# Stock assessment of the Queensland and New South Wales pearl perch (*Glaucosoma scapulare*) fishery

Queensland Government

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# 1 Executive Summary

Pearl perch (*Glaucosoma scapulare*) are found commonly in sub-tropical offshore-waters along the east coast of Australia and are a valuable table fish popular with commercial and recreational fishers. The species is long-lived, up to 30 years of age, and reaches sexual maturity at between 25 and 35 cm total length.

Pearl perch are predominantly line-caught and fishing is managed separately by New South Wales (NSW) and Queensland. Historical fishing data indicate that pearl perch harvests have been consistently higher from Queensland waters with 73% of the total catch landed in Queensland in 2013. Approximately 52% of the Queensland catch is taken by recreational fishers compared with 42% in NSW.

In Queensland, the Department of Agriculture and Fisheries (DAF) recently classified the stock status of pearl perch as “transitional depleting” (DAF Stock Status 2015). The status raised concern in both Queensland and NSW as to whether current management arrangements are adequate to protect the sustainability of pearl perch fishery.

This stock assessment incorporates data from both jurisdictions and assesses at the whole of stock level; establishes current stock status reference points including biomass and fishing pressure levels for pearl perch; and provides advice on whether additional management measures are required to reduce fishing pressure and rebuild fish stocks.

This assessment identified underlying limitations in the catch and effort data which would potentially affect the precision of model outputs and confidence in the stock status findings. These limitations include:

- a lack of consistent time series in the monitoring and reporting of commercial, charter and recreational catches of pearl perch
- uneven distribution in fishing pressure across the spatial extent of the stock due to concentration of fishing around the high population centers of southern Queensland and northern NSW
- improvements in the use of fishing technologies, such as depth sounders, global positioning systems and deep-water fishing-gear, which has contributed to increased and unaccounted fishing pressure.

To address these limitations, analyses have tested a range of data to document differences in the predictions of stock status and accuracy. The stock analyses of pearl perch were derived from the time series data on harvests, standardised catch rates and fish age-length. The analyses were strongly influenced by the trend in standardised catch rates which indicated a significant decline of about 40% between 2006 and 2014 in the commercial fishery. This decline was also observed in the charter and recreational fishing data.

The assessment predicted that, in 2014, the pearl perch population size ranged between 10-40% of unfished (virgin) levels. Equilibrium maximum sustainable yield was estimated between 100-250 tonnes per year. The tonnages represent a population-averaged maximum sustainable harvest for all fishing sectors and waters. Current harvest levels are below MSY probably because stock sizes have declined. The data and analyses support the stock status classification of “transitional depleting”, with the risk of recruitment overfishing uncertain.

Based on the results of the stock assessment, it is recommended that fishing effort on the stock should be reduced. If future average total harvests increase above 150-200 t and/or fishing effort does not reduce, then fish abundance and catch rates of pearl perch may decline further.

Pearl perch have a long-life span, slow growth rates, aggregate together in localised areas and possibly have low natural mortality rates. Careful management is required given these characteristics.

# 2 Acknowledgements

The stock assessment of pearl perch was managed through a ‘project team’ committee. The role of the team was collaborative and to share decision making on data, analyses and results. The following committee staff, in addition to the authors, assisted throughout the project and we would like to thank: John Kung, Michael Mikitis and Anthony Roelofs for their management contributions; James Webley and Daniella Teixeira for providing the recreational fishing data and assisting with the analysis of trends in recreational fishing; Anna Garland for providing and interpreting the fish length and age data for pearl perch; and Nadia Engstrom assisted with the commercial and charter data extraction and discussions of those data.

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Data on boat registrations was provided by Annick Mills from the Queensland Department of Transport and Main Roads.

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We would like to finally thank Warwick Nash and the project team for critically reviewing and providing comments on parts of the draft report.

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# 3 Introduction

## 3.1 Historical development

There is limited information on harvests of pearl perch before the mid-1900s. The early literature and accounts of offshore fishing are mainly restricted to descriptions of snapper, which has been regarded as the premier demersal fish species in southern Queensland and northern NSW waters.

Part of the reason for the lack of historical data is due to pearl perch being found exclusively in offshore waters in depths greater than 30 m, with more fish found in deeper waters greater than 50 m. These deeper and more distant waters have only been fully fished since the advancement of global positioning systems, depth sounder technology, fishing gear and more economical and reliable outboard engines. These technologies have enabled the exploitation of waters further offshore and made those areas more accessible to all fishers. Prior to the 1990s, most offshore fishing was restricted to water less than 150 m depth, whereas improved fishing technology has improved access to more remote and deeper fishing grounds.

## 3.2 Management in Queensland

The following provides a brief history of the development of management for pearl perch in Queensland waters.

There was limited management of rocky reef fin fish species, prior to the late 1970s when the Fish Board was disbanded and offshore line fishing began to expand. There was no management of pearl perch until 1993 when a 30 cm minimum size limit was first introduced. Prior to 1984, there were no limitations on commercial harvesting of fish other than the requirement for a person to hold a licence, the issue of which was cheap and 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, the number of licences issued under the *Fishing Industry Organisation and Marketing Act (FIOMA) 1984* were capped with no further primary boat licences issued. In 1987, a general 'freeze' on the grant of new commercial tender boat licences was enacted, a process that was later adopted into law in 1993. The potential number of offshore commercial operators were in the order of hundreds prior to 1988, with no formal catch reporting.

The Offshore Constitutional Settlement (OCS) came into force in 1987, at which time responsibility for management of rocky reef fin fish species, and others, was delegated by the Commonwealth Government to the Queensland Government. The jurisdiction, which was previously limited to a distance of 3 nautical miles, was replaced by a jurisdiction line set further to sea which largely encompasses the distribution of pearl perch off the coast of Queensland. The jurisdictional arrangements were further refined in 1995, but the change had no effect on the management of this species. Specific details, including fish species and boundaries of the Queensland jurisdiction on the east coast, are contained in the *Queensland Government Gazette* of 10 February 1995. These amendments caused further changes in the licensing arrangements for commercial fishing, to allow for the inclusion of additional active fishers who had operated in adjacent waters now the responsibility of the State, who had previously held Commonwealth licences. Evidence to suggest that these jurisdictional changes had impacted on the fishing of pearl perch in Queensland are unknown and not documented.

The Queensland Fish Board (QFB), which was responsible for marketing fisheries product, collected catch information from 1936 until 1981. This included buying and selling of some recreational catch, and it is also widely acknowledged that not all commercial fishers marketed their catch through the QFB. After the closure of the QFB, no catch or effort data were collected on any rocky reef species until the introduction of the CFISH compulsory commercial logbook system in 1988. Commercial fishers must report their daily catch and effort information under this system. Similar catch and effort information was collected from the charter boat fishery by way of a voluntary logbook established in 1993/4 which later became compulsory in 1996.

It was not until the mid-1990s that catch, and in some cases, effort data were collected from the recreational fishing sector. Data on recreational harvests have only been collected infrequently by way of phone and diary surveys (designed to estimate harvests of the more abundant species) as well as two dedicated field surveys (see Section 6.2 for details).

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

In 1993, new management arrangements were introduced for offshore rocky reef line fishing. The previous general line fishery endorsement (L) authorising commercial line fishing activities was replaced by a range of area-based endorsements (L1 – L9). The minimum legal size (MLS) of 30 cm was introduced for pearl perch. A 10 per person "in possession" recreational bag limit was also established. Prior to that time, there were no restrictions on the quantity of pearl perch that could be taken by recreational anglers, and no harvest limits on commercial or charter operators.

Commercial line fishers endorsed with an L1 symbol can effectively fish in all state-managed coastal and offshore waters south of the Great Barrier Reef (GBR) and are restricted to using line fishing gear and methods under the same restrictions as recreational fishers.

The introduction of the *Fisheries Act 1994* prompted a review of the management arrangements for the rocky-reef fin fish fishery (RRFFF). The *Rocky Reef Fish Fishery Discussion Paper* was released by QFMA in 1998 seeking public input on sustainability and access issues in the RRFFF prior to the development of a management plan. The management plan for the RRFFF was never developed due to structural changes to the fishery management agency in Queensland (then the QFMA, now the Department of Agriculture and Fisheries).

In December 2002, the management agency further increased the minimum size limits for pearl perch and snapper from 30 cm to 35 cm (total length). Possession limits were also decreased from 30 to 5 for snapper, and from 10 to 5 for pearl perch.

An investment warning was issued by the then Department of Primary Industries and Fisheries (now DAF Queensland) for the RRFFF in September 2003 to warn those with a current commercial interest or considering investing in the fishery, that increases in commercial catch levels or fishing effort may not be recognised as ‘historical involvement’ when developing future management arrangements.

Following the snapper stock assessments from 2006 to 2008 and significant stakeholder consultation which highlighted concerns of the sustainability of snapper, an interim six-week closure was implemented in March/April 2011 with a total ban on the harvest of snapper, pearl perch and teraglin by all sectors. Management of pearl perch was unaltered at that point and has remained unchanged to the present day for all fishing sectors.

## 3.3 Management in New South Wales

As pearl perch is endemic to the east coast of Australia, NSW is the only other jurisdiction where there is a fishery for this species. Although there are fisheries for other species of Glaucosomatidae in Western Australia and Northern Territory (Newman, 2002).

Fishing for pearl perch in NSW waters differs from Queensland as the species is also taken as a component in both the trap and multi-hook dropline fishery, although the majority of the catch is still taken by line as it is in Queensland.

The current minimum legal length of 30 cm total length was introduced in September 2007; there was no minimum legal length for pearl perch prior to that time.

The current recreational daily bag limit for pearl perch in NSW is five fish per person. The date of implementation was not known, but was in place by the year 2000. It is believed to have been introduced sometime around the establishment of the *Fisheries Management Act 1994* (NSW) (NSW recreational management, pers. comm.).

<u>*Escape panels in fish traps*</u>

Demersal fish traps in NSW are generally covered in 50 mm hexagonal wire mesh. Surveys during the late 1990s indicated substantial numbers of small pearl perch (generally between 20 cm and 28 cm fork length) were captured and discarded despite the absence of any minimum legal length. In 2008 ‘escape’ panels of 50 x 75 mm mesh in the ‘back’ of demersal fish traps were introduced. Research predicted zero loss of marketable pearl perch but with a reduction in the numbers of small pearl perch retained.

### 3.3.1 New South Wales commercial reporting

In NSW, commercial harvest information is available for most species since 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 is presented in Pease & Grinberg (1995) but pearl perch catch statistics were not described.

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

_Spatial resolution._

Since 1984, commercial logbooks reported fishing events by one degree latitudinal zones (~60 nm grids) with no data on distance offshore or depth (Figure 1).

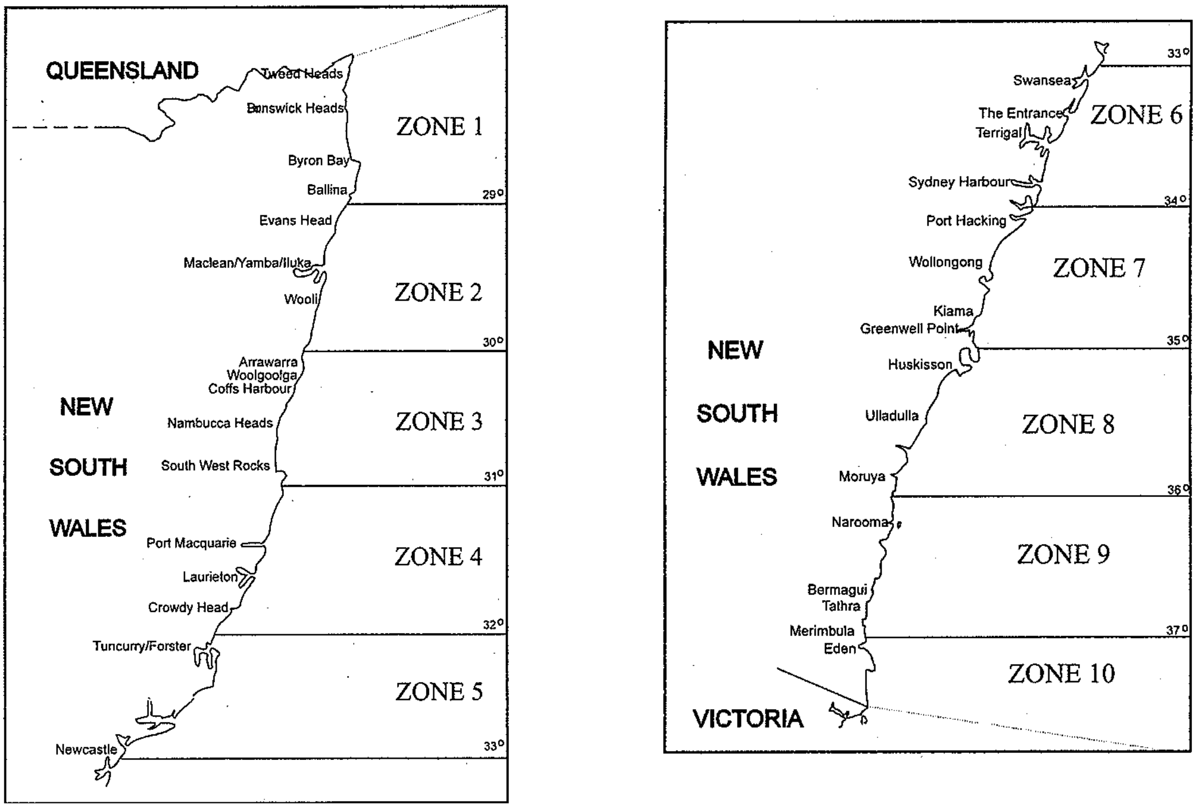


***Figure 1. Fishing zones used to categorise commercial catch and effort in NSW prior to 2009.***

NSW catch records changed substantially in July 2009, moving to a finer level of spatial and temporal reporting. This system is referred to as the "Fishonline" System. This system requires daily catch and effort reporting and, for the ocean fisheries, reporting to six minute grids (30 sq nm or 103 sq km).

Pearl perch were first listed on catch returns in July 1990 (Form 19); however, the structure of the form was that when pearl perch were reported, the fisher had to manually write in Pearl Perch at the end of the printed species list. Pearl perch were printed as a reportable species in the 'Comcatch' system from July 1997. It is very likely therefore that NSW landings of pearl perch before July 1997 were under-reported, a situation similar to the pre-2004 Queensland commercial catch data.

### 3.3.2 Areas closed to fishing in New South Wales

There are six marine parks in NSW:

- Cape Byron Marine Park – November 2002
- Solitary Islands Marine Park – January 1998
- Lord Howe Island Marine Park
- Port Stephens-Great Lakes Marine Park – December 2005

- Jervis Bay Marine Park - 1998
- Batemans Bay Marine Park – June 2007

Zoning restricting fishing within the Cape Byron and Solitary Islands Marine Parks have reduced the available fishing grounds for pearl perch; however, to what extent remains unknown. The significance of the small area as pearl perch habitat is unknown.

## 3.4 Previous Data and Assessments

The earliest biological data compiled on pearl perch was a summary of data collected as part of a targeted research project on snapper (*Chrysophrys auratus*) when data were also opportunistically collected on other Rocky Reef species such as pearl perch (Sumpton *et al*. 1998). Subsequently, Sumpton *et al*. (2013b) compiled more detailed information on pearl perch as part of a dedicated FRDC project investigating a range of issues in Queensland's rocky reef fisheries. The earlier report was basically a compilation of biological knowledge and simple fishery statistics, while the latter study undertook simple yield per recruit modelling, but was unable to do any length or age structured population modelling because only four years of length and age data were available. That report highlighted some deficiencies in the data and problems with completing a comprehensive harvest strategy for the fishery. However, since that time an additional four years of length and age data have been collected as well as two comprehensive state-wide recreational surveys, which have improved the ability to formulate a more comprehensive analyses of fishery performance.

Recent analysis of catch rates of pearl perch in both the commercial and charter fisheries indicate a significant decline since 2007. Concerns have been raised during the 2015 DAF stock status process, with the fishery being classified as "transitional depleting", based on these declining catch rate time series and relatively high fishing mortalities derived from fish length and age samples. The latest recreational surveys have, likewise, shown declining catches and catch rates.

## 3.5 Objectives

The primary objective of this report is to conduct a comprehensive stock assessment of the entire pearl perch stock, with additional data collected since previous research (Sumpton *et al*. 2013b) which addressed some of the information gaps for this fishery. The earlier research only presented simple yield-per-recruit modelling and did not provide a quantitative assessment of the status of the stock nor incorporated data from NSW. Since pearl perch are caught from both Queensland and NSW waters in separately managed fisheries, this report evaluates and incorporates all available data from both jurisdictions.

The assessment estimates current biomass and fishing pressure levels for pearl perch using an age based stock model, and provides advice on whether management measures are required to reduce fishing pressure and rebuild fish abundance (i.e. rebuild catch rates of fish ≈ catch-per-unit-effort). Reference points are also calculated and discussed.

# 4 Evaluation of Data

Data used in the pearl perch stock model are described in Section 5.3.1. The model does not use all the available data and, in some analyses, parameters which are normally direct inputs to the model are estimated (e.g. natural mortality). The following sections present the data that are available to describe the fishery and evaluate strengths and limitations of the data.

## 4.1 Commercial harvests

Commercial fish catch data have been collected in Queensland since 1936 and in NSW since 1940/41, although pearl perch have not been consistently reported since those times. The Queensland Fish Board (QFB) maintained catch records between 1936 and 1981. Recreational fishers were also able to sell limited amounts of fish through the Fish Board up until the late 1980s. There is uncertainty about the proportion of the commercial catch that was sold through the QFB, since in some areas many commercial fishers marketed their catch directly rather than processing through the Fish Board. Examination of annual QFB records show that records of pearl perch were not kept, with only limited recording of catches of this species for several years during the 1950s. Given the similarity in current catch trends of snapper and pearl perch over recent years, it would seem reasonable to assume that catches of pearl perch mirrored those of snapper. However, we would advise caution as pearl perch are generally found further offshore than snapper, and thus the fishery more likely developed later than snapper. In addition, differential expansion of either of these fisheries may also be influential in driving catches.

Fish Board records are used extensively as an index of change in catch over time for a number of species for which quantitative stock assessments are used. While there may be some issues surrounding the use of these data as an index of commercial harvests for the reasons previously stated, they have proven to be a reliable index for some species. In the case of barramundi, good correlation has been obtained between environmental flows and Fish Board records of catch, suggesting the utility of the data for that species at least (Halliday & Robins 2007). These authors also provide a useful summary of the utility of Queensland Fish Board records. There is also a good correlation between boat registrations and catch for a number of species recorded by the QFB. For rocky reef fish, only snapper is reported consistently in Fish Board records and, as such, we were unable to readily find any historical catch data for pearl perch prior to the 1990s. We were able to collect some data from retired commercial fishers who kept records of their catches during periods as early as the 1950s when daily catch rates of around half a tonne (30 cases each of 40 pounds) of pearl perch (as an example) were reported, but it was impossible to determine how representative these catches were of the general fishery conditions at the time, and therefore we did not progress any detailed analysis of those data. Other sources of commercial information considered are newspapers and other historical documents which may provide indices of change over a longer time period, but these data are scarce in comparison to information on the more widely reported snapper (Thurstan *et al*. 2014) and have not been used in this assessment.

Compulsory commercial catch and effort data have been collected in the Queensland commercial fishery since 1988, but there have been many developments that have affected the reporting of those data since that time. Many of these have been highlighted in Sumpton *et al.* (2013b) and in Section 5.2 of this report, but the following is a brief summary of some of the key analytical issues related to the CFISH data as they relate to any assessment of the pearl perch fishery.

Changes to the Line Fishery (LF) Logbook have impacted on the quantity of pearl perch reported and we believe that the logbook data greatly underestimate the commercial pearl perch harvest prior to 2004. This is due to the three versions of the LF Logbook up to July 2004 having snapper as the only listed rocky reef fish, with three “Other” fields available for voluntary recording the harvest of other species. It was not until the fourth version of the Logbook (LF04) made provision for the reporting of both snapper and pearl perch. Discussions with commercial fishers as well as analysis of early logbook data indicated that prior to this time the harvest of pearl perch would have been under-reported and in many cases it was likely included in “mixed” or aggregated species categories or infrequently recorded at a species level in the available “other” categories in the logs.

We have also included data collected from the NSW commercial fishery in our assessment model. As noted earlier in Section 3.3.1, the commercial fishery in NSW has historically been reported as part of the Ocean Trap and Line fishery with the majority taken by line fishing methods.

The standardisation of catch rates of pearl perch for all sectors are presented and discussed separately in section 4.5.

## 4.1.1 Queensland commercial and charter data

Historically, commercial and charter operators have mostly fished southern Queensland rocky reefs for snapper because of the species widespread availability and high consumer demand. More recently, as snapper catch rates have declined during the 1990s and early 2000s, both these sectors have diversified to fish for other species, such as pearl perch (although pearl perch have always been targeted by some fishers). In contrast to snapper where there are line, trap and net fishers, pearl perch are caught almost exclusively using line fishing methods due to their preference for ocean water habitats greater than 25 m depth, making them unavailable to be fished from near-shore and estuarine waters.

The commercial pearl perch fishery has expanded over the last 20 years and, nowadays, much of the harvest comes from areas north of Fraser Island (Figure 2).

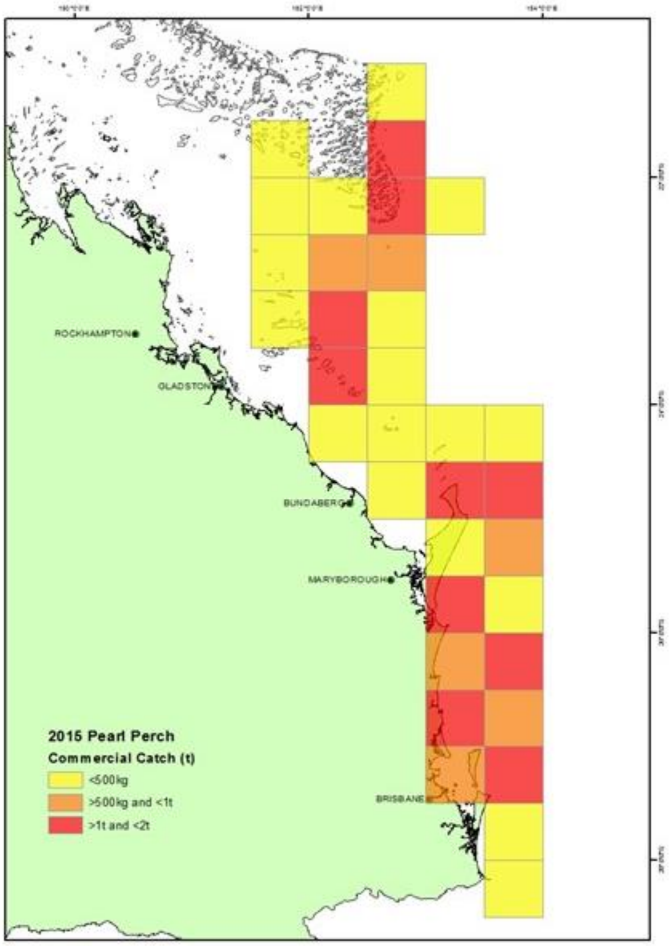


***Figure 2. Spatial 30 x 30 minute grid patterns of commercial harvest of pearl perch from Queensland waters.***

The pearl perch commercial harvest peaked in 2005 and has declined since that time (Figure 3). Data on the Queensland charter fishery have not been available for as long as the commercial fishery because the charter logs were initially voluntary, only being made compulsory in 1996. Reported harvests during the first few years (from 1993) indicate the increased uptake of catch logs by that sector. The recent decline in harvests are seen in both the commercial and charter sectors, with the harvest currently about 30% of what it was during the high catch years of 2003 to 2009.

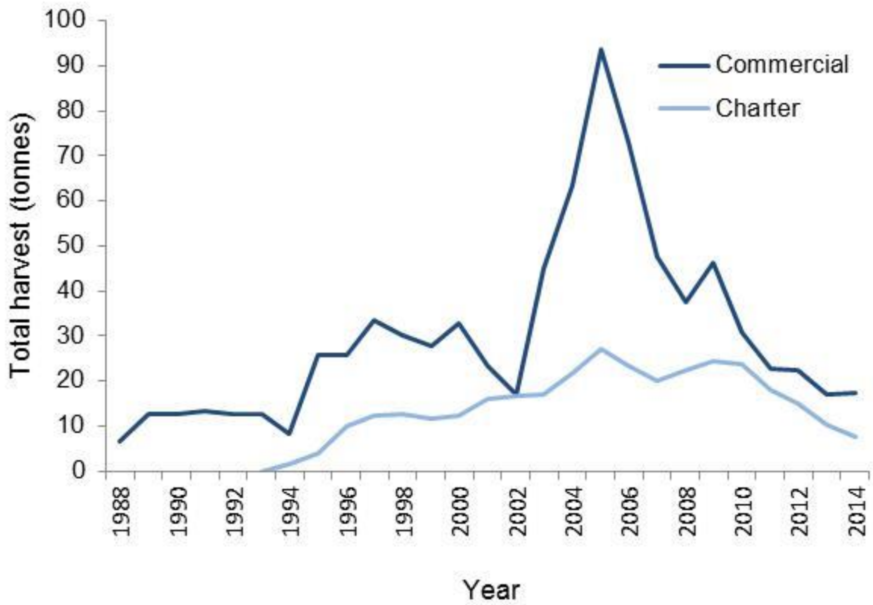


***Figure 3. Total annual commercial line and charter harvest of pearl perch (in tonnes from Queensland waters). Note: reporting of harvests by offshore charter vessels only became compulsory in 1996.***

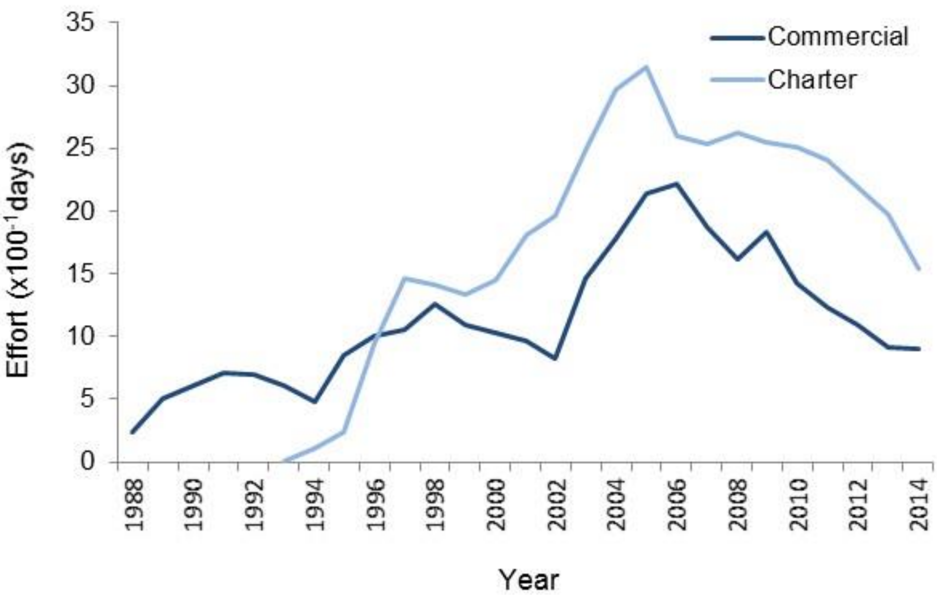


***Figure 4. The reported nominal commercial and charter fishing effort for pearl perch tallied by years. Note: Charter reporting only became compulsory after 1996.***

Charter and commercial effort also show a similar pattern to catch (Figure 4) with effort in both sectors declining after about 2004.

### 4.1.2 New South Wales commercial and charter data

***Table 1. Total harvest (kilograms) and effort (days) in various commercial fishery sectors in NSW from 1997 to 2015.***

| Fishery | Harvest (kg) | Effort (days) |
|---|---|---|
| Estuary General | 46 | 80 |
| Ocean Fish Trawl | 3030 | 368 |
| Ocean Hauling | 8 | 23 |
| Ocean Prawn Trawl | 10249 | 17979 |
| Ocean Trap and Line | 189519 | 94006 |

Table 1 shows that between 1997 and 2015 the majority of the NSW pearl perch harvest was landed by the Ocean Trap and Line fishery with 5% of landings coming from trawl fisheries (predominantly prawn trawl by-product) and relatively insignificant quantities taken by other sectors. Since 2009 and the implementation of more detailed logbooks, approximately 98% of pearl perch landings have come from the Ocean Trap and Line fishery and only 2% from the trawl fisheries. The data from the Ocean Trap and Line fishery are difficult to separate into line-caught and trap-caught prior to the introduction of the 'Fish online' database in 2009, because commercial trap fishers (predominantly targeting snapper) occasionally use line fishing methods for species such as pearl perch while they are servicing their traps. After the introduction of the 'Fish online' database, almost 82% of commercially caught pearl perch were landed on handline or rod and reel with a further 8% caught using droplines, and the balance landed by a range of techniques including trotline (3%) and demersal setline (4%). Since 2009, the more detailed logbook reports on Ocean Trap and Line fishing has shown that 42% of the pearl perch reported by that sector is reported as caught in traps. Fishing effort on pearl perch is difficult to quantify for trap fishing and so, in the catch rate standardisations presented in section 6.5, we have only standardised the line data because effort is more clearly identified and line catch-rate may provide a better index of relative fish abundance.

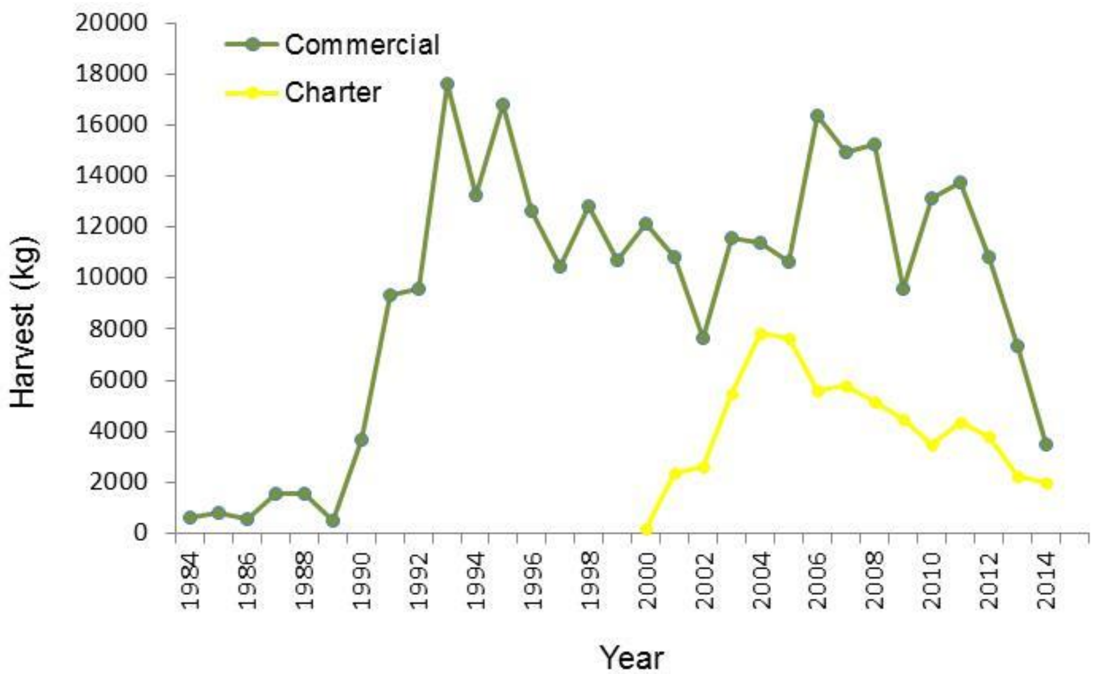


***Figure 5. Total New South Wales commercial and charter harvest from 1984 to 2014.***

Both the commercial and charter fisheries in NSW are currently experiencing a period of declining overall catches (Figure 5), similar to these fisheries in Queensland.

## 4.2 Recreational harvests

Recreational catch and effort data are critically important for assessment of the pearl perch fishery, as the harvests can form a significant component of fish mortality. While the commercial and charter harvests are reported daily by each vessel, recreational harvest data have been only sporadically collected. This is largely because of the cost and logistical difficulties in estimating recreational catch and effort.

### 4.2.1 Information prior to 1990

The earliest historical reports of recreational (predominantly from charter fishing) catches from the rocky reef fishery were of large catches of snapper taken from offshore reefs in southern Queensland in the late 1800s (Welsby 1905), but there is little mention of other species such as pearl perch in these reports. Other than these qualitative records and other observations made by early naturalists, there is little quantitative information on the recreational pearl perch catch prior to 1990. It is, however, widely accepted that the catch must have increased dramatically over time given the increase in the human-fishing population, boat registrations and improvements in fishing technology (Ferrell & Sumpton 1997). Early records from newspapers and other information sources (including historic personal logs of retired commercial fishers) are available, and some of this information has been collated and analysed. However, these early records concentrate predominantly on snapper, which were regarded as the premier offshore line caught fish from southern Queensland (Thurstan *et al.* 2014).

