Department of **Employment, Economic Development and Innovation**

Stock assessment summary of the Queensland snapper fishery (Australia) and management strategies for improving sustainability

Alexander B. Campbell
Michael F. O'Neill
Wayne Sumpton
John Kirkwood
Steve Wesche

April 2009

Toward Q2 Tomorrow's Queensland
Queensland Government

Non-technical summary

Snapper, *Pagrus auratus*, live for up to 30 years, can grow in excess of 10 kg and are highly prized for their angling, eating and marketing qualities. In Queensland waters, snapper have a long history of exploitation with annual harvests taken by commercial and recreational sectors expanding from 100-200 t in the early 20th centruy to 400-700 t in recent years. Concerns that snapper are being overfished have been expressed strongly by stakeholders, researchers and managers in recent years. This had led Queensland to management arrangements. This publication was commissioned by to support the management review process.

This stock assessment used a series of statistical analyses (generalised linear modelling, SALSA and SSRA population Models) to investigate to what extent, if any, the stock is overfished. Catch rates from the commercial sector were stable over time, appearing to indicate a low impact of fishing. Howerver, there are concerns that the commercial data were hyperstable (catch rates can remain stable while abundance is declining), and this concern is supported by charter data and two recreational data sources, which all showed consistent significant declines. Commercial catch-at-length-and-age frequencies changed from mostly small and young fish in the mid-1990s (suggesting high fishing pressure) to higher frequency of larger and older fish in 2006/07 (suggesting lower fishing pressure). Recreational catch-at-length-and-age frequencies all suggested high fishing pressure. Population modelling on the data quantified snapper exploitable biomass levels of between 15-50% of unfished or virgin biomass levels, with the majority of analyses putting biomass below 35%, the approximate level that achieves maximum yield (Figure i).

Simulations were conducted to test the effectiveness and risk associated with various manamement strategies, including changes in minimum legal size and the introduction of quotas. While it was found that an increased minimum size would better protect the stock against high levels of effort, size changes alone would be unlikely to promote stock rebuilding. Simulations that investigated what level of future harvest would allow stock rebuilding were sensitive to the model inputs. Two model input scenarios that had the most consensus in terms of plausibliity indicated that average harvests over the next 10 years should be kept to 285 t and 380 t respectively.

The level of uncertainty associated with data and model assumptions is non-trivial and every effort should be made to ensure the next assessment has the data and resources to reduce this uncertainty. A number of recommendations are made to support this process, including:

- the continuation of fisher-dependent monitoring of size and age requencies
- the improvement of recreational harvest estimates
- the continuation and refinement of recruitment surveys to provide an independent index of abundance
- further research into the impact of discard mortality, and monitoring to support that research
- the improvement of vulnerability and age/length estimates, possibly through the use of tag-recapture data.

