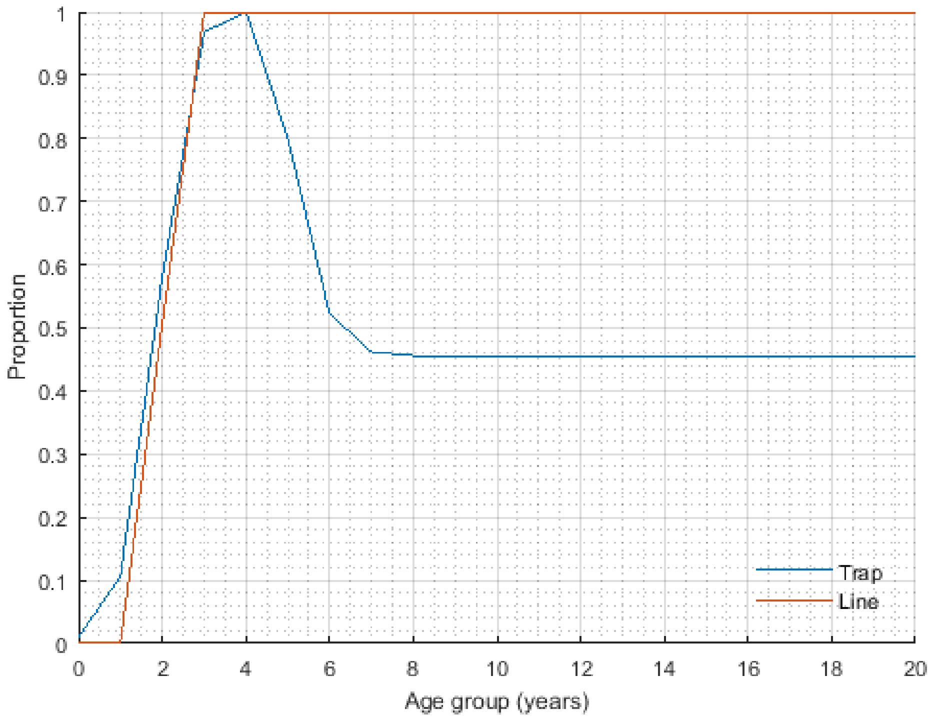

Figure 5.41. Estimated vulnerability schedules for the trap and line sectors. The vulnerability schedules for all analyses were similar, with parameter values: trap: Age at 50 per cent vulnerability (rise) 1.903829, difference age at 95 per cent vulnerability- age at 50 per cent vulnerability (rise) 0.2, age at 50 per cent vulnerability (falling dome) 5.152, asymptote 0.4373 and line: Age at 50 per cent vulnerability 1.998 and difference age at 95 per cent vulnerability- age at 50 per cent vulnerability 0.227.

5.11 Estimated recreational harvest

Predicted recreational harvest varied between analyses. The recreational harvest was influenced by the proxy of recreational effort and the biomass implied by the catch rate indices and levels of natural mortality. Model analyses that best fitted the recreational data assumed high natural mortality (0.211), lower recreational effort proxies and line catch rates (Figure 5.42 c). For these analyses, historical estimates of recreational harvest pre-1994 tended to reduce systematically along with effort proxy. Some of these results for 1960–1970 yielded higher estimates than what was expected. Other analyses, for example (Figure 5.42 b), yielded more of a perceived historical pattern of the earlier years, but did not fit the latter estimates as well. Overall, for all the analyses run, a large range of recreational harvest were modelled and examined, as shown by the error bars in (Figure 5.42 a).

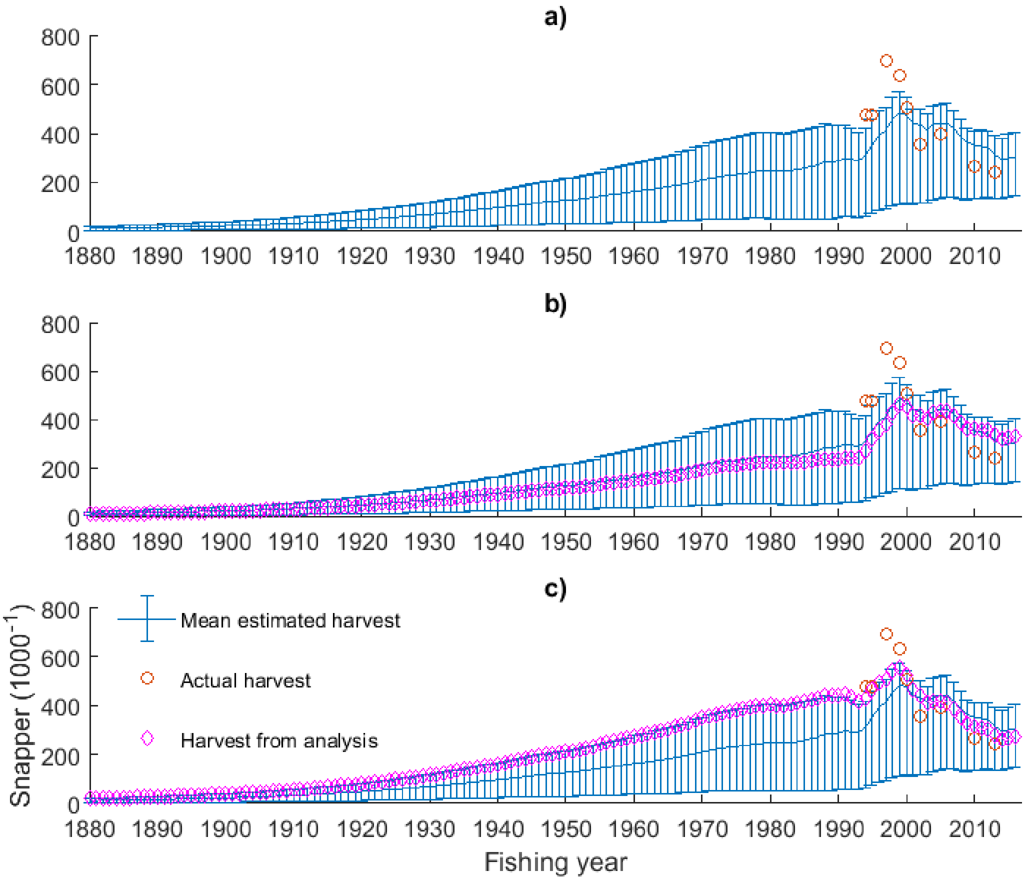

Figure 5.42. a) Mean estimated recreational harvest from analyses 1–48 with 95 per cent confidence intervals shown, b) Harvest estimates in pink from analysis 5 where model inputs were: natural mortality 0.163, Queensland commercial age data, low proxy for recreational effort, and Trap and historic catch rates, c) Harvest estimates in pink from analysis 28 where model inputs were: natural mortality 0.211, recreational age data, low proxy for recreational effort, and Queensland commercial line catch rate for reduced fishing power effects.