### 4.2.2 Research surveys after 1990

Recreational catch information has also been gathered by a number of on-site research surveys, but only three of these have provided information on pearl perch. These surveys and their results are described in detail in Steffe *et al.* (1996), Ferrell & Sumpton (1997) and Sumpton (2000); some key features of the methods and results as they apply to pearl perch are described below.

The first survey (Steffe *et al.* 1996) was conducted in NSW and was a random stratified survey covering many boat ramps throughout NSW with an emphasis on ramps used mainly by offshore recreational fishers. This survey was of trailer boats returning to the ramps during daylight hours and provided catch estimate of 9.2 tonnes of pearl perch during 1993/94 and 3.6 tonnes during 1994/95. The percentage of missed interviews and refusals was less than 5%.

The second survey (Ferrell & Sumpton 1997) was a random stratified catch (and catch rate) survey of recreational boat anglers returning to seven different access points (boat ramps) during daylight hours from Tweed Heads to Mooloolaba over a 12 month period during 1994/1995. Effort information was independently obtained from aerial surveillance of offshore waters at the same time as the catch survey. There was no assessment of Moreton Bay fishing effort during that survey, although catch information was collected. The ramp locations were chosen after the pilot surveys of ramps and, after consultation with enforcement officers and fishing club members who confirmed the most popular ramps used by offshore anglers targeting rocky reef fish. While non-random selection of ramps is considered a possible source of bias in determining catch rates, the fact that there were well over 100 ramps in the survey area necessitated a compromise. The assumption was that the skill of anglers did not vary significantly among ramps. It was also recognised that non-random selection of ramps would heavily bias any estimates of effort obtained from the survey. However, effort was assessed independently of the ramp survey using aerial surveillance during the same survey period (although on different days). Generally, an occupant from each vessel returning to boat ramps was surveyed, except at times when there were too many vessels to allow a total coverage. The overall percentage of missed interviews was less than 5% of those vessels returning, although on some weekends it reached 10% at the larger four-lane ramps (e.g. Raby Bay).

A potential source of bias in catch rate determination that includes released fish as well as harvest, relates to the spatial segregation of juveniles and adults. This is particularly relevant to snapper where release rates are higher in inshore areas (such as Moreton Bay). The fact that pearl perch were not reported in embayment fisheries such as Moreton Bay, suggests that this feature of their fisheries biology and dynamics may not be as much an issue, as the limited information does not suggest the same level of spatial size segregation.

While there were not large numbers of pearl perch measured during these surveys, the size frequency distributions (Figure 6) broadly reflect those obtained from other recreational and charter samples obtained during more recent years by the Fisheries Queensland long-term monitoring program (LTMP) (see Figure 36). The relatively small proportion of undersized fish during the 1994/95 survey was partially a reflection of the absence of these fish from Moreton Bay (an area of high fishing effort). The minimum legal size had also only recently been set for both snapper and pearl perch at 30 cm in 1993. Snapper showed even higher proportions of undersized fish retained particularly by those fishers who fished inside Moreton Bay (Ferrell & Sumpton 1997).

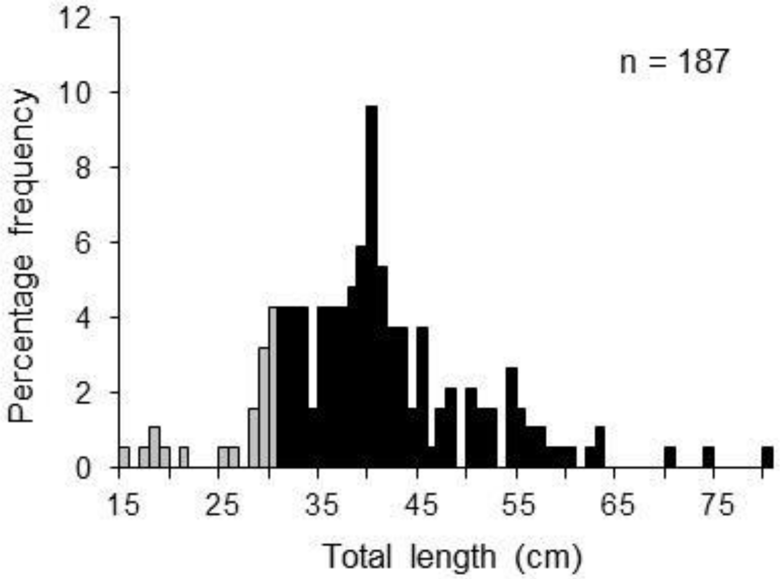


***Figure 6. Length frequency of recreationally caught pearl perch during on site boat surveys of southern Queensland line fishers during 1994 and 1995. Lighter bars indicate fish that were smaller than the 1993 minimum legal size of 30 cm.***

Subsequent surveys during 1999 (Sumpton 2000) showed a dramatic increase in compliance, and it was hypothesised that the high levels of undersized fish during the 1994/95 survey was related to a time lag needed for the regulation changes to be communicated effectively to the recreational sector, rather than an ongoing compliance issue (Sumpton 2000).

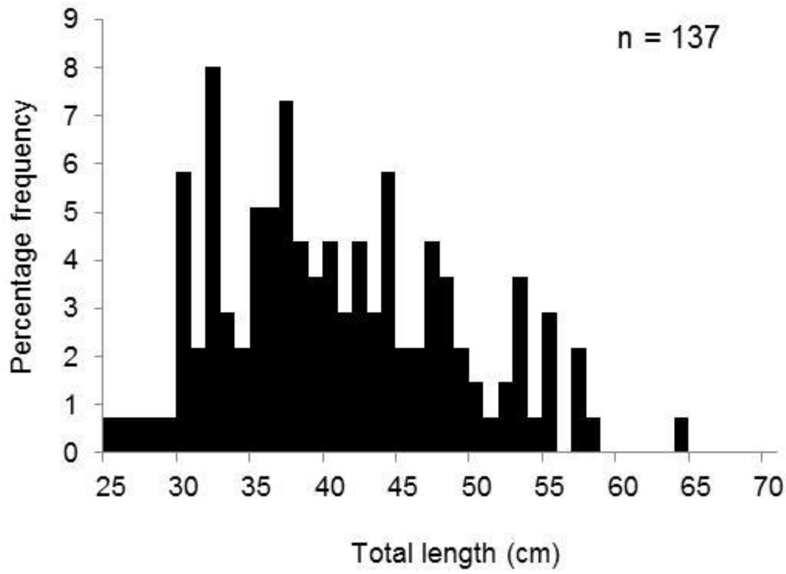


***Figure 7. Length frequency of recreationally caught pearl perch during on site boat surveys of NSW line fishers during 1993 to 1995. There was no MLS for pearl perch in NSW at this time.***

The NSW recreational catch data has a higher proportion of fish less than 35 cm reflecting the lack of an MLS at the time the surveys were conducted (Figure 7). There are also higher proportions of larger fish in the Queensland survey compared with NSW.

During 1994 and 1995, only 6% of offshore fishing trips in Queensland landed pearl perch reflecting a lack of targeting of these species at the time, and the generally lower abundance of the species compared with the main demersal target species (snapper) and other pelagic species, such as mackerel species. Figure 8 shows the distribution of various catch sizes for pearl perch and suggests that bag limits have had little impact on catch rates. The current (as at 2016) bag limit of five would have been exceeded on less than 2% of fishing trips where pearl perch were reported, even in these earlier surveys where the bag limit was higher. This has implications for future catch rate assessments that may use harvested catch as an index of abundance and does not include released fish. Obviously, catch rate interpretation is less of a concern if releases are included in the catch rate analysis, but there is always the issue of recall bias when dealing with released fish. If bag limits are to reduce further over time, this issue would be further exacerbated. In this assessment we have included releases in our catch rate estimates to enable better comparisons across time periods that had differing MLS.

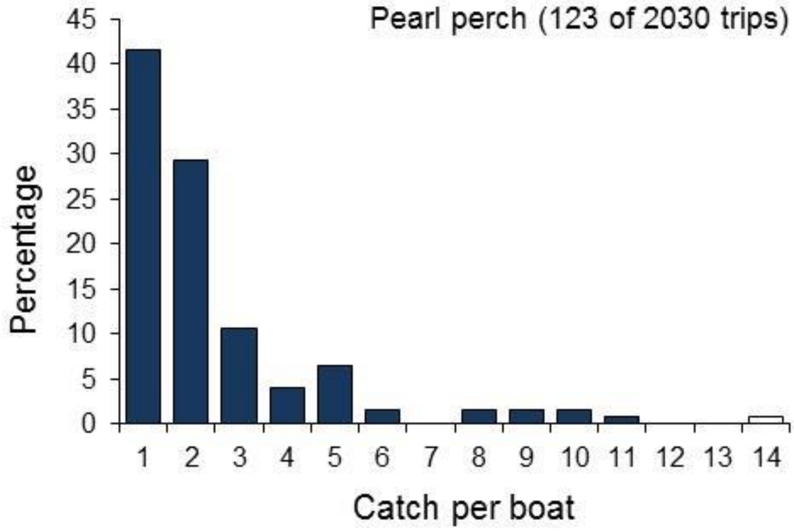


***Figure 8. The percentage of recreational fishing trips that harvested pearl perch as recorded during surveys of boat ramps in 1994 and 1995. The last (white) bar at 14 fish show those trips when the current bag limit of five fish per person would have been filled or exceeded.***

The third survey conducted in Moreton Bay during 1999 (Sumpton 2000) only measured 14 pearl perch and therefore, does not provide any useful information. This is not surprising given that the survey was designed to target recreational blue swimmer crab fishers who were fishing in Moreton Bay, an area where pearl perch are naturally absent.

### 4.2.3 "RFISH" surveys (diary and phone: 1996/7, 1998/9, 2001/2 & 2004/5)

State-wide RFISH (Recreational Fishing Information) surveys of recreational anglers were conducted in the years 1996/7, 1998/9, 2001/2 and 2004/5 (Higgs 1996, Higgs 1998 McInnes 2008). The methodology used telephone surveys of households to estimate participation rates in fishing (i.e. measure fishing effort). In addition, diary records of fish catch rates were combined with the telephone household-data to aggregate estimates of total catches by fish species, areas and time. The diary programs were conducted the year after the telephone surveys and the fishing data was reliant on the co-operation of a sample of anglers identified from the phone surveys. In the order of 4500 anglers have contributed to the surveys over time, but many discontinued their participation throughout the survey year. The issue of angler-survey-dropout was a limitation with the RFISH methodology.

The number of anglers who target a particular species is one of the results from the telephone survey. Pearl perch were less commonly targeted than other popular species like snapper, with the estimated number of target-anglers declining from 3700 to 1800 before an increase to 2000 anglers targeting pearl perch over the survey years (Table 2).

The RFISH calculations indicate that the number of pearl perch caught decreased by approximately 30% between the 1999 and 2002 surveys before increasing dramatically in 2005. Similar trends can be seen in the number of fish harvested as well as those released.

***Table 2  Estimated recreational catch of pearl perch from the 1997, 1999, 2002 and 2005 RFISH diary surveys. Relative standard errors (%) are shown in brackets.***

| **Pearl perch** | **1997** | **1999** | **2002** | **2005** | **2008#** | |
|---|---|---|---|---|---|---|
| **Number caught** | | 109 000 (21.8%) | 74 000 (13.9%) | 356 000 (14.2%) | 16 906 | |
| **Number released** | | 44 000 (31.1%) | 32 000 (16.6%) | 208 000 (15.9%) | 11 622 (42.1%) | |
| **Number harvested** | | 65 000 (18.1%) | 42 000 (13.8%) | 148 000 (13.2%) | 5 284 (39.9%) | |
| **Harvest weight (tonne)** | | 76[a] | 50[a] | 192[b] | 6.8[b] | |
| | | | | | | |

# Estimates in 2008 are only for boats launching from the Moreton region (refer Webley *et al.* 2009).

[a] Using an average weight of 1.2 kg based on catches measured during the mid-1990s.

[b] Using an average weight of 1.3 kg based on catches of pearl perch from 2006 to 2010.

The use of pearl perch catch rate data from the early RFISH surveys as an index of fish abundance is reliant on the temporal and spatial coverage and the appropriateness of the sampling frame for this species. It is also reliant on defining the use of "zero" catches by fishers. It is known for pearl perch that the temporal or spatial patterns of catches can be clumped rather than being distributed evenly throughout the fishing grounds and favoured habitat. In association with the patterns of fish abundance, the utility of the catch rate data can be influenced by the number and locations of survey respondents fishing for pearl perch. Fishers can at times target a particular species depending on the type of bait and gear used. The notion of a representative sample is difficult to determine, and requires a thorough understanding of the sampling frame as well as detailed knowledge of how pearl perch fishing was sampled. Irrespective of these difficulties, the comparison of trends with other data sets can reinforce and increase confidence in assessing fish abundance. This may not be the case for all species, but does appear to be the case for pearl perch (see Figure 23 and associated discussion).

The RFISH estimate of pearl perch catch in 2005 is problematic as the estimate was well above other years. The data weightings applied in 2005 were unable to be sourced and verified. Looking at the nominal counts of pearl perch, it is clear that the 2005 result was atypical of the other three surveys (Figure 9).

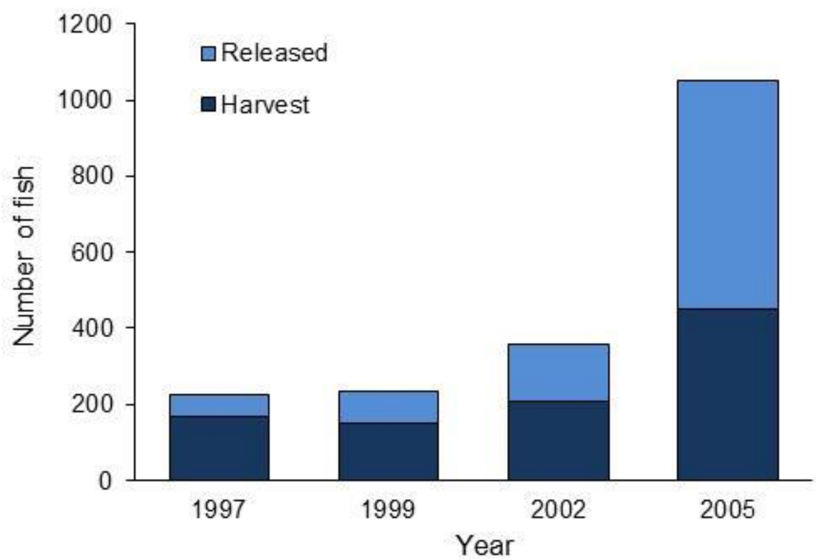


***Figure 9.  The reported numbers of pearl perch harvested and released by RFISH diary participants from 1997 to 2005.***

The standardisation of catch rates was tested for a range of assumptions about what constituted a fishing trip capable of catching a rocky reef species. This ranged from including only fishing trips that reported pearl perch to the most expansive assumption where all trips were used that recorded one of the 10 species defined as a rocky reef fishing. Under these definitions the pearl perch catch rates varied by over an order of magnitude (Table 3), although the overall trends of increasing catch rate up to 2005 were similar. The variance was obviously higher when released fish were included in the analyses.

***Table 3. Estimated scale range of pearl perch catch rates (fish per trip) obtained from recreational catches recorded in RFISH diaries from 1997 to 2005.***

| Species | 1997 | 1999 | 2002 | 2005 |
|---|---|---|---|---|
| Pearl perch | 3.32 - 1.54 x $10^{-3}$ | 3.95 - 1.39 x $10^{-3}$ | 4.31 - 1.42 x $10^{-3}$ | 5.16 - 2.16 x $10^{-3}$ |

### 4.2.4 Diary and phone surveys Henry & Lyle (2003) methods: 2000, 2010 and 2013)

There have been three surveys, similar to the RFISH surveys, conducted that have used updated methods which are more internationally recognised as best practise (but still not as thorough as field or licensed based methodologies). These methods are described in Henry & Lyle (2003) and have better "follow-up" resulting in less drop out of participants over time than the RFISH methods. The National Recreational and Indigenous Fishing Survey (NRIFS) undertaken in 2000, did not provide a reliable estimate of the pearl perch catch as they were grouped with several other species in the overall catch estimation process.

### 4.2.5 Bus route survey of Moreton region: 2007/08)

Readers are referred to Webley *et al.* (2009) for a complete discussion of this survey and its methodology, although it is based on a standard and well established "on-site" field technique that is used widely throughout the world to sample recreational catches. The survey aimed to sample offshore fishing in the Brisbane/Moreton region in 2007 and 2008. It is important to note that this survey was designed as a pilot study to collect information from vessels that left from, and returned to, public boat ramps in southern Queensland during daylight hours only. Offshore boat fishing from these ramps most likely contribute a significant (but unknown) proportion of the total fishing effort. No information was collected from fishers returning from their trips during night time hours. This limitation is still to be addressed due to logistic and safety constraints for survey staff at night (Ferrell & Sumpton 1997). It is clear that any estimates without the night time survey data would underestimate measures of catch rate. The night-time effect on time series analysis is unknown.

Overall this data provides information on catch rates for the region but cannot be used to scale up to regional harvest estimates. Data from this survey have not been used in this assessment. Despite the limitations of many of the surveys, the catch rates obtained from surveys conducted at different times over the life of the fishery, can provide valuable information on the relative abundance of pearl perch providing all features of the fishery (including impact of technology and fishery management changes) can be accounted for in the analyses.

### 4.2.6 Recreational boat registrations

Recreational effort data are only available for a few points of time when state-wide phone and diary surveys have collected this information. In previous stock assessments involving fisheries with significant recreational catches, this lack of data has necessitated surrogates of recreational fishing effort to be derived from different data sources. In some earlier stock assessments of snapper (Campbell *et al*. 2008) power boat registrations have been used as an index of change in recreational fishing effort under the assumption that vessels have been used for fishing, or at least that the proportion of vessels purchased each year that are used for fishing have remained relatively constant over time. This assumption is challenged by the recent trend towards increasing use of Personal Watercraft (PWC), known commonly as jet-skis, (Figure 10) and anecdotal information suggesting increased use of powered vessels for recreational activities other than fishing.

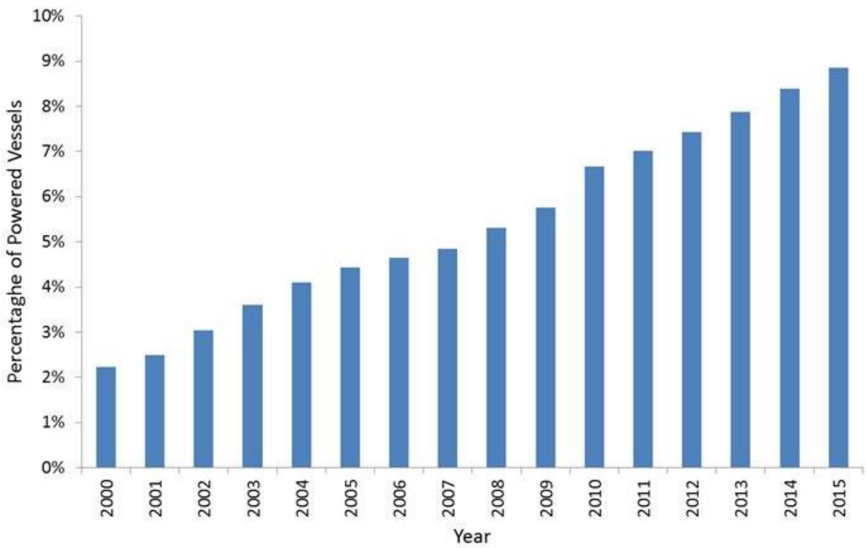


***Figure 10. Percentage of registered recreational power vessels that were classified as personal water craft (jet skis)***

To calculate a time series proxy for recreational fishing effort, boat registration data was sourced from the Queensland Department of Transport to identify changing patterns over time. There are no data that we are aware of that identifies alternative uses of powered recreational vessels. The overall pattern of power boat registration continues to increase through time, although the rate of increase has declined in the last five years (Figure 11).

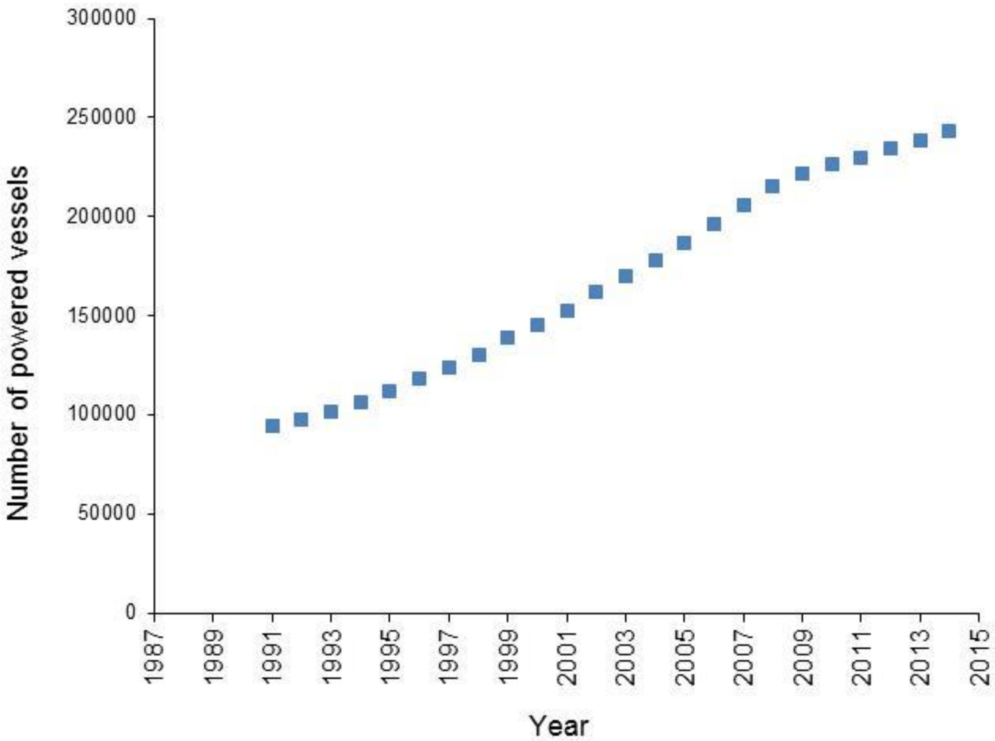


***Figure 11. Total number of powered recreational boats registered in Queensland.***

The registration data were further examined to look at the changing patterns in different size of boats in the region where pearl perch are caught (i.e. south of the town of 1770). These data show similar patterns in the northern and southern regions with registrations of boats less than 5m in length making up the bulk of vessels, and also show the greatest rate of increase since vessel size data were recorded in 2000 (Figure 12). Vessels greater than 5m in length are more likely used to catch pearl perch due to the offshore locations of the species.

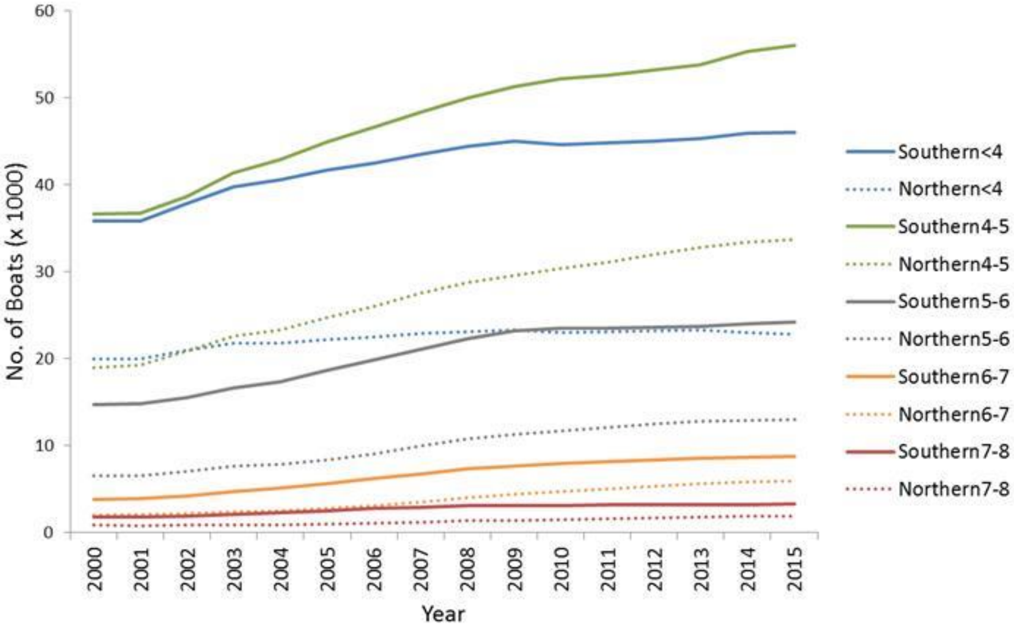


***Figure 12. Number of recreational pleasure vessels of various sizes (m) that were registered in northern and southern Queensland. Northern Queensland was categorised for waters north of the town of 1770.***

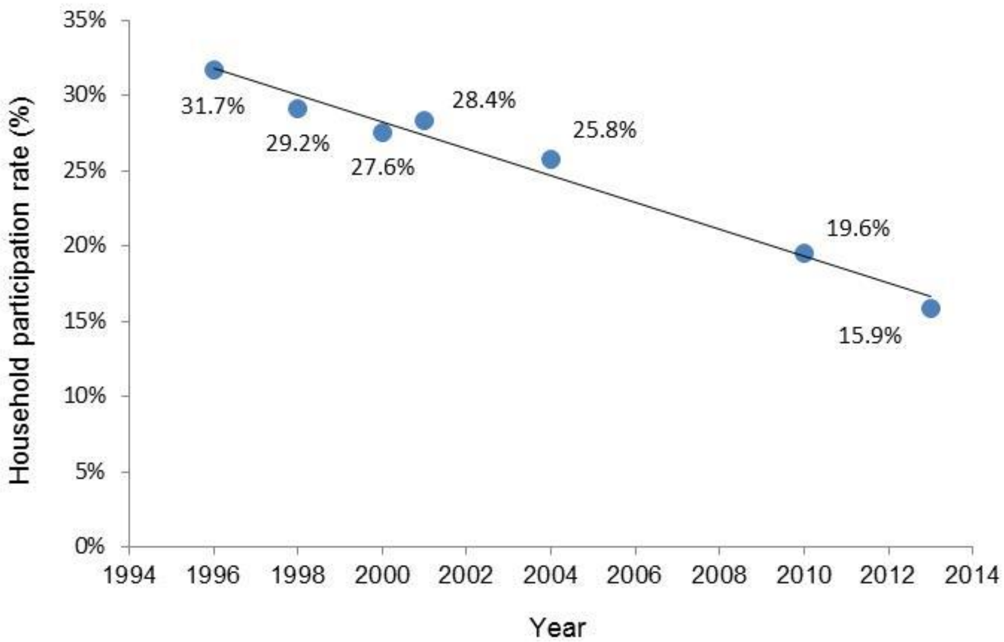


***Figure 13. Change in fishing participation in households surveyed during recreational surveys between 1995 and 2013.***

For the stock analyses, two different trends of recreational fishing effort were examined. The first trend assumed increasing effort as derived from all recreationally registered power boats (Figure 11). It is acknowledged that for pearl perch a better estimate may be to use registrations of boats greater than 5m in length. Vessels smaller than this size would be limited from targeting pearl perch due to the species offshore distribution (fishing deep oceanic waters require larger vessels). The vessel size data were only available from 2000, so for time-series consistency, the all-vessel index was used irrespective of vessel size; as in good weather a proportion of smaller (<5m) vessels (including kayaks) do catch pearl perch.

The second trend considered participation rates in fishing gathered from recreational phone surveys to provide an alternative scenario of declining recreational effort. It is important to note that fishing participation rates are overall rates of recreational fishers, irrespective of the type of fishing undertaken. We have not been able to further categorise participation rates into various forms of fishing such as beach fishing, offshore fishing etc.

Examination of fishing magazines and internet sites indicate that participation in some particular “styles” and “target species” of recreational fishing is increasing despite overall declines. There are no data to verify if the overall declining participation is applicable to offshore fishing that targets species such as pearl perch. Another limitation was that there were no data on when the presumed trend in declining fishing participation began, as data were only available for a few years from 1996 when the first RFISH survey collected this information. Both of the effort trends considered are arguably plausible, although they provide very different signals into the stock model (see Chapter 6).

The trends in offshore recreational fishing effort in NSW was assumed to mirror that in Queensland. The NSW recreational fishing licence database can provide valuable data to estimate fishing effort since 2001 (when the licence was introduced), but was not available for this assessment. The trends in the data are also difficult requiring models, as a large number of recreational fishers are exempt from requiring a fishing licence (for example, people under the age of 18, aboriginal people, people holding pensioner concession cards) and the database structure does not allow the number of distinct fishers to be easily determined in any year as a result of a combination of three-day, one-month, one-year and three-year licence sales. On advice of scientists from NSW these data were thus not used in this assessment.

### 4.2.7 General recreational data discussion

There are 10 rocky reef fish species that are classified for management in southern Queensland waters. These species include the three primary targets of snapper (*Chrysophrys auratus*), pearl perch (*Glaucosoma scapulare*) and teraglin (*Atractoscion aequidens*). The other rocky reef species include samsonfish (*Seriola hippos*), amberjack (*Seriola dumerili*), yellowtail kingfish (*Seriola lalandi*), mahi mahi (*Coryphaena hippurus*), cobia (*Rachycentron canadum*), grass emperor (*Lethrinus laticaudis*) and fryingpan snapper (*Argyrops spinifer*).

Despite the species classification by management, there are other species taken that are managed under the Coral Reef Finfish Fishery (CRFFF). Examples of these species include coral trout, venus tusk fish, pigfish and various lutjanids, lethrinids and serranids, which are sometimes seen in association with pearl perch and snapper (Sumpton *et al*. 2013b). This mix of species taken often causes confusion, particularly amongst fishers who access both rocky reef and coral reef species caught in the same locations but which have different management arrangements. Pelagic species including mahi mahi, *Seriola* spp. (amberjack etc.) and cobia are also sometimes caught without recording other rocky reef species that are more often associated with a demersal life history (e.g. snapper and pearl perch).

The range of species caught from rocky reefs makes the definition and monitoring of catch rates complex. The numbers of snapper monitored by RFISH diarists is over an order of magnitude higher than pearl perch, with relative standard errors reflecting higher precision of snapper estimates compared with other species. This provides confidence to the estimates of the recreational catch of snapper, but the survey methodology may not be optimal for less abundant species like pearl perch.

The spatial stratification of the RFISH surveys resulted in sampling being distributed according to fisher population density. This effectively meant that the majority of diary participants were from the high population districts of southern Queensland, providing survey coverage of species such as pearl perch.

For standardisation of catch rates of pearl perch or estimation of total catches, the definition of fishing effort and use of zero-catches in a trip is critical for producing unbiased estimates. Including zero catches for all trips that may have low probability of catching a particular species may result in deflated catch rate estimates. Likewise, only including catches when a species is actually caught has the potential of over-estimating sustainability and total catches, as unsuccessful trips that may have targeted that species are eliminated from the analysis and hyperstability of catches and catch rates becomes more likely. When a stock is in decline it is more likely that the number of such zero catches would increase. It is well known that it is possible to target some species of rocky reef fish while at the same time having a low probability of catching other species. Fishing techniques are often very species specific and sometimes size selective as well. The fact that it has been shown that snapper in particular are more widely distributed on the fishing grounds over a range of habitats (Sumpton *et al*. 2013b), confirms demersal fishing in many areas of the rocky reef fishery still has some probability of catching this species. While a thorough analysis of this was beyond the scope of this report, it is important to recognise that determining what constitutes a recreational fishing trip likely to catch a particular species of interest (such as pearl perch) is critical and warrants careful consideration and scenario modelling in survey estimates of total catches and stock assessment that seeks to use recreational catch rates as an index of stock abundance.

The handling of zero catches is not as problematic for the 1995/95 on-site survey data as the assumption that interviews of fishers at boat ramps were obtained from a random sample of all fishers who were fishing offshore, irrespective of their targeting behaviour. Effort estimates were obtained from counts of offshore fishing boats independent of the catch survey and also independent of any targeting preference. Thus, these catch rate estimates are less likely to be biased. Other on-site surveys that have adequate design would similarly provide better estimates of catch rates and would also be more likely to produce more accurate and precise estimates of released fish as recall bias would be reduced.

Bag limit changes will clearly influence the resultant catch rates obtained in any form of survey and based on catch rates obtained prior to the introduction of the five bag limit for pearl perch. In only a couple of cases, catches of more than double the bag limit were reported in earlier surveys prior to the lowering of the bag limit. Some individual high catches have also been reported in the charter fishery on the Gold Coast where very large catches were sporadically reported (Ray Joyce, personal communication). This same level of relatively high catches was also reported, particularly for snapper where the bag limit (even when it was as high as 30 fish per person) was regularly achieved by some anglers (Ferrell & Sumpton, 1997). Pearl perch are less of a problem here, as recreational catch rates of this species appear never to have been of the same scale as snapper, and thus catch rate estimates through time are less prone to time-series bias caused by reducing bag limits or changes in minimum legal fish size.