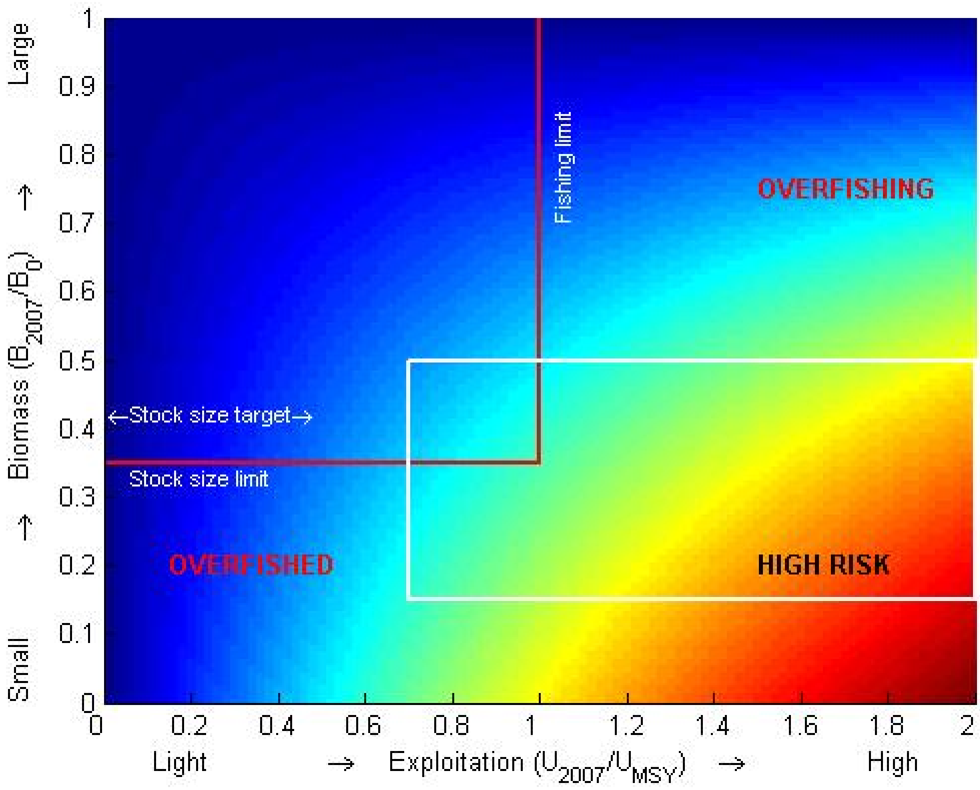

Figure i: the figure shows the stock status definitions based on the two axes (one is the rate of exploitation and the other relative stock size). The lower left hand corner of the figure denotes an overfished stock with light levels of exploitation and small stock size. Overfishing occurs at high exploitation rates and large stock size (top right hand corner of the graph). The high risk zone with overfished stock and high fishing pressure is highlighted in bottom right corner. Weight of evidence across data and analysis scenarios classified Queensland snapper status in 2007 between fully fished (at target levels) and overfished (white rectangle).

Introduction

Snapper, Pagrus auratus, is the icon demersal fish species caught commercially and recreationally in south-east Queensland. These fish, with their shimmering pink colouring and opalescent blue spots, are highly prized for their angling, eating and marketing qualities. In Queensland waters they can live up to 30 years and weigh in excess of 10 kg. Snapper have a long history of exploitation with commercial and recreational annual harvests in the order of 100-200 t being taken in the mid-1950s and increasing to 400-700 t in recent years. For a detailed description of the fishery and historical management arrangements see Allen, Sumpton, O'Neill, Courtney & Pine (2006). Concerns that snapper are being overfished have been expressed by stakeholders, managers and scientists over the last 30 years (Allen et al. 2006). In this time, fishing effort has increased substantially with advances in fishing power through enhanced vessel design, engine power, echo sounding, global positioning systems and fishing tackle technologies. Fishing poser is magnified further by fisher's increasing knowledge of fishing areas, times and methods.

Anecdotal information has indicated overfishing is greater in the southern part of the fishery, particularly in the Gold Coast area where severe declines in charter catches have been evident since the mid 1990s. The level of commercial effort has declined in the southern part of the state as commercial fishers have moved further north and into deeper water in order to maintain profitable catches. The last few decades have also seen a greater level of recreational catch as fishers have moved offshore in increasing numbers.

In 2006, the first quantitative assessment of snapper in Queensland waters was published (Allen et al. 2006). The data and analyses identified two alternate hypotheses on stock status: 1) underfished based on stable (but likely hyperstable) commercial snapper catches and 2) overfished based on declining snapper catches taken by Gold Coast charter vessels. Additionally, the assessment used snapper catch-at-age frequencies from the mid-1990s that consisted mostly of fish harvested between two and four years of age, with very few exceeding 10 years; this corroborates the declining trend in the charter catches. One of the recommendations of the 2006 assessment was the collection of up-date data on catch size and age structures to assist in future stock assessments and to provide a more accurate indication of stock status.

In Australia and New Zealand, snapper are managed by both input and output controls and there is considerable variation in the management regimes imposed across jurisdictions. Minimum legal size (MLS) limits range from 28 cm in Victoria to 50 cm in parts of Western Australia, while bag limits range from one to 15. There are also seasonal closures operating in both Western Australia and South Australia and some marine protected areas (MPA) protection in virtually all states. Most relevant to snapper management on the east coast of Australia is that Queensland and New South Wales share a common stock but management differs significantly between the two states. The current MLS of 35 cm in Queensland is 5 cm greater than in New South Wales, while the New South Wales recreational bag limit of 10 per person is double that existing in Queensland, In Queensland, the vast majority of the catch is line-caught while there is a significant commercial trap fishery in New South Wales (see Scandol, Rowling & Graham (2008) for the New South Wales 2006/7 report).

There is strong commitment by Queensland Primary Industries and Fisheries (QPIF) to develop improved management arrangements for the Queensland Rocky Reef Fin Fish Fishery in partnership with stakeholders and the community. To facilitate this, the QPIF commenced a review of this fishery in 2008. As part of this review an update of the snapper stock assessment using recently sampled snapper catch-at-age frequencies was commissioned. This review will support the stakeholder working group, and scientific advisory and management advisory committees to develop new management arrangements for the snapper fishery.