Bag limits being exceeded causing biased catch rate estimates are less of a problem when harvested fish, as well as released fish, are included to determine the catch rate as opposed to a harvest or retained catch rate. However, both precision and accuracy are often compromised when releases are included, largely due to recall bias. Fishers are less likely to remember a fish that they released, particularly if the numbers released are greater than the numbers caught. This issue is relevant to pearl perch, where undersized fish can be released in large numbers depending on the area fished and time of year.

In this assessment report we chose not to use the recreational catch rates as an index of abundance, and placed more weight on the commercial data as providing an index of relative abundance because of the problems identified above, and also because there is more commercial data which also extends over a much longer time series.

## 4.3 Length and age data

The length and age data we used in this assessment were from both Queensland and NSW. The Queensland data are as used in the 2016 Stock Status workshop and these have not been further adjusted or altered in the model inputs. The NSW data have been converted from fork length to total length for consistency, and this has caused some rounding errors in defining length class bins, but overall these differences are considered minor.

The monitoring data protocols are well established and have been reviewed to ensure catch sampling of each sector is representative of the catch. Data were aggregated into two spatial units (Queensland and NSW), and further subdivided into the commercial, charter and recreational fishing sectors (Table 4).

The 1993 Queensland commercial data in particular cannot be considered to be representative of the overall commercial catch, as these were opportunistically sampled from a set of fishers who could not necessarily be assumed to be representative of the sector at the time. However, in subsequent years, sample fractions improved, as did the coverage of fishers sampled. Similar issues occurred with the Queensland commercial samples collected in 2007, but later years more representatively covered the entire range of the fishery, and the sampling strategy involved regional sampling proportional to the catch (at least for commercial sampling). The length frequency data for Queensland prior to 2006 were not used to estimate catch age structures as otoliths were collected in order to estimate growth rather than gather information on representative age structures and total mortality. Charter sampling was discontinued in Queensland after 2011 due to the collapse of the peak bodies representing this sector, which were also responsible for co-ordinating sampling the charter sector.

The length and age structures used in the stock model are shown in Figure 35, Figure 36 and Figure 37.

***Table 4. Sample size of fish measured as part of regular monitoring of pearl perch catches in Queensland and NSW. Recreational lengths were available for NSW during 1993 to 1995 but as only 137 fish were measured they were not included in the assessment.***

| | | No. measured | |
|---|---|---|---|
| Year | Sector | QLD | NSW |
| 2006 | Charter | 327 | |
| 2007 | Charter | 1289 | |
| 2008 | Charter | 701 | |
| 2009 | Charter | 367 | |
| 2010 | Charter | 1570 | |
| 2011 | Charter | 2544 | |
| 2006 | Recreational | 355 | |
| 2007 | Recreational | 440 | |
| 2008 | Recreational | 529 | |
| 2009 | Recreational | 359 | |
| 2010 | Recreational | 594 | |
| 2011 | Recreational | 574 | |
| 2012 | Recreational | 545 | |
| 2013 | Recreational | 532 | |
| 2014 | Recreational | 322 | |
| 1993 | Commercial | 307 | |
| 1994 | Commercial | 514 | |
| 1995 | Commercial | 4291 | |
| 1996 | Commercial | 355 | |
| 1999 | Commercial | | 515 |
| 2000 | Commercial | | 597 |
| 2005 | Commercial | | 395 |
| 2006 | Commercial | | 713 |
| 2007 | Commercial | 809 | |
| 2008 | Commercial | 418 | |
| 2009 | Commercial | 1553 | 606 |
| 2010 | Commercial | 1121 | 1472 |
| 2011 | Commercial | 460 | 1040 |
| 2012 | Commercial | 812 | 922 |
| 2013 | Commercial | 410 | 496 |
| 2014 | Commercial | 1296 | 141 |

## 4.4 Effects of technology

### 4.4.1 Introduction

Globally, line-harvest fisheries that target deeper-water species like pearl perch began to expand in the 1960s and 1970s, coinciding with declines in fish catches from shallow-offshore waters (Roberts 2002). The number of boats fishing these "deep-water" areas have increased substantially since that time (Sumpton *et al*. 2013a). While fishing effort in deeper (>200m) offshore areas may be proportionally less than in near-shore areas, recent advances in fishing technology has allowed fishers easier and faster access to deeper, offshore fisheries. In addition to advances in fishing technology, the schooling behaviour and biology of many fish have resulted in the targeting of spawning populations which have been reduced in many deep-water areas (Rocky Reef Fishery Discussion Paper 1998). History has shown that deep-water fisheries often follow the pattern of high rates of exploitation and great rewards initially, followed by a decline of stocks after a decade or so of exploitation (Roberts 2002).

From the early 1990s, commercial fishers in Queensland were encouraged to fish in deep-water areas to reduce the pressure on more heavily fished shallow water areas, particularly those of the Great Barrier Reef. Initial entry policy to what was then to be developed as a multi-hook longline and dropline fishery, was generous with all Queensland holders of L1, L2 or L3 line fishery symbols on a primary commercial fishing boat entitled to apply for an L8 endorsement that enabled the use of multi-hook gear (>6 hooks) in water greater than 200 m. By 1999, 40 such L8 endorsements had been issued but in October 1999 a 'freeze' was placed on the granting of further L8 licenses. Subsequently, more stringent entry restrictions resulted in the reduction of the number of vessels carrying L8 endorsements to 5 today (January 2016). During this period, deep-water stocks continued to be accessed by commercial line fishers who did not have an L8 endorsement, as the usual L1, L2 and L3 entitlements allowed the use of up to six hooks per line. This limitation in the quantity of gear still enables economically viable catches of fish to be taken in waters greater than 200m and an examination of commercial and charter logbook harvests from remote locations (CFISH grids) throughout Queensland shows high levels of line fishing effort. In addition to the expansion of commercial and charter fishing effort, there is also evidence of expanding recreational interest in fishing deep-water areas (Sumpton *et al*. 2013a). Some of this effort is known to target pearl perch.

In this section, data are examined on the uptake of fishing technology by both commercial and recreational line fishers. The relative impacts of each of the sector's different management arrangements and access to modern technology are discussed. The data and inferences are limited to those fishers that are experienced offshore fishers, and describes advances in sounder, GPS and fishing gear technologies. Paucity of data limited descriptions of other advances in fishing techniques, motors and vessel designs. In terms of the permitted numbers of fishing lines and gear, Queensland line fisheries are unique in that there is no competitive advantage of commercial fishers over recreational fishers as both can use the same quantity and type of gear. The situation is marginally different in NSW as multi-hook drop lines can only be used by commercial fishers offering an advantage over recreational line fishers that are limited to two hooks per line.

### 4.4.2 Methods

A questionnaire was developed to gather information on changes in fishers' use of technology and their fishing practices over time. Time and budgetary constraints limited sampling to experienced commercial and recreational fishers who have fished throughout the timing of recent technology improvements in sounders and global positioning technologies. In the case of the commercial sector this greatly reduced the number of usable interviews as the requirement for 25+ years of commercial fishing experience eliminated 50% of those interviewed. Eighty-six interviews were conducted with recreational fishers and 45 with commercial fishers, but only those whose fishing career spanned over 25 years were used in the analysis (n=52). The questionnaire used to interview fishers can be seen in the Appendices of Sumpton *et al.* (2013a).

For much of the data, fishers were able to provide detailed records of purchases of different pieces of equipment and others were able to deduce fairly accurate times based on related events, we acknowledge the low level of precision in the overall time frame. However, comparisons between different sectors and the relative changes in temporal timing still provide a useful picture of the adoption of various technologies by offshore line fishers in both commercial and recreational sectors.

### 4.4.3 Results and discussion

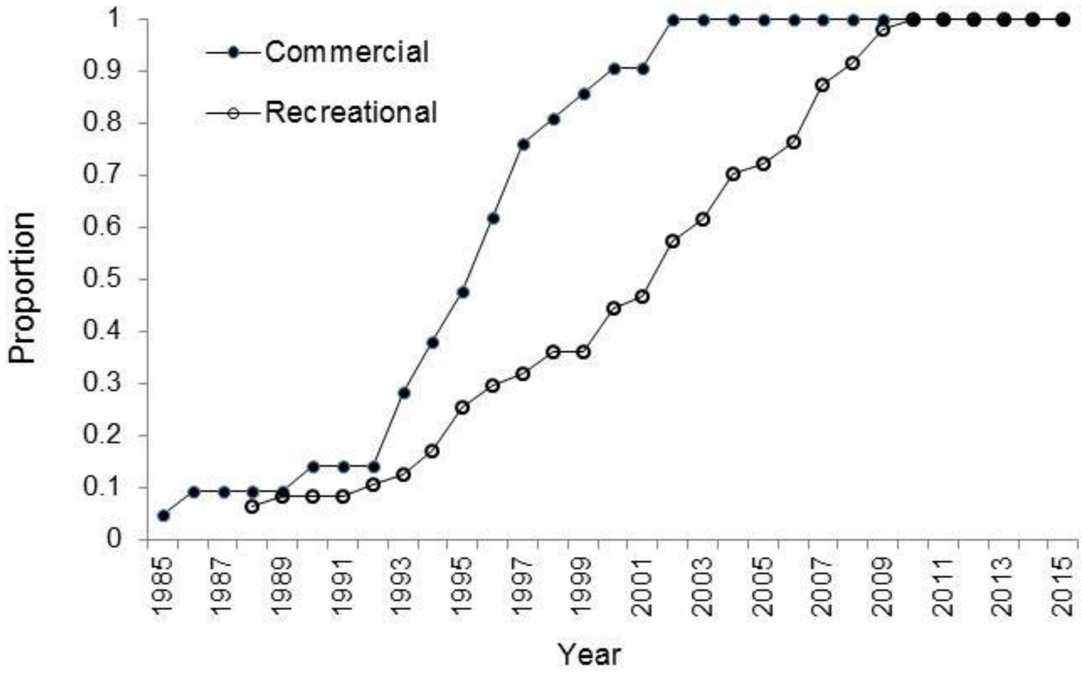


***Figure 14. Proportional uptake of colour sounder technology by experienced offshore commercial and recreational line fishers.***

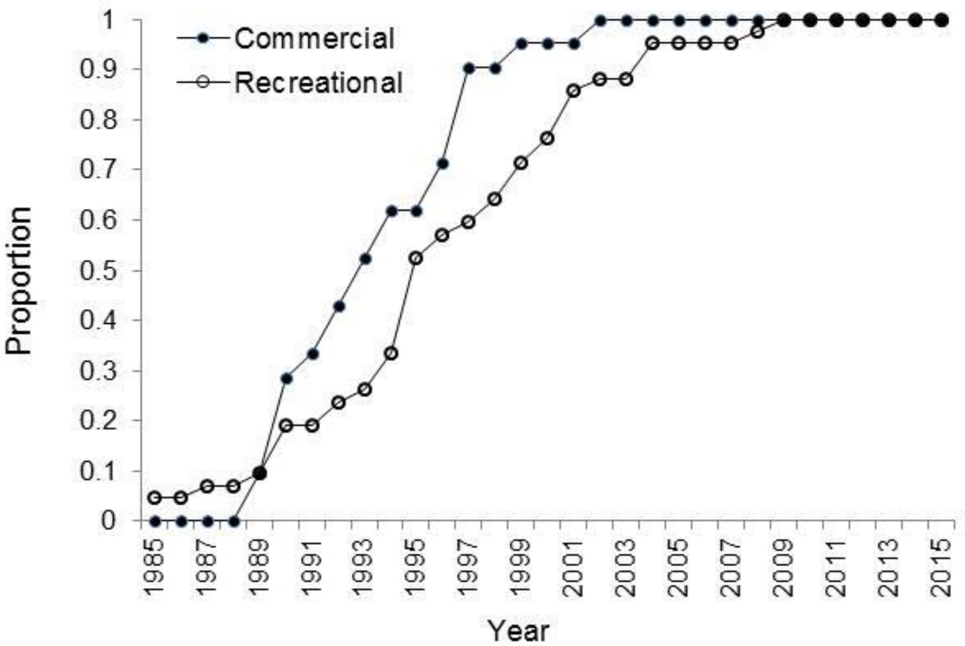


***Figure 15. Proportional uptake of global positioning technologies by experienced commercial and recreational line fishers.***

Both colour sounders and GPS technologies became available in the late 1980s (Figure 14 and Figure 15) with the uptake of this equipment faster in the commercial sector with virtually all of our surveyed fishers using these technologies by the early 2000s. While there was considerable expense associated with these technologies in the early phases of their development and release, there was clearly economic benefit to commercial fishers, in particular, adopting such technology once it became available. The slower uptake in colour sounders by the recreational sector was probably related to the continued use of black and white sounders which were available much earlier and which still improved fishing power, but which were not replaced by the more advanced sounders as quickly as by the commercial sector.

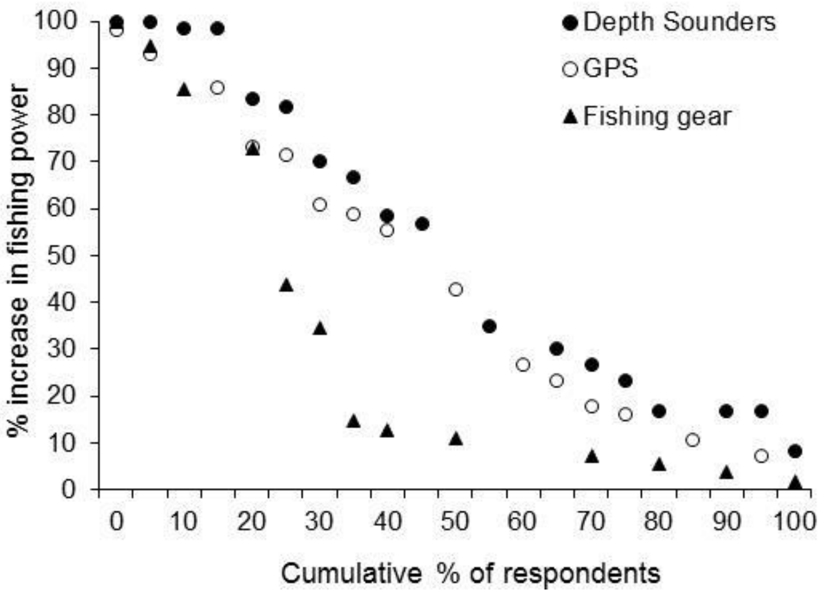


***Figure 16. Fishers' perceptions of increase in fishing power as a result of adoption of colour sounders, GPS and specialised fishing gear.***

The effect of depth sounders and GPS on fishing power were basically equally weighted by our respondents with over 50% of surveyed anglers believing that these two technologies were each at least responsible for a 40% increase in fishing power (Figure 16). Ninety-five percent of fishers interviewed believed that sounder and GPS technologies had at least a 10% increase in fishing power. In the assessment model we have chosen to use the response agreed to by at least 50% of our interviewed fishers, which is 40% increase in fishing power.

Questions on the power of fishing gear provided more variable responses; an approximate 25% increase in fishing power related to fishing gear was the common response for the main categories of braid, lures, chemically sharpened hooks etc. We have not included any adjustment for fishing power related to these technologies in the assessment as the range of different technologies and gears used was highly varied, particularly in the case of the recreational sector.

Prior to the introduction of GPS technology, fishers often had to rely on landmarks or chart navigation to position themselves over reefs and other areas which they had previously found to be productive fishing spots. Other fishers used sounders to find schools of fish around ledges and reef areas which they surveyed. Such practices were time consuming, allowing a limited number of locations to be fished. Nowadays, many of the most productive fishing locations for pearl perch are located well offshore and cannot be pinpointed using landmarks.

The fact that fishers attributed such a high level of impact of these technologies on their fishing capacity has important implications for catch standardisations used in stock assessments. If the perceptions of this group of anglers are correct, then catch rate trends that do not account for the impact of these technologies will present overly optimistic views of stock status due to increases in fishing power. In this assessment we use the uptake of technology and perceived effects as an annual offset variable in our statistical models to adjust for the impact of changing technology. This involved using the proportional annual uptake of technologies for each sector and then adjusting for the perceived effect of 40% increase in fishing power in the REML. In the case of the Queensland charter data and the NSW commercial data, the same offset derived for the Queensland commercial fishery was used.

## 4.5 Catch data standardisations

For the purposes of data standardisation, we use techniques which are well established and have been applied to similar fisheries in Queensland and elsewhere, and also form the basis of the analysis that is used for many species evaluated in Queensland's annual Stock Status reporting.

Daily commercial and charter catch data for pearl perch were supplied by Fisheries Queensland and commercial catch data for NSW were supplied by the Department of Primary Industries. Single catches reported for periods greater than one day (i.e. bulk data) were excluded from the catch rate analyses; but were tallied in the summation of annual harvests. The standardisations for pearl perch in both Queensland and NSW included only line catch, which made up >95% of the total catch in Queensland, but less than 65% of the overall catch in NSW.

In the case of commercial catch data supplied by NSW, these data were treated identically to the Queensland data, but as a higher proportion of the NSW data was from trap and trawl methods, a much higher proportion of data were excluded from the standardisations.

The influence of lunar phase on catch rates was initially tested by the addition of a sinusoidal luminance pattern as described by O'Neill & 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 which advanced the luminance measure seven days (~¼ lunar period).

Prior to REML analyses using Genstat (Version 16 -2015) statistical software catches were log transformed. Year, Month and Region were included as fixed factors with a fisher identifier field used as the only random factor. Lunar covariates were omitted from final standardisations as their effect on catch rates was not statistically significant (i.e. *P* >0.05).

The adjusted means and 95% confidence intervals were back-transformed and bias corrected according to methods used by Zhou and Gao (1997).

Mean catch rate in kilograms per boat per day were calculated as:

$$\theta_y = e^{\left(\mu_y + \frac{s^2}{2}\right)}$$

where $\theta_y$ is the bias–corrected back-transformed mean catch rate in year *y*, $\mu_y$ is the adjusted mean catch rate in the natural log scale in year *y* and $s^2$ is the residual mean square from the REML.

The 95% confidence intervals for $\theta_y$ were calculated as follows:

$$e^{\left[\left(\mu_y + \frac{s^2}{2}\right) - 1.96\sqrt{\frac{s^2}{n_y} + \frac{s^4}{2(n_y - 1)}}\right]} < \theta_y < e^{\left[\left(\mu_y + \frac{s^2}{2}\right) + 1.96\sqrt{\frac{s^2}{n_y} + \frac{s^4}{2(n_y - 1)}}\right]}$$

where $n_y$ is the number of observations in year *y* and 1.96 is the critical value for the 95% confidence limit.

**Table 5. Statistical significance of fixed effect factors used to standardise Queensland commercial catches of pearl perch in the REML model.**

| Fixed term | Wald statistic | n.d.f. | F statistic | d.d.f. | F pr |
|---|---|---|---|---|---|
| | | | | | |
| Year | 578.31 | 26 | 22.24 | 30278.5 | <0.001 |
| Month | 24.77 | 11 | 2.25 | 30148.2 | 0.010 |
| Region | 185.12 | 4 | 46.28 | 26077.7 | <0.001 |

Significant variance was identified between fishing vessels (used as a random term) in the model (Boatmark variance component = 0.474 SE= 0.036). There was no evidence to suggest lack of fit of the data to the model (Figure 17).

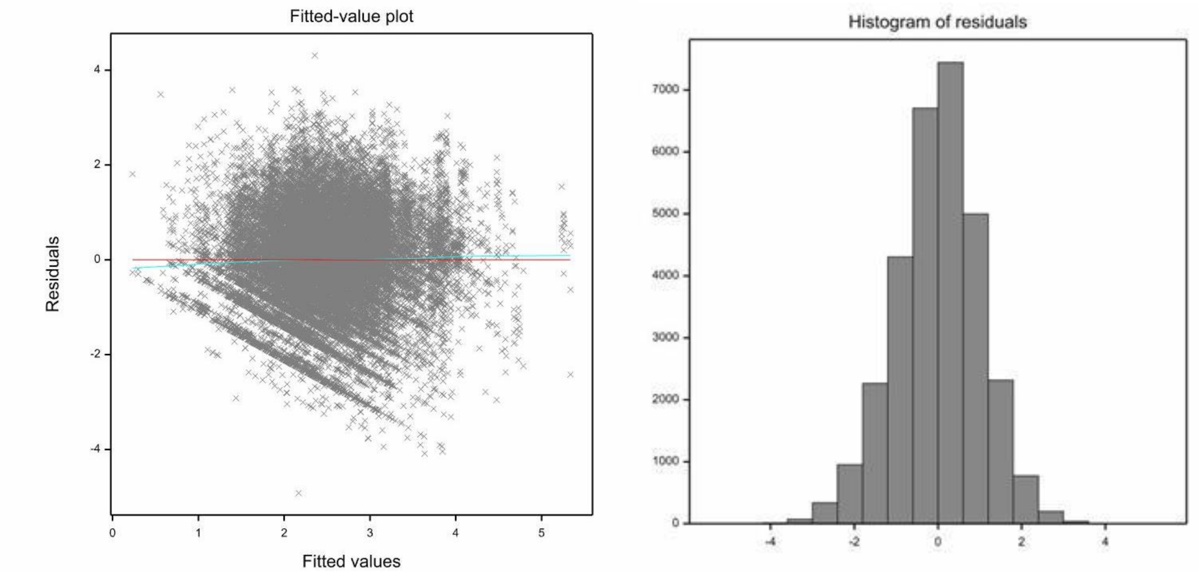


***Figure 17. Residual plots showing fit of modelled data to the standardised Queensland commercial harvest data.***

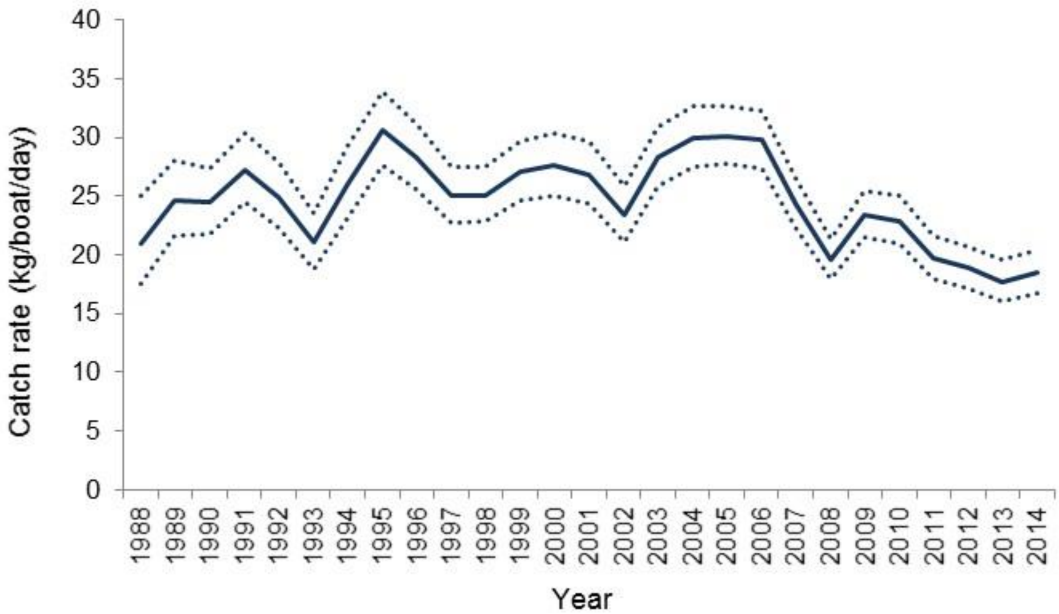


***Figure 18. Predicted mean catch rates of pearl perch (kg/boat/day) from Queensland commercial line fishers adjusted for effects of technology. Ninety-five percent confidence intervals are shown as dotted lines.***

There were no strong signals in the standardised commercial pearl perch line catch (Figure 18) apart from declining catch rates since about 2006. The adjustment for the effect of the technology effectively increased the catch rates during the early part of the data series but has little impact on the last 10 years of data, as the technological advances considered had virtually been fully adopted in the offshore fleets of both commercial and recreational fishers by 2004.

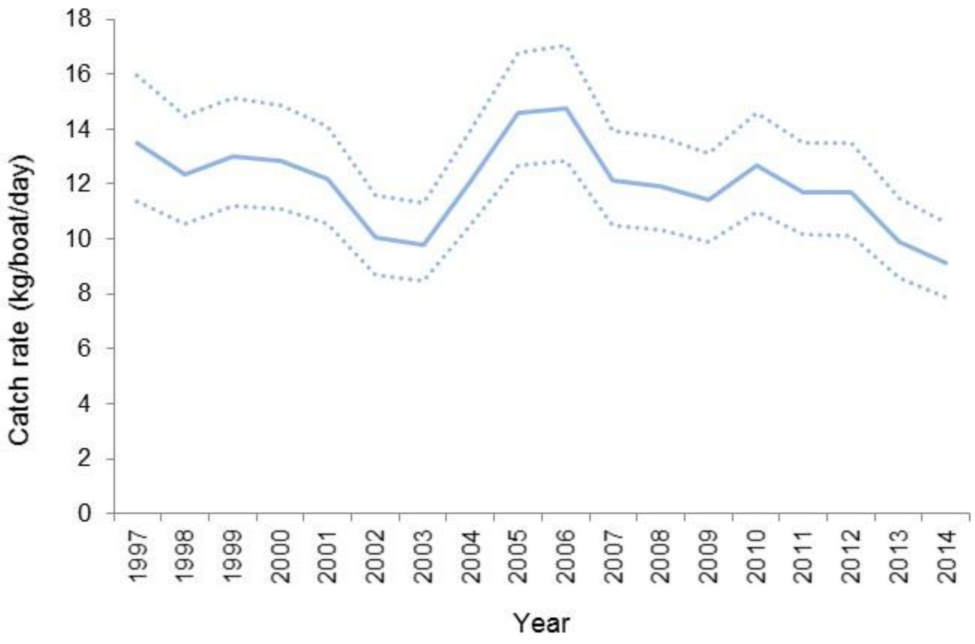


***Figure 19. Predicted mean catch rates of pearl perch (kg/boat/day) from the Queensland charter fishery adjusted for effects of technology. Ninety-five percent confidence intervals are shown as dotted lines.***

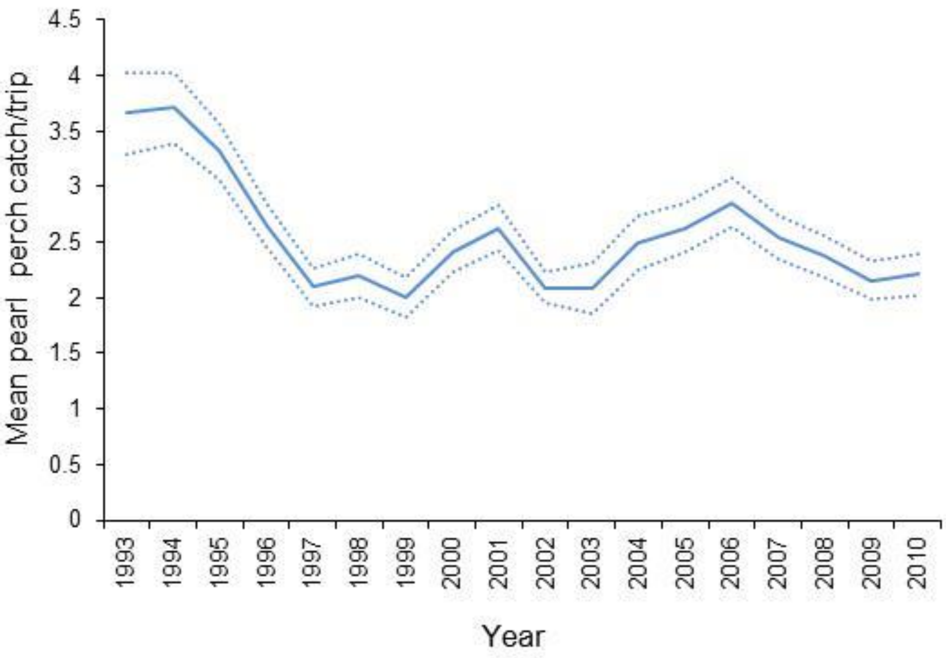


***Figure 20 .Predicted mean catch rates of pearl perch from a subsample of the Gold Coast charter fleet sampled by AMLI.***

Analysis of both the charter log book and the subset of the Gold Coast charter fleet (Figure 19 and Figure 20) show a similar pattern with peak catch rates in 2005 and 2006 and declining catch rates thereafter. The period prior to the compulsory reporting of charter catches in 1997 also showed a fairly rapid decline, although these data need to be treated with caution given that this was the period that logbooks were being introduced, which is often accompanied by initial poor data.

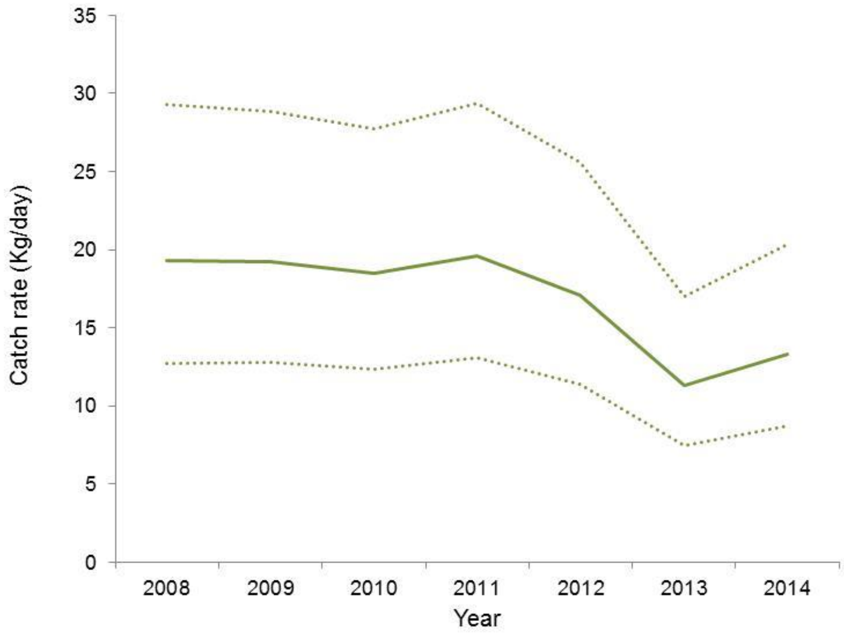


***Figure 21. Predicted mean catch rates of pearl perch (kg/boat/day) from New South Wales commercial line fishers adjusted for effects of technology. Ninety-five percent confidence intervals are shown as dotted lines.***

There was a higher degree of uncertainty in the modelled outcomes of the NSW line data due to the variation in catch sizes, and the overall lack of a large time series of line fishing catch for pearl perch in this jurisdiction.

In accord with the commercial and charter data from Queensland, the recreational catch of pearl perch has also declined since 2005 after a period of increasing catch rates from the 1990s (Figure 22).

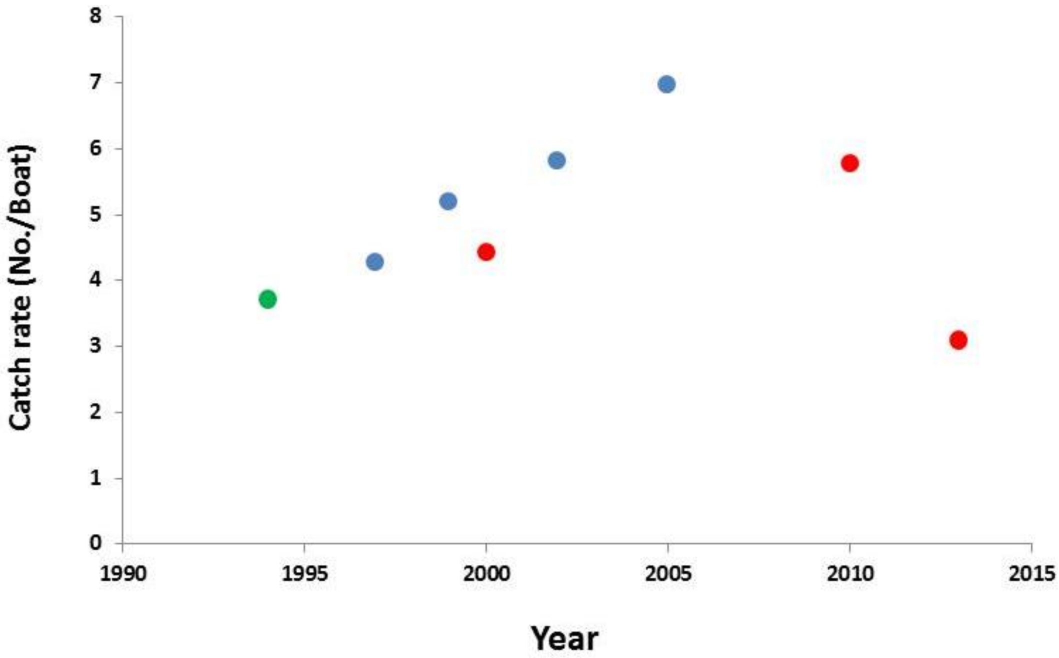


***Figure 22. Nominal catch rates of pearl perch from recreational fishing surveys conducted throughout Queensland (red dots use Henry & Lyle (2003) diary methods, green dot is an estimate based on boat-ramp surveys conducted from Qld/NSW border to Mooloolaba and blue dots are RFISH diary surveys.***

Figure 23 summarises the catch rate time series for the main datasets analysed. These data have been scaled to enable easier comparison of the overall trends in catch rates. A key feature of this graph is the consistency in declining trends over the last 10 years shown in the recreational, charter and commercial sectors as well as the NSW commercial sector.