The objectives of this assessment were to:

- Optimise the use of all available data and update the assessment of Allen et al. (2006) by incorporating more recent catch data and current size and age structures.
- Evaluate the effectiveness of a range of alternate management strategies.
- Advise on monitoring, reporting and/or further research required to improve future assessments of the snapper fishery in Queensland.

This assessment used a sex, age and length stock analysis (SALSA) model that we have recently developed. The model represents population structure explicitly in terms of numbers of individuals in a given sex, age and length class, and can be fitted against multiple information sources, including catch rate, length and age composition information. The SALSA model was used in a recent assessment of the Queensland Spanish mackerel fishery. In addition, the model (and software implementation) used in the previous assessment, stochastic stock reduction analysis (SSRA), was re-run with the updated data to provide a semi-independent cross-check. The models together confirmed that the stock in 2007 was fished down to B_{MSY} or below, and that effort needs to decline from existing levels to allow stock rebuilding.

Discussion

Findings

The assessment used all available biological and fisheries data to provide an indication of the current level of exploitation, and the sustainability, of snapper in Queensland waters. All indicators, apart from the stable commercial catch rates and 2007 commercial catch-at-age data, suggest that snapper are likely being harvested at or exceeding maximum sustainable levels. Models results indicate that exploitable biomass levels are 15-50% of unfished or virgin biomass levels and that effort needs to decline from current levels to enable stock rebuilding. These results are similar to those of Allen et al. (2006), though there is now more evidence that the underfished hypothesis (based on commercial catch rates) is correct.

The assessment indicates that snapper will benefit from more restrictive regulation under all but the most optimistic (lightly fished) hypotheses – the same conclusion reached by Allen et al. (2006). Even model input scenario 8, which used the commercial catch rate data, put MSY at 530 t–well below estimated harvest in 2007 (760 t). Furthermore, changes in size and bag limits alone will not promote larger stock sizes at current levels of fishing (the effect of reducing the bag limit for the recreational sector from five to two was estimated to lead to, at most, a 9% reduction in harvest). While discard mortality greater than around 20% negates the maximum yield benefits of a 45 cm size limit, and while discard mortality in reality is likely much greater than this (Stewart 2008), a higher MLS would provide greater protection for the stock under most circumstances, As the yield-effort curves indicate, a 45 cm MLS would increase the yield that can be sustained at higher levels of effort. Nevertheless, we do not necessarily recommend yet another change in size limits as this would compromise the ability of future assessments to obtain a better understanding of vulnerability (see below).

That leaves direct regulation of harvest or fishing effort as the only viable management option. Model input scenario 4 (perhaps somewhat optimistic) predicts that rebuilding to safe levels in 10 years should be possible with a 400 t fishery-wide quota. A risk analysis for this scenario suggests that the probability of being below target (1.2 B_{MYS}) in 10 years time is around 25%, and the risk of a fishery collapse under this strategy is very small (≈ 1%). In contrast, if model input scenario 1 (perhaps somewhat pessimistic) tells a truer story, then the same strategy (400 t quota) would have a 46% risk of not meeting the target and a 10% risk of collapsing the fishery.

Model uncertainties

Although the best available data were used to determine the status of the stock, there was an inherent level of uncertainty associated with the data and model assumptions. Major levels of uncertainty exist in the key biological parameters of natural mortality and stock–recruitment, as well as in the fisheries data of the historical and recreational catches; perhaps the greatest uncertainty in the assessment. Sensitivity analyses identified small influence on biomass ratios for most of these uncertainties. The transparent and comprehensive nature of the assessment should enable all stakeholders involved in the fishery to make more informed decisions concerning the management of snapper, with a thorough understanding of the associated uncertainties and risks. While we believe that we have examined the sensitivity of the model to variations in most of the key parameters it is important to note the effects of differences in some of these parameters to model outputs, particularly if they are outside the range of values tested in the sensitivity analysis. The following paragraphs detail five areas of uncertainty that were not modelled exhaustively in this assessment and require further investigation

The first uncertainty of note is the confounding between a variable stock –recruitment relationship and stock composition. An age (or Length) composition that has a high proportion of younger (smaller) individuals, with numbers decreasing sharply as age (length) increases, is typically taken to imply high levels of mortality. (Hilborn and Walters 1992, p. 370). The 1994/95 age and length structures are particularly good examples, with catch curves that indicate total mortality (and hence fishing mortality) was very high. However, if there is a significant level of stochastic variation on top of a presumed deterministic stock-recruitment relationship (one level of stock size gives rise to a range of recruitment levels (then this interpretation is not the only one possible. A high proportion of smaller animals relative to larger ones could also be due to the appearance of numerous strong recruitment years. This confounding is particularly vexing because the possible interpretations are quite divergent – one of high fishing mortality and the other low fishing mortality and strong recruitment. In order to remove this confounding it would be necessary to incorporate recruitment variation into the estimation process for the stock mode. One way to do this would be to estimate a recruitment 'anomaly' for each year of the fishery (for a concise summary of this topic and other approaches see Walters & Martell (2004, p. 96)). Preliminary runs of the model using this estimation approach ended up with very large recruitment anomalies estimated for the years 1993/94. The estimation process clearly preferred the strong recruitment interpretation to the high fishing mortality interpretation. The problem with this estimation is that we only had 'snapshots' of composition information (one in 1994/95 and one in 2006/07) to inform the model, not a time series. Time constraints prevented a detailed investigation of this issue; however, the following points are pertinent:

- While strong recruitment pulses are common in New Zealand snapper and snapper in southern Australia, there is little evidence of the same phenomena in the east coast stock. The limited Queensland data and a much longer time series of data from New South Wales both argue against strongly variable recruitment (Ferrell & Sumpton 1997). Also, assuming low fishing mortality, strong recruitment over a number of consecutive years would be needed to produce the 1994/95 composition structures, and this is unlikely.
- The median biomass ration in 2007 for the run with estimated recruitment anomalies was still within the main group of model input scenarios (15% to 35%), so even if strong recruitment years are a major factor the overall conclusions of the assessment are not likely to differ dramatically.
- While time constraints were a factor for this report, another issue was simply paucity of data: having only 'snapshots' of composition information rather than a full time series. Our recommendations are that a comprehensive age and length sampling program continue, and that some direct, fishery independent index of recruitment strength be measured (recruitment survey). For more on recommendations see section below 'Future research and monitoring requirements'. While we can never fill in the missing years, if these sampling and recruitment monitoring regimes are maintained in future years the next assessment will have the data needed to address this issue more thoroughly.

Another closely related complication that should be examined thoroughly once further age and length composition information become available is selectivity/vulnerability. As noted by Dr Walters in his review of the Allen et al. (2006) assessment, obtaining a good understanding of how selectivity changes with age/size is both important and difficult. Vulnerability schedules are difficult to estimate as they require information about the catchability of various year classes, and it is well known that representative sampling of population age composition is a virtually impossible task. Three minimum legal sizes that have existed during the recent history of this fishery, in addition to significant changes in commercial targeting (see below), have compounded this difficulty. Accurate vulnerability schedules are important because the extent to which vulnerability decreases with increasing age or size is critical in deciding whether a lack of abundance of older/larger fish is attributed to fishing mortality or simply to those older/larger fish not being caught. In this assessment we used a combination of equilibrium virtual population analysis (VPA) modelling and ad hoc domain knowledge (with significant contributions from the SAG (DPI&F 2008)) to arrive at selectivity schedules for the historical 25 cm. 30 cm and 35 cm minimum legal size periods, and for the proposed future 40 cm and 45 cm strategies. However, with more data available, a future assessment should be able to approach this more rigorously. It will never be possible to reconstruct historical vulnerability schedules for the vast majority of years where no age–length data were available; however, by gaining more knowledge about current selectivities, the plausibility of various historical hypotheses may be assessed. Some of the information provided by this additional data would be ‘used up’ on modelling the extra complexity of another change in MLS, and this is a reason we caution against this strategy. Another related reason is that there is a strong desire amongst stakeholders and managers for the impact of any complexity of another change in MLS, and this is a reason we caution against this strategy. Another related reason is that there is a strong desire amongst stakeholders and managers for the impact of any management change to be measurable, and there are difficulties with detecting impacts of MLS changes (Allen & Pine III 2000).

In discussing both of the above issues (stock recruitment-composition confounding and vulnerability schedules), and in the population model itself, we have assumed a constant age–length relationship through time. This is not necessarily true. In fact, one indication of heavy fishing is a change in the mean and variance of size at age with mortality rate. If larger individuals are subject to higher mortality rates, the mean length at age of surviving fish will shift downward as the fishing mortality rate increases, and the distribution of lengths at age may not remain normal (Walters & Martell 2004, p. 120). Although the SALSA model represents individuals’ size and age explicitly, and so is capable of capturing the effects of size= or age-selective fishing on the population structure, what is required is for individuals to have persistent growth rates throughout their lives within the model. In other words, we need to model a number of growth-type groups of individuals, each with differing growth rates, and track these individuals and their growth rates through the model. Again, this is something that needs to be looked at in a future assessment, and the extent to which this is possible will be increased once more age and length data become available.