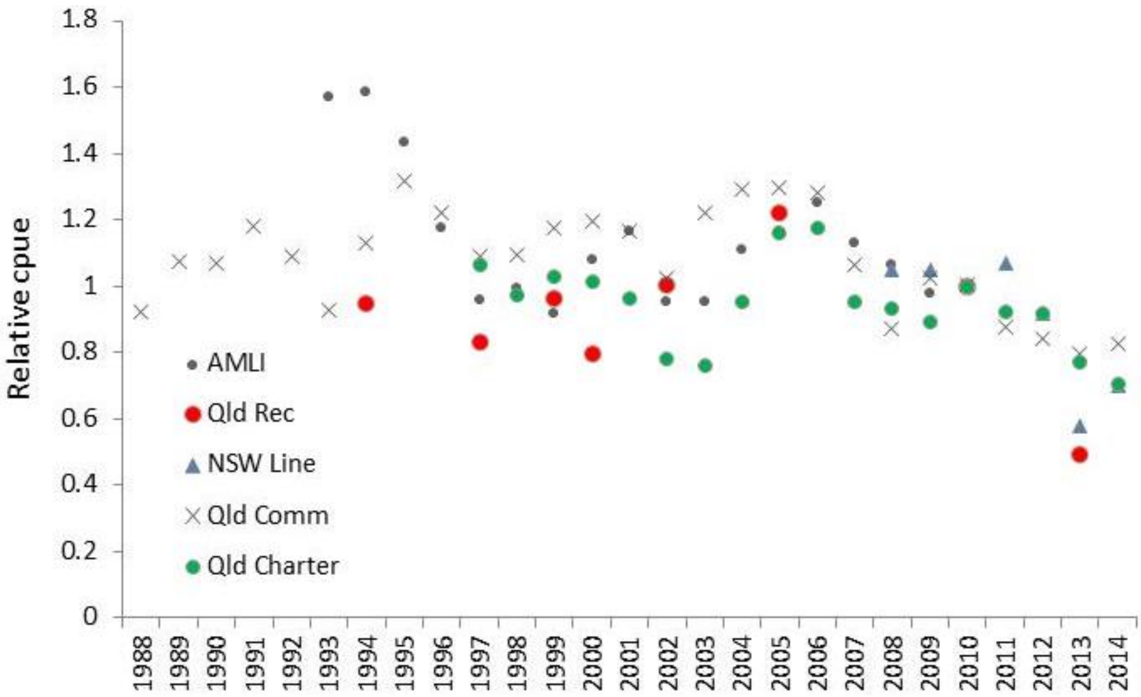


***Figure 23. Summary of relative standardised catch rates scaled so that the 2010 catch =1. AMLI refers to a sample of the Gold Coast charter fleet collected by the Australian Marine Life Institute.***

## 4.6 Biological data

The biological data used in the assessment predominantly comes from previous research as summarised in Sumpton *et al.* (1998), Sumpton *et al*. (2013b) and Campbell *et al.* (2014). While sampling was often fishery-based, there is a greater level of control exercised by scientists on data quality.

### Natural Mortality (M $yr^{-1}$)

Earlier yield per recruit modelling (Sumpton *et al.* 2013b) used Hoenig's (1983) estimator of natural mortality which provides an estimate of M $yr^{-1}$ of approximately 0.2 given a maximum age of 22 years. Recent research has indicated that a simpler method of calculation, also based on the maximum age, may be more appropriate (Then *et al.* 2014). Using a maximum age of 22, the estimated natural mortality using this method is 0.289 $yr^{-1}$. More recent sampling of pearl perch catches has seen fish as old as 25 years in the catch. This latter maximum age results in a lower value of M of 0.256 $yr^{-1}$. These latter estimates are considerably higher than those derived using the earlier Hoenig's (1983) method. For comparability purposes with the earlier data our modelling has used a value of M=0.289 as its base level. We also include a scenario of M $yr^{-1}$ = 0.2 to represent a lower likely value on natural mortality (as used as a scenario in the Yield modelling presented in Sumpton *et al.* (2013b)) and we also predict the level of natural mortality within the stock model to complete the range of analyses (see Table 10).

### Growth data

Despite the fact that there are statistically significant sexual differences in the growth of male and female pearl perch derived from the Queensland data (Sumpton *et al.* 2013b), and likely differences in growth along the latitudinal range of the species (Stewart *et al*. 2013), we use a single growth curve in our model with appropriate variance around the length at age to reflect variable growth, as sexual and latitudinal differences were considered to have limited impact on the model given the observed variable growth rate of the species (Figure 24).

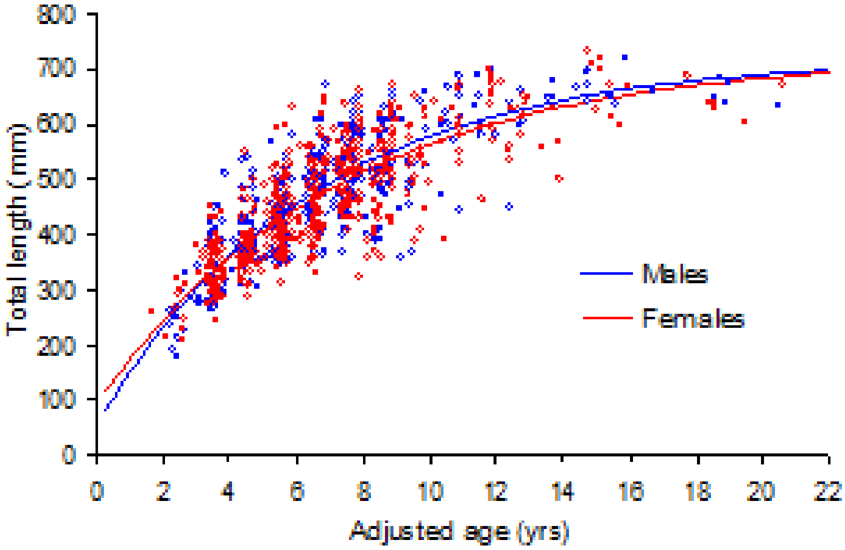


***Figure 24. von Bertalanffy growth curves of male and female pearl perch caught in Queensland waters.***

## Reproductive data

Fecundity data came from earlier research (Sumpton *et al.* 1998) and were based on replicate counts of mature oocytes of ripe female fish (Figure 25). These data were converted to fecundity at age using the length–at-age relationship. The relationship between relative fecundity and age used in the stock assessment model is shown in Figure 38b.

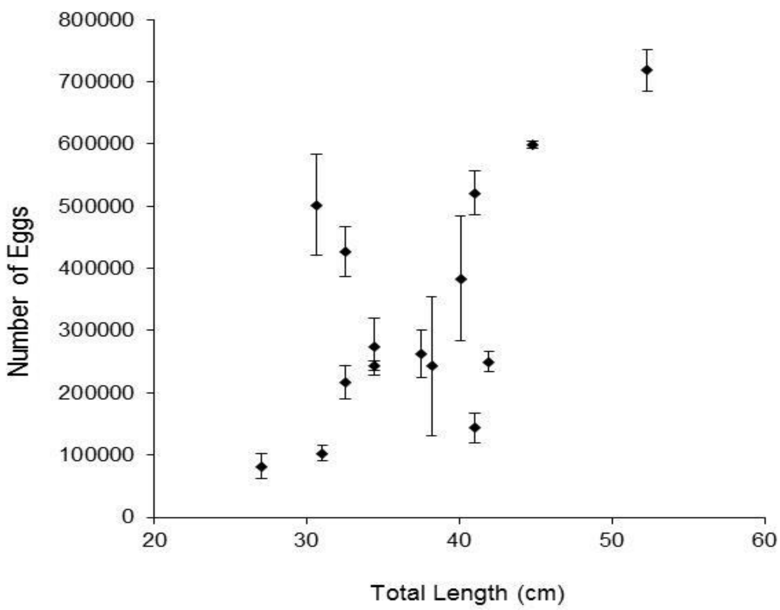


***Figure 25. Pearl perch fecundity data (average number of mature oocytes in the ovaries of ripe female fish). Bars represent the standard error of at least three replicate counts.***

Age-at-maturity data used in the stock assessment model (Figure 38a) were generated from the size-at-maturity data as described in Sumpton *et al*. (2013b). Most female pearl perch were first mature by 35–40cm TL (Figure 26).

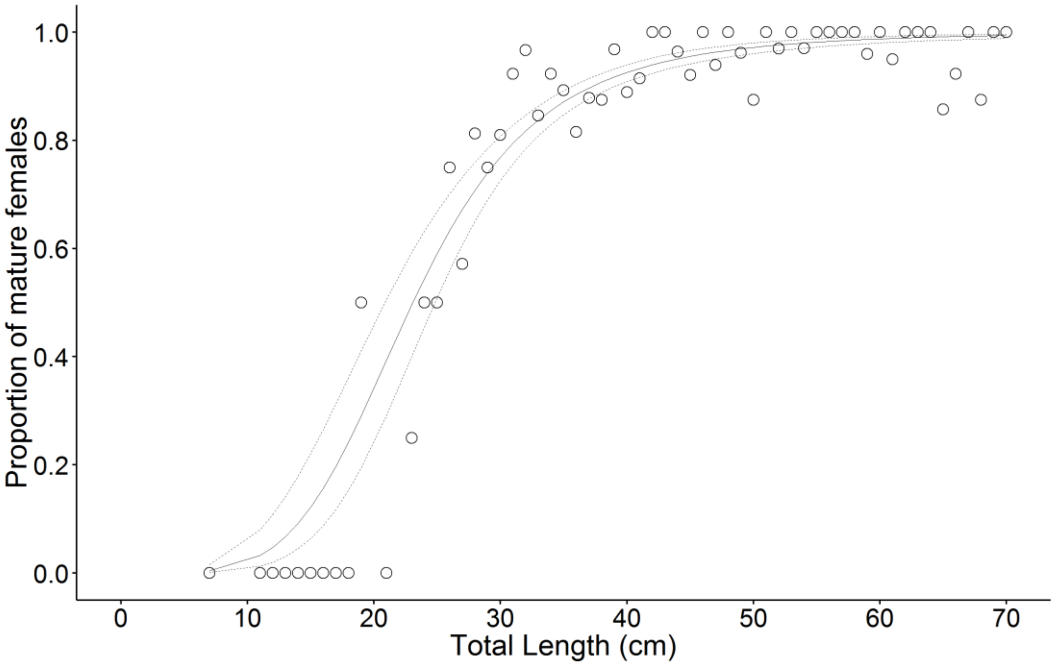


***Figure 26. Percentage maturity of sexually mature female pearl perch as a function of length.***

### Release mortality

Pearl perch are usually caught in depths between 30 and 250 m and are therefore susceptible to barotrauma; post-release mortality is therefore an important fisheries parameter particularly in fisheries that are managed by minimum legal size, where a proportion of the catch is discarded. The post-release mortality of pearl perch has been assessed at approximately 10% irrespective of capture depth (Campbell *et al.* 2014). It is certainly possible that poor handling and release practices can result in release mortality considerably higher than this, but this is the level that we have used in our stock model. One of the more positive features of the biology and physiology of pearl perch is this relatively low level of post-release mortality, which is due to this species' ability to "self-vent" (Campbell *et al.* 2014), reducing physiological stress and removing the need for fisher intervention to alleviate barotrauma symptoms.

## 4.7 Alternative and future data sources

There are few fishery-independent data sources that are available to aid in the assessment of pearl perch. Some of these have been described in Sumpton *et al.* (2013b) and they will not be discussed in detail here. Fish numbers from Baited Remote Underwater Videos (BRUVs) at this time was of little value to the current stock assessment, although we acknowledge that a properly designed and implemented BRUV program may provide a fishery-independent index of relative abundance suitable to include in stock assessments.

# 5 Stock Modelling

## 5.1 Introduction

There has been no previous attempt to construct a population model of the pearl perch fishery; only simple yield per recruit modelling assessing fish minimum legal sizes has been conducted (Sumpton *et al*.

2013b). In this chapter an annual age-structured stock model was used to predicted population trends from the fishery data. Pearl perch measures of stock size (egg production and exploitable biomass), as well as reference points of equilibrium maximum sustainable yield (MSY) and a proxy for maximum economic yield (MEY), were estimated for a range of analyses using different input data. Management strategies involving changes in fish minimum legal size (MLS) were also examined.

## 5.2 Methods

### 5.2.1 Population dynamics model

The population dynamic model (Table 6) calculated numbers (*N*) of pearl perch by the following categories:

- yearly (*t*) time categories from the fishing year 1988 to 2014, and
- age-group (*a*) from 1+ to the maximum age; scaled midyear 1.5, 2.5, … ,max.

No gender category was required as the growth curves between female and male fish were similar (See Figure 24).

The model accounted for the processes of fish births, growth, reproduction and mortality in every fishing year (time step *t*; Table 6). The model was run in two phases: (i) historical estimation of the pearl perch stock from the fishing years 1988–2014; and (ii) simulations of model values and errors to evaluate reference points (Figure 29). Fishing years were equal to calendar years to group the seasonal and biological patterns of pearl perch.

The harvests of pearl perch are taken from NSW and Queensland offshore waters by commercial and charter fishing operations and recreational fishers. Visual inspection of the pearl perch age-length distributions for these sectors (Figure 35) suggested similar fish vulnerabilities. The fish vulnerability assumptions were therefore simplified to be influenced by the different minimum legal size (MLS) between the State jurisdictions; and not between sectors. The fishing sector (f) components were therefore defined for:

- Queensland commercial + charter sectors (f=1),
- NSW commercial + charter sectors (f=2),
- Queensland recreational (f=3), and
- NSW recreational (f=4).

The fishery for pearl perch has operated for many years prior to 1988 in association with offshore snapper fishing (Thurstan et al., 2014). Although there are no reliable harvest data recorded before 1988, it was unrealistic to start the modelling in 1988 from an unexploited state (virgin population).To initialise population conditions in 1988, the model assumed a 1938–1987 annual hind casted average annual harvest and effort with respect to each sector’s data (Figure 27 and Figure 28). The hind casted values included random variation with respect to the data variance. The 1938–1987 values were calculated from an over-dispersed GLM based on the combined commercial and charter harvests for 1987–2014 and for years 1991–2008 for recreational boat registrations (Figure 27 and Figure 28b). This approach was similar to the method and assumption used to initialise population conditions for modelling southern rock lobster (McGarvey et al. 2014) and blue swimmer crab (Sumpton et al. 2015), but allowed for an increasing historical trend in the growth of the fishery (like: Begg *et al*. 2005; Begg *et al*. 2006). It is acknowledged that this assumption may not mimic the long term expansion of the pearl perch fishery, but the lack of early time series data necessitated a compromise to initialise realistic model conditions.

The model definition considered pearl perch being harvested by different fishing sectors (f). The sector-specific harvest rates ($u_{f,t}$ in equation 7, Table 6; which represented the fraction of exploitable biomass harvested by each sector in each fishing year) allowed for differences in reported harvests, fishing effort and fishing vulnerabilities between the sectors. The calculation required an iterative method (program loop around equation 7, Table 6 at each time step) to estimate harvest rates from each sector's harvest or fishing effort with different fish vulnerabilities $v_{f,a}$ (Leigh *et al*. 2014; O'Neill & Leigh, 2014).

In equation 7 (Table 6), harvest rates were calculated from the estimated harvests ($C_{f,t}$) for the commercial and charter fishing sectors. For the recreational fishing sector $C_{f,t}$ harvests were not estimated in some years. Therefore, the recreational harvest rates of pearl perch $u_{f,t}$ had to be calculated from a proxy measure of recreational fishing effort ($E$). For this the following formulas were used:

- $u_{f,t} = 1 - \exp\left(-q_f E_{f,t}\right)$, where the catchabilities $q_f$ were parameters to be estimated based on when $C_{f,t}$ was measured for the recreational fishing sector (f = 3 and 4). The estimated parameters $q_f$ for NSW and Queensland and recreational harvests were part of the overall model fitting and used in the iterative loop when estimating harvest rates from $C_{f,t}$ for the other sectors (f = 1 and 2).
- The model predictions of total pearl perch recreational harvests $\hat{C}_{f,t}$ from NSW and Queensland (f = 3 and 4) were conditioned on the effort proxies $E$ (Queensland vessel registrations excluding sail boats and adjusted effort based on declining fishing participation rates; Figure 28b) using equation 10 in Table 6. This prediction was used in the negative log-likelihood for recreational harvests and the estimation of $q_f$, where f= 3 and 4.

The estimation of fish growth and modelling of discrete lengths were not attempted in the stock model due to the limited temporal and spatial sampling of age-length data prior to 2006. An externally estimated von Bertalanffy growth curve (Table 6, equation 6; described in Haddon (2001)) based on calculated decimal ages was used for combined fish sexes and offshore waters (NSW + QLD); where $l_\infty$ is the average maximum fish total-length (cm), $\kappa$ is the growth rate parameter that determines how quickly $l_\infty$ is attained and $a_0$ is the theoretical age at which the expected length is zero – the value is typically negative and needed so that the function best represents the growth of exploitable sized fish. Data on small undersized pearl perch are discarded by the fishing sectors and under sampled through fishery dependent sampling. However, the growth curve prediction was improved for small and large fish by using sampled fish from deeper and more northern waters and scientific samples of undersized fish (Sumpton *et al*. 2013a).

From the growth curve, fish length at age was assumed to follow a normal distribution using the parameters from Table 9 for mean fish length and variance. For a given fish age in year time $t$ the normal distribution calculated the proportions of fish $p_{t,a}(l)$ at length $l$, such that $\sum_l p_{t,a}(l) = 1$.

The stock model length distributions of pearl perch for each fishing sector and time were approximated using the theory of Gaussian finite mixture models (McLachlan & Peel, 2000). The normal probability densities can be combined over any of the age groups to form a multivariate normal distribution of fish lengths. The multivariate normal distributions can be calculated, where the individual normal densities (with mean $\overline{l_a}$ and standard deviation $\sqrt{\sigma^2}$) are summed based on the mixing proportions $\pi_{f,t,a}$ calculated from the exploitable population numbers of fish $N_{t,a} v_{f,t,a}$.

Age-dependent vulnerability of pearl perch was calculated for fishing sector–time–age vulnerability $v_{f,t,a}$:

$$v_{\mathrm{f},t,a} = v_a \sum_l p_{t,a}(l)\left(r_{\mathrm{f},t,l} + \left(1 - r_{\mathrm{f},t,l}\right)d\right) \qquad \text{(16), and}$$

$$v_a = \frac{1}{1 + \exp\left(-\log(19)\dfrac{\left(a - a_{50}\right)}{\left(a_{95} - a_{50}\right)}\right)} \qquad \text{(17), where}$$

$r_{\mathrm{f},t,l}$ is the probability of retention (=0 if fish length $l$ was less than the minimum legal size (MLS) in fishing year $t$ and 1 otherwise), $d$ is the discard mortality rate for fish and $v_a$ is the logistic vulnerability of fish. All pearl perch caught above MLS were assumed to be kept. This assumption was supported by recreational survey data (James Webley, personal, communication.). The MLS was the minimum legal size at time $t$ in each jurisdiction (NSW or Queensland). For Queensland waters a 30cm total length MLS was first introduced in March 1993 and then increased to 35cm in December 2002 based on sustainability concerns. There was no MLS in NSW waters until September 2007 when a 30cm total length MLS was first introduced.

Model parameters (Table 7) were estimated by calibrating the model to standardised catch rates and age-length composition data (Table 8). Primary importance was placed on fitting the standardised catch rates (Francis, 2011). Effective sample sizes for scaling multinomial negative log-likelihoods were calculated within the model in order to give realistic weighting to the age-length composition data. Additional negative log-likelihood functions were also considered for predicting natural mortality ($M$), annual recruitment variation ($\eta_t$) and recreational pearl perch harvest (Table 8).

The model estimation process was conducted in Matlab® (MathWorks, 2015) and consisted of a maximum likelihood (ML) step followed by Markov chain Monte Carlo sampling (MCMC). The flow of the estimation process is summarised in Figure 29. The maximum likelihood step used Matlab global optimisation (comparing successfully the Quasi-Newton and simplex methods, MathWorks, 2015), followed by a customised simulated annealing program to find and check the parameter solutions and estimate the parameter covariance matrix. The maximum likelihood step was effective for searching and locating the optimal parameter estimates over the negative log-likelihood (combined NLL fitting functions). The simulated annealing was started from a NLL scaling factor of 100 and then reduced to 10, 1, 0.1 and 0.01. For each scaling factor, the annealing process was run for 10,000 iterations of each parameter. The covariance matrix was built up by measuring the differences in the negative log-likelihood with each parameter jump.

The MCMC followed on from the simulated annealing using a NLL scaling factor of 1 with fixed covariance. The MCMC used parameter-by-parameter jumping following the Metropolis-Hastings algorithm described by Gelman *et al*. (2004). The final parameter distributions were based on 1000 posterior MCMC samples thinned from 1 solution stored per 100 samples. MCMC parameter traces and autocorrelations were assessed for convergence and independence (Plummer et al. 2006).

The calculation of the whole-fishery equilibrium reference points were based on optimising the population model dynamics through a combined-sector average harvest rate ( $u = 1 - \exp(-F)$ ) for each MCMC posterior parameter sample and different minimum legal sizes. All parameter uncertainties were included except stochastic recruitment variation (the error term $\exp(\eta_t)$ in equation 3, Table 6 was fixed equal to one).

The age-model biomass equilibrium reference points for maximum sustainable yield ($B_{MSY} \approx 0.4B_0$) and a proxy for maximum economic yield ($B_{MEY} \approx 0.6B_0$) were calculated. The Australian Government's current proxy for $B_{MEY}/B_{MSY}$ is 1.2 (Australian Government, 2007). The origin of this proxy is not clear (Dr Sean

Pascoe, CSIRO, personal communication at the Fisheries Queensland harvest strategy workshop 4-5 August 2015), but likely based on the symmetric surplus production theory of $B_{MSY} \approx 0.5B_0$ (Zhou et al., 2013; Pascoe et al., 2014). This corresponds to $B_{MEY}/B_{MSY} \approx 1.5$ for the non-symmetric age-model dynamics.

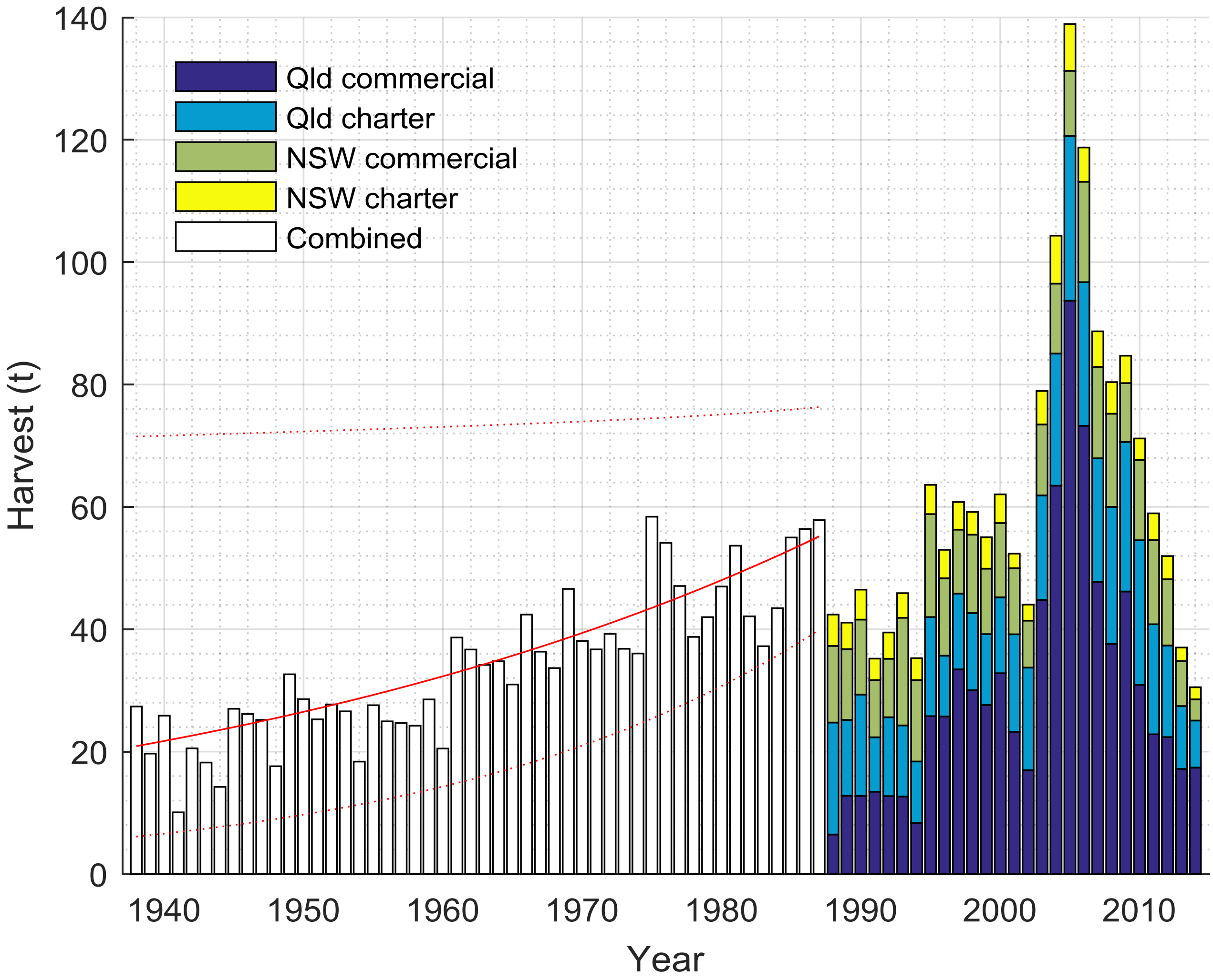


***Figure 27. Annual estimates of commercial and charter harvests of pearl perch that were inputted into the stock model. The data from 1988–2014 were tallied from logbooks by fishing sector. The tonnages (t) from 1938–1987 were estimated for all commercial and charter sectors from an over-dispersed Poisson Generalised Linear Model. For 1938–1987, the white bars illustrate random variation around the mean (solid red line); 95% confidence intervals are illustrated by the red dotted lines.***

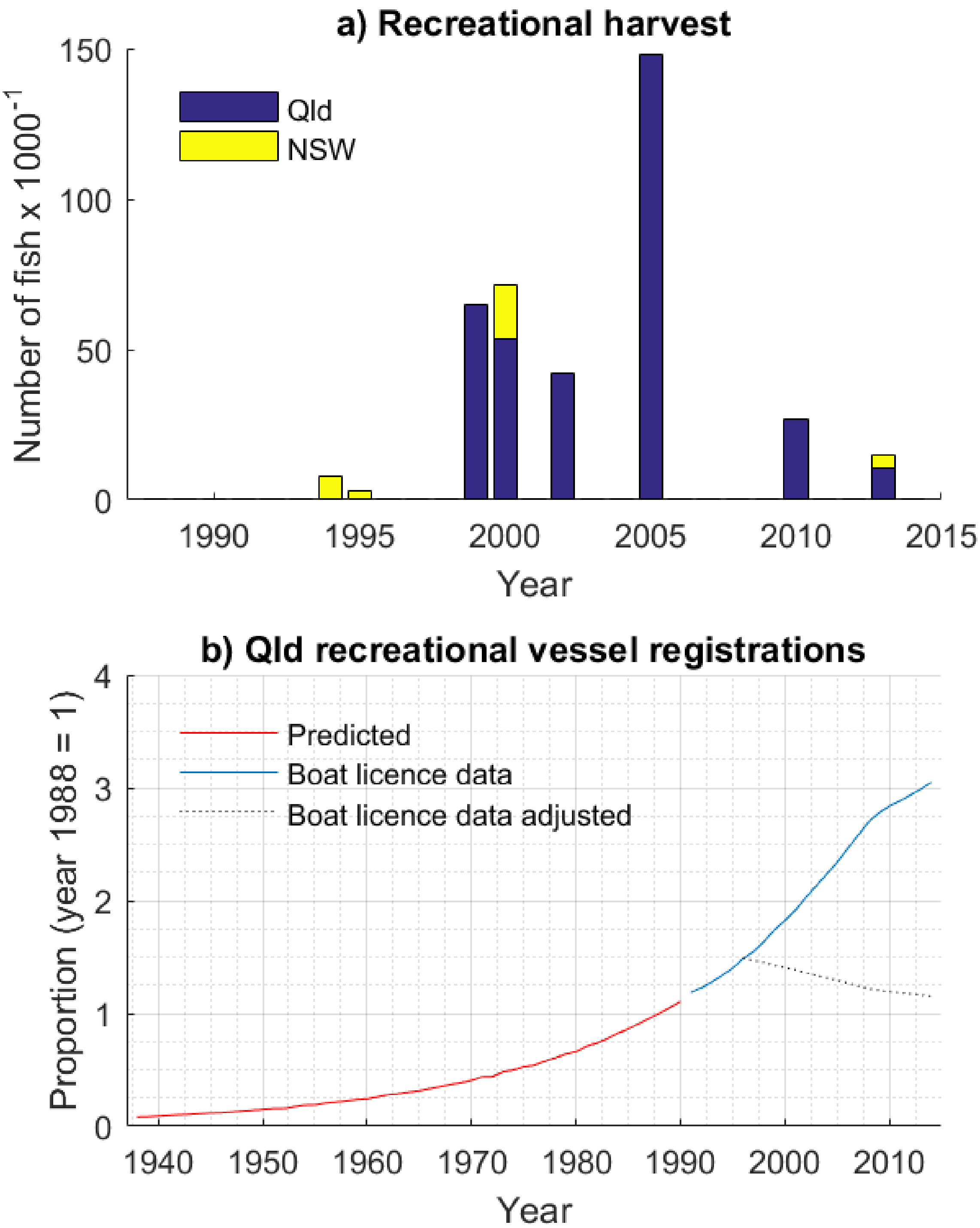


***Figure 28. Annual estimates of recreational harvests (subplot a) and proxy effort (subplot b) used to model pearl perch. The boat licence data (subplot b) from 1991–2014 were sourced from the Queensland Department of Transport. The effort estimates from 1938–1990 were predicted from an over-dispersed Poisson Generalised Linear Model. The adjusted series from 1996 onwards was scaled proportional to the decline in estimated oceanic recreational boat fishing effort (2000, 2010 and 2013) in south east Queensland (sourced from Dr J Webley, May 2016; DAF Recreational Fishing Monitoring; and presented in Figure 31).***