Fourthly, the east coast snapper stock is shared with New South Wales and yet this assessment treats the Queensland snapper fishery as one stock in isolation to the New South Wales fishery. Tagging studies (Sanders 1973, Sumpton, Sawynok & Castens 2003) have shown that while there are some extensive movements of snapper, the majority of the stock is relatively localised and undergoes movements on the scale of tens, rather than hundreds or thousands of kilometres. We thus contend that the degree of movement is relatively minor and is unlikely to affect this assessment. In any case catch and effort trends, as well as length composition information, tell a similar story in New South Wales (if any distinction is to be drawn one might say that the situation in New South Wales is more pessimistic). The snapper status report from New South Wales is available for download (Scandol et al. 2008). Little is known about the snapper larval distribution and the contribution that snapper spawning in one region has on other areas. The east Australian current (EAC) is believed largely responsible for maintaining the unit stock structure on the east coast snapper population (Sumpton, Ovenden, Keenan & Street 2008), largely due to the southerly transportation of eggs and larvae. To what extent there is ‘leakage’ of recruits to New South Wales is undetermined and this is one possible sources of uncertainty in our modelling of recruitment. A future assessment should incorporate all available information on the east coast snapper stock, not just Queensland data.

Fifthly, discard mortality is largely unknown. The discard mortality range we used was based primarily on a recent New South Wales DPI study of the New South Wales snapper trap fishery, focusing on how mortality varies with capture depth (Stewart 2008). This study reported mortality of 55% for snapper caught at depths between 45 m and 59 m, 39% for depths 30–44 m and about 2% for depths less than 30 m. The decision to go with 55% as the base case in our assessment was discussed extensively during the SAG (DPI&F 2008). It was based on the fact that the bulk of the Queensland catch comes from fish caught in depths of 30 m to 150 m. Clearly there are difficulties in translating the findings of this trap fishery study to the Queensland line fishery (to start with water depth gives only an upper bound on capture depth, and line fishing has its own particular mortality issues such as deep-hooking). Sensitivity analyses (scenarios 9 and 10 tested a 40% and 70% discard mortality rate) found very little effect in terms of the stock status. However, discard mortality is a critical input into the appropriateness of MLS strategies. The future projections showed that if discard mortality is 40% rather than 55%, a 45 cm MLS would both allow higher levels of harvest and lead to a higher biomass. This is an issue requiring further attention; however, beyond further sensitivity analysis there is little that can be done from a modelling perspective. Information from shallow water studies in Victoria (Conron, Gritxi & Morison 2004) and deep water studies in Western Australia (Jill St John, pers. comm.) gave snapper discard mortality rates of 5% and 70% respectively.

In summary, there are a number of modelling issues that should be examined an/or incorporated in a future assessment:

- estimation of individual yearly recruitment anomalies, carried out with an awareness of the stock recruitment-composition confounding issue
- better estimation and more thorough sensitivity analysis of vulnerability schedules
- model a number of distinct growth-type groups in the model, such that age length is meaningfully dependent on fishing mortality rates
- use the Forrest et al. (2008) leading management reparameterisation to get uncertainty directly in MSY and U_{MSY}
- incorporation of New South Wales data

The spatial dynamics of the fishery are also relevant in tackling these uncertainties. The significant differences in estimated catch rates from the Gold Coast region compared to the Sunshine Coast and Fraser regions are largely due to the predominance of different sectors in those regions–commercial in the north and recreational in the south. However, there may in fact be actual differences in terms of the population structure of the fishery. If that is the case a spatial modelling approach may be advantageous as it will benefit from the existence of this spatial contrast. Equivalently, if there are only sectoral differences then a sectoral modelling approach would still be useful. Furthermore, a spatially-disaggregated (or sectorally-disaggregated) management approach might be a very useful way of elucidating key parameters. For example, one might put a regionally higher size limit on snapper in the south, and monitor what happens. If the size/age composition changes in the south after the size limit it would be informative, and any response or lack of a response in the northern regions could serve as a 'control' (Mike Allen, pers. comm.)

Various other issues

The following sub-sections detail issues that have come up in discussion with stakeholders and provide additional information on various relevant topics.