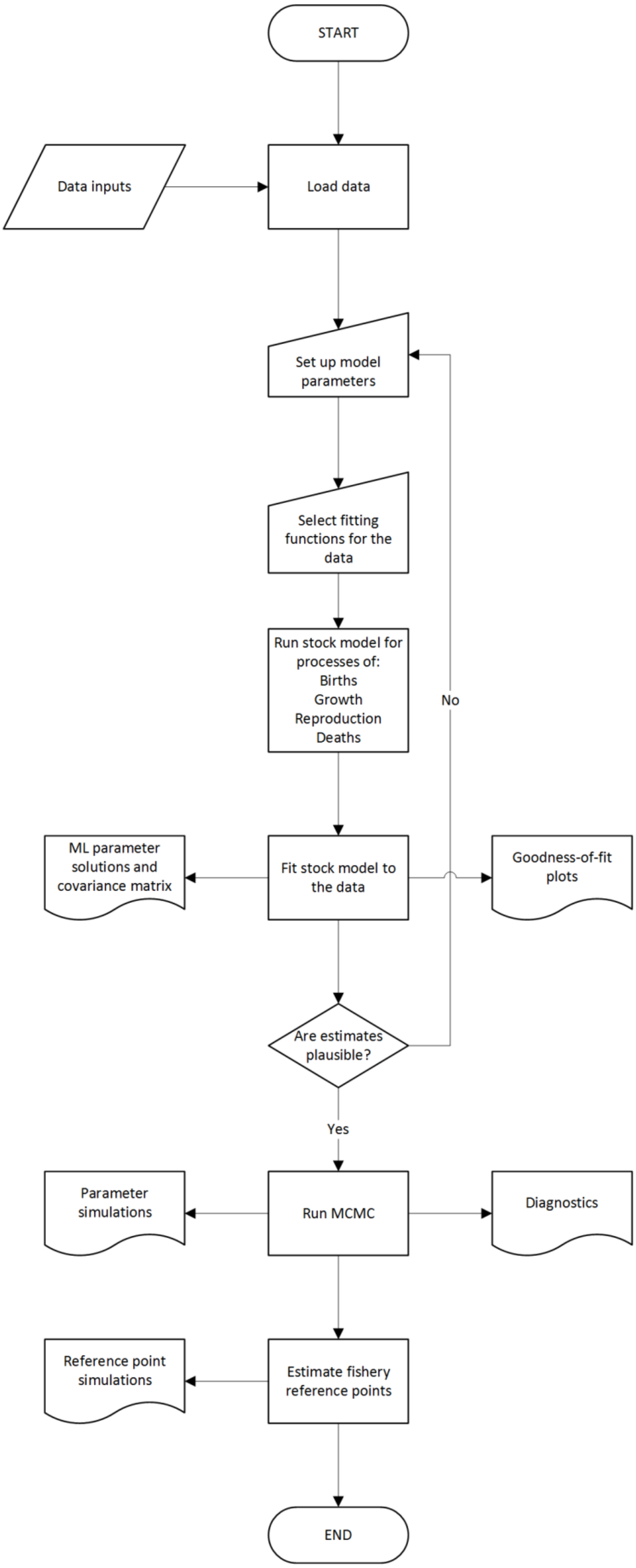


***Figure 29. Flow of operations for the stock model from loading the data to evaluating model predictions.***

*Table 6. Equations for calculating the pearl perch population dynamics.*

| Population dynamics | Equations |
|---|---|
| **Numbers of fish in the virgin year (*t*=1):** <br> $N_{t,a} = R_t \exp\left(-M\left(a-1\right)\right)$ | (1) |
| **Numbers of fish after the 1st year 1940 (*t*>1):** <br> $N_{t,a} = \begin{cases} R_t & \text{for} \quad a=1 \\ N_{t-1,a-1}\exp\left(-Z_{t-1,a-1}\right) & \text{for} \quad a=2\ldots\max\left(a\right) \end{cases}$ | (2) |
| **Recruitment number of fish – Beverton-Holt formulation:** <br> $R_t = \dfrac{S_{t-1}}{\alpha+\beta S_{t-1}}\exp\left(\eta_t\right)$ | (3) |
| **Spawning index – annual egg production:** <br> $S_t = 0.5\sum_a N_{t,a} m_a \vartheta_a$ , calculation for female fish, assuming an equal female–male sex ratio. | (4) |
| **Fish survival:** <br> $\exp\left(-Z_{t,a}\right) = \exp\left(-M\right)\prod_{\mathrm{f}}\left(1-v_{\mathrm{f},t,a}u_{\mathrm{f},t}\right)$ | (5) |
| **Mean fish length in each cohort:** <br> $\bar{l}_a = l_\infty\left(1-\exp\left(-\kappa\left(a-a_0\right)\right)\right)$ | (6) |
| **Harvest rate (f = 1 and 2):** <br> $u_{\mathrm{f},t} = C_{\mathrm{f},t} \Big/ \exp\left(-0.5M\right)\sum_a N_{t,a}\bar{w}_a v_{\mathrm{f},t,a}\sqrt{\prod_{\mathrm{f}'\neq\mathrm{f}} 1-v_{\mathrm{f}',t,a}u_{\mathrm{f}',t}}$ , where the square root term considered all other sectors $\mathrm{f}' \neq \mathrm{f}$ , including f = 3 and 4. | (7) |
| **Midyear exploitable biomass – forms 1 and 2:** <br> $B^1_{\mathrm{f},t} = \sum_a N_{t,a}\bar{w}_a v_{\mathrm{f},t,a}\exp\left(-0.5M\right)$ | (8) |
| $B^2_{\mathrm{f},t} = \sum_a N_{t,a}\bar{w}_a v_{\mathrm{f},t,a}\exp\left(-0.5M\right)\sqrt{\prod_{\mathrm{f}}\left(1-v_{\mathrm{f},t,a}u_{\mathrm{f},t}\right)}$ | (9) |
| **Recreational harvest:** <br> $\hat{C}_{\mathrm{f},t} = \sum_a \dfrac{v_{\mathrm{f},t,a}q_{\mathrm{f}}E_{\mathrm{f},t}}{Z_{t,a}} N^2_{\mathrm{f},t,a}\left(1-\exp\left(-Z_{t,a}\right)\right)$ for f = recreational fishing sectors 3 and 4, where $N^2_{\mathrm{f},t,a}$ is the form 2 calculated number of exploitable fish removing $\bar{w}_a$ from equation 9. | (10) |
| **Catch rate:** <br> $c_{\mathrm{f},t} = q_{\mathrm{f}} q^{\tilde{t}}_{inc} B^2_{\mathrm{f},t}$ , where $\tilde{t}$ is a proportional adjustment to $q_{\mathrm{f}}$ . This was only applied for predicting Queensland commercial catch rates (f = 1) for the years *t* = 1988…2003; otherwise $q^{\tilde{t}}_{inc} = 1$ . | (11) |

***Table 7. Parameter definitions for pearl perch population dynamics.***

| Parameter | Equations and values | Notes |
|---|---|---|
| ***Assumed*** | | |
| $\mathrm{Max}(a)$ | 30 | Based on considering the maximum fish age recorded (=22 yrs). Larger values can be set in the model as no plus-group was programmed in the dynamics for combining old fish > 22 yr. |
| *l* | $TL = 0.0831 + 1.0504 \times l$<br>$l_\infty, \kappa, a_0$ | Fish length conversion from fork length to total length (*l*) measured in cm (Sumpton et al., 2013a).<br>The estimated von Bertalanffy growth curve parameters (Table 9). |
| $w_a$ | $w_a = \sum_l p_a(l) x l^y$ | Fish weight (kg) at total length (cm) was based on the parameters *x* = 0.0000396 and *y* = 2.7528 using 1990s sampled fish (Sumpton et al., 2013a). Conversion to weight at age summed values over the probabilities at length. |
| $m_a$ | $m_a = \sum_l p_a(l) m_l$<br>$m_l = \frac{\exp(\varsigma)}{1+\exp(\varsigma)}$<br>$\varsigma = -8.12 + 3.057 \times l$ | Logistic maturity schedule $p(\mathrm{mature} \mid l)$ by total length (cm) for female fish. The schedule was estimated using binomial regression and logit link (Sumpton et al., 2013). The length-dependent maturity was converted to age-dependent maturity following the process like for weight-at-age and length vulnerability. Length at maturity was estimated at 36 cm. |
| $\vartheta_a$ | $\vartheta_a = \sum_l p_a(l) x l^y$ | Female batch fecundity (number of eggs) based on the relationship estimated from only mature ripe staged fish (Sumpton et al., 2013a). The parameters were: *x* = 89.044, *y* = 2.2345 and *l* was the fish total length (cm). The length-dependent fecundity was converted to age dependent fecundity following the process like for weight-at-age and length vulnerability. |
| *d* | 0.1 | The assumed fish discard mortality was low at 10% (Sumpton et al., 2013) |
| ***Estimated*** | | |
| $\Upsilon$ and $\xi$ | $\alpha = S_0(1-h)/(4hR_0)$<br>$\beta = (5h-1)/(4hR_0)$<br>$R_0 = \exp(\Upsilon) \times 10^6$<br>$h = r_{comp}/(4 + r_{comp})$<br>$r_{comp} = 1 + \exp(\xi)$ | Two parameters for the Beverton-Holt spawner-recruitment function, equation 3 Table 6, that define *α* and *β* (Haddon, 2001). Virgin recruitment ($R_0$) was estimated on the log scale for the first model year. One estimated value of steepness (*h*) was assumed for the stock. $S_0$ was the calculated as the overall virgin egg production in the first model year from equation 4 Table 6. The $r_{comp}$ parameter is the recruitment compensation ratio (Goodyear, 1977), based on the log scale coefficient $\xi$ . |
| $a_{50}$ and $a_{95}$ | | Parameters for the logistic vulnerability equation (Haddon, 2001). $a_{50}$ was the fish age in years at 50% vulnerability and $a_{95}$ at 95%. No fishing sector f differences were modelled given the similar patterns of age-length data. |
| *M* | | One parameter for instantaneous natural mortality year$^{-1}$, according to the log-likelihood equation 14 Table 8 The prior distribution allowed for a lifespan of about 22 years. Sumpton *et al*. (2013) considered a range of estimates 0.15, 0.2 and 0.25. The Hoenig (1983) equation assuming the maximum age of 22 years was 0.2 year$^{-1}$. The estimate for using the age based estimator of Then et al. (2015) was 0.289 year$^{-1}$ assuming a maximum age of 22 years. Sumpton *et al*. (2013) also quoted and considered the value of 0.23 year$^{-1}$ based on Jensen (1996) method. |
| $\zeta$ | $\boldsymbol{\eta} = \boldsymbol{\zeta}\mathbf{e}$<br>e = zeros(nparRresid, nparRresid+1);<br>for i = 1:nparRresid<br>hh = sqrt(0.5 * i ./ (i + 1));<br>e(i, 1:i) = -hh ./ i; e(i, i + 1) = hh;<br>end; e= e ./ hh; | Recruitment parameters to ensure log deviations sum to zero with standard deviation *σ*, equation 15 Table 8. $\zeta$ were the estimated parameters known as barycentric or simplex coordinates, distributed $NID(0,\sigma)$ with number nparRresid = number of recruitment years – 1 (Möbius, 1827; Sklyarenko, 2011). **e** was the coordinate basis matrix to scale the distance of residuals (vertices of the simplex) from zero (O'Neill et al., 2011). |
| $q_f$ and $q_{inc}^{\tilde{t}}$ | $q_{f=1,t_{2004...2014}} = \exp\left(\mathrm{mean}\left(\log\left(\frac{c_{f=1,t_{2004...2014}}}{B^2_{f=1,t_{2004...2014}}}\right)\right)\right)$,<br>and<br>$q_{f=1,t_{1988...2003}} = q_{f=1,t_{2004...2014}} / q_{inc}^{\tilde{t}}$ | Fish catchability parameter $q_f$ measured the proportion of the exploitable stock taken by one unit of standardised fishing effort by each fishing sector f. For commercial and charter fishing, the parameter was derived as a closed-form median estimate of standardised catch rates divided by the midyear biomass form 2 (Table 6) (Haddon, 2001). For recreational fishing, $q_f$ were estimated parameters for sectors 3 and 4 in equation 10 (Table 6). For a constant proportional change in Queensland commercial catch rates (f = 1) using $q_{inc}^{\tilde{t}}$ , the closed form equations for the median and slope of change from Haddon (2001) were used. $\tilde{t}$ was the number of year scaled back from 2004 (e.g. 2004 - 2001 =3) and $\tilde{t}$ = 0 for $t \geq$ 2004. This was employed to quantify an assumed increased reporting rate ($q_{inc}$) of pearl perch in the Qld logbook 1988–2003. A new Qld logbook including pearl perch was implemented in 2004. |

***Table 8. Negative log-likelihood functions for calibrating population dynamics.***

| ***-LL* functions for:** | **Theory description** | **Equations** |
|---|---|---|
| **Log standardised catch rates for each fishing sector f =1 ($c_{f,t}$); also used for recreational harvests f = 3 and 4 ($C_{f,t}$):** <br> $\frac{n}{2}\left(\log(2\pi)+2\log(\hat{\sigma})+1\right)$, or simplified as $n\log(\hat{\sigma})$, <br> where $\hat{\sigma}=\sqrt{\sum\left(\left(\log(c_{f,t})-\log(\hat{c}_{f,t})\right)^2\right)/n}$ and $n$ was the number of annual data for each annual time series of catch rates or harvest component. | Normal distribution <br> (Haddon, 2001) | (12) |
| **Fish length ($l$) and age ($a$) composition data:** <br> $-\sum\left(\log\left(T^{(\tilde{n}-1)/2}\right)-\left(\frac{1}{2}(\tilde{n}-1)\frac{T}{\hat{T}}\right)\right)$, or simplified as <br> $-\sum\frac{1}{2}(\tilde{n}-1)\left(\log T-T/\hat{T}\right)$, <br> where $\tilde{n}$ was the total number of categories ($l$ or $a$) with proportion-frequency > 0, $\hat{T}=(\tilde{n}-1)/2\sum\hat{p}\log(\hat{p}/p)$, $T=\max(2,\hat{T})$ specified sample size bounds, $\hat{p}$ were the observed proportions > 0 and $p$ were predicted. | Effective sample size (*T*) in multinomial likelihoods (Leigh, 2011; O'Neill *et al*., 2011; Leigh *et al*., 2014; Leigh, 2016) | (13) |
| **Instantaneous natural mortality $M$ year$^{-1}$:** <br> $0.5\left(\frac{M-0.2}{\sigma}\right)^2$, where $\sigma=0.05$ defined the prior distribution ≅ 25% CV based on the description in Table 7. | O'Neill *et al*. (2014) | (14) |
| **Annual log recruitment deviates $\eta$ :** <br> $\frac{n}{2}\left(\log(2\pi)+2\log(\sigma)+(\hat{\sigma}/\sigma)^2\right)$, or simplified as <br> $n\left(\log\sigma+\frac{1}{2}(\hat{\sigma}/\sigma)^2\right)$, <br> where $\sigma=\min\left(\max(\hat{\sigma},\sigma_{\min}),\sigma_{\max}\right)$, $\sigma_{\min}=0.1$ and $\sigma_{\max}=0.4$ specified bounds, $\hat{\sigma}=\sqrt{\sum\eta^2/n}$ and $n$ was the number of recruitment years modelled with variance. The default upper bound of 0.4 was changed to 0.2 in analysis 3. | O'Neill *et al*. (2014) | (15) |

## 5.3 Results and discussion

The results and discussion section describes trends in pearl perch data, predictions from analyses and general conclusions and recommendations. The key data and analyses results are structured under two sub-headings for the ‘data inputs’ into the model and the ‘population dynamic model’ estimates and diagnostics. The flow of stock model operations from data inputs to evaluating outputs are illustrated in Figure 29.

The procedure for the stock assessment of pearl perch required an iterative process of testing key input data, with practical simplification and refinement of the population dynamics model. This process defined five different scenarios for MCMC analysis and two additional analyses using maximum likelihood estimation only. The scenarios aimed to deliver results that adequately explained aspects of the data and uncertainties in model predictions. The range of estimates across analyses, including confidence intervals on predictions, should be viewed carefully to understand the uncertainty in outputs and caveats for appropriately managing the pearl perch fishery.

### 5.3.1 Data inputs

#### 5.3.1.1 Harvests

The pearl perch harvest data was analysed primarily for the fishing years 1988–2014 (Figure 30), but also considered hind casted average annual harvest and effort with respect to each sector’s data (Figure 27). This was to account for the lack of early time series data needed to enable a realistic starting condition for the model in 1998. The data analyses were summarised to calendar years, with the descriptive terms ‘fishing year’ or ‘year’ synonymous. The data from each jurisdiction was described using the labels: “NSW” = New South Wales and “Qld” = Queensland.

From the combined commercial and charter logbook data across NSW and Queensland waters, the estimated pearl perch annual harvests ranged 30–70 t between 1988 and 2002 (Figure 30). The estimated annual harvests increased to near 140t between 2003 and 2005. After 2005, the annual harvests declined to a low of 30–40 t in 2013 and 2014.

Missing records on pearl perch harvests from the Queensland charter 1988–1995, NSW commercial 1988–1990 and NSW charter 1988–2000 were estimated to enable a time series for stock assessment (Figure 30). Queensland charter harvests 1988–1995 were estimated from an over-dispersed Poisson GLM modelling the 1996–2014 trend. The standard errors on the estimated Queensland charter harvests ranged 4.5–2.9 t respectively for 1988–1995. The NSW commercial 1988–1990 and charter 1988–2000 harvests were estimated based on their observed averages and standard errors of 7 t and 6 t respectively.

The recreational annual harvests of pearl perch varied with estimates ranging 3–18t from NSW waters and 11–148t from Queensland waters (Figure 28). These estimates were used as tuning data for the stock model to predict harvests based on the annual proxy-effort data of recreational vessel registrations, and the trend in estimated oceanic recreational boat fishing effort (Figure 28 and Figure 31). The decline in Queensland recreational oceanic (>5 km offshore) fishing effort was about 18% between the 2000 and 2013 survey estimates (Figure 31).

The harvest estimates described were used as inputs into the population dynamic model. Alternate historical patterns of higher or lower commercial or charter harvests are possible, but at this time they were unclear and no alternate values were reconstructed. To cover uncertainty in estimated recreational harvests and effort, two different proxies of recreational fishing effort were examined from around the year 1996 onwards (Figure 28): a) correlated with increasing offshore vessel registrations (excluding sail boats), and b) adjusted downwards from 1996 for the declining trend in estimated oceanic recreational boat fishing effort derived from phone and diary surveys. Such scenarios may impact the estimates sustainable yields (e.g. higher input harvests may increase estimated yields and lower recreational effort may decrease estimated yields).

The base harvest schedules above considered all reported pearl perch harvests from commercial and charter operations and from recreational fishing. Additional unreported harvests and fishing effort are unknown. From examination of the recreational pearl perch data, there was no evidence of duplicated charter data.

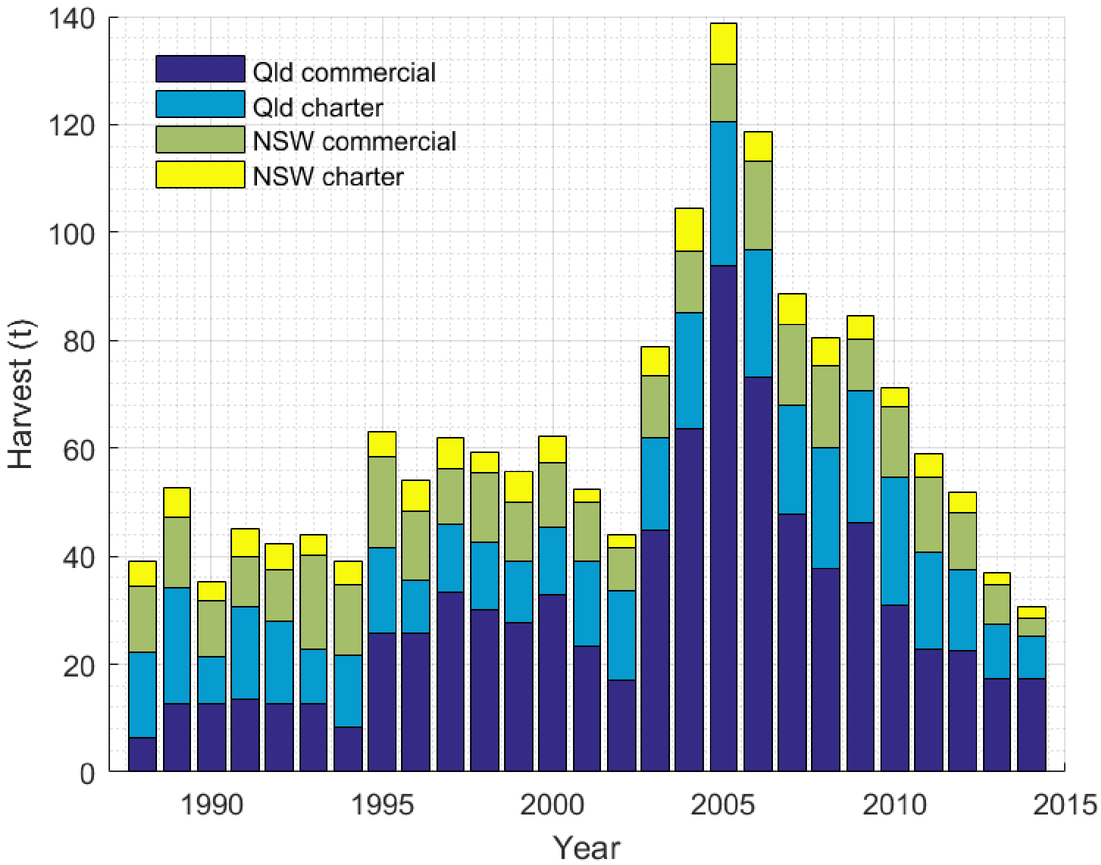


***Figure 30. Estimated total harvests of pearl perch by calendar year from the NSW and Queensland (Qld) logbook databases. The stacked bars compare harvests taken by commercial and charter fishing operations. The measure of annual harvests was the total fish weight in tonnes (t). Missing records on harvests from Qld charter 1988–1995, NSW commercial 1988–1990 and NSW charter 1988–2000 were estimated.***

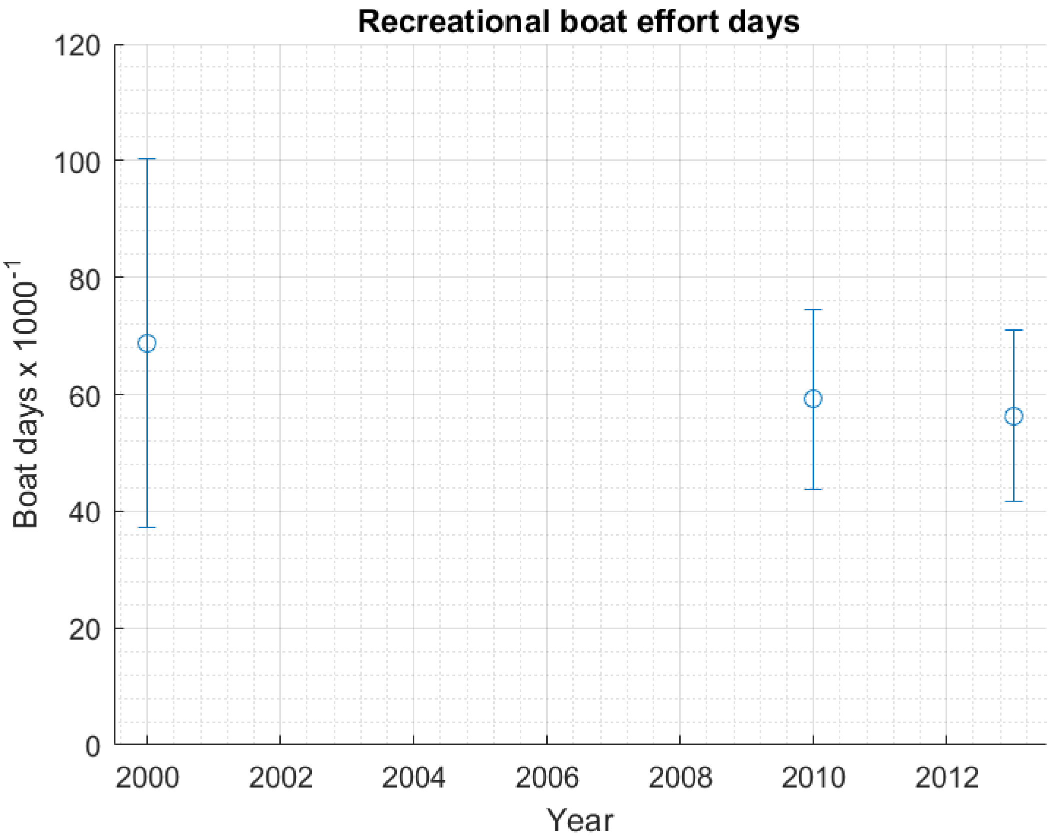


***Figure 31. Survey estimate of recreational boat-based fishing-effort-days for oceanic locations (>5 km offshore) from the Fraser coast to south-east Queensland. The estimates exclude Moreton Bay and Rockhampton coastal waters. Errors bars illustrate asymptotic confidence intervals (± 2 s.e.). The estimates were calculated by DAF Recreational Fishing Monitoring (Dr J Webley, email dated 5 May 2016).***

#### 5.3.1.2 Catch rates

For the pearl perch stock assessment, relative long term trends in fish abundance were inferred from the Queensland commercial logbook standardised catch rate. This index is of great importance to the stock assessment model as it informs proportionally on the magnitude of change in the pearl perch fished (exploitable) population. The inferences from the catch rate index were also balanced with the signals from the recent (≥2006) monitoring of pearl perch age-length data. No fishery-independent data were available for pearl perch.

The assumption of proportionality was made only after employing a fishing power offset regression model (Section 6.4) and adjusting for the assumed increased reporting rate ($q_{inc}$) of pearl perch in the Queensland logbook 1988–2003 data (Table 6; pearl perch was a voluntary reported species over this time and compulsory thereafter). This was completed in order to standardise the biases or variation in the data by accounting for factors affecting relative fish abundance and fishing efficiency. The result aims to generate a time series of standardised catch rates that is more representative of trends in the fished population. If a catch rate trend measure is calculated on only raw catch and effort data, then this could produce a false outcome unless sources of variability are identified and corrected as needed (Hilborn & Walters, 1992). This error can occur due to logbook reporting practises, efficiency changes in fishing effort and locations fished through time and between fishing vessels.

The Queensland commercial pearl perch catch rate data (kg of fish reported per boat-day) between 1988 and 2014 was first summarised to understand the distributional properties. The catch rate data had high variance and was highly skewed with a nominal median = 14 kg vessel-day$^{-1}$, mean = 27 kg and standard deviation = 45 kg (CV = 167%). All harvests were reported as weight of fish and not numbers. Significant variance in catch rates between primary vessels was evident, with some surprisingly large harvests (>100 kg boat-day$^{-1}$; maximum = 1132 kg). The variance in catch rate data by year is illustrated in Figure 32. Control chart analysis of the data further illustrates the skewness and magnitude of some harvests (Figure 33).

The stock signals in REML standardised catch rate of pearl perch between fishing years is shown in Figure 34. The following results were noted:

- Both indices highlight a significant decline in catch rates of about 40% between 2006 and 2014.
- Both indices illustrated increasing catch rates 1988–2003. The magnitude of change was dependent on the assumed fishing power. The increase in catch rates was about 1/3 for 10% fishing power and ¾ for 40% fishing power.
- Confidence intervals for these standardised predictions were about ± 20% and illustrated in Figure 18.

The significance of the REML model terms used to standardise catch rates are listed in Table 5. For the purposes of data standardisation, we use techniques which are well established and have been applied to similar fisheries in Queensland and elsewhere, and also form the basis of the analysis that is used for many species evaluated in Queensland's annual Stock Status reporting.

Daily commercial and charter catch data for pearl perch were supplied by Fisheries Queensland and commercial catch data for NSW were supplied by the Department of Primary Industries. Single catches reported for periods greater than one day (i.e. bulk data) were excluded from the catch rate analyses; but were tallied in the summation of annual harvests. The standardisations for pearl perch in both Queensland and NSW included only line catch, which made up >95% of the total catch in Queensland, but less than 65% of the overall catch in NSW.

In the case of commercial catch data supplied by NSW, these data were treated identically to the Queensland data, but as a higher proportion of the NSW data was from trap and trawl methods, a much higher proportion of data were excluded from the standardisations.

The influence of lunar phase on catch rates was initially tested by the addition of a sinusoidal luminance pattern as described by O'Neill & 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 which advanced the luminance measure seven days (~¼ lunar period).

Prior to REML analyses using Genstat (Version 16 -2015) statistical software catches were log transformed. Year, Month and Region were included as fixed factors with a fisher identifier field used as the only random factor. Lunar covariates were omitted from final standardisations as their effect on catch rates was not statistically significant (i.e. *P* >0.05).

The adjusted means and 95% confidence intervals were back-transformed and bias corrected according to methods used by Zhou and Gao (1997).

Mean catch rate in kilograms per boat per day were calculated as:

$$\theta_y = e^{\left(\mu_y + \frac{s^2}{2}\right)}$$

where $\theta_y$ is the bias–corrected back-transformed mean catch rate in year *y*, $\mu_y$ is the adjusted mean catch rate in the natural log scale in year *y* and $s^2$ is the residual mean square from the REML.

The 95% confidence intervals for $\theta_y$ were calculated as follows:

$$e^{\left[\left(\mu_y+\frac{s^2}{2}\right)-1.96\sqrt{\frac{s^2}{n_y}+\frac{s^4}{2(n_y-1)}}\right]} < \theta_y < e^{\left[\left(\mu_y+\frac{s^2}{2}\right)+1.96\sqrt{\frac{s^2}{n_y}+\frac{s^4}{2(n_y-1)}}\right]}$$

where $n_y$ is the number of observations in year *y* and 1.96 is the critical value for the 95% confidence limit.

Table 5Significant variance was identified between the fishing vessels (Boatmark variance component = 0.474 SE= 0.036).

- Scatter plot of the standardised residuals against fitted values are displayed in Figure 17. The residual plot showed no lack of model fit.

The annual standardised catch rate trends (all years) from the REML + 40% fishing power model was assessed in the stock model. The inclusion of $q_{inc}$ in the stock model estimation cancelled the 1988–2003 difference in fishing power. Stock model sensitivity was examined by only using the standardised catch rates from 2004 and onwards. This removed any assumptions required for the 1988–2003 reported catch rates, but placed greater emphasis on interpreting the 2004–2014 decline in catch rates.

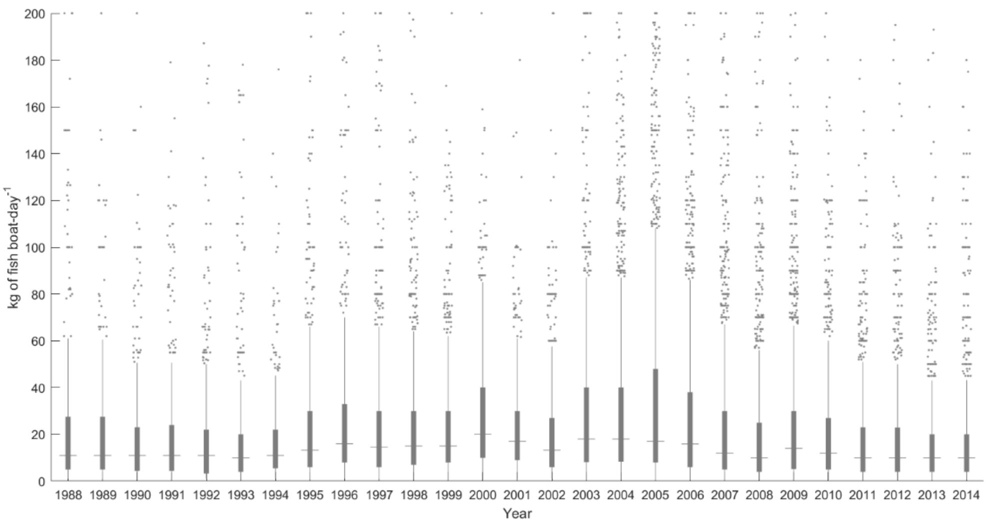


***Figure 32. Box plot of each vessel's daily harvest of pearl perch. The plot displays the skewed distributions of harvest around their medians (line in the middle of each box). The bottom and top of each box were the 25th and 75th percentiles. The whisker lengths indicate about 99% coverage of each year's harvests. Outlier points are drawn as dots. To improve the display the y-axis was limited to 200 kg, with 288 outlying harvests between 201 and 1132 kg not shown. Overall, the upper skewness of the data was 6.810 (s.e. = 0.0140) and the calculated box-cox power transformation to normalised the data and analysis residuals was λ <0.1. Total number of data points N = 30424 (unfiltered).***

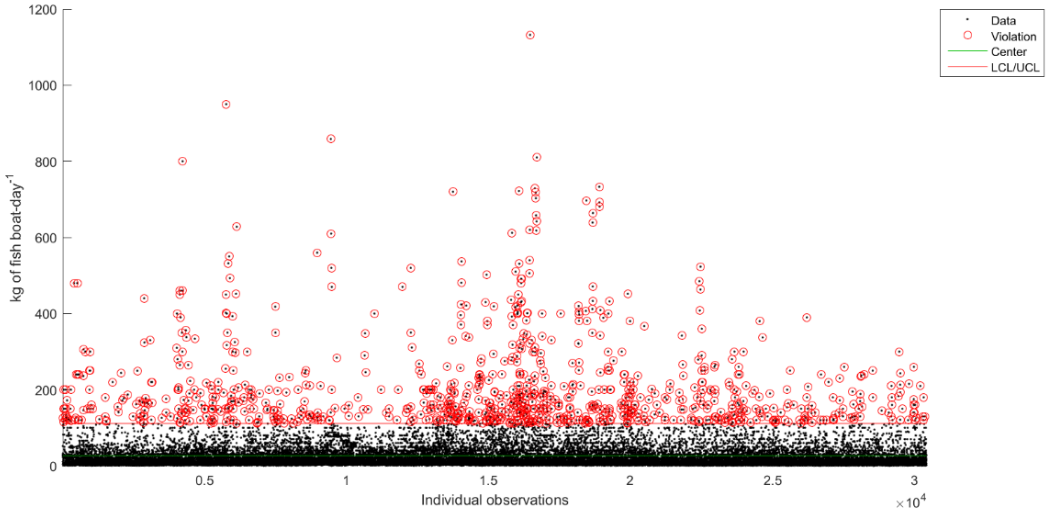


***Figure 33. Shewhart control chart for each daily pearl perch harvest by vessel (observed data unfiltered). The centre green line is the overall mean and upper and lower control limits (UCL, LCL) at three standard errors from the centre line. Out of control limits for normally distributed data/expectations are marked with a red circle.***

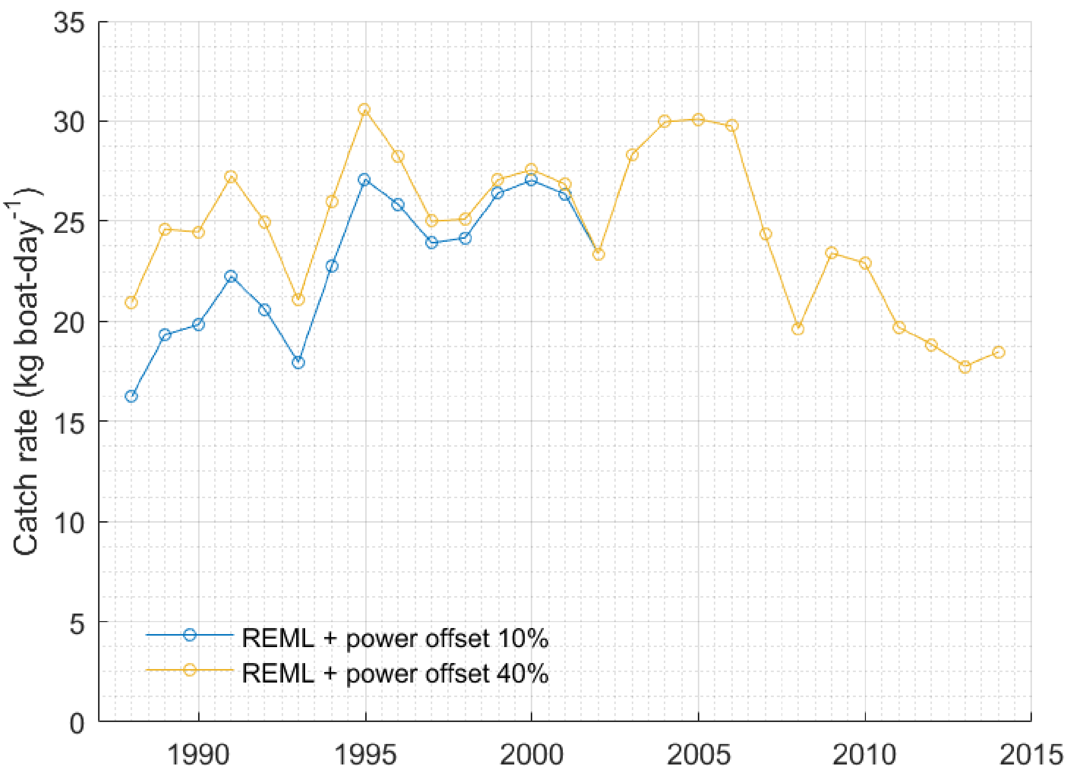


***Figure 34. Comparison of Queensland commercial standardised catch rates of pearl perch by calendar year. The two standardised indices were estimated from REML for a 10% and 40% total fishing power adjustment between 1988 and 2003. No $q_{inc}$ adjustment was applied in the figure for an increased logbook reporting rate 1998–2003. $q_{inc}$ was applied in the stock model code in order to explain the remaining increase in catch rates 1988–2003.***

### 5.3.1.3 Fish age-length composition data

The age-length structure of pearl perch has only been monitored consistently in recent years from Queensland waters. The available age frequencies (calculated by DAF-FQ long term monitoring) showed limited numbers of old fish above 8–10 years of age (Figure 35). Most of the sampled fish were aged in the 3 to 7 year age-groups. The age structures were similar between fishing sectors; noting that the same annual age-length key (ALK) was used for each fishing sector, but the length frequencies varied with sector (Figure 36). The maximum fish age found was 25 years. No recent aging data are available to verify trends in NSW waters.