Sensitivity to uncertain catch history

The use of boat registration information and Fish Board records to construct historical changes in harvest has been criticised as a source of model bias. Likewise, there is uncertainty about the accuracy of recreational harvest estimates. There is also some concern about the correctness of some commercial catches since the 2003 investment warning. Despite this, we nota that biomass ratios in 2007 were relatively robust to the variations in catch ($\pm$20%), a result similar to that obtained in the Allen et al. (2006) assessment which modelled a 50% variation in catch and likewise noted the relative insensitivity of the model to this variation. Even when pre-1988 catches were modelled to vary by 100%, biomass ratios were relatively consistent with the trends exemplified by the base case.

Feeder sub-stock near the Swains Reefs

In the past there has been a widespread belief that there is an unfished/lightly fished snapper stock (near the Swains Reefs) that contributed the bulk of recruits to the fishery. We are aware of no evidence to support this idea of a snapper stock in deeper water off southern Queensland. Information from the Coral Sea fishery and deepwater (>200m) line fishery logbooks confirm that snapper are not a significant component of those fisheries. Commercial fishers who fish the Coral Sea and deeper areas off the Swains also do not support this hypothesis.

Natural and discard mortality

Natural mortality has been modelled as either 0.15 (assuming relatively large maximum age of 30 years) or 0.19 (assuming short longevity of 23 years). Stock assessments of similar sparid fisheries in South Africa routinely use a natural mortality figure of 0.15, while in New Zealand the slower growth rate and longevity of most snapper stocks result in estimated levels of natural mortality being half those used in the present Queensland assessment. If natural mortality is lower than levels used in this assessment it would provide for an even more pessimistic view of the stock status. We consider it highly unlikely that natural mortality is greater than our base case estimate of 0.19.

Discard mortality is a key parameter and we have chosen to model a range based on snapper research from Victoria, New South Wales (Stewart 2008) and Western Australia (Jill St John, pers. comm.). We believe, however, that these estimated may not provide sound absolute estimates of line-caught discard mortality and more likely highlight the relative effects of depth of capture of mortality. This is because the estimates in New South Wales are based on trap caught and held fish while the Victorian studies are restricted to relatively shallow water and there is some uncertainty around the high estimates (70%) derived from studies in Western Australia. Certainly, lower levels of discard mortality than those used here would leas to more optimistic assessment outcomes. A better understanding of size specific discard mortality is highlighted later as a key area for further investigation.

Sumpton & Jackson (2005) have described the possible impacts of inadvertent trawl discard mortality on subsequent snapper fishery yields. Based on levels of trawl effect during the mid 1990s they estimated that on average 30 t of snapper were lost to the fishery due to trawl discards. Recent management changes have seen a considerable (50%) in trawl effort in Moreton Bay and elsewhere so it is unlikely that the impact of trawl discard mortality continues to have this level of impact.

Differences between 1990s and 2006/2007 size and age structures

Marked differences exist between the Queensland snapper catch size and age structure of the mid-1990s and those of 2006/2007. The data suggest an increase in the proportion of older age classes in recent years. This is particularly the case for the commercial fishery, which nowadays clearly has a higher proportion of larger/older fish than during the latter part of the last century. At the same time, that age structures of snapper from the commercial fishery in New South Wales have continue to reflect those of the 1994/1995 data from Queensland (1.e. suggesting high level of total mortality). The commercial fishery in New South Wales is predominantly a trap fishery and traditionally features a high proportion of smaller size classes, possibly suggesting selectivity against larger fish.

Recent total mortality (Z) estimates for the Queensland stock were almost half those calculated during the mid 1990s. There are several possible reasons for this, two of which–changes in vulnerability, and confounding with recruitment pulses–have already been mentioned. Vulnerability may have changed over time for a number of reasons including the targeting of certain sized fish due to market price differentials based on size, as well as different fishing techniques increasing the selectivity on larger size classes. Different fishing techniques can greatly influence the size of fish landed. For example 'patanosta' rigs (relatively heavy bottom sinkers with hooks placed above) select against the larger and older fish in a school when compared with 'floating rigs' (usually a lighter running ball sinker). The relatively recent introduction of soft plastic lures is also believed to be responsible for the increased catch of larger snapper, in the recreational sector in particular.

There was a premium paid for smaller snapper during the 1990s and prior to that time, which may have resulted in the selective targeting of small fish by the commercial sector (Ferrell & Sumpton 1997). In an earlier yield-per-recruit assessment (Ferrell & Sumpton, 1997), the price quoted for different sized snapper in the Sydney fish markets during 1995 was:

- 24-32 cm FL $10.54/kg
- 30-40 cm FL $ 9.23/kg
- > 41 cm FL $ 8.64/kg

No such price differential exists in the fishing in 2008, which suggests the incentives for targeting smaller snapper no longer exist.

Effect of recent and proposed spatial closures

There are a number of recent and proposed spatial closures that my have (or will in future) impact on the Queensland snapper fishery, but the effect of these has not been incorporated into the current assessment. Approximately 16% of Moreton bay will be protected by no-take marine reserves from March 2009. Likewise, there are parts of the Great Sandy Marine Park and the Capricornia Section of the Great Barrier Reef Marine Park (GBRMP) that offer limited protection to both adult and juvenile snapper. When the extent of snapper habitat in Queensland is considered these areas protect less than a couple of percent of the snapper habitat and would not contribute significantly to reductions in fishing mortality necessary to enable rebuilding of snapper stocks. This is particularly the case given that the individual protected zones (particularly outside the GBRMP) are relatively small in area and therefore offer even less protection to relatively mobile species such as snapper.

Management in other jurisdictions

There is a wide rant of management measures used to manage snapper fisheries in other Australian states, with most relying on input controls such as size limits. There is also considerable variation in the reported status of snapper stocks in those states.

Similar fisheries in the Gulf of Mexico (United States) have traditionally relied on input management controls to rebuild depleted stocks of fish with similar life histories to snapper. In this review of Allen et al. (2006) stock assessment, Dr Carl Walters observed that increasing recruitment rates as Gulf of Mexico fish stocks rebuild have led to very high discard rates, and consequent consideration of alternative management controls (such as effort limits). Output controls (such as total allocated catch (TAC)) are relatively simple to implement in large scale commercial fisheries but are much less effective in recreational fisheries where there are difficulties in determining the precise catch, let alone providing a mechanism for reducing the catch should the TAC be approached (or reached).

In New Zealand, output controls have been used to rebuild some overexploited snapper stocks. However, the snapper fishery in New Zealand is dominated by the commercial sector, in which it is much easier to limit catch due to reporting requirements and the relatively limited number or participants compared to recreational fisheries.

Management to ensure MSY may in part also be compromised in this fishery by the possible desire to more equitably share the resource amongst an ever-increasing number or recreational anglers. Increasing MLS may have effect of increasing the yield in terms of weight but it will also possibly cause a reduction in the number of fish that can be sustainably harvested, and therefore reduce each angler's numerical share of the available stock. Model outputs were also particularly sensitive to the level of discard mortality, with predicted gains in yield caused by increasing the MLS being reduced with increasing discard mortality.

Future research and monitoring requirements

One of the key requirements for future stock assessments is the accurate and precise estimation of total recreational catch. This is particularly the case in the snapper fishery since over 60% of the catch is believed to be taken by recreational fishers and yet there is a considerable uncertainty in the catch and effort estimates obtained for this sector (RFISH diary and phone surveys). Model outputs were relatively insensitive to the level of recreational catch, yet any bias in estimated wither way will influence the modelled stock status. If output controls are contemplated in this fishery, then timely, accurate and precise estimates of recreational catch and effort are even more important.

We believe that the impact of discard mortality, both in terms on incidental trawl catch as well as release of line-caught fish, is a key area for further research and one which would greatly aid future assessments. Line discard mortality is a parameter that is poorly known but which is critically important in determining model outputs. The status of the fishery would be assessed to be in a more favourable position if discard mortality was lower than the range tested in the models. Low levels of discard mortality would also increase the confidence in using MLS as management controls. This is because released fish would survive to contribute to future catches and contribute to spawning and further recruitment. Barotrauma is clearly an important issue in this fishery since the bulk of the catch comes from fish caught in depths of 30 m to 150 m. At these depths barotrauma is likely to cause mortality of released fish. This indicates a need for better assessment of mortalities associated with the capture and release of snapper in deeper offshore waters. Any steps to ameliorate the effects of barotraumas through better fish handling/treatment would also benefit the snapper fishery and fishers should be encouraged to appropriately treat fish suspected of suffering from barotrauma.

Likewise, we believe that every effort should be taken to minimise the mortality of juvenile snapper incidentally taken in prawn otter trawls. This may involve the use of bycatch reduction devices to minimise the incidental catch, as well as hoppers to improve the survival of those juveniles that are retained by the nets and sorted with the target catch. While it has been argued that recent management changes have reduced trawl effort, and bycatch reduction devices (BRDs) have reduced the level of incidental mortality we believe that there is scope for even more improvement in bycatch reduction and hopper technology to benefit of this fishery.

The complexity and temporal variability of vulnerability schedules used in models has been highlighted as a reason for increased uncertainty in model outputs. These schedules have a marked influence or model outputs and increasing complexity of these schedules over time only serves to reduce model accuracy and precision.