Simple log-linear modelling (cross sectional catch curve, over-dispersed Poisson, p ~ year +age) of the year-by-year proportional age-structures suggested average total fish mortality rates (*Z*) at 0.40 (s.e. = 0.02), 0.57 (s.e. = 0.03) and 0.54 (s.e. = 0.02) year$^{-1}$ for the Queensland commercial, charter and recreational fishing sectors respectively. These rough *Z* values for pearl perch were in order of twice the assumed natural mortality (2M ~ 0.4–0.58). The 2M reference point can be used to gauge the fishing harvest rate at maximum sustainable yields which is approximately equal to the natural mortality (Leigh & O'Neill, 2016). Higher *Z* values also provide a relative measure of age truncation (reduced numbers of old fish).

The length frequencies (LF) of pearl perch are illustrated in Figure 36 and Figure 37. For Queensland waters, the frequencies show that large fish were sampled in 1995 and 1996 as a result of wider spatial sampling compared to the smaller fish sampled 1993–1994. For the 2006–2014 Fisheries Queensland Fishery Monitoring, the LF were generally similar between sectors in each year. This was a little surprising given the spatial and temporal variance in fishing between sectors. The main sectoral difference was in 2014 with larger fish observed commercially compared to smaller fish caught recreationally. No samples have been provided by the Queensland charter sector since 2011 due to changes in the representative peak bodies for the charter sector.

For NSW waters, the current minimum legal fish size (MLS) of 30 cm is lower compared to the 35 cm MLS in Queensland. The NSW pattern of commercially sampled fish from 1999–2014 therefore started at smaller fish compared to Queensland and was variable between years (Figure 37). From 2009-2013 the LF has gradually built towards larger fish, but the frequency of small legal sized fish 30–35 cm declined; possibly suggesting a decline in recruitment. Further examination of effective samples sizes and age determination is required to verify this pattern. This LF pattern was not evident in the Queensland LF data.

The Queensland pearl perch age frequencies (Figure 35) and LF 1993–1996 (Figure 36) were deemed consistent for input and analysis in the stock model. The Queensland LF 2006–2014 were not inputted as their information was already contained in the ALK x LF derived age structures. A more complex age–length dynamics stock model is required to fit the different LF patterns from Queensland and NSW. The NSW LF data were not inputted due to the dynamic pattern, but acknowledge the shift in the 2009–2014 LF pattern may indicate a change in recruitment of pearl perch.

The estimated age–length growth curves parameters for pearl perch are listed in Table 9. The age-based biological schedules used in the stock model are illustrated in Figure 38. Pearl perch were generally not mature until ≥four years of age.

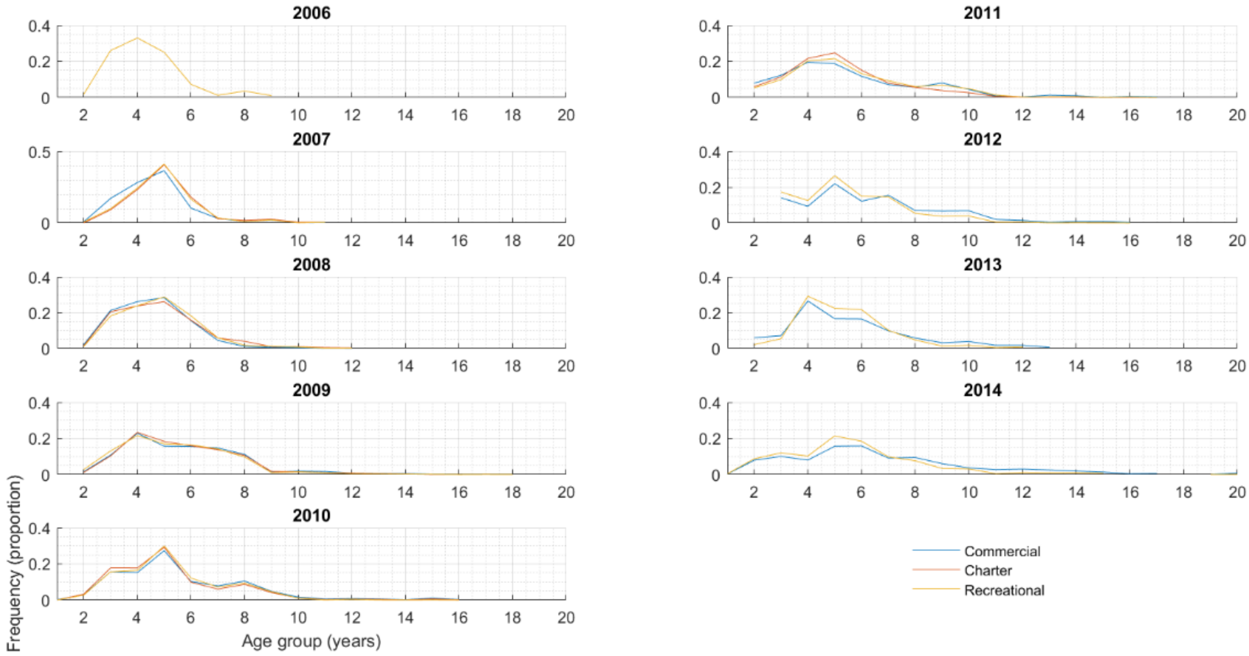


***Figure 35. Age group frequencies of pearl perch by calendar year and fishing sector from Queensland waters.***

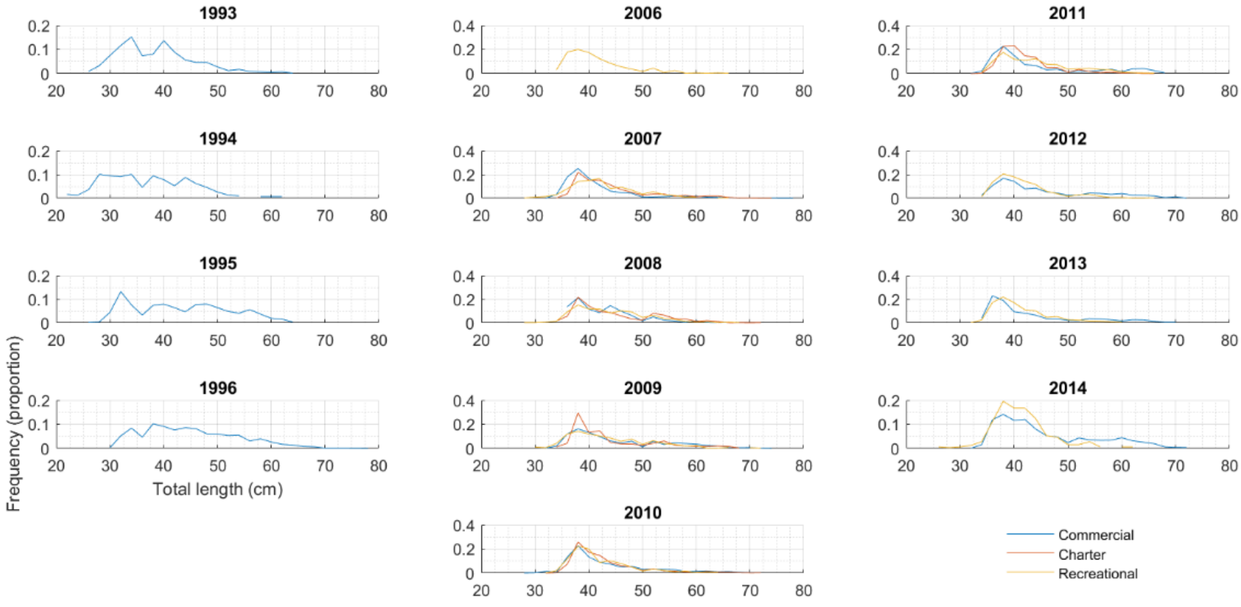


***Figure 36. Total length (TL cm) frequencies of pearl perch by calendar year and fishing sector from Queensland waters. The 2006–2014 data were collected using Fisheries Queensland monitoring procedures and the 1993–1996 data were collected for biological research.***

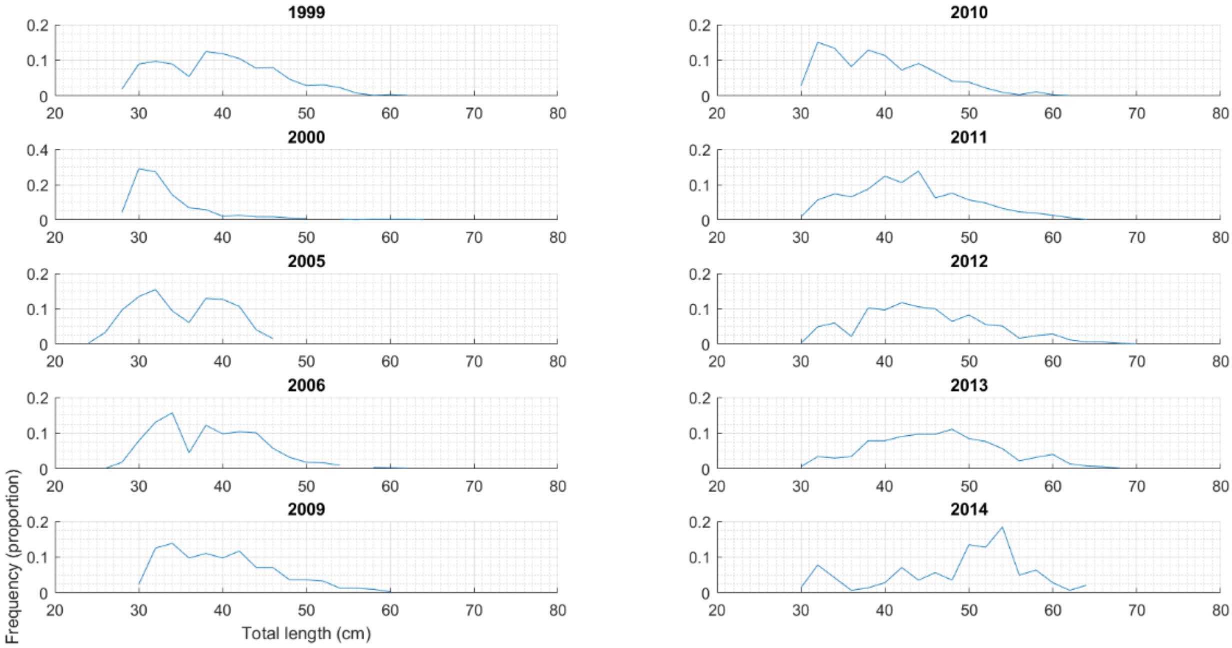


***Figure 37. Total length (TL cm) frequencies of pearl perch by calendar year from NSW waters. All samples were collected from commercial fishing operations.***

***Table 9. von Bertalanffy growth parameters used to predict fish total length (cm) from age group data (years). Parameter standard errors are in brackets.***

| Parameter | Estimate |
|---|---|
| $l_\infty$ | 72.08 |
| $k$ | 0.154 |
| $t_0$ | -0.52 |
| RMSE (std) | 6.28 |
| d.f. | 1118 |
| Adjusted $R^2$ | 0.58 |

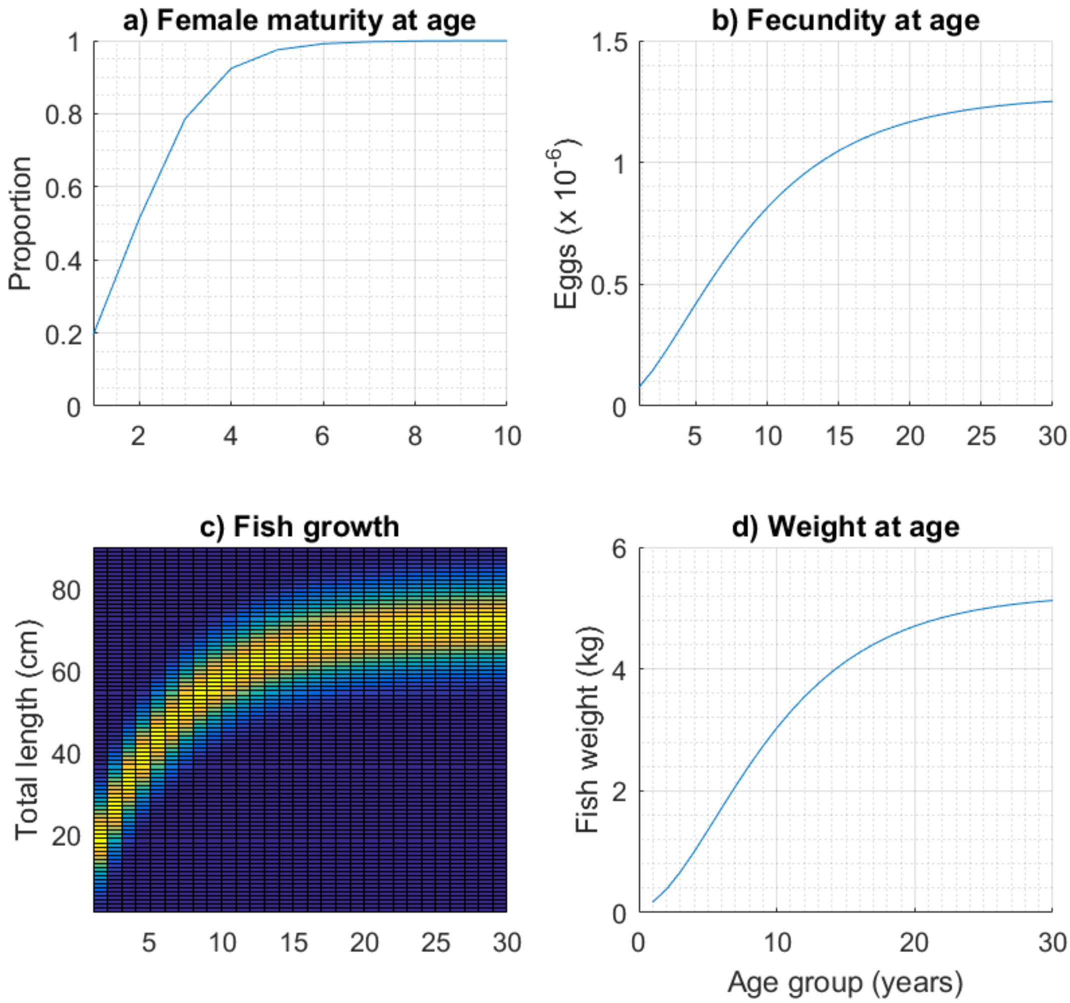


***Figure 38. Pearl perch age-based biological schedules for a) maturity, b) fecundity, c) growth and d) fish weight. Subplots a, b and d illustrate the mean estimates and subplot c illustrates the variance of the growth curve (parameters in Table 9); the lighter colours in subplot c indicate higher probability of fish growth compared to the darker low probability colour.***

## 5.4 Population dynamics model

In total, seven stock analyses were conducted to explore uncertainty in model-predicted stock status and equilibrium harvests (Table 10). The analyses varied the assumed natural mortality (*M*), catch rate index, recruitment variation and the trend in recreational fishing effort. The analyses were conducted through maximum likelihood estimation and MCMC simulation (Figure 29).

Estimation of natural mortality (*M*) was conducted in analyses 4 and 7 only, to examine the parameter's behaviour in relation to the values fixed in other analyses (Table 10). The fixed *M* values of 0.289 and 0.2 per year were used to be consistent with previous yield modelling and the longevity of pearl perch ≥22 years (Sumpton *et al*. 2013).

The index of pearl perch abundance was evaluated using a) all years of standardised catch rates (≥1988) and b) removing the pre-2004 indices (Table 10). The ≥2004 annual indices were considered to contain less uncertainty in fishing power and logbook reporting.

After model development and testing, the estimation of annual recruitment variation was not favoured in the final outputs due to the incomplete time series of age-length data and concerns over data-observation errors between years and sectors. In estimation, the full number of recruitment parameters would begin to saturate the model fit compared to the number of years of data present; an extra 26 annual recruitment parameters are needed to cover the model years 1988–2014. In the majority of analyses, the calculation of annual fish recruitment was assumed deterministic according to the Beverton-Holt function with no error (Table 10). Confidence intervals on model predictions should be viewed with consideration of broader uncertainty. The effect of recruitment variation was only presented for analysis 3 (Table 10), with the sigma negative log-likelihood setting limited to 0.2 rather than default $\square_{max}$ = 4 (Table 8).

Two proxies of recreational fishing effort were examined to test the effect of increased fishing as suggested by the licencing data and reduced fishing based on adjustment using survey data (Figure 28 and Figure 31).

***Table 10. Model input data settings for 7 scenarios tested using the stock model.***

| Analysis | Natural mortality (*M*) | Qld commercial catch rate years | Recruitment variation | Recreational effort proxy |
|---|---|---|---|---|
| 1 | 0.289 | ≥ 1988 | 0 = deterministic | BL = boat licences |
| 2 | 0.289 | ≥ 2004 | 0 | BL |
| 3 | 0.289 | ≥ 1988 | Estimated ≥ 2006 | BL |
| 4 | Estimated | ≥ 1988 | 0 | BL |
| 5 | 0.289 | ≥ 1988 | 0 | BL adjusted |
| 6 | 0.2 | ≥ 2004 | 0 | BL |
| 7 | Estimated | ≥ 2004 | 0 | BL adjusted |

The parameter estimates for the seven stock analyses are listed in Table 11. The estimates were sensitive to the assumed combination of data and parameters. Pearl perch productivity was measured through the Beverton-Holt stock recruitment function (parameters $r_{comp}$ or $h$ and $R_0$). The estimates of virgin recruitment ($R_0$) generally had large standard error (= standard deviation of MCMC simulations). $R_0$ increased 2–3 times when estimated in combination with natural mortality $M$ (analyses 4 and 7). For analyses 4 and 7, $M$ per year was estimated at 0.383 and 0.321 respectively and much higher than the range of 0.2–0.289 derived from general empirical methods. The estimate of $R_0$ was lowest for M = 0.2 and using only catch rate data from the years 2004–2014 (analysis 6). The modelled effects of using only catch rate data from the years 2004–2014 reduced the estimate of stock resilience $h$ (comparing analyses 1 and 2). The estimate of $R_0$ was higher and $h$ lower when assuming the adjusted recreational effort proxy (comparing analyses 1 and 5). The inclusion of recruitment variation in the model increased the estimated stock resilience $h$ (analysis 3 compared to analysis 1). The estimates of pearl perch 50% and 95% age-at-vulnerability were consistent between analyses, with $a_{50}$ ≈ 2.7 years and $a_{95}$ ≈ 4.5 years (Table 11).

Stock model diagnostics for the seven analyses are illustrated in Appendix 1. Serial plots of the retained parameter simulations showed the MCMC sampling performed credibly (Figure 44, Figure 45, Figure 46, Figure 47, Figure 48, Figure 49 and Figure 50). The MCMC traces and variation generally showed no obvious trends and made frequent jumps to cover parameter uncertainty. The key parameter uncertainties and behaviours to note in the MCMC traces (Appendix 1) were for $R_0$ in analyses 1, 3, 5 and 6; $h$ in analyses 4 and 7;NSW recreational catchability in analysis 5; $M$ and the recreational catchabilities in analysis 7. The estimated values of these parameters differed between models and indicate that caution is needed when interpreting stock productivity and for setting management targets for harvest and fishing effort.

Model fits to the standardised catch rates and age-length data were sound and visually similar between models (Appendix 1). Example goodness-of-fit plots, for maximum likelihood solutions, are shown for analyses 2 and 5 for catch rates (Figure 51 and Figure 52), and analyses 3 and 5 for age data (Figure 53 and Figure 54). The maximum likelihood predictions of recreational harvests were improved for the adjusted proxy of recreational effort compared to the boat registrations (Figure 55); the predictions showed more uncertainty for Queensland harvests.

***Table 11. Maximum likelihood parameter estimates for the stock model analyses. Standard errors for all estimates are shown in parenthesis. $r_{comp}$ is the recruitment compensation ratio, $h$ = steepness (proportion) and was calculated from $r_{comp}$, $R_0$ = virgin recruitment-numbers of fish (millions), $a_{50}$ = age at 50% vulnerability and $a_{95}$ = age at 95% vulnerability, and $M$ = natural mortality $yr^{-1}$.***

| **Analysis** | **Estimates (s.e.)** | | | | | |
|---|---|---|---|---|---|---|
| | $r_{comp}$ | $h$ | $R_0$ | $a_{50}$ | $a_{95}$ | $M$ |
| **1** | 2.888 (2.695) | 0.419 (0.104) | 1.245 (1.377) | 2.796 (0.131) | 4.534 (0.354) | 0.289 (0) |
| **2** | 1.617 (0.433) | 0.288 (0.03) | 1.33 (0.615) | 2.765 (0.126) | 4.512 (0.35) | 0.289 (0) |
| **3** | 3.158 (3.445) | 0.441 (0.126) | 1.125 (0.588) | 2.583 (0.134) | 4.162 (0.358) | 0.289 (0) |
| **4** | 1.108 (0.184) | 0.217 (0.021) | 3.438 (1.797) | 2.899 (0.129) | 4.618 (0.309) | 0.383 (0.016) |
| **5** | 1.666 (0.129) | 0.294 (0.016) | 1.49 (2.743) | 2.709 (0.129) | 4.484 (0.354) | 0.289 (0) |
| **6** | 3.773 (2.047) | 0.485 (0.073) | 0.809 (0.798) | 2.651 (0.143) | 4.586 (0.424) | 0.2 (0) |
| **7** | 1.216 (0.607) | 0.233 (0.031) | 3.146 (2.658) | 2.725 (0.144) | 4.46 (0.351) | 0.321 (0.026) |

This assessment represents the first exploratory stock analyses for pearl perch and analyses data up to the end of 2014. The analyses estimated a range of possible population sizes. The interpretation of results should be cautious and must consider the uncertainty in data and assumptions. The estimated stock ratios (comparing the year 2014 level to unfished virgin levels) differed markedly between analyses (Figure 39) and the medians ranged between 15% and 50% for spawning egg production, and 15% and 40% for exploitable biomass. This was a consequence of uncertainty in the standardised catch rate series and harvest data. Across the analyses the stock ratios were estimated as follows (Figure 39):

- Estimated egg production and biomass ratios were near 45% and 40% respectively, when all catch rate data and recruitment variation were included (analyses 1 and 3).
- Recruitment variation was estimated to be $\sigma \approx 0.28$ for log recruitment deviates in analysis 3 and elevated the predicted stock ratios compared to the assumption of deterministic recruitment in analysis 1. Relaxation of the maximum sigma in the default negative log-likelihood (Table 8) resulted in an unreasonably high $\sigma \approx 0.5$ and the median egg-spawning ratio increased to 0.53; the resulting median exploitable biomass ratio was unchanged.
- Egg production and biomass ratios were near 40% from analysis 4 when $R_0$ and $M$ were estimated to be large and all years of catch rate data were used.

- The remaining stock analyses (2 and 5–7) estimated the stock ratios as generally less than 30%. The main drivers for the lower predictions were the decline in 2004–2014 catch rates, lower M and the adjusted recreational effort proxy.

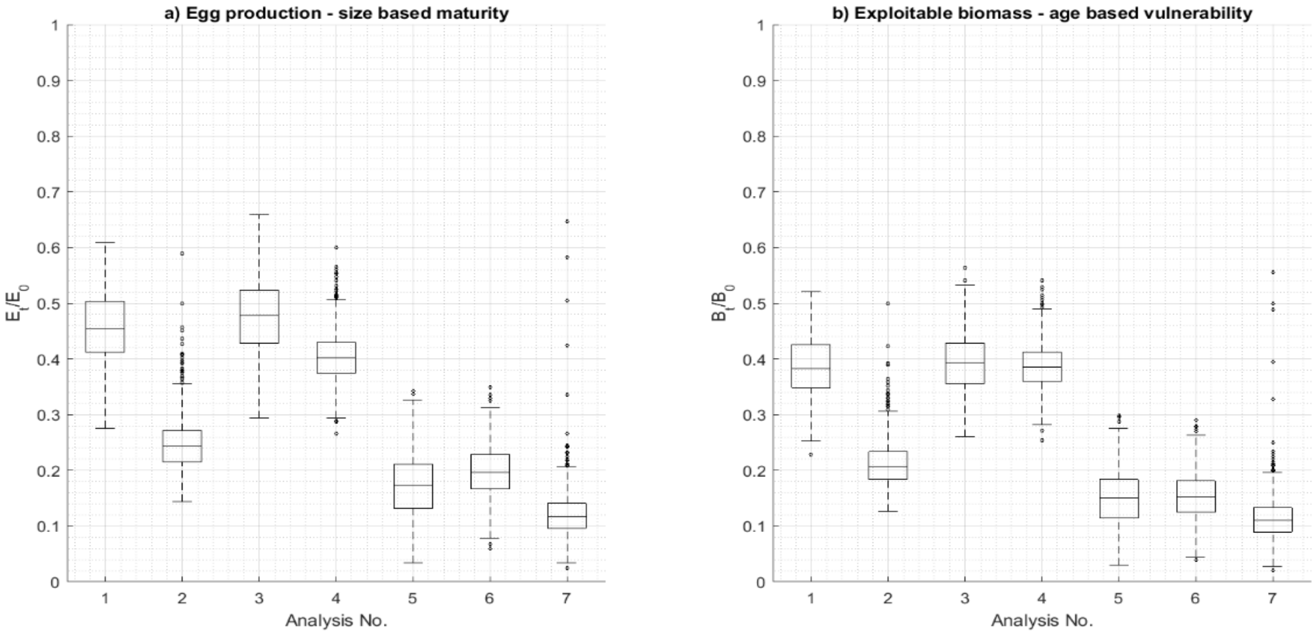


***Figure 39. The estimated stock status ratios of pearl perch for a) egg production in the t = 2014 fishing year compared with virgin egg production t = 0 and b) exploitable biomass compared with virgin biomass. Each boxplot illustrates the distribution around the median (line in the middle of each box). The bottom and top of each box were the 25$^{th}$ and 75$^{th}$ percentiles. The whisker lengths indicate about 99% coverage of the MCMC simulations; outlying estimates are represented by small circles.***

As outlined in the methods section, fishery management reference points were estimated corresponding to equilibrium (average) $B_{MSY}$ and assumed $B_{MEY} \approx 0.6B_0$. These bench marks correspond to the limit and target reference point concepts used by the Australian Government (Australian Government, 2007). No formal or other reference points have yet been set for pearl perch. The estimated reference points encompass all fishing sectors across NSW and Queensland waters.

The pearl perch reference point estimates and their variances are displayed in Figure 40. The estimates varied with analysis settings; and will continue to vary without improved long-term monitoring and validation of fishery data. The estimates suggest that historical harvests and fishing effort of pearl perch were near or exceeded maximum sustainable levels. The reference point predictions are summarised as follows:

- Median MSY was estimated near 250 t for analyses 1, 3 and 6 (Figure 40a).
- Median MSY was below 200 t for analyses 2, 4, 5 and 7 (Figure 40a). The lowest median MSY was near 110 (analysis 4).
- Median harvests to attain $B_{0.6}$ were below 200 t (Figure 40b).
- The median Queensland commercial catch rate for inferring $B_{MSY}$ was about 20 kg pearl perch operation-day$^{-1}$ (CI: 7–48). The median Queensland commercial catch rate for inferring $B_{0.6}$ was

higher at 34 kg pearl perch operation-day$^{-1}$ (CI: 19–80). The estimates assume constant fishing power and can be proportionally adjusted if required.

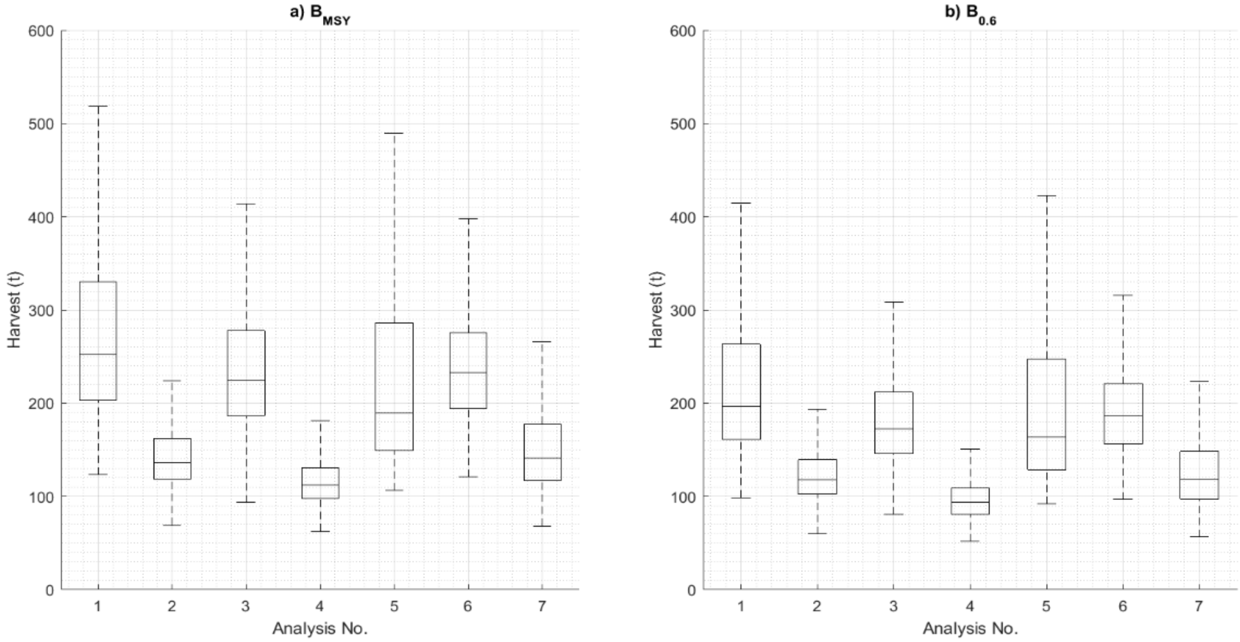


***Figure 40. The estimated equilibrium reference points for pearl perch harvest. Subplot a) shows the estimates for the exploitable biomass at MSY and subplot b) shows the estimates for higher exploitable biomass at 60% of virgin. Each boxplot illustrates the distribution around the median (line in the middle of each box). The bottom and top of each box were the 25$^{th}$ and 75$^{th}$ percentiles. The whisker lengths indicate about 99% coverage of the MCMC simulations.***

In addition to the analyses defined in Table 10, an alternate inflated harvest series for the pre-2004 commercial catch data was examined. This supplementary analysis was conducted to explore the possibility that harvests were under-reported due to limitations in logbook (see Section 5.2). This analysis (No. 8) was conducted based on inflating the annual harvest from 1988–2003 by 66% (Figure 41).The inflation rate of 66% was calculated by comparing the mean annual harvests pre and post 2004.