While we acknowledge that the independent that the independent assessment of population age structures is a worthwhile area to consider, given the sensitivity of the model to the size and age structures of the catch, we note that this is not an easy task. We believe that the current fishery-dependent monitoring should be maintained as the information collected becomes more valuable the longer the monitoring continues. Although the vulnerability of fish may change over time (due to market forces and technology), a properly designated sampling program that representatively samples both recreational and commercial catch will be vital to improving future assessments.

We have already noted that independent assessment of the adult population is a difficult task, but we recommend that the fishery-independent sampling of juvenile snapper may provide an index of relative abundance that will aid future assessments. The fishery-independent monitoring should continue to collect data designed to assess snapper recruitment using beam trawl sampling. The data will provide an index of juvenile snapper abundance that can be used in future stock assessments. The benefits of these surveys are clearly seen in other Australian jurisdictions, (i.e South Australia and Western Australia) where beam trawl surveys of pre-recruits are part of their snapper monitoring and assessment programs.

Regardless of what management changes are contemplated or introduced in the near future, it is imperative that monitoring and future research provides timely information that will increase the accuracy and precision of the next assessment. Give some of the difficulties highlighted in this assessment, we believe this can best be achieved through a workshop that brings together the expertise of scientists and modellers from around Australia and New Zealand to design a program that will assist researchers and stock assessment scientists by proving the types of accurate and precise information needed to aid management of the snapper industry.

References

Allen, M. S. & Pine III, W. E. (2000), ‘Detecting fish-population responses to a minimum length limit: effects of variable recruitment and duration of evaluation’, *North American Journal of Fisheries Management* **20**, 672–682.

Allen, M., Sumpton, W., O’Neill, M., Courtney, T. & Pine, B. (2006), Stochastic stock reduction analysis for assessment of the pink snapper (*Pagrus auratus*) fishery in Queensland, Technical Report QI06069, Department of Primary Industries and Fisheries, Queensland.

Conron, S., Gritxi, D. & Morison, A. (2004), Assessment of morality of under-size snapper and black bream caught and released by recrational anglers, Technical report, Primary Industries Research Victoria, Queenscliff.

DPI&F (2008), ‘Reef MAC Scientific Advisory Group: minutes for meeting 2/08’. 9 pages.

Ferrell, D. & Sumpton, W. D. (1997), Assessment of the fishery for snapper (*Pagrus auratus*) in Queensland and New South Wales, Report to the Fisheries Research and Development Corporation. Project 93/074, Department of Primary Industries and Fisheries.

Forrest, R. E., Martell, S. J., Melnychuk, M. C. & Walters, C. J. (2008), ‘An age-structured model with leading management parameters, incorporating age-specific selectivity and maturity’, *Canadian Journal of Fisheries and Aquatic Sciences* **65**.

Hilborn, R. & Walters, C. J. (1992), *Quantitative Fisheries Stock Assessment: Choice Dynamics and Uncertainty*, Chapman and Hall, New York.

Sanders, M. (1973), ‘Tagging indicates at least two stocks of snapper Chrysophrys auratus in south-east Australian waters’, *New Zealand Journal of Marine and Freshwater Research* **8**, 371–4.

Scandol, J., Rowling, K. & Graham, K. (2008), Snapper, pp 251-254, *in* J. Scandol, K. Rowling & K. Graham, eds, 'Status of Fisheries Resources in NSW 2006/07', NSW Department of Primary Industries, Cronulla. Available at http://www.dpi.nsw.gov.au/research/areas/systems-research/wildfisheries/outputs/2008/972.

Stewart, J. (2008), 'Capture depth related mortality of discarded snapper (Pagrus auratus) and implications for management', *Fisheries Research* **90(1-3)**, 289–295.

Sumpton, W. & Jackson, S. (2005), 'The effects of incidental trawl capture of juvenile snapper (*Pagrus auratus*) on yield of a subtropical line fishery in Australia: an assessment examining habitat preference and early life history characteristics', *Fisheries Research* **71**, 335–347.

Sumpton, W., Ovenden, J., Keenan, C. & Street, R. (2008), 'Evidence for a stock discontinuity of snapper (*Pagrus auratus*) on the east coast of Australia', *Fisheries Research* **94**, 92–98.

Sumpton, W., Sawynok, B. & Castens, N. (2003), 'Localised movement of pink snapper (*Pagrus auratus*) in a large subtropical marine embayment', *Marine Freshwater Research* **54**, 1–7.

Walters, C. J. & Martell, S. J. D. (2004), *Fisheries Ecology and Management*, Princeton University Press.