The resulting maximum likelihood estimates using the same input settings as analysis 1 but with the increased harvests were: $r_{comp}$ = 2.3579, $h$ = 0.37086, $R_0$ = 1.1165, $a_{50}$ = 2.7362, $a_{95}$ = 4.5135, and $M$ = 0.289

These parameter estimates were similar to the base analysis (Analysis 1). However, the stock recruitment parameters showed a lower steepness ($h$) and virgin recruitment numbers ($R_0$). The fitted recreational harvest was also marginally lower by about 10 t and better in line with data (Appendix I, Figure 56).

The stock status ratios were also lower relative to Analysis 1 estimates, with egg production ($E_{2014}/E_0$) = 0.38 and exploitable biomass ratio ($B_{2014}/B_0$) = 0.33. Likewise MSY was reduced to approximately 158 t and $B_{0.6}$ harvest was about 132 t. While the exploratory inflation of harvests better explained the data, we have no real measure to suggest that it is more appropriate. The supplementary analysis estimated a more pessimistic stock status outcome compared with analyses using unadjusted commercial harvests.

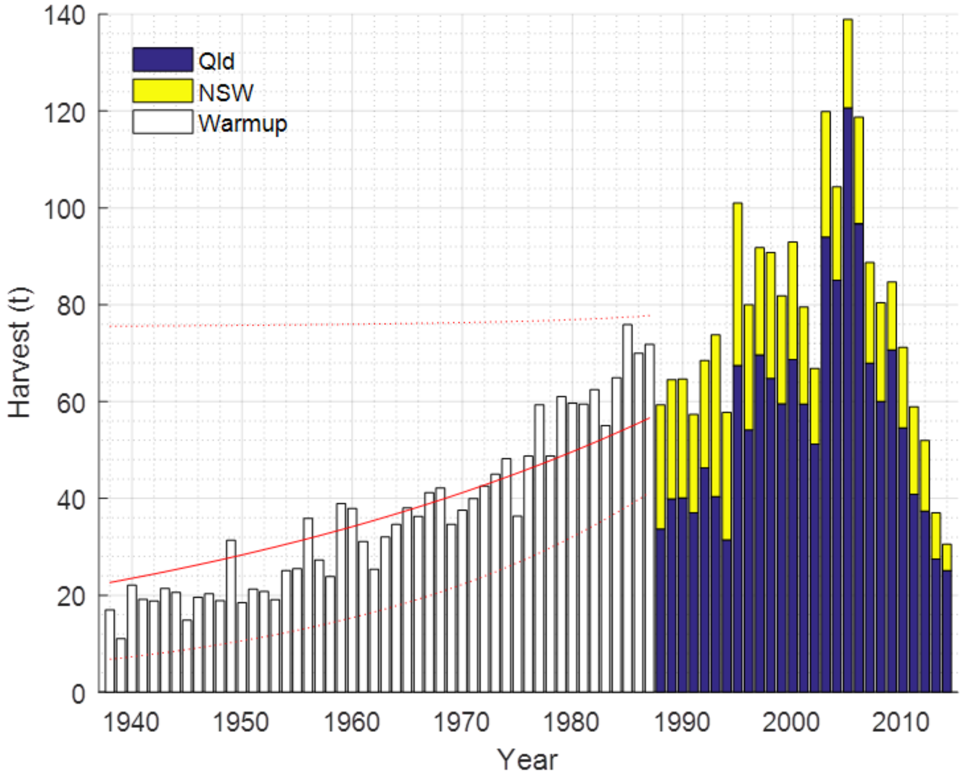


***Figure 41. An alternative harvest time series modelled based on an ad hoc inflation of the pre-2004 commercial catches. See Figure 27 for a detailed explanation of the figure.***

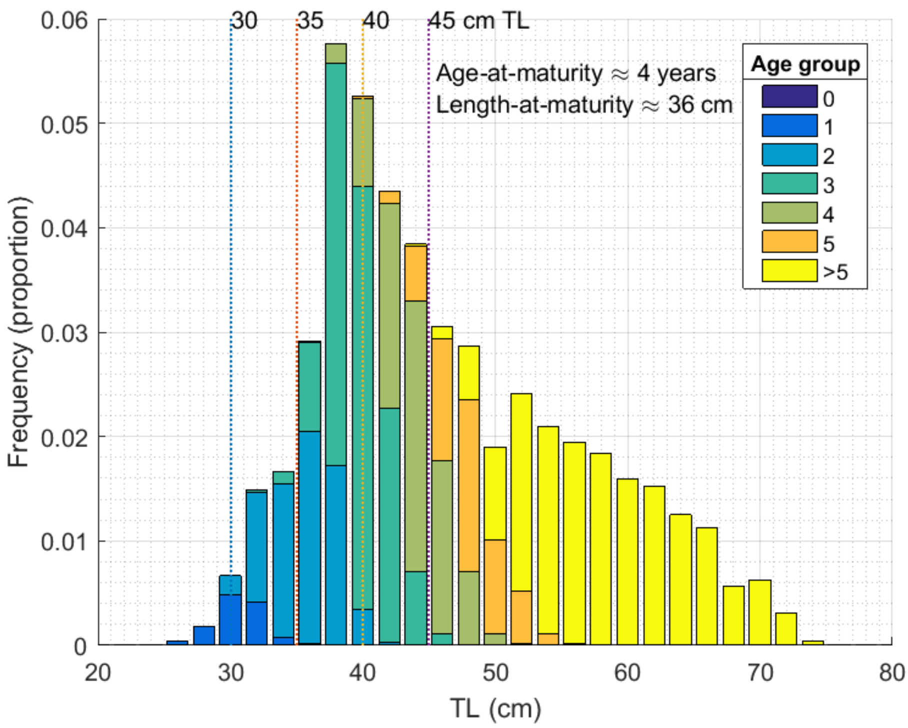


***Figure 42. Combined length frequency (2 cm categories for total lengths) of pearl perch over fishing years and sectors, with age groupings overlaid as predicted from the von Bertalanffy growth curve (Table 9).***

Figure 42 illustrates the combined length frequency of pearl perch sampled over all fishing years and sectors. Expected age frequencies at length were overlaid as calculated from the von Bertalanffy growth curve and variance, with age groups >5 years combined. For each 2 cm length category, the expected age distribution can be used as a guide for judging the spawning protection provided by the minimum legal size limit (MLS).

The length and age at maturity statistics for female pearl perch are shown in Figure 38 and Figure 42 (see also: Sumpton *et al*. 2013). Approximately 90% of female 4 year old fish were estimated to be mature and capable of spawning, with about 80% of 3 year old females mature. Younger fish (<3 years old) were generally not mature. Using these measures of maturity, Figure 42 shows:

- the Queensland MLS of 35 cm total length (TL) and NSW 30 cm MLS is protecting a low proportion of 3–4 year old fish
- only a 45 cm MLS would safely protect most 3–4 year old (typical years of first effective spawning)
- a 40 cm MLS would protect more female 3 year olds for spawning, but not sufficiently for 4 year olds.

If changes in MLS are considered in order to protect more spawning fish, then the expected mean impacts on catch rates (weight of fish caught per boat trip) may be in the order of at least 10% (Figure 43). For fishing effort set near status quo (≥MSY), an increase in MLS from 35 cm to 40 cm or 45 cm would reduce mean catch rates by about 15% and 35% respectively (Figure 43a). If fishing effort was reduced significantly to rebuild the pearl perch stock towards 60% of virgin biomass ($B_{0.6}$), then an increase in MLS from 35 cm to 40 cm or 45 cm would reduce mean catch rates by a lesser amount of about 10% and 25% respectively (Figure 43b). A reduction in MLS would increase catch rates by about 10% under both biomass scenarios. The predicted impacts on catch rates assumed fishing effort or mortality were managed to attain $B_{MSY}$ or $B_{0.6}$ stock levels. These results complement the different yield-per-recruit modelling by Sumpton *et al*. (2013), that show a 30–40 cm MLS can support a similar total fishery yield through optimising maximum fishing effort but a 45 cm MLS was less likely to do so.

Model outputs clearly suggest that, of the management measures available, the preferred option in terms of improving catch rates is a reduction in fishing mortality/effort. Any increases to the minimum legal size would cause a short-term reduction in catch rates, but may improve the quality of future catch rates as fish will be of a larger average size. The preferred strategy is clearly one of reducing effort. Other output controls, such as a reduced TAC (total allowable catch) or bag limit, could be used to reduce overall fishing mortality but the uncertainty around these outputs and the fact that the recreational catch is not regularly quantified limits the use of these management strategies. In fisheries, TACs and bag limits may limit catches in years of strong recruitment when higher catches could be attained to improve profitability in commercial fisheries and better fishing experiences for recreational fishers.

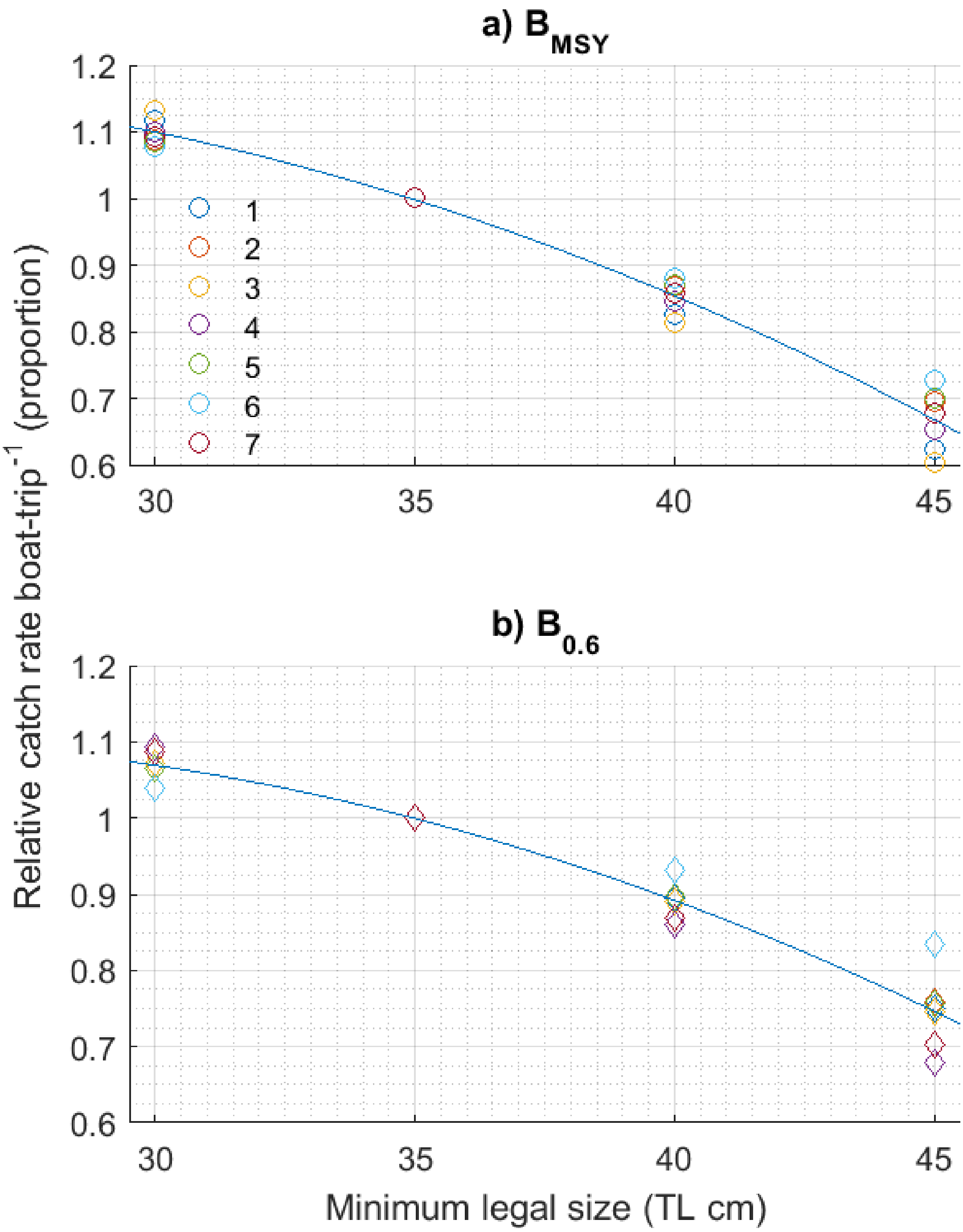


***Figure 43. Predicted proportional change in catch rates (kg) of pearl perch at different minimum legal sizes (MLS) for a) higher fishing effort at $B_{MSY}$ and b) lower fishing effort at $B_{0.6}$ for each of the seven analyses (coloured circles or diamonds). The proportions were scaled relative to a 35 cm MLS (=1 or 100%).***

# 6 Discussion

## 6.1 Stock status

The assessment of pearl perch was complex due to the different patterns and paucity of data. A weight-of evidence approach across model predictions and data was used to judge stock status. The approach provided a framework to review the credibility of different results. Expert judgment is important in stock status determination, with emphasis on documenting the key evidence and rationale for conclusions. The process of stock status determination was undertaken with the 'project team' committee.

In order to judge the stock model predicted population ratios, the following guidelines were used as described by Sloan *et al.* (2014), Flood *et al*. (2014) and the Australian Government (2007):

- Limit reference points (LRP): indicator values below a LRP are 100% not considered acceptable and relate to recruitment overfishing. Stock status ratios for a LRP default to about 20% of unfished biomasses (spawning or exploitable). The Australian Government (2007) conditions state that there should be no more than 10% chance of the stock falling below the recruitment overfished LRP.
- Trigger reference point (TrRP): indicator values below a TrRP are not desirable and is a point at which changes in management is considered and adopted. In essence, this is also a LRP. Stock status ratios for the TrRP are generally gauged to about 40% of unfished biomasses ≈ $B_{MSY}$. Given the deterministic nature of the analyses, the population MSY reference points of 40% and 35% were used respectively to gauge the TrRP on egg production and exploitable biomass ratios for MSY.
- Target reference points (TRP): indicator values that are desirable and safe and at which management should aim. They generally relate to desired economic and social objectives; e.g. a level of catch rate that is profitable and provides a quality fishing experience in terms of the number of fish caught and their size. A proxy for maximum economic yield ($B_{MEY} \approx B_{60\%}$) was used to judge this state. This is the reference point described in the recent Green paper on fisheries management reform in Queensland, July 2016.

***Table 12. Classification of the pearl perch fishery relative to limit (red), trigger (yellow) and target (green) reference points for three key lines of evidence. (Fishing pressure includes measures of fishing effort and mortality). The colour and cross 'X' symbol indicates an activated reference point, and'?' indicates uncertainty and possible trigger. See Fisheries Queensland (2010) for a description of resource assessment class (RAC; where A … D scales data knowledge and confidence from high to low respectively).***

| Evidence | LRP | TrRP | TRP | RAC |
|---|---|---|---|---|
| Standardised catch rates | ? | X | | C |
| Fishing pressure | ? | X | | B |
| Stock assessment | ? | X | | A |

Resource Assessment Class is no longer used by Fisheries Queensland in its formal stock status process, yet it provides a useful framework to describe uncertainties around the classification (Table 12). While this stock assessment and classification of input data scales the overall Resource Assessment Class (RAC) as an "A", some data inputs are uncertain and this should be considered in the overall rating of the stock assessment. Mortality estimates are ranked at the lower end of the available RAC scale (B) because of our inability to weight the contribution of each sector to the overall fishing mortality. Without more frequent estimates of recreational catch, this is not likely to improve in the near future. In addition, estimates of natural mortality are not clear and values change with the method of calculation. The time series of pearl perch harvests was also ranked on the lower end of the RAC scale (C) because of problems already discussed about commercial and charter logbook reporting in early years (however, this is better in the later years since 2004) and the error in estimates of recreational harvest.

For the standardised catch rate and fishing pressure indicators, limit reference levels have not been formally adopted (although data used to derive both these lines of evidence are incorporated in the stock assessment).

Earlier frameworks for defining stock status had target fishing mortality reference points at $F <= 0.66M$, where $M$ represents natural mortality and also defines the trigger reference point of F=M (Fisheries Queensland 2010). As previously noted, the estimation of fishing mortality is influenced by the method used and the level of assumed natural mortality. Use of the traditional estimators of natural mortality, such as Hoenig (1983), result in measures of fishing greater than natural mortality (F>M), but they were borderline ($F>\approx M$) using the more recent high natural mortality estimator of Then *et al*. (2014).

The declining indicators of catch and standardised catch rates in recent years are evidence of possible overfishing using criteria presented in Fisheries Queensland (2010) and Flood *et al*. (2016), and this is also reflected in the outcomes of the 2015 Stock Status Workshop and the outcomes of the stock assessment. The Queensland standardised commercial catch rates of pearl perch in the years 2011–2014 were below the $B_{MSY}$ indicator of 20 kg (Figure 34).

Based on the guidelines described above and the results from the stock model, the pearl perch fishery can be arguably assessed as either overfished or having reached trigger reference points (Table 12). The judgement depends on the definition of reference points and the results selected to represent the state of the fishery. From the stock analyses, the probabilities are uncertain that fishery has exceeded the guideline of a 10% chance of falling below 20% of $B_0$ ($B_{20\%}$).

The overall assessment of the pearl perch fishery suggest the stock status classification of “transitional depleting”, with the risk of recruitment overfishing uncertain. This is consistent with the results of the Queensland Government stock status workshop held in June 2016, (Queensland Department of Agriculture, Fisheries and Forestry 2016, Queensland Stock Status Assessment Workshop 2016, 14–15 June 2016, Brisbane, Queensland DAF, Brisbane) which likewise classified the stock as “transitional depleting” based on review of the data but not the stock assessment (which was not available at the time of the workshop). After the completion of the stock assessment, 20% of the project team members overseeing this assessment re-classified their rating of the stock to over-fished after considering the stock analysis outputs and accuracy.

The fishery is clearly not in any of the target reference areas based on the other available lines of evidence (Table 12). Target levels of total mortality have clearly been exceeded and standardised catch rates have steadily reduced in all sectors in recent years. All lines of evidence indicate that the combined NSW and Queensland fisheries have at least reached trigger reference levels (coloured yellow in Table 12) suggesting that effective management intervention across the entire stock is required to arrest declining fish abundance and catch rates.

## 6.2 Recommendations

a) [*Management*] *Reduce fishing pressure on pearl perch to arrest the decline in catch rates and associated fish abundance.*
Setting regulations to achieve a reduction in effective fishing is dependent on establishing target operational-objectives for the fishery. Regulations on limiting the exploitation rates (i.e. input controls on fishing pressure / numbers of fishers or boats / catchability) are considerations for all sectors. The relatively high post-release survival of pearl perch (90%) means that size limits are an effective supplementary way to manage harvests. This can be considered in combination with effective limitations on fishing effort, annual quota using a low stock size estimate and time-area closures. The open access nature of fishing (inadequate knowledge of and limitation on fishing) needs to be addressed in order to improve fishery performance, reduce overly competitive reef fishing and mitigate the technological drive of fishing. The ongoing development of improved fishing technology, in general, is a challenge to manage in fisheries. A decision tree for these generic management options are discussed by Walters & Martell (2004).

b) [*Monitoring*] *Collect time-series data on commercial and charter fishing power through compulsory logbook gear sheets*.
The impact of improved technology in hook and line fisheries is an important consideration for standardising indicators of fish abundance (catch rates). Some technologies have been included in this assessment, but there are others that have not been included due to lack of information. In many fisheries there are advances in technology in addition to the ones assessed in this report. The challenge will be to adequately model these in recreational fisheries in particular, as fishing power will continue to increase as a response to ongoing technological advancement.

c) [*Monitoring*] *Re-establish length and age monitoring of the catch of the charter sector.*
Length and age structured data is collected for both the commercial and recreational sectors, but a similar program for the charter sector was discontinued a couple of years ago, greatly eroding the value of the data collected for the other sectors.

d) [*Monitoring*] *Validate records of daily fishing effort and harvest in the commercial and charter logbooks.*
Improving validation of catch data is a current priority for fisheries management across all commercial fisheries. Information on hours fished, more precise fishing location information (through VMS/GPS) would also improve the ability model changing dynamics of the fishery and produce better indices of abundance.

e) [*Monitoring*] Us*e of recreational vessels for pursuits other than recreational fishing be quantified so that changes in fishing effort can be better understood and incorporated into stock assessments.*
Understanding and interpreting recreational fishing data continue to be a challenge, particularly the conflicting signals of declining participation rate (determined from phone surveys) and the increasing trend in effort provided by various scenarios of changes in boat registration. It will be important to better quantify the overall changes in recreational fishing effort to improve assessments in the future. This can best be achieved by examining the patterns of alternative uses of boats (for reasons other than fishing), and improved survey methodology for less frequent species like pearl perch.

f) [*Stock assessment*] *Validated commercial and charter catch and effort data for the pre-2004 era when pearl perch catches were not fully reported*.
Changes to logbooks over time have caused uncertainties in the pearl perch catch prior to 2004 when pearl perch were first included as a dedicated species in the logbooks. This is a difficult issue to address retrospectively.

g) [R*esearch*] *Gain a better understanding of the spawning dynamics of pearl perch and areas where they may aggregate to spawn*.
Pearl perch differ from other rocky reef species (such as snapper) where the spatial and temporal extent of spawning is fairly well known. There is still uncertainty around the spawning and reproductive biology of this species as previous research, as well as ongoing monitoring, has sampled very few fish in spawning condition. Given the number of fish sampled by extensive research and long-term monitoring project (LTMP) sampling over many years, this is surprising and suggests an unusual reproductive dynamic.

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# 8 Appendices.

## 8.1 Appendix 1: Stock model diagnostics.

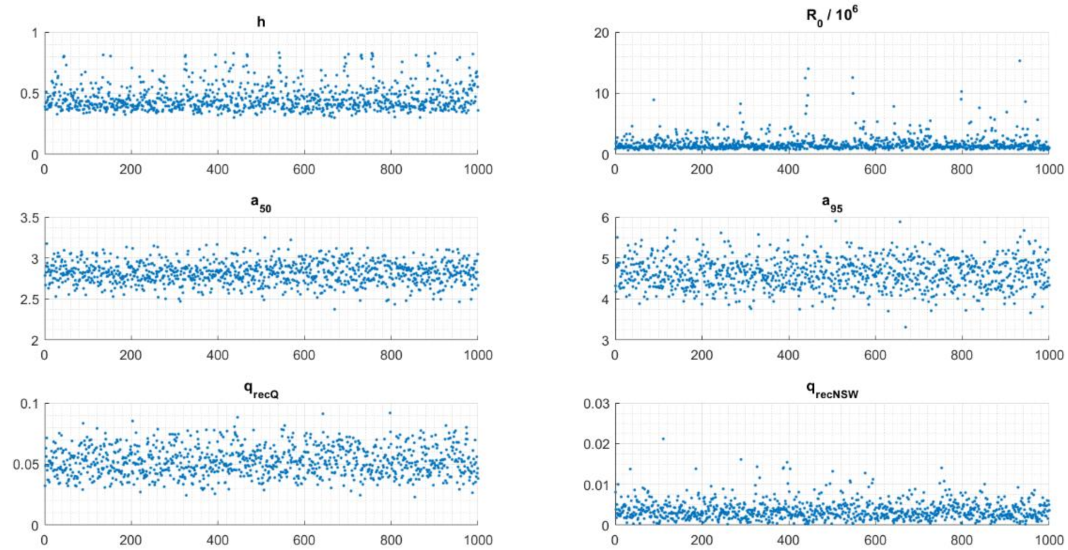


***Figure 44. Serial plot of the retained parameter values from stock model analysis 1. The listed Markov chain Monte Carlo optimisation (MCMC) parameters were: h = steepness (proportion), $R_0$ = virgin recruitment-numbers of fish, $a_{50}$ = age at 50% vulnerability, $a_{95}$ = age at 95% vulnerability, $q_{recQ}$ = Qld recreational catchability and $q_{recNSW}$ = NSW recreational catchability. n = 1000 data points per subplot. The heidel test for convergence was stationary for all parameters p>0.1.***

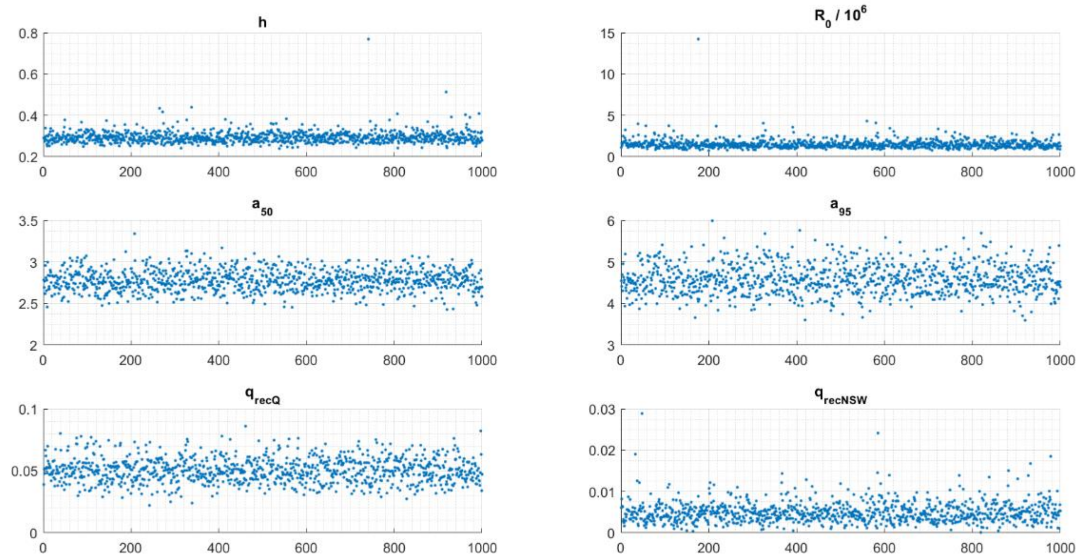


***Figure 45. Serial plot of the retained parameter values from stock model analysis 2. The listed Markov chain Monte Carlo optimisation (MCMC) parameters were: h = steepness (proportion), R0 = virgin recruitment-numbers of fish, a50 = age at 50% vulnerability, a95 = age at 95% vulnerability, qrecQ = Qld recreational catchability and qrecNSW = NSW recreational catchability. n = 1000 data points per subplot. The heidel test for convergence was stationary for all parameters p>0.1.***

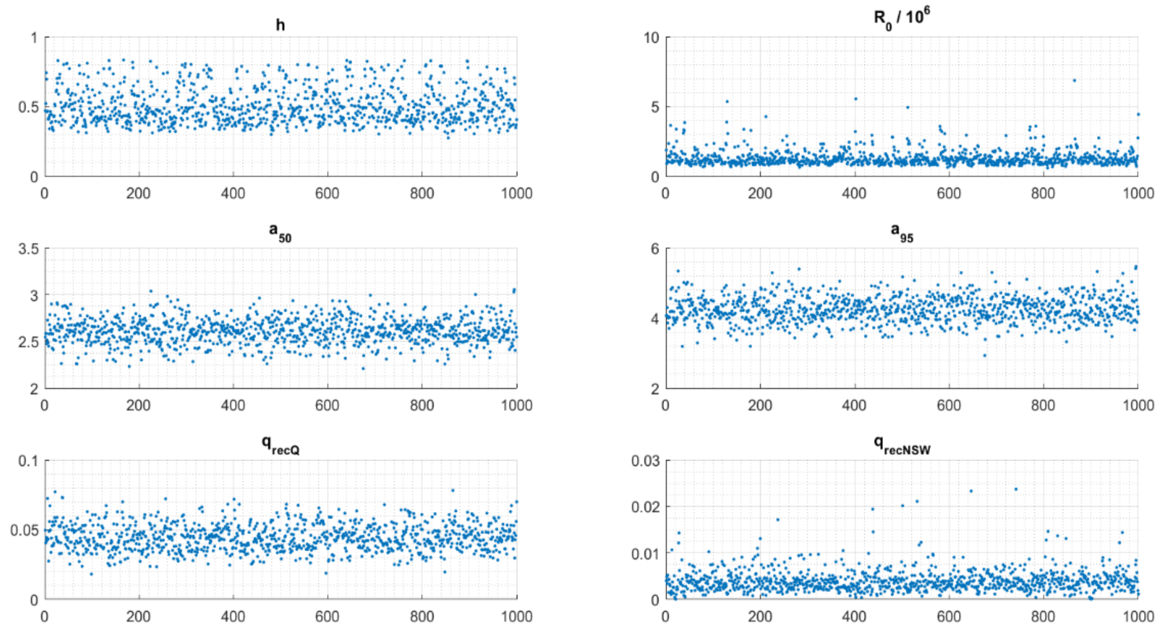


***Figure 46. Serial plot of the retained parameter values from stock model analysis 3. The listed Markov chain Monte Carlo optimisation (MCMC) parameters were: h = steepness (proportion), $R_0$ = virgin recruitment-numbers of fish, $a_{50}$ = age at 50% vulnerability, $a_{95}$ = age at 95% vulnerability, $q_{recQ}$ = Qld recreational catchability and $q_{recNSW}$ = NSW recreational catchability. n = 1000 data points per subplot. The heidel test for convergence was stationary for all parameters including the recruitment deviations (p>0.1), except $q_{recNSW}$.***

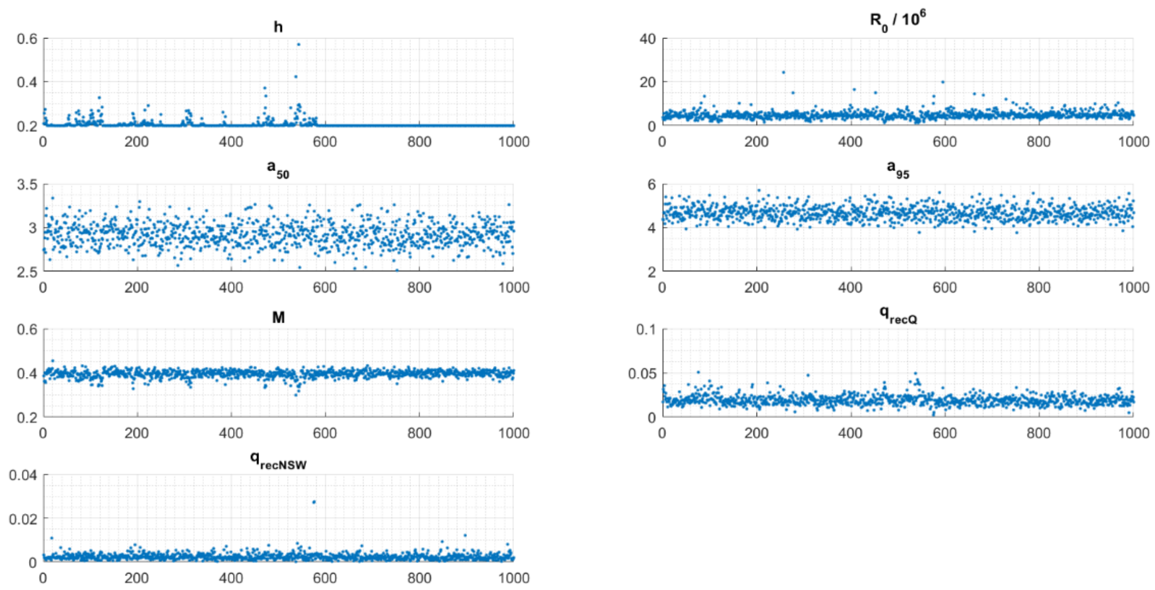


***Figure 47. Serial plot of the retained parameter values from stock model analysis 4. The listed Markov chain Monte Carlo optimisation (MCMC) parameters were: h = steepness (proportion), $R_0$ = virgin recruitment-numbers of fish, $a_{50}$ = age at 50% vulnerability, $a_{95}$ = age at 95% vulnerability, M = natural mortality year$^{-1}$, $q_{recQ}$ = Qld recreational catchability and $q_{recNSW}$ = NSW recreational catchability. n = 1000 data points per subplot. The heidel test for convergence was stationary for all parameters (p>0.1), except h which was estimated near the lower bound of 0.2.***

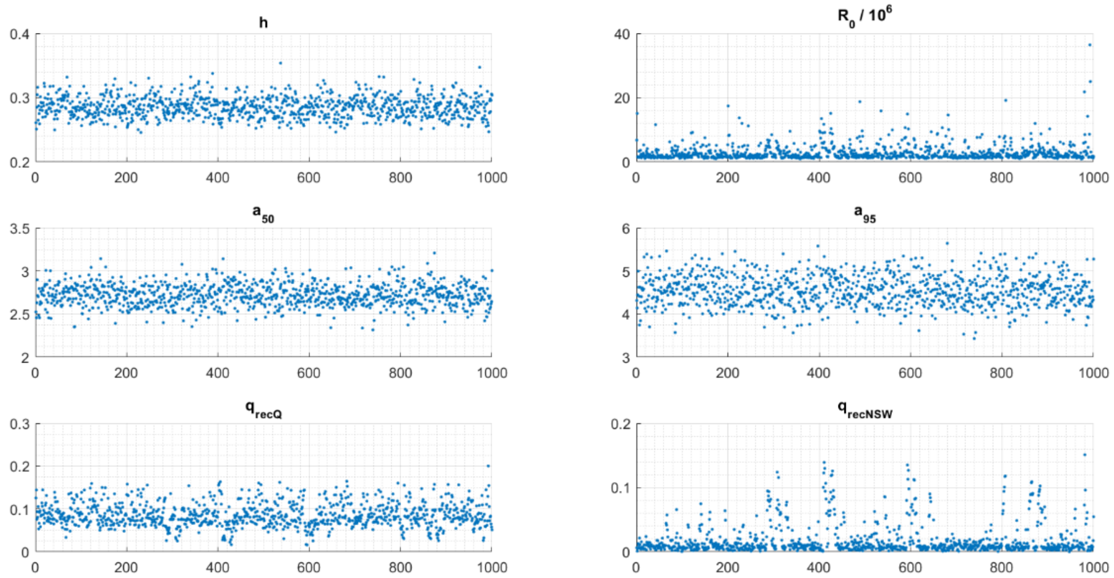


***Figure 48. Serial plot of the retained parameter values from stock model analysis 5. The listed Markov chain Monte Carlo optimisation (MCMC) parameters were: h = steepness (proportion), $R_0$ = virgin recruitment-numbers of fish, $a_{50}$ = age at 50% vulnerability, $a_{95}$ = age at 95% vulnerability, $q_{recQ}$ = Qld recreational catchability and $q_{recNSW}$ = NSW recreational catchability. n = 1000 data points per subplot. The heidel test for convergence was stationary for all parameters p>0.1.***

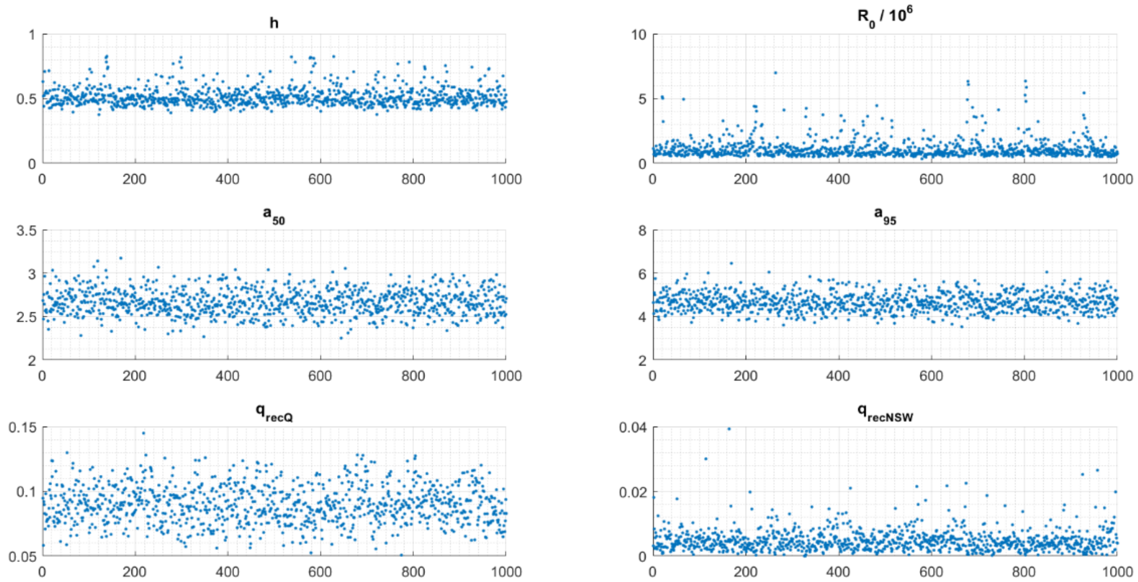


***Figure 49. Serial plot of the retained parameter values from stock model analysis 6. The listed Markov chain Monte Carlo optimisation (MCMC) parameters were: h = steepness (proportion), $R_0$ = virgin recruitment-numbers of fish, $a_{50}$ = age at 50% vulnerability, $a_{95}$ = age at 95% vulnerability, $q_{recQ}$ = Qld recreational catchability and $q_{recNSW}$ = NSW recreational catchability. n = 1000 data points per subplot. The heidel test for convergence was stationary for all parameters p>0.1.***

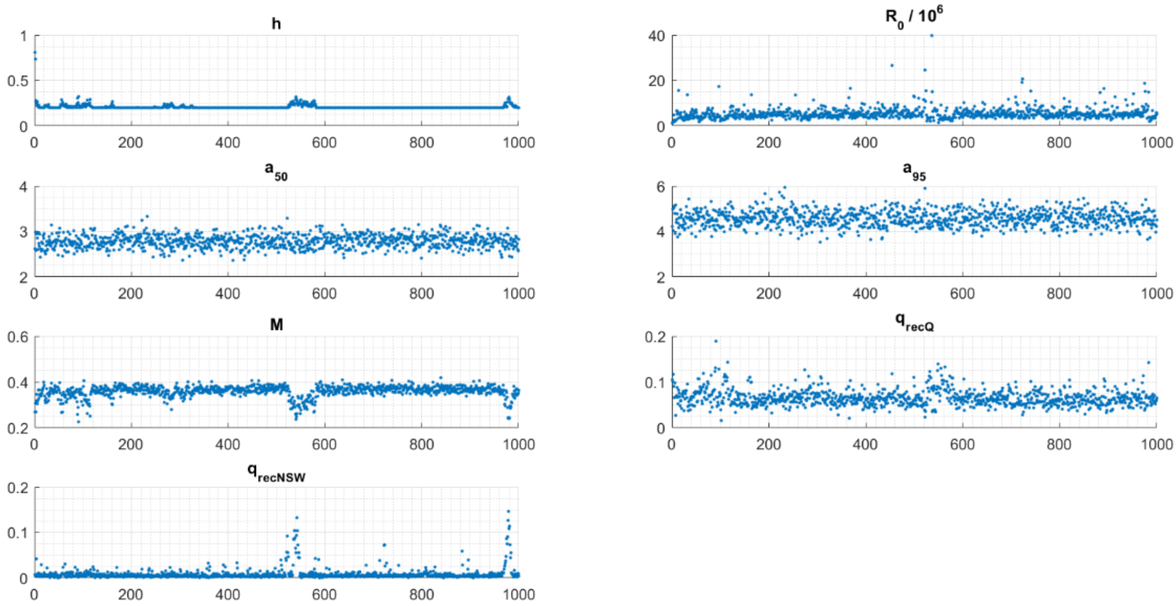


***Figure 50. Serial plot of the retained parameter values from stock model analysis 7. The listed Markov chain Monte Carlo optimisation (MCMC) parameters were: h = steepness (proportion), $R_0$ = virgin recruitment-numbers of fish, $a_{50}$ = age at 50% vulnerability, $a_{95}$ = age at 95% vulnerability, M = natural mortality year$^{-1}$, $q_{recQ}$ = Qld recreational catchability and $q_{recNSW}$ = NSW recreational catchability. n = 1000 data points per subplot. The heidel test for convergence was stationary for all parameters p>0.1.***

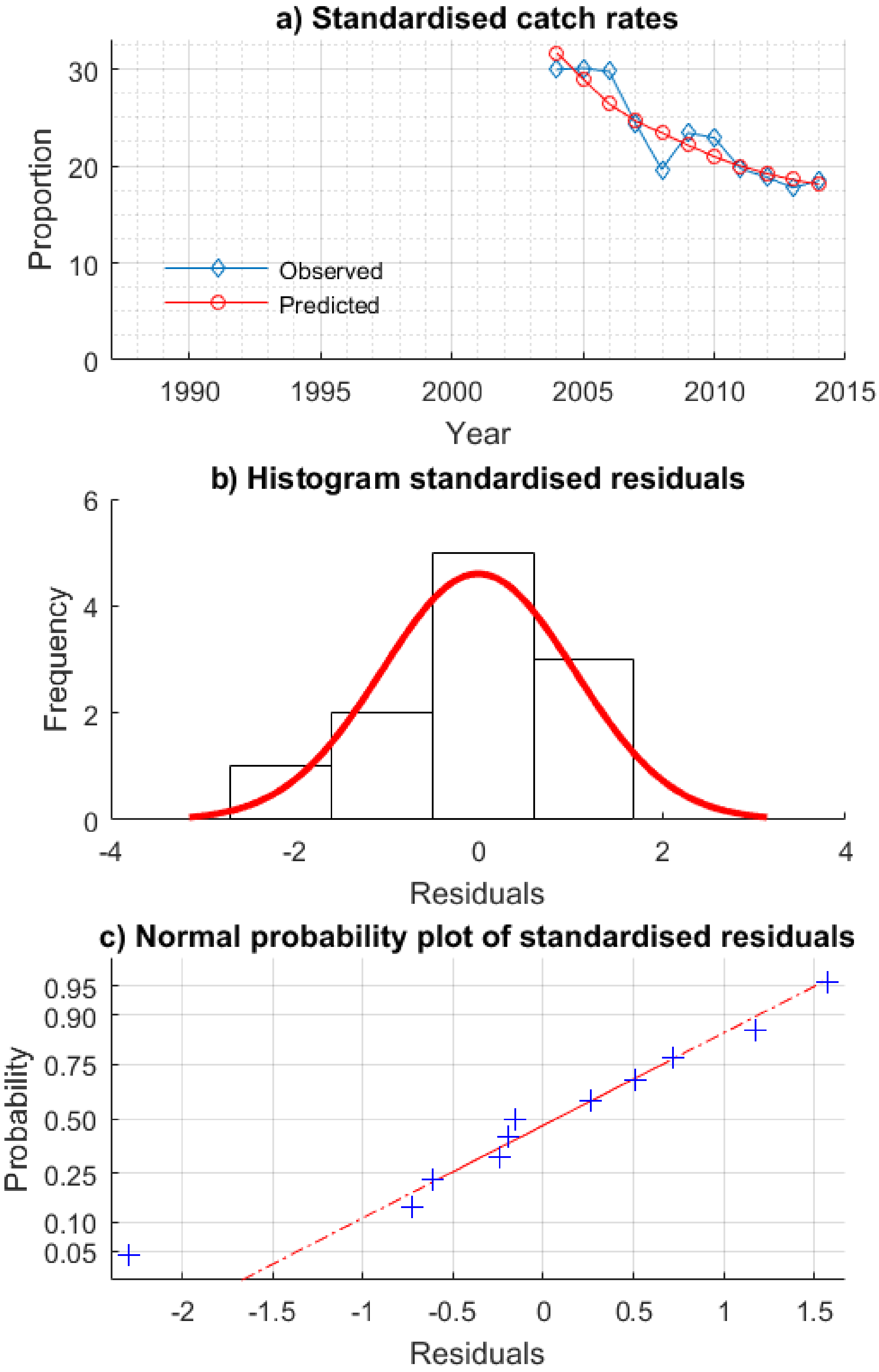


*Figure 51. Stock analysis 2 catch rate fit and standardised residuals.*

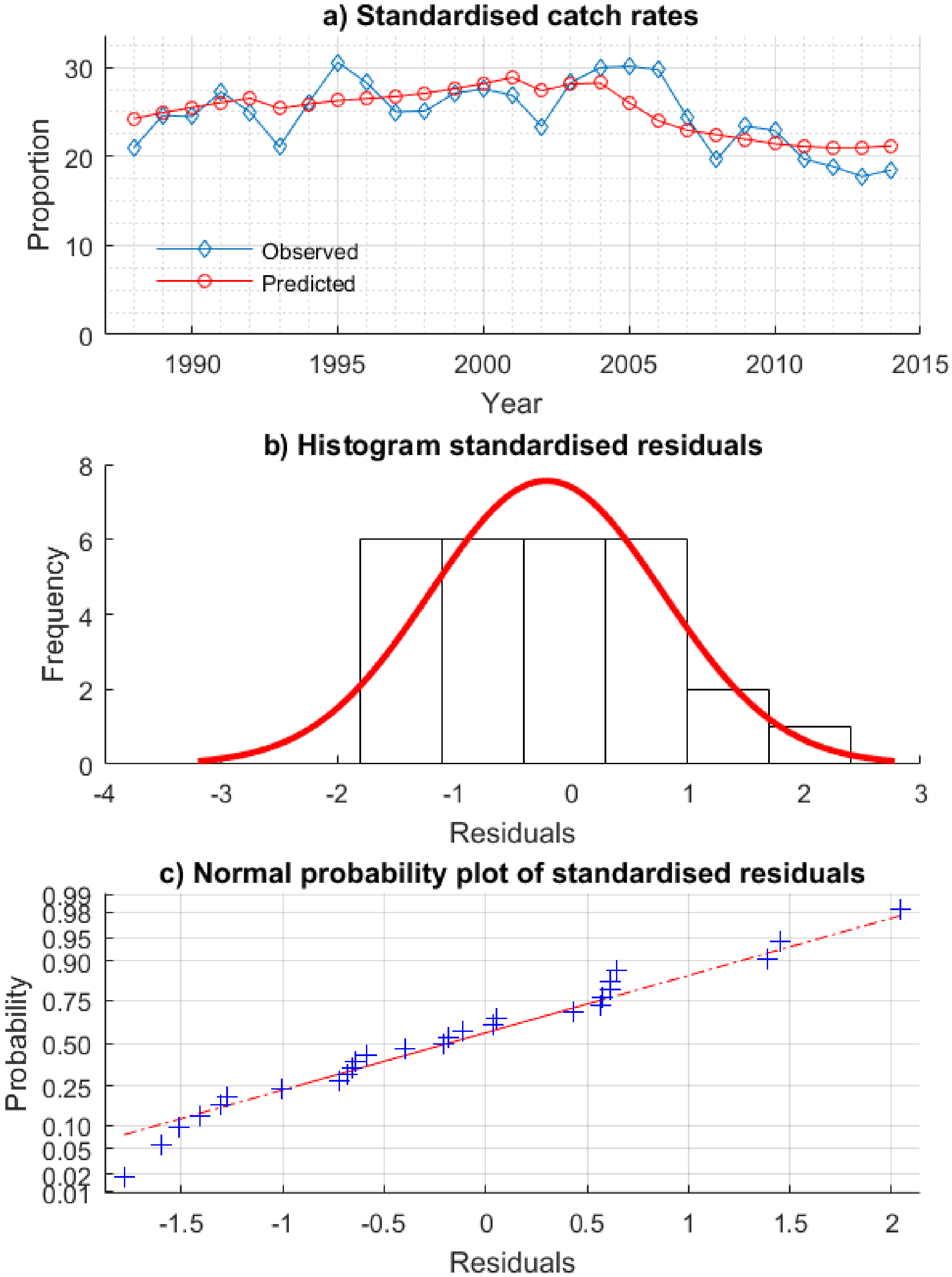


***Figure 52. Stock analysis 5 catch rate fit and standardised residuals.***

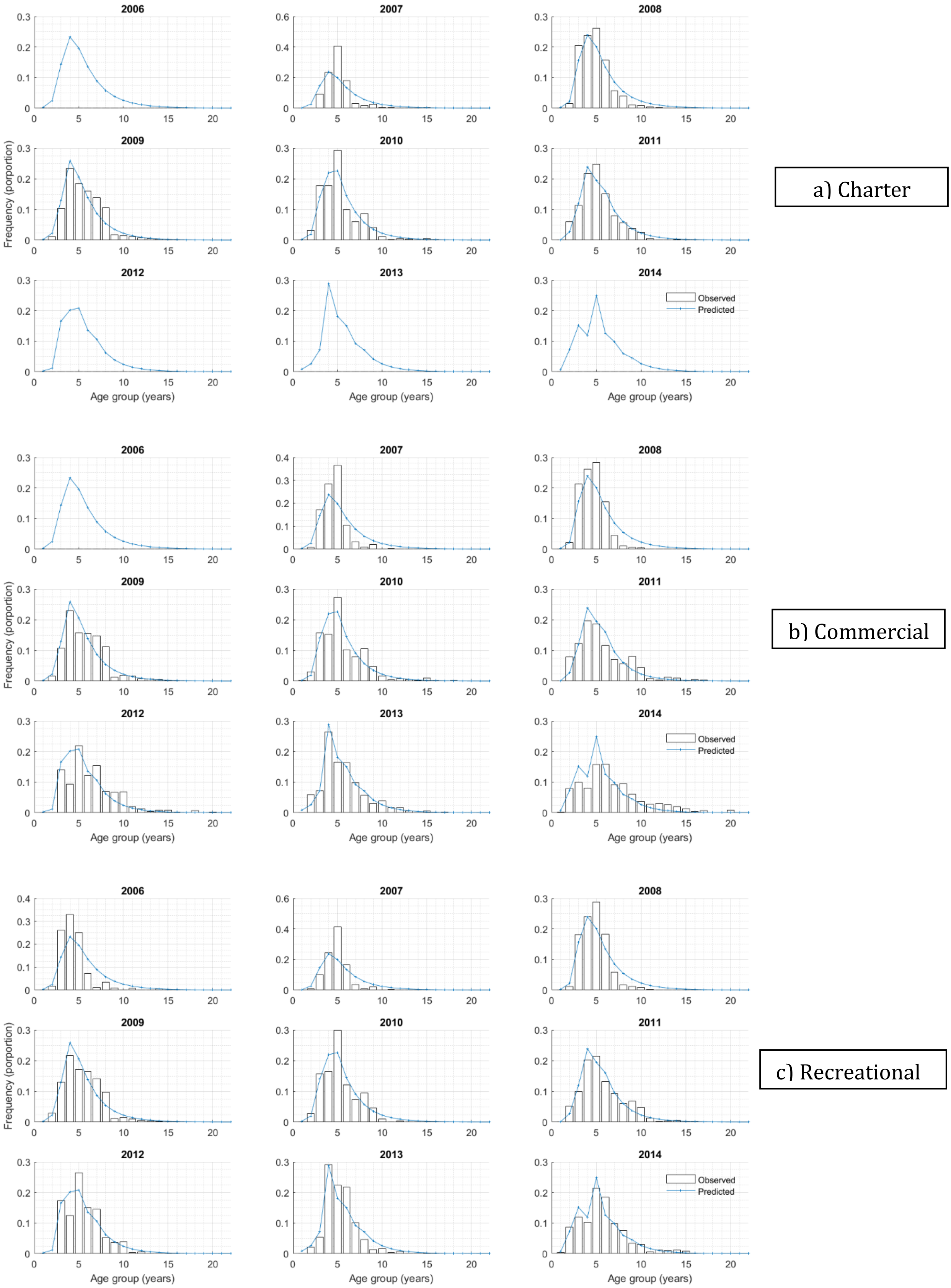


***Figure 53. Stock analysis 3 prediction of fish ages from Qld waters.***

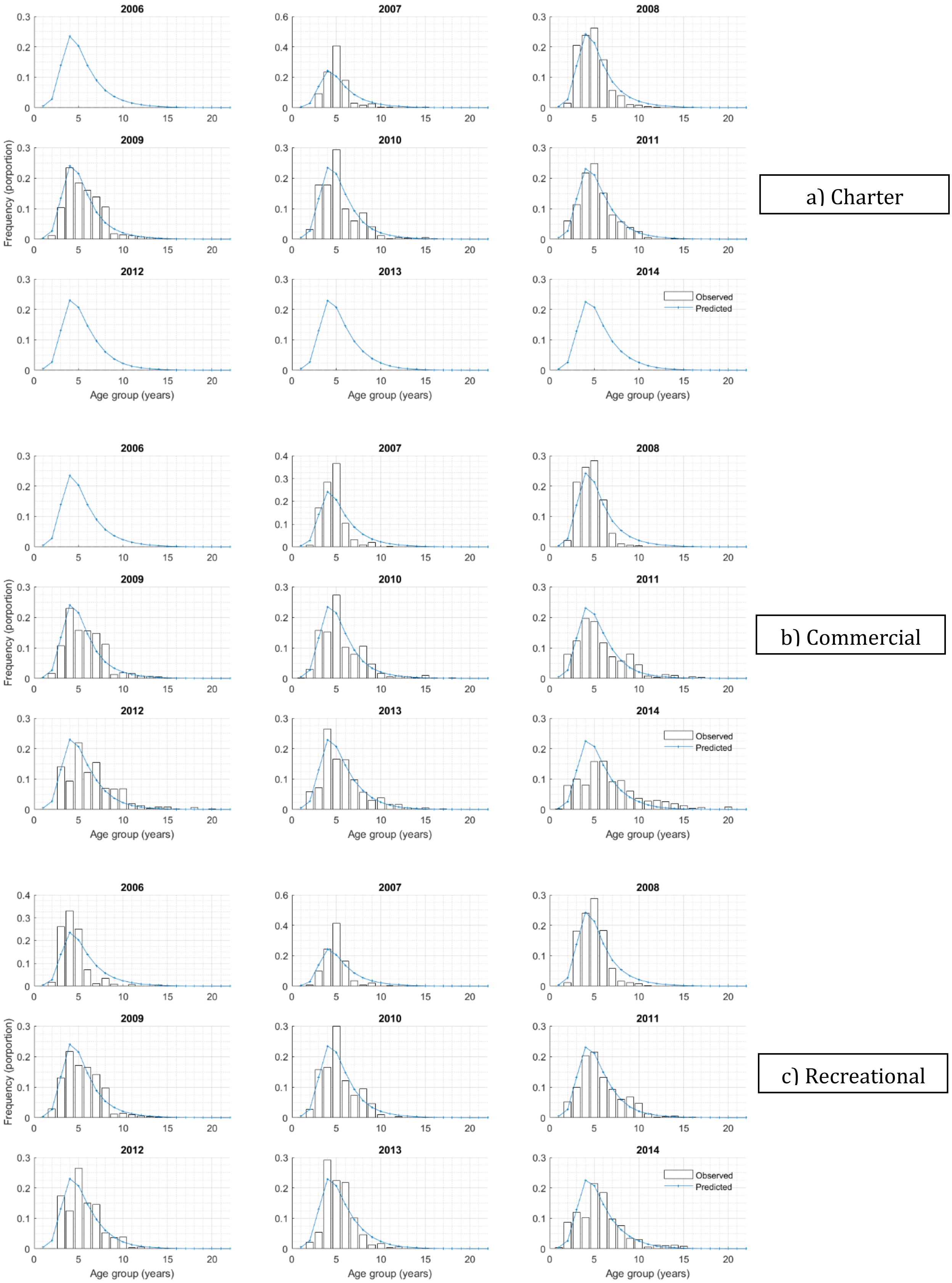


***Figure 54. Stock analysis 5 prediction of fish ages from Qld waters.***

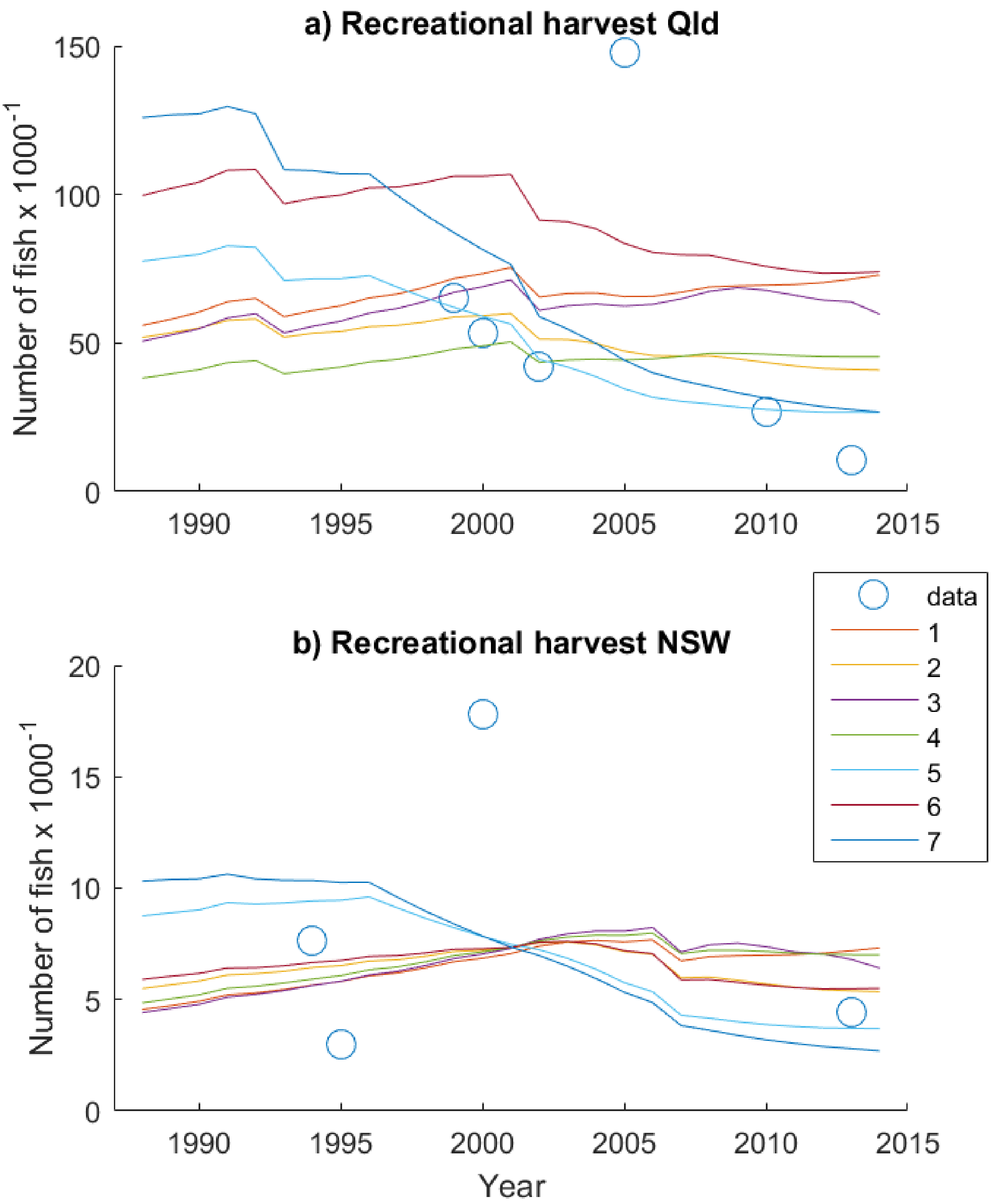


***Figure 55. Fit of model predicted recreational harvests to observed data for model scenarios 1 to 7.***

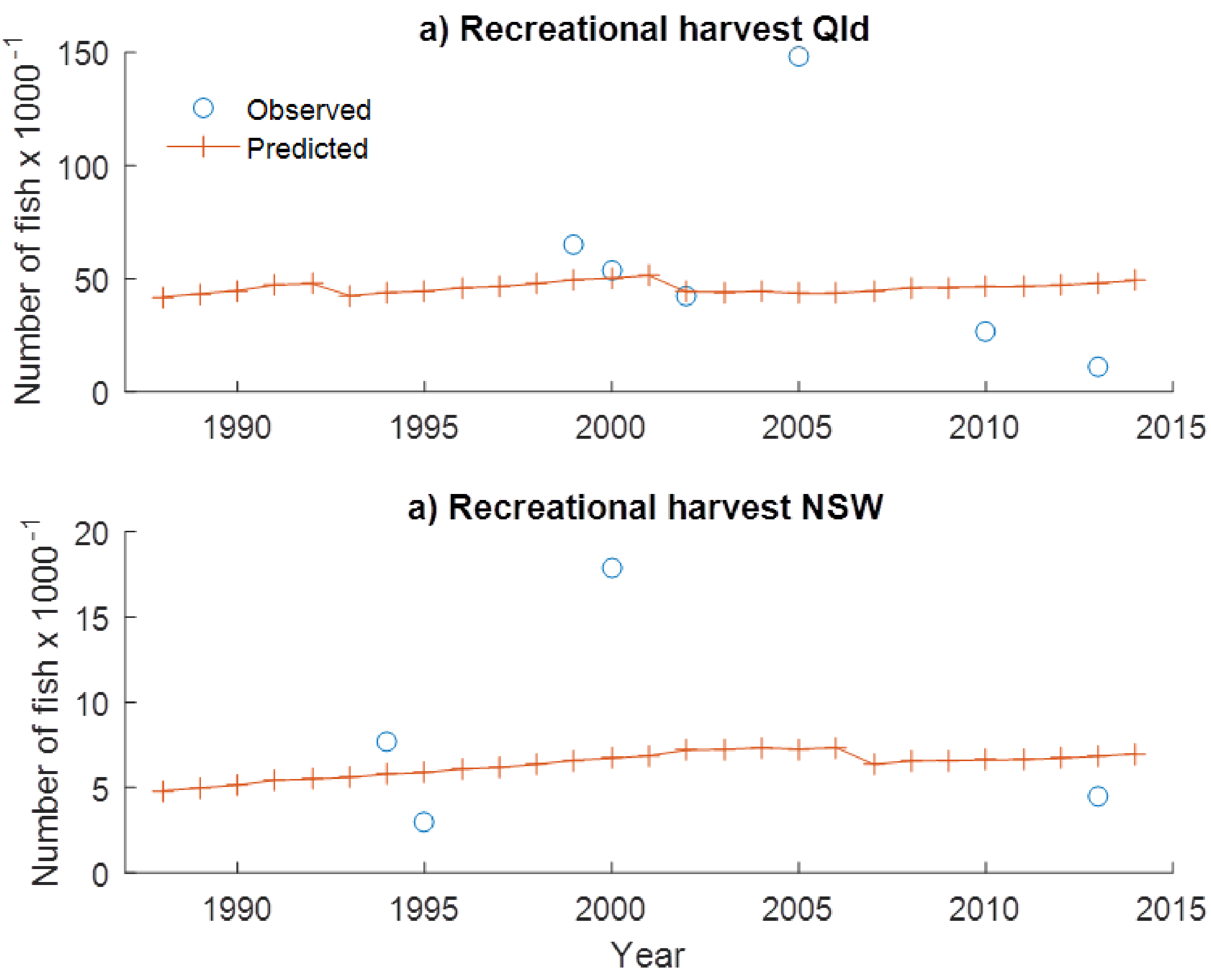


***Figure 56. Fit of model-estimated recreational catch to observed data based on ad hoc inflated pre-2004 commercial catches.***

## 8.2 Appendix 2: Data limitations and improvements

The design of logbook catch-recording sheets continue to affect the quality and consistency of data collected from the commercial and charter fishing sectors. Without validation and appropriate variables to record daily catch and effort data by every fishing operation, the accuracy and precision problems of data fidelity, hyperstability and recording anomalies will continue to complicate analyses and effect measures of fish abundance and mortality. The uncertainty in the pre-2004 levels of reported harvest was a significant issue for the assessment, complicated both by the 2003 investment warning and the lack of dedicated pearl perch catch and effort fields in the commercial line fishing logbook. While retrospective validation of historic catch is difficult, it is vital that data collected in the future are authenticated.

Another requirement to improve data for stock assessment is to monitor the time series of recreational catch rates of offshore fish from boat ramps (fishing access points). This needs to consider monitoring a number of different species, some with relatively narrow spatial/temporal distributions which are not well represented in the current catch records from diarists. Logistic and budgetary concerns makes this type of monitoring difficult, but is crucial for fisheries that have a large recreational component.

Fishing power will continue to increase as technological innovations improve fishers' abilities to catch fish. This assessment has considered two key technologies for offshore fishing: depth sounders and global positioning systems. Other techniques, such as side-scan sonar, to hold position on a fishing mark, deep water fishing-gear and other advances in technology continue to increase fishing power. Assessing annual increases in fishing power require ongoing data collected through commercial and charter logbook gear-sheets.

The issue of not identifying zero catches in the data (all fishing sectors) is an issue that can mask localised depletion of fish. If fish abundance declines, the probability of catching fish will reduce. Herein, analyses have not included zero catches, a simplifying assumption that likely provides optimistic interpretations of fish abundance and catch rates.

Surveys involving single listed phone directories (white pages) as the sampling frame for gathering fisheries information are increasingly being scrutinised and replaced by door knocking, dual frame mail surveys and other methods. While there is published evidence that fishing activity does not vary between listed and unlisted fishers (Teixeira *et al*. 2016), assumptions regarding uniform participation rates between unlisted and listed sampling frames and across fisher age groups remain untested. An improved survey design is needed to help quantify total catches of less common species like pearl perch; as was done for small mackerels (Cameron & Begg, 2002).

Licensing registries are utilised in many jurisdictions as the preferred sampling frame for gathering information from the recreational fishing population, but such a sampling frame is not possible without some form of recreational fishing licence. We note this as an advantage of a recreational licence system.

Historic levels of recreational effort were vital inputs to this assessment, yet there is limited information to better inform fishery models. Data on the annual number of boats registered and population size of people have been used, but the trends have been questioned by data showing a decline in the participation rate of recreational fishing. This stock assessment included analyses of both trends and highlighted different stock model results. Improving these data is a priority area for further investigation.